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HIGH PRESSURE HYDRAULIC SEALS

Z.J. Janczur

Parker Bertea Aerospace Group
Control Systems Division
14300 Alton Parkway
Irvine, California 92718-1814

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Air Force Wright Aeronautical Laboratories
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This technical report has been reviewed and is approved for publication.

Kristen Schario

KRISTEN SCHARIO
Mechanical Engineer
Power Technology Branch

Phillip G Colegrove

PHILLIP G. COLEGROVE, TAM
Power Technology Branch
Aerospace Power Division
Aero Propulsion and Power Laboratory

For the Commander

WILLIAM U. BORGER
Chief, Aerospace Power Division
Aero Propulsion & Power Laboratory

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An R&D Program was conducted to develop and demonstrate Dynamic Seal Designs (Rod and Piston Seals) for Advanced Aircraft 55.2 MPa (8,000 psi) hydraulic systems using nonflammable CTFE fluid over a temperature range of -54°C (-65°F) to +135°C (275°F). Two sizes of each seal design were tested in simplex, unbalanced flight type actuators using dual unvented rod seals under simulated flight control surface air loads. The rod seal designs were tested in MIL-G-5514 grooves and clearances.

Several elastomer energized and spring energized plastic rod seal designs backed with high modulus plastic back-up rings completed successfully the 12,200,000-cycle test. None of the tested piston seal designs completed the test.

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22a. NAME OF RESPONSIBLE INDIVIDUAL
Kristen A. Schario

22b. TELEPHONE (Include Area Code)
(513) 255-6241

22c. OFFICE SYMBOL
AFWAL/POOS-1

FOREWORD

This report was prepared by the Parker Bertea Aerospace Group, Control Systems Division (CSD) for the United States Air Force under Contract Number F33615-84-C-2416, which was conducted between September 1984 and June 1988. This contract was accomplished under Project Number 320100. The work was administered under the direction of the Aero Propulsion Laboratory at the Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright Patterson AFB, Ohio. Air Force Program Managers were in turn Mr. W.B. Campbell and Ms. Kristen Schario (AFWAL/POOS). Technical assistance with the hydraulic fluid was provided by Mr. C.E. Snyder and Mrs. L. Gschwender of the Materials Laboratory at Wright Patterson AFB (AFWAL/MLBT). Mr. R. Snowdon and Mr. D.S. Schoellerman were Program Managers in turn; Mr. Z.J. Janczur was Principal Investigator and Mr. A. Swenson was test engineer for Parker Bertea CSD. Mr. J. Kosty and Dr. A. Naderi were in turn Principle Investigators for Parker Seal.

This report encompasses the three phases of the program. During the contract period of performance, progress by program phase has been reported to the Air Force in one interim report and bi-monthly reports. The interim and bi-monthly reports are compiled in this final report.

ACKNOWLEDGEMENTS

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The support and cooperation of the Abex Corporation who supplied the program test pumps, Teledyne Linair Engineering who supplied the Rynqlok Fitting system for both test stands and McDonnell Aircraft Company (MCAIR) who performed Abex Pump System Hytran Analysis is gratefully acknowledged.

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1.0 INTRODUCTION

The Air Force Contract Number F33615-84-C-2416, "High Pressure Hydraulic Seals," was awarded to Parker Bertea Aerospace Group, Control Systems Division, (CSD) on September 4, 1984.

The objective of the program was to develop and demonstrate the dynamic rod and piston seals for 8,000 psi Chlorotrifluoroethylene (CTFE) Hydraulic Systems. The performance of the seals were demonstrated in two sizes of flight weight actuators over a temperature range of -65 to 275°F.

The program was divided into three phases:

Phase I : Data Search and Evaluation

Phase II : Screening Test

Phase III : Long Life Test

2.0 BACKGROUND

Loss of aircraft caused by hydraulic fluid fires has been one of the Air Force's serious problems in recent years. Concerted efforts were made, through a series of contracts, to develop a nonflammable hydraulic fluid. These efforts resulted in selection of Halocarbon Corporation's Chlorotrifluoroethylene (CTFE) base A02 fluid. The CTFE fluid formulation for this program contains the A02 fluid plus the lubricity enhancement additive 3M and the rust-inhibiting additive barium sulfonate (BSN).

While the nonflammability goals were achieved, a significant weight increase for a 3,000 psi system was predicted due to the high density of the nonflammable fluid. To minimize the weight penalty of the CTFE fluid in future Air Force aircraft, 8,000 psi operating pressure systems were designed and their performance was demonstrated.

The overall utilization of aircraft flight control systems has changed from the mechanical input flight control system to the present day fly-by-wire systems. This trend has resulted in complex surface control actuation with increased sealing requirements. Additionally, new aircraft designs with relaxed static stability require increased activity of the control surfaces, hence more duty cycles from the actuators. High pressure (8,000 psi) systems sealing design requirements (i.e. extrusion gap, cylinder breathing, etc.) are different than for 3,000 psi systems. We must consider these changes in design and requirements to determine the required seal design technology for 8,000 psi CTFE fluid aircraft hydraulic systems.

3.0 PROGRAM PLAN

As stated previously, the program was divided into three phases. Phase I consisted of the following tasks:

Task I : Airframe Manufacturers' Survey
Task II : Seal Users' Survey
Task III : Seal Suppliers Survey
Task IV : Parker Seal Subcontract
- Material Evaluation
- Basic Functional Seal Testing

Task V : MTI Subcontract
- Analytical Seal Design
- Friction and Wear Testing of Seal Materials

Task VI : Evaluation Criteria of Seal Designs
Task VII : Oral and Written Interim Report

In Phase II, the test actuators and fixtures were designed and fabricated and the screening tests on selected rod seal and piston seal configurations were performed. The screening test consisted of 10 percent of the total required duty cycle of the long life test.

In Phase III, the long life test was conducted on the most promising rod and piston seal configurations.

4.0 SUMMARY

To establish basic requirements for the development and testing of the seals, surveys of airframe manufacturers, users, and seal vendors were conducted and the existing 8,000 psi test literature was reviewed.

Two sizes of test actuators were decided upon and the cycle schedule was defined.

Evaluation of potential seal material candidates and seal configurations for use in the nonflammable CTFE hydraulic fluid was performed.

Seal configurations for screening tests were selected and ordered. Test actuators and test system were designed and fabricated. Screening Tests on 31 seal configurations were performed, and seals for the final Long Life Test were selected. The Long Life Test was successfully completed.

5.0 PHASE I DATA SEARCH AND EVALUATION

As a part of the program, surveys of airframe manufacturers, users, and seal vendors were conducted and the existing 8,000 psi test literature was reviewed. Results of these surveys were used to form the basis for test actuator sizes and requirements. They also provided data on current and past testing. Seal vendors provided recommendations for new seal designs.

Copies of survey letters along with the names of companies and individuals contacted are enclosed in Appendix G.

5.1 Airframe Manufacturer's Survey

To obtain expert opinion on performance requirements for future 8,000 psi CTFE flight control actuators, a questionnaire was sent to 36 airframe manufacturer representatives. Thirteen responses were received and the results are summarized in Table I.

Recommendations for two actuator sizes were sought so that testing of "typical" actuator seal sizes could be conducted. The results ranged from a 600 to 40,000 pound output force with a 2.5 to 6.58 inch stroke for the small actuators and a 25,000 to 125,000 pound output force with a 4.0 inch stroke for the large actuators.

TABLE 1

AIR FRAME MANUFACTURERS SURVEY

SURVEY INPUTS / SURVEY QUESTIONS			1	2	3	4	5	6	
ACTUATOR A	CYLINDER BORE (IN)		2.0	1.0	2.0	.625		1.57	
	ROD DIAMETER (IN)		1.0	.74	1.12	.50		.75	
	STROKE (IN)		5.0	5.5	4.5	1.0		4.0	
	OUTPUT FORCE LBS	FLIGHT ACTUATOR	15000 MIN	2900	15000	500	3000	12000	
		UTILITY ACTUATOR	---	4000	---	---			
	STRUCTURAL MOUNTING SPRING RATE (LBS/IN)			120000	200000	NO RESPONSE		100000	
ACTUATOR B	CYLINDER BORE (IN)		3.5	2.4	* 3.25	6.0		2.70	
	ROD DIAMETER (IN)		1.5	1.2	1.50	3.0		1.25	
	STROKE (IN)		8.0	6.58	7.00	6.0		8.0	
	OUTPUT FORCE (LBS)	FLIGHT ACTUATOR	120000 MAX	55000	40000	90000	10000	16000	
		UTILITY ACTUATOR		125000	---	---			
	STRUCTURAL MOUNTING SPRING RATE (LBS/IN)			200000	750000	NO RESPONSE		100000	
OPNL TEMPERATURE °F	AMBIENT °F		-65 TO +400	-65 TO 250 ENG, TYC 150	-65 TO +160	-65 TO +500	-65 TO 300	-65 TO 650	-65
	FLUID °F		-40 TO 275	-25 TO 160	-65 TO 325	-65 TO 275	-20 TO 300	-65 TO 500	-65
# OF DUTY CYCLES & CYCLING RATES AT SPECIFIED LOAD-STROKE SCHEDULE	1.0 PERCENT STROKE LOAD					8 x 10^5 @ 5 HZ		10^7 @ 20 HZ	5.42 x
	2.0 PERCENT STROKE LOAD			10^7 @ 1HZ	4 x 10^6 @ NO INPUT	10^6 @ 5 HZ		10^7 @ 20 HZ	3.5 x
	10.0 PERCENT STROKE LOAD		10^7	1.7 x 10^6 @ 1 HZ	.7 x 10^6 @ NO INPUT	.8 x 10^6 @ 2 HZ		10^5 @ 5 HZ	2.5 x
	50.0 PERCENT STROKE LOAD			.675 x 10^6 @ .25 HZ	.25 x 10^6 @ NO INPUT	.19 x 10^6 @ .5 HZ		10^5 @ 1 HZ	6.0 x
	100.0 PERCENT STROKE LOAD			.125 x 10^6 @ .12 HZ	.05 x 10^6 @ NO INPUT	.01 x 10^6 @ .25 HZ		10^4 @ .25 HZ	[illegible]
# OF DUTY CYCLES AT TEST TEMPERATURE (PERCENT OF TOTAL CYCLES)	-40°F FLUID				1.0 @ -65 OP & AMB			10 @ -65 UP & AMB	
	-20°F FLUID			5 TO 10					
	0°F FLUID							40 @ -40 AMB	
	110°F FLUID								
	160°F FLUID		10^7			60 @ ROOM AMB			
	225°F FLUID			90		25 @ 150°F AMB			90 @/250
	250°F FLUID				79 @ 80°F AMB				
	275°F FLUID					15 @ 500°F AMB			10.0 @
	300°F FLUID				20 @ 110°F AMB				
	350°F FLUID								
NO LOAD BOTTOMING CYCLES (% OF TOTAL CYCLES)	FLIGHT CONTROL ACTUATORS		NONE	25 TO 30	1.0	.005		.0009	
	UTILITY ACTUATORS		---	100	—	---	---	---	
RECOMMENDED DIAMETRAL EXTRUSION GAPS (IN)				.002	NO RECM	MIL-G-5514			
EXPECTED SYSTEM PRESSURE PULSATION			2300PSI@840HZ	3200 PSI	—	MIL-H-5440		125% OF 4000 @ 10 HZ	
EXPERIENCE WITH CTFE FLUID			---	LIMITED	---				
RECOMMENDED WEARING SURFACE MATERIALS AND FINISHES			NO RECM	NO RECM	NO RECM	NO RECM			

TABLE 1

ANUFACTURERS SURVEY RESULTS

	6	7	8	9	10	11	12	13
	1.57	3.0	2.75	1.5	2.62	A = 2.1 IN^2 x 2	A = 2.0 IN^2	1.69
	.75	1.185	1.25	1.0	1.12			1.30
	4.0	6.58	2.5	3.0 TO 4.0	4.38	5.03	6.0	6.0
	12000	40000	37000	5000	35000	28000	10000	23200
		---	---	---	---	---	---	---
	130000		350000	100000	150000	16000 - 34000		
	2.70	4.27	2.5	2.0	3.38	A = 6.66 IN^2 x 2	A = 7.0 IN^2	3.25
	1.25	2.875	1.5	1.5	1.68			2.12
	4.3	6.84	5.0	5.0	7.88	8.39	9.0	6.0
	16000	125000	50000	25000	54000	38800	90000	76100
	500000		4000000	500000	140000	160000 - 140000		
	-65 TO 450	-65 TO 250	-65 TO 115	-65 TO 130	-65 TO 450	-65 TO 160	-65 TO 350	-65 TO 275
	-65 TO 500	-65 TO 275	-65 TO 275	-65 TO 300	-65 TO 350	150 TO 275	-65 TO 275	-65 TO 275
	10^7 @ 20 HZ	3.62 x 10^7 @ 10 HZ	10^6 @ 3 HZ	.5 x 10^6 @ 20 HZ	5.25 x 10^6 @ 2 HZ			2 x 10^7 @ 5 HZ
	10[illegible] @ 20 HZ	3.5 x 10^6 @ 4 HZ	5 x 10^6 @ 3 HZ	.5 x 10[illegible] @ 20 HZ	5.25 x 10^5 @ 1 HZ			2 x 10[illegible] @ 1 HZ
	10^5 @ 5 HZ	2.5 x 10^5 @ 1 HZ	1.5 x 10^6 @ 1.67 HZ	1.0 x 10[illegible] @ 20 HZ	1.0 x 10[illegible] @ .5 HZ			2.5 x 10[illegible] @ 1 HZ
	10^5 @ 1 HZ	4.0 x 10[illegible] @ .36 HZ	2 x 10^6 @ .8 HZ	1.0 x 10^6 @ 1 HZ	.25 x 10^6 @ .3 HZ			4 x 10[illegible] @ .5 HZ
	10[illegible] @ .25 HZ	10[illegible] @ .1 HZ	1.5 x 10^6 @ .25 HZ	2.0 x 10[illegible] @ .5 HZ	.75 x 10[illegible] @ .1 HZ	7.87 x 10^6		2 x 10[illegible] @ .25 HZ
	10 @ -65 UP & AMB							
	40 @ -40 AMB		5 @ -65 AMB				5 @ -65 AMB	
						10 @ -40 AMB		
			70 @ 75 AMB	90 W/140 OIL @ 70 AMB	100	60 W/130 OIL @ 75 AMB	95 W/200 OIL @250 AMB	90 @ 130 AMB
		70 W/250 OIL @140 AMB		20 @ 240 OIL @ 140 AMB		30 @ 120 AMB		
		10.0 @ 250 AMB	75 @ 275 AMB					10 @ 275 AMB
					10 @ 450 AMB			
	.0005	.0013	6.0	.5	6.0	.8		.01
	---	---	---	---	---	---	---	---
		.002 MAX		MIL-G-5514		NO EXP		NO EXP
	125% OF 4000 @ 10 HZ		4250 PSI @ 400 HZ			4250 PSI @ 450-600 HZ		NO EXP
						NO EXP		- -
						NO EXP		NO EXP

The survey results were presented to the Air Force representatives after which the test actuator sizes were agreed upon.

The small actuator will have a 4.000 inch nominal stroke, 1.492 ± 0.001 inch diameter bore, and 0.997 ± 0.001 inch diameter rod. The actuator will produce 13,986 pounds extend force and 7,741 pounds retract force at 8,000 psi pressure differential. The large actuator will have a 4.000 inch stroke, 2.369 ± 0.001 inch diameter bore, and 1.622 ± 0.001 inch diameter rod. The actuator will produce 35,262 pounds extend force and 18,732 pounds retract force at 8,000 psi pressure differential.

The survey indicated no consensus for the life of the actuators or number of bottoming cycles; therefore, testing was conducted according to the cycling schedules presented in Figure 15 (Screening Test) and Figure 26 (Long Life Test). The cycling schedules were agreed upon by the Air Force. One hundred percent load is defined as the load generated with an 8,000 psi pressure differential across the piston. Total required life test cycling was originally 21,515,350 cycles. This number was later reduced to 12,200,000 cycles.

5.2 Previous Experience Survey

To learn of and to evaluate the experiences of the seal users, survey letters were sent to 12 user companies. Eight responses were received and the results are summarized in Table 2.

The results indicate that numerous materials can be used in CTFE but that limited data on seal life exists. Some users have indicated that reduced (0.001 - 0.003 inch) diametral clearances improve seal life.

5.3 Seal Vendor Survey

Twenty—two seal vendors were contacted to obtain seal design recommendations. Eight responses were received in the form of seal configuration proposals. Very limited actual test data in support of the proposed seals was supplied.

5.4 8,000 psi Test Literature Search

A list of the reviewed papers and reports on 8,000 psi systems and components testing is attached in Appendix H.

TABLE 2
SEAL USERS SURVEY

SURVEY INPUTS / SURVEY QUESTIONS		1	2	3	4	
	ELASTOMERS TESTED	PNF BUNA N	EPDM, PNF, VITONS & FLUORELS VARIOUS OTHER OFF THE SHELF COMPOUNDS	NUMEROUS	EP, EPDM & PNF COMPOUNDS	EPDM, ETHEL CHLOR
	SEAL CONFIGURATIONS TESTED	O-RINGS	O-RINGS	NUMEROUS	SHAMBAN: HAT & PLUS GREENE TWEED: T-SEAL CONOVER: CON-O-HEX TETRAFLUOR:	
	TEST FLUIDS USED	MIL-H-5606	CTFE	MIL-H-83282, MS-6, CTFE (A02)	CTFE	
TEST CONDITIONS	OPERATING PRESSURES (PSI)	3000	AMBIENT TO 8000	8000	0 TO 8000	
	OPERATING TEMPERATURES (°F)	130	275	AMBIENT TO 275	-20 TO 275	
	EXTERNAL LOADS		NONE	REP OF A-7E & RASC		
	CYCLE SCHEDULES & RATES	±1% @ 3HZ & 30HZ	COMPATIBILITY TEST ONLY	PER MIL-C-5503		.5 HZ @ WITH DI
	PISTON ROD & CYLINDER BORE FINISHES	ROD FINISH 10µ	N/A	CURRENT INDUSTRY PRACTICE	MIL-G-5514	
	EXTRUSION GAPS (IN)	MIL-G-5514	MIL-G-5514	MIL-G-5514	DIAMETRAL 0.0005 TO 0.003	
	GLAND CONFIGURATIONS	MIL-G-5514	N/A	MIL-G-5514		
PROBLEMS EXPERIENCED	INCOMPATIBILITY WITH FLUID		ALL EXCEPT EPDM, PNF, VITONS & FLUORELS			SIGNIF EXTRACT
	EXCESSIVE SWELL		35% FREE 14 TO 16% WHEN IN MIL-G-5514 GROOVES	NO		YES. NI EPDM, F
	EXCESSIVE SOFTENING		YES	NO		RELATED
	LOSS OF STRENGTH		YES	NO	IN TEST NO RESULTS YET	POLYMER ATTACKE
	BECOMING BRITTLE			NO		NITRILE
	ABRASIVENESS			YES WITH GLASS FILLED PLASTICS		NO PROB
	CORROSIVENESS			NO		NO PROB
	ANY OTHER PROBLEMS			METAL BACKUPS NOT RECM		
	RECOMMENDATIONS	.001-.0015DIA CLEAR FOR 8000 PSI. DO NOT SUPERIM-POSE SHORT STROKE CYCLES ON LONG STROKE CYCLES USE TEFLON CAPS ON O-RINGS				

TABLE 2

SEAL USERS SURVEY

3	4	5	6	7	8
NUMEROUS	EP, EPDM & PNF COMPOUNDS	EPDM, PNF, VITON, CHLORINATED POLY-ETHELYNE & BLENDS OF ABOVE NITRILES, CHLOROPRENE	VITON	MIL-P-83461	MIL-83461
NUMEROUS	SHAMBAN: HAT & PLUS GREENE TWEED: T-SEAL CONOVER: CON-O-HEX TETRAFLUOR:		O-RINGS WITH TFE BACKUPS	VARIOUS TYPES SINGLE & TWO STAGE	VARIOUS TYPES SINGLE & TWO STAGE
IL-H-83282, MS-6, CTFE A02)	CTFE	CTFE	MIL-H-83282	MIL-H-83282	MIL-H-83282
8000	0 TO 8000		8000	0 TO 8000	0 TO 8000
AMBIENT TO 275	-20 TO 275	-65 TO 275	220 TO 280	-40 TO 275	60 TO 275
EP OF A-7E & RASC		NIL		6280 LBS MAX	130 TO 40000 LBS
PER MIL-C-5503		.5 HZ @ FULL STROKE & HIGHER FREQ WITH DITHER.		410 HRS TEST 172618 CYCLES @ ±1.75 IN 80076 CYCLES @ ±0.01 IN	2,000,000 CYCLES AT VARIOUS LOAD/STROKE SEQUENCES
CURRENT INDUSTRY PRACTICE	MIL-G-5514	2 RMS TO 32 RMS		PISTON ROD CHROME 8 TO 16 RMS	PISTON ROD CHROME 8 TO 16 RMS
MIL-G-5514	DIAMETRAL 0.0005 TO 0.003	RADIAL .001 TO .005	1/2 OF THOSE FOR 3000 PSI	DIAMETRAL 0.001 TO 0.003	DIAMETRAL 0.001 TO 0.003
MIL-G-5514		MIL-G-5514 2 BACKUP		MIL-G-5514 EXCEPT CLEARANCE	MIL-G-5514 EXCEPT CLEARANCE
	IN TEST NO RESULTS YET	SIGNIFICANT - SEAL DEGRADATION, EXTRACTION & SWELLING		NONE	NONE
NO		YES. NITRILES LOW BUT ARE OXIDIZED. EPDM, PNF, VITONS 25% OR MORE		NONE	NONE
NO		RELATED TO SWELL SEVERE WITH PNF		NONE	NONE
NO		POLYMERS OTHER THAN VITONS SERIOUSLY ATTACKED @ 275°F & ABOVE.		NOT MEASURED	NOT MEASURED
NO		NITRILE & CHLOROPRENE POLYMERS			NONE
YES WITH GLASS FILLED PLASTICS		NO PROBLEMS EXPERIENCED		NONE	SCRATCHES CAUSED BY GLASS FILLED BACKUP RING
NO		NO PROBLEMS WITH CRES OR NITRONIC		NONE	NONE
METAL BACKUPS NOT RECM			VIB @ 100HZ LOW AMP CC	SOME PERMANENT SET	FAIL OF METAL BKUP RINGS
				USE THERMAL BLANKETS FOR HEATING. PUT TEMP PICKUPS CLOSE TO SEAL AREA.	

6.0 MECHANICAL TECHNOLOGY INC. (MTI) SUBCONTRACT

A part of the contract was awarded to MTI, a company with expertise in theoretical analysis of seal designs and equipment, to evaluate the wear properties of the candidate seal materials in conjunction with potential wear sealing surfaces.

The subcontract issued to MTI had the following objectives:

1. Determine the friction and wear characteristics of selected plastic materials on two metal surfaces in CTFE fluid.

2. Design a piston and rod seal using computer aided analytical techniques.

The following summarizes MTI's effort. MTI's full report is presented in Appendix I.

6.1 Summary MTI's Subcontract

Evaluation of potential seal material candidates for use in the new generation of nonflammable chlorotrifluoroethylene (CTFE) hydraulic fluid was performed. Studies were also carried out on new or improved sealing devices capable of operating in CTFE at pressures up to 8,000 psi.

Out of a number of potential material candidates, three materials were selected for evaluation on a new test vehicle specifically designed to simulate conditions of rod seal operation in CTFE fluid.

The selected materials were:

- Greene Tweed's Arlon 1000 (PEEK)
- Dupont's Vespel SPI
- Bal Seal's GFD (PTFE plus graphite)

Coefficients of friction and wear, and resistance to "cold flow" (extrusion) under pressure and at a temperature of 275°F served as the main criteria for material ranking.

The test was conducted in a disc brake type fixture. Two discs were fabricated; one with a hard chrome surface and the other with a tungsten carbide surface. One side of each disc was ground to an 8 rms finish and the other side to a 12 rms finish. One disc at a time was cycled through a 120° arc at a peak velocity of 12 in/sec. The material samples were put under a load of 56 pounds. A load higher than this would extrude filled teflon. The friction coefficients presented in Table 3 represent the average values for the 8 and 12 rms finishes.

The wear characteristics of each material are presented in Table 4.

Current hydraulic seal designs were reviewed and new concepts studied. The high pressures and reduced lubricity expected in CTFE systems necessitate an engineering approach to seal design. We found that for PEEK and Vespel, currently available finite element structural programs can be employed in the design process to calculate stresses and deflections; although, the long term effect of pressure, temperature, and fluid on the structural integrity of the materials is as yet unknown. PTFE, however, cannot be handled with a linear code because of its apparent visco-elastic behavior. Utilizing a different modeling technique, the linear program employed predicts that with proper confinement, materials such as PTFE could possibly be used under the conditions anticipated in hydraulic applications using CTFE fluids.

TABLE 3
SUMMARY OF FRICTION COEFFICIENTS

MATERIAL	DRY		IN CTFE AT ROOM TEMP		CTFE @ 275°F	
	SLIDING	STATIC	SLIDING	STATIC	SLIDING	STATIC
VESPEL						
Hard Chrome	0.26	N/O	0.04	0.16	0.15	0.20
Tungsten Carbide	0.26	N/O	0.044	0.15	0.10–0.13	0.14–0.18
PEEK						
Hard Chrome	0.21	N/O	0.06	0.15	0.16	0.16
Tungsten Carbide	0.18	N/O	0.064	0.18	0.12–0.14	0.16–0.20
GFD						
Hard Chrome	0.19	N/O	0.06	0.12	0.063	0.095
Tungsten Carbide	0.16		0.04	0.11	0.056–0.06	0.072

N/O Not Observed

TABLE 4
AVERAGE VOLUMETRIC WEAR RATES

(Based On Slope of Travel vs. Wear Curve)

		AVERAGE WEAR RATE (in^3/in of travel)	
		SPEC #1 (Smooth)	SPEC #2 (Rough)
Vespel			
	Hard Chrome	0.952×10^{-9}	0.613×10^{-9}
	Tungsten Carbide	0.857×10^{-9}	0.607×10^{-9}
PEEK			
	Hard Chrome	0.469×10^{-9}	0.432×10^{-9}
	Tungsten Carbide	0.558×10^{-9}	0.347×10^{-9}
GFD			
	Hard Chrome	0.387×10^{-9}	0.561×10^{-9}
	Tungsten Carbide	1.32×10^{-9}	2.38×10^{-9}

A simple, one piece rod seal configuration was selected for analysis and design. This configuration employs an "0" ring for secondary sealing. The seal is pressure balanced to reduce the radial load acting on the rod. This in turn reduces the heat generated at the seal-to-rod interface and indirectly aids in the improvement of wear and leakage characteristics. Most of the current hydraulic seals put little emphasis on this aspect of seal design. Figure 1 shows the design of the rod seal.

The piston ring represents a less critical component because excessive leakage does not result in the loss of hydraulic fluid from the system and is noticed only in the deterioration of actuator performance. For this application, a three piece piston ring design was suggested. The central ring is solid and made of filled PTFE (Rulon "J"). Split rings on each side made of PEEK provide the confinement required to avoid extrusion. Figure 2 represents the design of the high pressure piston seal set.

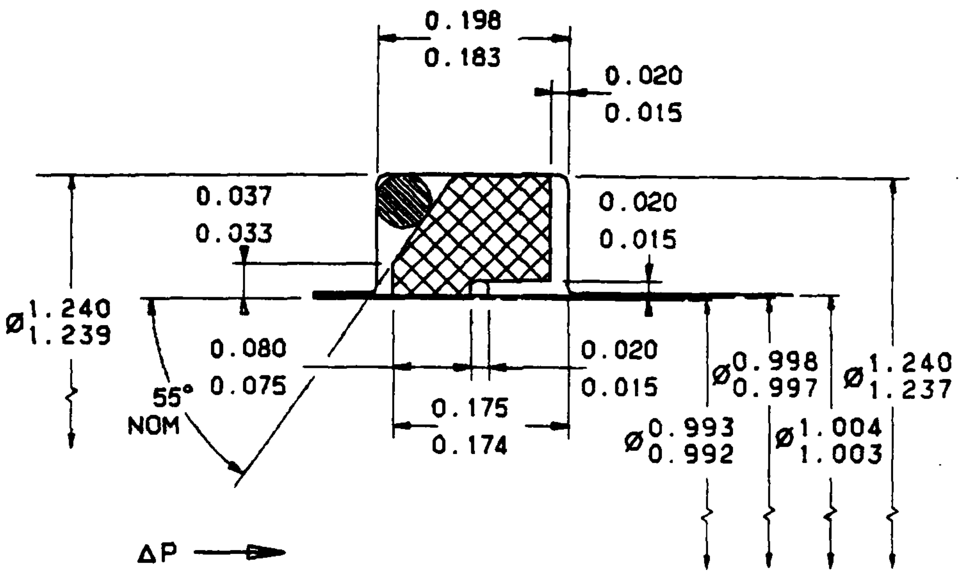
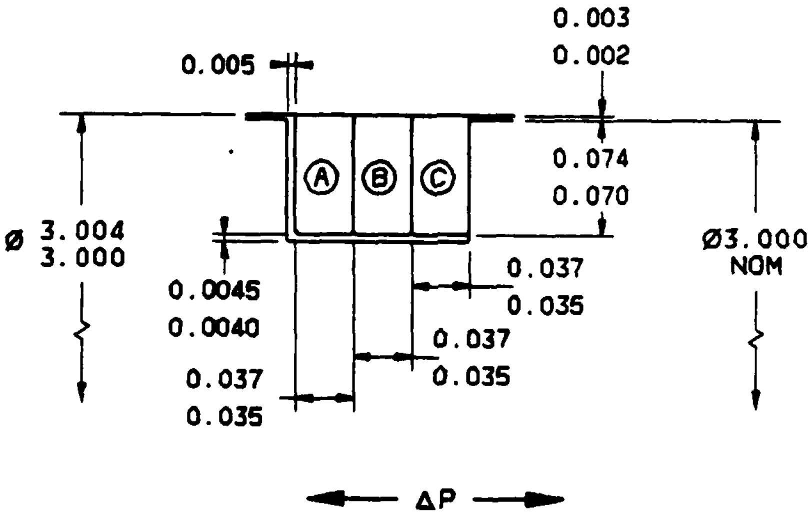


FIGURE 1. ROD SEAL DESIGN



MATERIALS: A - PEEK OR OTHER PLASTIC

B - RULON "J"

FIGURE 2. HIGH PRESSURE PISTON RING SET

6.2 Conclusions

The results of the MTI program lead to the following conclusions:

- The lowest friction was produced by filled teflon.
- Both PEEK and Vespel retained their shape during wear tests, filled teflon extruded.
- The lowest wear was registered with PEEK.
- No significant differences were observed between chrome plate and tungsten carbide coatings in the wear tests, with the exception of filled teflon whose wear rate against tungsten carbide was high.
- Current linear programs can be used in the design of seals made with modern plastics, such as PEEK, which exhibit a low degree of visco-elastic behavior.
- More data on the mechanical properties of modern plastics are needed to gain a higher degree of confidence in the analysis.
- Materials exhibiting a high degree of visco-elasticity require improved nonlinear codes to enhance the design process.
- The lubricity of CTFE, with viscosities less than one centipoise at high temperatures, falls in the regime of boundary lubrication. This is shown by the increase in coefficients of friction at 275°F.

7.0 PARKER SEAL SUBCONTRACT

Parker Seal, a division of the Parker Hannifin Corporation, provided services on a subcontract basis. Their task was to provide basic test data to aid in the selection of seal candidates. The test data provided was in the following areas:

1. Fluid compatibility of elastomeric and thermoplastic materials
2. Static extrusion resistance of seal configurations.
3. Dynamic rod testing of seal configurations.

7.1 Material Compatibility Evaluation

Physical properties determination after fluid exposure is essential in the development of sealing systems; therefore, th. materials of the seals were subjected to a compatibility screening test.

7.1.1 Material Compatibility Testing

7.1.1.1 Compatibility Test Procedure

The material compatibility evaluation included physical properties tests conducted according to the applicable ASTM test method. The properties measured are as follows, when applicable:

a. Tensile strength

b. Ultimate elongation

c. 100 percent modulus

d. Hardness

e. Compression set

f. Volume swell

The fluid immersion test was conducted for 168 hours at 275°F in the fully formulated CTFE A02 fluid. The test specimens were standard size O-rings or ASTM dumbbells. Table 5 tabulates the materials tested.

TABLE 5
MATERIALS TESTED FOR COMPATIBILITY

VENDOR	MATL. I.D.	SAMPLE TYPE	DESCRIPTION
SHAMBAN	20073	2	ETHYLENE PROPYLENE GRAY
SHAMBAN	1501T	2	GLT FLUOROCARBON LOW TEMPERATURE
SHAMBAN	1108	2	EP/PNF BLEND
STILLMAN	SR789-90	1	ETHYLENE PROPYLENE
STILLMAN	SR786-90	1	ETHYLENE PROPYLENE
GREEN TWEED	818	2	ETHYLENE PROPYLENE SEAL COMPOUND
GREEN TWEED	959	2	ETHYLENE PROPYLENE WIPER COMPOUND
CE CONOVER	XF785	1	PHOSPHONITRILIC FLUOROELASTOMER
PARKER SEAL	E515-80	2	ETHYLENE PROPYLENE NAS1613
PARKER SEAL	E692-75	2	ETHYLENE PROPYLENE - STEAM COMPOUND
PARKER SEAL	E740-75	2	ETHYLENE PROPYLENE - RADIATION RESISTANT
PARKER SEAL	E962-90	2	ETHYLENE PROPYLENE - GEOTHERMAL COMPOUND
PARKER SEAL	F953-70	2	PHOSPHONITRILIC FLUOROELASTOMER - GREEN (PNF)MIL-P-87175
PARKER SEAL	F988-65	2	PHOSPHONITRILIC FLUOROELASTOMER - BLACK
PARKER SEAL	V835-75	2	FLUOROCARBON - LOW TEMP - MIL-R-83485
PARKER SEAL	V747-75	2	FLUOROCARBON - MIL-R-83248 (BLACK)
PARKER SEAL	V884-75	2	FLUOROCARBON - MIL-R-83248 (BROWN)
PARKER SEAL	V975-100	2	FLUOROCARBON
PARKER SEAL	V1041-85	2	AFLAS
PARKER SEAL	HI 23-65	2	HYPALON
PARKER SEAL	L677-70	2	FLUOROSILICONE - MIL-R-25988
PARKER SEAL	Y1038-70	2	EPICHLOROHYDRIN
PARKER SEAL	C873-70	2	NEOPRENE AMS 3209E
DUPONT	4079	2	KALREZ
PARKER SEAL	PEEK	3	POLYETHERETHERKETONE
GENERAL ELECTRIC	ULTEM	3	POLYETHERIMIDE
1C1	PES	3	POLYETHERSULFONE
DART INDUSTRIES	XYDAR	3	POLYESTER LIQUID CRYSTAL

7.1.1.2 Compatibility Test Results

ELASTOMERS

Of the elastomers tested, the low temperature fluorocarbon compounds display the best resistance to the CTFE fluid. The compounds do show a fairly high volume swell and tensile loss. The low temperature properties are improved by about 10°C (18°F) due to the swelling in the CTFE fluid. Both the black and brown MIL-R-83248, Type I, Class 1 materials show compatible resistance to the CTFE fluid. The brown, mineral filled compound does have a slightly lower volume swell. The uniquely formulated high durometer compound V975 100 displays good physical properties retention and much lower volume swell than previous fluorocarbon compounds. The short elongation and normal low temperature properties may cause difficulties in -65°F systems.

The ethylene propylene (EP) materials and the fluorosilicone materials would be the second choice for use with CTFE. The ethylene propylene compounds show a high volume swell and tensile strength loss. The fluorosilicone compounds (MIL-R-25988) show a high compression set and tensile strength loss.

The Shamban 20073 gray ethylene propylene displays a degradation of physical properties but displays good compression set. The Stillman SR786-90 ethylene propylene compound has a similar degradation profile but poorer compression set. The Stillman SR789-90 displays better physical properties retention but much poorer compression set.

The Greene Tweed 818 ethylene propylene has good physical properties retention but poor compression set. The volume swell is lower than that of most ethylene propylene compounds.

The Shamban 1108 ethylene propylene and PNF blend compound displays a profile similar to standard ethylene propylene compounds. The GLT fluorocarbon based compound 1501T displays good properties similar to most GLT compounds.

The PNF material is not recommended for use in CTFE fluid due to the high volume swell and compression set and the erosion of the physical properties by the fluid.

The Hypalon, epichlorohydrin, and neoprene compounds display degradation of physical properties and compression set.

The Kalrez and the Aflas compounds both display degradation of physical properties and high volume swell in the CTFE fluid.

The physical properties of the original and aged elastomers may be found in Table 6.

THERMOPLASTICS

The four thermoplastic materials (PES, PEEK, ULTEM, XYDAR) tested exhibited minor changes in physical properties. The elongation in both the original and aged samples was erratic but did indicate some losses.

The physical properties of the original and aged thermoplastic materials can be found in Table 6.

7.2 Fluid Matrix Testing

To determine the effects of the additives used in the base CTFE fluid package, additional testing of selected elastomeric compounds was performed with four CTFE fluid formulations obtained from WPAFB. The fluid formulations are defined as follows:

Batch No.	Formulation
MLO 83-326	Neat CTFE
MLO 85-285	CTFE + 0.05% 3M ADDITIVE
MLO 85-286	CTFE + 0.5% BARIUM SULFONATE
MLO 85-287	CTFE + 0.05% 3M & 0.5% BARIUM SULFONATE

Three elastomeric compounds were subjected to the compatibility tests at temperatures of 275, 300, and 350°F. The selected materials were V835-75 GLT fluorocarbon, E692-75 ethylene propylene, and PNF 200 (PN1487). The PNF material was received from the University of Dayton and was molded according to the recommended procedure.

The 168 hour fluid immersion test at 275°F according to the procedure described in Paragraph 7.1.1.1 followed.

The V835-75 compound displayed the best resistance to all four CTFE fluids with only slight increase in deterioration of properties when the test temperature was raised from 275 to 350°F. The effect of temperature was much more pronounced on the ethylene propylene material with a large drop in physical properties at 275 to 300°F test temperatures.

The PNF material displayed relatively poor resistance to the fluids at all test temperatures and was completely destroyed at 350°F.

The barium sulfonate additive appears to break down at temperatures above 275°F, forming a black residue, sulfur smells, and acidic conditions. The ethylene propylene compounds are affected by the above at the higher test temperatures.

The compounds do not seem to be affected by the addition of the 3M additive to the CTFE fluid. Also there is no combined effect or reaction between both additives.

TABLE 6
MATERIAL COMPATIBILITY WITH CHLOROTRIFLUOROETHYLENE

	SHAMBAN 20073 GREY EP	SHAMBAN 1501T GLT	SHAMBAN 1108 EP/PNE	STILLMAN SR789-90 EP	STILLMAN SR786-90 EP	GREENE TWEED 818 EP
ORIGINAL PHYSICAL PROPERTIES						
HARDNESS, TYPE A, PTS	77	74	75	88	87	77
TENSILE STRENGTH, PSI	1500	1780	1180	1530	1950	1370
ELONGATION, %	348	136	282	191	147	195
MODULUS @ 100%, PSI	450	1350	640	1040	1270	636
SPECIFIC GRAVITY	1.04	1.75	1.12	1.31	1.13	1.21
FLUID AGING - CTFE FLUID 168 HOURS @ 135°C (275°F)						
HARDNESS, TYPE A, (CHG, PTS)	65(-12)	64(-10)	69(-6)	76(-12)	75(-12)	57(-20)
TNSILE STRENGTH, PSI (CHG, %)	473(-68)	1290(-28)	898(-24)	1180(-23)	931(-52)	1140(-17)
ELONGATION, % (CHG, %)	164(-53)	106(-22)	167(-41)	117(-39)	88(-40)	183(-6)
MODULUS @ 100%, PSI (CHG, %)	336(-25)	1240(-8)	636(-1)	1030(-1)	--	462(-27)
VOLUME CHANGE, %	+32.8	+34.0	+37.3	+30.5	+32.8	+18.4
COMPRESSION SET IN CTFE FLUID 168 HOURS @ 135°C (275°F)						
% OF ORIGINAL DEFLECTION	10.3	-4.6	37.3	58.1	36.2	67.8
FLUID BATCH MLO#	85-166	85-166	85-166	85-166	85-166	

TABLE 6 (continued)
MATERIAL COMPATIBILITY WITH CHLOROTRIFLUOROETHYLENE

	PARKER HYPALON H723-65	PARKER HYDRIN Y1038-70	PARKER NEOPRENE C873-70	DUPONT KALREZ 4079	PARKER AFLAS Y1041-85
ORIGINAL PHYSICAL PROPERTIES					
HARDNESS, TYPE A, PTS	66	67	72	78	82
TENSILE STRENGTH, PSI	3030	1370	2060	1970	2480
ELONGATION, %	318	321	293	138	155
MODULUS @ 100%, PSI	427	475	595	1050	1550
FLUID AGING - CTFE FLUID 68 HOURS 135°C (275°F)					
HARDNESS, TYPE A, (CHG, PTS)	77(+11)	45(-22)	81(+9)	54(-24)	54(-28)
TENSILE STRENGTH, PSI (CHG, %)	411 (-86)	418(-69)	241 (-88)	592 (-70)	508 (-80)
ELONGATION, % (CHG, %)	58(-82)	300(-7)	14(-95)	128(-7)	135(12)
MODULUS @ 100%, PSI (CHG, %)	---	138(-71)	---	342(-67)	289(-81)
VOLUME CHANGE, %	+13.3	+10.8	+10.0	+65.0	+159.4
COMPRESSION SET IN CTFE FLUID 68 HOURS @ 135°C (275°F)					
% OF ORIGINAL DEFLECTION	80.0	90.5	60.0	8.6	-87.2*
FLUID BATCH MLO#	84-343	84-343	84-343	84-343	84-343

* LARGER THAN ORIGINAL

TABLE 6 (continued)
MATERIAL COMPATIBILITY WITH CHLOROTRIFLUOROETHYLENE

	GREENE TWEED EP	CONOVER XF785 PNF	G. E. PEI UTLEM	DART XYDAR 500	PARKER PEEK W4685	TCT PES
ORIGINAL PHYSICAL PROPERTIES						
HARDNESS, TYPE A, PTS	95	72	--	--	--	--
TENSILE STRENGTH, PSI	1520	1290	14180	19950	12830	11870
ELONGATION, %	120	198	89.5	0.57	35.9	54
MODULUS @ 100%, PSI		695				
FLUID AGING - CTFE FLUID 68 HOURS @ 135°C (275°F)						
HARDNESS, TYPE A, (CHG, PTS)	84(-11)	55(-17)	--	--	--	--
TENSILE STRENGTH, PSI (CHG, %)	215(-86)	120(-91)	15150(+68)	17170(-13.9)	13870(+8.1)	11360(-4)
ELONGATION, % (CHG, %)	32(-73)	83(-58)	14.5(-83.7)	.57(0)	29.8(-12.0)	23(-57)
VOLUME CHANGE, %	+28.1	+31.6	+0.06	+0.14	+.28	-0.4
COMPRESSION SET IN CTFE FLUID 168 HOURS @ 135°C (275°F) % OF ORIGINAL DEFLECTION	35.0	72.7	--	--	--	--
FLUID BATCH MLO#	84-343	84-343	84-343	84—343	85-243	85-287

TABLE 6 (continued)
MATERIAL COMPATIBILITY WITH CHLOROTRIFLUOROETHYLENE

	PARKER PNF F953-70	PARKER PNF F988-65	PARKER EP E740-70	PARKER GLT V835-75	PARKER FLUORO-SILICONE L677-70
ORIGINAL PHYSICAL PROPERTIES					
HARDNESS, TYPE A, PTS	64	65	70	77	66
TENSILE STRENGTH, PSI	1300	890	1660	1820	990
ELONGATION, %	202	120	199	146	175
MODULUS @ 100%, PSI	582	710	602	1250	533
FLUID AGING - CTFE FLUID 168 HOURS @ 135°C (275°F)					
HARDNESS, TYPE A, (CHG, PTS)	48(-16)	50(-15)	57 (-13)	68(-9)	54(-12)
TENSILE STRENGTH, PSI (CHG, %)	256(-80)	256(-82)	886(-47)	1200(-34)	486(-51)
ELONGATION, % (CHG, %)	126(-38)	119(-1)	182(-9)	138(-5)	174(-1)
MODULUS @ 100%, PSI (CHG, %)	190(-67)	125(-82)	280(-53)	770(-38)	257(-52)
VOLUME CHANGE, %	+51.1	+57.7	+47.9	+38.9	+19.0
COMPRESSION SET IN CTFE FLUID 168 HOURS @ 135°C (275°F) % OF ORIGINAL DEFLECTION	88.2	58.8	6.7	0.1	48.0
LOW TEMPERATURE PROPERTIES TEMPERATURE RETRACTION ASTM D1329 TRIO °C (°F)	--	--	--	-29°C(-22°F)	--
AFTER AGING IN CTFE FLUID 168 HOURS @ 135°C (275°F) LOW TEMPERATURE PROPERTIES TEMPERATURE RETRACTION ASTM D1329 TRIO°C (°F)	--	--	--	-39°C(-39°F)	--
FLUID BATCH MLO#	84-343	84-343	84-343	84-343	84-343

TABLE 6 (continued)
MATERIAL COMPATIBILITY WITH CHLOROTRIFLUOROETHYLENE

	PARKER E/P E962-90	PARKER E/P E515-80	PARKER E/P E692-75	PARKER V747-75	PARKER V975-100	PARKER V884-75
ORIGINAL PHYSICAL PROPERTIES						
HARDNESS, TYPE A, PTS	92	83	79	76	96	74
TENSILE STRENGTH, PSI	1810	1380	1480	1720	2320	2100
ELONGATION, %	67	170	154	199	53	205
MODULUS @ 100%, PSI	--	796	886	796	--	802
AGING IN NEW CTFE FLUID 168 HOURS @ 135°C (275°F)						
HARDNESS, TYPE A, PTS (CHG, PTS)	82(-10)	58(-27)	67(-12)	66(-10)	94(-2)	67(-7)
TENSILE STRENGTH, PSI (CHG, %)	905(-50)	1320 (-4)	986 (-33)	1305 (-24)	2220 (-4)	1510(-28)
ELONGATION, % (CHG, %)	56(-16)	245(+44)	138(-10)	205(+3)	65(+23)	183(-11)
MODULUS @ 100%, PSI (CHG, %)	--	232(-71)	551(-38)	446(-44)	--	558(-30)
BLUME CHANGE, %	+28.5	+41.0	+32.4	+37.4	+19.7	+33.5
COMPRESSION SET IN CTFE FLUID 70 HOURS @ 135°C (275°F) % OF ORIGINAL DEFLECTION	25.5	13.3	4.8	-5.7	24.5	-3.8
FLUID BATCH MLO#	84-343	84-343	84-343	84-343	84-343	84-343

TABLE 6 (continued)
MATERIAL COMPATIBILITY WITH CHLOROTRIFLUOROETHYLENE

	CAMERON CAMLAST 109-04	CAMERON CAMLAST 109-80	PRECISION RUBBER EP 3317	PRECISION RUBBER FLUOROSILICONE 11648		PRECISION RUBBER VITON 19318
ORIGINAL PHYSICAL PROPERTIES						
HARDNESS, TYPE A, PTS	79	82	72	79		78
TENSILE STRENGTH, PSI	3060	2280	1360	617		1100
ELONGATION, %	229	135	323	108		211
MODULUS 100%, PSI	1260	1674	347	588		618
SPECIFIC GRAVITY	1.25	1.21	--	--		--
TEMP. RT10, °F	+1	-14	--	--		--
FLUID AGING - CTFE FLUID 168 HOURS @ 135°C (275°F)						
HARDNESS, TYPE A, (CHG, PTS)	80(+1)	80(-2)	46(-26)	66(-13)		65(-13)
TENSILE STRENGTH, PSI (CHG, %)	3050(-0-)	1250(-45)	634(-53)	502(19)		775(-30)
ELONGATION, % (CHG,%)	155(-32)	72(-47)	437(+35)	139(+29)		221(+5)
MODULUS @ 100%, PSI (CHG, %)	1812(+44)	--	-113(-67)	376(-36)		378(-39)
VOLUME CHANGE, %	+8.3	+22.1	+31.3	+17.8		+31.2
COMPRESSION SET IN CTFE FLUID 168 HOURS @ 135°C (275°F)						
% OF ORIGINAL DEFLECTION	71.4	45.7	87.2	41.7	8.3	
FLUID BATCH - MLO#	84-453	84-453	86-114	86-114	86-114	

The test results are summarized in Table 7.

7.3 Static Extrusion Test

A static extrusion test was performed on each seal configuration candidate. The test was used to categorize the seal extrusion resistance to proof pressure and a sustained operating pressure at a temperature of 275°F.

7.3.1 Extrusion Test Procedure

A static extrusion test was conducted with concentric radial gaps of 0.004 and 0.008 inch.

The test specimen was installed into the fixture shown in Figure 3. A pressure of 12,000 psi was applied for a period of 2 minutes at room temperature.

With zero pressure, the fixture and the test specimen temperatures were raised to 275°F. The fixture required approximately 2 hours to stabilize at this temperature.

A hydraulic pressure of 8,000 psi was applied to the seals for a period of 2 hours.

The specimen was removed from the fixture and the extrusion measured and recorded.

7.3.2 Extrusion Test Results

All the high modulus plastics tested (e.g. PEEK, Vespel, Torlon, PES) exhibited no extrusion at the 0.008 inch gap. The highly loaded teflons had measured extrudite of approximately 0.060 inch.

Refer to Table 8 for tabulated results of seal configurations tested. Refer to Appendix D for test seal photographs.

7.4 Dynamic Rod Test

The Dynamic Rod Test is a comparative type test used to evaluate the dynamic characteristics of a seal configuration.

Every rod seal procured for this program was submitted to this prescreening test.

7.4.1 Dynamic Rod Test Procedure

Description of the Test Equipment

The rod (chew) tester is used as a dynamic screening tester. The gland grooves are designed in accordance with MIL-G-5514 for a -214 O-ring (Refer to Figures 4 and 5.) The gland is extra wide to provide space for various backup ring thicknesses.

TABLE 7
FLUID MATRIX MATERIAL COMPATIBILITY

ORIGINAL PHYSICAL PROPERTIES	V835-75 VITON-GLT
HARDNESS, TYPE A, PTS.	73
TENSILE STRENGTH, PSI	1960
ELONGATION %	159
MODULUS @ 100%, PSI	1130

	MLO 83-326 NEAT CTFE	MLO 85-285 CTFE + 0.05% 3M	MLO 85-286 CTFE + 0.5% BSN	MLO 85-287 CTFE 0.05% 3M 0.5% BSN
FLUID AGING 168 HOURS @ 275°F				
HARDNESS, TYPE A,(CHG.,PTS.)	65(-8)	65(-8)	65(-8)	65(-8)
TENSILE STRENGTH, PSI (CHG., %)	1380(-30)	1330(32)	1270(-35)	1260(-36)
ELONGATION, % (CHG., %)	151(-5)	149(-6)	151(-5)	149(-6)
MODULUS @ 100%, PSI (CHG.,%)	755(-33)	729(35)	712(-37)	687(-39)
VOLUME CHANGE, %	+38.4	+40.1	+39.5	+41.6
COMPRESSION SET 168 HOURS @ 275°F % OF ORIGINAL DEFLECTION	-5.9	-4.9	-5.9	-5.9
TEST SPECIMEN 2-214 0-RING				
FLUID AGING 168 HOURS @ 350°F				
HARDNESS, TYPE A, (CHG.,PTS.)	65(-8)	65(-8)	64(-9)	64(-9)
TENSILE STRENGTH, PSI (CHG., %)	1170(-40)	1280(-35)	1130(-42)	1170(-40)
ELONGATION, % (CHG., %)	150(-6)	150(-6)	152(-4)	160(+1)
MODULUS 100%, PSI (CHG.,%)	629(-44)	653(-42)	590(-48)	574(-49)
VOLUME CHANGE, %	+40.1	+40.3	+41.0	+40.9
COMPRESSION SET 168 HOURS @ 350°F % OF ORIGINAL DEFLECTION	5.9	2.9	7.8	8.8
TEST SPECIMEN 2-214 0-RING				

TABLE 7 (continued)
FLUID MATRIX MATERIAL COMPATIBILITY

ORIGINAL PHYSICAL PROPERTIES	E692-75 EPDM
HARDNESS, TYPE A, PTS.	72
TENSILE STRENGTH, PSI	1710
ELONGATION %	200
MODULUS @ 100%, PSI	692

	MLO 83-326 NEAT CTFE	MLO 85-285 CTFE + 0.05% 3M	MLO 85-286 CTFE + 0.5% BSN	MLO 85-287 CTFE 0.05% 3M 0.5% BSN
FLUID AGING 168 HOURS 275°F				
HARDNESS, TYPE A, (CHG.,PTS.)	60(-12)	60(-12)	60(-12)	60(-12)
TENSILE STRENGTH, PSI (CHG., %)	1170(-32)	1110(-35)	1160(-32)	1110(-35)
ELONGATION, % (CHG., %)	191(-5)	186(-7)	184(-8)	165(-18)
MODULUS @ 100%, PSI (CHG.,%)	353(-49)	346(-50)	374(-46)	368(-47)
VOLUME CHANGE, %	+30.8	+30.6	+31.9	+32.4
COMPRESSION SET 168 HOURS @ 275°F				
% OF ORIGINAL DEFLECTION	11.4	12.4	11.4	12.4

TEST SPECIMEN 2-214 0—RING

	MLO 83-326 NEAT CTFE	MLO 85-285 CTFE + 0.05% 3M	MLO 85-286 CTFE + 0.5% BSN	MLO 85-287 CTFE 0.05% 3M 0.5% BSN
FLUID AGING 168 HOURS @ 300°F				
HARDNESS, TYPE A, (CHG.,PTS.)	60(-12)	60(-12)	60(-12)	59(-13)
TENSILE STRENGTH, PSI (CHG., %)	639(-63)	783(-54)	1010(-41)	747 (-56)
ELONGATION, % (CHG., %)	141(-30)	162(-19)	176(-12)	161(-20)
MODULUS @ 100%, PSI (CHG.,%)	342(-51)	340(-51)	361(-48)	296(-57)
VOLUME CHANGE, %	+34.4	+33.9	+37.1	+38.5
COMPRESSION SET 168 HOURS @ 300°F				
% OF ORIGINAL DEFLECTION	25.7	23.8	22.9	25.7

TEST SPECIMEN 2-214 0-RING

TABLE 7 (continued)
FLUID MATRIX MATERIAL COMPATIBILITY

ORIGINAL PHYSICAL PROPERTIES	E692-75 EPDM
HARDNESS, TYPE A, PTS.	72
TENSILE STRENGTH, PSI	1710
ELONGATION %	200
MODULUS @ 100%, PSI	692

	MLO 83-326 NEAT CTFE	MLO 85-285 CTFE + 0.05% 3M	MLO 85-286 CTFE + 0.5% BSN	MLO 85-287 CTFE 0.05% 3M 0.5% BSN
FLUID AGING				
168 HOURS @ 350°F				
HARDNESS, TYPE A, (CHG.,PTS.)	50(-22)	50 (-22)	44(-28)	44 (-28)
TENSILE STRENGTH, PSI (CHG., %)	301(-82)	309(-82)	90(-95)	70(-96)
ELONGATION, % (CHG., %)	219(+10)	207(+4)	187(-7)	145(-28)
MODULUS @ 100%, PSI (CHG.,%)	129(-81)	141(-80)	69(-90)	61(-91)
VOLUME CHANGE, %	+76.5	+69.3	+55.1	+56.1
COMPRESSION SET				
168 HOURS @ 350°F				
% OF ORIGINAL DEFLECTION	57.1	63.8	81.9	80.0
TEST SPECIMEN 2-214 0-RING				
FLUID AGING				
168 HOURS @ 275°F				
HARDNESS, TYPE A, (CHG.,PTS.)	58(-17)	57(-18)	57(-18)	58(-17)
TENSILE STRENGTH, PSI (CHG., %)	418(-71)	412(-71)	475(-67)	436(-70)
ELONGATION, % (CHG., %)	141 (+2)	140(+1)	149(+8)	136(-1)
MODULUS @ 100%, PSI (CHG.,%)	315(-69)	298(-70)	31(-69)	320(-68)
VOLUME CHANGE, %	+31.0	+32.1	+40.3	+38.8
COMPRESSION SET				
168 HOURS @ 275°F				
% OF ORIGINAL DEFLECTION	52.4	53.3	51.4	50.5
TEST SPECIMEN 2-214 0-RING				

TABLE 7 (continued)
FLUID MATRIX MATERIAL COMPATIBILITY

ORIGINAL PHYSICAL PROPERTIES	E692-75 EPDM
HARDNESS, TYPE A, PTS.	75
TENSILE STRENGTH, PSI	1430
ELONGATION %	138
MODULUS @ 100%, PSI	1000

	MLO 83-326 NEAT CTFE	MLO 85-285 CTFE + 0.05% 3M	MLO 85-286 CTFE + 0.5% BSN	MLO 85-287 CTFE 0.05% 3M 0.5% BSN
~~FLUID AGING~~				
168 HOURS @ 300°F				
HARDNESS, TYPE A, (CHG.,PTS.)	51(-24)	50(-25)	37(-38)	50(-25)
TENSILE STRENGTH, PSI (CHG., %)	172(-88)	138(-90)	60(-96)	201(-86)
ELONGATION, % (CHG., %)	96(-30)	87(-37)	60(-54)	114(-18)
MODULUS @ 100%, PSI (CHG.,%)	—	—	—	192(-81)
VOLUME CHANGE, %	+31.3	+30.2	+35.3	+37.2
COMPRESSION SET				
168 HOURS @ 300°F				
% OF ORIGINAL DEFLECTION	71.4	77.1	70.5	70.5
TEST SPECIMEN 2-214 0-RING				
FLUID AGING				
168 HOURS @ 350°F				
HARDNESS, TYPE A, (CHG.,PTS.)				
TENSILE STRENGTH, PSI (CHG., %)		DESTROYED		
ELONGATION, % (CHG., %)				
MODULUS @ 100%, PSI (CHG.,%)				
VOLUME CHANGE, %				
COMPRESSION SET				
168 HOURS @ 350°F				
% OF ORIGINAL DEFLECTION				
TEST SPECIMEN 2-214 0-RING				

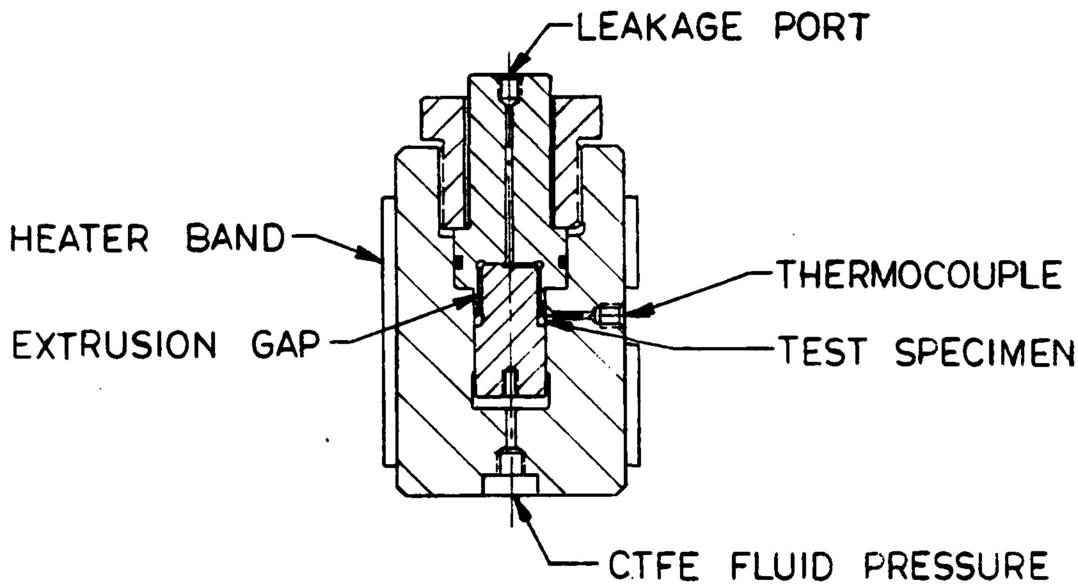


FIGURE 3. EXTRUSION TEST FIXTURE

TABLE 8

EXTRUSION TEST RESULTS
PISTON FIXTURE WITH MIL-H-83282 OIL

TEST NO.	IDENTIFICATION	MEASURED ESTRUDITE (IN) 0.004 IN. GAP	0.008 IN. GAP
1	BAL SEAL FSU-305-(OP)-214 GFP	0.030	0.130
2	ADVANCED PRODUCTS 46146	0.030	EXTRUDED
3	ADVANCED PRODUCTS 46152	0.010/0.015	0.070
4	ADVANCED PRODUCTS 46164	0.050	1/4

ROD TYPE FIXTURE WITH CTFE A02 FLUID

TEST NO.	IDENTIFICATION	0.004 IN. GAP	0.008 IN. GAP
5	GREENE TWEED 265-21400-818-1200	INSTALLATION PROBLEM TEST TO BE REPEATED	
6	PARKER ML1663 BACK-UP W4685 PEEK E868-80 0-RING	ZERO	ZERO
7	TETRAFLUOR TF74S-214 (430) E692-75 0-RING	1/4 BACK UP	1/4
8	PARKER/GNP ML1817 BACK UP 15% PEEK-FILLED TFE E692-75 O-RING	3/32	3/8
9	PARKER/SEAL ML1817 BACK-UP 25% PEEK-FILLED TFE E692-75 0-RING	1/16	1/4
10	PARKER/SEAL ML1817 BACK-UP TFE 4692-75 0-RING	1/16	1/4
11	PARKER/SEAL ML1817 BACK-UP 25% GRAPHITE-FILLED TFE E692-75 0-RING	1/64	1/16

TABLE 8 (continued)

EXTRUSION TEST RESULTS
ROD TYPE FIXTURE WITH CTFE A02 FLUID

TEST NO.	IDENTIFICATION	MEASURED ESTRUDITE (IN) 0.004 IN. GAP	0.008 IN. GAP
12	PARKER/SEAL ML1819 BACK-UP 25% ECKONOL-FILLED TEFLON E692-75 0-RING	1/64	1/16
13	TETRAFLUOR TF548-214-3 SPIRAL BACK-UP E692-75 0-RING	--	ZERO
14	PARKER ML1818 BACK UP XP2715-1 (PES) + E692-75	--	ZERO
15	PARKER ML1818 BACK-UP W4685 PEEK E692-75 0-RING	--	ZERO
16	PARKER ML1818 BACK-UP XP2414--2 PEEK E692-75 0-RING	--	ZERO
17	GREENE TWEED 265--21400-818-1200	VERY FINE EXTRUDITE ON I.D. OF BACKUPS AT 0.004 AND 0.008 GAPS. NEITHER IS MEASURABLE.	
18	BAL SEAL 3L-EH-U305-(OP) -(0.998)GFPM(W.122)X10243 REV B	ZERO	ZERO
19	BAL SEAL 3L-EH-U305-(OP) -(0.998)GFPM(W.122)X10244 REV B	--	ZERO
20	SHAMBAN S35704 PLUS SEAL VITON GLT WITH TORLON BACK-UP	--	ZERO
21	GREENE TWEED 4655-21400-D818	--	1/16

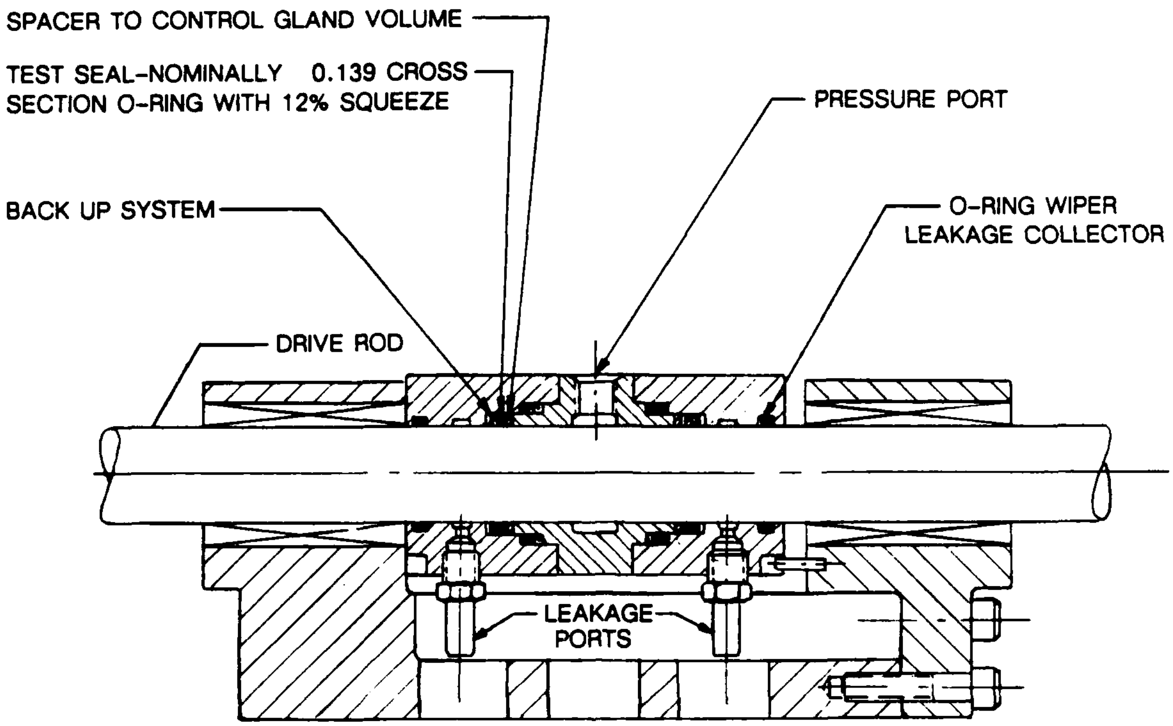


FIGURE 4. ONE-INCH, VARIABLE STROKE ROD TEST FIXTURE

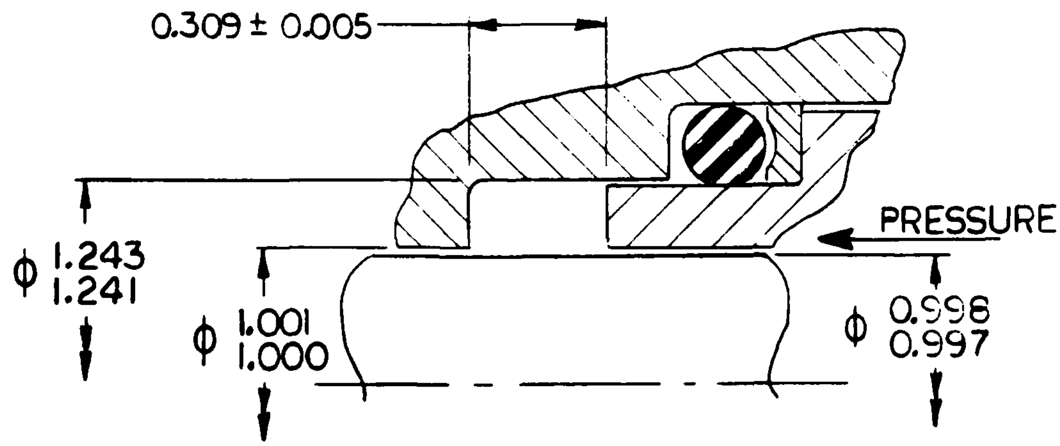


FIGURE 5. ROD TEST FIXTURE GLAND DIMENSIONS

The nominal seal squeeze is 12 percent; the nominal diametral clearance is 0.003 inch. The temperature is provided by an environmental chamber. The rod stroke is 2 inches, the maximum cycle rate is 30 cpm. Three fixtures are available for use during each test.

Leakage is monitored continuously. The maximum allowable leakage rate is 1 ml/1000 cycles.

The basic test procedure followed is as outlined below:

a. The test specimens are visually inspected for defects. After acceptance of the visual inspection, the test specimens are installed into the fixture. Spacers are placed upstream of the seals to provide the proper gland width.

b. The fixtures are placed into an environmental chamber and connected to a hydraulic pressure source. After bleeding the air from the pressure system, the fixtures are pressurized to 12,000 psig for 1 minute. The pressure is then reduced to 8,000 psig. The fixtures are cycled for ten complete cycles. Leakage is then monitored for 1 hour. If no leakage is evident, the test sequence starts.

c. The environmental chamber and fixture temperature is reduced to -65°F with 40 psig pressure applied. After stabilization at -65°F, the pressure is raised to 8,000 psig, and the fixtures are cycled for 10 complete cycles. Leakage at the pressure of 8,000 psig is then monitored for 1 hour and recorded. if the leakage exceeds 4 cc, the test is stopped.

d. The pressure is reduced to 40 psig, and the environmental chamber and fixture temperature is raised to 275°F and allowed to stabilize. Once the temperature has stabilized, cycling starts at the cycling rate of 30 cpm. Following a cycle at 40 psig, pressure is increased to 8,000 psig for the next cycle and then dropped back to 40 psig. This pressure cycling continues throughout the day. The leakage is continuously collected and periodically recorded.

e. The system is completely shut down at the end of the shift and allowed to cool to room temperature. The leakage collected at the end of the shift is recorded. The fixtures are pressurized with 40 psig overnight.

f. The next day, the test is restarted as outlined in paragraphs (d) and (e) above. This sequence is repeated until 100,000 cycles have been accumulated or until seal failure.

g. The test specimens are removed from the fixture and examined. General characteristics of the seal conditions are noted on the data sheet.

7.4.2 Dynamic Rod Test Results

Forty two seal samples were subjected to the Dynamic Rod Test. Because of the delays in setting up the CTFE test, the decision was made to start testing using MIL-H-83282 hydraulic fluid to obtain at least some useful data. Tests on the initial 17 samples were performed using MIL-H-83282 hydraulic fluid. Test seal and back—up configurations were compatible with both the MIL-H-83282 and CTFE fluid.

The test stand was modified to permit starting the test of sample number 18 with the fully formulated CTFE fluid.

In general, seals which used filled teflon to bridge the extrusion gaps were marginal at best. Seal configurations which used structural plastic back-up rings (e.g. PEEK, Torlon, Vespel) successfully completed the 100,000 cycle test.

Seal configurations with the elastomer sliding on the piston rod, particularly in the CTFE fluid, generally failed. Eight seal configurations using structural plastic back-up rings successfully completed the 100,000 cycle test in the CTFE fluid. These were:

SEAL IDENTIFICATION	CYCLES	COMMENTS
Shamban EP Slipper, S30775-3048 Backup #S13122-3012 Backup #S35091 Torlon inner backup S35092-3007 TF74S-214 (430) spacer	118,000	Total leakage 8cc. No significant damage was observed on the sealing elements.
Shamban GLT Slipper S30775-214T-19 Backup #S13122-3012 Backup #S35091 PEEK inner backup, S35092-3005 TF 745-214 (430) spacer	100,354	Total leakage 13cc; 5cc front seal, 8cc rear seal. No significant damage.
Tetrafluor TF 888 S061385-2 PEEK backup 0.050 Thickness TF 745-214 (430) spacer	100,120	Rear seal leaked 35 cc.
Bal Seal 3L-EH-U305-(OP)-(0.998) GFP (W.122) X 10243 Rev B	100,100	14cc of leakage on front seal, 6cc on rear. Good physical appearance.
Shamban GLT slipper, S30775-214T-19 PEEK inner backup S35092-3011 (1 each side) backup S35091 (1 on each side of slipper)	100,000	Total leakage 1cc on the front seal.
Parker GNP slipper, K-Lon809, (ML1839-1) XV2690-18D Ring XP2714-4 Backups, (ML1841)	100,000	7cc leakage on front seal, 17cc on rear. Both slippers badly damaged.
Parker GNP slipper, K-Lon833, (ML1839-1) XV2690-18D Ring XP2714-4 Backups, (ML1841)	100,000	Total leakage 6cc Rear seal looked good, front seal cracked.
American Variseal/Shamban P/N AS-1272	100,493	110cc leakage on rear seal, 31cc on front.

Refer to Table 9 for tabulated test results.

Refer to Appendix D for test seal photographs.

TABLE 9

PRESCREENING
DYNAMIC TEST RESULTS
MIL-H-83282

TEST NO.	IDENTIFICATION	RESULTS
1.	BAL SEAL FSU-305-(OP)-214-GFP SPRING ENERGIZED SEAL	TEST STOPPED FOR EXCESSIVE LEAKAGE AFTER 28,686 CYCLES. SOME NIBBLING AND FEATHERING ON THE HEAL OF THE SEAL.
2.	BAL SEAL FSU-305-(OP)-214-GFP SPRING ENERGIZED SEAL	REPEAT TEST. TEST STOPPED FOR EXCESSIVE LEAKAGE AFTER 41,952 CYCLES. NIBBLING AND FEATHERING ON HEEL OF THE SEAL.
3.	ADVANCED PRODUCTS 46146 SPRING ENERGIZED SEAL	TEST STOPPED AFTER 19,500 CYCLES. LEAKAGE EXCEEDED 50 CC. EXCESSIVE EXTRUSION ON HEEL OF SEAL.
4.	ADVANCED PRODUCTS 46152 SPRING ENERGIZED SEAL	TEST STOPPED FOR EXCESSIVE LEAKAGE AFTER 8,985 CYCLES. NIBBLING AND FEATHERING ON HEEL OF SEAL.
5.	ADVANCED PRODUCTS 46164 SPRING ENERGIZED SEAL	TEST TERMINATED FOR HIGH LEAKAGE AFTER 24,718 CYCLES.LEAKAGE BEGAN AFTER 3200 CYCLES AND REMAINED HIGH THROUGHOUT TEST. AVERAGE RATE OF 3.6 ML/1000 CYCLE WAS RECORDED.
6.	TETRAFLUOR TF1097M-214 N756-75 0-RING ENERGIZED SEAL	TOTAL LEAKAGE PER SEAL WAS 57 ML AT 44,900 CYCLES. TEST TERMINATED AT 76,225 CYCLES WITH EXCESSIVE LEAKAGE OF 218 ML ON ONE SEAL. THE SEAL LIP EXTRUDED OR FOLDED UNDER THE SEAL. DAMAGE MAY HAVE BEEN DUE TO ASSEMBLY. SOME NIBBLING OR FEATHERING ON HEEL OF SEAL.
7.	TETRAFLUOR TF-548-214-2 & 3 VESPEL SPIRAL BACKUPS TEFLON BACKUP N756-75 0-RINGS	COMPLETED THE 100,000 CYCLES WITH A TOTAL OF 12 ML LEAKAGE PER SEAL. THE -2 BACKUP BROKE. THE TEFLON BACKUP HAD MINOR FEATHERING.
8.	FLUOROCARBON AR 10103-214.T. 15%, GRAPHITE, INC. 718 SPRING ENERGIZED SEAL	TEST TERMINATED AFTER 5,092 CYCLES. SEALING LIP EXTRUDED.
9.	FLUOROCARBON AR 10103-214-PH GLASS MOLY, 17-755 SPRING ENERGIZED SEAL	TEST TERMINATED AFTER 13,323 CYCLES. LARGE SECTION OF THE SEAL INSIDE DIAMETER EXTRUDED.
10.	FLUOROCARBON AR 10400-214-PC GLASS MOLY, 304SS SPRING ENERGIZED SEAL	TEST STOPPED AFTER 9,167 CYCLES DUE TO EXCESSIVE LEAKAGE. MINOR EXTRUSION OR FEATHERING AT HEEL OF THE SEAL.

TABLE 9 (continued)

PRESCREENING
DYNAMIC TEST RESULTS
MIL-H-83282

TEST NO.	IDENTIFICATION	RESULTS
11.	FLUOROCARBON AR 10400B-214-TC 20% RYTON CARBON, 304SS SPRING ENERGIZED SEAL	TEST STOPPED AFTER 3,600 CYCLES. SEVERE DAMAGE TO SEALING LIP.
12.	FLUOROCARBON AR 10401-214.C. 15% GRAPHITE 304SS SPRING ENERGIZED SEAL	TESTS STOPPED AFTER 1,820 CYCLES. SEVERELY EXTRUDED.
13.	FLUOROCARBON AR 10401-214-PC	TEST TERMINATED AFTER 11,150 CYCLES. SEVERE EXTRUSION.
14.	SHAMBAN S35266 PLUS SEAL WITH TEFLON CODE 19 AND ULTEM BACKUP	TESTS TERMINATED AFTER 25,900 CYCLES. THE HIGH MODULUS (ULTEM) BACKUP FAILED RESULTING IN EXTRUSION OF THE TEFLON.
15.	PARKER SEAL EXPERIMENTAL HARD SHELL SCL SEAL. PEEK AND RUBBER ML-1721	COMPLETED 100,000 CYCLES WITH A TOTAL OF 4 ML LEAKAGE PER SEAL. THE RUBBER ELEMENT LIP WAS FOUND TO BE FRACTURED.
16.	TETRAFLUOR TF888-214 PF-2	COMPLETED 87,000 CYCLES. TEST TERMINATED FOR EXCESSIVE LEAKAGE. INSPECTION OF THE SEALS REVEALED FEATHERED EXTRUSION ON THE I.D. OF EACH SEAL, AND A GRADUAL WEARING OF THE I.D., PARTICULARLY THE REAR SEAL WHICH EXHIBITED THE HIGHEST LEAKAGE.
17.	PARKER ML1817 BACKUP PEEK N756-75 0-RING	SEALS COMPLETED 97,000 CYCLES. TERMINATED FOR EXCESSIVE LEAKAGE. THE GLAND WIDTH WAS FOR A DOUBLE BACKUP. THE SEAL PACKAGE USED A SINGLE BACKUP. THIS MAY HAVE ATTRIBUTED TO THE EXCESSIVE WEAR OF THE 0-RING. THE TEST TO BE REPEATED WITH CORRECT GLAND WIDTHS.

PRESCREENING
DYNAMIC TEST RESULTS
A02 CTFE FLUID

TEST NO.	IDENTIFICATION	RESULTS
18.	GREENE TWEED SEAL 265-21400-818-1200	EXCESSIVE LEAKAGE AT 30,908 CYCLES. PRESSURE SIDE OF REAR SEAL SEVERELY CHEWED. SEAL EVENTUALLY COLLAPSED.
19.	PARKER GNP SEAL 25% GRAPHITE FILLED TEFLON 2-214 O-RING E692-75	EXCESSIVE LEAKAGE AT 7,000 CYCLES. I.D. OF THE BACKUP EXTRUDED SEVERELY. O-RING CHUNKED OUT.

TABLE 9 (continued)

PRESCREENING
DYNAMIC TEST RESULTS
A02 CTFE FLUID

TEST NO.	IDENTIFICATION	RESULTS
20.	TETRAFLUOR'S VESPEL TF548-214-3 TF74S-214 (430) 2-214 0-RING E692-75	EXCESSIVE LEAKAGE AT 12,350 CYCLES. BACKUPS LOOK GOOD. FACE OF 0-RING SEVERELY CHEWED, PERMITTING HIGH LEAKAGE.
21.	PARKER GNP SEAL 25% PEEK FILLED TEFLON 2-214 0-RING E692-75	I.D. OF BACKUP GAVE AWAY AT 3,769 CYCLES, CAUSING THE 0-RING TO FAIL.
22.	SHAMBAN PLUS SEAL WITH A TORLON INNER RING S35704	STOPPED TEST AT 118,000 CYCLES. 8CC TOTAL LEAKAGE. MOST OF THE DAMAGE OBSERVED WAS ON THE SPACER.
23.	GREENE TWEED SEAL 4635 21400 D818	STOPPED BECAUSE OF CATASTROPHIC FAILURE AT 7085 CYCLES. BACKUPS AND SEALS SEVERELY EXTRUDED.
24.	BAL SEAL 3L-EH-U3D05 (OP) -(0.998) GFP (W.122) X 10243 REV B (WIDE GLAND)	STOPPED AT 100,100 CYCLES. 14 CC FRONT SEAL, 6 CC REAR
25.	DYNABAK DB12-02-214 STILLMAN SR786-90 0-RING TF74S-214 (430) SPACER	CATASTROPHIC FAILURE AT 25,018 CYCLES. FRONT BACKUP SEVERELY EXTRUDED CAUSING SEAL FAILURE. REAR BACKUP EXTRUDED SOME.
26.	SHAMBAN PLUS SEAL WITH GLT AND PEEK INNER RING (3005)	COMPLETED 100,354 CYCLES. LEAKAGE AT FRONT SEAL 5CC LEAKAGE AT REAR SEAL 8CC.
27.	GREENE TWEED CAPPED GT RING 265-21400-818-1260 TF-74S-214 (430) SPACER	CATASTROPHIC FAILURE AT 14,450 CYCLES. REAR SEAL SEVERELY EXTRUDED.
28.	SHAMBAN PLUS SEAL WITH GLT AND PEEK INNER RING, 3011. (BALANCED SYSTEM)	COMPLETED 100,000 CYCLES TOTAL LEAKAGE 1 CC.
29.	TETRAFLUOR TF888S061385-2, VIRGIN PEEK BACK-UP TF-74S-214(430) SPACER	COMPLETED 100,120 CYCLES. REAR SEAL LEAKED 35 CC
30.	PARKER POLY BIPAK W4685, MACHINED ML 1663 ML1822, SEAL ELEMENT XV2690-18	FAILED AT 31,483 CYCLES. BOTH RUBBER SEALS SEVERELY CHEWED. PLASTICS SHELLS LOOKED GOOD.

TABLE 9 (concluded)

PRESCREENING
DYNAMIC TEST RESULTS
A02 CTFE FLUID

TEST NO.	IDENTIFICATION	RESULTS
31.	AMERICAN VARYSEAL/ SHAMBAN P/N S65357	COULD NOT PRESSURIZE BECAUSE OF EXCESSIVE START-UP LEAKAGE.
32.	ADVANCED PRODUCTS CO. P/N 46176	FAILED AT 5,237 CYCLES. THE I.D. OF BOTH SEALS WAS SEVERELY EXTRUDED.
33.	FLUOROCARBON AR 104304	EXCESSIVE LEAKAGE AT 58,894 CYCLES. THE OUTSIDE DIAMETER LIP OF THE REAR SEAL WAS PARTIALLY COLLAPSED.
34.	PARKER GNP SLIPPER, K-LON 809 (ML1839-1) XV2690-18 D RING XP2714-4 BACKUPS, (ML1841)	COMPLETED 100,000 CYCLES. 7 CC LEAKAGE ON FRONT SEAL, 17 CC ON REAR. BOTH SLIPPERS BADLY DAMAGED.
35.	PARKER GNP SLIPPER, K-LON 811 (ML1839-1) XV2690-18 D RING XP2714-4 BACKUPS, (ML1841)	EXCESSIVE LEAKAGE AT 68,247 CYCLES. 82 CC ON FRONT SEAL, 37 CC ON REAR. SLIPPERS AND SEALS BADLY DAMAGED.
36.	PARKER GNP SLIPPER, K-LON 833 (ML1839-1) XV2690-18 D RING XP2714-4 BACKUPS. (ML1841)	COMPLETED 100,100CYCLES TOTAL LEAKAGE 6 CC. REAR SEAL LOOKED GOOD. FRONT SEAL CRACKED.
37.	CONOVER SANDWICH SEAL CEC 4981C-214-D8	CATASTROPHIC FAILURE AT 5,918 CYCLES. BACKUPS SEVERELY DETERIORATED.
38.	AMERICAN VARISEAL/ SHAMBAN P/N AS-1272	TESTED THROUGH 100,493 CYCLES. EXCESSIVE LEAKAGE 110 CC ON REAR SEAL, 31 CC ON FRONT.
39.	PARKER XV2690-18 2-214 0-RING XP2714-1 BACKUPS (SANDWICH)	CATASTROPHIC FAILURE AT 8,655 CYCLES. THE ELASTOMER WAS SEVERELY DETERIORATED.
40.	TETRAFLUOR'S TF 481-7214 (591)	FAILED AT 470 CYCLES, SEAL PACKAGE VIRTUALLY DESTROYED.
41.	KOPPERS GLT/K-304	CATASTROPHIC FAILURE OF REAR SEAL AT 3,144 CYCLES. BOTH SEALS SEVERELY CHEWED.
42.	CAMERON'S CAMLAST 109-80	TESTED THROUGH 100,753 CYCLES. FRONT SEAL LEAKED 2 1/2 CC. REAR SEAL LEAKED 35 CC. SEALS SUFFERED HIGH COMPRESSION SET BECAME SQUARE AND EXTREMELY BRITTLE. REAR SEAL WAS BADLY CHEWED.

8.0 DYNAMIC SEAL EVALUATION CRITERIA

At the time of the proposal, it was not anticipated that Parker Seal would be conducting dynamic testing of seal designs submitted by all the various suppliers. The seal supplier surveys yielded proposed seal configuration responses but very little substantiation of design for the CTFE 8,000 psi hydraulic system.

In reviewing all the current data and responses by the seal suppliers, a list of parameters was considered for the evaluation criteria of seal designs for submission to the screening test as defined by the contract.

Six basic parameters were considered:

1. Material Compatibility
2. Dynamic Chew Test Data
3. Extrusion Data
4. Gland Requirements
5. Seal Design
6. Cost

The following is a review of all six parameters and the reasons for accepting or rejecting them as part of the evaluation criteria.

8.1 Material Compatibility

All materials used within a seal design must be able to function within the CTFE fluid. To establish compatibility, tests have been conducted as outlined in the attached prescreening test procedures. These tests address several of the items listed in the proposal to be part of the evaluation criteria. These parameters are as listed below:

1. Hardness
2. Tensile Strength
3. Modulus
4. Compression Set (as applicable)
5. Volume Changes
6. Fluid Compatibility (changes of physical properties)

7. High Temperature Capability

Based upon compatibility testing conducted under this contract and some published data, the materials used in seal designs shall be formulated from the following polymers:

A. Elastomers: Ethylene Propylene (EPDM) Fluorocarbon (VitonGLT)

B. Thermoplastics:
Filled Teflon
Polyetherimide (Ultem)
Polyamideimide (Torlon)
Polyimide (Vespel)
Polyetheretherketone (PEEK)
Polyethersulfone (PES)
Polyester Liquid Crystal (Xydar)
Nylons

No other materials were accepted unless compatibility to the CTFE fluid was demonstrated.

8.2 Dynamic Chew Testing

The Parker Seal dynamic chew test has proven to be a very effective method for comparison of seal performance.

This type of equipment has been used for several years by the Materials Laboratory at Wright Patterson Air Force Base to qualify seal materials to MIL-P-83461 and MIL-P-25732. They have also used this type of equipment to evaluate seals in the CTFE fluid.

The Chew Test as described in the attached prescreening test procedures evaluated several aspects of the seal performance. These were as follows:

1. High and low temperature performance

2. Leakage or sealing ability

3. Wear

4. Abrasion

5. Friction as related to seal performance

6. Deflections and deformation

7. Nibbling resistance

The Chew Test results were weighted heavily within the evaluation criteria.

8.3 Extrusion Resistance

The ability of the seal to bridge the gap at high pressure is another important characteristic of the seal configuration. The test measures the degree of extrusion into two radial gaps (0.004 and 0.008 inch) at 275°F. Tests to date indicate that if the seal extrudes at the 0.008 gap, seal life in the dynamic test will be very limited. Therefore the degree of extrusion at the 0.008 inch gap was a factor in our evaluation criteria.

8.4 Seal Design

Seal design was also considered as a parameter for the evaluation criteria. The following were some of the seal design characteristics considered.

a. Complexity of Design

   Number of pieces which have to be installed in proper position.

b. Orientation

   Is the seal symmetrical? Can it be installed in either direction?

c. Ease of Installation

   Compared to an O-ring and backup.

d. Seal System

   Is the seal designed to provide for low leakage over the pressure range, or does the seal require a secondary seal of a different design to meet the low leakage requirement?

e. Standard MIL-G-5514 Gland

   Meets all requirements of the specification. Provides interchangeability with other seal configurations.

f. Reduced Gap

   Assumes standard gland with tighter clearances and tolerances resulting in increased hardware cost. The goal of this program is to develop seals which will perform satisfactorily in the standard MIL-G-5514 glands and clearances.

g. Split Gland

If required, would increase weight and hardware cost.

h. Special Gland Design

Would not allow seal interchangeability. Depending on design, could either be advantageous or not with respect to weight and cost.

i. Size

Gland Width: Compared to standard 0, 1, 2 O-ring and backup groove widths. Smaller results in lower weight.

8.5 Cost

Ultimately cost will become a factor in using a given seal design. The first priority is to obtain a seal that works; and therefore, cost of the seal assembly for the screening test evaluation criteria will be a very minor factor.

8.6 Seal Evaluation Factors

If the seal assembly does not contain the approved materials, it will not be considered for test. If the seal contains the approved material, then it will be rated as follows:

1. Chew test will be 80 percent of the rating.
2. Extrusion test will be 10 percent of the rating.
3. Seal design will be 10 percent of the rating.

9.0 CONCLUSIONS

Twenty nine elastomers and nine thermoplastics were tested with the following results:

- A very limited experience with high pressure CTFE servo controls and seal designs amongst airframe manufacturers, users, and seal vendors was evident.
- Only low temperature fluorocarbon and ethylene propylene elastomers exhibited acceptable mechanical properties.
- All thermoplastics exhibited only very minor changes in physical properties.
- High modulus thermoplastic backup rings to prevent seal extrusion are a necessity.
- Filled teflon seals energized by springs or elastomers are performing satisfactorily when supported with high modulus thermoplastic backups.

- Elastomers should not be used in direct contact with moving metal elements.

10.0 SELECTION OF SEAL CONFIGURATIONS FOR THE SCREENING TEST

Throughout the duration of the extrusion and dynamic rod tests, Parker CSD was in contact with the suppliers of the test seals. The test results and the suggested design improvements were discussed resulting in the modifications of the designs, use of improved materials, and retesting of improved designs. Full cooperation of the seal suppliers, including visits to Parker CSD, Irvine facility, has been extended throughout the program.

The test results were evaluated by Parker CSD and the Air Force representatives and the most promising seal configurations were selected for the Phase II Screening Test.

11.0 PHASE II SCREENING TEST

This phase of the program covers the design and fabrication of the test actuators, test fixtures and controls, ordering of the selected test seals, and performing of the screening test.

The review of the actuators and the test system designs was conducted at Wright Patterson AFB on Dec. 2, 1985.

12.0 TEST SYSTEM DESCRIPTION

The closed loop computer controlled test system consists of a 15 gpm, 8,000 psi, variable displacement pumping station, operating 2 test fixtures of 10 actuators each. The test system is shown in Figures 6 through 10. The test system is designed to simulate control surface air loads. The loads are obtained using a concentric torsion bar and tube spring as illustrated in Figures 12 and 13. The actuator end mounts are spherical bearings which provide automatic, reversing, friction moments which are reacted by rod bending and, hence, introduce a reversing rod side load in proportion to the actuator output load, 320 pounds maximum for the small and 690 pounds maximum for the large actuators. Each actuator and load mechanism is mechanically independent permitting individual attention for maintenance and seal replacement. All 10 actuators in each system are driven by a single two stage Electrohydraulic Servovalve. The control schematic is shown in Figure 11. The first stage Electrohydraulic Servovalve uses 3,000 psi CTFE fluid to drive the second stage pressurized to 8,000 psi. The second stage main control valve, incorporates a Linear Variable Differential Transformer (LVDT) which provides position feedback which is incorporated into position loop closed around each one of the test actuators by a Rotary Variable Differential Transformer (RVDT). The feedback from only one of the test actuators is used at a time. The remaining nine actuators travel until they match loads with the position servoactuator. Since the torsion bar spring rates are matched within 5 percent the actuator strokes will correspond within 5 percent.

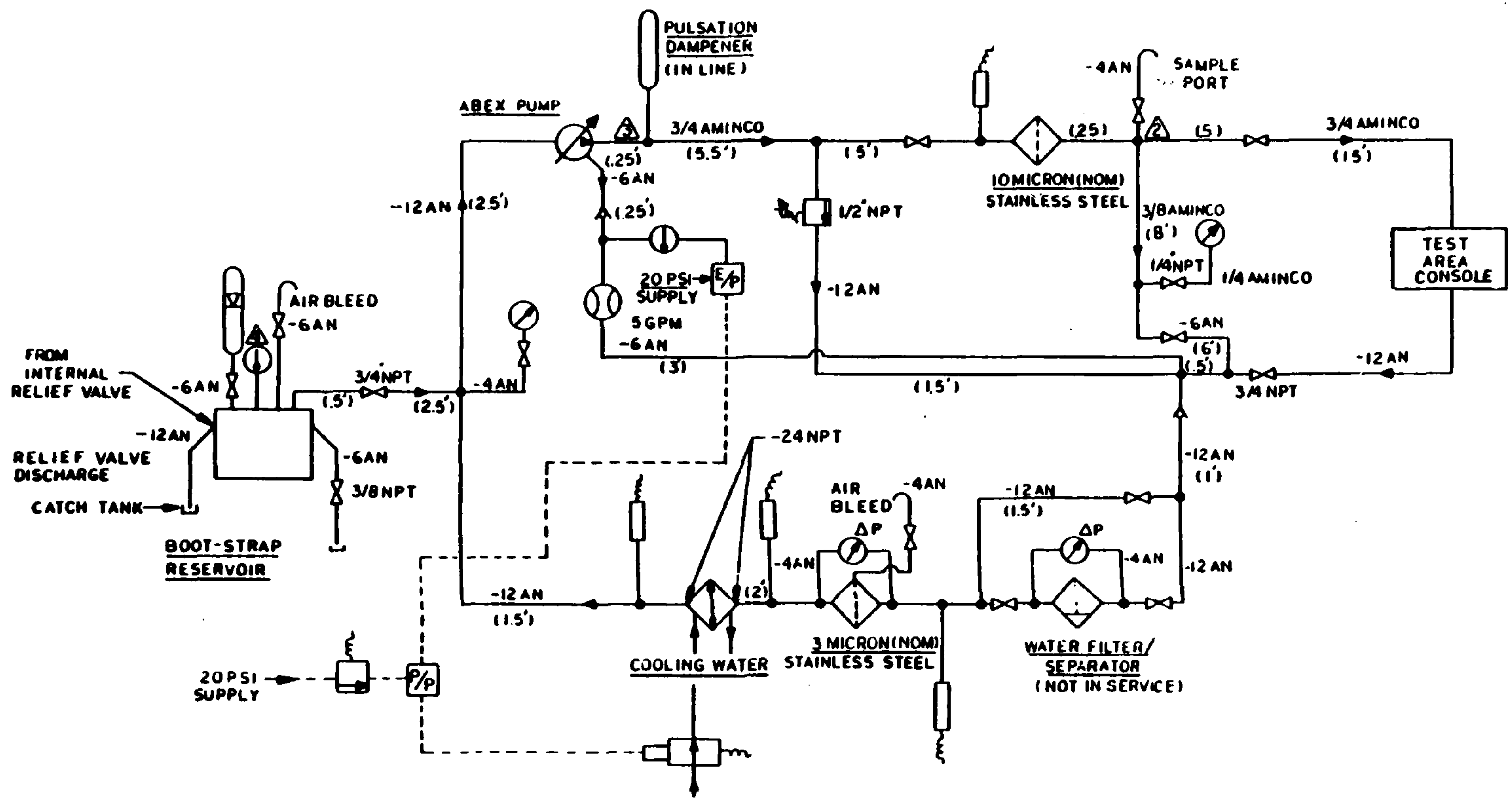


FIGURE 6. 8,000 PSI CTFE PUMPING SYSTEM HYDRAULIC SCHEMATIC

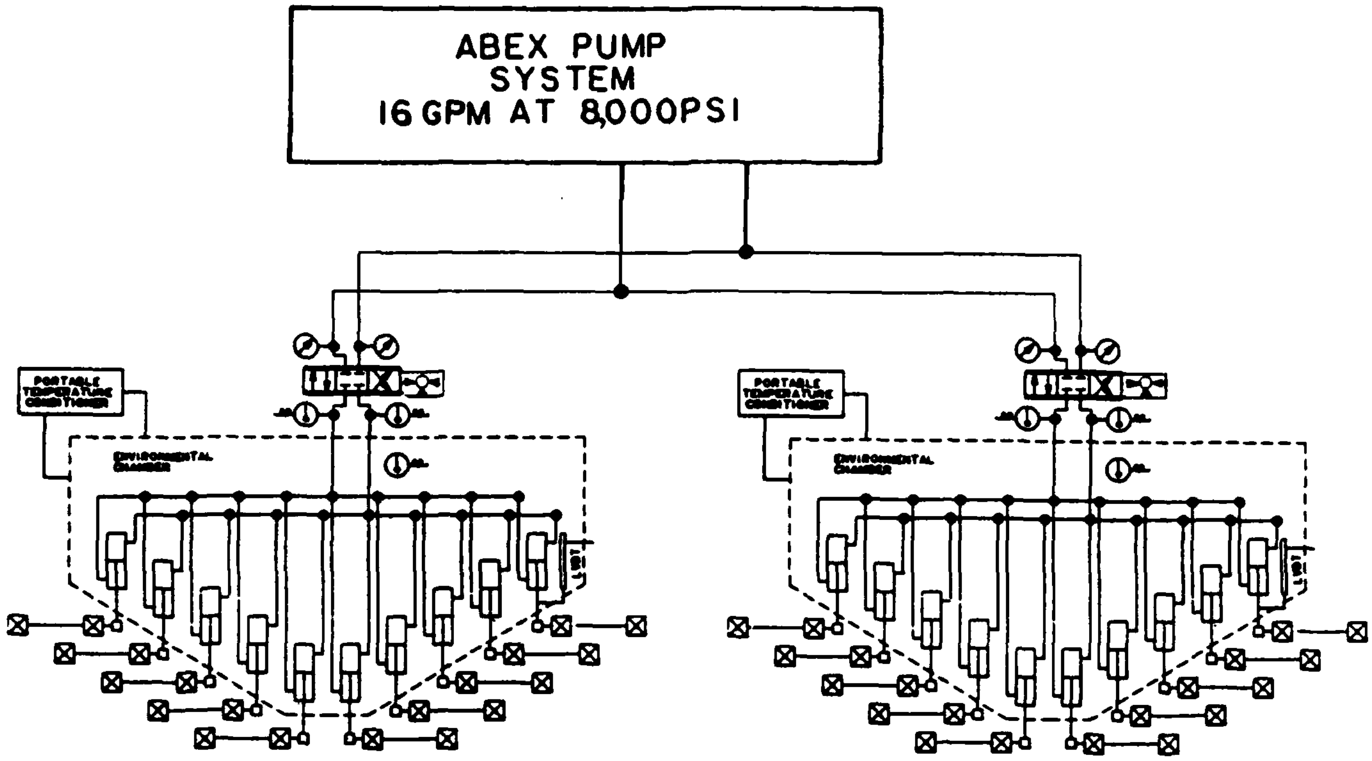


FIGURE 7. 8,000 PSI CTFE PUMPING SYSTEM - SEAL TEST ACTUATORS HYDRAULIC SCHEMATIC

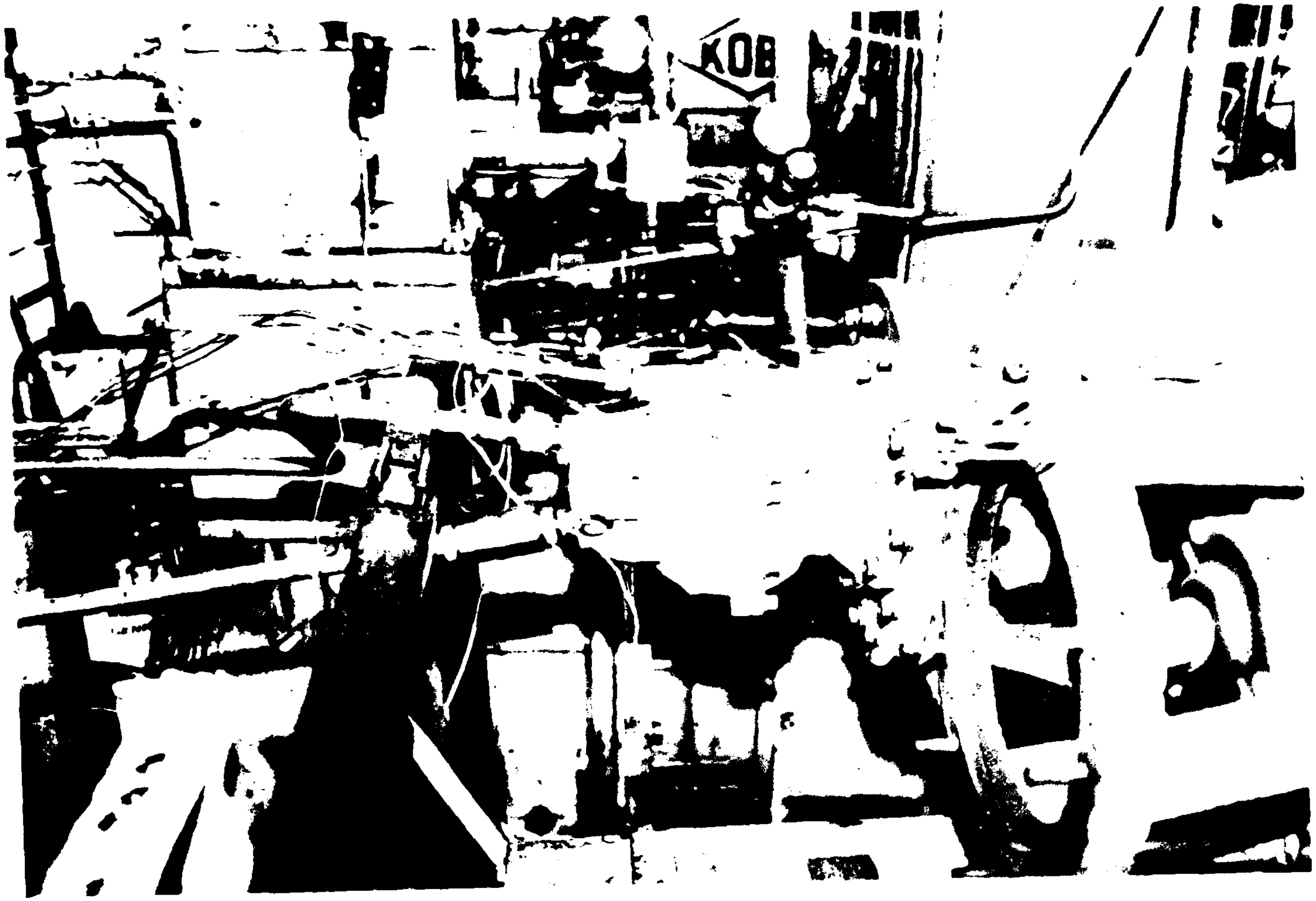


FIGURE 8. 8,000 PSI CTFE PUMPING SYSTEM

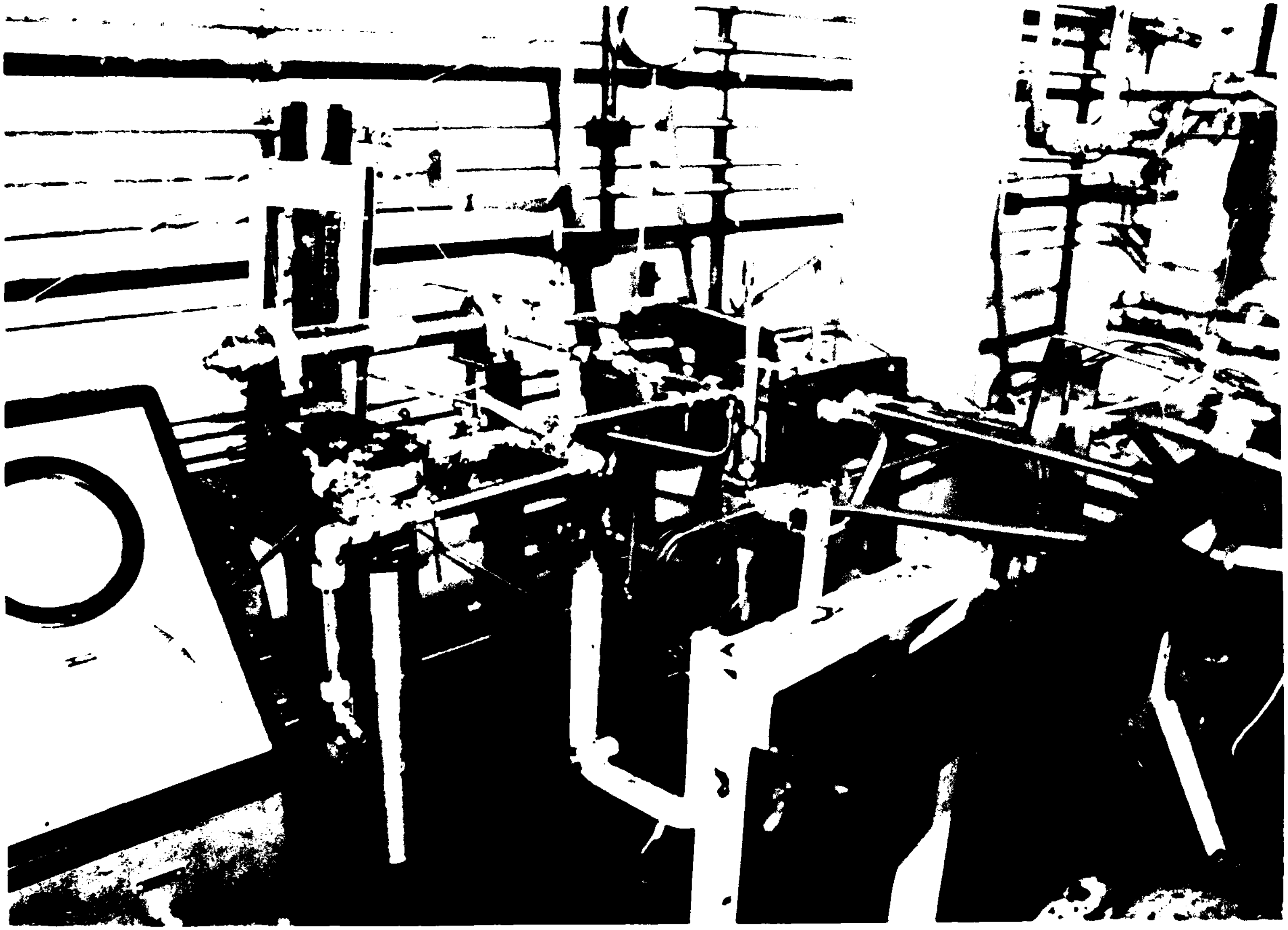


FIGURE 9. 8,000 PSI CTFE PUMPING SYSTEM

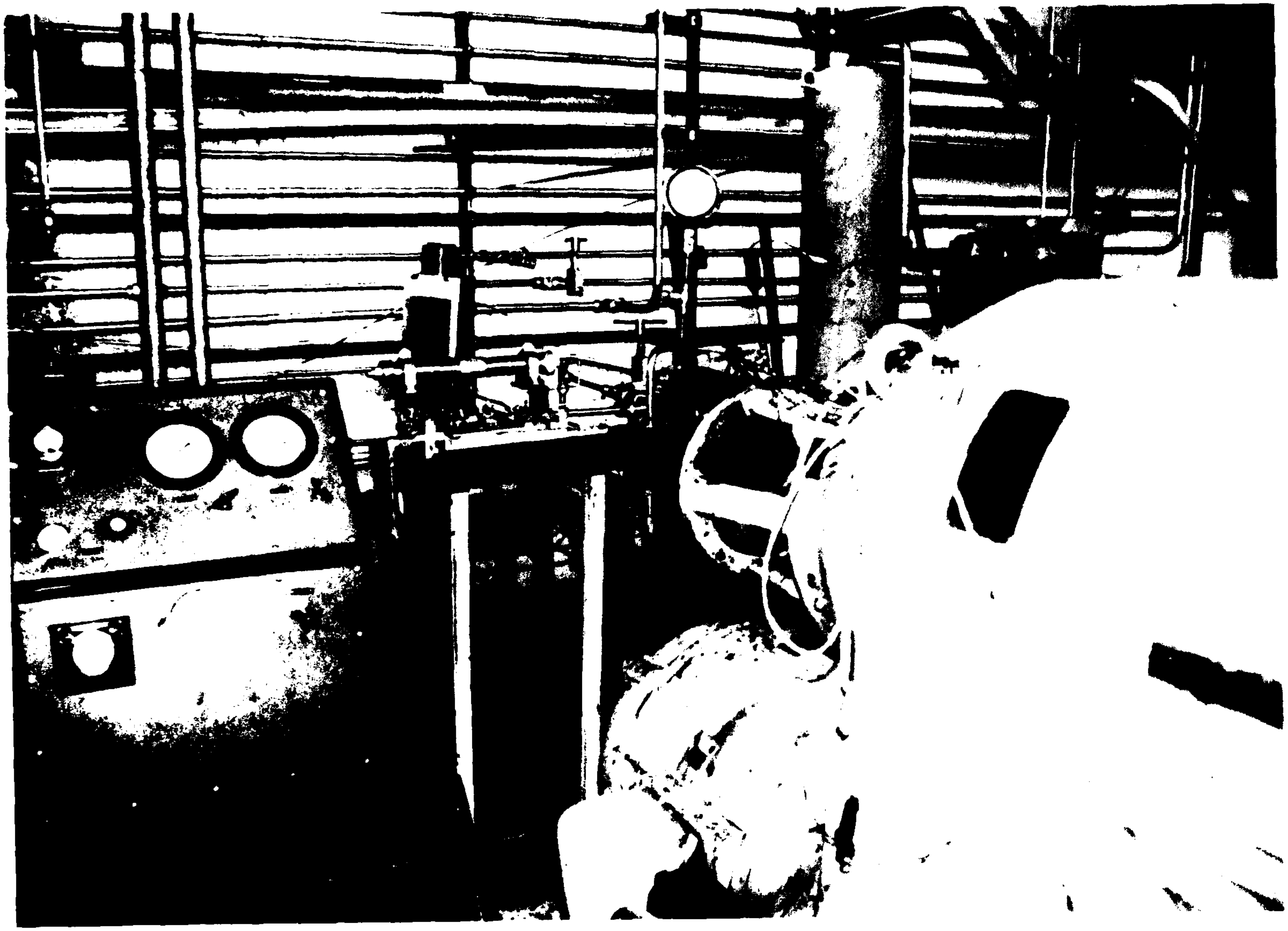


FIGURE 10. 8,000 PSI CTFE PUMPING SYSTEM

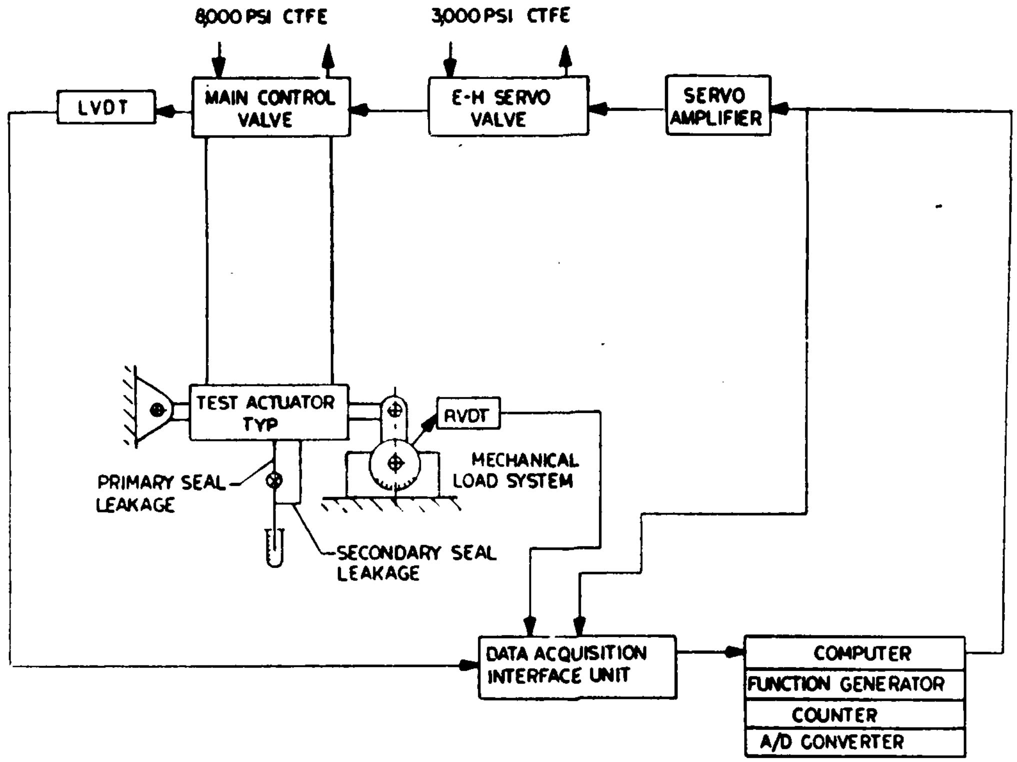


FIGURE 11. CONTROL SCHEMATIC

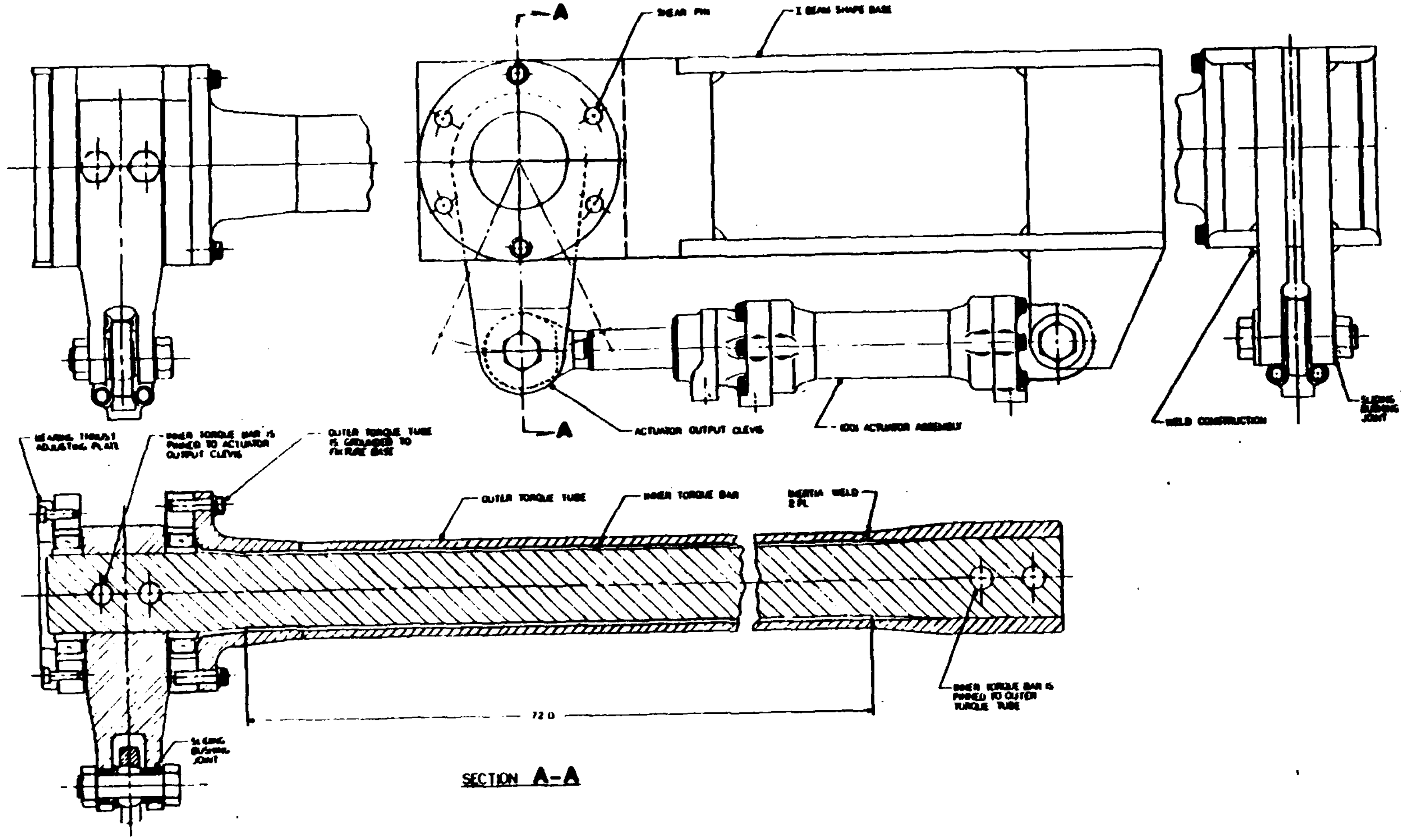


FIGURE 12. TEST FIXTURE DETAIL

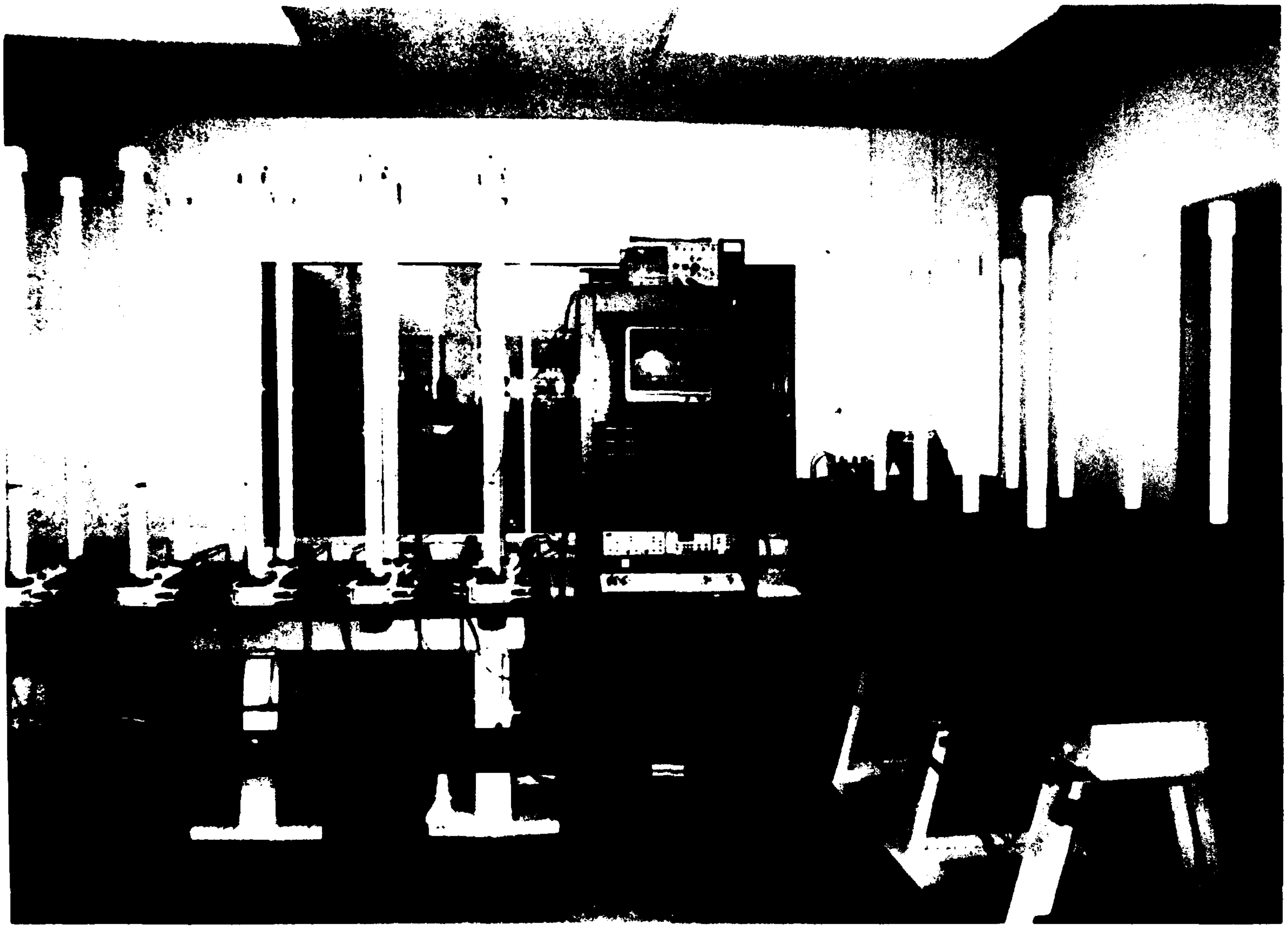


FIGURE 13. TEST FIXTURES AND CONTROLLER

The Seal Test System (STS) electronics and software provide complete position control of both hydraulic systems. The fixtures are controlled independently or together by the integration of two independent function generators into the STS. When running both fixtures together, the function generator output signals (command signals) are synchronized such that Small Fixture cycling is 180° out of phase from that of the Large Fixture. This phase difference in fixture cycling smoothes out the combined flow demand of the two fixtures, permits cycling at reasonable frequencies and extends the life of the pump. The STS keeps track of all Cycling Data for both fixtures and monitors ambient and oil temperatures and oil pressure in both systems.

The heart of the STS is an IBM PC/XT computer running a Turbo Pascal Control program which provides all control and monitoring functions. All cycling information and monitored data for both fixtures is presented clearly on a color monitor. The operator may observe and record data directly from the screen, may Stop and Start the system as necessary, may access the Test Database (cycles, layers, etc.), and may manually control or monitor any part of the system from the keyboard. The controller is shown in Figure 13.

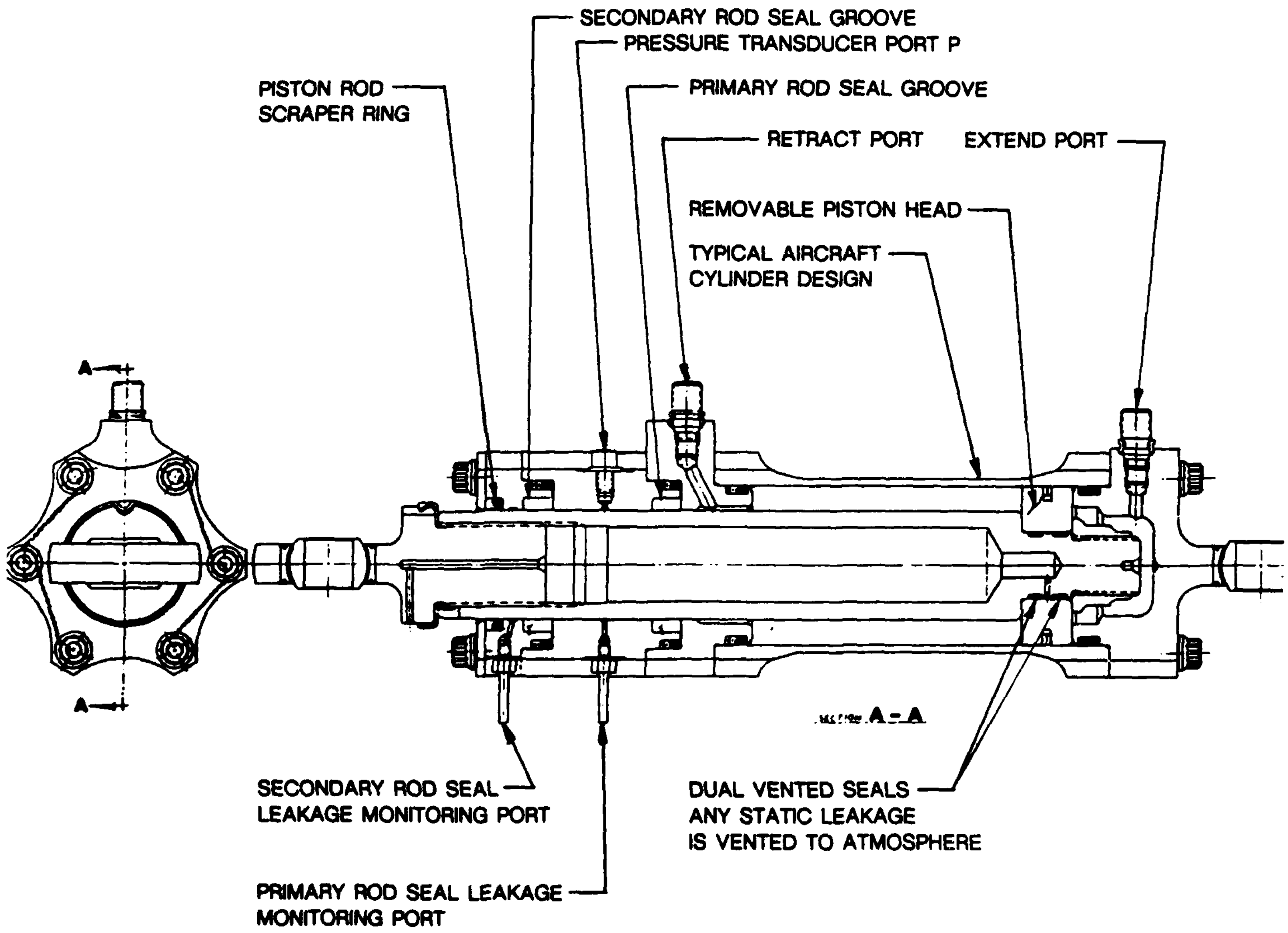
13.0 TEST ACTUATOR DESCRIPTION

The test actuators were designed to simulate flight hardware. The actuators are of the simplex completely unbalanced design. Configuration of the actuators and their basic characteristics are shown in Figure 14. Following is the pertinent design information.

- The small actuators have 4.000 inch nominal stroke, 1.492 ± 0.001 inch diameter bore, and 0.997 ± 0.001 inch diameter rod. The actuator produces 13,986 pounds extend force and 7,741 pounds retract force at 8,000 psi pressure differential. The large actuators have a 4.000 inch stroke, 2.369 ± 0.001 inch diameter bore, and 1.622 ± 0.001 inch diameter rod. The actuator produces 35,262 pounds extend force and 18,732 pounds retract force at 8,000 psi pressure differential.
- All piston rod seal grooves are in accordance with MIL-G-5514. The grooves are open to facilitate seal installation.
- All clearances between the moving parts (piston rod diameters to gland bores, piston head diameters to cylinder bores) are in accordance with MIL-G-5514.
- All cylinders were designed for 0.009 inch breathing under 8,000 psi pressure.

14.0 ACTUATOR MATERIAL SELECTION

- Ten large actuator and eight small actuator cylinders are manufactured from Custom 455 corrosion resistant steel heat treated to H950 condition. Cylinder bores are chromium plated in accordance with MIL-STD-1501, Class 1, Type II and finished to RMS 16.



	LARGE ACTUATORS	SMALL ACTUATORS
ROD DIA :	1.675 IN	1.000 IN
BORE DIA :	2.375 IN	1.500 IN
STROKE :	4.00 IN	4.00 IN
EXT AREA :	4.430 SQ IN	1.767 SQ IN
RET AREA :	2.356 SQ IN	0.987 SQ IN

FIGURE 14. TEST ACTUATORS

Two large actuator and two small actuator cylinders are manufactured from Ti6AL-4V titanium in STA condition. They are anodic treated in accordance with AMS 2488. The finish of the bore is RMS 16.

- Ten large actuator and eight small actuator glands are manufactured from 17-4PH corrosion resistant steel per AMS 5643, heat treated to H1025 condition per MIL-H-6875 and passivated per MIL-S-5002.
- Two large actuator and two small actuator glands are manufactured from Ti6AL-4V titanium in STA condition and anodic treated in accordance with AMS 2488.
- All piston heads are manufactured from 17-4PH corrosion resistant steel per AMS 5643 heat treated to H1025 condition in accordance with MIL-H-6875, and passivated per MIL-S-5002. All piston seal grooves were machined in accordance with seal supplier's specifications.
- All piston rods are manufactured from PH13-8Mo corrosion resistant steel, heat treated to H1000 condition per MIL-H-6875, chromium plated per MIL-STD-1501, Class 1, Type II, finished to RMS 8, and passivated per MIL-S-5002.
- Rod end and cylinder end bearings are of MS14101 type.

15.0 SCREENING TEST

The screening tests were performed on seal configurations selected on the basis of their performance during Phase I Testing and on several promising designs proposed by the industry.

Thirty-one seal configurations, twenty-one rod and ten piston, supplied by twelve suppliers were tested. A list of seal suppliers is shown in Table 10.

To accommodate the seal configurations, allowing repeat tests on same designs and thus eliminating isolated failure influence on the selection of the seal configurations for the final long life test, the screening test was divided into two parts. Only the large steel actuators were used in the screening tests, ten actuators in Screening Test I, and ten actuators in Screening Test II.

Each Screening Test consisted of 2,151,535 cycles performed according to the 320100ST Screening Test Plan shown in Appendix A.

TABLE 10
SUPPLIERS OF THE SEALS SELECTED FOR SCREENING TEST

Company Name	Address
The Advanced Products Company	North Haven, Connecticut 06473
Bal Seal Engineering Company, Inc.	Santa Ana, California 92707-3398
C.E. Conover & Co., Inc.	Fairfield, New Jersey 07006
Dover Corporation/Cook Airtomic Division	Louisville, Kentucky 40201
Fluorocarbon	Los Alamitos, California 90720
Greene, Tweed & Co.	North Wales, Pennsylvania 19454
Parker Bertea Aerospace Group/Pacific Piston Ring	Irvine, California 92718-1814
Shamban	Fort Wane, Indiana 46801
Tetrafluor, Inc.	El Segundo, California 90245
Parker Seal Company	Culver City, California 90230
Koppers Company, Inc.	Baltimore, Maryland 21203
American Variseal Corp.	Broomfield, Colorado 80020

The test actuator parts were serialized and assigned to the individual actuators. The cylinder bores, piston head and rod diameters, gland bores, and all seal groove dimensions were inspected and recorded. This procedure was repeated following Screening Tests I and II. Any discrepancies found during the post Screening Tests I inspection were corrected prior to the installation of the seals for the Screening Test II.

The assigned seals were assembled into the actuators and the actuators were proofed at 10,000 psi with CTFE fluid.

Several seal configurations did not meet the required leakage requirement and were, after several attempts, eliminated from further testing.

The final Screening Test actuator/seal configuration schedule is shown in Table 11.

- 97.18 minute cycle schedule per layer (1.62 hour - 1 layer)
- 115 layers
- 1 bottoming cycle per layer
- 1 hour shut down every 14.58 hours 4 hours at 275°F per 14.58 hour test
- cold test at 60 and 120 hours

One Layer										Total
% Stroke	100	10	1	50	2	10	2	50	100	
% Load	100	10	1	50	2	10	2	50	100	
Time (min) ...	3.12	20.0	15.0	15.0	15.0	2.5	15.0	15.0	6.67	97.18 min
Rate (Hz)	.075	1.2	7.5	0.14	5	1.2	5	0.14	.075	
# of Cycles ...	22	225	9000	126	4500	180	4500	126	30	18,709 cycles

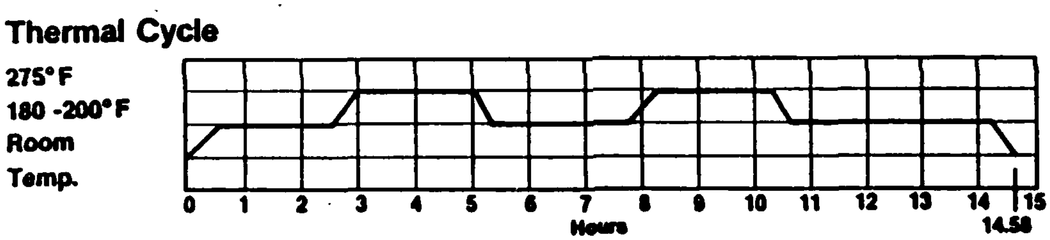


FIGURE 15. SCREENING TEST CYCLING SCHEDULE

Each Screening Test was divided into 115 layers of cycling consisting of 100, 50, 10, 2 and 1 percent stroke/load cycles. Nine layers of cycling constitutes one thermocycle controlling fluid temperatures at which cycling is performed. Two cold, -65°F, tests are performed during each screening test.

The screening test cycling schedule is shown in Figure 15.

15.1 Screening Test I

Screening Test I started on August 14, 1986 and was completed on October 17, 1986. The test actuators with the assigned numbers 1, 2, 3, 4, 5, 6, 7, 10, 13 and I5 were used in this test. The pressure between the primary and secondary rod seals of the test actuator 1 was monitored through a part of the test in addition to system temperatures, pressures, and seal leakages. Actuator number 1 was selected because of the configuration of the primary rod seal, the Bal Seal, which acts as a check valve, relieving the trapped pressure when system pressure on the seal decreases during the cycle. The recorded between seals pressure varied between 140 psi and 5340 psi indicating that the secondary rod seal was not continuously subjected during cycling to high system pressure caused by the leaky primary rod seal. Note here that fluctuations of the between seals pressure could be to some extent caused by movement of the seals under pressure.

Several piston seal configurations failed during testing. In each case the failed seals were replaced with the same configurations and testing continued. A complete history of the seal performance throughout the Screening Test I is shown in Table 12.

15.1.1 Results of Screening Test I

All rod seals, primary and secondary, completed the test without replacement. Six piston seal configurations completed the test without replacement. Failures of four piston seal configurations were recorded. Photographs of the failed piston seals are shown in Figures 16 through 18.

Various degrees of wear and/or extrusion were evident on some of the test seal configurations which completed Screening Test I without replacement. Photographs of the individual test seals before and after their removal from the actuators are shown in Appendix E.

TABLE 11
SCREENING TEST
ACTUATOR TEST SEAL CONFIGURATIONS

ACTUATOR DASH NO.	SEAL TYPE	MANUFACTURER	PART NO.	MATERIAL	SKETCH
-1001/1	PRIMARY ROD	BAL SEAL	X 6789	FILLED TEFLON STAINLESS STEEL	
	SECONDARY ROD	C.E. CONOVER	CEC 6001-326-D8	FILLED TEFLON EPDM	
	PISTON	PARKER CSD	301641ADP-1	TORLON 4203 STAINLESS STEEL	
-1001/2	PRIMARY ROD	W.S. SHAMBAN	S35968	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	W.S. SHAMBAN	S35971	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	GREENE, TWEED	266-32900-818-1160	FILLED TEFLON ARLON EPDM	
-1001/3	PRIMARY ROD	BAL SEAL	X 15033	FILLED TEFLON STAINLESS STEEL	
	SECONDARY ROD	GREENE, TWEED	265-32600-818-1200	FILLED TEFLON NYLON EPDM	
	PISTON	TETRAFLUOR	TF500A-329 (592)	FILLED TEFLON STAINLESS STEEL	
-1001/4	PRIMARY ROD	PARKER-CHP	ML1851/V1098-85/ XP2714-4	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	TETRAFLUOR	SDM51216-6 TFM8MS121685-4	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	PISTON	PARKER-CSD	301641ADP-1	TORLON 4203 STAINLESS STEEL	
-1001/5	PRIMARY ROD	W.S. SHAMBAN	S35968	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	C.E. CONOVER	CEC5056C-326-D8	FILLED TEFLON VITON	
	PISTON	W.S. SHAMBAN	S35985	HIGH MODULUS PLASTIC STAINLESS STEEL	
-1001/6	PRIMARY ROD	W.S. SHAMBAN	S35971	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	W.S. SHAMBAN	S35968	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	GREENE TWEED	266-32900-818-1160	FILLED TEFLON ARLON EPDM	
-1001/7	PRIMARY ROD	PARKER-CHP	ML1851/V835-75/ XP2714-2	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	GREENE TWEED	265-32600-818-1160	FILLED TEFLON ARLON EPDM	
	PISTON	TETRAFLUOR	SDM51212-2-2 SDM51212-2-1 MB3485/1-226	FILLED TEFLON HIGH MODULUS PLASTIC VITON	

TABLE 11 (continued)
SCREENING TEST
ACTUATOR TEST SEAL CONFIGURATIONS

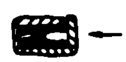
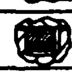
ACTUATOR DASH NO.	SEAL TYPE	MANUFACTURER	PART NO.	MATERIAL	SKETCH
-1001/8	PRIMARY ROD	BAL SEAL	X15033	FILLED TEFLON STAINLESS STEEL	
	SECONDARY ROD	ADVANCED PRODUCTS	46194/46195	HIGH MODULUS PLASTIC VITON	
	PISTON	W.S. SHAMBAN	S35979	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
-1001/9	PRIMARY ROD	KOPPERS	C5267A6U	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	C.E. CONOVER	CEC6001C-326-D8	FILLED TEFLON VITON	
	PISTON	GREENE TWEED	5979A32900F001	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
-1001/10	PRIMARY ROD	TETRAFLUOR	TF456-7326 TF1097M-7326 M83485/1-326	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	C.E. CONOVER	CEC6U01C-326-D8	FILLED TEFLON VITON	
	PISTON	PARKER-CSD	301641 ADP-1 (2 ea.)	TORLON 4203 STAINLESS STEEL	
-1001/11	PRIMARY ROD	TETRAFLUOR	TF8M8S121685-41 SD851216-61	FILLED TEFLON, HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREENE TWEED	265-32600-777-1160	FILLED TEFLON, ARLON VITON	
	PISTON	DOVER CORP.	ABP17573	COOK'S 05-059 STAINLESS STEEL	
-1001/12	PRIMARY ROD	FLUOROCARBON	AR104974	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	C.E. CONOVER	CEC5056-326-D8	FILLED TEFLON EPDM	
	PISTON	DOVER CORP.	ABP17573 (2 ea)	COOK'S 05-059 STAINLESS STEEL	
-1001/13	PRIMARY ROD	TETRAFLUOR	TF851216-6 TF8M8S121685-4	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	TETRAFLUOR	TF456-7326 TF1097M-7326	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	TETRAFLUOR	TF500A-329 (2 ea)	FILLED TEFLON STAINLESS STEEL	
-1001/14	PRIMARY ROD	TETRAFLUOR	TF1097M-7326(582) TF456-7326(801)	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	W.S. SHAMBAN	S35968	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	PARKER-CSD	330446ADP-5	PEEK STAINLESS STEEL	
-1001/15	PRIMARY ROD	AMERICAN VARISEAL	AS-1316	HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREENE TWEED	265-32600-818-1160	FILLED TEFLON ARLON EPDM	
	PISTON	PARKER-CSD	301641ADP-1	TORLON 4203 STAINLESS STEEL	

TABLE 11 (concluded)
SCREENING TEST
ACTUATOR TEST SEAL CONFIGURATIONS

ACTUATOR DASH NO.	SEAL TYPE	MANUFACTURER	PART NO.	MATERIAL	SKETCH
-1001/16	PRIMARY ROD	ADVANCED PRODUCTS	46194/46195	HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	SHAMBAN	S35971	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	KOPPERS	C5H16A60	HIGH MODULUS PLASTIC STAINLESS STEEL	
-1001/17	PRIMARY ROD	GREENE TWEED	265-3260-818-1160	FILLED TEFLON ARLON EPDM	
	SECONDARY ROD	BAL SEAL	X 6789	FILLED TEFLON STAINLESS STEEL	
	PISTON	KOPPERS	C5H16A60	HIGH MODULUS PLASTIC STAINLESS STEEL	
-1001/18	PRIMARY ROD	CONOVER	CEC6001C-326-08	FILLED TEFLON VITON	
	SECONDARY ROD	ADVANCED PRODUCTS	46194/46195	HIGH MODULUS PLASTIC VITON	
	PISTON	PARKER CSD	330446ADP-3	TORLON 4203 STAINLESS STEEL	
-1001/19	PRIMARY ROD	GREENE TWEED	265-3260-818-1200	FILLED TEFLON NYLON EPDM	
	SECONDARY ROD	AMERICAN VARISEAL	AS-1316	HIGH MODULUS PLASTIC STAINLESS STEEL	
	PISTON	PARKER-CSD	330446ADP-5	PEEK STAINLESS STEEL	
-1001/20	PRIMARY ROD	FLUOROCARBON	AR 104974	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREENE TWEED	265-32600-777-1160	FILLED TEFLON ARLON, VITON	
	PISTON	GREENE TWEED	5979A32900P001	FILLED TEFLON HIGH MODULUS PLASTIC VITON	

TABLE 12

HISTORY OF SEAL TEST PERFORMANCE-SCREENING TEST #1

ACTUATOR #1

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	3CC	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	11CC	0	0	0	0.5CC
3	11.5CC	0	0	0	0
4	72CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	57CC	0	0	0	N/A
5	90CC	0	0	0	0
6	48CC	0	0	0	0
7	37CC	0	0	1 DROP	0
8	52CC	0.15CC	6 DROPS	0	0
9	56CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	200CC	0	0	0	N/A
10	440CC	0	0	0	0
11	390CC	0	0	0	0
12	360CC	0	0	0	0
13	420CC	0	0	0	0

1) PARKER CSD P/N 301641ADP-1

2) BAL SEAL P/N X6789

3) C.E. CONOVER P/N CEC 6001-326-D8

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

TABLE 12(cont'd)

ACTUATOR #2

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0.5CC	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	0	0	0	0	0
3	4CC	0	0	0	0
4	0.8CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	30CC	0	0	0	N/A
5	1.5CC	0	0	0	0
6	[10] 0	0	0	0	0
7	18CC	0.15CC	15 DROPS	1 DROP	0
8	7CC	0.2CC	16 DROPS	0	0
9	0.5CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	0	0	N/A
10	0.1CC	0	0	0	0
11	0	0	0	0	0
12	0.2CC	0	0	0	0
13	0	0	0	0	0

1) GREENE TWEED P/N 266-32900-818-1160

2) W.S. SHAMBAN P/N S35968

3) W.S. SHAMBAN P/N S35971

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION DURING THERMO CYCLE 6 (FREE FLOW FAILURE)

TABLE 12(cont'd)

ACTUATOR #3

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	7.5CC	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	4CC	0	0	0	0.55CC
3	4CC	0	0	0	0
4	20CC	0	0	0	0.15CC
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	18CC	0	0	0	N/A
5	70CC	0	0	0	0
6	[10] 16CC	0	0	0	0
7	15CC	0	4 DROPS	2 DROPS	0
8	12CC	0.1CC	16 DROPS	0	0
9	12CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	5CC	0	0	0	N/A
10	2CC	0	0	0	0
11	0	0	0	0	0.7CC
12	35CC	0	0	0	1CC
13	28CC	0	0	0	0.45CC

1) TETRAFLUOR P/N TF500A-329 (592)

2) BAL SEAL P/N X15033

3) GREENE TWEED P/N 265-32600-818-1200

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION DURING THERMO CYCLE 6 (FREE FLOW FAILURE)

TABLE 12(cont'd)

ACTUATOR #4

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	6CC	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	6.5CC	0	0	0	0.95CC
3	1.5CC	0	0	0	0
4	4CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	5CC	0	0	0	N/A
5	2CC	0.1CC	0	0	0
6	[10] 6CC	0	0	0	0
7	0.6CC	0	0	2 DROPS	0
8	1CC	0.25CC	16 DROPS	0	0
9	7CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	2CC	0	0	0	N/A
10	10CC	0	0	0	0
11	20CC	0	0	0	0
12	10CC	0	0	0	0
13	30CC	0	0	0	0

1) PARKER-CSD P/N 301641ADP-1

2) PARKER-GNP P/N ML1851/V1098-85/XP2714-4

3) TETRAFLUOR P/N SD851216-6,TF888S121685-41

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION DURING THERMO CYCLE 6 (FREE FLOW FAILURE)

TABLE 12(cont'd)

ACTUATOR #5

THERMO CYCLE CONDITION [4]	PISTON SEAL [1] CC/MINUTE [5]	PRIMARY ROD SEAL [2] DROPS/ MINUTE [6]	DROPS 50 CYCLES [7]	SECONDARY ROD SEAL [3] DROPS 50 CYCLES [8]	34CC 14.58 HOURS [9]
PRETEST	0.4	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	2CC	0	0	0	0.75CC
3	0.05CC	0	0	0	0
4	0.5CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	0.05CC	0	0	0	N/A
5	0	0	0	0	0
6	3CC	0	0	0	0
7	0.1CC	0	6 DROPS	0	0
8	0	0.3CC	18 DROPS	0	0
9	0.5CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	0.2CC	0	0	0	N/A
10	1CC	0	0	0	0
11	0.1CC	0	0	0	0
12	0	0	0	0	0
13	3CC	0	0	0	0

1) W.S. SHAMBAN P/N S35985

2) W.S.SHAMBAN P/N S35968

3) C.E. CONOVER P/N CEC5056C-325-D8

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

TABLE 12(cont'd)

ACTUATOR #6

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0.4CC	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	0	0	0	0	1.15CC
3	0.05CC	0	0	0	0
4	0.5CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	0.1CC	0	0	0	N/A
5	0	0	0	0	0
6	2CC	0	0	0	0
7	29CC	0	12 DROPS	0	0
8	0	5 DROPS	24 DROPS	0	0
9	0.5CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	1CC	0	0	0	N/A
10	0.2CC	0	0	0	0
11	0	0	0	0	0
12	0.3CC	0	0	0	0.2CC
13	0.6CC	0	0	0	0

1) GREENE TWEED P/N 266-329-818-1160
2) W.S. SHAMBAN P/N S35971
3) W.S. SHAMBAN P/N S35968
4) 168,381 CYCLES PER THERMO CYCLE
5) 20 CC/MINUTE REQUIREMENT
6) 1 DROP/MINUTE REQUIREMENT
7) 2 DROPS PER 50 CYCLES REQUIREMENT
8) 2 DROPS PER 50 CYCLES REQUIREMENT
9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

TABLE 12(cont'd)

ACTUATOR #7

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	140CC	0	0	0	0.8CC
3	[10] 420CC	0	0	0	0
4	1CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	9CC	0	0	0	N/A
5	0	0	0	0	0
6	[11] 1CC	0	0	0	0
7	0	0	4 DROPS	0	0
8	0	2 DROPS	3 DROPS	0	0
9	0.5CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	0.2CC	0	0		N/A
10	0	0	0	0	0
11	0	0	0	0	0
12	12CC	0	0	0	0
13	1CC	0	0	0	0

1) TETRAFLUOR P/N SD8512-2-2,SD8512-2-1,M83485/1-226

2) PARKER-GNP P/N ML1851/V835-75/XP2714-2

3) GREENE TWEED P/N 265-32600-818-1160

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION EXCEPT M83485/1-226 O-RING REPLACED WITH SQUARE CROSS-SECTION RING

TABLE 12(cont'd)

ACTUATOR #10

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	3CC	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	4CC	0	0	0	0
3	1.8CC	0	0	0	0
4	6CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	8CC	0	0	0	N/A
5	2CC	0	0	0	0
6	6CC	0	0	0	0
7	3CC	0	0	0	0
8	2.5CC	0.3CC	3 DROPS	0	0
9	10CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	3CC	0	0	0	N/A
10	6CC	0	0	0	0
11	4CC	0	0	0	0
12	4CC	0	0	0	0
13	4CC	0	0	0	0

1) PARKER-CSD P/N 301641 ADP-1 (2 EA)

2) TETRAFLUOR P/N SD8512-2-2,SD8512-2-1,M83485/1-226

3) C.E. CONOVER P/N CEC6001C-326-D8

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

TABLE 12(cont'd)

ACTUATOR #13

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	5CC	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	8CC	0	0	0	1.05CC
3	1.1CC	0.05CC	0	0	0
4	1.5CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	0.5CC	0	0	0	N/A
5	3CC	0	2 DROPS	0	0
6	10CC	0	0	0	0
7	13CC	0	6 DROPS	0	0.15CC
8	5CC	0.25CC	5 DROPS	0	0
9	10CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	1CC	0	0	0	N/A
10	2CC	0	0	0	0
11	7CC	0	0	0	0
12	1CC	0	0	0	0
13	6CC	0	0	0	0

1) TETRAFLUOR P/N TF500A-329

2) TETRAFLUOR P/N TF851216-6, TF888S121685-41

3) TETRAFLUOR P/N TF456-7326, TF109M-7326

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

TABLE 12(concluded)

ACTUATOR #15

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	4CC	0	0	0	N/A
1	N/A	N/A	N/A	N/A	N/A
2	3CC	0	0	0	0.85CC
3	1.8CC	0	0	0	0
4	7CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	7CC	0	0	0	N/A
5	2.5CC	0.1CC	2 DROPS	0	0
6	24CC	0		0	0
7	80CC	0	6 DROPS	0	0
8	[10] 400CC	0.25CC	12 DROPS	0	0
9	2CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	1CC	0	0	0	N/A
10	1CC	0	0	0	0
11	2CC	0	0	0	0
12	1CC	0	0	0	0.5CC
13	6CC	0	0	0	2.05CC

1) PARKER-CSD P/N 301641ADP-1
2) AMERICAN VARISEAL P/N AS-1316
3) GREENE TWEED P/N 265-32600-818-1160
4) 168,381 CYCLES PER THERMO CYCLE
5) 20 CC/MINUTE REQUIREMENT
6) 1 DROP/MINUTE REQUIREMENT
7) 2 DROPS PER 50 CYCLES REQUIREMENT
8) 2 DROPS PER 50 CYCLES REQUIREMENT
9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE
10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

FIGURE 16. SCREENING TEST I FAILED TETRAFLUOR PISTON SEAL - 505140 CYCLES TO FAILURE FAILURE CAUSED BY NIBBLING OF THE ENERGIZER

FIGURE 17. SCREENING TEST I FAILED GREENE TWEED PISTON SEAL P/N 266-32900-818-1160, 940,000 CYCLES TO FAILURE

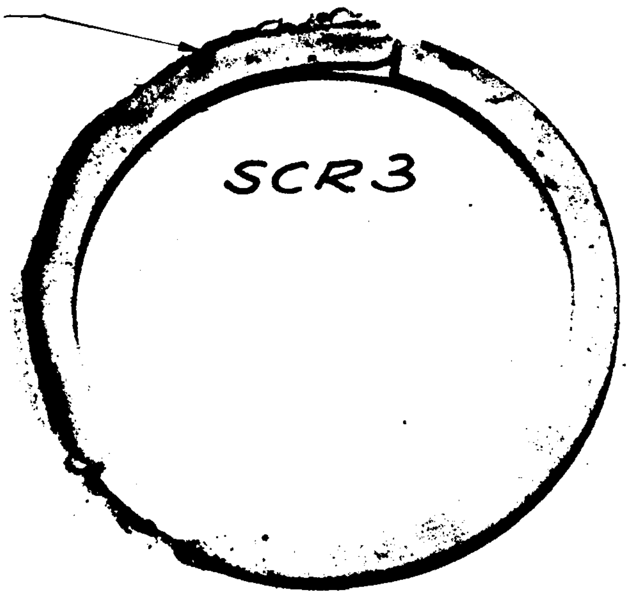


FIGURE 18. SCREENING TEST I FAILED TETRAFLUOR PISTON SEAL P/N TF 500A-329 (592), 940,000 CYCLES TO FAILURE

15.2 Screening Test II

The actuator parts were cleaned and the critical dimensions inspected and recorded. The actuators were reidentified as numbers 8, 9, 11, 12, 14, 16, 17, 18, 19 and 20 and the test seals were installed. Screening Test II started on November [illegible], 1986 and was completed on January 22, 1987. The pressure between the primary and secondary rod seals of the test actuator 8 was monitored throughout this test. The primary rod seal of the test actuator 8 was Bal Seal X15033. The maximum recorded between seals pressure was 5,000 psi, the minimum 40 psi.

Several piston seal configurations failed during testing. They were replaced with either the same configurations or different designs and testing continued. Several piston rod seals showed excessive intermittent leakage during some layers of testing, however, they were not replaced. A complete history of the seal performance throughout the Screening Test II is shown in Table 13.

15.2.1 Results of Screening Test II

All rod seals, primary and secondary, completed the test without replacement. All seven piston seal configurations failed. Photographs of typical seal failures are shown in Figures 19 through 22. Photographs of the individual test seals before and after their removal from the actuators are shown in Appendix E.

16.0 PHASE III LONG LIFE TEST

Following completion of the Screening Tests, the test seals were carefully examined and their performance evaluated by the Air Force and Parker CSD team. The candidates for the Long Life Test were selected. Wear and sealing capabilities were the prime factors in determining which seals were to be used as primary and which as secondary rod seals. Wear and extrusion resistance were used as the criteria for the selection of the piston seals.

Twelve rod seal configurations and four piston seal configurations were chosen. The same materials and design principles were used by the suppliers in the large and small seal configurations. Fourteen modified piston seal configurations were added to the test later. These seals were replacing the failed original designs.

Table 14 lists the seal assignment for the Long Life Test.

TABLE 13

HISTORY OF SEAL TEST PERFORMANCE-SCREENING TEST #2

ACTUATOR #8

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0.5CC	0	0	0	N/A
1	4CC	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	2CC	0	0	0	0
5	4CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	2 DROPS	0	N/A
6	0.2CC	0	5 DROPS	0	0
7	3CC	0	14 DROPS	0	0
8	4CC	0	1 DROP	0	0.55CC
COLD TEST#2	N/A	N/A	N/A	2 DROPS	N/A
POST COLD TEST	0	0	4 DROPS	7 DROPS	N/A
9	0	0	9 DROPS	0	0.3CC
10	0	0	0	0	0.6CC
11	1CC	0	10 DROPS	1 DROPS	0.75CC
12	0.2CC	0	14 DROPS	3 DROPS	3.5CC
13	0.2CC	2 DROPS	10 DROPS	1 DROP	1.55CC

1) W.S. SHAMBAN P/N S35979

2) BAL SEAL P/N X15033

3) ADVANCED PRODUCTS P/N 46194/46195

4) 168.381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

TABLE 13(cont'd)

ACTUATOR #9

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	2CC	0	0	0	N/A
1	2CC	0	0	0	0
2	0	0	0	0	0
3	0	0	5 DROPS	0	0
4	2CC	0	0	0	0
5	3CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	15 DROPS	0	N/A
6	0.2CC	0	25 DROPS	0	0
7	3CC	0	12 DROPS	0	0
8	[10] FREE FLOW	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	6 DROPS	0	N/A
9	0	0	5 DROPS	0	0
10	0	0	0	0	0
11	0.5CC	0	2 DROPS	0	0
12	0	0	14 DROPS	0	0
13	14CC	1 DROP	13 DROPS	0	0

1) GREENE TWEED P/N 5979A32900P001

2) KOPPERS P/N C5267A60

3) C.E. CONOVER P/N CEC6001C-326-D8

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 13(cont'd)

ACTUATOR #11

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	3.5CC	0	0	0	N/A
1	1CC	0	0	0	0
2	NO DATA	NO DATA	NO DATA	NO DATA	0
3	4CC	0	4 DROPS	0	0
4	[10] FREE FLOW	NO DATA	NO DATA	NO DATA	0
5	5CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	2CC	0	6 DROPS	0	N/A
6	2CC	0	8 DROPS	0	0
7	4CC	0	0	0	0
8	6CC	0	0	0	0.45CC
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	1CC	0	0	0	N/A
9	11CC	0	0	0	0.35CC
10	12CC	0	0	0	0.5CC
11	200CC	0	0	0	2.35CC
12	20CC	0	4 DROPS	0	0.45CC
13	18CC	1 DROP	3 DROPS	0	0.1CC

1) DOVER CORP. P/N ABP17573

2) TETRAFLUOR P/N TF888S121685-41,SD85116-61

3) GREENE TWEED P/N 265-32600-777-1160

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 13(cont'd)

ACTUATOR #12

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0	0	0	0	N/A
1	1CC	0	0	0	0
2	1CC	0	0	0	0
3	7CC	0	7 DROPS	0	0
4	16CC	0	0	0	0
5	4CC	0	0	0	0.1CC
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	9CC	0	0	0	N/A
6	8CC	0	3 DROPS	0	0
7	14CC	0	0	0	0
8	8CC	0	4 DROPS	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	8CC	0	0	0	N/A
9	10CC	0	2 DROPS	0	0
10	14CC	0	0	0	0
11	32CC	0	2 DROPS	0	0.1CC
12	8CC	0	0	0	0
13	220CC	0	7 DROPS	0	0

1) DOVER CORP. P/N ABP17573 (2EA)

2) FLUOROCARBON P/N AR104974

3) C.E. CONOVER P/N CEC5056-326-08

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

TABLE 13(cont'd)

ACTUATOR #14

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	1CC	0	0	0	N/A
1	[10] FREE FLOW	NO DATA	NO DATA	NO DATA	0
2	[11] FREE FLOW	NO DATA	NO DATA	NO DATA	0
3	[12] FREE FLOW	0	0	0	0
4	[13] FREE FLOW	NO DATA	NO DATA	NO DATA	0
5	8CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	5 DROPS	0	N/A
6	12CC	0	0	0	0
7	[14] FREE FLOW	NO DATA	NO DATA	NO DATA	0
8	16CC	0	7 DROPS	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	4CC	0	2 DROPS	0	N/A
9	[15] FREE FLOW	NO DATA	NO DATA	NO DATA	0.1CC
10	16CC	0	0	0	0
11	20CC	0	0	0	0.15CC
12	FREE FLOW	0	8 DROPS	0	0.05CC
13	FREE FLOW	1 DROP	0	0	0.1CC

1) PARKER-CSD P/N 301641ADP-1
2) TETRAFLUOR P/N TF1097M-7326, TF456-7326(801)
3) W.S. SHAMBAN P/N S35968
4) 168,381 CYCLES PER THERMO CYCLE
5) 20 CC/MINUTE REQUIREMENT
6) 1 DROP/MINUTE REQUIREMENT
7) 2 DROPS PER 50 CYCLES REQUIREMENT
8) 2 DROPS PER 50 CYCLES REQUIREMENT
9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE
10) REPLACED PISTON SEAL WITH SAME CONFIGURATION
11) REPLACED PARKER CSD 330446ADP-1 PISTON SEAL WITH PARKER CSD 330446ADP-5 PISTON SEAL
12) REPLACED PISTON SEAL WITH SAME CONFIGURATION
13) REPLACED PISTON SEAL WITH SAME CONFIGURATION
14) REPLACED PARKER CSD 330446ADP-5 PISTON SEAL WITH PARKER CSD 330446ADP-7 PISTON SEAL
15) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 13(cont'd)

ACTUATOR #16

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0.5CC	0	0	0	N/A
1	2CC	0	0	0	0
2	1CC	0	0	0	0
3	[10] 250CC	0	0	0	0
4	4CC	0	0	0	0.15CC
5	1CC	0	0	0	0.1CC
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	FREE FLOW	0	10 DROPS	0	N/A
6	[11] 3CC	0	10 DROPS	0	0
7	3CC	0	0	0	0.15CC
8	3CC	0	5 DROPS	0	0.25CC
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	10 DROPS	0	N/A
9	55CC	0	2 DROPS	0	0.05CC
10	FREE FLOW	0	0	0	0.25CC
11	[12] 15CC	0	0	0	0.35CC
12	8CC	FREE FLOW	FREE FLOW	0	1.4CC
13	9CC	FREE FLOW	FREE FLOW	0	1.6CC

1) KOPPERS P/N C5816A60

2) ADVANCED PRODUCTS P/N 46194/46195

3) SHAMBAN P/N S35971

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION DURING THERMOCYCLE 6

12) REPLACED KOPPERS C5816A60 PISTON SEAL WITH PARKER CSD 301641ADP-1 PISTON SEAL DURING THERMO CYCLE 11

TABLE 13(cont'd)

ACTUATOR #17

	PISTON SEAL [1]	PRIMARY ROD SEAL [2]		SECONDARY ROD SEAL [3]	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0	0	0	0	N/A
1	3CC	0	0	0	0
2	1CC	0	0	0	0
3	10CC	0	6 DROPS	0	0
4	95CC	0	0	0	0
5	FREE FLOW	NO DATA	NO DATA	NO DATA	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	FREE FLOW	0	4 DROPS	0	N/A
6	[10] 3CC	0	0	0	0
7	4CC	0	18 DROPS	0	0
8	80CC	0	0	0	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	40CC	0	15 DROPS	0	N/A
9	FREE FLOW	NO DATA	NO DATA	NO DATA	0.05CC
10	[11] 16CC	0	0	0	0.15CC
11	20CC	0	2 DROPS	2 DROPS	0.6CC
12	35CC	FREE FLOW	FREE FLOW	0	3.85CC
13	25CC	FREE FLOW	FREE FLOW	0	1.95CC

1) KOPPERS P/N C5816A60

2) GREENE TWEED P/N 265-3260-818-1160

3) BAL SEAL P/N X6789

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION DURING THERMOCYCLE 6

11) REPLACED KOPPERS C5816A60 PISTON SEAL WITH PARKER CSD 301641ADP-1 DURING THERMO CYCLE 10

TABLE 13(cont'd)

ACTUATOR #18

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0.5CC	0	0	0	N/A
1	1CC	0	0	0	0
2	1CC	0	0	0	0
3	3CC	0	0	0	0
4	[10] 5CC	0	0	0	0
5	[11] FREE FLOW	NO DATA	NO DATA	NO DATA	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	FREE FLOW	0	0	0	N/A
6	[12] 4CC	0	5 DROPS	0	0
7	6CC	0	0	0	0
8	FREE FLOW	NO DATA	NO DATA	NO DATA	0
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	0	3 DROPS	N/A
9	[13] FREE FLOW	NO DATA	NO DATA	NO DATA	0.25CC
10	6CC	0	0	0	0
11	[14] FREE FLOW	0	0	0	0.2CC
12	FREE FLOW	0	4 DROPS	0	0
13	FREE FLOW	0	0	0	0.55CC

1) PARKER CSD P/N 330446ADP-3

2) CONOVER P/N CEC6001C-326-D8

3) ADVANCED PRODUCTS P/N 46194/46195

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PARKER CSD 330446ADP-3 PISTON SEAL WITH PARKER CSD 330446ADP-5 PISTON SEAL

11) REPLACED PARKER CSD 330446ADP-5 PISTON SEAL WITH PARKER CSD 330446ADP-7 PISTON SEAL

12) REPLACED PISTON SEAL WITH SAME CONFIGURATION

13) REPLACED PARKER CSD 330446ADP-7 PISTON SEAL WITH PARKER CSD 330446ADP-1 PISTON SEAL

14) REPLACED PARKER CSD 330446ADP-1 PISTON SEAL WITH PARKER CSD 330446ADP-3 PISTON SEAL

TABLE 13(cont'd)

ACTUATOR #19

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	6CC	0	0	0	N/A
1	2CC	0	0	0	0
2	[10] FREE FLOW	NO DATA	NO DATA	NO DATA	0
3	12CC	0	2 DROPS	0	0
4	10CC	0	0	0	0
5	FREE FLOW	NO DATA	NO DATA	NO DATA	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	[11] FREE FLOW	0	0	0	N/A
6	4CC	0	0	0	0
7	5CC	0	3 DROPS	0	0
8	9CC	0	0	0	0.25CC
COLD TEST #2	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	0	3 DROPS	N/A
9	[12] FREE FLOW	0	NO DATA	NO DATA	0
10	6CC	0	0	0	0.6CC
11	5CC	0	0	0	4.95CC
12	7CC	0	0	0	1.3CC
13	7CC	0	1 DROP	0	0

1) PARKER-CSD P/N 330446ADP-1 (2EA)

2) GREENE TWEED P/N 265-3260-818-1200

3) AMERICAN VARISEAL P/N AS-1316

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PARKER CSD 330446ADP-1 PISTON SEALS WITH PARKER CSD 330446ADP-5 PISTON SEALS

11) REPLACED PARKER CSD 330446ADP-5 PISTON SEALS WITH PARKER CSD 330446ADP-7 PISTON SEALS

12) REPLACED PISTON SEALS WITH SAME CONFIGURATION

TABLE 13(concluded)

ACTUATOR #20

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 14.58 HOURS
PRETEST	0.3CC	0	0	0	N/A
1	1CC	0	0	0	0
2	0	0	0	0	0
3	0	0	3 DROPS	0	0
4	0.5CC	0	0	0	0
5	0.5CC	0	0	0	0
COLD TEST #1	N/A	N/A	N/A	0	N/A
POST COLD TEST	0	0	0	0	N/A
6	0.1CC	0	0	0	0
7	0.2CC	0	0	0	0
8	[10] FREE FLOW	NO DATA	NO DATA	NO DATA	0
COLD TEST #2	N/A	N/A	1 DROP	0	N/A
POST COLD TEST	0	0	0	4 DROPS	N/A
9	0	0	0	0	0
10	0	0	0	0	0.25CC
11	0.2CC	0	1 DROP	1 DROP	5.2CC
12	0	0	0	0	0.8CC
13	0.1CC	0	1 DROP	0	0.9CC

1) GREENE TWEED P/N 5979A32900P001

2) FLUOROCARBON P/N AR104974

3) GREENE TWEED P/N 265-3260-777-1160

4) 168,381 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/14.58 HOUR WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEALS WITH SAME CONFIGURATION

EXCESSIVE WEAR
OF TEFLON-PEEK OUTER RING
RESULTED IN OPENING "Z"
CUT ALLOWING FREE FLOW
THROUGH THE GAP

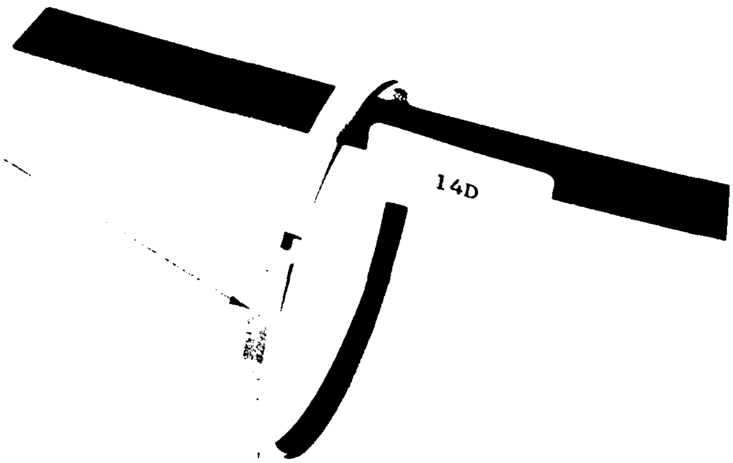


FIGURE 19. SCREENING TEST II - FAILED PARKER PISTON SEAL P/N 330446ADP-5. 168,000 CYCLES TO FAILURE

WEAR OF THE HIGH MODULUS
PLASTIC OUTER RING
RESULTED IN OPENING
OF THE "Z" CUT REDUCING
SUPPORT OF THE LIP
WHICH EVENTUALLY
BROKE OFF UNDER
PRESSURE

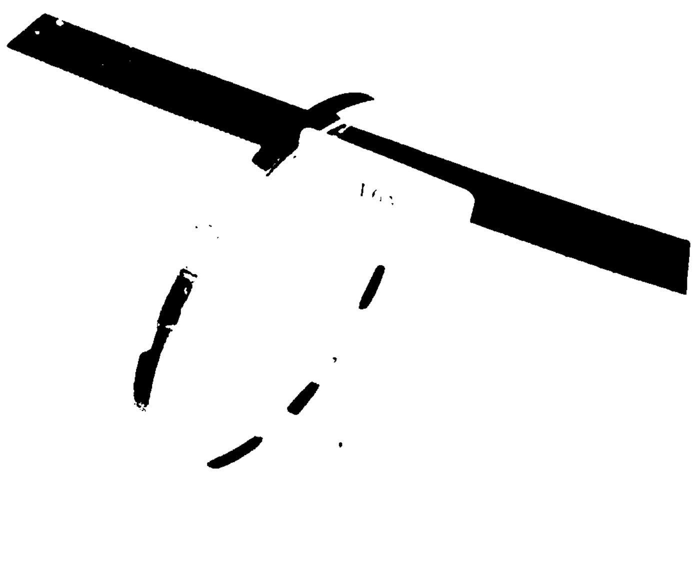


FIGURE 20. SCREENING TEST II - FAILED KOPPERS PISTON SEAL P/N C5816A60. 615,000 CYCLES TO FAILURE

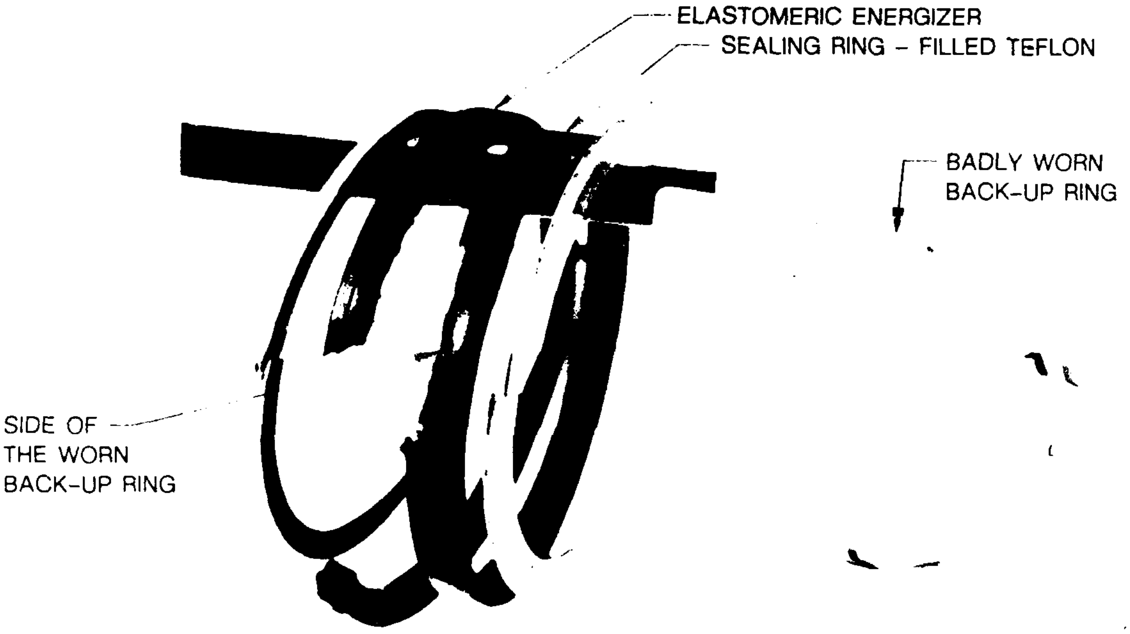


FIGURE 21. SCREENING TEST II - FAILED GREENE TWEED PISTON SEAL P/N 59794A32900P001. 1,340,000 CYCLES TO FAILURE

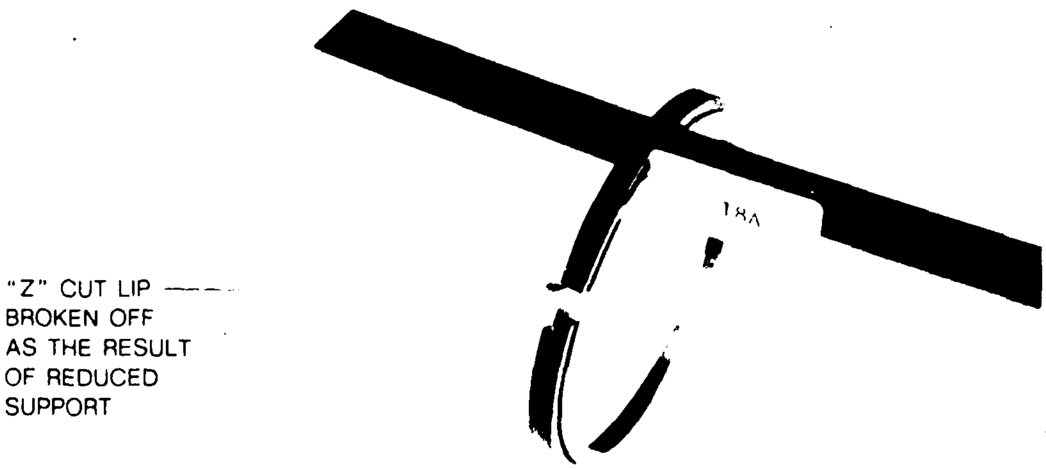


FIGURE 22. SCREENING TEST II - FAILED PARKER CSD PISTON SEAL P/N 330446ADP-3. 615,000 CYCLES TO FAILURE

TABLE 14
LONG LIFE TEST SEAL ASSIGNMENT

• ROD SEALS	• PISTON SEALS
Advanced Products secondary rod seal	Dover
Bal Seal primary rod seal	Parker Bertea/
C.E. Conover secondary rod seal	Pacific Piston Ring
Fluorocarbon primary rod seal	Shamban
Greene Tweed secondary rod seal	Koppers
Shamban primary and secondary rod seals	
Tetrafluor primary and secondary rod seals	
Parker Seal primary rod seal	
American Variseal primary rod seal	
Koppers primary rod seal	

All components of the test actuators used in the Screening Tests were inspected and, when required, brought to conformance with the drawings. The large steel actuators were reidentified as Numbers 1, 2, 3, 4, 5, 6, 7 and 8; the new titanium (cylinders and glands) actuators were identified as Numbers 9 and 10. Similarly the small steel actuators were identified as Numbers 1, 2, 3, 4, 5, 6, 7 and 8 and the titanium actuators as No. 9 and 10. The assigned seals were assembled into the test actuators according to the schedule shown in Table 15.

The Long Life Test consisted of 12,200,000 cycles performed in accordance with the 320100LT Long Life Test Plan shown in Appendix B. The Long Life Test started in April, 1987 and was completed in June 1988. The test was divided into 468 layers of cycling consisting of 100, 50, 10, 2 and 1 percent load stroke cycles. Nine layers of cycling constitutes one thermocycle controlling fluid temperatures at which cycling is performed. Two cold, -65°F, tests are performed during the Life Cycle Test. Because of the problems experienced with controlling fluid temperature without overheating the pump it was decided, with the Air Force program management concurrence, to control the ambient temperature in the test cylinders compartments in lieu of the fluid temperature. Thermotron Industries Model 5200 Temperature Controller was used to accomplish that task.

- 112.56 minute cycle schedule per layer (1.88 hour - 1 layer)
- 468 layers
- 1 bottoming cycle per layer
- 1 hour shut down every 16.88 hours 4 hours at 275°F per 16.88 hour test
- cold test at 430 and 860 hours

One Layer										Total
% Stroke	100	10	1	50	2	10	2	50	100	
% Load	100	10	1	50	2	10	2	50	100	
Time (min) ...	4.89	7.5	20.0	15.0	18.75	6.0	18.75	6.67	15.0	112.56 min
Rate (Hz)	.075	.5	7.5	0.14	4	.5	4	.075	7.5	
# of Cycles ...	22	225	9000	126	4500	180	4500	30	7500	26,083 cycles

Thermal Cycle

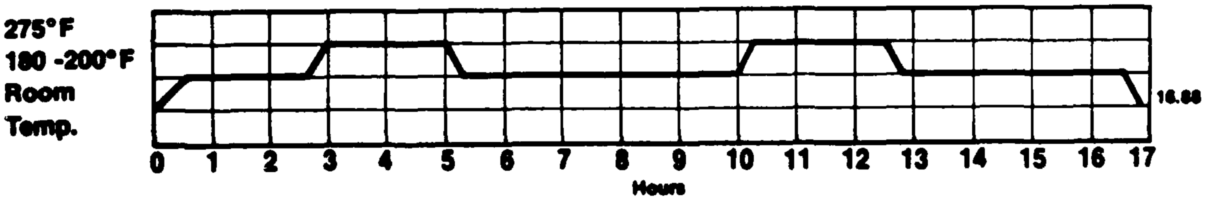


FIGURE 23. LONG LIFE TEST CYCLING SCHEDULE

TABLE 15
LONG LIFE TEST
SMALL ACTUATOR TEST SEAL CONFIGURATIONS

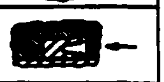
ACTUATOR DASH NO.	SEAL TYPE	MANUFACTURER	PART NO.	MATERIAL	SKETCH
-1001/1	PRIMARY ROD	BAL SEAL	X10243	FILLED TEFLON STAINLESS STEEL	
	SECONDARY ROD	ADVANCED PRODUCTS	46203/46204	HIGH MODULUS PLASTIC VITON	
	PISTON	DOVER CORP.	ABP17572	COOK'S 05-059 STAINLESS STEEL	
-1001/2	PRIMARY ROD	AMERICAN VARISEAL	AS1272	HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREEN TWEED	265-21400-777-1160	FILLED TEFLON ARLON VITON	
	PISTON	DOVER CORP.	ABP17572	COOK'S 05-059 STAINLESS STEEL	
-1001/3	PRIMARY ROD	KOPPERS	C5270360	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	C. E. CONOVER	CEC6001-214-L9	FILLED TEFLON VITON	
	PISTON	DOVER CORP.	ABP17572 (2 EA)	COOK'S 05-059 STAINLESS STEEL	
-1001/4	PRIMARY ROD	TETRAFLUOR	SD851216-51 TF888S121685-31	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	SHAMBAN	S36471	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	SHAMBAN	S35982	HIMOD PLASTIC STAINLESS STEEL	
-1001/5	PRIMARY ROD	PARKER - CSP	ML189-2/KLON833 ML1854/V1098-85 ML1841-XP2714-2	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	TETRAFLUOR	TF888S121685-31 SD851216-51	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	PISTON	SHAMBAN	S35982	HIMOD PLASTIC STAINLESS STEEL	
-1001/6	PRIMARY ROD	FLUOROCARBON	AR104304	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREENE TWEED	265-21400-777-1160	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	SHAMBAN	S35982 (2 EA)	HIMOD PLASTIC STAINLESS STEEL	
-1001/7	PRIMARY ROD	W. S. SHAMBAN	S36470	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	SHAMBAN	S36471	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	PARKER CSD	301641ADP-7	HIGH MODULUS PLASTIC STAINLESS STEEL	

TABLE 15 (continued)
LONG LIFE TEST
SMALL ACTUATOR TEST SEAL CONFIGURATIONS

ACTUATOR DASH NO.	SEAL TYPE	MANUFACTURER	PART NO.	MATERIAL	SKETCH
-1001/8	PRIMARY ROD	KOPPERS	C5270B60	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	C. E. CONOVER	CEC6001-214-L9	FILLED TEFLON VITON	
	PISTON	PARKER CSD	301641ADP-7	HIGH MODULUS PLASTIC STAINLESS STEEL	
-1001/9	PRIMARY ROD	AMERICAN VARISEAL	AS1272	HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREEN TWEED	265-21400-777-1160	FILLED TEFLON ARLON VITON	
	PISTON	PARKER CSD	301641ADP-7 (2 EA)	HIGH MODULUS PLASTIC STAINLESS STEEL	
-1001/10	PRIMARY ROD	PARKER - CHP	ML1839-2/KLON833 ML1854/V1098-85 ML1841-XP2714-2	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	TETRAFLUOR	SD851216-51 TP888S121685-31	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	PISTON	PARKER CSD	301641ADP-7	HIGH MODULUS PLASTIC STAINLESS STEEL	

LARGE ACTUATOR TEST SEAL CONFIGURATIONS

ACTUATOR DASH NO.	SEAL TYPE	MANUFACTURER	PART NO.	MATERIAL	SKETCH
-1001/1	PRIMARY ROD	BAL SEAL	X15033	FILLED TEFLON STAINLESS STEEL	
	SECONDARY ROD	ADVANCED PRODUCTS	46194/46195	HIGH MODULUS PLASTIC VITON	
	PISTON	DOVER CORP.	ABP17573	COOK'S 05-059 STAINLESS STEEL	
-1001/2	PRIMARY ROD	AMERICAN VARISEAL	AS-1316	HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREEN TWEED	265-32600-818-1200	FILLED TEFLON NYLON EPON	
	PISTON	DOVER CORP.	ABP17573	COOK'S 05-059 STAINLESS STEEL	
-1001/3	PRIMARY ROD	KOPPERS	C5267B60	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	C. E. CONOVER	CRC6001-326-88	FILLED TEFLON VITON	
	PISTON	DOVER CORP.	ABP17573 (2 EA)	COOK'S 05-059 STAINLESS STEEL	
-1001/4	PRIMARY ROD	TETRAFLUOR	SD851216-61 TP888S121685-41	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	SHAMBAN	S35971	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	SHAMBAN	S35985	NINOD PLASTIC STAINLESS STEEL	

TABLE 15 (concluded)
LONG LIFE TEST
LARGE ACTUATOR TEST SEAL CONFIGURATIONS

ACTUATOR DASH NO.	SEAL TYPE	MANUFACTURER	PART NO.	MATERIAL	SKETCH
-1001/5	PRIMARY ROD	PARKER - CHP	ML1851/V1098-85/ XP2714-4	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	TETRAFLUOR	TFN88S121685-41 SD851216-61	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	PISTON	SHAMBAN	S35985	HIMOD PLASTIC STAINLESS STEEL	
-1001/6	PRIMARY ROD	FLUOROCARBON	AR104974	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREENE TWEED	265-32600-777-1160	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	SHAMBAN	S35985 (2 EA)	HIMOD PLASTIC STAINLESS STEEL	
-1001/7	PRIMARY ROD	W. S. SHAMBAN	S35968	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	SHAMBAN	S35971	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	PISTON	KOPPERS	C5980A60	STAINLESS STEEL	
-1001/8	PRIMARY ROD	KOPPERS	C5267B60	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	C. E. CONOVER	CEC6001-326-D8	FILLED TEFLON VITON	
	PISTON	PARKER CSD	301641ADP-1	HIGH MODULUS PLASTIC STAINLESS STEEL	
-1001/9	PRIMARY ROD	AMERICAN VARISEAL	AS-1316	HIGH MODULUS PLASTIC STAINLESS STEEL	
	SECONDARY ROD	GREEN TWEED	265-3260-818-1200	FILLED TEFLON NYLON EPDM	
	PISTON	PARKER CSD	301641ADP-1 (2 EA)	HIGH MODULUS PLASTIC STAINLESS STEEL	
-1001/10	PRIMARY ROD	PARKER - CHP	ML1851/V1098-85/ XP2714-4	FILLED TEFLON HIGH MODULUS PLASTIC VITON	
	SECONDARY ROD	TETRAFLUOR	SD851216-61 TFN88S121685-41	FILLED TEFLON HIGH MODULUS PLASTIC STAINLESS STEEL	
	PISTON	PARKER CSD	301641ADP-1	HIGH MODULUS PLASTIC STAINLESS STEEL	

At the request of the Air Force program management, the cycling schedule was revised to increase the number of 1 percent cycles and reduce the number of 50 percent cycles. The cycling rates were revised at the same time to prevent pump cavitation. The final cycling schedule is shown in Figure 23.

16.1 Results of Long Life Test

Two large and four small primary rod seal configurations completed the Long Life Test without replacement. Five large and four small primary rod seal configurations failed.

Four large and four small secondary seal configurations completed the Long Life Test without replacement. Two large and two small secondary rod seal configurations failed.

One piston seal configuration, Koppers' all metal seal, completed Long Life Test reduced to 9,390,000 cycles (1 set) and 8,922,000 cycles (1 set) because of the test fixtures failure. Seven large and eight small piston seal configurations failed. In general, the recorded failures were caused by excessive wear of the seal materials. A summary of the seal failures is shown in Table 16.

A summary of the no failure performance of the substitute seal configurations is shown in Table 18.

A list of the successful seal configurations is shown in Table 17. The photographs of the successful seal configurations are shown in Figures 24 through 35.

The photographs of typical seal failures are shown in Figures 36 through 42.

A complete history of the seal performance throughout the Long Life Test is shown in Table 19.

TABLE 16
SUMMARY OF SEAL FAILURES

Cycle to Failure – Small Actuator Seals

Manufacturer Part No.	Number of Cycles To Failure	Number of Failed Seal Sets
PISTON SEALS:		
DOVER P/N ABP17572	469,000	2
	704,000	4
	938,000	2
DOVER P/N ABP19341	469,000	2
DOVER P/N ABP17572 REV 2	1,173,730	1
	1,643,230	1 DBL SET
KOPPERS P/N C6000—60	234,000	2
KOPPERS P/N C6123-60	234,000	2
PARKER CSD P/N 301641ADP-7	2,817,000	1 DBL SET (BOTH RINGS)
	3,990,000	1
	4,695,000	1
	5,869,600	1
	8,450,890	1
PARKER CSD P/N 301641SK4	469,490	1
SHAMBAN P/N S35982	1,643,000	3
	1,878,000	1
	2,582,000	1
	2,817,000	2
	3,051,700	1
	3,521,000	1
SECONDARY ROD SEALS:		
CONOVER P/N CEC6001-214-L9	5,869,600	1
	9,392,000	1
GREENE TWEED P/N 265-21400-777-1160	9,392,000	1
	10,329,000	1
	10,335,500	1
PRIMARY ROD SEALS:		
AMERICAN VARISEAL P/N AS1217	469,500	1
	678,160	1
	939,000	1
	9,392,000	1
	10,335,500	1
KOPPERS P/N C5270B70	6,807,660	2
PARKER GNP P/N ML189-2/KLON833	9,624,530	1
ML1854/V1098-85		
ML1841-XP2714-2		
	7,746,650	1
SHAMBAN P/N S36470	11,033,110	1

TABLE 16 (CONCLUDED)
SUMMARY OF SEAL FAILURES

Cycle to Failure – Large Actuator Seals

Manufacturer Part No.	Number of Cycles To Failure	Number of Failed Seal Sets
PISTON SEALS:		
DOVER P/N ABP17573	234,000	1
	469,000	3
	704,000	1
	938,000	2
	1,173,000	1
	1,643,230	1
	5,399,180	1 DBL SET
DOVER P/N ABP17573 REV 3	1,643,000	1
DOVER P/N ABP17343	938,900	1
SHAMBAN P/N S35985	469,400	2
	1,643,000	2
	2,112,000	1
	3,286,000	1
PARKER CSD P/N 301641ADP-1	3,521,000	1
	4,604,000	1
PARKER CSD P/N 301641SK5	938,000	1
SECONDARY ROD SEALS:		
ADVANCED PRODUCTS P/N 46194/46195	3,286,460	1
	3,652,000	1
	4,094,650	1
GREENE TWEED P/N 265-32600-777-1160	11,033,110	1
PRIMARY ROD SEALS:		
BAL SEAL P/N X16033	2,582,220	1
	7,277,150	1
AMERICAN VARISEAL P/N AS1316	938,990	1
	3,286,460	1
	5,164,400	1
	5,399,180	1
KOPPERS P/N C5267B60	6,338,170	1
	6,807,660	1
FLUOROCARBON P/N AR104974	6,338,170	1
SHAMBAN P/N S35968	6,338,170	1

TABLE 17
SUMMARY OF SUCCESSFUL SEAL CONFIGURATIONS

12,200,000 Cycle Small Actuator Seals

Manufacturer Part No.	Number of Seals Tested	Number of Seals Passed
SECONDARY ROD SEALS:		
ADVANCED PRODUCTS P/N 46203/46204	1	1
GREENE TWEED P/N 265-21400-777-1160	3	1
SHAMBAN P/N S36471	2	2
TETRAFLUOR P/N TF888S121685-31/ SD851216-51	2	2
PRIMARY ROD SEALS:		
BAL SEAL P/N X10243	1	1
FLUOROCARBON P/N AR104304	1	1
SHAMBAN P/N S36470	1	1
TETRAFLUOR P/N TF888S121685-31/ SD851216-51	1	1

12,200,000 Cycle - Large Actuator Seals

Manufacturer Part No.	Number of Seals Tested	Number of Seals Passed
SECONDARY ROD SEALS:		
CONOVER P/N CEC6001-326-D8	1	1
GREENE TWEED P/N 265-32600-818-1200	1	1
SHAMBAN P/N S35971	1	1
TETRAFLUOR P/N TF888S121685-41/ SD851216-61	2	2
PRIMARY ROD SEALS:		
PARKER GNP P/N ML1851/V1098-85/XP2714-4	2	2
TETRAFLUOR P/N TF888S121685-41/ SD851216-61	1	1

TABLE 18
SUMMARY OF SUBSTITUTE SEAL CONFIGURATIONS NO FAILURE PERFORMANCE

Small Actuator Seals

Manufacturer Part No.	Number of Test Cycles	Number of Seals Passed
PISTON SEALS:		
PARKER CSD P/N301641SK3	2,817,000	4
PARKER CSD P/N301641ADP-7	6,103,000	1
SECONDARY ROD SEALS:		
CONOVER P/N CEC6001-214-L9	5,399,000	1
PRIMARY ROD SEALS:		
BAL SEAL P/N 26266(LESS BACK UP)	3,286,000	1

Large Actuator Seals

Manufacturer Part No.	Number of Test Cycles	Number of Seals Passed
PISTON SEALS:		
KOPPERS P/N C5980A60	8,922,000	1
	9,390,000	1
PARKER CSD P/N 301641SK1	6,574,000	2
SHAMBAN P/N S35985	6,574,000	1
SECONDARY ROD SEALS:		
CONOVER P/N CEC6001-326-D8	11,270,000	1
GREENE TWEED P/N 265-3200-818-1200	11,270,000	2
SHAMBAN P/N S35971	8,922,000	1
PRIMARY ROD SEALS:		
SHAMBAN P/N S35968	8,922,000	1

TABLE 19

HISTORY OF SEAL PERFORMANCE-LONG LIFE TEST

LARGE ACTUATOR #1

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	2CC	0	0	0	N/A
1	5CC	0	0	0	0.1CC
2	10CC	0	18 DROPS	0	1.2CC
3	FREE FLOW	0	25 DROPS	0	2.5CC
4	FREE FLOW	0	10 DROPS	0	0.1CC
5	[10] FREE FLOW	0	23 DROPS	0	0
6	8CC	0	0	0	0
7	42CC	0	0	0	0
8	FREE FLOW	0	2 DROPS	0	0
9	FREE FLOW	0	0	0	0.3CC
10	FREE FLOW	0	0	0	0
11	FREE FLOW	0	0	0	0
12	[11] FREE FLOW	0	15 DROPS	0	0.1CC
13	45CC	0	0	0	0.05CC
14	60CC	0	50 DROPS	0	0.4CC

1) DOVER CORP. P/N ABP17573

2) BAL SEAL P/N X15033

3) ADVANCED PRODUCTS P/N 46194/46195

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

LARGE ACTUATOR #1

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
15	80CC	0	0	0	0.1CC
16	80CC	0	0	[12] 0	0
17	50CC	0	0	0	0.9CC
18	65CC	0	0	0	2.25CC
19	66CC	0	50 DROPS	0	2.25CC
20	100CC	0	0	0	0.2CC
21	FREE FLOW			0	0.25CC
22	FREE FLOW	1.5CC	15CC	0	0.6CC
23	FREE FLOW	1CC	16CC	0	0
24	40CC	0	15 DROPS	0	1.2CC
25	60CC	0	16 DROPS	0	0.25CC
26	60CC	0	0	0	1.05CC
27	60CC	0	0	0	0
28	60CC	0	0	0	0.05CC
29	36CC	0	0	0	0.15CC
30	FREE FLOW	0	0	0	0
31	[13] FREE FLOW	0	[14] 20CC	0	0
32	20CC	0	0	0	0
33	35CC	0	0	0	0
COLD TEST 1	N/A	N/A	2CC	0	N/A
POST COLD TEST	40CC	0	0	0	N/A

12) REPLACED SECONDARY SEAL WITH SAME CONFIGURATION

13) REPLACED DOVER ABP17573 PISTON SEAL WITH A REDESIGNED CONFIGURATION DOVER ABP17573 REV 3 PISTON SEAL

14) REPLACED PRIMARY SEAL WITH SAME CONFIGURATION

TABLE 19 (cont'd)

LARGE ACTUATOR #1

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
34	50CC	0	0	0	1.05CC
35	40CC	0	0	0	0
36	40CC	0	0	0	0
37	FREE FLOW	0	0	0	0.6CC
38	240CC	0	0	0	2.25CC
39	[15] FREE FLOW	0	1 DROP	0	0.6CC
40	50CC	0	25 DROPS	0	0.3CC
41	20CC	0	0	0	0.25CC
42	16CC	0	60 DROPS	1DROP	4.65CC
43	16CC	0	10 DROPS	0	2.25CC
44	16CC	0	FREE FLOW	0	0.65CC
45	8CC	0	FREE FLOW	0	0.35CC
46	13CC	0	21CC	0	0.1CC
47	14CC	0	[16] 19.5CC	[17] 0	0.1CC
48	20CC	0	0	0	0
49	[18] N/A	N/A	N/A	N/A	N/A
COLD TEST 2	N/A	N/A	N/A	N/A	N/A
POST COLD TEST	N/A	N/A	N/A	N/A	N/A

15) REPLACED DOVER ABP17573 REV 3 PISTON SEAL WITH A REDESIGNED CONFIGURATION DOVER ABP TYPE 105 PISTON SEAL

16) REPLACED PRIMARY SEAL WITH SAME CONFIGURATION

17) REPLACED ADVANCED PRODUCTS 46194/46195 SECONDARY SEAL WITH CONOVER CEC6001-326-L9 SECONDARY SEAL

18) REMOVED ACTUATOR FROM TEST

TABLE 19(cont'd)

LARGE ACTUATOR #2

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	0	1 DROP	5 DROPS	0	N/A
1	3CC	0	7 DROPS	0	0
2	8CC	0	4 DROPS	0	0
3	6CC	0	25 DROPS	0	0
4	18CC	0	5 DROPS	0	0
5	[10] FREE FLOW	0	26 DROPS	0	0
6	8CC	0	0	0	0
7	14CC	0	0	0	0
8	16CC	0	0	0	0
9	FREE FLOW	0	0	0	0
10	FREE FLOW	0	3 DROPS	0	0
11	FREE FLOW	0	0	0	0
12	[11] FREE FLOW	0	3 DROPS	0	0
13	40CC	0	0	0	0
14	70CC	0	0	0	0.05CC

1) DOVER CORP. PN APB17573

2) AMERICAN VARISEAL P/N AS1316

3) GREENE TWEED P/N 265-32600-818-1200

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

LARGE ACTUATOR #2

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
15	FREE FLOW	0	0	0	0.15CC
16	[12] FREE FLOW	0	0	0	0
17	FREE FLOW	0	0	0	0.1CC
18	FREE FLOW	0	0	0	0.15CC
19	FREE FLOW	0	0	0	0
20	[13] FREE FLOW	0	0	0	0
21	100CC	0	0	0	0
22	180CC	0	23 DROPS	0	0.5CC
23	110CC	0	20 DROPS	0	0
24	[14] 100CC	0	20 DROPS	0	0.65CC
25	2CC	0	23 DROPS	0	0.2CC
26	5CC	0	0	0	0
27	7CC	0	12CC	0	0
28	15CC	0	[15] 10CC	0	0.05CC
29	1CC	0	0	0	0
30	17CC	0	10 DROPS	0	0
31	10CC	0	0	0	0
32	15CC	0	10 DROPS	0	0.3CC
33	15CC	0	20 DROPS	0	0.3CC
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	10CC	0	5CC	0	N/A

12) REPLACED PISTON SEAL WITH SAME CONFIGURATION

13) REPLACED DOVER ABP17573 PISTON SEAL WITH A REDESIGNED CONFIGURATION DOVER ABP17343 PISTON SEAL (ALL STEEL)

14) REPLACED DOVER ABP17573 PISTON SEAL WITH A REDESIGNED CONFIGURATION PARKER CSD 301641SKI PISTON SEAL

15) REPLACED PRIMARY SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

LARGE ACTUATOR #2

	PISTON SEAL	PRIMARY ROD SEAL		SECONDARY ROD SEAL	
THERMO CYCLE CONDITION	CC/MINUTE	DROPS/ MINUTE	DROPS 50 CYCLES	DROPS 50 CYCLES	34CC 16.88 HOURS
34	25CC	0	4CC	0	0.05CC
35	25CC	0	20CC	0	0
36	35CC	0	5CC	0	0
37	40CC	0	0	0	0
38	40CC	2CC	250 DROPS	0	0
39	54CC	0	4CC	0	0.1CC
40	45CC	0	3.5CC	0	0.2CC
41	38CC	6 DROPS	250 DROPS	0	4.6CC
42	36CC	0	60 DROPS	1 DROP	0.55CC
43	64CC	0	12 DROPS	0	1.9CC
44	46CC	0	1CC	0	0.05CC
45	24CC	0	20 DROPS	0	0.15CC
46	50CC	0	16CC	0	0
47	52CC	0	[16] 7.5 CC	0	0
48	40CC	0	0	0	2.05CC
49	[17] N/A	N/A	N/A	N/A	N/A
CJLD TEST 2	N/A	N/A	N/A	N/A	N/A
POST COLD TEST	N/A	N/A	N/A	N/A	N/A

16) REPLACED AMERICAN VARISEAL AS-316 PRIMARY SEAL WITH BAL SEAL X6789 REV A PRIMARY SEAL

17) REMOVED FROM TEST PISTON HEAD AND SEAL MOVED TO LARGE ACTUATOR #3

TABLE 19(cont'd)

LARGE ACTUATOR #3

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	18CC	0	0	0	N/A
1	100CC	0	18 DROPS	0	0
2	FREE FLOW	0	10 DROPS	0	0
3	FREE FLOW	0	27 DROPS	0	0
4	FREE FLOW	0	10 DROPS	0	0.1CC
5	[10] FREE FLOW	0	25 DROPS	0	0.75CC
6	66CC	0	0	0	0
7	30CC	0	0	0	0
8	8CC	0	6 DROPS	0	0
9	4CC	0	0	0	0.5CC
10	8CC	0	6 DROPS	0	0
11	7CC	0	0	0	0.8CC
12	3CC	0	5 DROPS	0	0
13	10CC	0	0	0	0.05CC
14	4CC	0	1 DROP	0	0.25CC

1) DOVER CORP. PN APB17573 (2 EA)

2) KOPPERS P/N C5267B60

3) C.E.CONOVER P/N CEC6001-326-D8

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

LARGE ACTUATOR #3

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
15	8CC	0	0	0	0.15CC
16	8CC	0	0	0	0.2CC
17	8CC	0	0	0	0.15CC
18	9CC	0	0	0	0
19	3CC	0	0	0	2.2CC
20	9CC	0	0	0	0
21	13CC	0	0	0	0
22	10CC	0	0	0	0.6CC
23	10CC	0	0	0	0.55CC
24	12CC	0	0	0	0.8CC
25	20CC	0	0	0	0.2CC
26	10CC	0	0	1CC	0
27	16CC	0	12 DROPS	0	0
28	140CC	0	10 DROPS	0	0.15CC
29	76CC	0	2CC	0	0.05CC
30	FREE FLOW	0	10 DROPS	0	0.1CC
31	[11] FREE FLOW	0	0	0	0.1CC
32	15CC	0	15 DROPS	0	0.1CC
33	20CC	0	25 DROPS	0	0.2CC
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	16CC	0	10 DROPS	1 DROP	N/A

11) REPLACED DOVER ABP17573 PISTON SEAL WITH REDESIGNED CONFIGURATION DOVER ABP17573 REV 3 PISTON SEALS (2 EA)

TABLE 19(cont'd)

LARGE ACTUATOR #3

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
34	20CC	0	0	0	0.15CC
35	20CC	0	0	0	0.2CC
36	20CC	0	0	0	0.4CC
37	25CC	0	0	0	0.2CC
38	32CC	0	25 DROPS	0	0.4CC
39	[12] 60CC	0	[13] 5 DROPS	0	0.3CC
40	13CC	0	0	0	0
41	12CC	0	0	0	0
42	16CC	0	0	0	0
43	12CC	0	5 DROPS	0	0
44	16C	0	1 DROP	0	0
45	10CC	0	3 DROPS	0	0
46	12CC	0	0	0	0
47	12CC	0	10 DROPS	0	0
48	17CC	0	0	0	0
[14] 49	38CC	0	2 DROPS	0	0.35CC
50	50CC	0	0	0	0
51	18CC	0	0	0	0
52	60CC	0	0	0	0
COLD TEST 2	N/A	0	0	0	N/A
POST COLD TEST	50CC	0	0	0	N/A

12) REPLACED DOVER ABP17573 REV 3 PISTON SEALS WITH A REDESIGNED CONFIGURATION DOVER ABP19432 TYPE 105 PISTON SEALS (2 EA)

13) REPLACED KOPPERS C5267B60 PRIMARY SEAL WITH FLOROCARBON AR104974 PRIMARY SEAL

14) INSTALLED PISTON HEAD AND SEAL PARKER CSD 301641SK1 FROM LARGE ACTUATOR #2

TABLE 19(cont'd)

LARGE ACTUATOR #4

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	0	0	0	0	N/A
1	0	0	7 DROPS	0	0
2	7CC	0	8 DROPS	0	0
3	10CC	0	8 DROPS	0	0
4	15CC	0	10 DROPS	0	0
5	15CC	0	9 DROPS	0	0
6	36CC	0	4 DROPS	0	0
7	FREE FLOW	0	0	0	0
8	FREE FLOW	0	0	0	0
9	FREE FLOW	0	0	0	0
10	FREE FLOW	0	2 DROPS	0	0
11	FREE FLOW	0	0	0	0
12	[10] FREE FLOW	0	1 DROP	0	0
13	60CC	0	0	0	0
14	160CC	0	0	0	0
15	FREE FLOW	0	0	0	0

1) SHAMBAN P/N S35985

2) TETRAFLUOR P/N SD851216-61, TF888S121685-41

3) SHAMBAN P/N 35985

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

LARGE ACTUATOR #4

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
16	[11] FREE FLOW	0	0	0	0
17	70CC	0	0	0	0
18	70CC	0	0	0	0
19	92CC	0	0	0	0
20	100CC	0	0	0	0
21	70CC	0	0	0	0
22	2CC	0	0	0	0
23	FREE FLOW	0	0	0	0
24	[12] FREE FLOW	0	0	0	0
25	20CC	0	0	0	0.2CC
26	8CC	0	0	0	0
27	15CC	0	0	0	0
28	15CC	0	0	0	0
29	5.5CC	0	0	0	0
30	18CC	0	0	0	0
31	8CC	0	0	0	0
32	FREE FLOW	0	2 DROPS	0	0
33	FREE FLOW	0	0	0	0
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	720CC	0	0	0	N/A

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION

12) REPLACED SHAMBAN S35985 PISTON SEAL WITH PARKER CSD 301641SK2 PISTON SEAL

TABLE 19(cont'd)

LARGE ACTUATOR #4

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
34	25CC	0	0	0	0
35	15CC	0	0	0	0
36	20CC	0	0	0	0
37	200CC	0	0	0	0
38	840CC	0	0	0	0
39	[13] 252CC	0	0	0	0
40	50CC	0	0	0	0
41	60CC	0	0	0	0
42	[14] 125CC	0	1 DROP	0	0
43	24CC	0	0	0	0
44	240CC	0	1 DROP	0	0
45	240CC	0	2 DROPS	0	0
46	FREE FLOW	0	0	0	0
47	400CC	0	5 DROPS	0	0
48	FREE FLOW	0	0	0	0
49	[15] 350CC	0	1 DROP	0	0
50	FREE FLOW	0	0	0	0
51	FREE FLOW	0	0	0	0
52	FREE FLOW	0	0	0	0
COLD TEST 2	N/A	0	0	0	N/A
POST COLD TEST	FREE FLOW	0	0	0	N/A

13) REALIGNED PISTON SEAL (ONE OUTER RING JUMPED CLOCKING BALL)

14) REALIGNED PISTON SEAL (ONE OUTER RING JUMPED CLOCKING BALL)

15) INSTALLED TITANIUM CYLINDER BARREL AND PISTON HEAD WITH PARKER CSD PISTON SEAL 301641SKI FROM LARGE ACTUATOR #9

TABLE 19(cont'd)

LARGE ACTUATOR #5

THERMO CYCLE CONDITION [4]	PISTON SEAL [1] CC/MINUTE [5]	PRIMARY ROD SEAL [2] DROPS MINUTE [6]	DROPS 50 CYCLES [7]	SECONDARY ROD SEAL [3] DROPS 50 CYCLES [8]	34CC 16.88 HOURS [9]
PRETEST	8CC	0	0	0	N/A
1	5CC	0	0	0	0
2	5CC	0	0	0	0
3	1CC	0	7 DROPS	0	0
4	2CC	0	8 DROPS	0	0
5	2CC	0	5 DROPS	0	0.1CC
6	12CC	0	7 DROPS	0	0
7	6CC	0	0	0	0
8	32CC	0	10 DROPS	0	0
9	FREE FLOW	0	0	0	0
10	FREE FLOW	0	4 DROPS	0	0
11	FREE FLOW	0	0	0	0
12	[10] FREE FLOW	0	10 DROPS	0	0
13	56CC	0	0	0	0
14	60CC	0	0	0	0
15	50CC	0	0	0	0
16	50CC	0	0	0	0
17	40CC	0	0	0	0

1) SHAMBAN P/N S35985 (2 EA)

2) PARKER-GNP P/N ML1851/V1098-85/XP2714-4

3) TETRAFLUOR P/N TF888S121685-41, SD851216-61

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIRE ENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED SHAMBAN S35985 PISTON SEAL WITH KOPPERS C5980A60 PISTON SEAL (ALL STEEL)

TABLE 19(cont'd)

LARGE ACTUATOR #5

THERMO CYCLE CONDITION	PISTON SEAL	PRIMARY ROD SEAL		SECONDARY ROD SEAL	
	CC/MINUTE	DROPS/ MINUTE	DROPS 50 CYCLES	DROPS 50 CYCLES	34CC 16.88 HOURS
18	40CC	0	0	0	0
19	32CC	0	0	0	0
20	40CC	0	0	0	0
21	70CC	0	0	0	0
22	30CC	0	0	0	0.1CC
23	5CC	0	0	0	0
24	20CC	0	0	0	0.25CC
25	30CC	0	0	0	0
26	25CC	0	0	0	0.2CC
27	20CC	0	7 DROPS	0	0
28	25CC	0	5 DROPS	0	0
29	5CC	0	0	0	0.05CC
30	20CC	0	5 DROPS	0	0
31	10CC	0	0	0	0
32	12CC	0	7 DROPS	0	0
33	10CC	0	25 DROPS	0	0
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	1CC	0	0	0	N/A

TABLE 19(cont'd)

LARGE ACTUATOR #5

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
34	15CC	0	3 DROPS	0	0
35	8CC	0	3 DROPS	0	0
36	8CC	0	4 DROPS	0	0
37	12CC	0	0	0	0.05CC
38	6CC	0	100 DROPS	0	0
39	6CC	0	2 DROPS	0	0.15CC
40	2CC	0	0	0	0
41	5CC	0	0	0	0
42	2CC	0	1 DROP	0	0
43	2CC	0	0	0	0
44	3.5CC	0	0	0	0.1CC
45	6CC	0	0	0	0
46	4CC	0	10 DROPS	0	0
47	16CC	0	6 DROPS	0	0.1CC
48	32CC	0	0	0	0
49	9.5CC	0	0	0	0
50	20CC	0	0	0	0
51	230CC	0	0	0	0
52	40CC	0	0	0	0
COLD TEST 2	N/A	0	0	0	N/A
POST COLD TEST	36CC	0	0	0	N/A

TABLE 19(cont'd)

LARGE ACTUATOR #6

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	30CC	0	0	5 DROPS	N/A
1	32CC	0	2 DROPS	0	0
2	25CC	0	0	0	0.35CC
3	15CC	0	15 DROPS	0	0.15CC
4	11CC	0	2 DROPS	0	0.2CC
5	17CC	0	15 DROPS	0	0
6	28CC	0	0	0	0
7	42CC	0	0	0	0
8	24CC	0	6 DROPS	0	0
9	40CC	0	0	0	0.3CC
10	31CC	0	10 DROPS	0	0
11	40CC	0	0	0	0
12	3CC	0	2 DROPS	0	0.05CC
13	7CC	0	0	0	0
14	FREE FLOW	0	1 DROP	0	0
15	FREE FLOW	0	0	0	0.05CC
16	FREE FLOW	0	0	0	0.05CC
17	FREE FLOW	0	0	0	0

1) DOVER CORP. PN APB17573

2) AMERICAN VARISEAL P/N AS1316

3) GREENE TWEED P/N 265-32600-818-1200

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

LARGE ACTUATOR #6

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	FREE FLOW	0	0	0	0
19	FREE FLOW	0	10 DROPS	0	0.05CC
20	[10] FREE FLOW	0	0	0	0.55CC
21	100CC	0	0	0	0
22	440CC	0	0	0	0.05CC
23	FREE FLOW	0	0	0	0.5CC
24	[11] FREE FLOW	0	0	0	2.25CC
25	0	0	0	0	0
26	1CC	0	0	3CC	0
27	6CC	0	3CC	0	0
28	3CC	0	45 DROPS	0	0
29	0	0	2CC	0	0
30	1CC	0	15 DROPS	0	0
31	1CC	0	0	0	0
32	1CC	0	25 DROPS	0	0
33	1CC	0	[12] 25 DROPS	0	0
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	4CC	0	0	0	N/A

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION

12) REPLACED PRIMARY ROD SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

LARGE ACTUATOR #6

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
34	1CC	0	7 DROPS	0	0
35	1CC	0	5 DROPS	0	0
36	1CC	0	10 DROPS	0	0.1CC
37	0	0	0	0	0.15CC
38	0	0	0	0	0.05CC
39	0.2CC	0	2 DROPS	0	0
40	1CC	0	0	0	0
41	7CC	2CC	100 DROPS	0	0.3CC
42	2CC	0	2 DROPS	0	2.4CC
43	0	0	0	0	3.8CC
44	0	0	0	3 DROPS	2.95CC
45	4CC	0	0	2 DROPS	6.9CC
46	1CC	0	0	0	2.35CC
47	47CC	0	10 DROPS	[13] 0	5.1CC
48	1CC	0	0	0	0.1CC
49	0	0	0	0	0
50	0	0	0	0	0
51	24CC	0	0	0	0
52	250CC	0	0	0	0
COLD TEST 2	N/A	0	0	0	N/A
POST COLD TEST	FREE FLOW	0	0	0	N/A

13) REPLACED GREENE TWEED 265-32600-777-1160 SECONDARY ROD SEAL WITH TETRAFLU-OR TF8885121685-41 & SD851216-61 SECONDARY ROD SEAL

TABLE 19(cont'd)

LARGE ACTUATOR #7

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	36CC	0	0	2 DROPS	N/A
1	48CC	0	0	0	0
2	52CC	0	0	0	0
3	40CC	0	10 DROPS	0	0
4	20CC	0	2 DROPS	0	0.4CC
5	5CC	0	10 DROPS	0	0.3CC
6	26CC	0	2 DROPS	0	0
7	54CC	0	0	0	0
8	12CC	0	0	0	0
9	50CC	0	0	0	0.45CC
10	19CC	0	2 DROPS	0	0
11	55CC	0	0	0	0
12	46CC	0	1 DROP	0	0
13	45CC	0	0	0	0.05CC
14	64CC	0	2 DROPS	0	0.05CC
15	45CC	0	0	0	0.3CC
16	70CC	0	0	0	0.05CC
17	60CC	0	0	0	0.05CC

1) KOPPERS P/N C5980A60

2) SHAMBAN P/N S35968

3) SHAMBAN P/N S35971

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

LARGE ACTUATOR #7

	PISTON SEAL	PRIMARY ROD SEAL		SECONDARY ROD SEAL	
THERMO CYCLE CONDITION	CC/MINUTE	DROPS/ MINUTE	DROPS 50 CYCLES	DROPS 50 CYCLES	34CC 16.88 HOURS
18	65CC	0	0	0	0.1CC
19	40CC	0	0	0	0
20	60CC	0	0	0	0.1CC
21	60CC	0	0	0	0
22	75CC	0	0	0	0.15CC
23	30CC	0	0	0	0
24	40CC	0	0	0	0.05CC
25	40CC	0	0	0	0
26	23CC	0	0	1CC	0
27	32CC	0	10 DROPS	0	0.15CC
28	45CC	0	8 DROPS	0	0
29	12CC	0	7CC	0	0.05CC
30	40CC	0	10 DROPS	0	0
31	30CC	0	0	0	0
32	40CC	0	18 DROPS	0	0
33	20CC	0	20 DROPS	0	0
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	16CC	0	1CC	0	N/A
34	25CC	0	0	0	0
35	20CC	0	0	0	0
36	18CC	0	0	0	0.05CC
37	16CC	0	0	0	0.95CC
38	[10] 8CC	0	0	0	0

10) TORQUE TUBE BROKE ON FIXTURE, TESTING STOPPED

TABLE 19(cont'd)

LARGE ACTUATOR #8

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	1CC	0	0	0	N/A
1	185CC	0	0	0	0
2	5CC	0	0	0	0
3	4CC	0	35 DROPS	0	1.2CC
4	10CC	0	0	0	0
5	8CC	0	30 DROPS	0	0.3CC
6	40CC	0	0	0	0
7	20CC	0	0	0	0
8	9CC	0	3 DROPS	0	0
9	40CC	0	0	0	0
10	26CC	0	0	0	0
11	45CC	0	0	0	0
12	39CC	0	7 DROPS	0	0
13	45CC	0	0	0	0
14	60CC	0	3 DROPS	0	0
15	70CC	0	0	0	0.3CC
16	90CC	0	0	0	0
17	80CC	0	0	0	0

1) PARKER CSD P/N 301641-1

2) KOPPERS P/N C5267B60

3) C.E.CONOVER P/N CEC6001-326-D8

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

LARGE ACTUATOR #8

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	80CC	0	0	0	0
19	62CC	0	8 DROPS	0	0
20	[10] FREE FLOW	0	0	0	2.15CC
21	5CC	0	0	0	0
22	8CC	0	2 DROPS	0	0
23	2CC	0	20 DROPS	0	0
24	10CC	0	1 DROP	0	0
25	40CC	0	2 DROPS	0	0
26	14CC	0	0	0	0
27	21CC	0	0	0	0
28	30CC	0	0	0	0
29	12CC	0	3CC	0	0
30	30CC	0	0	0	0
31	25CC	0	0	0	0
32	30CC	0	20 DROPS	0	0
33	[11] 25CC	0	10 DROPS	0	0.65CC
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	12CC	0	0	0	N/A

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED PARKER CSD 301641ADP-1 PISTON SEAL WITH PARKER CSD 301641SK5 PISTON SEAL TO TEST NYLON KEVLAR MATERIAL

TABLE 19(cont'd)

LARGE ACTUATOR #8

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
34	4CC	0	4 DROPS	0	0
35	20CC	0	5 DROPS	0	0
36	30CC	0	0	0	0
37	80CC	0	0	0	0
38	660CC	0	200 DROPS	0	0
39	[12] FREE FLOW	0	[13] 4 DROPS	0	0
40	5CC	0	0	0	0
41	24CC	0	0	0	0
42	[14] 300CC	0	0	0	0
43	4CC	0	0	0	0
44	38CC	0	0	0	0
45	44CC	0	4 DROPS	0	0
46	15CC	0	25 DROPS	0	0
47	24CC	0	12 DROPS	0	0
48	[15] 12CC	0	0	0	0

12) REPLACED PARKER CSD 301641SK5 PISTON SEAL WITH A REDESIGNED CONFIGURATION PARKER CSD 301641SK2 PISTON SEAL

13) REPLACED KOPPERS C5267B60 PRIMARY ROD SEAL WITH SHAMBAN S35968 PRIMARY ROD SEAL

14) REALIGNED PISTON SEAL ONE OUTER RING JUMPED CLOCKING BALL

15) ACTUATOR REMOVED FROM TEST

TABLE 19(cont'd)

LARGE ACTUATOR #9

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	1CC	0	0	0	N/A
1	8CC	0	0	0	0
2	8CC	0	0	0	0
3	10CC	0	4 DROPS	0	0
4	21CC	0	7 DROPS	0	0
5	30CC	0	4 DROPS	0	0
6	31CC	0	0	0	0
7	16CC	0	0	0	0
8	7CC	0	0	0	0
9	15CC	0	0	0	0
10	13CC	0	3 DROPS	0	0
11	30CC	0	0	0	0
12	20CC	0	0	0	0
13	20CC	0	0	0	0.1CC
14	32CC	0	0	0	0.15CC
15	50CC	0	0	0	0.4CC
16	90CC	0	0	0	0.1CC
17	50CC	0	0	0	0.1CC

1) PARKER CSD P/N 310641ADP-1 (2 EA)

2) AMERICAN VARISEAL P/N AS1316

3) GREENE TWEED P/N 265-32600-818-1200

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

LARGE ACTUATOR #9

	PISTON SEAL	PRIMARY ROD SEAL		SECONDARY ROD SEAL	
THERMO CYCLE CONDITION	CC/MINUTE	DROPS/ MINUTE	DROPS 50 CYCLES	DROPS 50 CYCLES	34CC 16.88 HOURS
18	50CC	0	0	0	0.15CC
19	18CC	0	0	0	0
20	40CC	0	0	0	0.05CC
21	40CC	0	0	0	0
22	64CC	0	13 DROPS	0	0.05CC
23	40CC	0	10 DROPS	0	0.1CC
24	40CC	0	15 DROPS	0	0.5CC
25	40CC	0	13 DROPS	0	0.25CC
26	42CC	4CC	25CC	0	0.25CC
27	32CC	FREE FLOW	FREE FLOW	0	0.05CC
28	50CC	0	[10]FREE FLOW	0	0
29	20CC	0	0	0	0.2CC
30	50CC	FREE FLOW	FREE FLOW	0	0
31	40CC	0	0	0	0.6CC
32	35CC	0	0	0	0
33	[11] 45CC	0	12 DROPS	0	0.2CC
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	1CC	0	10 DROPS	0	N/A

10) REPLACED PRIMARY ROD SEAL WITH SAME CONFIGURATION

11) REPLACED PARKER CSD 301641ADP-1 PISTON SEALS WITH A REDESIGNED CONFIGURATION PARKER CSD 301641SK1 PISTON SEALS

TABLE 19(cont'd)

LARGE ACTUATOR #9

	PISTON SEAL	PRIMARY ROD SEAL		SECONDARY ROD SEAL	
THERMO CYCLE CONDITION	CC/MINUTE	DROPS/ MINUTE	DROPS 50 CYCLES	DROPS 50 CYCLES	34CC 16.88 HOURS
34	7CC	0	0	0	0.3CC
35	7CC	0	0	0	0
36	5CC	0	0	0	0.05CC
37	10CC	0	0	0	0.5CC
38	4CC	0	0	0	0.65CC
39	2.5CC	0	0	0	0.25
40	4CC	0	0	0	0
41	7CC	0	50 DROPS	0	0.3CC
[12] 42	3CC	0	10 DROPS	0	1.25CC
43	3CC	0	2 DROPS	0	0.2CC
44	2.5CC	0	1CC	0	2CC
45	3CC	0	20 DROPS	0	0.55CC
46	2CC	0	56CC	0	0
47	4CC	0	[13]FREE FLOW	0	0
48	[14] 15CC	0	0	0	0

12) REPLACED ORIGINAL TITANIUM CYLINDER BARREL WITH NIBRON (AMS2433) FINISHED TITANIUM CYLINDER BARREL TO TEST FINISH

13) REPLACED PRIMARY ROD SEAL WITH A REDESIGNED CONFIGURATION

14) REMOVED FROM TEST BARREL, PISTON HEAD & PISTON SEAL MOVED TO LARGE ACTUATOR #4

TABLE 19(cont'd)

LARGE ACTUATOR #10

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	52CC	0	0	0	N/A
1	7CC	0	0	0	0
2	7CC	0	0	0	0
3	4CC	0	3 DROPS	0	0
4	13CC	0	3 DROPS	0	0
5	5CC	0	5 DROPS	0	0
6	4CC	0	2 DROPS	0	0
7	24CC	0	0	0	0
8	11CC	0	4 DROPS	0	0
9	40CC	0	0	0	0
10	45CC	0	4 DROPS	0	0
11	40CC	0	0	0	0
12	66CC	0	12 DROPS	0	0
13	60CC	0	0	0	0
14	60CC	0	0	0	0
15	FREE FLOW	0	0	0	0
16	[10] FREE FLOW	0	0	0	0
17	20CC	0	0	0	0

1) PARKER CSD P/N 301641ADP-1

2) PARKER-GNP P/N ML1851/V1098-85/XP2714-4

3) TETRAFLUOR P/N SD851216-61, TF888S121685-41

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

LARGE ACTUATOR #10

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	40CC	0	0	0	0
19	16CC	0	10 DROPS	0	0
20	40CC	0	0	0	0.05CC
21	40CC	0	0	0	0
22	60CC	0	0	0	0.05CC
23	30CC	0	0	0	0
24	11 45CC	0	0	0	0.05CC
25	30CC	0	0	0	0.05CC
26	5CC	0	0	1CC	0
27	6CC	0	8 DROPS	0	0
28	7CC	0	8 DROPS	0	0
29	.5CC	0	0	0	0
30	8CC	0	5 DROPS	0	0
31	15CC	0	0	0	0
32	8CC	0	19 DROPS	0	0
33	15CC	0	0	0	0
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	2CC	0	0	0	N/A

11) REPLACED PARKER CSD 301641ADP-1 PISTON SEAL WITH A REDESIGNED CONFIGURATION PARKER CSD 301641SK1 PISTON SEAL

TABLE 19(cont'd)

LARGE ACTUATOR #10

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
34	15CC	0	0	0	0
35	20CC	0	0	0	0
36	25CC	0	0	0	0
37	18CC	0	0	0	0
38	30CC	0	150 DROPS	0	0
39	20CC	0	1 DROP	0	0
40	30CC	0	4 DROPS	0	0
41	20CC	0	150 DROPS	0	0
42	32CC	0	40 DROPS	0	0
43	28CC	0	10 DROPS	0	0
44	16CC	0	0	0	0
45	18CC	0	0	0	0.15CC
46	27CC	0	0	0	0
47	8CC	0	2 DROPS	0	0
48	35CC	0	0	0	0
49	28CC	0	0	0	N/A
50	30CC	0	0	0	0
51	FREE FLOW	0	0	0	0
52	30CC	0	0	0	0
COLD TEST 2	N/A	0	0	0	N/A
POST COLD TEST	18CC	0	0	0	N/A

TABLE 19(cont'd)

SMALL ACTUATOR #1

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROP/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	3CC	0	0	0	N/A
1	13CC	0	0	0	0
2	FREE FLOW	0	0	0	0
3	[10]FREE FLOW	0	3 DROPS	0	0
4	36CC	0	0	0	0.25CC
5	36CC	0	2 DROPS	0	2CC
6	FREE FLOW	0	0	0	0.75CC
7	FREE FLOW	0	0	0	0.45CC
8	FREE FLOW	0	4 DROPS	0	0.05CC
9	FREE FLOW	1 DROP	1 DROP	0	0.45CC
10	FREE FLOW	0	0	0	0.3CC
11	FREE FLOW	0	0	0	0.1CC
12	FREE FLOW	0	0	0	0
13	FREE FLOW	0	0	0	0
14	FREE FLOW	0	0	0	0
15	FREE FLOW	0	0	0	0
16	FREE FLOW	0	0	0	0
17	FREE FLOW	0	0	0	0

1) DOVER CORP. PN AP817572

2) BAL SEAL P/N X10243

3) ADVANCED PRODUCTS P/N 42603/42604

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1 DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #1

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	FREE FLOW	0	0	0	0
19	FREE FLOW	0	0	0	0
20	FREE FLOW	0	0	0	0
21	FREE FLOW	0	0	0	0
22	[11] FREE FLOW	0	0	0	0
23	0	0	0	0	0.2CC
24	1CC	0	0	0	0.05CC
25	FREE FLOW	0	0	0	0
26	[12] FREE FLOW	0	0	0	0
27	92CC	0	0	0	0
28	100CC	0	0	0	0.2CC
29	140CC	0	0	0	1.15CC
30	70CC	0	0	0	0.95CC
31	80CC	0	0	0	1.05CC
32	60CC	0	0	0	0.45CC
33	49CC	0	1 DROP	0	0.55CC
34	59CC	0	0	0	0.55CC
35	60CC	0	0	0	0.15CC
36	25CC	0	0	0	0.2CC
37	40CC	0	0	0	0

11) REPLACED DOVER ABP17572 PISTON SEAL WITH DOVER 19340 PISTON SEAL

12) REPLACED DOVER ABP19340 PISTON SEAL WITH A REDESIGNED CONFIGURATION DOVER ABP19341 (ALL STEEL) PISTON SEAL

TABLE 19(cont'd)

SMALL ACTUATOR #1

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
38	35CC	0	0	0	0.05CC
39	50CC	0	2 DROPS	0	0.05CC
40	[13] 35CC	0	0	0	0
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	100CC	0	0	1 DROP	N/A
41	2CC	0	0	0	0.3CC
42	4CC	0	0	0	0
43	20CC	0	0	0	0
44	20CC	0	0	0	0.2CC
45	FREE FLOW	0	0	0	0.15CC
46	FREE FLOW	0	0	0	0
47	[14] FREE FLOW	0	0	0	0
48	6CC	0	0	0	0
49	6CC	0	2 DROPS	0	1.1CC
50	5CC	0	0	0	3.6CC
51	16CC	0	0	0	3.4CC
52	30CC	0	0	0	7.05CC
COLD TEST #2	N/A	0	0	0	N/A
POST COLD TEST	28CC	0	0	0	N/A

13) REPLACED DOVER ABP19341 (ALL STEEL) PISTON SEAL WITH A REDESIGNED CONFIGURATION DOVER ABP 17572 REV 2 PISTON SEAL

14) REPLACED DOVER ABP17572 REV 2 PISTON SEAL WITH A REDESIGNED CONFIGURATION DOVER ABP19341 TYPE 105 PISTON SEAL

TABLE 19(cont'd)

SMALL ACTUATOR #2

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	10CC	0	0	0	N/A
1	20CC	0	0	0	0
2	FREE FLOW	0	0	0	0
3	[10] FREE FLOW	0	0	0	0
4	FREE FLOW	0	0	0	0
5	15CC	0	0	0	0
6	FREE FLOW	0	2 DROPS	0	0
7	FREE FLOW	0	0	0	0.05CC
8	FREE FLOW	0	2 DROPS	0	0
9	FREE FLOW	0	0	0	0
10	FREE FLOW	0	0	0	0
11	FREE FLOW	0	0	0	0
12	FREE FLOW	0	0	0	0
13	FREE FLOW	0	0	0	0
14	FREE FLOW	0	0	0	0
15	FREE FLOW	0	0	0	0
16	FREE FLOW	0	0	0	0
17	FREE FLOW	0	0	0	0

1) DOVER CORP. PN APB17572

2) AMERICAN VARISEAL P/N AS1272

3) GREENE TWEED P/N 265-21400-777-1160

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #2

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	FREE FLOW	0	0	0	0
19	FREE FLOW	0	0	0	0
20	FREE FLOW	0	0	0	0
21	FREE FLOW	0	0	0	0
22	[11] FREE FLOW	0	0	0	0
23	FREE FLOW	0	0	0	0
24	FREE FLOW	0	0	0	0
25	FREE FLOW	0	0	0	0.1CC
26	FREE FLOW	0	0	0	0
27	200CC	0	0	0	0
28	FREE FLOW	0	0	0	0
29	200CC	0	0	0	0
30	140CC	0	0	0	0
31	170	0	0	0	0
32	160CC	0	0	0	0
33	220CC	0	0	0	0
34	132CC	0	0	0	0
35	160CC	0	0	0	0
36	FREE FLOW	0	0	0	0
37	160CC	0	0	0	4.5CC

11) REPLACED DOVER ABP17572 PISTON SEAL WITH A REDESIGNED CONFIGURATION DOVER ABP19431 (ALL STEEL)

TABLE 19(cont'd)

SMALL ACTUATOR #2

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
38	150CC	0	0	0	5.4CC
39	180CC	0	3 DROPS	0	3.9CC
40	[12] FREE FLOW	25 DROPS	[13] 5CC	[14] 4CC	26.75CC
COLD TEST 1	N/A	0	0	1 DROP	N/A
POST COLD TEST	8CC	0	0	0	N/A
41	3CC	0	0	0	0.05CC
42	6CC	0	0	0	0.15CC
43	20CC	0	0	0	0.25CC
44	[15] 28CC	50 DROPS	60 DROPS	0	0.35CC

12) REPLACED DOVER ABP 19431 (ALL STEEL) PISTON SEAL WITH PARKER CSD 301641SK3 PISTON SEAL

13) REPLACED PRIMARY ROD SEAL WITH SAME CONFIGURATION

14) REPLACED SECONDARY ROD SEAL WITH SAME CONFIGURATION

15) ACTUATOR REMOVED FROM TEST, PISTON HEAD AND PISTON SEAL MOVED TO SMALL ACTUATOR #1

TABLE 19(cont'd)

SMALL ACTUATOR #3

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	10CC	0	0	0	N/A
1	10CC	0	0	0	0
2	25CC	0	0	0	0
3	[10] 60CC	0	0	0	0
4	21CC	0	5 DROPS	0	0
5	15CC	0	0	0	0
6	FREE FLOW	0	2 DROPS	0	0
7	FREE FLOW	0	0	0	0
8	FREE FLOW	0	0	0	0
9	FREE FLOW	0	1 DROP	0	0
10	FREE FLOW	0	0	0	0
11	FREE FLOW	0	1 DROP	0	0
12	FREE FLOW	0	0	0	0
13	FREE FLOW	0	0	0	0
14	FREE FLOW	0	0	0	0
15	FREE FLOW	0	0	0	0
16	FREE FLOW	0	0	0	0
17	FREE FLOW	0	0	0	0

1) DOVER CORP. PN APB17572 (2 EA)

2) KOPPERS P/N C5270360

3) C.E.CONOVER P/N CEC6001-214-L9

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #3

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	34CC 16.88 HOURS
18	FREE FLOW	0	0	0	0
19	FREE FLOW	0	0	0	0
20	FREE FLOW	0	0	0	0
21	FREE FLOW	0	0	0	0
22	[11] FREE FLOW	0	0	0	0
23	FREE FLOW	0	0	0	0.2CC
24	40CC	0	0	0	0.2CC
25	50CC	0	0	0	0.25CC
26	50CC	0	0	0	0
27	90CC	0	0	0	0
28	70CC	0	0	0	0
29	80CC	0	0	0	0
30	30CC	0	0	0	0
31	50CC	0	0	0	0.2CC
32	40CC	0	0	0	0
33	50CC	0	2 DROPS	0	1.75CC
34	56CC	0	0	0	0.95CC
35	50CC	0	0	0	0.2CC
36	30CC	0	0	0	0.15CC
37	50CC	0	0	0	0

11) REPLACED DOVER ABP 17572 PISTON SEALS WITH A REDESIGNED CONFIGURATION DOVER ABP19341 (ALL STEEL) PISTON SEALS

TABLE 19(cont'd)

SMALL ACTUATOR #3

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
38	45CC	0	2 DROPS	0	0
39	55CC	0	2 DROPS	0	0
40	[12] 40CC	0	[13] 26 DROPS	[14] 4CC	0
COLD TEST 1	N/A	0	1.5CC	1CC	N/A
POST COLD TEST	2CC	0	0	2 DROPS	N/A
41	3CC	0	0	0	0.05CC
42	6CC	0	0	0	0
43	10CC	0	0	0	0
44	10CC	0	0	0	0.2CC
45	8CC	0	0	0	0.05CC
46	18CC	0	0	0	0.05CC
47	[15] 22CC	0	0	5 DROPS	0.2CC
[16] 48	9CC	0	0	0	0

12) REPLACED PISTON SEAL WITH A REDESIGNED CONFIGURATION

13) REPLACED PRIMARY ROD SEAL WITH SAME CONFIGURATION

14) REPLACED CONOVER CEC6001-214-L9 SECONDARY ROD SEAL WITH GREENE TWEED 265-21400-777-1160 SECONDARY ROD SEAL

15) REPLACED DOVER ABP19341 (ALL STEEL) PISTON SEAL WITH A REDESIGNED CONFIGURATION DOVER ABP17572 REV 2 PISTON SEAL

16) ACTUATOR REMOVED FROM TEST

TABLE 19(cont'd)

SMALL ACTUATOR #4

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	5CC	0	0	0	N/A
1	FREE FLOW	0	0	0	0
2	FREE FLOW	0	0	0	0
3	20CC	0	0	0	0
4	26CC	0	0	0	0
5	20CC	0	0	0	0
6	5CC	0	0	0	0
7	FREE FLOW	0	0	0	0
8	FREE FLOW	0	0	0	0
9	FREE FLOW	0	0	0	0
10	FREE FLOW	0	0	0	0
11	FREE FLOW	0	0	0	0
12	FREE FLOW	0	0	0	0
13	FREE FLOW	0	0	0	0
14	FREE FLOW	0	0	0	0
15	FREE FLOW	0	0	0	0
16	FREE FLOW	0	0	0	0
17	FREE FLOW	0	0	0	0

1) SHAMBAN P/N S35982

2) TETRAFLUOR P/N SD851216-51, TF888S121685-31

3) SHAMBAN P/N S36471

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

SMALL ACTUATOR #4

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	FREE FLOW	0	0	0	0
19	FREE FLOW	0	0	0	0
20	FREE FLOW	0	0	0	0
21	FREE FLOW	0	0	0	0
22	[10] FREE FLOW	0	0	0	0
23	[11] FREE FLOW	0	0	0	0
24	FREE FLOW	0	0	0	0
25	FREE FLOW	0	0	0	0
26	[12] FREE FLOW	0	0	0	0
27	10CC	0	0	0	0
28	8CC	0	0	0	0.05CC
29	2CC	0	0	0	0
30	1CC	0	0	0	0
31	7CC	0	0	0	0
32	3CC	0	0	0	0.05CC
33	1CC	0	0	0	0
34	1CC	0	0	0	0
35	4CC	0	0	0	0
36	0.5CC	0	0	0	0
37	1CC	0	0	0	0
38	FREE FLOW	0	0	0	0
39	FREE FLOW	0	2 DROPS	0	0

10) REPLACED SHAMBAN S35982 PISTON SEAL WITH A REDESIGNED CONFIGURATION KOPPERS C6000-60 (ALL STEEL) PISTON SEAL

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION

12) REPLACED KOPPERS C6000-60 PISTON SEAL WITH SHAMBAN S35982 PISTON SEAL

TABLE 19(cont'd)

SMALL ACTUATOR #4

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	34CC 16.88 HOURS
40	[13] FREE FLOW	0	0	0	0
COLD TEST 1	N/A	0	0	1 DROP	N/A
POST COLD TEST	410CC	0	0	0	N/A
41	400CC	0	0	0	0
42	FREE FLOW	0	0	0	0
43	FREE FLOW	0	0	0	0
44	[14] FREE FLOW	0	0	0	0
45	12CC	0	0	0	0.2CC
46	2CC	0	0	0	0
47	6CC	0	2 DROPS	0	0.1CC
48	20CC	0	0	0	0
49	42CC	0	0	0	0.15CC
50	30CC	0	0	0	0
51	42CC	0	0	0	0
52	45CC	0	0	0	0
COLD TEST #2	N/A	0	0	0	NA/
POST COLD TEST	28CC	0	0	0	N/A

13) REPLACED SHAMBAN S35982 PISTON SEAL WITH KOPPERS C6123-60 (ALL STEEL) PISTON SEAL

14) REPLACED KOPPERS C6123-60 (ALL STEEL) PISTON SEAL WITH SHAMBAN S35982 PISTON SEAL

TABLE 19(cont'd)

SMALL ACTUATOR #5

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	8CC	0	0	0	N/A
1	9CC	0	0	0	0.45CC
2	NO DATA	NO DATA	NO DATA	NO DATA	0
3	1CC	0	0	0	0
4	5CC	0	0	0	0
5	2CC	0	0	0	0
6	3CC	0	0	0	0
7	3CC	0	0	0	0
8	4CC	0	6 DROPS	0	0
9	18CC	0	0	0	0
10	18CC	1 DROP	0	0	0
11	FREE FLOW	0	0	0	0
12	FREE FLOW	0	0	0	0
13	FREE FLOW	0	0	0	0
14	FREE FLOW	0	0	0	0
15	FREE FLOW	0	0	0	0.15CC
16	FREE FLOW	0	0	0	0
17	FREE FLOW	0	0	0	0

1) SHAMBAN P/N 35982

2) PARKER-GNP P/N ML189-2/KLON833, ML1854/V1098-85, ML1841-XP2714-2

3) TETRAFLUOR P/N TF888S121685-31, SD851216-51

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

SMALL ACTUATOR #5

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	FREE FLOW	0	0	0	0
19	FREE FLOW	0	0	0	0
20	FREE FLOW	0	0	0	0
21	FREE FLOW	0	0	0	0.3CC
22	[10] FREE FLOW	0	0	0	0
23	8CC	0	0	0	0.05CC
24	5CC	0	0	0	0
25	5CC	0	0	0	0
26	3.5CC	0	0	0	0
27	4CC	0	0	0	0
28	1CC	0	0	0	0
29	110CC	0	0	0	0
30	FREE FLOW	0	0	0	0
31	[11] FREE FLOW	0	0	0	0
32	25CC	0	0	0	0
33	12CC	0	0	0	0.5CC
34	12CC	0	0	0	0
35	20CC	0	0	0	0
36	0	0	0	0	0
37	3CC	0	0	0	0
38	40CC	0	0	0	0
39	FREE FLOW	0	3 DROPS	0	0.05CC

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #5

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	34CC 16.88 HOURS
40	[12] FREE FLOW	0	0	0	0
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	220CC	0	0	0	N/A
41	250CC	0	6 DROPS	0	0.1CC
42	FREE FLOW	0	5 DROPS	0	0.05CC
43	FREE FLOW	0	5 DROPS	0	0
44	[13] 300CC	17 DROPS	[14] 10 DROPS	0	0
45	12CC	0	0	0	0
46	8CC	0	0	0	0
47	4CC	0	0	0	0
48	1CC	0	0	0	0
49	1CC	0	2 DROPS	0	0.1CC
50	0	0	0	0	3.2CC
51	0	0	0	0	2.45CC
52	90CC	0	0	0	2.5CC
COLD TEST #2	N/A	0	0	0	N/A
POST COLD TEST	400CC	0	0	0	N/A

12) REPLACED SHAMBAN 35982 PISTON SEAL WITH KOPPERS C6123-60 (ALL STEEL) PISTON SEAL

13) REPLACED KOPPERS C6123-60 (ALL STEEL) PISTON SEAL WITH SHAMBAN S35982 PISTON SEAL

14) REPLACED PRIMARY ROD SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #6

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	55CC	0	0	0	N/A
1	7CC	0	0	0	0.05CC
2	5CC	0	0	0	0
3	20CC	0	0	0	0
4	14CC	0	0	0	0
5	120CC	0	0	0	0
6	160CC	0	0	0	0
7	FREE FLOW	0	0	0	0
8	FREE FLOW	1 DROP	4 DROPS	0	0
9	FREE FLOW	0	0	0	0
10	FREE FLOW	0	0	0	0.05CC
11	FREE FLOW	0	0	0	0
12	FREE FLOW	0	1 DROP	0	0
13	FREE FLOW	0	0	0	0
14	FREE FLOW	0	0	0	0
15	FREE FLOW	0	0	0	0
16	FREE FLOW	0	0	0	0
17	FREE FLOW	0	0	0	0

1) SHAMBAN P/N S35982 (2 EA)

2) FLUOROCARBON P/N AR104304

3) GREENE TWEED P/N 265-21400-777-1160

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

SMALL ACTUATOR #6

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	FREE FLOW	0	0	0	0
19	FREE FLOW	0	0	0	0
20	FREE FLOW	0	0	0	0
21	FREE FLOW	0	0	0	0
22	[10] FREE FLOW	0	0	0	0
23	22CC	0	0	0	0.1CC
24	10CC	0	0	0	0
25	8CC	0	0	0	0
26	12.5CC	0	0	0	0
27	7CC	0	0	0	0
28	3CC	0	0	0	0
29	0	0	0	0	0.45CC
30	1CC	0	0	0	0.1CC
31	1CC	0	0	0	0.1CC
32	0	0	0	0	0
33	0.5CC	0	0	0	0.1CC
34	0	0	0	0	0.05CC
35	FREE FLOW	0	0	0	0
36	FREE FLOW	0	0	0	0.05CC
37	[11] FREE FLOW	0	0	0	0
38	20CC	0	0	0	0
39	4CC	0	1 DROP	0	0

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #6

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
40	20CC	0	0	0	0
COLD TEST 1	N/A	0	0	1 DROP	N/A
POST COLD TEST	16CC	0	0	0	N/A
41	4CC	0	0	0	0
42	1CC	0	0	0	0
43	1CC	0	0	0	0.05CC
44	16CC	0	0	0	0.05CC
45	6CC	0	0	0	0.15CC
46	4CC	0	0	0	0.05CC
47	0.5CC	0	0	0	0.2CC
48	1CC	0	0	0	0.5CC
49	1.2CC	0	0	0	5CC
50	0	0	0	0	4.2CC
51	180CC	0	0	0	18.45CC
52	FREE FLOW	0	7 DROPS	0	16.5CC
COLD TEST #2	N/A	0	0	0	N/A
POST COLD TEST	FREE FLOW	0	0	0	N/A

TABLE 19(cont'd)

SMALL ACTUATOR #7

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	15CC	0	0	0	N/A
1	18CC	0	0	0	0.05CC
2	7CC	0	0	0	0
3	6CC	0	0	0	0
4	18CC	0	0	0	0
5	7CC	0	0	0	0
6	30CC	0	0	0	0.4CC
7	20CC	0	0	0	0.25CC
8	28CC	0	0	0	0
9	19CC	0	2 DROPS	0	0.2CC
10	14CC	2 DROPS	0	0	0
11	24CC	0	0	0	0.1CC
12	21CC	0	0	0	0
13	45CC	0	0	0	0
14	31CC	0	0	0	0
15	32CC	0	0	0	0
16	45CC	0	0	0	0
17	32CC	0	0	0	0

1) PARKER CSD P/N 301641ADP-7

2) W.S.SHAMBAN P/N S36470

3) SHAMBAN P/N S36471

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

SMALL ACTUATOR #7

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	82CC	0	0	0	0
19	38CC	0	0	0	0
20	29CC	0	0	0	0
21	FREE FLOW	0	0	0	0.35CC
22	62CC	0	0	0	0
23	42CC	0	0	0	7.05CC
24	30CC	0	0	0	0.05CC
25	[10] FREE FLOW	0	0	0	0.05CC
26	FREE FLOW	0	0	0	0
27	20CC	0	0	0	0
28	40CC	0	0	0	0
29	28CC	0	0	0	0
30	25CC	0	0	0	0
31	45CC	0	0	0	0
32	FREE FLOW	0	0	0	0
33	20CC	0	0	0	0.35CC
34	32CC	0	0	0	0.15CC
35	50CC	0	0	0	0.15CC
36	40CC	0	0	0	0.15CC
37	50CC	0	0	0	0.05CC
38	40CC	0	0	0	0.1CC
39	60CC	0	0	0	0.15CC

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #7

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
40	[11] 50CC	0	0	0	0.65CC
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	6CC	0	0	0	N/A
41	30CC	0	0	0	1.2CC
42	100CC	0	0	0	0.1CC
43	FREE FLOW	0	0	0	0.25CC
44	[12] FREE FLOW	0	0	0	0.4CC
45	28CC	0	0	0	0.15CC
46	25CC	0	0	0	0.2CC
47	62CC	0	[13] 0	0	2.2CC
48	40CC	0	0	0	0.25CC
49	150CC	0	0	0	0.4CC
50	50CC	0	0	0	N/A
51	60CC	0	0	0	1.8CC
52	80CC	0	0	0	0
COLD TEST #2	N/A	0	0	0	N/A
POST COLD TEST	35CC	0	0	0	N/A

11) REPLACED PARKER CSD 301641ADP-7 PISTON SEAL WITH A REDESIGNED CONFIGURATION PARKER CSD 301641SK4 PISTON SEAL

12) REPLACED PARKER CSD 301641SK4 PISTON SEAL WITH A REDESIGNED CONFIGURATION PARKER CSD 301641SK3 PISTON SEAL

13) REPLACED PRIMARY ROD SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #8

THERMO CYCLE CONDITION [4]	PISTON SEAL [1]	PRIMARY ROD SEAL [2]		SECONDARY ROD SEAL [3]	
	CC/MINUTE [5]	DROPS/ MINUTE [6]	DROPS 50 CYCLES [7]	DROPS 50 CYCLES [8]	34CC 16.88 HOURS [9]
PRETEST	15CC	0	0	0	N/A
1	12CC	0	20 DROPS	0	0
2	10CC	0	8 DROPS	0	0.5CC
3	9CC	0	5 DROPS	0	0.5CC
4	8CC	0	5 DROPS	0	0.1CC
5	36CC	0	25 DROPS	0	0.4CC
6	32CC	0	15 DROPS	0	0
7	96CC	0	0	0	0
8	31CC	1 DROP	0	0	0
9	16CC	2 DROPS	1 DROP	0	0
10	32CC	0	1 DROP	0	0
11	28CC	0	1 DROP	0	0
12	40CC	0	17 DROPS	0	0
13	51CC	0	0	0	0
14	57CC	0	0	0	0
15	40CC	0	0	0	0
16	42CC	0	0	0	0
17	46CC	0	0	0	0

1) PARKER CSD P/N 301641ADP-7

2) KOPPERS P/N C5270B60

3) C.E.CONOVER P/N CEC6001-214-L9

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

SMALL ACTUATOR #8

THERMO CYCLE CONDITION	PISTON SEAL	PRIMARY ROD SEAL		SECONDARY ROD SEAL	
	CC/MINUTE	DROPS/ MINUTE	DROPS 50 CYCLES	DROPS 50 CYCLES	34CC 16.88 HOURS
18	46CC	0	0	0	0
19	88CC	0	0	0	0
20	FREE FLOW	0	0	0	0
21	FREE FLOW	0	0	0	0
22	[10] 41	0	0	0	0
23	8CC	0	0	10 DROPS	31.6CC
24	5CC	0	0	10 DROPS	36.5CC
25	9CC	0	0	[11]10 DPS	63.5CC
26	8CC	0	25 DROPS	0	54.6CC
27	19CC	0	0	0	0.05CC
28	30CC	0	0	0	0
29	38CC	0	15 DROPS	0	1.25CC
30	25CC	0	15 DROPS	0	0.65CC
31	35CC	0	14 DROPS	0	0.05CC
32	30CC	0	19 DROPS	0	0
33	33CC	0	0	0	0
34	24CC	0	12 DROPS	0	0
35	30CC	0	12 DROPS	0	0
36	20CC	0	0	0	0.05CC
37	30CC	0	15 DROPS	0	0

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

11) REPLACED SECONDARY ROD SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #8

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
38	25CC	0	0	0	0
39	30CC	0	8 DROPS	0	0
40	20CC	0	[12]40 DROPS	0	0.1CC
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	20CC	0	0	0	N/A
41	25CC	0	0	0	0.15CC
42	20CC	0	0	0	0
43	25CC	0	0	0	0
44	24CC	0	0	0	0.35CC
45	24CC	0	20 DROPS	0	0.1CC
46	25CC	0	0	0	0
47	20CC	0	2 DROPS	0	1.95CC
[13] 48	130CC	0	0	0	1.25CC

12) REPLACED PRIMARY SEAL WITH SAME CONFIGURATION

13) ACTUATOR REMOVED FROM . ST

TABLE 19(cont'd)

SMALL ACTUATOR #9

[4] THERMO CYCLE CONDITION	[1] PISTON SEAL [5] CC/MINUTE	[2] PRIMARY ROD SEAL [6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[3] SECONDARY ROD SEAL [8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	4CC	0	0	0	N/A
1	12CC	0	0	0	0.05CC
2	8CC	0	0	0	0
3	10CC	0	0	0	0
4	10CC	0	0	0	0
5	10CC	0	0	0	0
6	20CC	0	0	0	0
7	17CC	0	0	0	0
8	18CC	0	0	0	0
9	96CC	0	3 DROPS	0	0
10	12CC	0	0	0	0.05CC
11	8CC	0	1 DROP	0	0.15CC
12	19CC	0	0	0	0
13	25CC	0	0	0	0
14	15CC	0	0	0	0
15	61CC	0	0	0	0
16	10CC	0	0	0	0
17	36CC	0	0	0	0

1) PARKER CSD P/N 301641ADP-7 (2 EA)

2) AMERICAN VARISEAL P/N AS1272

3) GREENE TWEED P/N 265-21400-777-1160

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

TABLE 19(cont'd)

SMALL ACTUATOR #9

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	38CC	0	0	0	0
19	32CC	0	0	0	0
20	36CC	0	0	0	0
21	40CC	0	0	0	0
22	36CC	0	0	0	0
23	18CC	0	0	0	0.05CC
24	25CC	0	0	0	0
25	35CC	0	0	0	0
26	25CC	0	0	0	0
27	40CC	0	0	0	0
28	50CC	0	0	0	0
29	13CC	0	0	0	0
30	55CC	0	0	0	0
31	45CC	0	0	0	0
32	50CC	0	0	0	0
33	4CC	10 DROPS	0	20 DROPS	0
34	23CC	0	15 DROPS	0	0
35	45CC	0	15 DROPS	0	0
36	FREE FLOW	0	200 DROPS	0	0
37	[10] FREE FLOW	0	17 DROPS	0	0

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #9

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	34CC 16.88 HOURS
38	5CC	0	0	0	1.3CC
39	8CC	0	3 DROPS	0	2.75CC
40	[11] 10CC	0	0	0	2.5CC
COLD TEST 1	N/A	0	0	1 DROP	N/A
POST COLD TEST	20CC	0	0	0	N/A
41	15CC	0	0	0	2.25CC
42	18CC	0	0	0	5.5CC
43	30CC	0	0	0	6.5CC
44	12CC	0	0	0	5.75CC
45	14CC	0	[12] 3 DROPS	[13] 0	3.5CC
46	11CC	0	0	0	2.2CC
47	22CC	0	[14] 10 DROPS	0	0
48	[15] 25CC	0	0	0	0

11) REPLACED PARKER CSD 301641ADP-7 PISTON SEALS WITH A REDESIGNED CONFIGURATION PARKER CSD 301641SK3 PISTON SEALS

12) REPLACED PRIMARY ROD SEAL WITH SAME CONFIGURATION

13) REPLACED SECONDARY ROD SEAL WITH SAME CONFIGURATION

14) REPLACED AMERICAN VARISEAL AS1272 PRIMARY SEAL WITH SHAMBAN S36470 PRIMARY SEAL

15) REMOVED ACTUATOR FROM TEST: BARREL, PISTON HEAD & PISTON SEAL TO SMALL ACTUATOR #4

TABLE 19(cont'd)

SMALL ACTUATOR #10

	[1] PISTON SEAL	[2] PRIMARY ROD SEAL		[3] SECONDARY ROD SEAL	
[4] THERMO CYCLE CONDITION	[5] CC/MINUTE	[6] DROPS/ MINUTE	[7] DROPS 50 CYCLES	[8] DROPS 50 CYCLES	[9] 34CC 16.88 HOURS
PRETEST	2CC	0	0	0	N/A
1	10CC	0	0	0	0
2	7CC	0	0	0	0
3	10CC	0	0	0	0
4	12CC	0	0	0	0.1CC
5	10CC	0	1 DROP	0	0.35CC
6	20CC	0	0	0	0.7CC
7	15CC	0	0	0	0.6CC
8	10CC	0	0	0	0
9	115CC	2 DROPS	2 DROPS	0	0.75CC
10	18CC	1 DROP	2 DROPS	0	0
11	24CC	0	0	0	0.4CC
12	16CC	0	0	0	0
13	25CC	0	0	0	0
14	22CC	0	0	0	0
15	41CC	0	0	0	0
16	25CC	0	0	0	0
17	[10] FREE FLOW	0	0	0	0

1) PARKER CSD P/N 301641ADP-7

2) PARKER-GNP P/N ML1839-2/KLDN833, ML1854/V1098-85, ML1851-XP2714-2

3) TETRAFLUOR P/N SD851216-51, TF888S121685-31

4) 234,747 CYCLES PER THERMO CYCLE

5) 20 CC/MINUTE REQUIREMENT

6) 1DROP/MINUTE REQUIREMENT

7) 2 DROPS PER 50 CYCLES REQUIREMENT

8) 2 DROPS PER 50 CYCLES REQUIREMENT

9) 34 CC/16.88 HOURS WAS CONSIDERED A FAILURE

10) REPLACED PISTON SEAL WITH SAME CONFIGURATION

TABLE 19(cont'd)

SMALL ACTUATOR #10

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
18	17CC	0	0	0	0
19	14CC	0	0	0	0
20	30CC	0	0	0	0
21	20CC	0	0	0	0.35CC
22	FREE FLOW	0	0	0	0
23	21CC	0	0	0	0.05CC
24	25CC	0	0	0	0
25	30CC	0	0	0	0
26	40CC	0	0	0	0
27	40CC	0	0	0	0
28	80CC	0	0	0	0
29	FREE FLOW	0	0	0	0
30	[11] FREE FLOW	0	0	0	0.05CC
31	10CC	0	0	0	0
32	15CC	0	0	0	0
33	5CC	0	0	0	0
34	14CC	0	0	0	0
35	30CC	0	0	0	0
36	2CC	0	0	0	0
37	35CC	0	0	0	0
38	30CC	0	[12] 100CC	0	0
39	3CC	0	0	0	0

11) REPLACED PISTON SEAL WITH SAME CONFIGURATION

12) REPLACED PARKER-GNP P/N ML1839-2/KLON833, ML1854/V1098-85, ML1851-XP2714-2 PRIMARY ROD SEAL WITH BAL SEAL P/N X26266 LESS BACKUP RING

TABLE 19(concluded)

SMALL ACTUATOR #10

THERMO CYCLE CONDITION	PISTON SEAL CC/MINUTE	PRIMARY ROD SEAL DROPS/ MINUTE	PRIMARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL DROPS 50 CYCLES	SECONDARY ROD SEAL 34CC 16.88 HOURS
40	[13] 25CC	0	0	0	0.05CC
COLD TEST 1	N/A	0	0	0	N/A
POST COLD TEST	1CC	0	0	0	N/A
41	4CC	0	0	0	0.05CC
42	6CC	0	0	0	0
43	10CC	0	0	0	0
44	6CC	0	0	0	0
45	10CC	0	0	0	0
46	4CC	0	0	0	0
47	10CC	0	3 DROPS	0	0
48	7CC	0	0	0	0
49	10CC	0	1 DROP	0	0
50	5CC	0	0	0	0
51	8CC	0	0	0	0
52	8CC	0	0	0	0
COLD TEST #2	N/A	0	0	0	N/A
POST COLD TEST	9CC	0	0	0	N/A

13) REPLACED PARKER CSD 301641ADP-7 PISTON SEAL WITH A REDESIGNED CONFIGURATION PARKER CSD 301641SK3

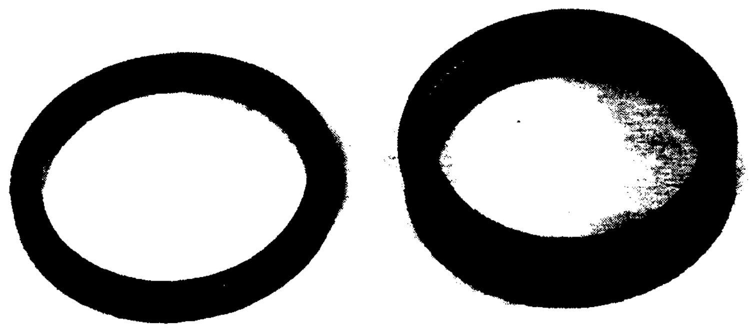


FIGURE 24. LONG LIFE TEST - BAL SEAL
SMALL ACTUATOR PRIMARY ROD SEAL
P/N X10243. 12,200,000 CYCLES - NO FAILURE

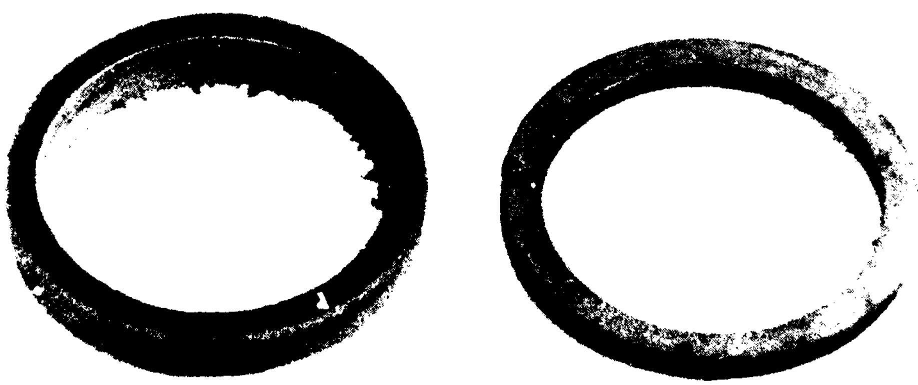


FIGURE 25. LONG LIFE TEST - ADVANCED PRODUCTS
SMALL ACTUATOR SECONDARY ROD SEAL
P/N 46203/46204. 12,200,000 CYCLES - NO FAILURE

FIGURE 26. LONG LIFE TEST - TETRAFLUOR
SMALL ACTUATOR PRIMARY ROD SEAL
P/N TF888S121685-31/SD851216-51. 12,200,000 CYCLES - NO FAILURE

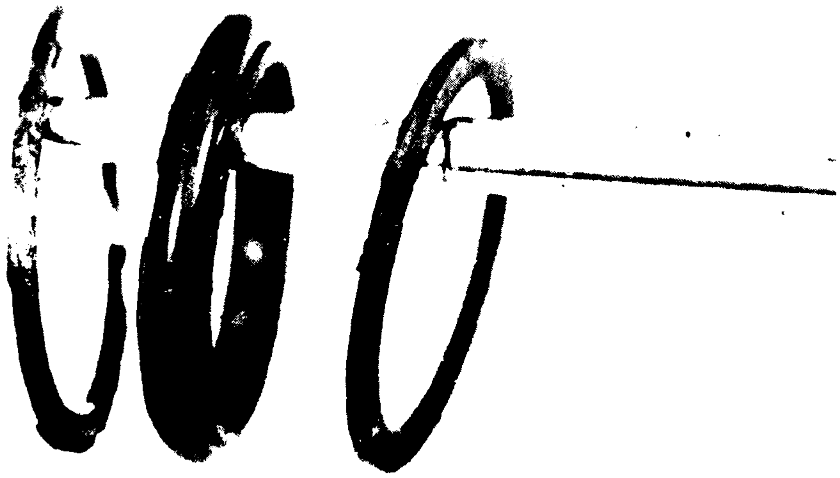


FIGURE 27. LONG LIFE TEST - SHAMBAN
SMALL ACTUATOR SECONDARY ROD SEAL
P/N S36471. 12,200,000 CYCLES - NO FAILURE

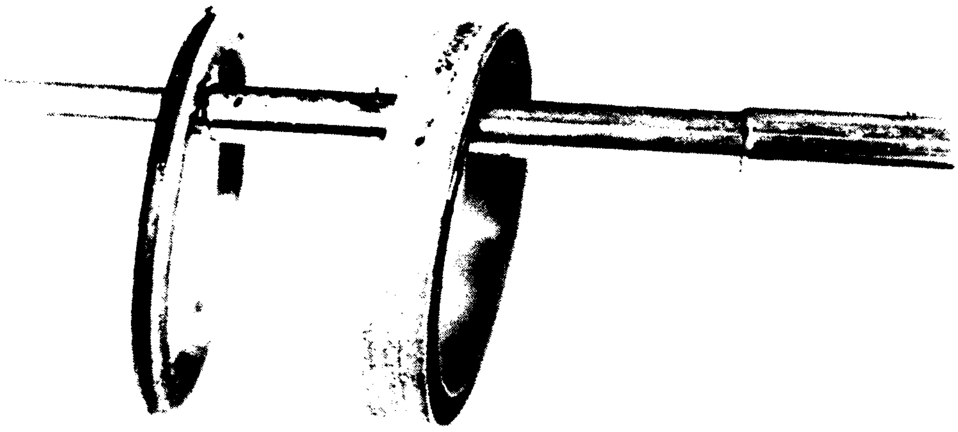


FIGURE 28. LONG LIFE TEST - TETRAFLUOR
SMALL ACTUATOR SECONDARY ROD SEAL
P/N TF888S121685-31/SD851216-5. 12,200,000 CYCLES - NO FAILURE

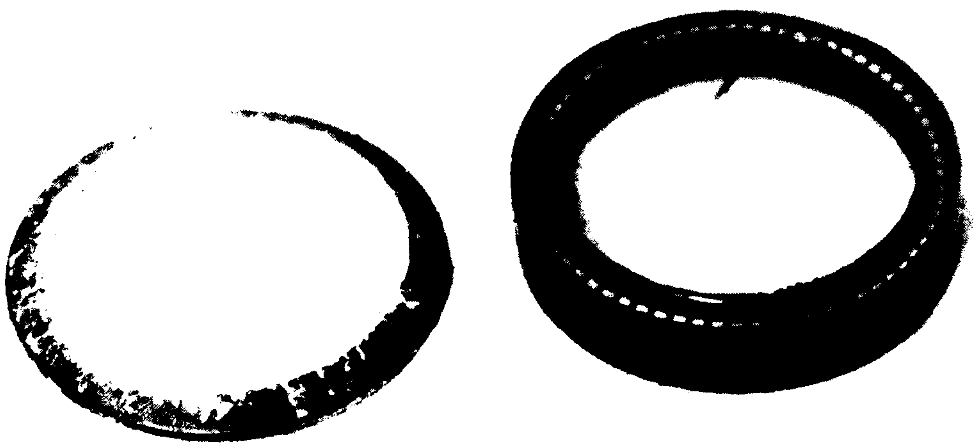


FIGURE 29. LONG LIFE TEST - FLUOROCARBON
SMALL ACTUATOR PRIMARY ROD SEAL
P/N AR104304. 12,200,000 CYCLES - NO FAILURE

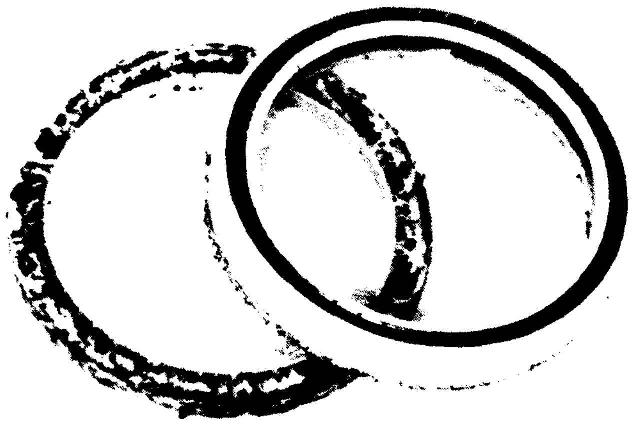


FIGURE 30. LONG LIFE TEST - TETRAFLUOR
LARGE ACTUATOR PRIMARY ROD SEAL
P/N TF888S121685-41/SD851216-61. 12,200,000 CYCLES - NO FAILURE

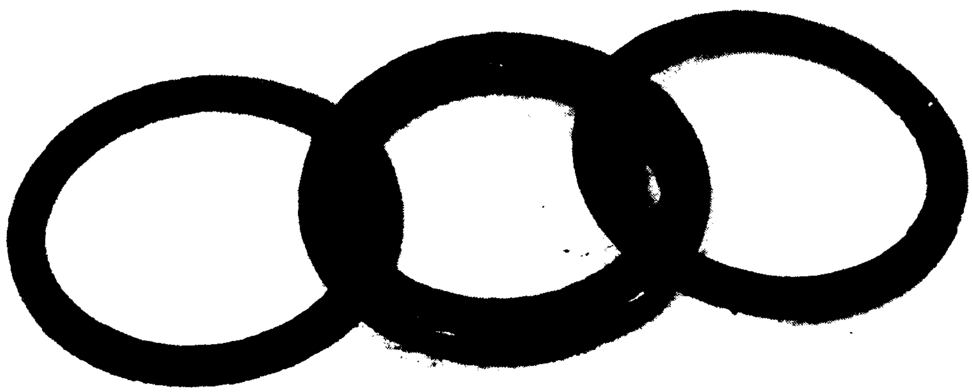


FIGURE 31. LONG LIFE TEST - SHAMBAN
LARGE ACTUATOR SECONDARY ROD SEAL
P/N S35971. 12,200,000 CYCLES - NO FAILURE

FIGURE 32. LONG LIFE TEST - TETRAFLUOR
LARGE ACTUATOR SECONDARY ROD SEAL
P/N TF888S121685-41/SD851216-61. 12,200,000 CYCLES - NO FAILURE

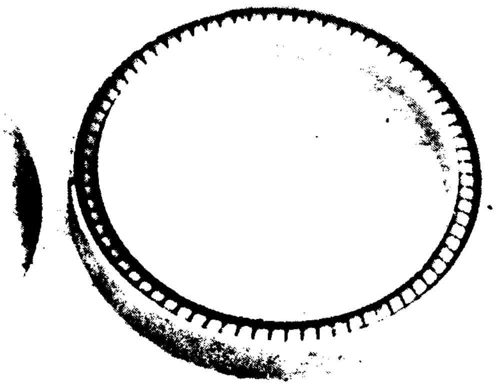


FIGURE 33. LONG LIFE TEST - FLUOROCARBON
LARGE ACTUATOR PRIMARY ROD SEAL
P/N AR104974. 12,200,000 CYCLES - NO FAILURE

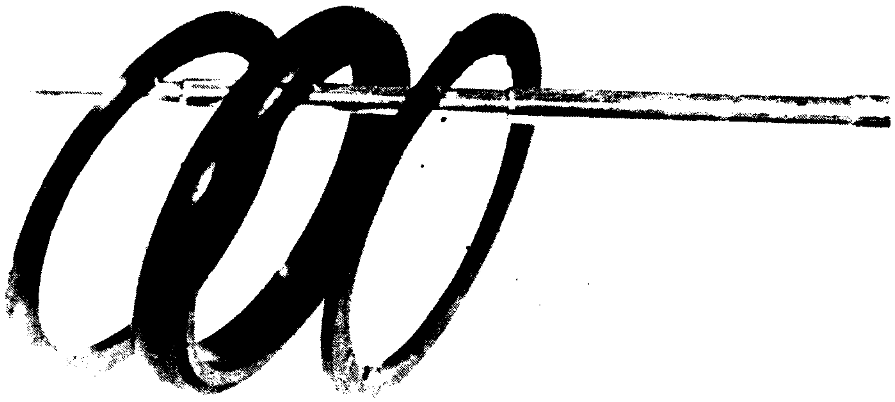


FIGURE 34. LONG LIFE TEST - PARKER SEAL
LARGE ACTUATOR PRIMARY ROD SEAL
P/N ML1851/V1098-85/XP2714-4. 12,200,000 CYCLES - NO FAILURE

FIGURE 35. LONG LIFE TEST - CONOVER
LARGE ACTUATOR SECONDARY ROD SEAL
P/N CEC6001-326-D8. 12,200,000 CYCLES - NO FAILURE

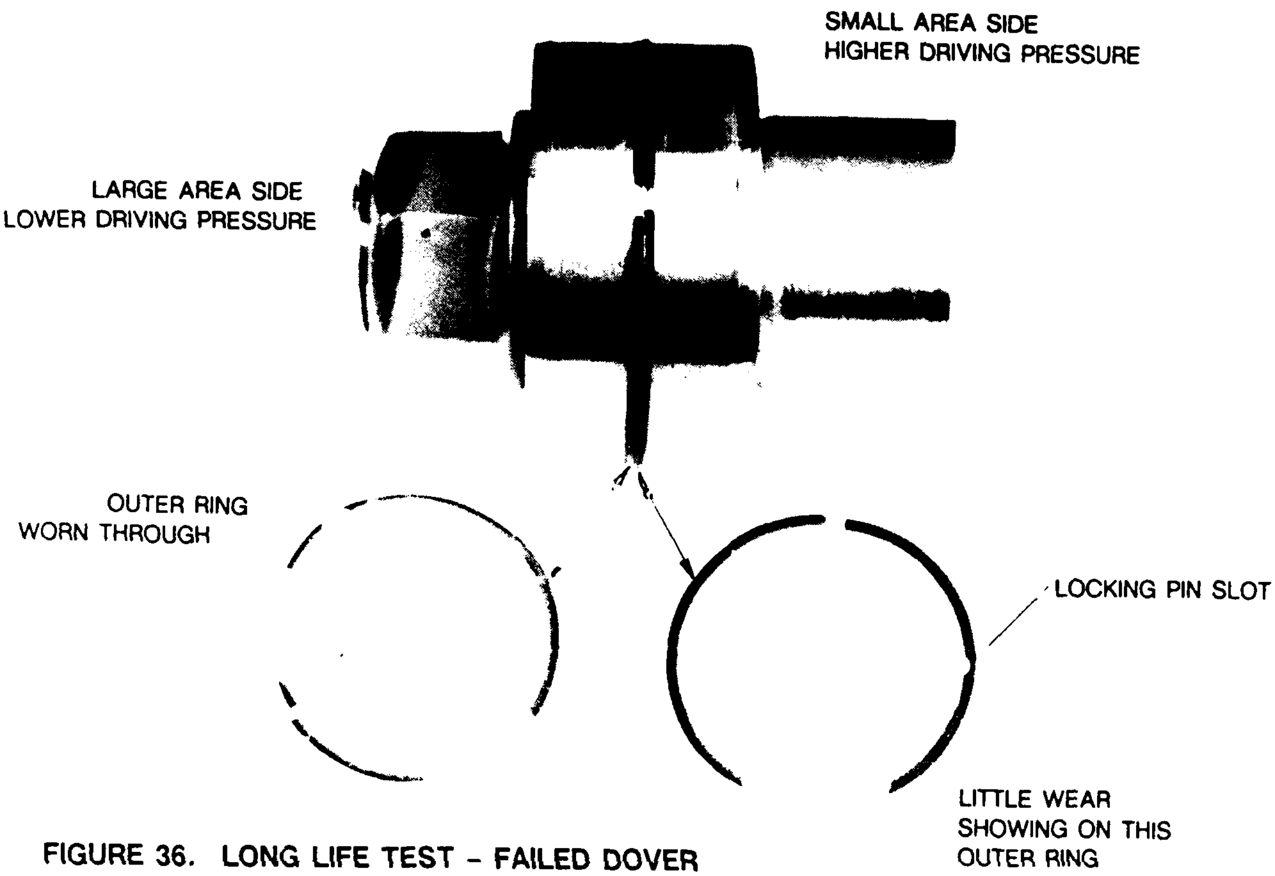


FIGURE 36. LONG LIFE TEST - FAILED DOVER
SMALL ACTUATOR ROD SEAL
(INNER RING NOT SHOWN)
P/N ABP17572. 469,000 CYCLES - TO FAILURE

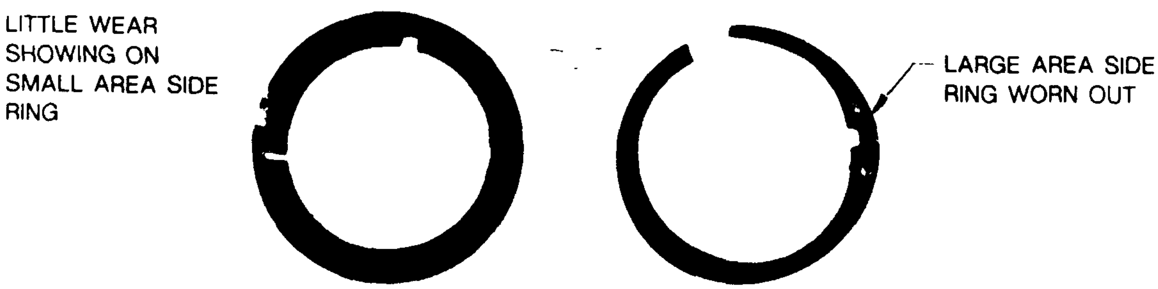


FIGURE 37. LONG LIFE TEST - FAILED SHAMBAN
SMALL ACTUATOR PISTON SEAL
P/N S35982. 1,643,000 CYCLES - TO FAILURE
SEAL REMOVED AFTER 4,929,000 CYCLES

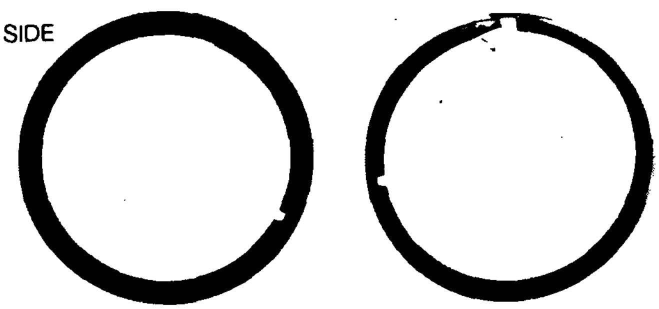


FIGURE 38. LONG LIFE TEST - FAILED SHAMBAN
LARGE ACTUATOR PISTON SEAL
P/N S35985. 2,112,000 CYCLES - TO FAILURE

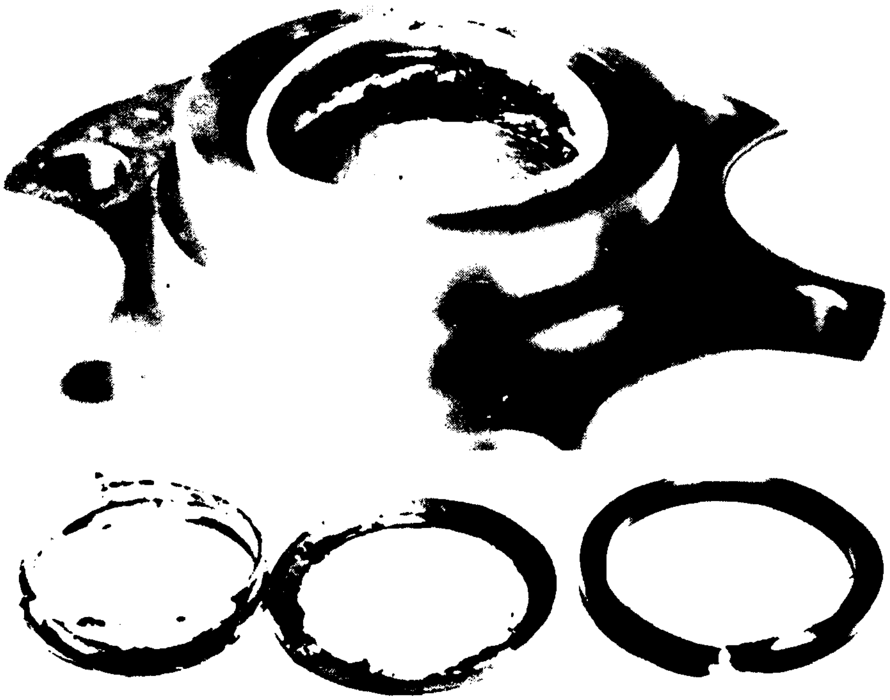


FIGURE 39. LONG LIFE TEST - FAILED CONOVER
SMALL ACTUATOR SECONDARY ROD SEAL
P/N CEC 6001-214-L9. 5,868,000 CYCLES - TO FAILURE

FIGURE 40. LONG LIFE TEST - FAILED ADVANCED PRODUCTS LARGE ACTUATOR SECONDARY ROD SEAL P/N 46194/46195. (46195 RING NOT SHOWN) 2,112,000 CYCLES - TO FAILURE

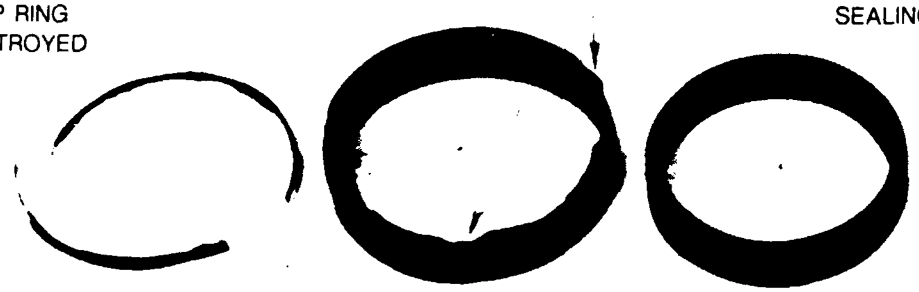


FIGURE 41. LONG LIFE TEST - FAILED KOPPERS SMALL ACTUATOR PRIMARY ROD SEAL P/N C5270B60. 1,878,000 CYCLES - TO FAILURE

SMALL PISTON AREA
HIGHER DRIVING PRESSURE

LARGE PISTON AREA
LOWER DRIVING PRESSURE

SEQUENCE OF FAILURE : SAME FAILURE MODE FOR BOTH PISTON SEAL SETS

FAILURE IS THE RESULT OF OUTER RINGS WEAR CAUSING OPENING OF THE GAP AND THUS WIDENING THE UNSUPPORTED AREA OF THE PRESSURIZED RING. THIS IN TURN CAUSES INCREASING BENDING STRESS IN THE PRESSURIZED RING AND EVENTUAL FAILURE.

FIGURE 42. LONG LIFE TEST - FAILED DOVER SMALL ACTUATOR PISTON SEAL P/N ABP17572 REV 2. 1,643,230 CYCLES

17.0 CONCLUSIONS AND RECOMMENDATIONS

Seals performing satisfactorily in CTFE at 8,000 psi in MIL-G-5514 grooves and and clearances have been identified.

- Filled TFE seals energized by springs or elastomers supported with high modulus thermoplastic backups perform satisfactorily.
- Elastomers should not be used in direct contact with moving metal elements.
- Continuation of efforts to improve performance of the piston seals is required.
- Seal failures were, in general, the result of excessive wear of the seal materials.
- No significant differences were observed between wear of anodic treated 6AL-4V titanium and chrome plated custom 455 steel cylinders or anodic treated 6AL-4V titanium and passivated 17-4PH steel glands.

APPENDIX A

SCREENING TEST PLAN

Parker

SCREENING TEST PLAN

HIGH PRESSURE HYDRAULIC SEAL PROGRAM

DOCUMENT NUMBER 320100ST

US AIR FORCE CONTRACT NUMBER F33615-84-C-2416

Revision: B

PREPARED BY: Albert Swenson 4-4-86 **DATE**

APPROVED BY: Z. Janunn 4-4-86 **DATE**

APPROVED BY: Amkkernna 4-19-86 **DATE**

BERTEA

Bertea Control Systems Division
Irvine, California

Parker Hannifin Corporation

1.0 SCOPE

This document establishes, when approved by the United States Air Force, the test procedure for evaluation (screening) of the seal configuration to be used in chlorotrifluoroethylene (CTFE) base A02 8000 psi hydraulic fluid systems. The seal configurations which successfully complete the prescribed screening test will be subjected to a full life test in accordance with 320100LT procedure.

2.0 SUMMARY AND DISCUSSION

The summary of the report will present the purpose of the test program, a brief review of the testing conducted and the results of the testing. The test data will be included. Fluid samples will be taken at periodic intervals and the results will be included.

The discussion will include comments on significant tests and events occurring during the screening test program.

Photographs will be included to illustrate test setups and problems where applicable.

3.0 EQUIPMENT LIST

All data collecting instruments shall be periodically recalled and calibrated in accordance with Parker Bertea Quality Instruction 006 in compliance with MIL-C-45662A. All calibrations shall be traceable to the National Bureau of Standards. The equipment listed below, or the equivalent, shall be utilized.

INSTRUMENT	RANGE	ACCURACY
Doric Digital Trendicator Model 400A	-328 to 1712	.6%
Pressure Transducer Precise Sensor Inc.	0-10K	.25%
Ashcroft Pressure Gauges	Various	.5%
Fluke 8000A	0-1200VDC 0-1200VAC 0-2 AMP	.5%

4.0 GENERAL PROCEDURE

4.1 Test Fluid

The test fluid used for the test program shall be chlorotrifloroethylene (CTFE) non-flammable hydraulic fluid. The acceptable fluid contamination levels shall be per BMF 5106 Rev N. During the screening tests a fluid sample shall be taken daily. During all other testing the system shall be sampled at weekly intervals.

4.2 References

The following documents form a part of this test program to the extent shown herein. In the event of a conflict between the documents referenced, the contents of this document shall take precedence.

Bertea Documents	Government Documents
320100	F33615-84-C-2416

4.0 **GENERAL PROCEDURE** (cont)

4.3 Standard Tolerances, Conditions, & Test Set-up

The following tolerances, as applicable, apply to any untolerated nominal value specified in this document. All measurements shall be made using instruments, where possible, with an accuracy of one-quarter of the tolerance specified for the test parameter minimum.

Pressure	± 2%
Flow	± 2%
Time	± .5 second
Force	± 5%
Temperature	± 5%
Dimensions	.xx ± .040 inch
	.xxx ± .010 inch

Unless otherwise specified, testing shall be conducted under the following conditions:

Ambient Temperature	60°F to 100°F
Fluid Temperature	80°F to 140°F
Atmospheric Pressure	25.5 to 30.5 inches HG

Unless otherwise specified, testing shall be conducted under the following test set-ups:

Set-up per Figure 1

Pressure port	8000 psig
Return port	40-100 psig

4.4 Preassembly Inspection

Prior to the assembly of the 320150 Test Actuators, the 320157 Piston, 320151 Barrels, 320154 Bearings, 320153 Glands, 320155 Glands, and the 320158 Piston Heads shall be inspected and initial dimensions and finishes recorded.

4.5 Acceptance Testing

Prior to performing the screening tests, an acceptance test shall be performed on each of the test actuators.

4.6 Order of Testing

Testing shall be conducted on the test actuators in the sequence of the following table. Except that the low temperature test is run within the duty cycle schedule and the pressure screen test may be run at any time as required.

4.6 Order of Testing (Cont)

Test Activity	Paragraph
Acceptance:	
Pre-assembly Inspection	6.1
Examination of Product	6.2
Pressure Proof	6.3
Operation and Leakage	6.4
Screening Tests:	
Duty Cycle	5.1
Low Temperature	5.2
Pressure Screen Test	5.3
Disassembly and Inspection	5.4

4.7 Disposition of Test Article and Test Records

Following the completion of the screening test program, the test actuators shall be refurbished as necessary and remain at Parker Bertea for the long life test.

The original test data records shall be maintained on file at Parker Bertea. Copies shall be furnished upon written request.

5.0 SCREENING TESTS

Should any seal configuration fail during the screening tests, the Air Force (WPAFB) shall be notified to verify a re-test or to try a new seal configuration.

5.1 Duty Cycle

NOTE: This test shall consist of 115 layers of duty cycle per actuator. If a catastrophic seal failure occurs during a layer, the cycle shall be stopped, and the failed test article removed from the fixture. The cycle shall then be restarted to finish the remaining actuators' duty cycle layer.

5.1.1 Procedure

With the 320150 Actuators installed in the 320170 Test Fixture per Figure 1, the test actuators shall be cycled per Table 1 for 9 consecutive layers while controlling the oil temperature per Table II.

The stroke and frequency are microprocessor controlled to complete each layer in a 1.62 hour time period. A 1 hour minimum shut down period shall follow each thermocycle run.

5.1.1 Procedure (Cont)

The dynamic leakage at the secondary piston rod seal shall be monitored and recorded. The primary piston rod seal leakage port shall be plugged during the 14.58 hour thermo-cycle period.

Prior to performing each thermo-cycle run, an operation and leakage test shall be conducted (para 6.4 of this procedure).

Prior to performing the 5th and 9th thermo-cycle period, a low temperature test (para 5.2 of this procedure) shall be conducted.

The 13th thermo-cycle period shall be 7 layers of cycle only. Upon completing the 7th layer the duty cycle test shall be considered complete. An operation and leakage test (para 6.4) shall be performed prior to disassembly (para 5.4).

5.1.2 REQUIREMENTS:

A. 34 cc/14.58 hours dynamic leakage at the secondary piston rod seal port shall be considered a seal failure.

B. Operation and leakage test para 6.4 leakage rates are for engineering information only.

• Cycling Schedule

- 97.18 minute cycle schedule per layer (1.62 hour - 1 layer)
- 115 layers per block
- 1 hour shutdown every 14.58 hours
  4 hours at 275°F per 14.58 hour test
- cold test at 60 and 120 hours

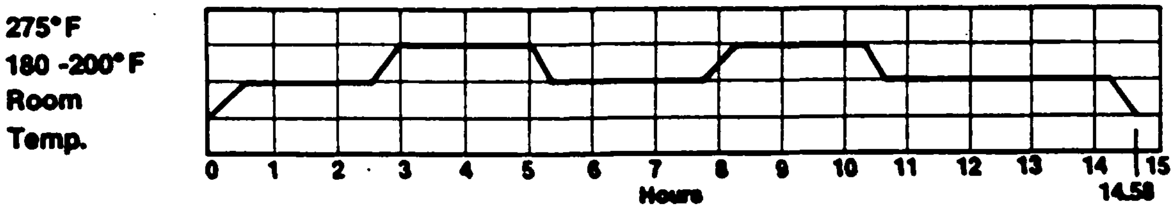
TABLE I

One Layer

										Total
% Stroke	100	10	1	50	2	10	2	50	100	
% Load	100	10	1	50	2	10	2	50	100	
Time (min)	4.89	3.12	20.0	15.0	15.0	2.5	15.0	15.0	6.67	97.18 min
Rate (Hz)	.075	1.2	7.5	0.14	5	1.2	5	0.14	.075	
# of Cycles	22	225	9000	126	4500	180	4500	126	30	18,709 cycles

TABLE II

Thermal Cycle



5.1.3 DATA

ACTUATOR SN____________

LAYER	LEAKAGE	OIL TEMPERATURE/PRESSURE @ PRIMARY
1	_______	______________________________
2	_______	______________________________
3	_______	______________________________
4	_______	______________________________
5	_______	______________________________
6	_______	______________________________
7	_______	______________________________
8	_______	______________________________
9	_______	______________________________

Thermo Cycle No. ____________________

Date _______________

Technician __________________

Additional Comments ____

____

____

____

____

____

5.2 Low Temperature Test

5.2.1 Procedure

With the test actuators installed in the 320170 Test Fixture and inside an environmental chamber, this test shall be performed according to the following steps:

Step 1: With 50 ± 10 psi applied to the pressure and return ports of the control valve, lower the chamber temperature to -65°F. Stabilize the actuator temperature at -65°F.

Step 2: Soak the actuators at -65°F for a 4 hour minimum time period. Leakage shall be continuously monitored during the 4 hour period. The leakage rate shall be recorded.

Step 3: Following the completion of the 4 hour soak period, apply 8000 psi to the control valve and cycle the test actuators 5 complete full stroke cycles. The oil temperature shall be 150 ± 20°F. Leakage at the secondary seal port shall be monitored and recorded.

Step 4: Reduce the pressure at the control valve to reservoir pressure. Raise the chamber temperature to room temperature ambient, and allow the the test actuators to stabilize.

Step 5: Perform the operation and leakage test, Paragraph 6.4. Upon completion of Paragraph 6.4, continue the duty cycle testing.

5.2.2 Requirements

A. Step 2 - Leakage from the secondary seal port shall not exceed 5 cc/hour/seal

B. Step 3 - 1 drop/seal

C. Step 5 - The actuators shall meet the requirements of Paragraph 6.4

5.2.3 DATA

Actuator S/N ____________		ACCEPT	REJECT
Step 2	______________cc/Hour	_____	_____
Step 3	________________drops	_____	_____
Step 5	Meets requirements of 6.4	_____	_____

Date ________________

Technician ________________________

5.3 Pressure Screen Test

This test shall be performed on test article configurations designated by Parker Bertea Engineering or by the Air Force (WPAFB) by written concurrance.

5.3.1 Procedure

A pressure transducer shall be installed at the 320154 bearing port (Refer to Figure 2). The pressure shall be monitored at the 320154 bearing port during the duty cycle testing. The pressure shall be recorded for one complete thermo-cycle period and at the 275° portion of the thermo-cycle period every 3rd day thereafter.

5.3.2 Requirements

None - Record for information only.

5.4 Disassembly and Inspection

5.4.1 Procedure

Following the completion of the duty cycle test, Paragraph 5.1. The 320150 actuators shall be disassembled and inspected to see what if any wear occurred. Critical dimensions shall be measured and recorded at the :

320157 Piston
320151 Barrel
320154 Bearing
320153 Gland 1st Stage
320155 Gland 2nd Stage
320158 Piston Head

The piston seals, primary rod seals, and secondary rod seals shall be carefully bagged and identified to insure traceability.

Photographs shall be taken of the piston seals, primary rod seals, and secondary rod seals.

6.0 ACCEPTANCE TEST

6.1 Pre-Assembly Inspection

6.1.1 Procedure

Prior to assembly of the 320150 Test Actuators, the following parts shall be inspected and recorded. Prior to the assembly of the test actuators, correct configuration of each shall be verified. Serial numbers and seal part numbers shall be recorded.

6.1.1 Procedure (Cont)

320157 Piston
320151 Barrel
320154 Bearing
320153 Gland 1st Stage
320155 Gland 2nd Stage
320158 Piston Head

Critical dimensions shall be recorded. Serialization of each part shall be verified and also recorded.

6.1.2 Requirements

The parts inspected shall conform dimensionally, and each part shall have a serial number.

6.1.3 Data

The dimensional data and configuration verification data shall be recorded on data sheets in Appendix A.

	ACCEPT	REJECT
Correct dimensions	______	______
Correct configuration	______	______

Date ____________

Technician ________________

6.2 Examinat_on of Product

6.2.1 Procedure

The test article shall be examined to verify conformance with Parker Bertea Drawing Number 320100 as to:

Quality of Workmanship
Correct Markings
Correct Configuration
Mounting Requirements
Interface Dimensions
Seal Configurations

6.2.2 Requirements

The test article shall meet the requirements of Parker Bertea Drawing Number 320100.

6.2.3 Data

	ACCEPT	REJECT
Quality of workmanship	____	____
Correct markings	____	____
Correct configuration	____	____
Mounting requirements	____	____
Interface dimensions	____	____
Seal configurations	____	____

Date ______________

Technician ____________________

6.3 PROOF PRESSURE

6.3.1 Procedure

With the 320150 actuators installed in the 320170 test fixture, this test shall be performed according to the following steps:

Step 1: Drive the actuators to the hard over extend position and raise the supply pressure to 10,000 psi for one minute.

Step 2: Drive the actuators to the hard over retract position and raise the supply pressure to 10,000 psi for one minute.

6.3.2 Requirements

There shall be no external leakage, permanent set or losening of parts in either direction.

6.3.3 Data

	ACCEPT	REJECT
External leakage	______	______
Permanent set	______	______
Loosening of parts	______	______

Date ________________

Technician ________________________

6.4 OPERATION AND LEAKAGE

6.4.1 Procedure

With the 320150 test actuators installed in the 320170 test fixture, this test shall be performed according to the following steps:

Step 1: Cycle the actuators 5 full stroke cycles to bleed air from the system.

Step 2: Install the 320142-1 Drain Fittings in the primary and secondary piston seal leakage ports. Drive the actuators to the full retract position. Measure and record the internal leakage from the actuator extend port. Measure and record the internal leakage from the primary rod seal port.

Step 3: Cycle the test actuators 50 full stroke cycles. Measure and record the dynamic leakage from the primary rod seal (320142-1 fittings).

Step 4: Remove the 320142-1 drain fitting from the primary rod seal port. Plug the primary rod seal port. Cycle the actuators an additional 50 full stroke cycles. Measure and record the dynamic leakage from the 320142-1 drain fitting at the secondary rod seal port.

6.4.2 Requirements

Step 2: 20 cc/min from the actuator extend port

1 drop/min from the primary rod seal port

Step 3: 2 drops per 50 cycles at the primary rod seal fitting.

Step 4: 2 drops per 50 cycles at the secondary rod seal fitting.

Requirements

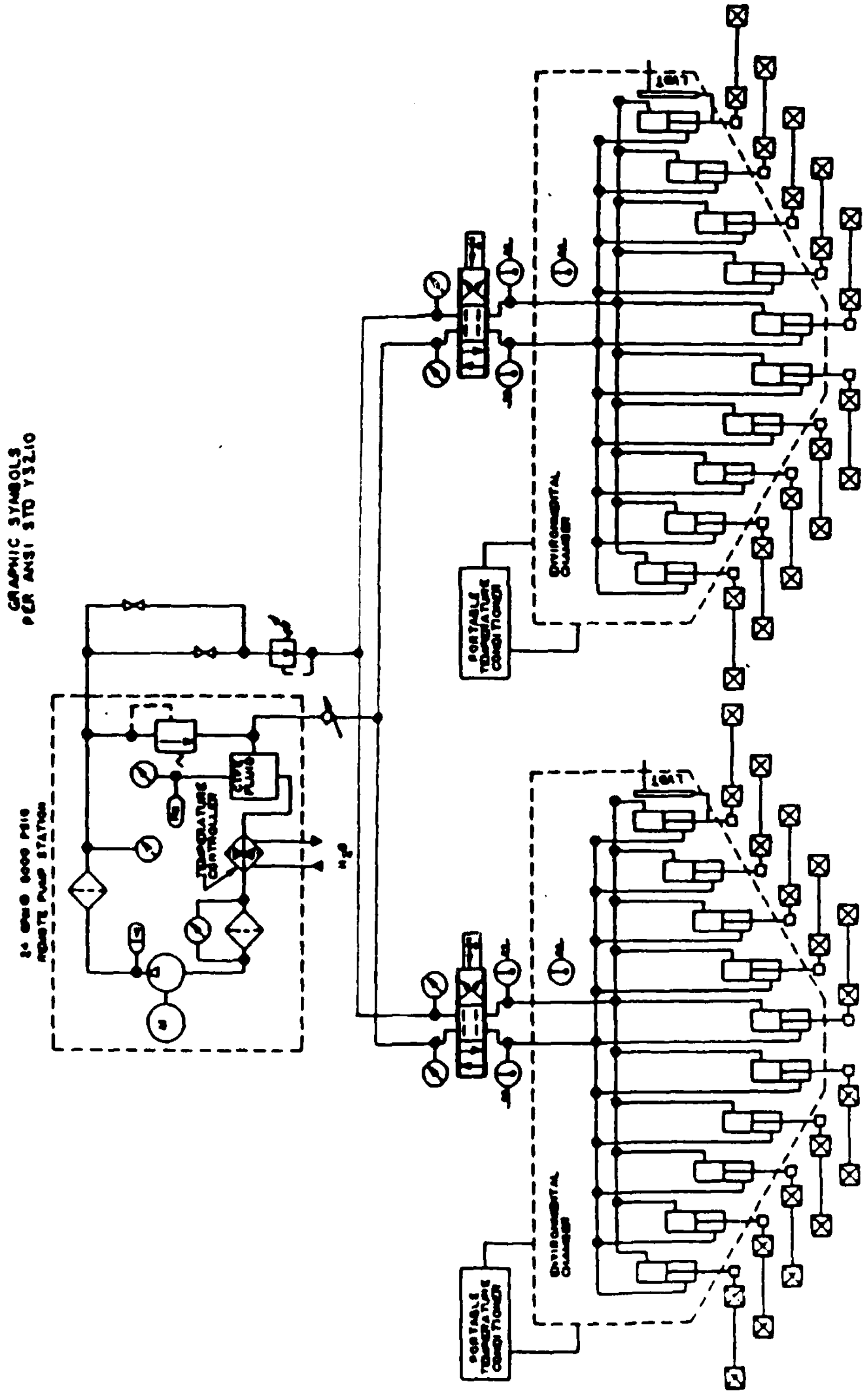
Steps 2, 3 & 4

6.4.3 Data

	ACCEPT	REJECT
Actuator serial number ________	____	____
Step 2:		
Extend port ________ cc/minute	____	____
Primary seal fitting ________ cc/minute	____	____
Step 3:		
Primary seal fitting ________ drops	____	____
Step 4:		
Secondary seal fitting ________ drops	____	____

Date: ________

Technician: ____________



TEST FIXTURE AND HYDRAULIC SCHEMATIC

FIGURE 1

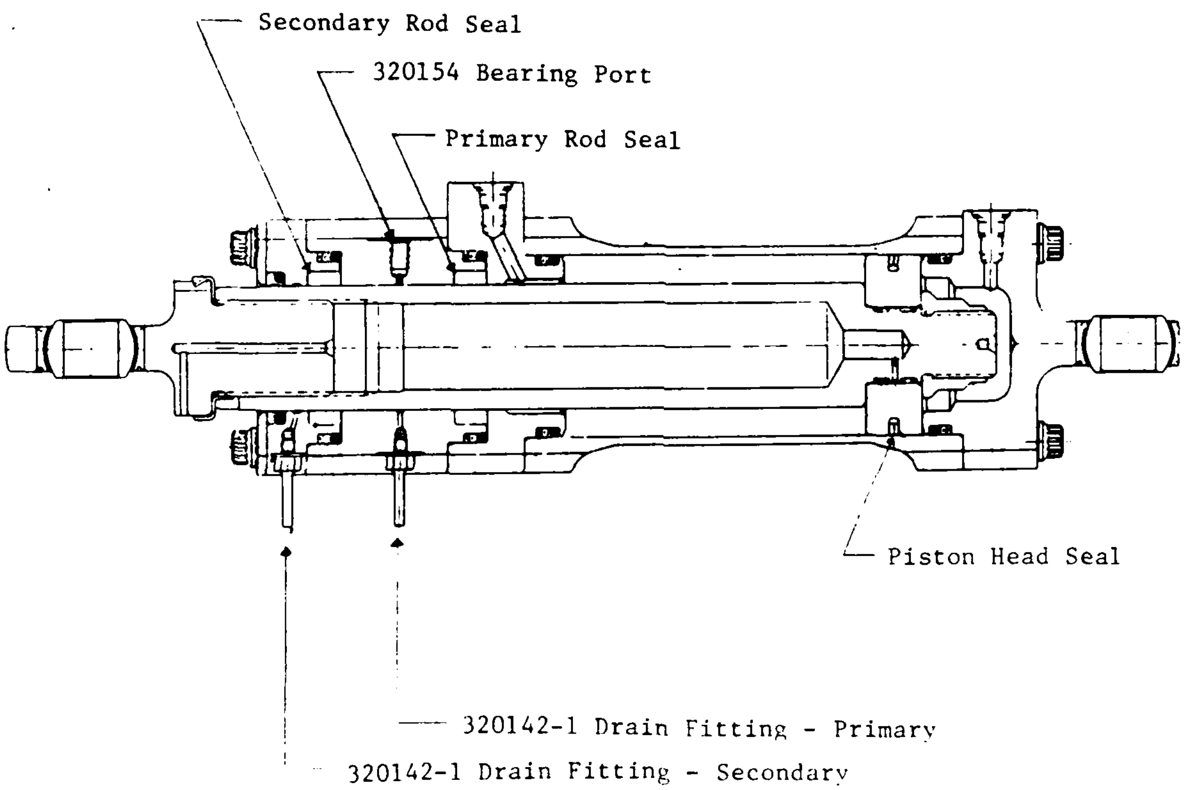
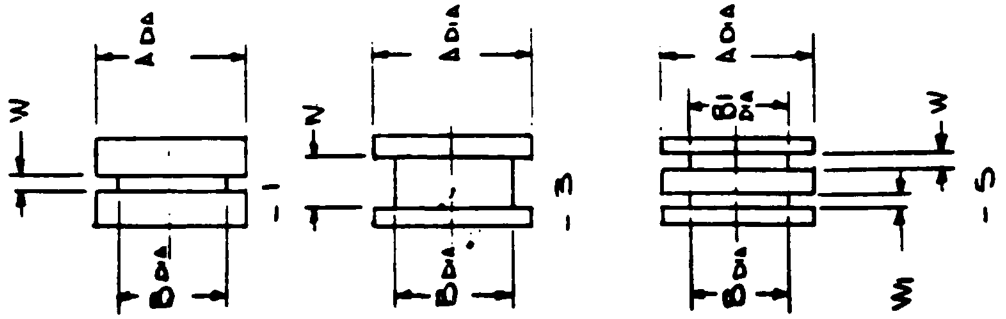

Secondary Rod Seal
320154 Bearing Port
Primary Rod Seal
Piston Head Seal
320142-1 Drain Fitting - Primary
320142-1 Drain Fitting - Secondary

FIGURE 2

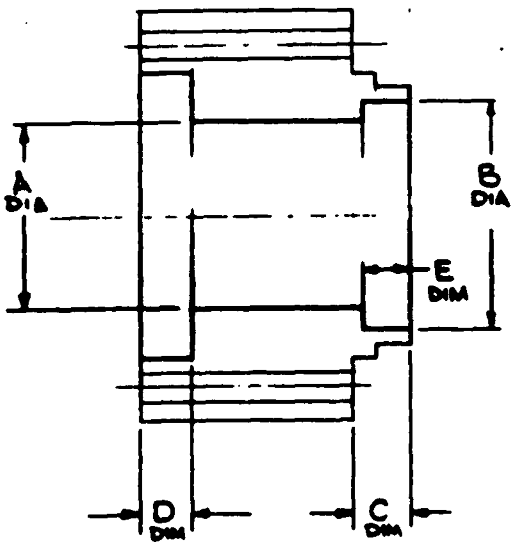
APPENDIX A

This Appendix contains
significant dimensions - pre-assembly inspection
and configuration verification pre-assembly data sheets



S/N	DASH NO.	A DIA REQD	A DIA ACTUAL	B DIA REQD	B DIA ACTUAL	B1 DIA REQD	B1 DIA ACTUAL	W WIDTH REQD	W WIDTH ACTUAL	W1 WIDTH REQD	W1 WIDTH ACTUAL	INSIDE DIA REQD	INSIDE DIA ACTUAL
	-1	2.3645 ±.0005 DIA		1.936 ±.004 DIA		N/A		.1265 ±.0010		N/A		.992 ±.001 DIA	
	-1												
	-1												
	-1												
	-1												
	-3			1.995 ±.001 DIA		N/A				N/A			
	-3												
	-3												
	-3												
	-3												
	-5			1.936 ±.004 DIA		1.936 ±.004 DIA		.1265 ±.0010		.1265 ±.0010			
	-5												
	-5												
	-5												
	-5												

PRE-ASSEMBLY INSPECTION RECORD
320158 PISTON HEAD



	S/N	A DIA		B DIA		C DIM		D DIM		E DIM	
		REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	REQ'D	ACTUAL
-1		1.626 ±.001 DIA		1.996 ±.001 DIA		.5230 ±.0005		.450 ±.001		.429 ±.002	
-3											

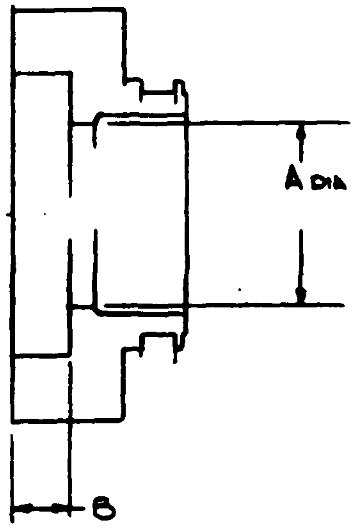
PRE-ASSEMBLY INSPECTION RECORD
320154 BEARING

Form 1040-01

Bertea Parker

PAGE	320100ST	REV.
ORIG. DATE 03-12-86	REV. DATE	

TITLE SCREENING TEST PLAN



S/N	A DIA		B DIM	
	REQ'D	ACTUAL	REQ'D	ACTUAL
	1.682 ±.002 DIA		.828 ±.001	

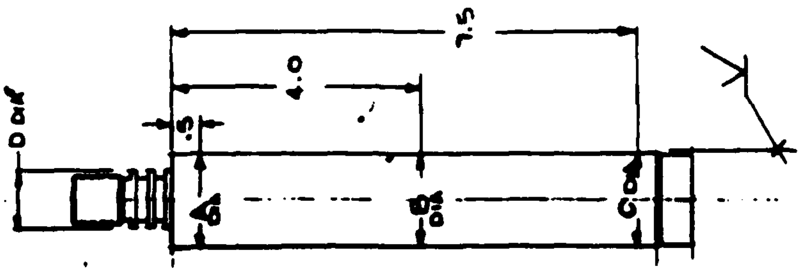
PRE-ASSEMBLY INSPECTION RECORD
320153 GLAND 1ST STAGE

Form 1040-01

Bertea Parker

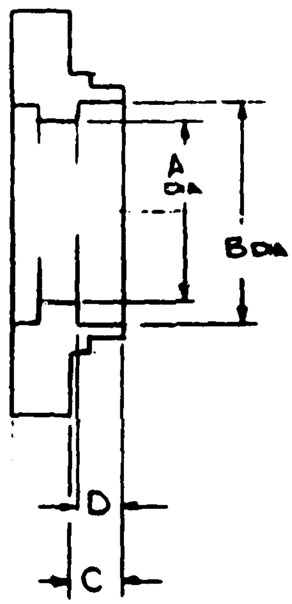
PAGE	320100ST	REV.
ORIG. DATE 03-12-86	REV. DATE	

TITLE SCREENING TEST PLAN



S/N	A DIA		B DIA		C DIA		D DIA		FINISH
	REQD	ACTUAL	REQD.	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	
	1.622 ±.001 DIA		1.622 ±.001 DIA		1.622 ±.001 DIA		.9885 ±.0005 DIA		

PRE-ASSEMBLY INSPECTION RECORD
320157 PISTON



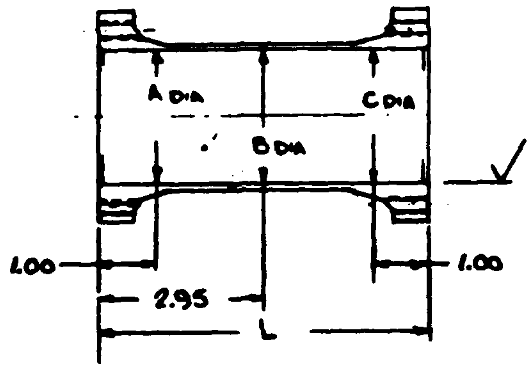
S/N	A DIA		B DIA		C Length		D Length	
	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL
	1.626 ±.001 DIA		1.996 ±.001 DIA		.4480 ±.0005		.429 ±.002	

PRE-ASSEMBLY INSPECTION RECORD
320155 GLAND 2nd STAGE

Bertea Parker

PAGE	320100ST	REV.
ORIG. DATE 03-12-86	REV. DATE	

TITLE SCREENING TEST PLAN



	S/N	DRAWING DIM.	ACTUAL A DIA	B DIA	C DIA	L Length	FINISH
-1		2.369 ±.001 DIA 16√					
		L=5.850 ±.005					
-3							

PRE-ASSEMBLY INSPECTION RECORD
320151 BARREL

Form 1040-01

CONFIGURATION VERIFICATION

Actuator Serial Number:________________

Configuration Number:________________

320154 Bearing: SN __________ Dash Number __________

320158 Piston Head: SN __________ Dash Number __________

320151 Barrel: SN __________ Dash Number __________

320157 Piston: SN __________

320153 Gland 1st stage: SN __________

320155 Gland 2nd Stage: SN __________

Piston Head Seal: Part Number ________________

Primary Rod Seal: Part Number ________________

Secondary Rod Seal: Part Number ________________

Accept ________________ Reject ________________

Technician ________________

Date ________________

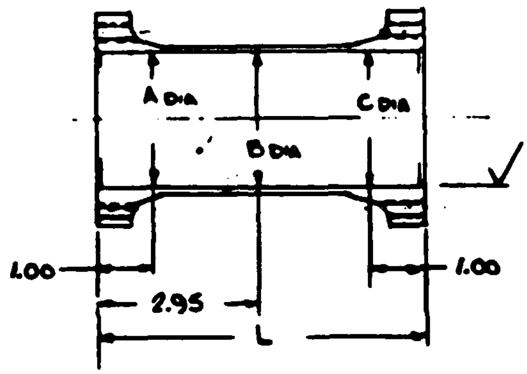
APPENDIX B

This Appendix contains significant dimensions for post screen test inspection

Bertea Parker

PAGE	320100ST	REV.
ORIG. DATE 03-12-86	REV. DATE	

TITLE SCREENING TEST PLAN



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-1		2.369 ±.001 DIA 16√					
		L=5.850 ±.005					
-3							

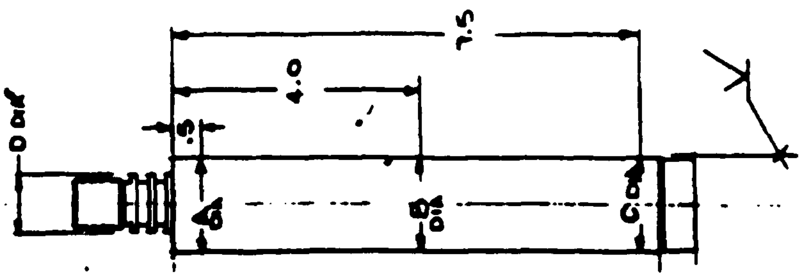
320151 BARREL

Form 1040-01

Bertea Parker

PAGE	320100ST	REV.
ORIG. DATE 03-12-86	REV. DATE	

TITLE SCREENING TEST PLAN



S/N	A DIA		B DIA		C DIA		D DIA		FINISH
	REQD	ACTUAL	REQD.	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	
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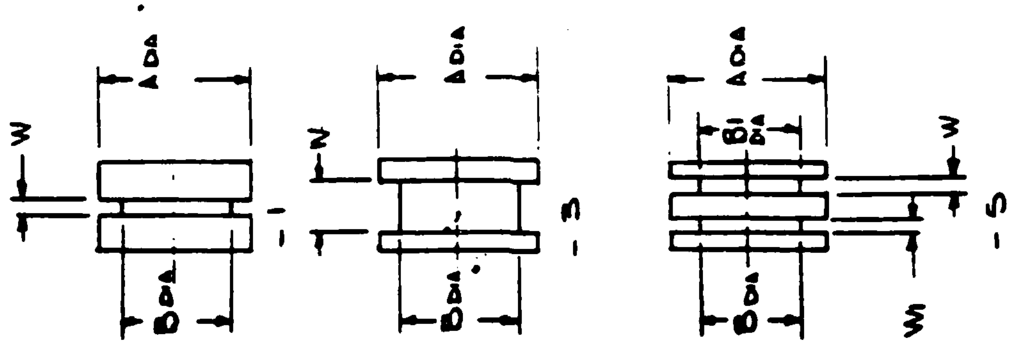
320157 PISTON

Form 1040-01



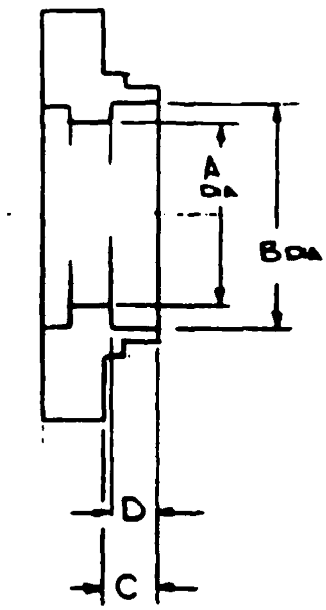
S/N	DASH NO.	A DIA REQD	A DIA ACTUAL	B DIA REQD	B DIA ACTUAL	B1 DIA REQD	B1 DIA ACTUAL	W WIDTH REQD	W WIDTH ACTUAL	W1 WIDTH REQD	W1 WIDTH ACTUAL	INSIDE DIA REQD	INSIDE DIA ACTUAL
	-1	2.3646 ±.0005 DIA		1.936 ±.004 DIA		N/A		.1265 ±.0010		N/A		.992 ±.001 DIA	
	-1												
	-1												
	-1												
	-1												
	-3			1.995 ±.001 DIA		N/A				N/A			
	-3												
	-3												
	-3												
	-3												
	-5			1.936 ±.004 DIA		1.936 ±.004 DIA		.1265 ±.0010		.1265 ±.0010			
	-5												
	-5												
	-5												
	-5												

320158 PISTON HEAD

Bertea Parker

PAGE	320100ST	REV.
ORIG. DATE 03-12-86	REV. DATE	

TITLE SCREENING TEST PLAN



S/N	A DIA REQ'D	A DIA ACTUAL	B DIA REQ'D	B DIA ACTUAL	C Length REQ'D	C Length ACTUAL	D Length REQ'D	D Length ACTUAL
	1.626 ±.001 DIA		1.996 ±.001 DIA		.4480 ±.0005		.429 ±.002	

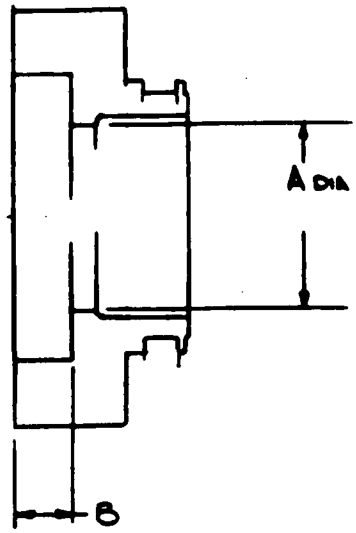
320155 GLAND 2nd STAGE

Form 1040-01

Bertea | Parker

PAGE	320100ST	REV.
ORIG. DATE 03-12-86	REV. DATE	

TITLE SCREENING TEST PLAN



S/N	A DIA REQ'D	A DIA ACTUAL	B DIM REQ'D	B DIM ACTUAL
	1.682 ±.002 DIA		.828 ±.001	

320153 GLAND 1ST STAGE

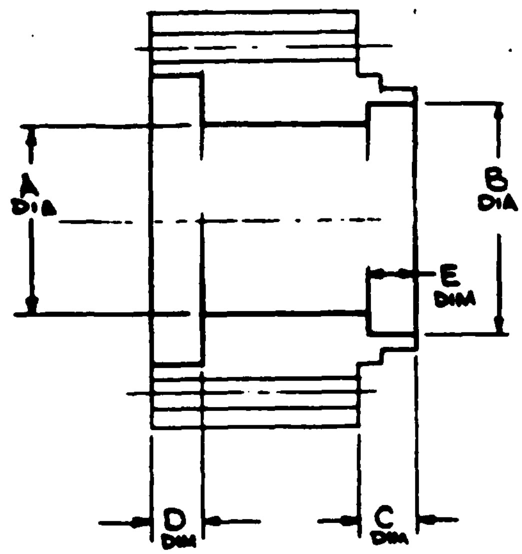
Form 1040-01

Bertea

Parker

PAGE	320100ST	REV.
ORIG. DATE 03-12-86	REV. DATE	

TITLE SCREENING TEST PLAN



S/N	A DIA REQ'D	A DIA ACTUAL	B DIA REQ'D	B DIA ACTUAL	C DIM REQ'D	C DIM ACTUAL	D DIM REQ'D	D DIM ACTUAL	E DIM REQ'D	E DIM ACTUAL
	1.626 ±.001 DIA		1.996 ±.001 DIA		.5230 ±.0005		.450 ±.001		.429 ±.002	

320154 BEARING

Form 1040-01

APPENDIX B

LONG LIFE TEST PLAN

Parker

LONG LIFE PLAN

HIGH PRESSURE HYDRAULIC SEAL PROGRAM

DOCUMENT NUMBER 320100LT

US AIR FORCE CONTRACT NUMBER F33615-84-C-2416

REVISION: A

PREPARED BY: A. Swenson 1-30-87 DATE
A. SWENSON

APPROVED BY: J. Janczur 1-30-87 DATE
J. JANCZUR

APPROVED BY: [illegible] 1-30-87 DATE

Parker Bertea Aerospace Group
Control Systems Division
Irvine, California

Parker Hannifin Corporation

1.0 SCOPE

This document establishes, when approved by the United States Air Force, the test procedure for Long Life Test of the seal configurations which successfully completed the prescribed screening test in accordance with 320100ST procedure. Testing will be performed using ten (10) 1.625 diameter rod and ten (10) 1.000 diameter rod actuators.

2.0 SUMMARY AND DISCUSSION

The summary of the report will present the purpose of the test program, a brief review of the testing conducted and the results of the testing. The test data will be included. Fluid samples will be taken at periodic intervals and the results will be included.

The discussion will include comments on significant tests and events occurring during the screening test program.

Photographs will be included to illustrate test setups and problems where applicable.

3.0 EQUIPMENT LIST

All data collecting instruments shall be periodically recalled and calibrated in accordance with Parker Bertea Quality Instruction 006 in compliance with MIL-C-45662A. All calibrations shall be traceable to the National Bureau of Standards. The equipment listed below, or the equivalent, shall be utilized.

INSTRUMENT	RANGE	ACCURACY
Doric Digital Trendicator Model 400A	-328 to 1712	.6%
Pressure Transducer Precise Sensor Inc.	0-10K	.25%
Ashcroft Pressure Gauges	Various	.5%
Fluke 8000A	0-1200VDC 0-1200VAC 0-2 AMP	.5%

4.0 GENERAL PROCEDURE

4.1 Test Fluid

The test fluid used for the test program shall be chlorotrifloroethylene (CTFE) non-flammable hydraulic fluid. The acceptable fluid contamination levels shall be per BMF 5106 Rev N. During the tests a fluid sample shall be taken at weekly intervals.

4.2 References

The following documents form a part of this test program to the extent shown herein. In the event of a conflict between the documents referenced, the contents of this document shall take precedence.

Bertea Documents	Government Documents
320100	F33615-84-C-2416

4.3 Standard Tolerances, Conditions, & Test Set-up

The following tolerances, as applicable, apply to any untolerated nominal value specified in this document. All measurements shall be made using instruments, where possible, with an accuracy of one-quarter of the tolerance specified for the test parameter minimum.

Pressure	± 2%
Flow	± 2%
Time	± .5 second
Force	± 5%
Temperature	± 5%
Dimensions	.xx ± .040 inch
	.xxx ± .010 inch

Unless otherwise specified, testing shall be conducted under the following conditions:

Ambient Temperature	60°F to 100°F
Fluid Temperature	80°F to 140°F
Atmospheric Pressure	25.5 to 30.5 inches HG

Unless otherwise specified, testing shall be conducted under the following test set-ups:

Set-up per Figure 1
Pressure port 8000 psig
Return port 40-100 psig

4.4 Preassembly Inspection

Prior to the assembly of the 320140 & 320150 Test Actuators, the 320137 & 320157 Piston Rods, 320131 & 320151 Barrels, 320134 & 320154 Bearings, 320133 & 320153 Glands, 320135 & 320155 Glands, and the 320138 & 320158 Piston Heads shall be inspected and initial dimensions and finishes recorded.

4.5 Acceptance Testing

Prior to performing the long life tests, an acceptance test shall be performed on each of the test actuators.

4.6 Order of Testing

Testing shall be conducted on the test actuators in the sequence of the following table, except that the low temperature test shall be run within the duty cycle schedule and the pressure screen test may be run at any time.

Test Activity	Paragraph
Acceptance:	
Pre-assembly Inspection	6.1
Examination of Product	6.2
Pressure Proof	6.3
Operation and Leakage6.4	
Long Life Tests:	
Duty Cycle	5.1
Low Temperature	5.2
Pressure Screen Test	5.3
Disassembly and Inspection	5.4

4.7 Disposition of Test Article and Test Records

Following the completion of the Long Life Test Program, the test actuators shall be refurbished as necessary and waiting for the disposition by the Air Force (WPAFB).

The original test data records shall be maintained on file at Parker Bertea. Copies shall be furnished upon written request.

5.0 LONG LIFE TESTS

Should any seal configuration fail during the Long Life tests, the Air Force (WPAFB) shall be notified.

5.1 Duty Cycle

NOTE: This test shall consist of 1150 layers of duty cycle per actuator. If a catastrophic seal failure occurs during a layer, the cycle shall be stopped, and the failed test article removed from the fixture. The cycle shall then be restarted to finish the remaining actuators' duty cycle layer.

5.1.1 Procedure

With the 320140 & 320150 Actuators installed in the 320100 Test Fixtures per Figure 1, the test actuators shall be cycled per Table 1 for 9 consecutive layers while controlling the oil temperature per Table II.

The stroke and frequency are microprocessor controlled to complete each layer in a 1.88 hour time period. A 1 hour minimum shut down period shall follow each thermo-cycle run.

The dynamic leakage at the secondary piston rod seal shall be monitored and recorded. The primary piston rod seal leakage port shall be plugged during the 16.88 hour thermo-cycle period.

Prior to performing each thermo-cycle run, an operation and leakage test shall be conducted (para 6.4 of this procedure).

Prior to performing the 40th and 70th thermo-cycle period, a low temperature test (para 5.2 of this procedure) shall be conducted.

The 128th thermo-cycle period shall be 7 layers of cycle only. Upon completing the 7th layer the duty cycle test shall be considered complete. An operation and leakage test (para 6.4) shall be performed prior to disassembly (para 5.4).

5.1.2 REQUIREMENTS:

A. 34 cc/16.88 hours dynamic leakage at the secondary piston rod seal port shall be considered a seal failure.

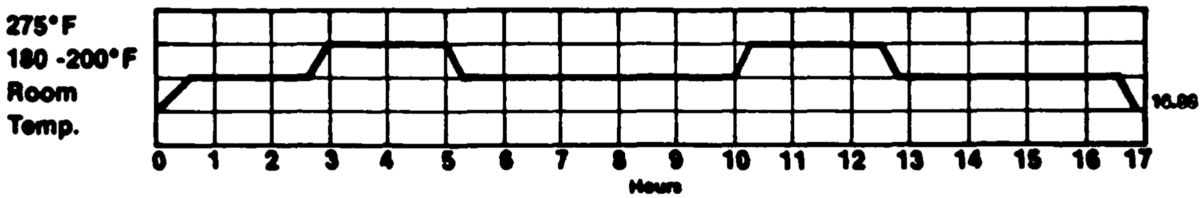
B. Operation and leakage test para 6.4 leakage rates are for engineering information only.

TABLE I

One Layer										Total
% Stroke	100	10	1	50	2	10	2	100	1	
% Load	100	10	1	50	2	10	2	100	1	
Time (min) ..	4.89	7.5	20.0	15.0	18.75	6.0	18.75	6.67	15.0	112.56 min
Rate (Hz)	.075	.5	7.5	0.14	4	.5	4	.075	7.5	
# of Cycles	22	225	9000	126	4500	180	4500	30	7500	26083 cycles

TABLE II

Thermal Cycle



5.1.3 DATA

ACTUATOR SN ____________

LAYER	LEAKAGE	OIL TEMPERATURE/PRESSURE @ PRIMARY
1	______	______________________________
2	______	______________________________
3	______	______________________________
4	______	______________________________
5	______	______________________________
6	______	______________________________
7	______	______________________________
8	______	______________________________
9	______	______________________________

Thermo Cycle No. ________________

Date ____________

Technician ______________

Additional Comments ____

____

____

____

____

____

5.2 Low Temperature Test

5.2.1 Procedure

With the test actuators installed in the 320100 Test Fixtures and inside an environmental chambers, this test shall be performed according to the following steps:

Step 1: With 50 ± 10 psi applied to the pressure and return ports of the control valve, lower the chamber temperature to -65°F. Stabilize the actuator temperature at -65°F.

Step 2: Soak the actuators at -65°F for a 4 hour minimum time period. Leakage shall be continuously monitored during the 4 hour period. The leakage rate shall be recorded.

Step 3: Following the completion of the 4 hour soak period, apply 8000 psi to the control valve and cycle the test actuators 5 complete full stroke cycles. The oil temperature shall be 150 ± 20°F. Leakage at the secondary seal port shall be monitored and recorded.

Step 4: Reduce the pressure at the control valve to reservoir pressure. Raise the chamber temperature to room temperature ambient, and allow the the test actuators to stabilize.

Step 5: Perform the operation and leakage test, Paragraph 6.4. Upon completion of Paragraph 6.4, continue the duty cycle testing.

5.2.2 Requirements

A. Step 2 - Leakage from the secondary seal port shall not exceed 5 cc/hour/seal

B. Step 3 - 1 drop/seal

C. Step 5 - The actuators shall meet the requirements of Paragraph 6.4

5.2.3 DATA

Actuator S/N ________		ACCEPT	REJECT
Step 2	________ cc/Hour	____	____
Step 3	________ drops	____	____
Step 5	Meets requirements of 6.4	____	____

Date ________

Technician ________

5.3 Pressure Screen Test

This test shall be performed on test article configurations designated by Parker Bertea Engineering or by the Air Force (WPAFB) by written concurrance.

5.3.1 Procedure

A pressure transducer shall be installed at the 320154 and/or 320134 bearing port(s) ;Refer to Figure 2). The pressure shall be monitored at the 320154 and/or 320134 bearing port(s) during the duty cycle testing. The pressure shall be recorded for one complete thermo-cycle period and at the 275° portion of the thermo-cycle period once every week of testing.

5.3.2 Requirements

None - Record for information only.

5.4 Disassembly and Inspection

5.4.1 Procedure

Following the completion of the duty cycle test, Paragraph 5.1. The 320140 & 320150 actuators shall be disassembled and inspected to see what if any wear occurred. Critical dimensions shall be measured and recorded at the:

320157 Piston Rod	320137 Piston Rod
320151 Barrel	320131 Barrel
320154 Bearing	320134 Bearing
320153 Gland 1st Stage	320133 Gland 1st Stage
320155 Gland 2nd Stage	320135 Gland 2nd Stage
320158 Piston Head	320138 Piston Head

The piston seals, primary rod seals, and secondary rod seals shall be carefully bagged and identified to insure traceability.

Photographs shall be taken of the piston seals, primary rod seals, and secondary rod seals.

6.0 ACCEPTANCE TEST

6.1 Pre-Assembly Inspection

6.1.1 Procedure

Prior to assembly of the 320140 & 320150 Test Actuators, the following parts shall be inspected and recorded. Prior to the assembly of the test actuators, correct configuration of each shall be verified. Serial numbers and seal part numbers shall be recorded.

6.1.1 Procedure (Cont)

320157 Piston Rod	320137 Piston Rod
320151 Barrel	320131 Barrel
320154 Bearing	320134 Bearing
320153 Gland 1st Stage	320133 Gland 1st Stage
320155 Gland 2nd Stage	320135 Gland 2nd Stage
320158 Piston Head	320138 Piston

Critical dimensions shall be recorded. Serialization of each part shall be verified and also recorded.

6.1.2 Requirements

The parts inspected shall conform dimensionally, and each part shall have a serial number.

6.1.3 Data

The dimensional data and configuration verification data shall be recorded on data sheets in Appendix A.

	ACCEPT	REJECT
Correct dimensions	_____	_____
Correct configuration	_____	_____

Date ____________

Technician ______________

6.2 Examination of Product

6.2.1 Procedure

The test article shall be examined to verify conformance with Parker Bertea Drawing Number 320100 as to:

Quality of Workmanship
Correct Markings
Correct Configuration
Mounting Requirements
Interface Dimensions
Seal Configurations

6.2.2 Requirements

The test article shall meet the requirements of Parker Bertea Drawing Number 320100.

6.2.3 Data

	ACCEPT	REJECT
Quality of workmanship	______	______
Correct markings	______	______
Correct configuration	______	______
Mounting requirements	______	______
Interface dimensions	______	______
Seal configurations	______	______

Date ________________

Technician ________________________

6.3 PROOF PRESSURE

6.3.1 Procedure

With the 320140 & 320150 actuators installed in the 320100 test fixtures, this test shall be performed according to the following steps:

Step 1: Drive the actuators to the hard over extend position and raise the supply pressure to 10,000 psi for one minute.

Step 2: Drive the actuators to the hard over retract position and raise the supply pressure to 10,000 psi for one minute.

6.3.2 Requirements

There shall be no external leakage, permanent set or losening of parts in either direction.

6.3.3 Data

	ACCEPT	REJECT
External leakage	____	____
Permanent set	____	____
Loosening of parts	____	____

Date ________________

Technician ________________________

6.4 OPERATION AND LEAKAGE

6.4.1 Procedure

With the 320140 & 320150 test actuators installed in the 320100 test fixtures, this test shall be performed according to the following steps:

Step 1: Cycle the actuators 5 full stroke cycles to bleed air from the system.

Step 2: Install the 320142-1 Drain Fittings in the primary and secondary piston seal leakage ports. Drive the actuators to the full retract position. Measure and record the internal leakage from the actuator extend port. Measure and record the internal leakage from the primary rod seal port.

Step 3: Cycle the test actuators 50 full stroke cycles. Measure and record the dynamic leakage from the primary rod seal (320142-1 fittings).

Step 4: Remove the 320142-1 drain fitting from the primary rod seal port. Plug the primary rod seal port. Cycle the actuators an additional 50 full stroke cycles. Measure and record the dynamic leakage from the 320142-1 drain fitting at the secondary rod seal port.

6.4.2 Requirements

Step 2: 20 cc/min from the actuator extend port

1 drop/min from the primary rod seal port

Step 3: 2 drops per 50 cycles at the primary rod seal fitting.

Step 4: 2 drops per 50 cycles at the secondary rod seal fitting.

Requirements

Steps 2, 3 & 4

6.4.3 Data

	ACCEPT	REJECT
Actuator serial number ________	______	______
Step 2:		
Extend port ________ cc/minute	______	______
Primary seal fitting ________ cc/minute	______	______
Step 3:		
Primary seal fitting ________ drops	______	______
Step 4:		
Secondary seal fitting ________ drops	______	______

Date: ________

Technician: ________________

Parker

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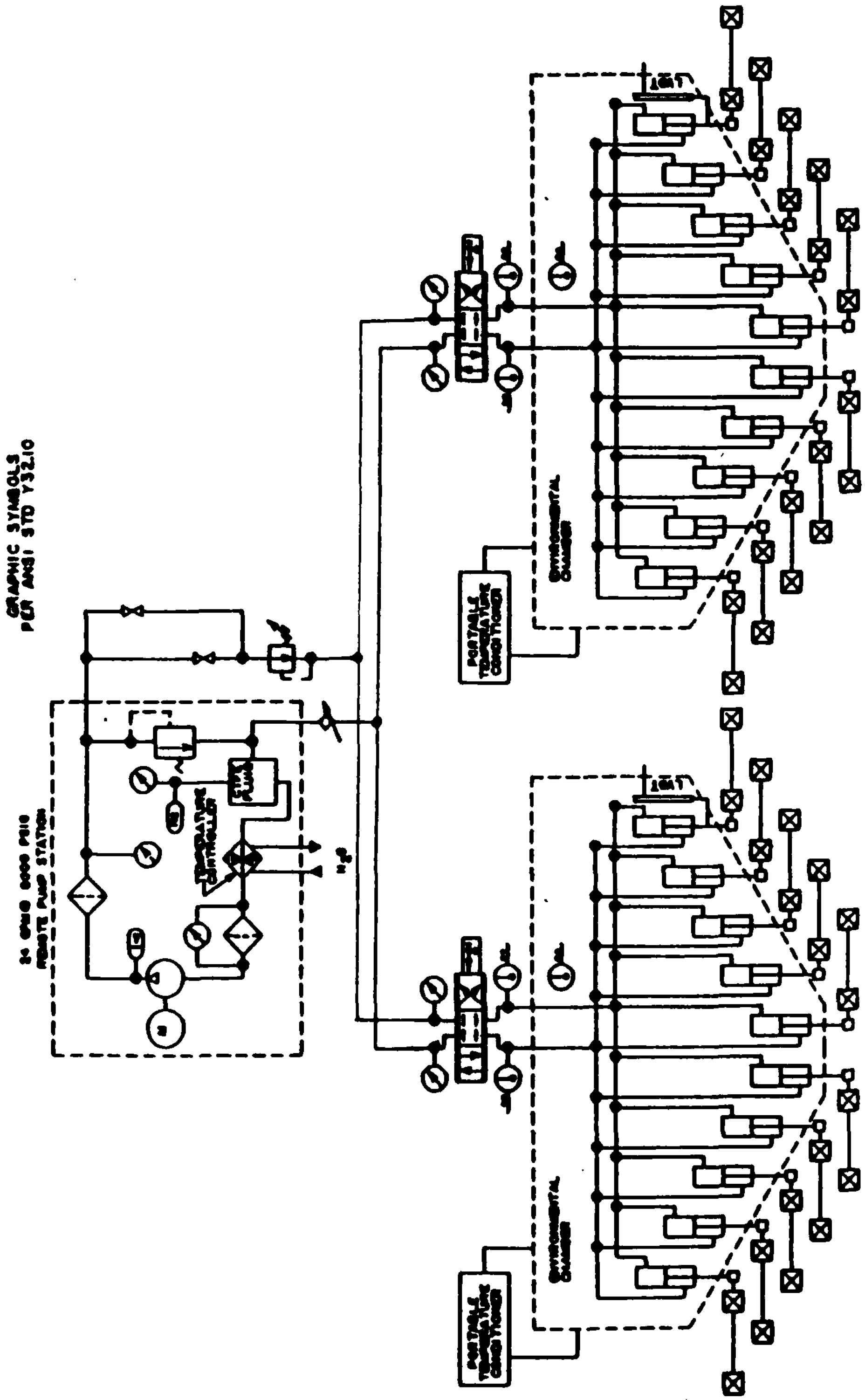
TITLE LONG LIFE TEST PLAN



TEST FIXTURE AND HYDRAULIC SCHEMATIC

FIGURE 1

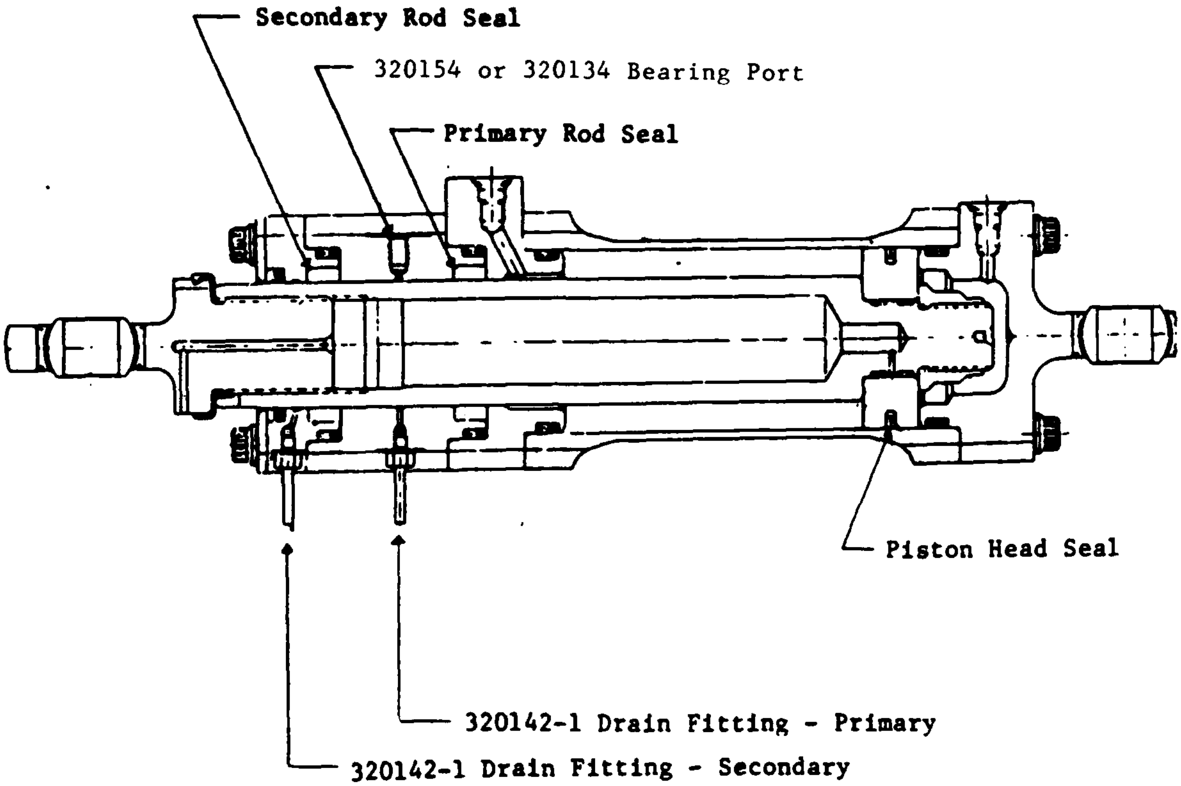
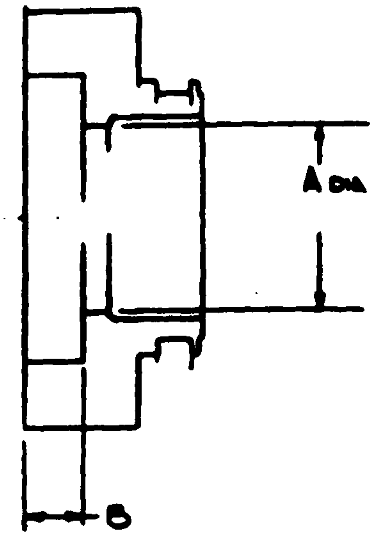

Secondary Rod Seal
320154 or 320134 Bearing Port
Primary Rod Seal
Piston Head Seal
320142-1 Drain Fitting - Primary
320142-1 Drain Fitting - Secondary

FIGURE 2

APPENDIX A

This Appendix contains
significant dimensions - pre-assembly inspection
and configuration verification pre-assembly data sheets

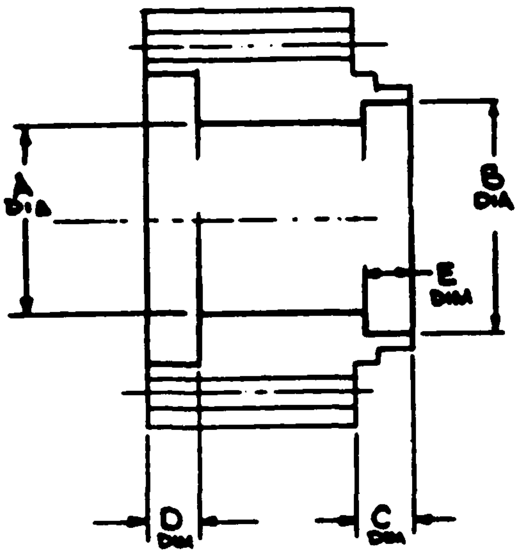


S/N	A DIA		B DIM	
	REQD	ACTUAL	REQD	ACTUAL
	1.682 ±.002 DIA		.328 ±.001	

PRE-ASSEMBLY INSPECTION RECORD

320153 GLAND 1ST STAGE

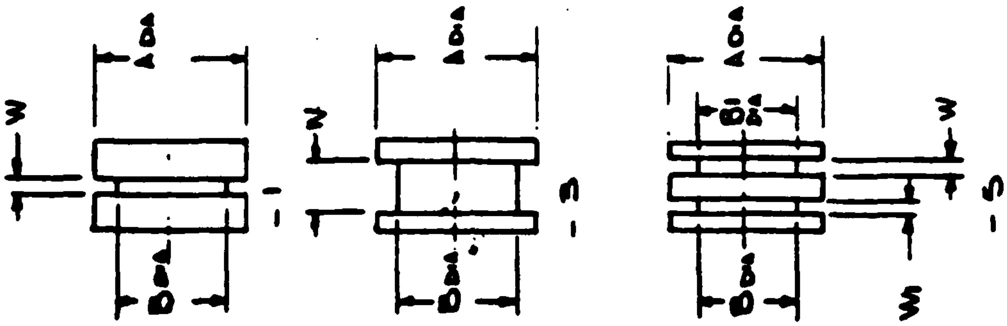
TITLE LONG LIFE TEST PLAN



S/N	A DIA		B DIA		C DIM		D DIM		E DIM	
	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL
	1.626 ±.001 DIA		1.996 ±.001 DIA		.5230 ±.0005		.450 ±.001		.429 ±.002	

PRE-ASSEMBLY INSPECTION RECORD

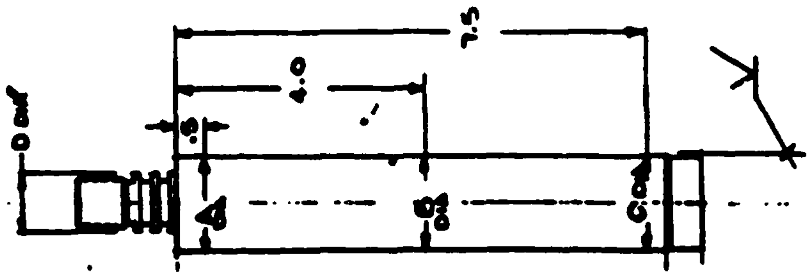
320154 BEARING



S/N	DASH NO.	A DIA REQD	A DIA ACTUAL	B DIA REQD	B DIA ACTUAL	B1 DIA REQD	B1 DIA ACTUAL	W WIDTH REQD	W WIDTH ACTUAL	W1 WIDTH REQD	W1 WIDTH ACTUAL	INSID[E] REQD	INSID[E] ACTUAL
	-1	2.3646 ±.0005 DIA		1.936 ±.004 DIA		N/A		.1265 ±.0010		N/A		.998 ±.001 DIA	
	-1												
	-1												
	-1												
	-1												
	-3			1.995 ±.001 DIA		N/A				N/A			
	-3												
	-3												
	-3												
	-3												
	-5			1.936 ±.004 DIA		1.936 ±.004 DIA		.1265 ±.0010		.1265 ±.0010			
	-5												
	-5												
	-5												
	-5												

PRE-ASSEMBLY INSPECTION RECORD

320158 PISTON HEAD

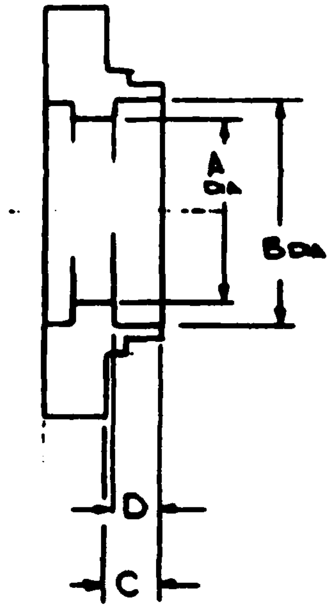


S/N	A DIA REQD	A DIA ACTUAL	B DIA REQD.	B DIA ACTUAL	C DIA REQD	C DIA ACTUAL	D DIA REQD	D DIA ACTUAL	FINISH
	1.622 ±.001 DIA		1.622 ±.001 DIA		1.622 ±.001 DIA		.9885 ±.0005 DIA.		

PRE-ASSEMBLY INSPECTION RECORD

320157 PISTON ROD

TITLE LONG LIFE TEST PLAN

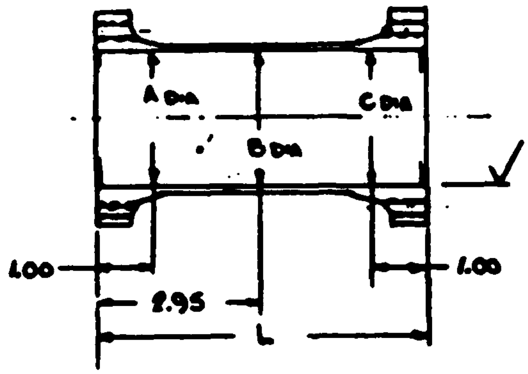


S/N	A DIA		B DIA		C Length		D Length	
	[illegible]	ACTUAL	[illegible]	ACTUAL	[illegible]	ACTUAL	[illegible]	ACTUAL
	1.626 ±.001 DIA		1.996 ±.001 DIA		.4480 ±.0005		.429 ±.002	

PRE-ASSEMBLY INSPECTION RECORD

320155 GLAND 2ND STAGE

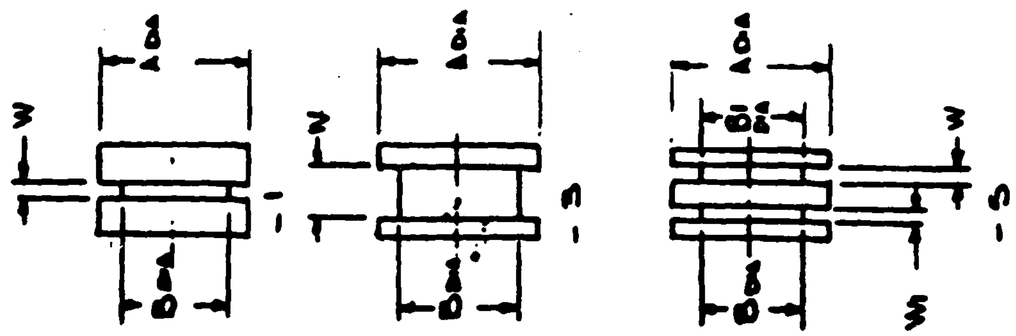
Form 1040-01



	S/N	DRAWING DIM.	ACTUAL A DIA	B DIA	C DIA	L Length	FINISH
-1		2.369 ±.001 DIA 16/					
		L= 5.850 ±.005					
-3							

PRE-ASSEMBLY INSPECTION RECORD

320151 BARREL

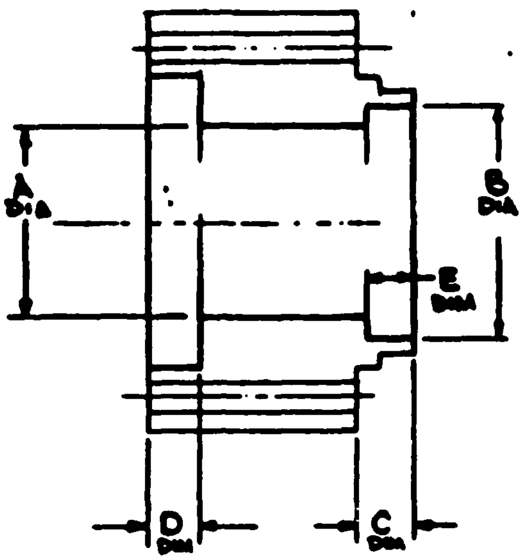


S/N	DASH NO.	A DIA REQD	A DIA ACTUAL	B DIA REQD	B DIA ACTUAL	B1 DIA REQD	B1 DIA ACTUAL	W WIDTH REQD	W WIDTH ACTUAL	W1 WIDTH REQD	W1 WIDTH ACTUAL	INSIDE REQD	INSIDE ACT
	-1												
	-1	1.4885		1.040				.1265				.801	
	-1	±.0005		±.004				±.001				±.001	
	-1	DIA		DIA		N/A				N/A			
	-1												
	-3												
	-3			1.247				.309					
	-3			±.001		N/A		±.005		N/A			
	-3			DIA									
	-3												
	-5												
	-5			1.060		1.060		.1265		.1265			
	-5			±.004		±.004		±.001		±.0010			
	-5			DIA		DIA							
	-5												

PRE-ASSEMBLY INSPECTION RECORD

320138 PISTON HEAD

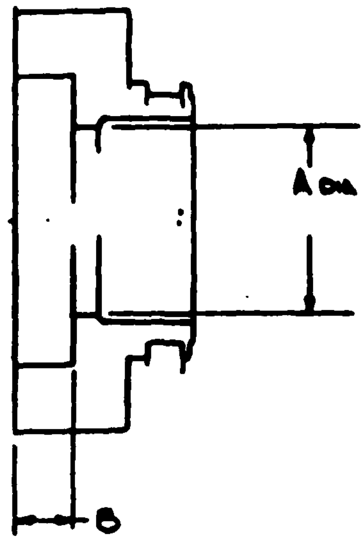
TITLE LONG LIFE TEST PLAN



S/N	A DIA REQD	A DIA ACTUAL	B DIA REQD	B DIA ACTUAL	C DIM REQD	C DIM ACTUAL	D DIM REQD	D DIM ACTUAL	E DIM REQD	E DIM ACTUAL
	1.0005 ±.0005 DIA		1.242 ±.001 DIA		.4480 ±.0005		.450 ±.001		.309 ±.002	

PRE-ASSEMBLY INSPECTION RECORD

320134 BEARING

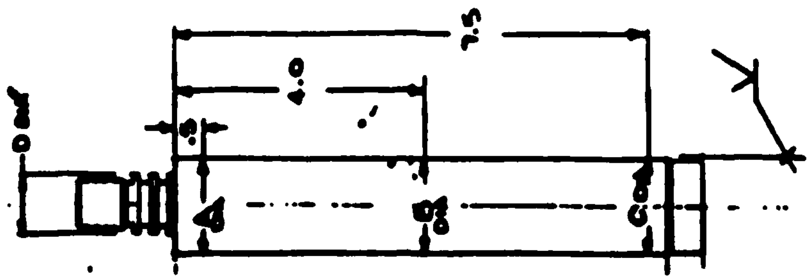


S/N	A DIA		B DIM	
	REQ'D	ACTUAL	REQ'D	ACTUAL
	1.004		.450	
	±.001		±.001	
	DIA			

PRE-ASSEMBLY INSPECTION RECORD

320133 GLAND 1ST STAGE

TITLE LONG LIFE TEST PLAN

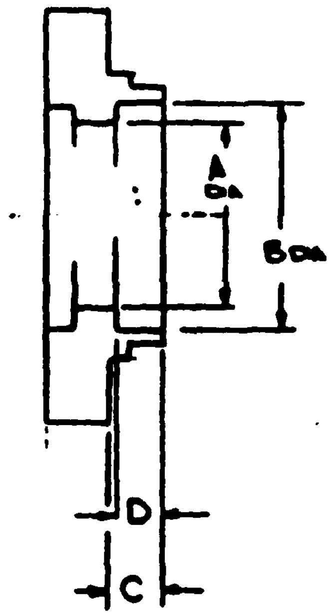


S/N	A DIA		B DIA		C DIA		D DIA		FINISH
	REQD	ACTUAL	REQD.	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	
	.997 ±.001 DIA		.997 ±.001 DIA		.997 ±.001 DIA		.7975 ±.0005 DIA		

PRE-ASSEMBLY INSPECTION RECORD

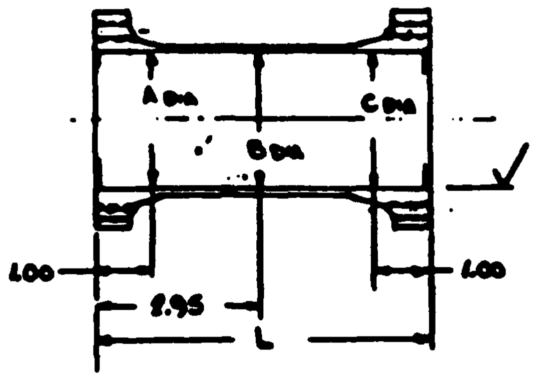
320137 PISTON ROD

TITLE LONG LIFE TEST PLAN



S/N	A DIA		B DIA		C Length		D Length	
	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL
					.4480		.309	
	1.0005		1.242		±.0005		±.002	
	±.0005		±.001					
	DIA		DIA					

PRE-ASSEMBLY INSPECTION RECORD
320135 GLAND 2ND STAGE



	S/N	DRAWING DIM.	ACTUAL A DIA	ACTUAL B DIA	ACTUAL C DIA	ACTUAL L Length	FINISH
-1		1.492 ±.001 DIA. √16 L = 5.750 ±.005					
-1							
-1							
-1							
-1							
-1							
-1							
-1							
-1							
-1							
-1							
-1							
-3							
-3							
-3							
-3							

PRE-ASSEMBLY INSPECTION RECORD

320131 BARREL

CONFIGURATION VERIFICATION

Actuator Serial Number: ____________________

Configuration Number: ____________________

320154 Bearing: SN ____________ **Dash Number** __________

320158 Piston Head: SN __________ **Dash Number** ________

320151 Barrel: SN ____________ **Dash Number** __________

320157 Piston: SN ____________

320153 Gland 1st stage: SN ______________

320155 Gland 2nd Stage: SN ______________

Piston Head Seal: Part Number ____________________

Primary Rod Seal: Part Number ____________________

Secondary Rod Seal: Part Number __________________

Accept ______________________ **Reject** ________________

Technician __________________

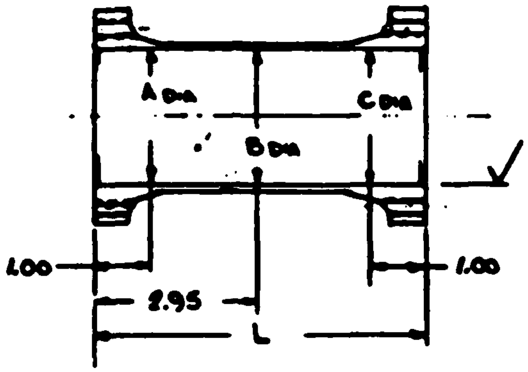
Date ________________________

APPENDIX B

This Appendix contains significant dimensions for post Long Life Test Inspection

PAGF	320100LT	REV.	
ORIG. DATE	1-28-87	REV. DATE	

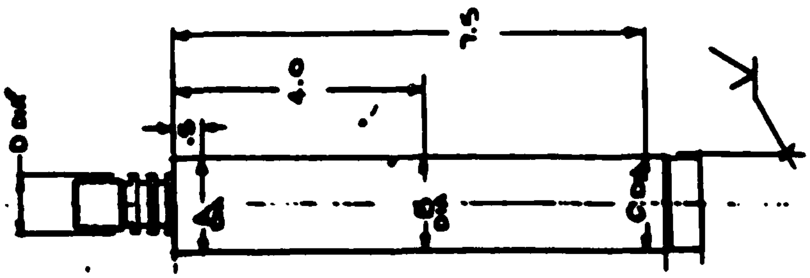
TITLE LONG LIFE TEST PLAN



	S/N	DRAWING DIM.	ACTUAL A DIA	B DIA	C DIA	L LENGTH	FINISH
		2.369 ±.001 16/ DIA					
-1		L=5.850 ±.005					
-3							

320151 BARREL

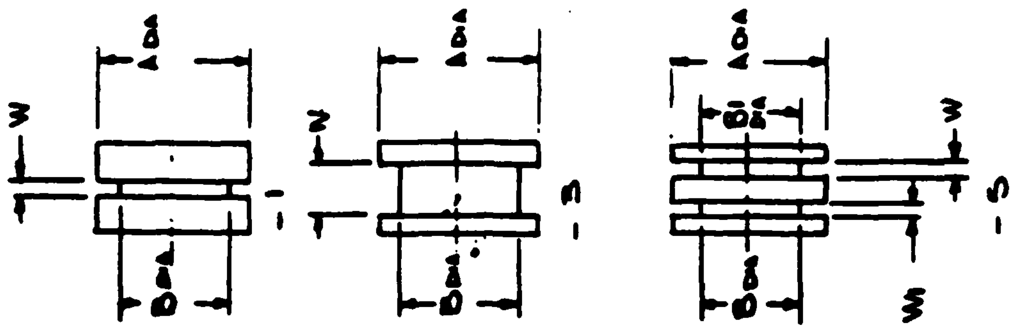
Form 1040-01



S/N	A DIA REQD	A DIA ACTUAL	B DIA REQD.	B DIA ACTUAL	C DIA REQD	C DIA ACTUAL	D DIA REQD	D DIA ACTUAL	FINISH
	1.622 ±.001 DIA		1.622 ±.001 DIA		1.622 ±.001 DIA		.9885 ±.0005 DIA.		

321057 PISTON ROD

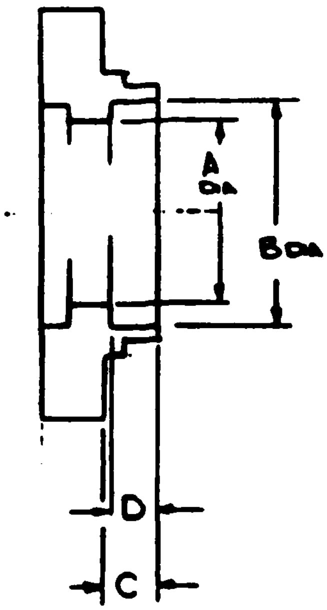
TITLE LONG LIFE TEST PLAN



S/N	DASH NO.	A DIA REQD	A DIA ACTUAL	B DIA REQD	B DIA ACTUAL	B1 DIA REQD	B1 DIA ACTUAL	W WIDTH REQD	W WIDTH ACTUAL	W1 WIDTH REQD	W1 WIDTH ACTUAL	INSIDE DIA REQD	INSIDE DIA ACTUAL
	-1												
	-1	2.3646 ±.0005 DIA		1.936 ±.004 DIA				.1265 ±.0010				.998 ±.001 DIA	
	-1												
	-1					N/A				N/A			
	-1												
	-3			1.995 ±.001 DIA									
	-3												
	-3					N/A				N/A			
	-3												
	-3												
	-5			1.936 ±.004 DIA		1.936 ±.004 DIA		.1265 ±.0010		.1266 ±.0010			
	-5												
	-5												
	-5												
	-5												

320158 PISTON HEAD

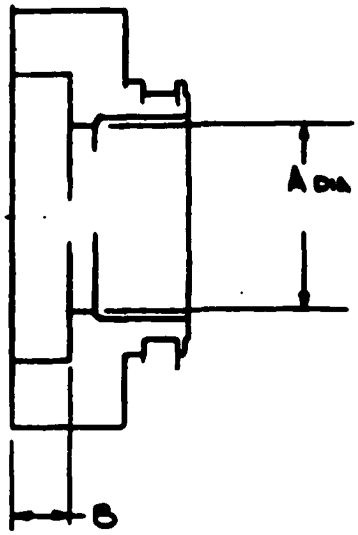
Form 1040-01



S/N	A DIA		B DIA		C Length		D Length	
	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL
	1.626 ±.001 DIA		1.996 ±.001 DIA		.4480 ±.0005		.429 ±.002	

320155 GLAND 2ND STAGE

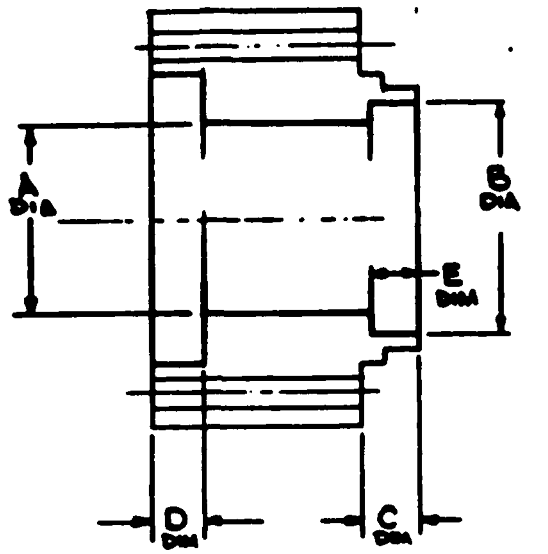
TITLE LONG LIFE TEST PLAN



S/N	A DIA		B DIM	
	REQ'D	ACTUAL	REQ'D	ACTUAL
	1.682 ±.002 DIA		.525 ±.001	

320153 GLAND 1ST STAGE

TITLE LONG LIFE TEST PLAN

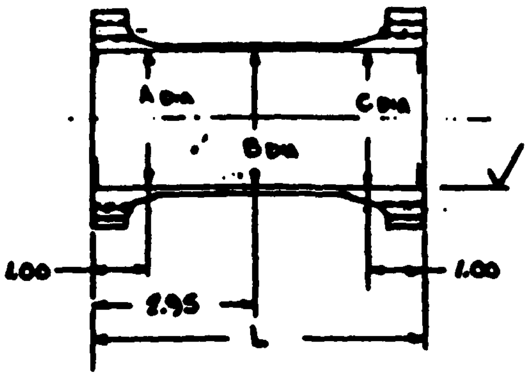


S/N	A DIA		B DIA		C DIM		D DIM		E DIM	
	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL
	1.626 ±.001 DIA		1.996 ±.001 DIA		.5230 ±.0025		.450 ±.001		.429 ±.002	

320154 BEARING

Parker	PAGE	320100LT	REV.
	ORIG. DATE 1-28-87	REV. DATE	

TITLE LONG LIFE TEST PLAN



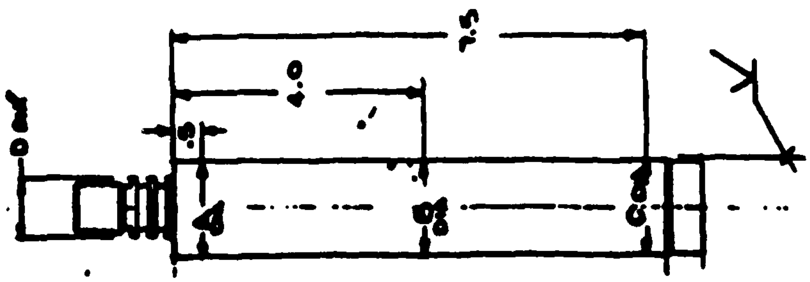
	S/N	DRAWING DIM.	ACTUAL A DIA	B DIA	C DIA	L Length	FINISH
-1		1.492 ±.001 DIA √16 L= 5.750 ±.005					
-3							

320131 BARREL

Form 1040-01

				REV.
PAGE		320100LT		
ORIG. DATE	1-28-87	REV. DATE		

TITLE LONG LIFE TEST PLAN



S/N	A DIA		B DIA		C DIA		D DIA		FINISH
	REQD	ACTUAL	REQD.	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	
	.997 ±.001 DIA		.997 ±.001 DIA		.997 ±.001 DIA		.7975 ±.0005 DIA		

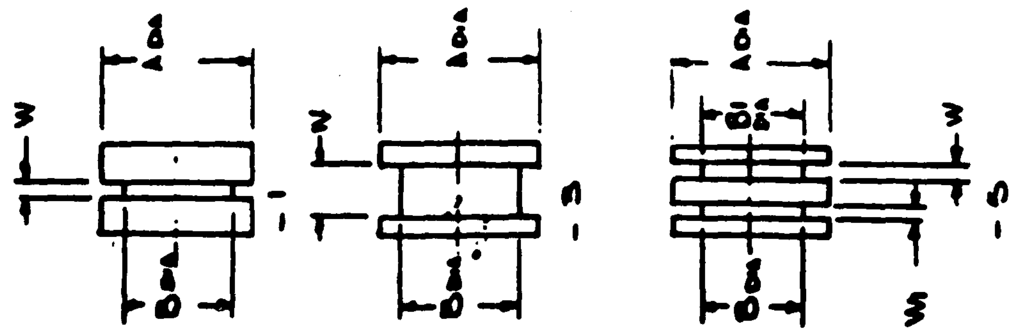
320137 PISTON ROD

Form 1040-01

Parker

PAGE	321000Lt	REV.
ORIG. DATE 1-28-87	REV. DATE	

TITLE LONG LIFE TEST PLAN

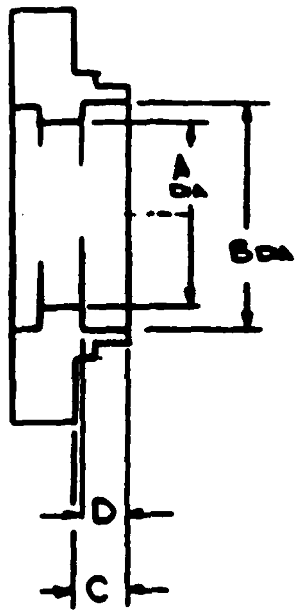


S/N	DASH NO.	A DIA REQD	A DIA ACTUAL	B DIA REQD	B DIA ACTUAL	B1 DIA REQD	B1 DIA ACTUAL	W WIDTH REQD	W WIDTH ACTUAL	W1 WIDTH REQD	W1 WIDTH ACTUAL	INSIDE REQD	INSIDE ACT
	-1												
	-1	1.4885		1.040				.1265				.801	
	-1	±.0005		±.004				±.001				±.01	
	-1	DIA		DIA		N/A				N/A			
	-1												
	-3												
	-3			1.247				.309					
	-3			±.001				±.005					
	-3			DIA		N/A				N/A			
	-3												
	-5												
	-5			1.060		1.060		.1265		.1265			
	-5			±.004		±.004		±.001		±.0010			
	-5			DIA		DIA							
	-5												

320138 PISTON HEAD

Form 1040-01

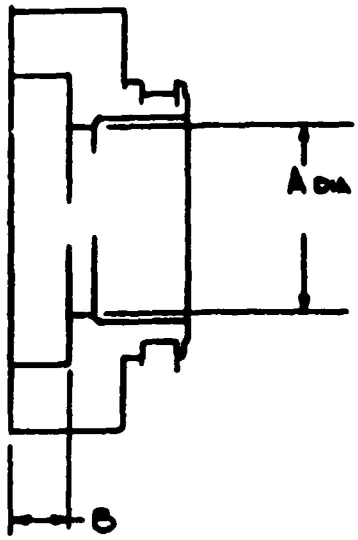
TITLE LONG LIFE TEST PLAN



S/N	A DIA		B DIA		C Length		D Length	
	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL	REQD	ACTUAL
	1.0005		1.242		.4480		.309	
	±.0005		±.001		±.0005		±.002	
	DIA		DIA					

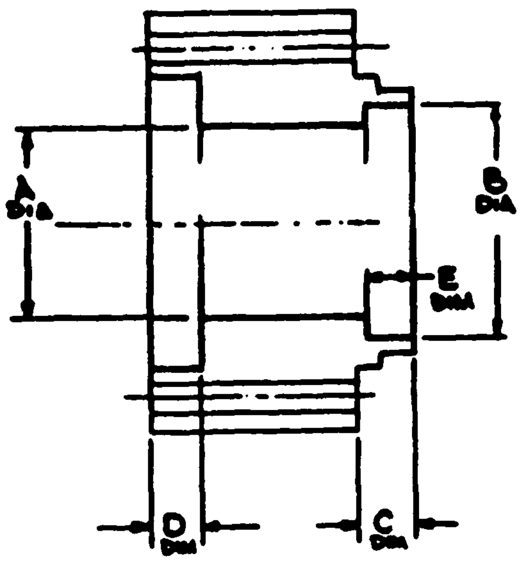
320135 GLAND 2ND STAGE

TITLE LONG LIFE TEST PLAN



S/N	A DIA REQ'D	A DIA ACTUAL	B DIM REQ'D	B DIM ACTUAL
	1.004		.450	
	±.001		±.001	
	DIA			

320133 GLAND 1ST STAGE

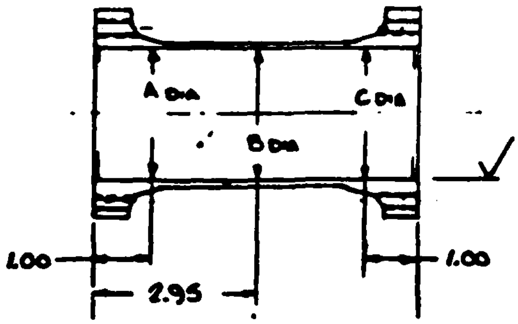


S/N	A DIA		B DIA		C DIM		D DIM		E DIM	
	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL
	1.0005 ±.0005 DIA		1.242 ±.001 DIA		.4480 ±.0005		.450 ±.001		.309 ±.002	

320134 BEARING

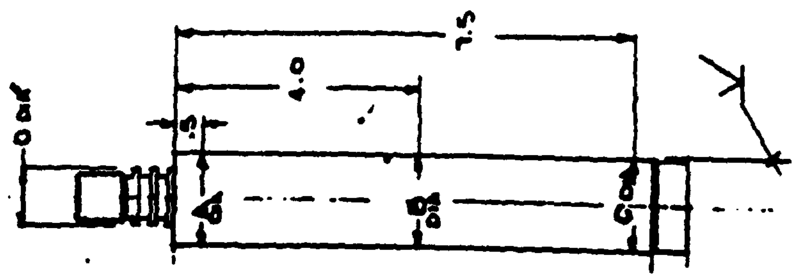
APPENDIX C

RESULTS OF THE ACTUATOR PARTS WEAR



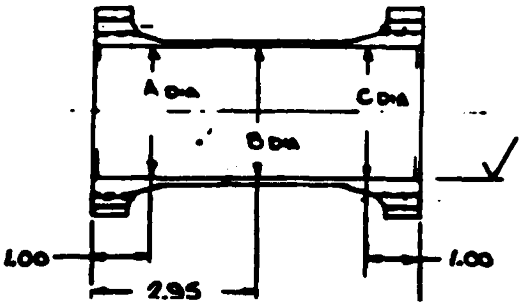
320131 BARREL

		A DIA	B DIA	C DIA
SERIAL NUMBER #1	PRE LIFE	1.4921	1.4921	1.4921
	POST LIFE	1.4922	1.4952	1.4922
	DIFFERENCE	-0.0001	-0.0031	-0.0001
SERIAL NUMBER #2	PRE LIFE	1.4921	1.4921	1.492
	POST LIFE	1.4921	1.4936	1.492
	DIFFERENCE	0	-0.0015	0
SERIAL NUMBER #3	PRE LIFE	1.4922	1.4921	1.4921
	POST LIFE	1.4921	1.494	1.4921
	DIFFERENCE	0.0001	-0.0019	0
SERIAL NUMBER #4	PRE LIFE	1.4919	1.492	1.492
	POST LIFE	1.4918	1.4935	1.4922
	DIFFERENCE	0.0001	-0.0015	-0.0002
SERIAL NUMBER #5	PRE LIFE	1.4922	1.4925	1.4929
	POST LIFE	1.4923	1.4937	1.4927
	DIFFERENCE	-0.0001	-0.0012	0.0002
SERIAL NUMBER #6	PRE LIFE	1.4925	1.4922	1.4925
	POST LIFE	1.4925	1.4935	1.4925
	DIFFERENCE	0	-0.0013	0
SERIAL NUMBER #7	PRE LIFE	1.4923	1.4923	1.4925
	POST LIFE	1.4925	1.494	1.4923
	DIFFERENCE	-0.0002	-0.0017	0.0002
SERIAL NUMBER #8	PRE LIFE	1.4926	1.4922	1.4924
	POST LIFE	1.4935	1.495	1.4923
	DIFFERENCE	-0.0009	-0.0028	0.0001
SERIAL NUMBER #10	PRE LIFE	1.4938	1.4928	1.4938
	POST LIFE	1.4937	1.4943	1.4937
	DIFFERENCE	0.0001	-0.0015	0.0001
SERIAL NUMBER #11	PRE LIFE	1.4938	1.4938	1.4938
	POST LIFE	1.4937	1.494	1.4937
	DIFFERENCE	0.0001	-0.0002	0.0001



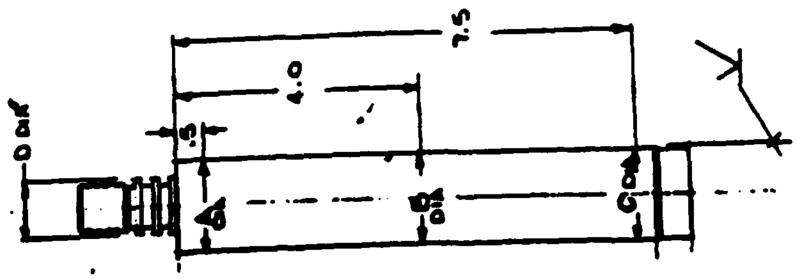
320137 PISTON

		A DIA	B DIA	C DIA
SERIAL NUMBER #1	PRE LIFE	0.9974	0.9974	0.9975
	POST LIFE	0.9971	0.9971	0.9976
	DIFFERENCE	0.0003	0.0003	-0.0001
SERIAL NUMBER #2	PRE LIFE	0.9975	0.9978	0.9979
	POST LIFE	0.9973	0.9972	0.9978
	DIFFERENCE	0.0002	0.0006	0.0001
SERIAL NUMBER #3	PRE LIFE	0.9974	0.9977	0.9979
	POST LIFE	0.9972	0.9973	0.9972
	DIFFERENCE	0.0002	0.0004	0.0007
SERIAL NUMBER #4	PRE LIFE	0.9972	0.9975	0.9977
	POST LIFE	0.9972	0.9972	0.9975
	DIFFERENCE	0	0.0003	0.0002
SERIAL NUMBER #5	PRE LIFE	0.9974	0.9977	0.9978
	POST LIFE	0.9973	0.9973	0.9975
	DIFFERENCE	0.0001	0.0004	0.0003
SERIAL NUMBER #6	PRE LIFE	0.9974	0.9976	0.9977
	POST LIFE	0.9972	0.9973	0.9973
	DIFFERENCE	0.0002	0.0003	0.0004
SERIAL NUMBER #7	PRE LIFE	0.9975	0.9977	0.9978
	POST LIFE	0.9972	0.9975	0.9979
	DIFFERENCE	0.0003	0.0002	-0.0001
SERIAL NUMBER #8	PRE LIFE	0.9972	0.9974	0.9976
	POST LIFE	0.9971	0.9971	0.9975
	DIFFERENCE	0.0001	0.0003	0.0001
SERIAL NUMBER #9	PRE LIFE	0.9972	0.9975	0.9977
	POST LIFE	0.9972	0.9971	0.9975
	DIFFERENCE	0	0.0004	0.0002
SERIAL NUMBER #10	PRE LIFE	0.9973	0.9976	0.9378
	POST LIFE	0.9973	0.9973	0.9977
	DIFFERENCE	0	0.0003	0.0001



320151 BARREL

		A DIA	B DIA	C DIA
SERIAL NUMBER #1	PRE LIFE	2.3692	2.3728	2.3702
	POST LIFE	2.3683	2.3713	2.3685
	DIFFERENCE	0.0009	0.0015	0.0017
SERIAL NUMBER #2	PRE LIFE	2.3712	2.3725	2.3692
	POST LIFE	2.3695	2.372	2.3695
	DIFFERENCE	0.0017	0.0005	-0.0003
SERIAL NUMBER #3	PRE LIFE	2.3715	2.3736	2.3702
	POST LIFE	2.3702	2.3738	2.3695
	DIFFERENCE	0.0013	-0.0002	0.0007
SERIAL NUMBER #4	PRE LIFE	2.3698	2.373	2.3708
	POST LIFE	2.3692	2.373	2.3686
	DIFFERENCE	0.0006	0	0.0022
SERIAL NUMBER #5	PRE LIFE	2.37	2.373	2.3702
	POST LIFE	2.3695	2.3747	2.3693
	DIFFERENCE	0.0005	-0.0017	0.0009
SERIAL NUMBER #6	PRE LIFE	2.3702	2.37	2.3703
	POST LIFE	2.3693	2.3724	2.3698
	DIFFERENCE	0.0009	-0.0024	0.0005
SERIAL NUMBER #7	PRE LIFE	2.3713	2.374	2.37
	POST LIFE	2.3696	2.374	2.3693
	DIFFERENCE	0.0017	0	0.0007
SERIAL NUMBER #8	PRE LIFE	2.371	2.3725	2.3713
	POST LIFE	2.3697	2.374	2.3693
	DIFFERENCE	0.0013	-0.0015	0.002
SERIAL NUMBER #12	PRE LIFE	2.371	2.3725	2.3715
	POST LIFE	2.369	2.3698	2.3692
	DIFFERENCE	0.002	0.0027	0.0023
SERIAL NUMBER #13	PRE LIFE	2.3708	2.3722	2.3708
	POST LIFE	2.369	2.3698	2.3692
	DIFFERENCE	0.0018	0.0024	0.0016



320157 PISTON

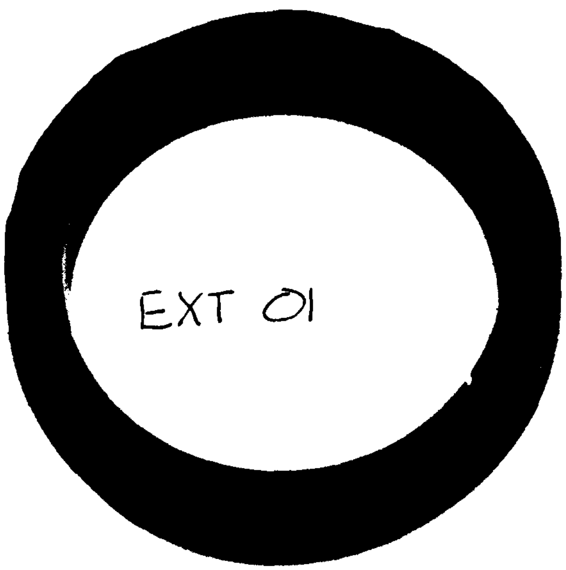
		A DIA	B DIA	C DIA
SERIAL NUMBER #1	PRE LIFE	1.6219	1.6223	1.6223
	POST LIFE	1.622	1.6222	1.6222
	DIFFERENCE	-0.0001	0.0001	0.0001
SERIAL NUMBER #2	PRE LIFE	1.6219	1.6222	1.6223
	POST LIFE	1.6222	1.6224	1.6225
	DIFFERENCE	-0.0003	-0.0002	-0.0002
SERIAL NUMBER #3	PRE LIFE	1.6218	1.622	1.622
	POST LIFE	1.6219	1.622	1.6219
	DIFFERENCE	-0.0001	0	0.0001
SERIAL NUMBER #4	PRE LIFE	1.6223	1.6224	1.6224
	POST LIFE	1.6223	1.6224	1.6223
	DIFFERENCE	0	0	0.0001
SERIAL NUMBER #5	PRE LIFE	1.6218	1.6223	1.6223
	POST LIFE	1.6219	1.6221	1.622
	DIFFERENCE	-0.0001	0.0002	0.0003
SERIAL NUMBER #6	PRE LIFE	1.6217	1.622	1.622
	POST LIFE	1.622	1.6208	1.622
	DIFFERENCE	-0.0003	0.0012	0
SERIAL NUMBER #7	PRE LIFE	1.6222	1.6223	1.6224
	POST LIFE	1.6226	1.6222	1.6224
	DIFFERENCE	-0.0004	0.0001	0
SERIAL NUMBER #8	PRE LIFE	1.6224	1.6224	1.6224
	POST LIFE	1.6225	1.6225	1.6225
	DIFFERENCE	-0.0001	-0.0001	-0.0001
SERIAL NUMBER #9	PRE LIFE	1.6219	1.6221	1.6221
	POST LIFE	1.622	1.6221	1.6222
	DIFFERENCE	-0.0001	0	-0.0001
SERIAL NUMBER #10	PRE LIFE	1.6221	1.6222	1.6222
	POST LIFE	1.6221	1.622	1.6224
	DIFFERENCE	0	0.0002	-0.0002

APPENDIX D

PHASE I TEST SEAL PHOTOS

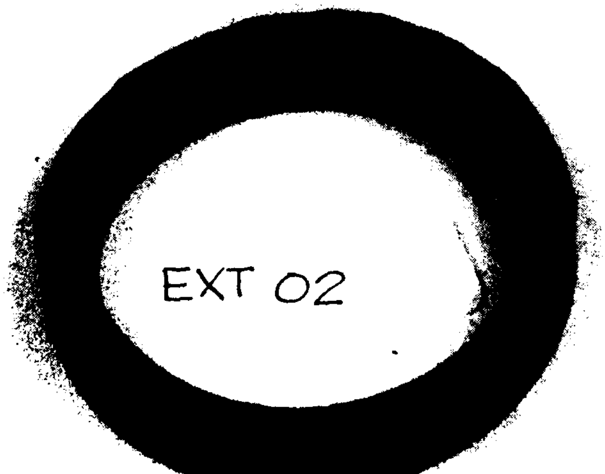
EXTRUSION TEST

BAL SEAL EXTRUSION AT .008 GAP
MIL-H-83282

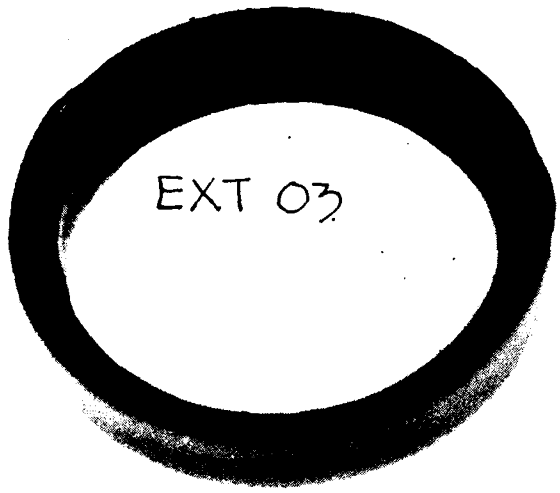


BAL SEAL EXTRUSION AT .004 GAP
MIL-H-83282

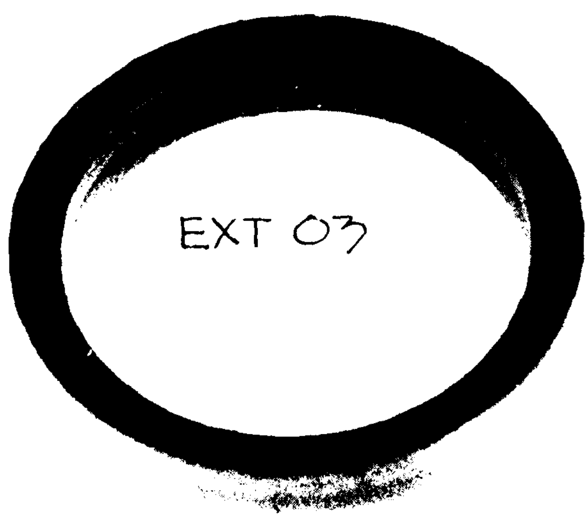
APCO 46146 EXTRUSION TEST AT .008 GAP
MIL-H-83282



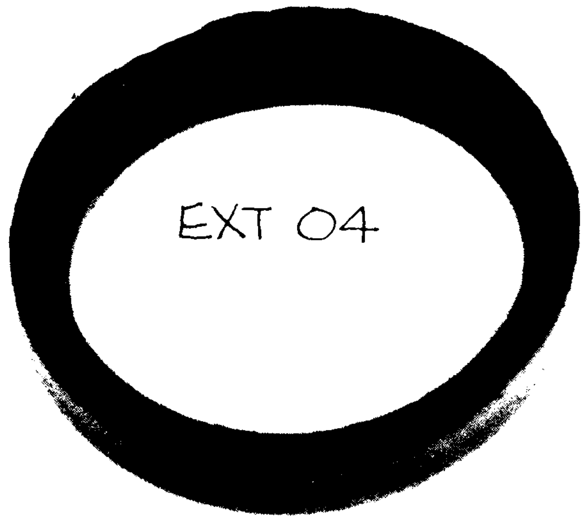
APCO 46146 EXTRUSION TEST AT .004 GAP
MIL-H-83282



APCO 46152 EXTRUSION TEST AT .008 GAP
MIL-H-83282

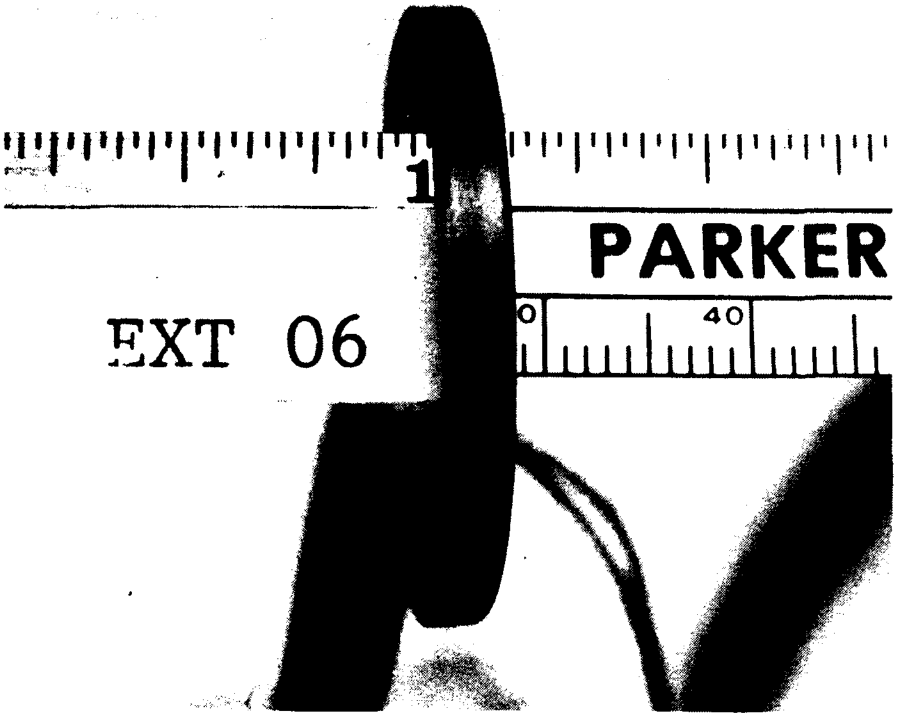


APCO 46152 EXTRUSION TEST AT .004 GAP
MIL-H-83282

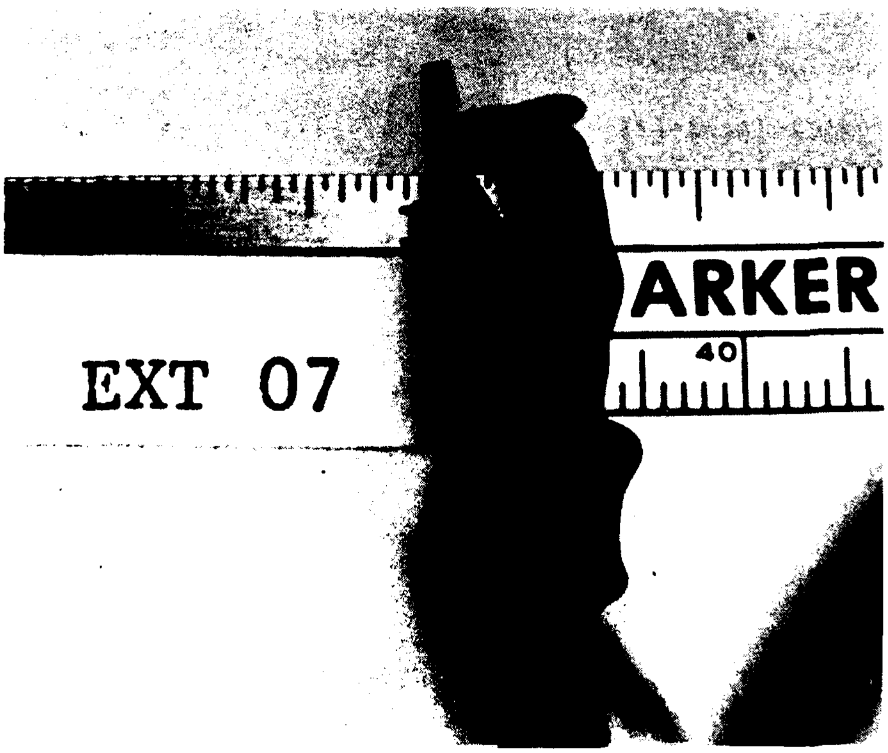


APCO 46164 EXTRUSION TEST AT .004 GAP
MIL-H-83282

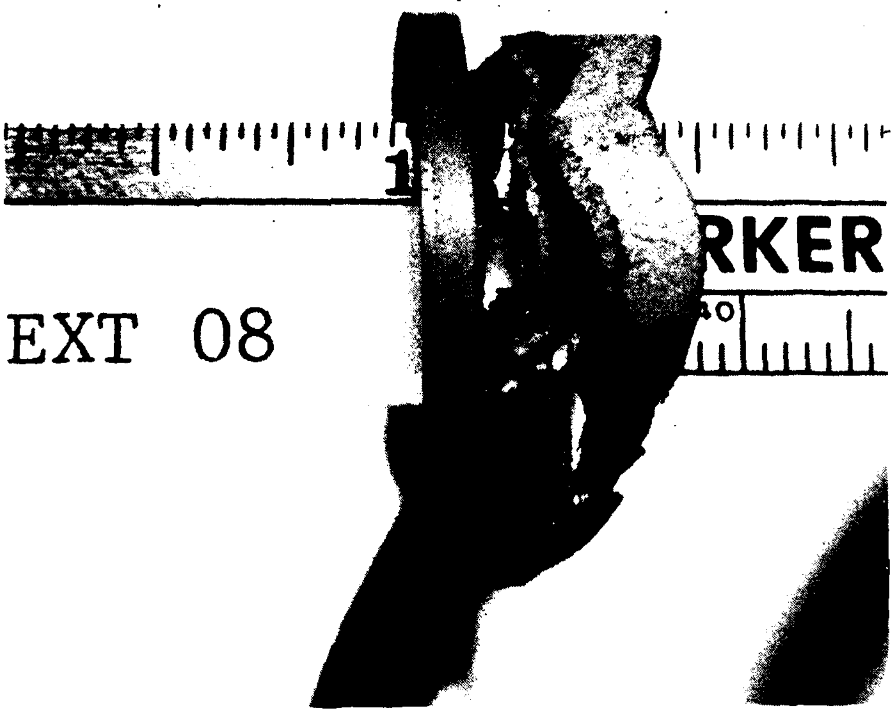
06 THRU 21 TESTED WITH CTFE



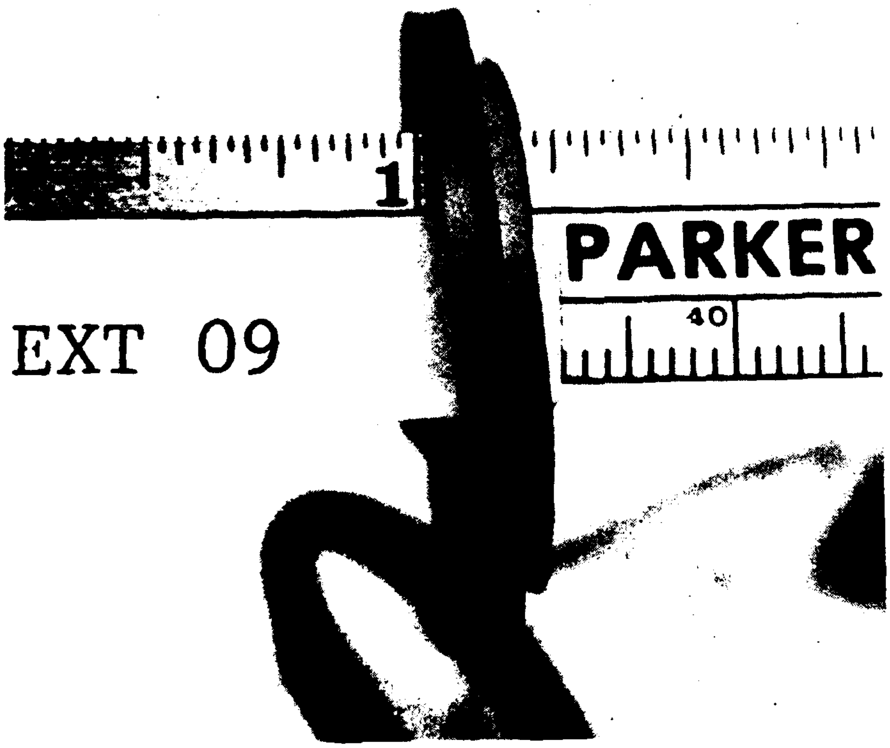
PARKER ML 1663 PEEK (.008 GAP)



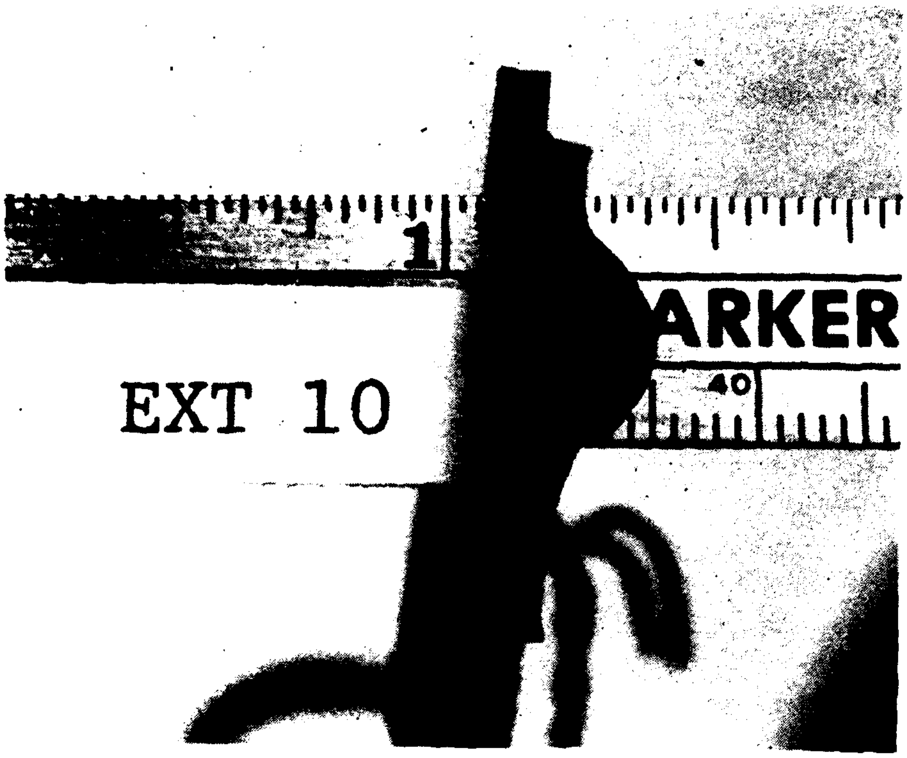
TETRAFLUOR TF74S-214 (430)
FILLED TEFLON (.008 GAP)



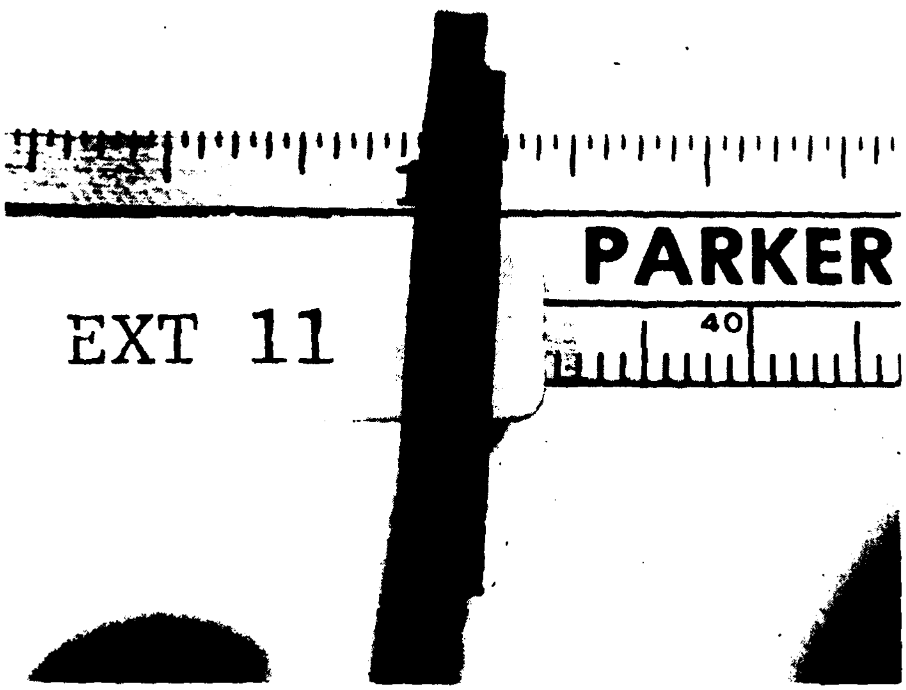
PARKER GNP ML 1817 15 PEEK FILLED TFE
(.008 GAP)



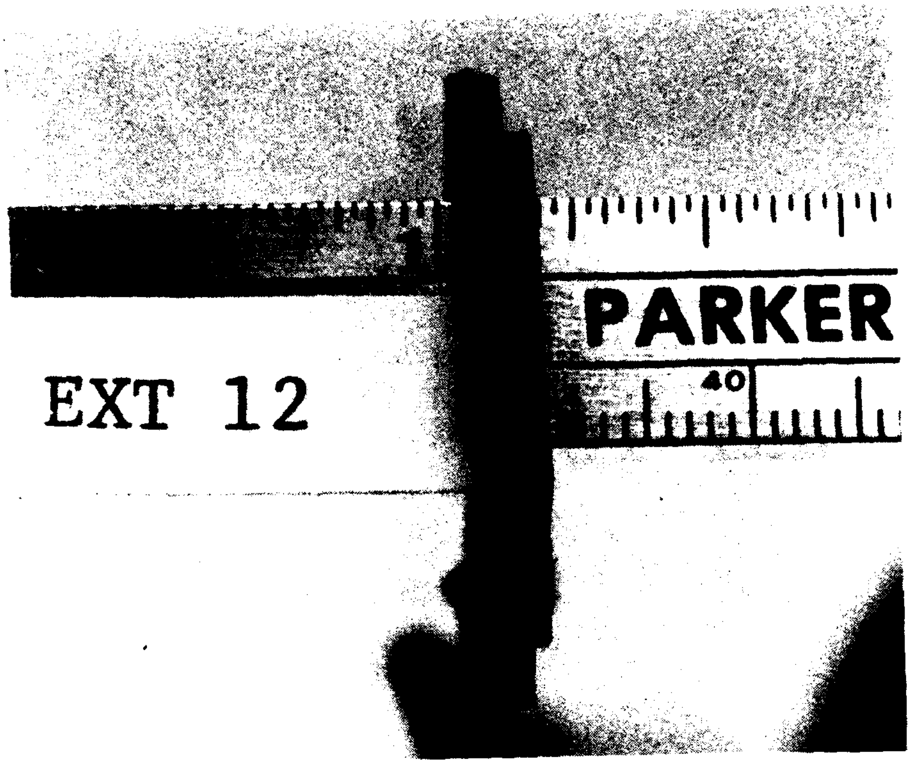
PARKER GNP ML 1817 25% PEEK FILLED TFE
(.008 GAP)



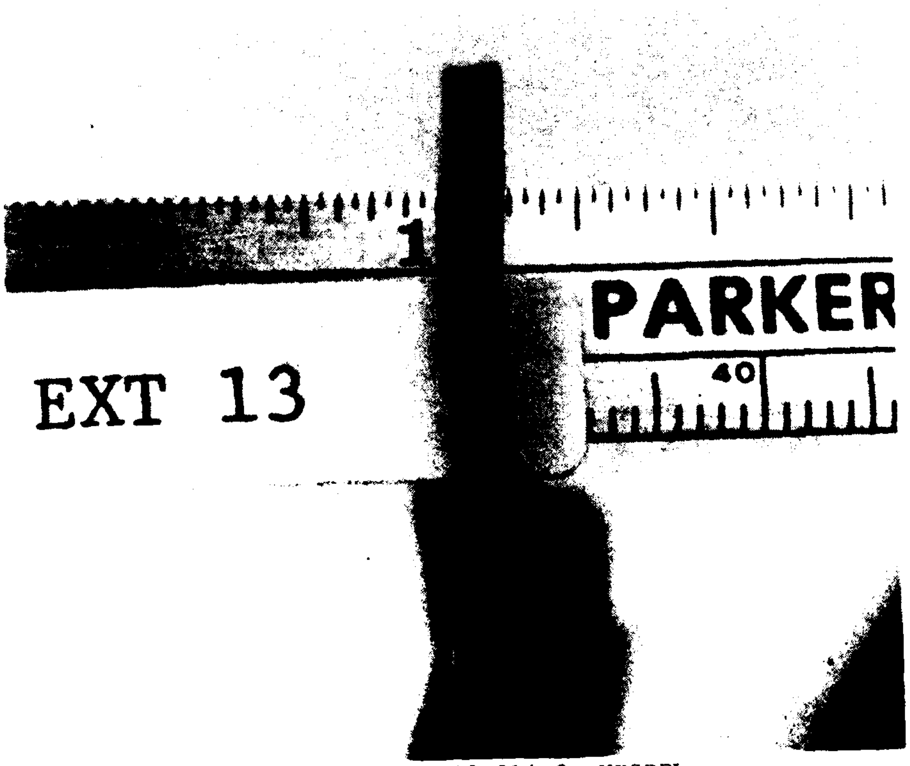
PARKER GNP ML 1817 15% GRAPHITE/TFE
(.008 GAP)



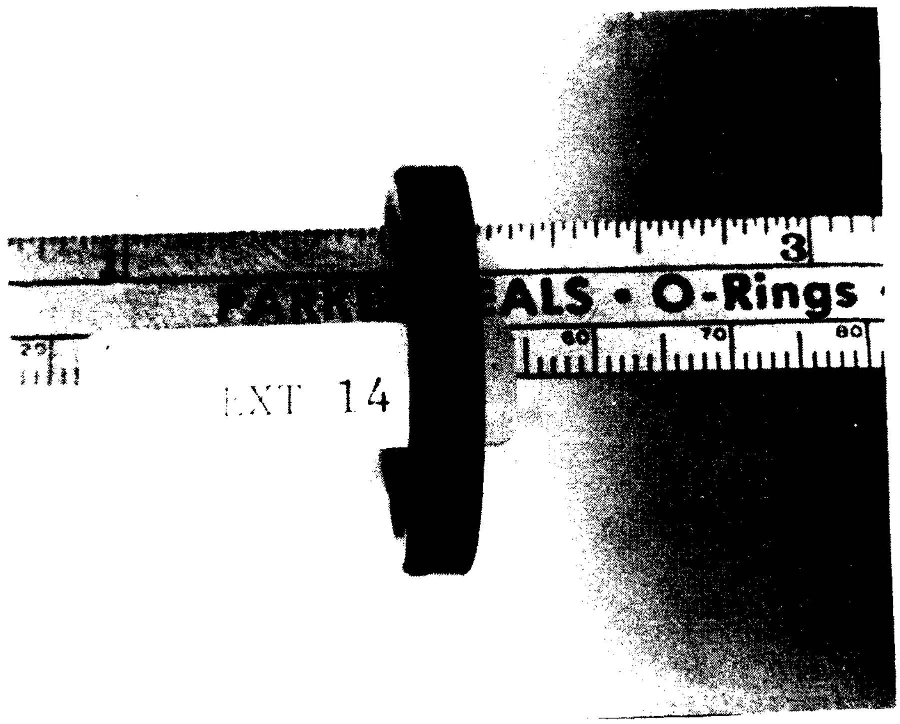
PARKER GNP ML 1817 25% GRAPHITE/TFE
(.008 GAP)



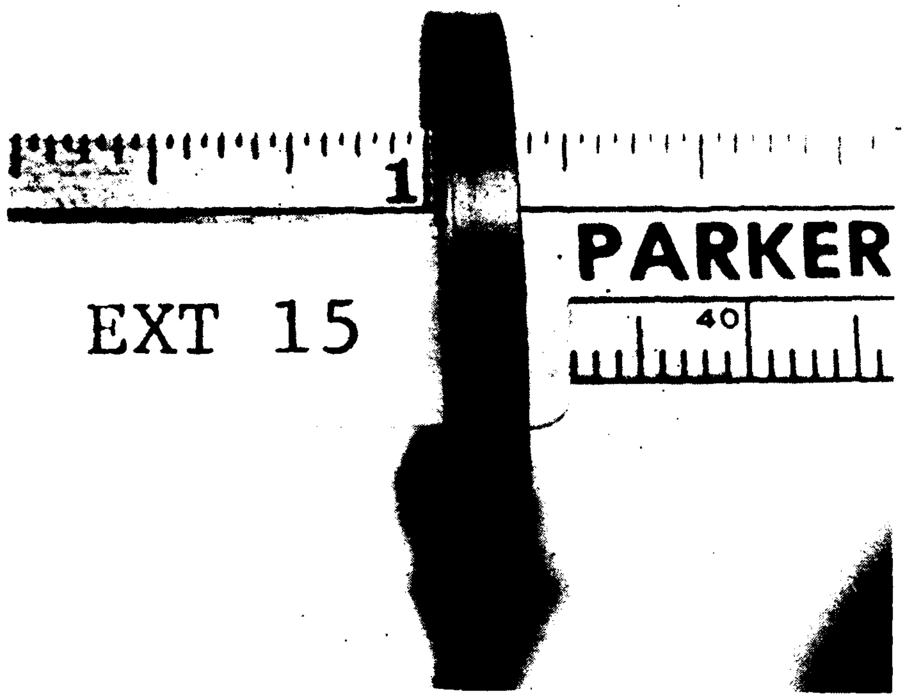
PARKER GNP ML 1817   25% ECKONOL/TFE
(.008 GAP)



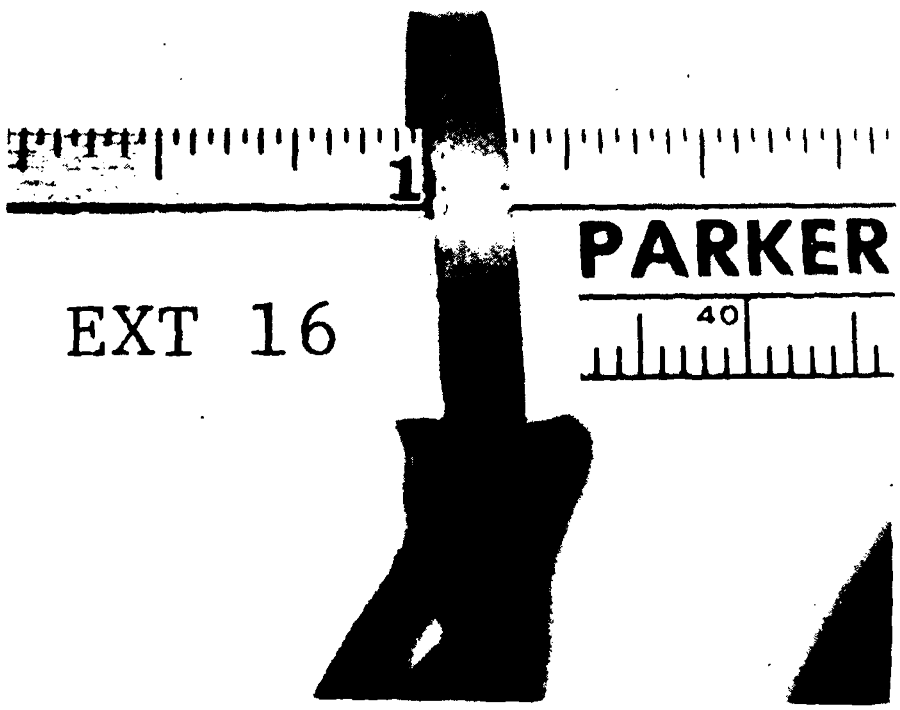
TETRAFLUOR TF548-214-3   VESPEL
(.008 GAP)



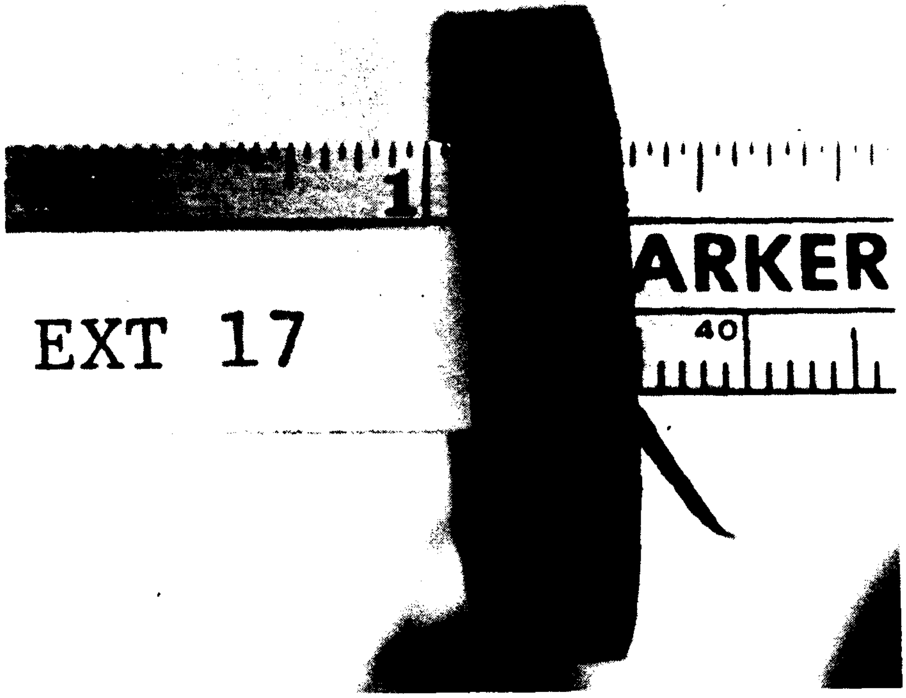
PARKER ML1818
XP2715-1 (PES)
E692-75
(.008 CAP)



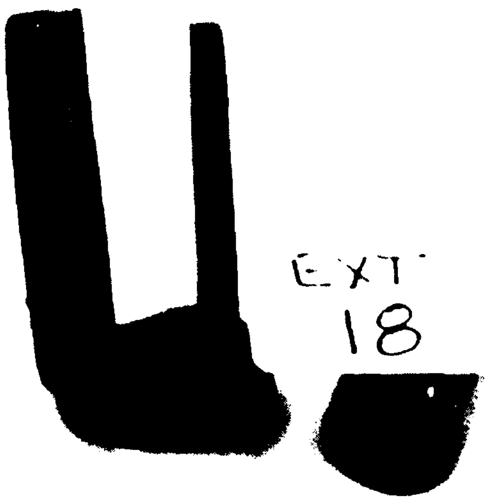
PARKER ML 1818 PEEK
(.008 GAP)



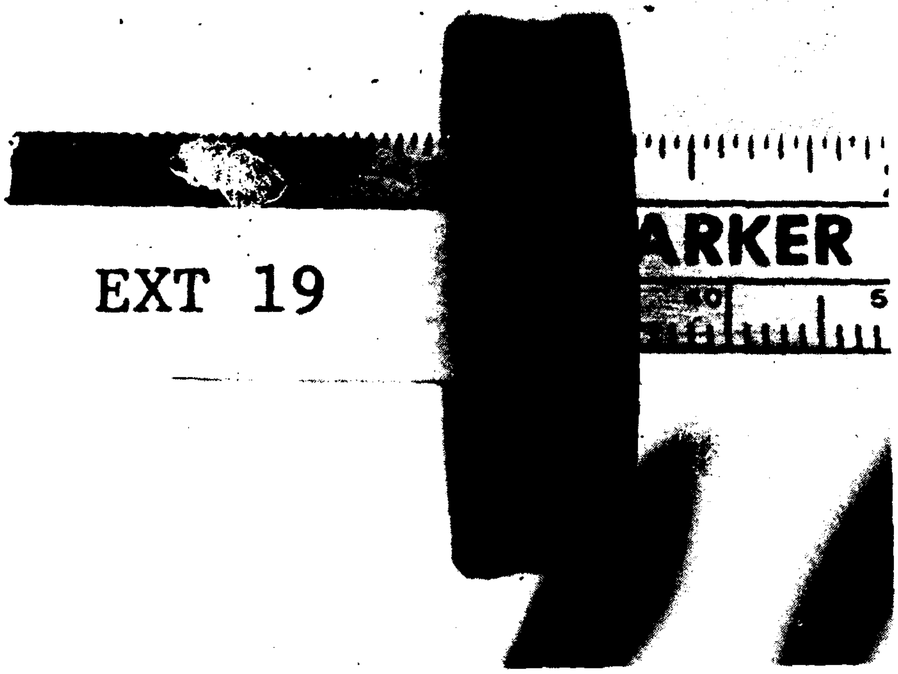
PARKER ML 1818 7% TFE/PEEK
(.008 GAP)



GREENE TWEED 265-21400-818-1200
(.008 GAP)

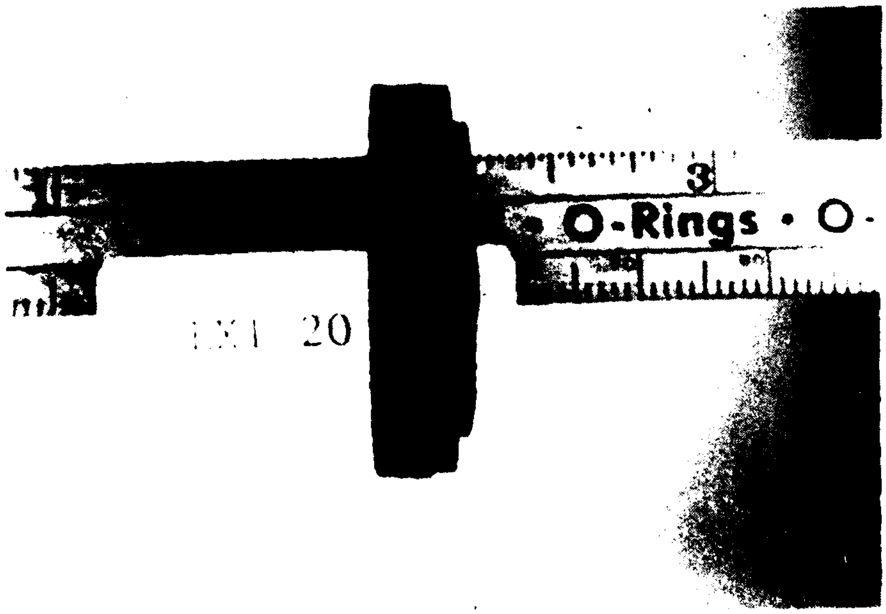


BAL SEAL 3L-EH-U305-(OP)-(.998) GFP
(W.122)X10243 REV B
(.008 GAP)



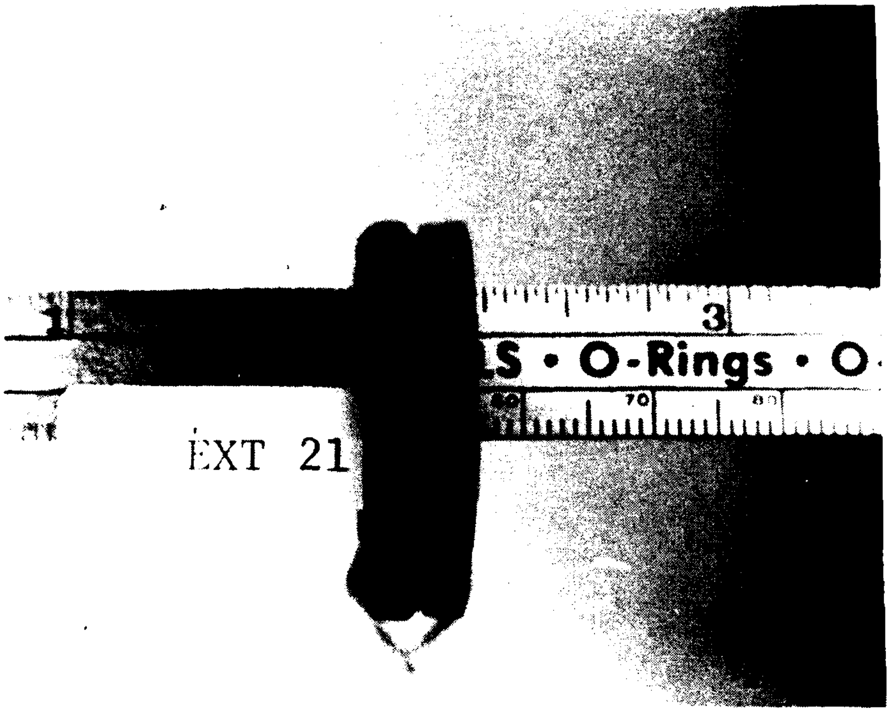
BAL SEAL 3L-EH-U305-(OP)-(.998) GFPM
(W.122)X10244 REV B

(.008 GAP)



SHAMBAN S35704
PLUS SEAL TORLON BACKUP

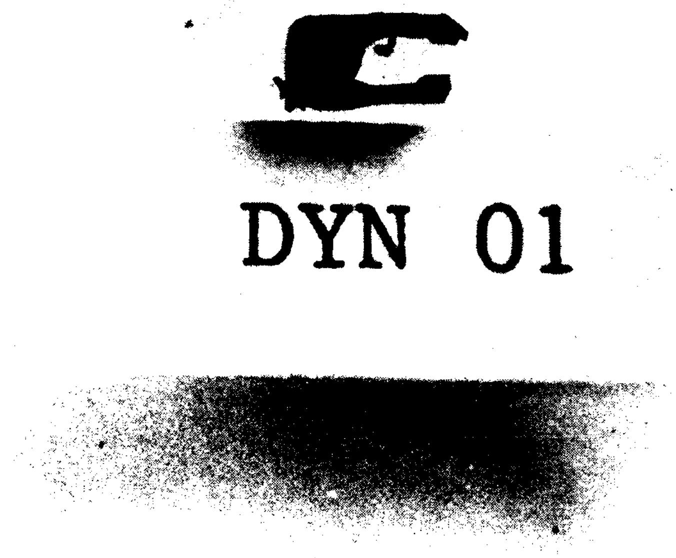
(.008 GAP)

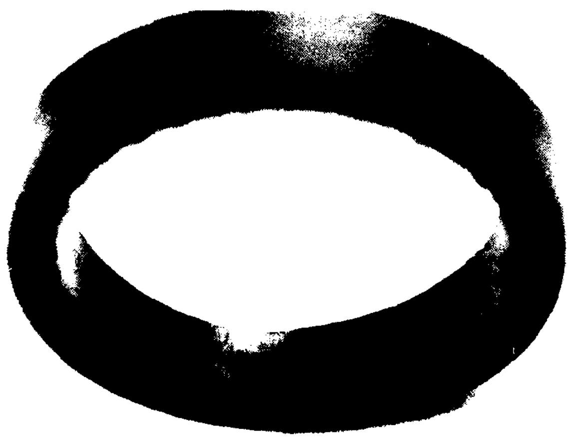


GREENE TWEED
4635-21400-D818

(.008 GAP)

DYNAMIC TEST





DYN 01

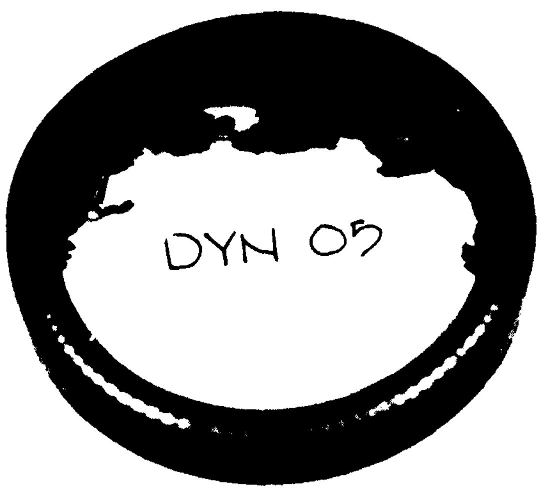
BAL SEAL FSU-305-(OP)-214 GFP
28,686 CYCLES

BAL SEAL FSU-305-(OP)-214 GFP
41,952 CYCLES

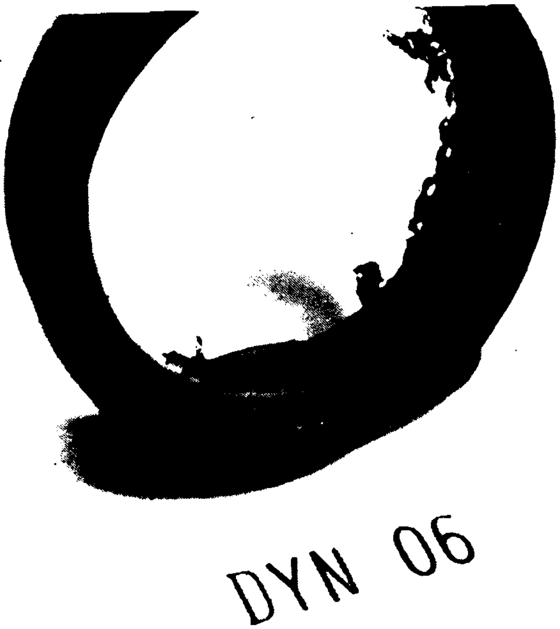
DYN 03

APCO 46146 FAILED AT 19,500 CYCLES

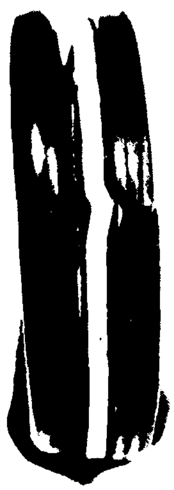
APCO 46152 FAILED AT 8980 CYCLES



APCO 46164 FAILED AT 24,718 CYCLES

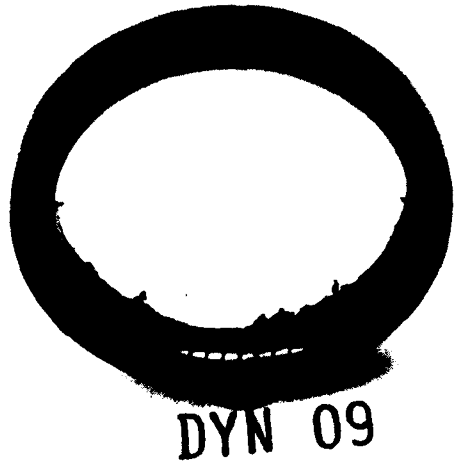


TETRAFLUOR TF1097M-214
44,900 CYCLES

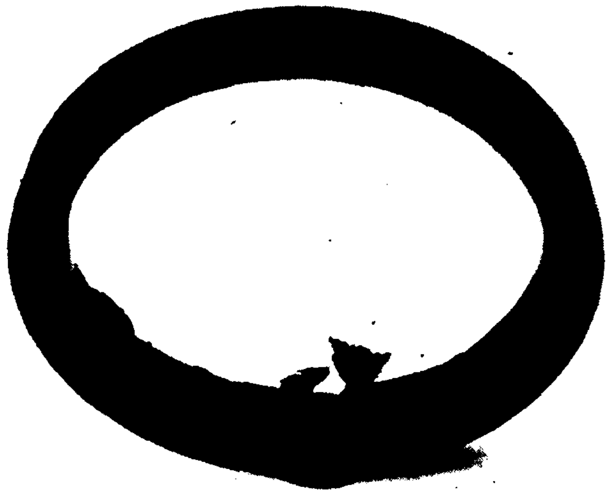


TETRAFLUOR TF-548-214-2 & 3
100,000 CYCLES

FLUORCARBON AR 10103-214-G
5092 CYCLES



FLUORCARBON AR 10103-214-PH
13,323 YCLES



DYN 10

FLUOROCARBON AR 10400-214-PC
9167 CYCLES

DYN 11

FLUORCARBON AR 10400B-214-TC
3600 CYCLES

FLUORCARBON AR 10401-214-G.C.
1820 CYCLES

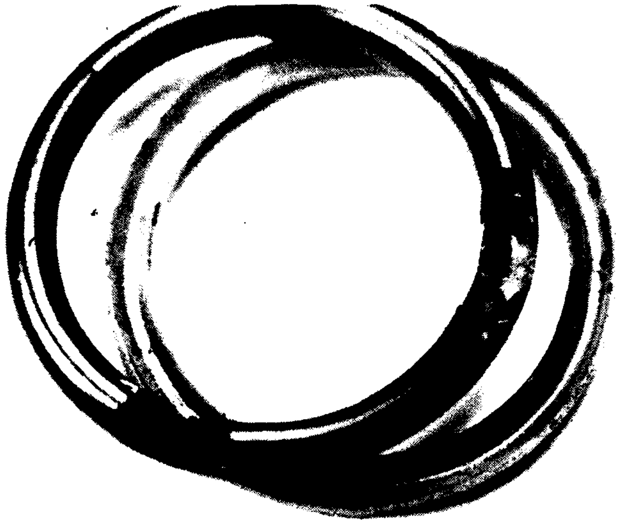
FLUORCARBON AR 10401-214-P.C.
11,150 CYCLES

DYN 14

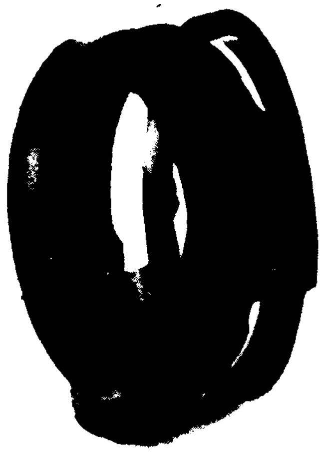
SHAMBAN S35266(S21577)
25,900 CYCLES

DYN 15

PARKER SEAL ML-1721
100,000 CYCLES



PARKER ML1817 & N756-75
97,000 CYCLES

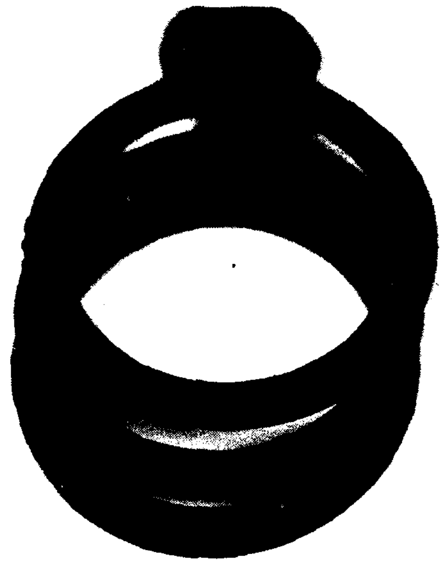


DYN 18

GREENE TWEED 265 21400 818 1200
30908 Cycles

DYN 19

GNP ML1817 Back-up
25% Graphite Filled Teflon
2-214 E692-75 O-Ring
7000 Cycles



DYN 20

TETRAFLOUR TF548-214-3
Vespel Spiral Back-up E692-75 O-Ring
12,350 Cycles

DYN 21

GNP ML1817 Back-up
25% PEEK Filled Teflon
E692-75 O-Ring
3769 Cycles

DYN 22

SHAMBAN 535704 Plus Seal
VITONGLT-TORLON
118,000 Cycles

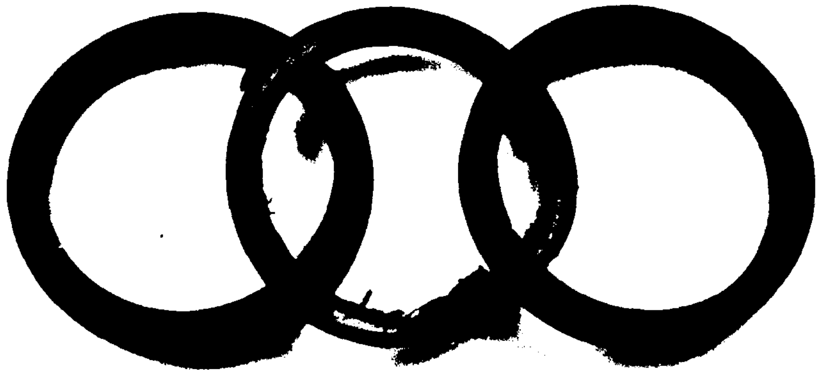
GREENE TWEED 4635-21400 D818
7085 Cycles

DYN 24

BAL SEAL 3L-EH-U305-(OP)-.998 GFP (W.122)
X 10243 REV B
100,100 Cycles

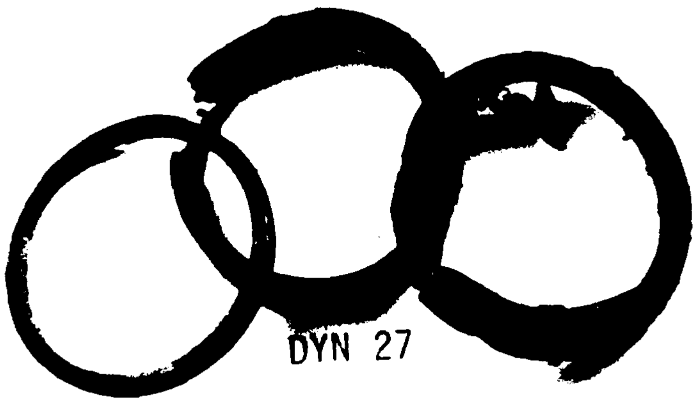
DYN 25

BOEING DYNABAK DB12-02-214 Teflon
Stillman SR786-90 O-Ring
25,018 Cycles



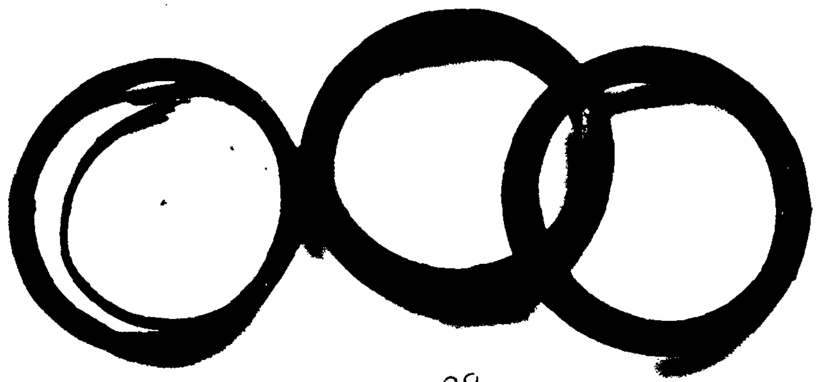
DYN 26

SHAMBAN PLUS SEAL
W/GLT & PEEK INNER RING
(3005)
100,354 CYCLES



DYN 27

GREEN TWEED
CAPPED GT RING
265-21400-818-1260
TF-74S-214 (430) SPACER
14,450 CYCLES

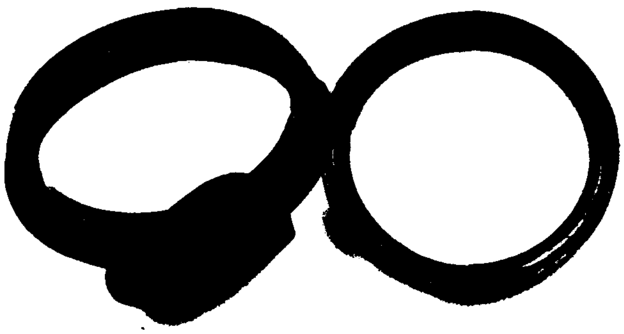


DYN 28

SHAMBAN PLUS SEAL
W/GLT AND PEEK INNER RING
3011 (BALANCED SYSTEM)
100,000 CYCLES

DYN 29

TETRAFLUOR TF888S061385-2
VIRGIN PEEK BACK-UP
TF-74S-214 (430)
SPACER
100,120 CYCLES

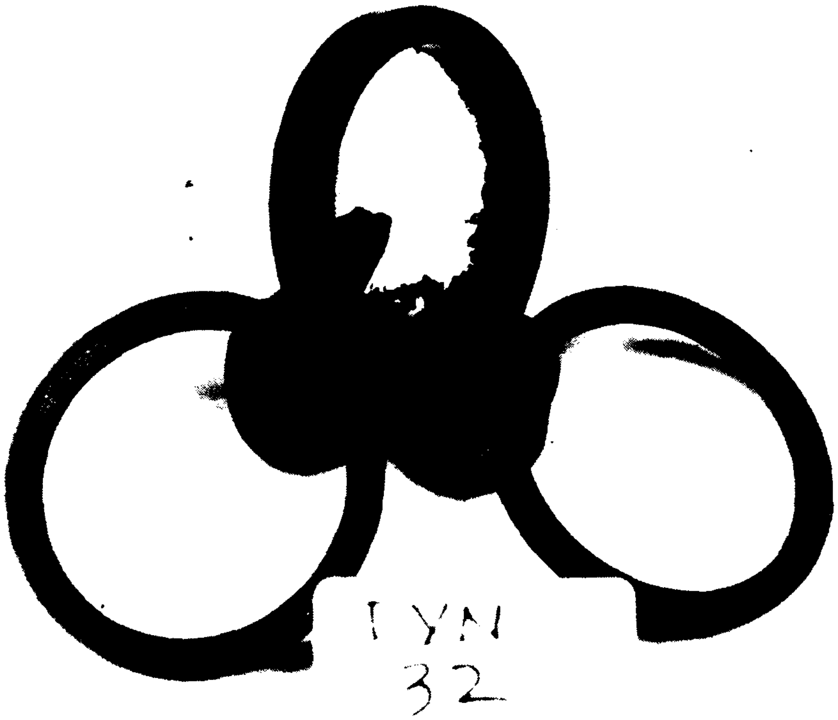


DYN 30

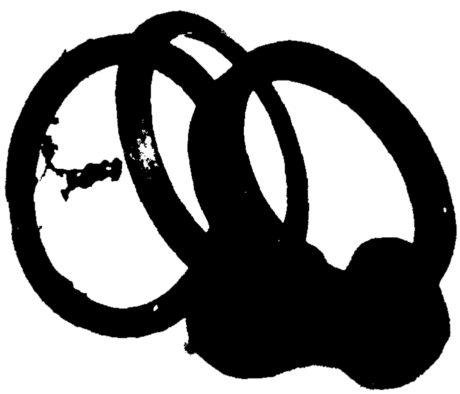
PARKER POLY BIPAK
#4685, MACHINE ML 1663
ML1822, SEAL ELEMENT
XV2690-18
31,483 CYCLES

DYN 31

AMERICAN VARY SEAL/
SHAMBAN P/N S65357
0 CYCLES
(EXCESSIVE START-UP LEAKAGE)

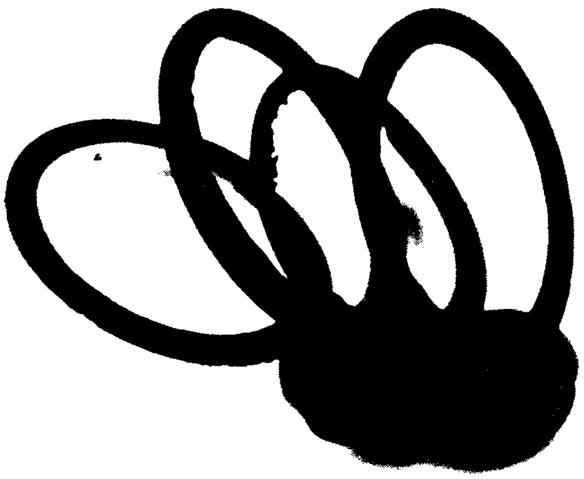


ADVANCED PRODUCTS CO.
P/N 46176. 5237 CYCLES



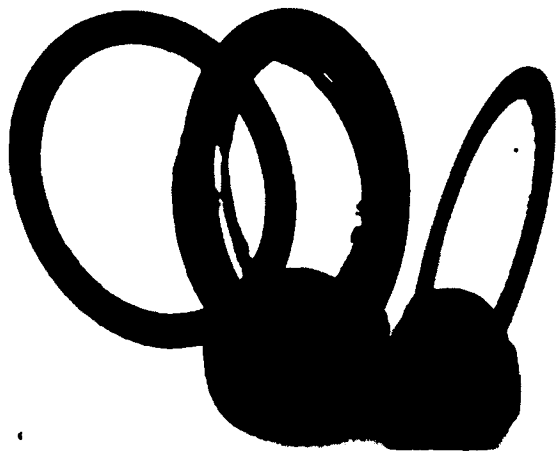
DYN
33

FLUOROCARBON P/N AR 104304
58,894 CYCLES



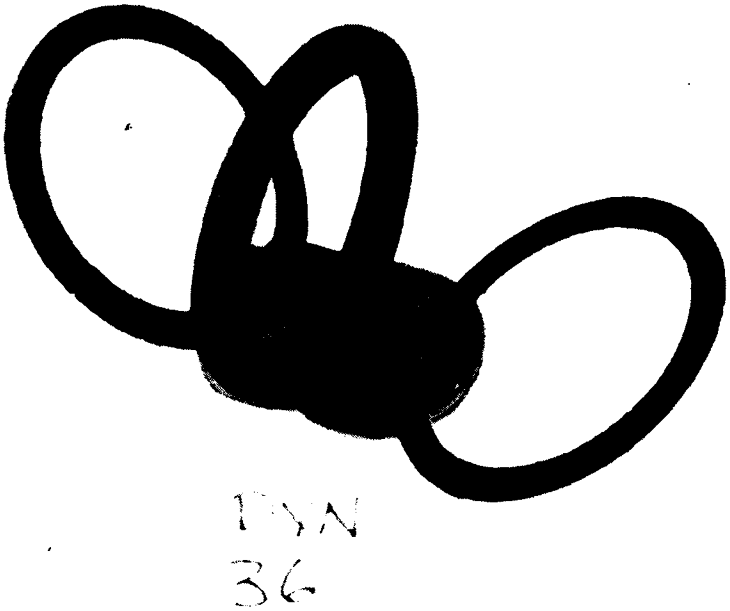
DYN
34

PARKER GNP SLIPPER K-LON 809 (ML1839-1),
XV2690-18D RING, XP2714-4 BACKUPS (ML1841)
COMPLETED 100,000 CYCLES



DYN
35

PARKER GNP SLIPPER K-LON 811 (ML1839-1)
XV2690-18D RING, XP2714-4 BLACKUPS (ML1841)
68,247 CYCLES



PARKER GNP SLIPPER K-LON 833 (ML1839-1)
XV2690-18D RING, XP2714-4 BACKUPS (ML1841)
COMPLETED 100,000 CYCLES

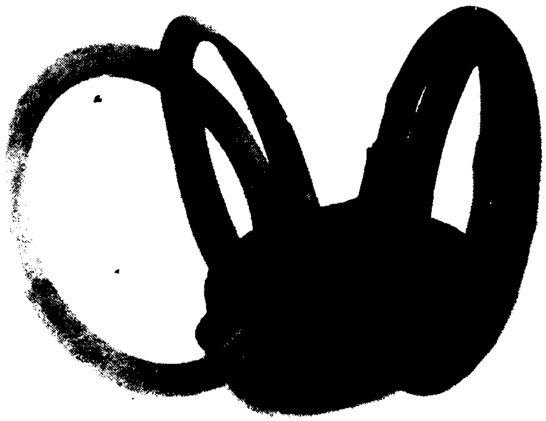
CONOVER SANWICH SEAL P/N CEC 4981C-214-D8
5918 CYCLES

DYN
[illegible]

AMERICAN VARISEAL P/N AS-1272
COMPLETED 100,493 CYCLES

DYN
39

PARKER XV2690-18, 2-214 O-RING
XP2714-1 BACKUPS (SANDWICH)
8655 CYCLES



TETRAFLUOR P/N TF481-7214(591)
470 CYCLES

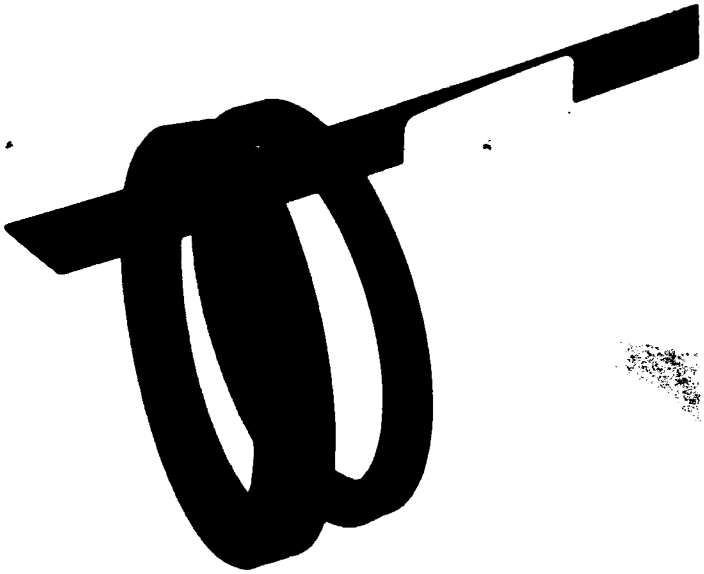
DYN
41

KOPPERS P/N GLT/K-305
31,944 CYCLES

CAMERON CAMLAST O-RING 109-80
100,753 CYCLES
BROKE AT DISASSEMBLY

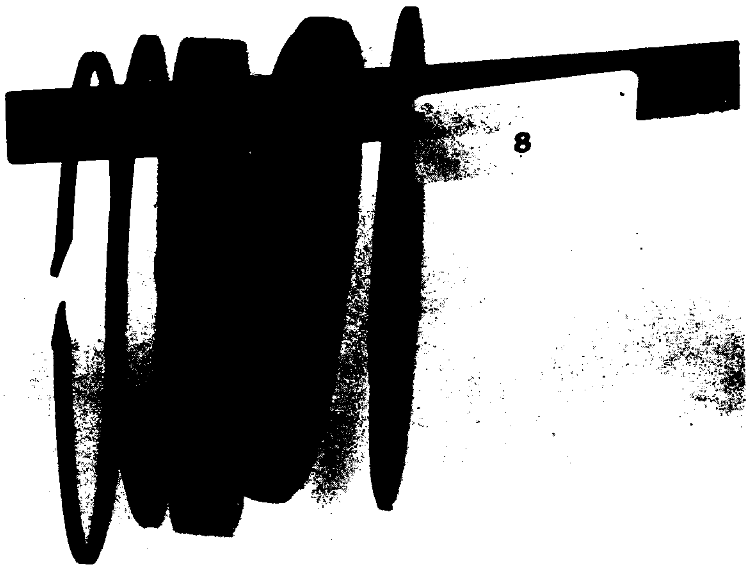
APPENDIX E

PHOTOS OF THE SCREENING TEST SEALS

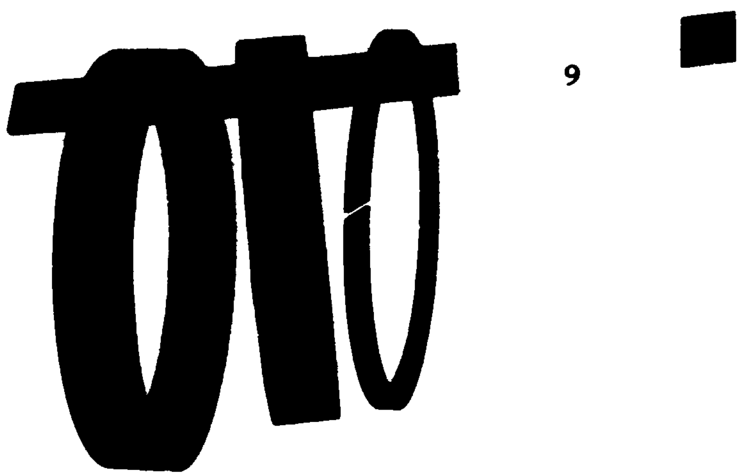


ACTUATOR #8
PRIMARY ROD SEAL
BAL SEAL X15033

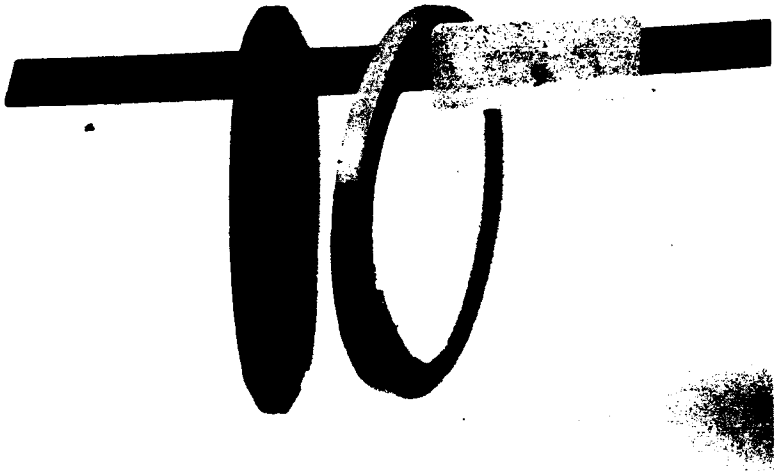
ACTUATOR #8
SECONDARY ROD SEAL
ADVANCED PRODUCTS 46194/46195



ACTUATOR #8
PISTON SEAL
HAMBAN S35979



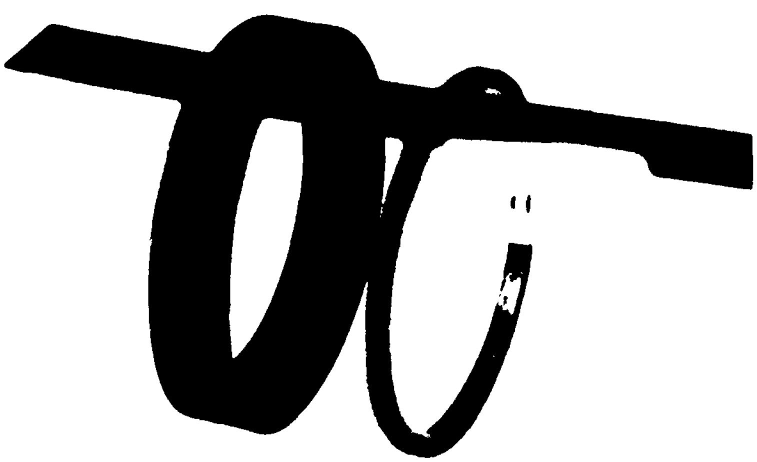
ACTUATOR #9
PRIMARY ROD SEAL
KOPPERS C5267B60



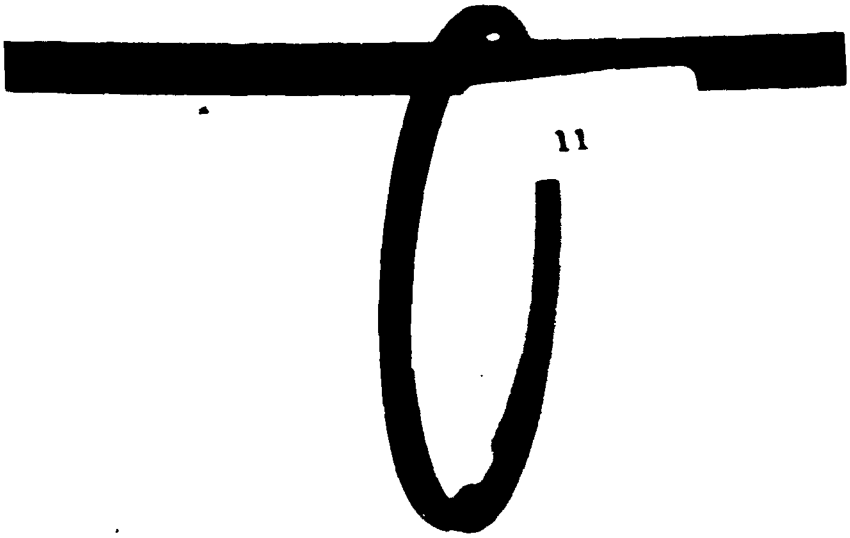
ACTUATOR #9
SECONDARY ROD SEAL
C.E. CONOVER CEC6001C-326-D8

ACTUATOR #9
PISTON SEAL
GREENE, TWEED 5979A32900P001
1,340,000 CYCLES

ACTUATOR #11
PRIMARY ROD SEAL
TETRAFLUOR TF888S121685-41
SD851216-61

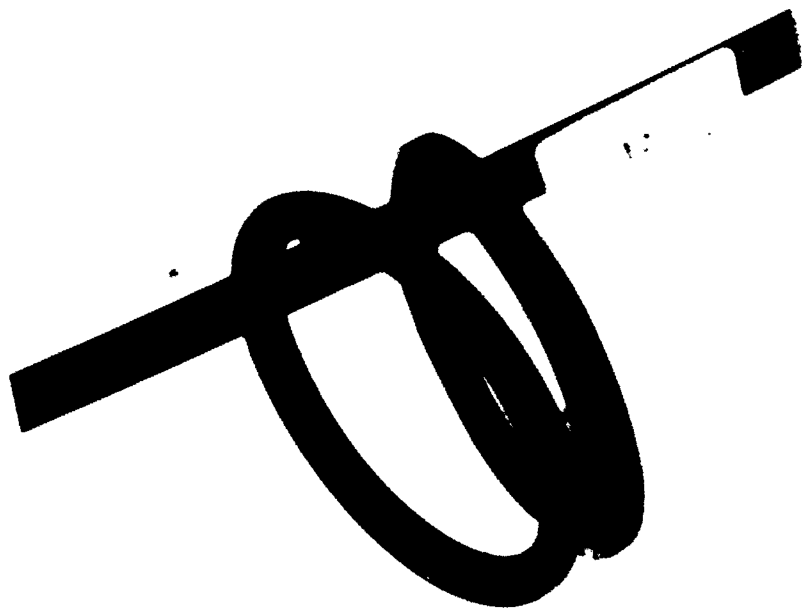


ACTUATOR #11
SECONDARY ROD SEAL
GREENE, TWEED 265-32600-777-1160

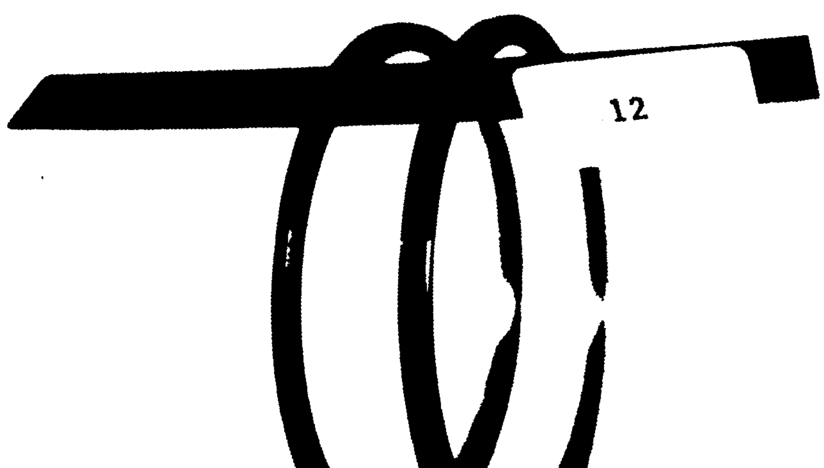


ACTUATOR #11
PISTON SEAL
DOVER ABP17573

ACTUATOR #12
PRIMARY ROD SEAL
FLUOROCARBON AR104974



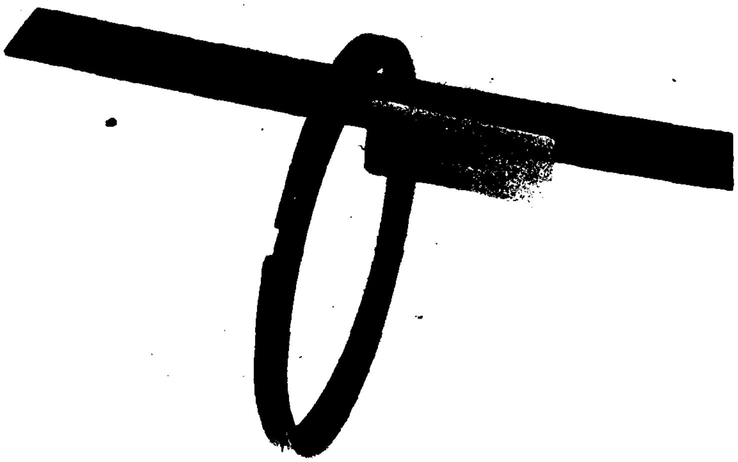
ACTUATOR #12
SECONDARY ROD SEAL
C.E. CONOVER CEC5056-326-D8



ACTUATOR #12
PISTON SEAL
DOVER ABP17573 (2 ea)

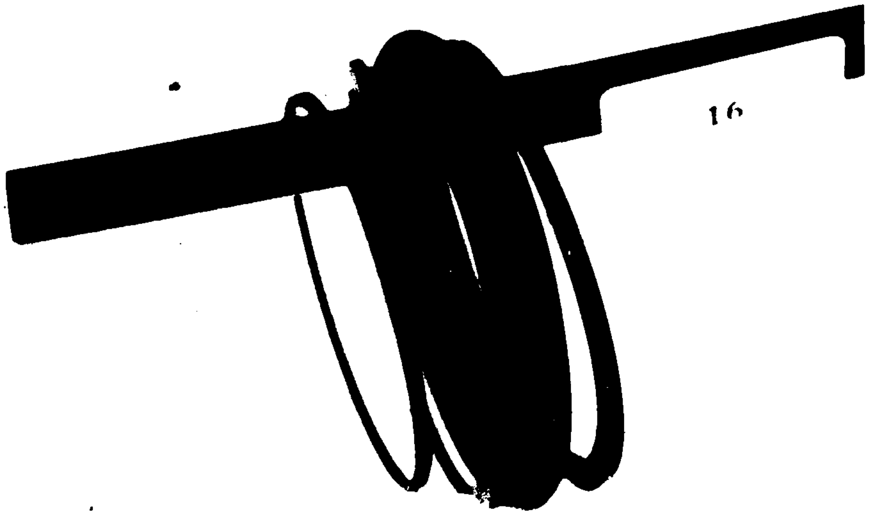
ACTUATOR #14
PRIMARY ROD SEAL
TETRAFLUOR TF1097M-7326(582)
TF456-7326(801)

ACTUATOR #14
SECONDARY ROD SEAL
SHAMBAN S35968

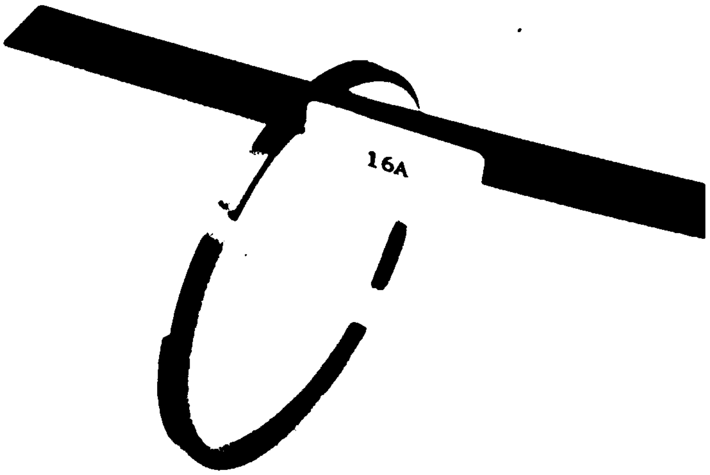


ACTUATOR #14
PISTON SEAL
PARKER CSD 330446ADP-5
168,000 CYCLES

ACTUATOR #16
PRIMARY ROD SEAL
ADVANCED PRODUCTS 46194/46195

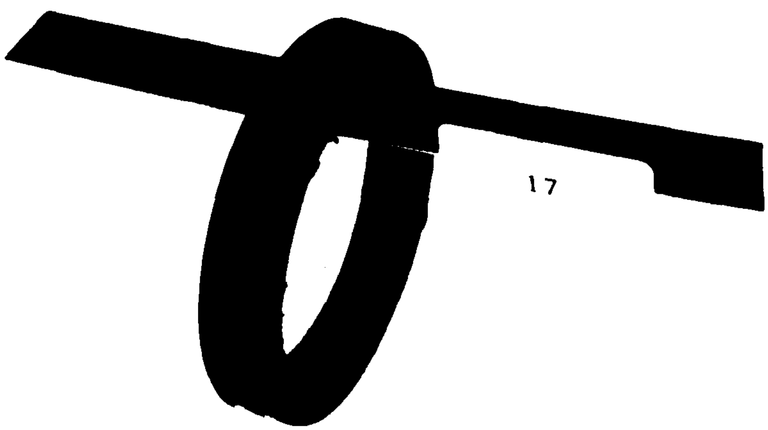


ACTUATOR #16
SECONDARY ROD SEAL
SHAMBAN S35971

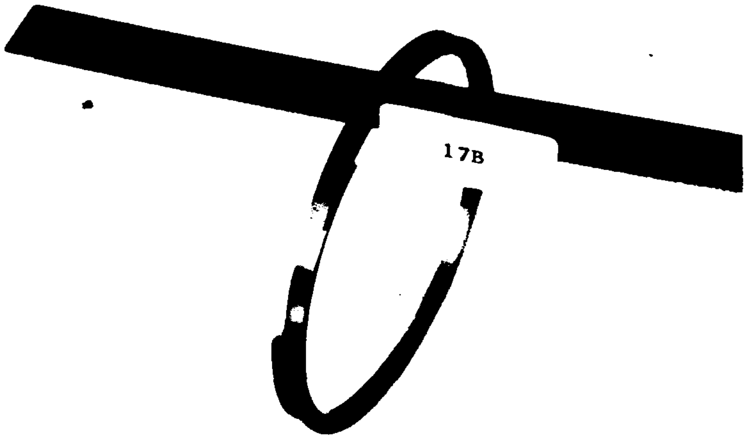


ACTUATOR #16
PISTON SEAL
KOPPERS C5816A60 PISTON SEAL
615,000 CYCLES

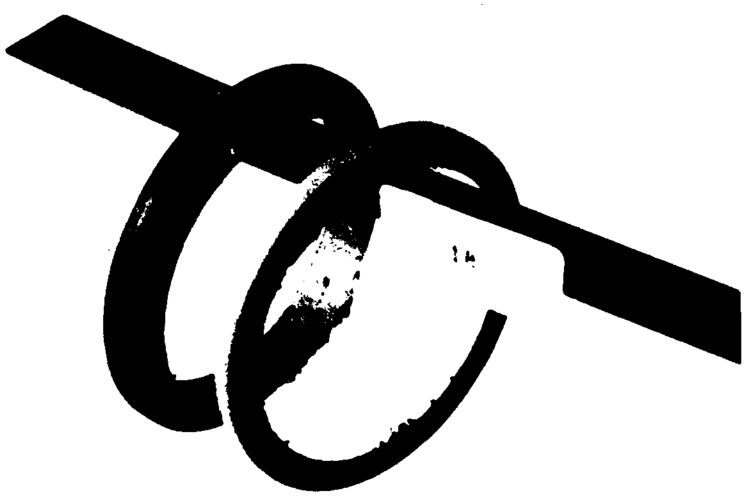
ACTUATOR #17
PRIMARY ROD SEAL
GREEN, TWEED 265-3260-818-1160



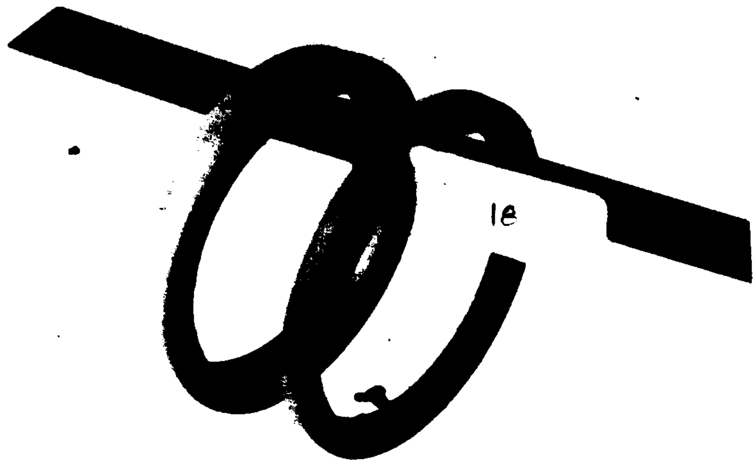
ACTUATOR #17
SECONDARY ROD SEAL
BAL SAL X6789



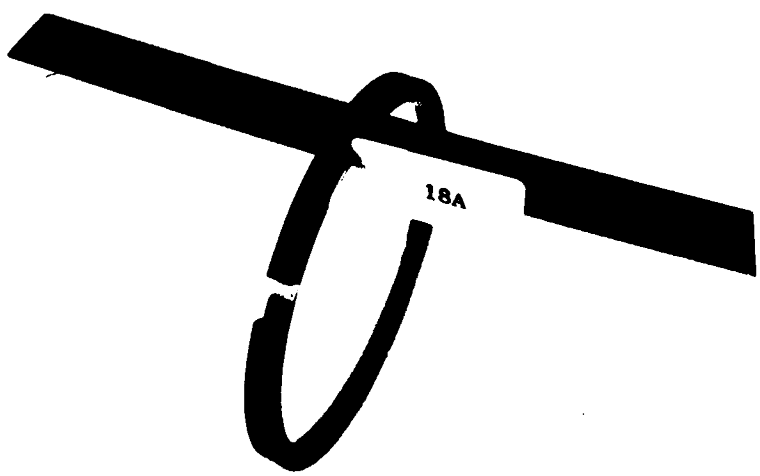
ACTUATOR #17
PISTON SEAL
KOPPERS C5816A60 PISTON SEAL
615,000 CYCLES



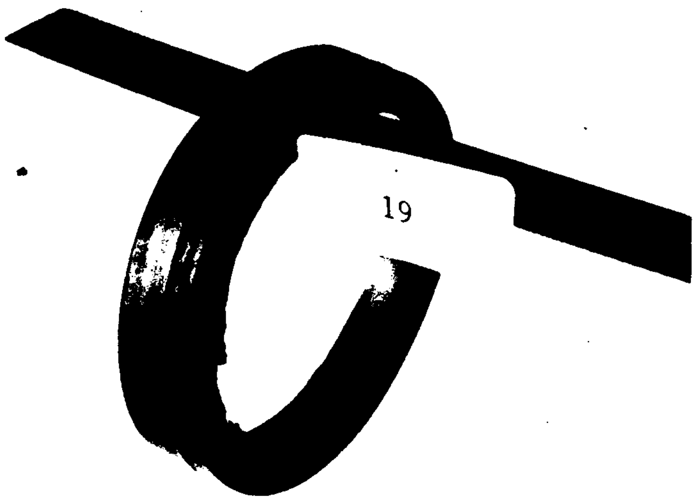
ACTUATOR #18
PRIMARY ROD SEAL
CONOVER CEC6001C-326-D8



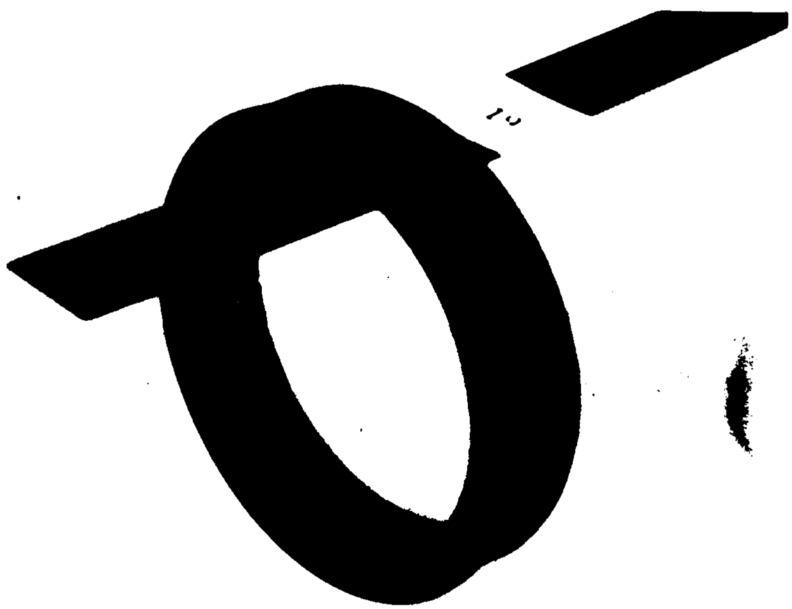
ACTUATOR #18
SECONDARY ROD SEAL
ADVANCED PRODUCTS
46194/46195



ACTUATOR #18
PISTON SEAL
PARKER CSD 330446ADP-3
615,000 CYCLES

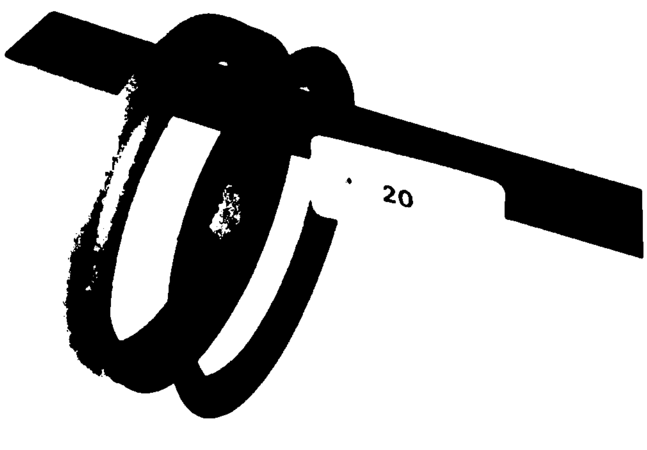


ACTUATOR #19
PRIMARY ROD SEAL
GREENE, TWEED 265-32600-818-1200

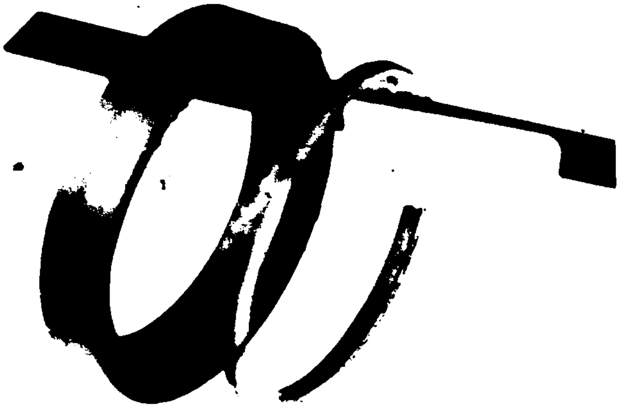


ACTUATOR #19
SECONDARY ROD SEAL
AMERICAN VARISEAL AS1316

ACTUATOR #19
PISTON SEAL
PARKER CSD 330446ADP-5
168,000 CYCLES

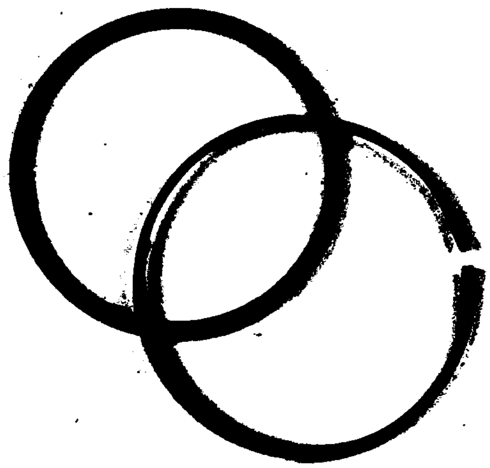


ACTUATOR #20
PRIMARY ROD SEAL
FLUOROCARBON AR104974

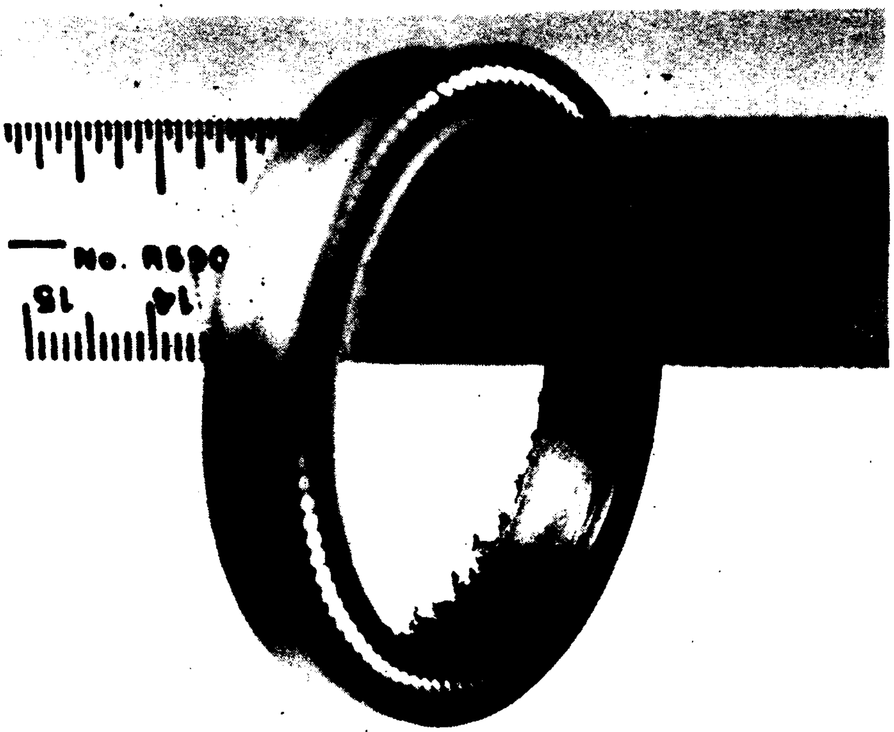


ACTUATOR #20
SECONDARY ROD SEAL
GREENE, TWEED 265-32600-777-1160

ACTUATOR #20
PISTON SEAL
GREENE, TWEED 59794A32900P001
1,340,000 CYCLES

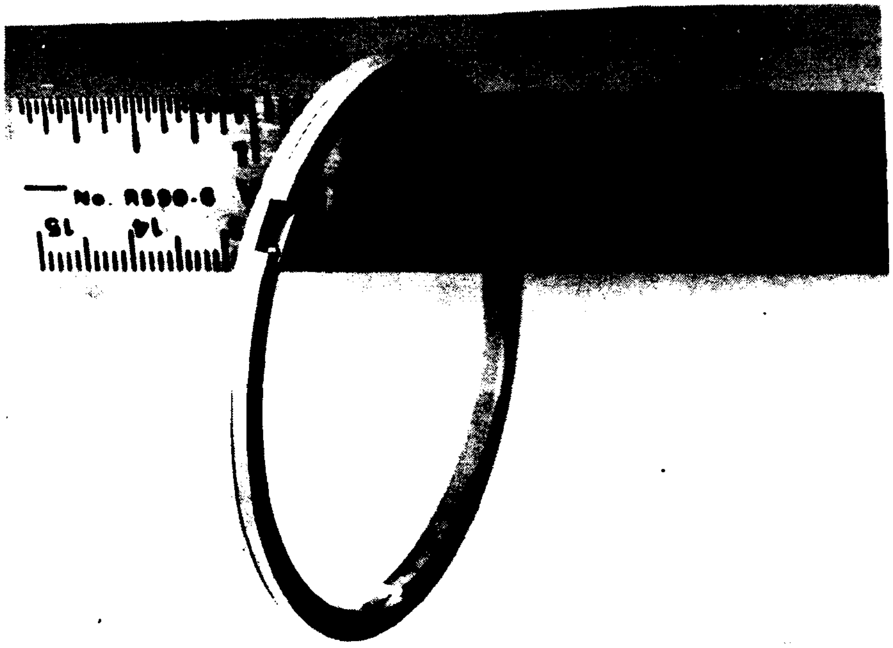


ACTUATOR #20
BACK UP RINGS FROM GREENE TWEED
59794A32900P001 PISTON SEAL

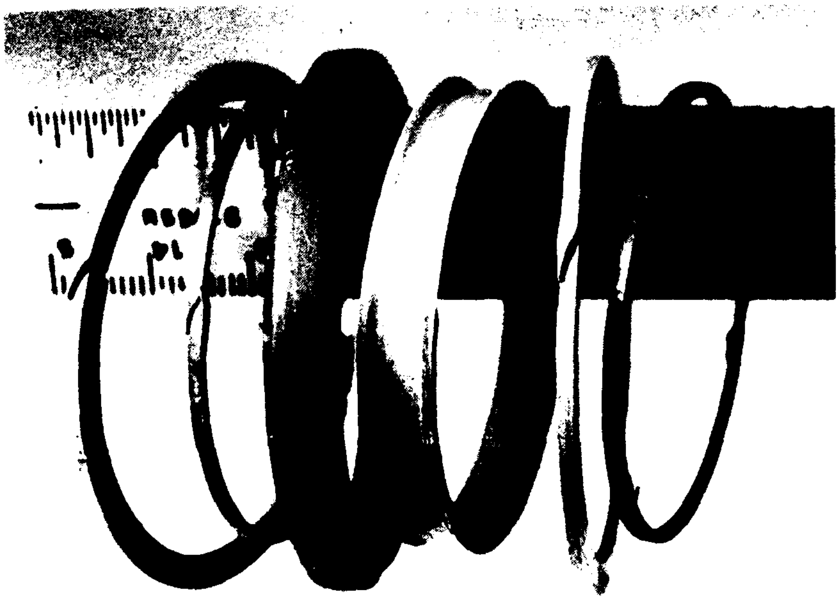


ACTUATOR #1
PRIMARY ROD SEAL
BAL SEAL X6789

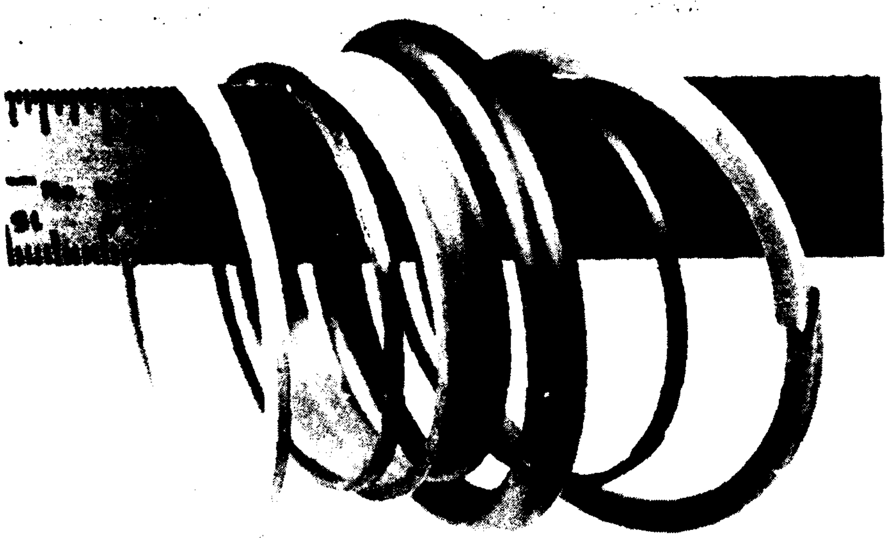
ACTUATOR #1
SECONDARY ROD SEAL
C.E. CONOVER CEC6001—326-D8



ACTUATOR #1
PISTON SEAL
PARKER CSD 301641ADP-1

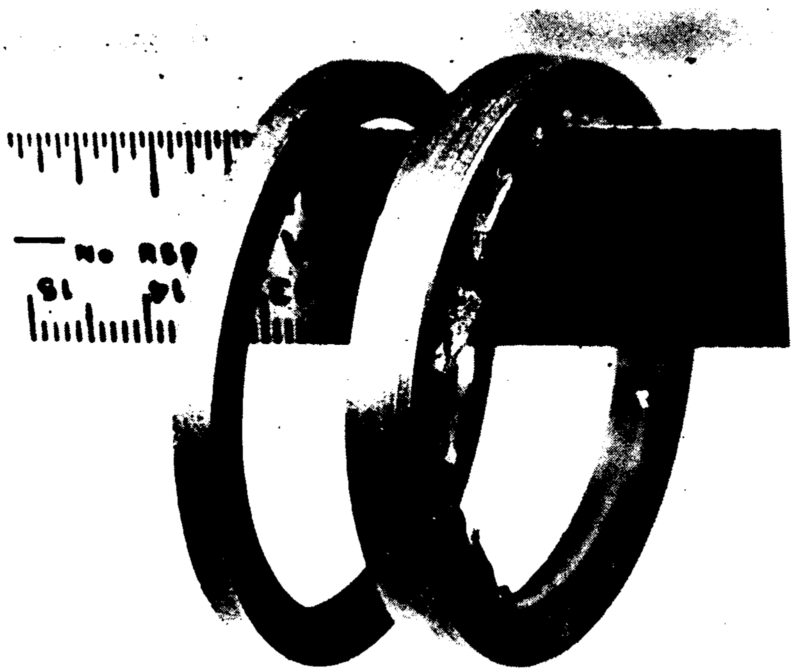


ACTUATOR #2
PRIMARY ROD SEAL
SHAMBAN S35968

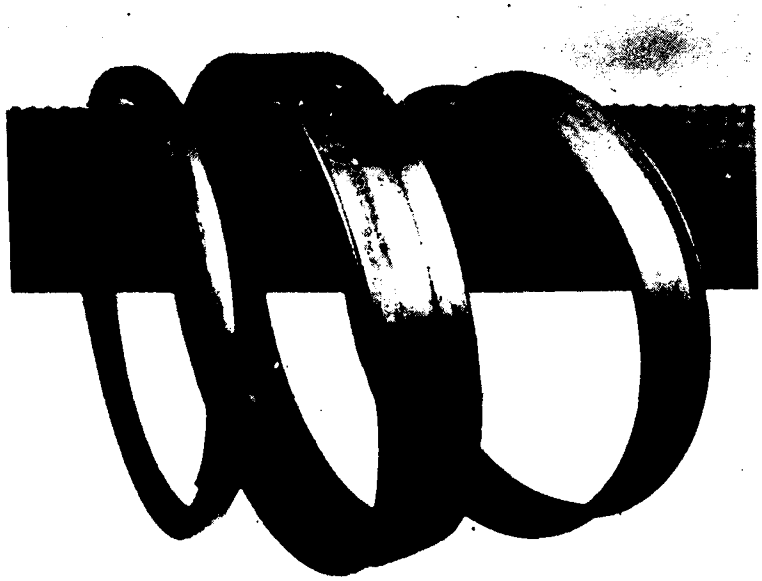


ACTUATOR #2
SECONDARY ROD SEAL
SHAMBAN S35971

ACTUATOR #2
PISTON SEAL
GREENE TWEED 266-32900-818-1160

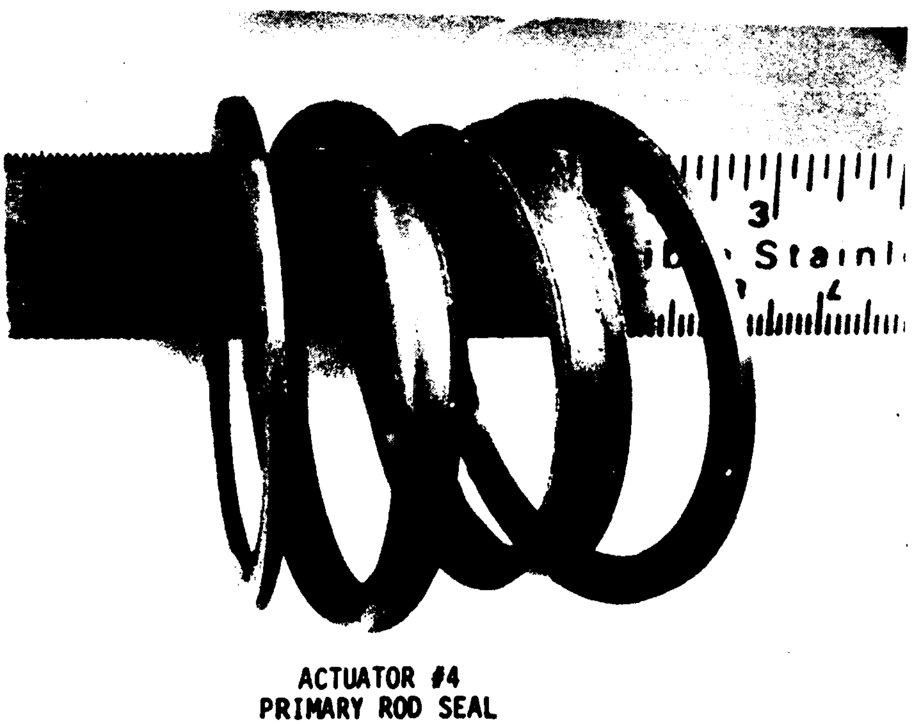


ACTUATOR #3
PRIMARY ROD SEAL
BAL SEAL X15033

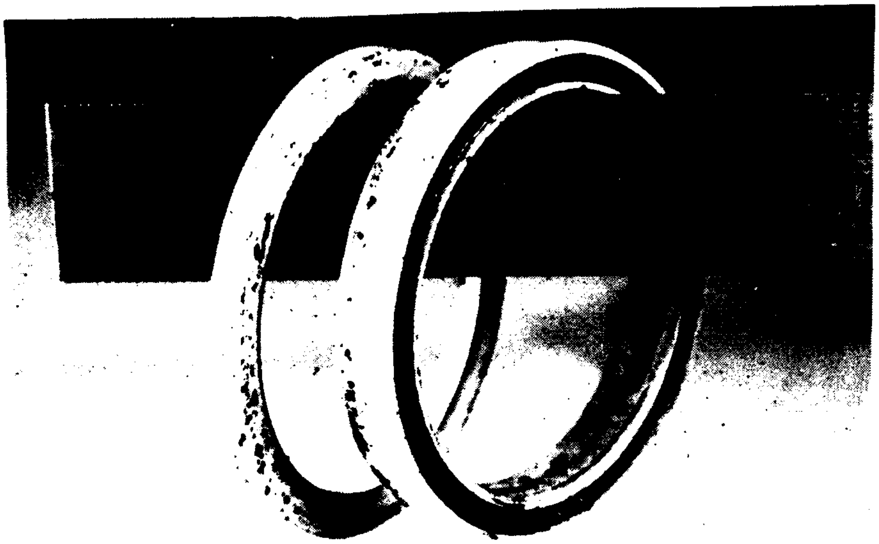


ACTUATOR #3
SECONDARY ROD SEAL
GREENE TWEED 265-32600-818-1200

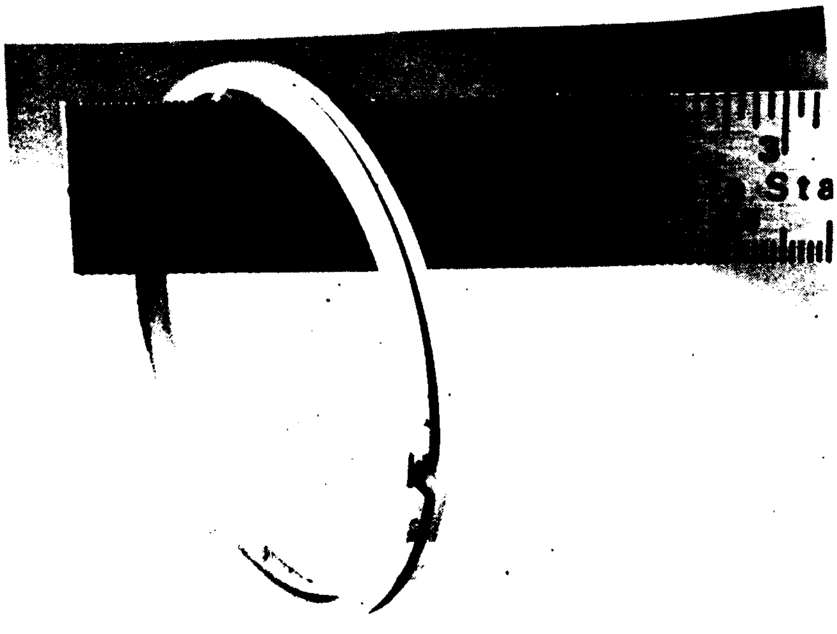
ACTUATOR #3
PISTON SEAL
TETRAFLUOR TF500A-329 (592)



ACTUATOR #4
PRIMARY ROD SEAL
PARKER GNP ML1851/V1098-85/XP2714-4

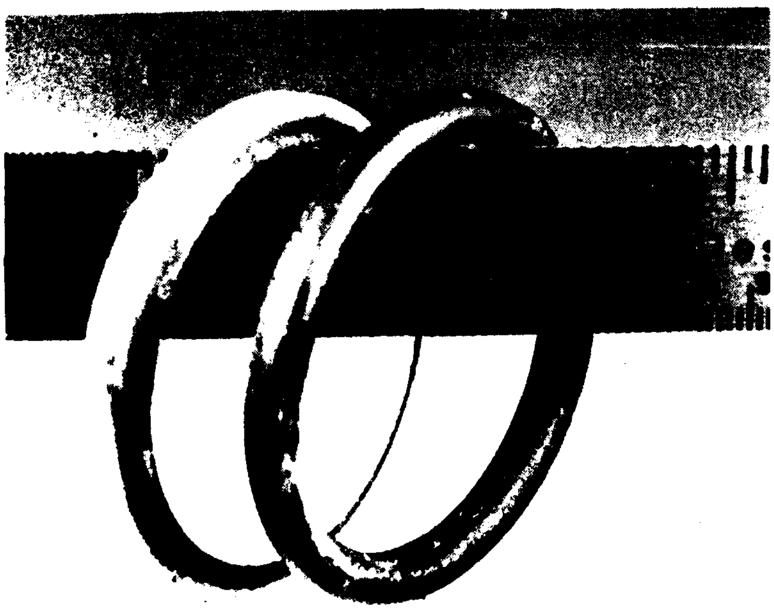


ACTUATOR #4
SECONDARY ROD SEAL
TETRAFLUOR SD851216-6
TF888S121685-4

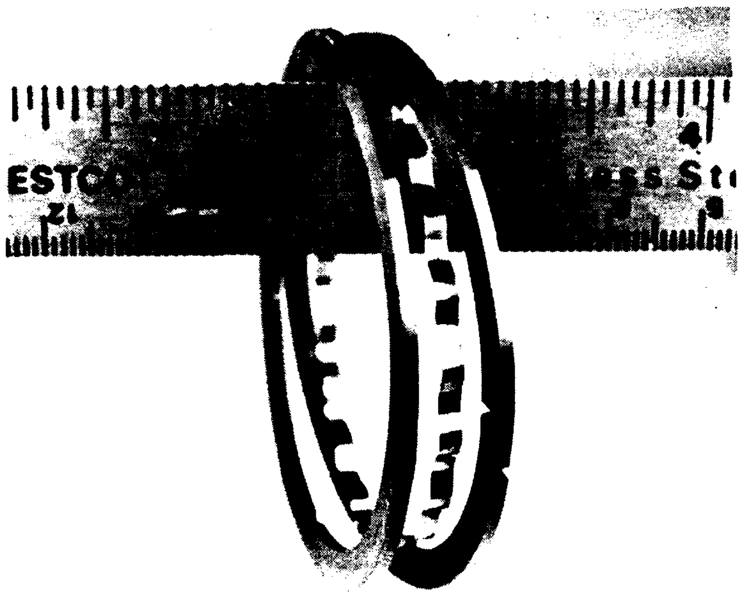


ACTUATOR #4
PISTON SEAL
PARKER CSD 301641ADP-1

ACTUATOR #5
PRIMARY ROD SEAL
SHAMBAN S35968

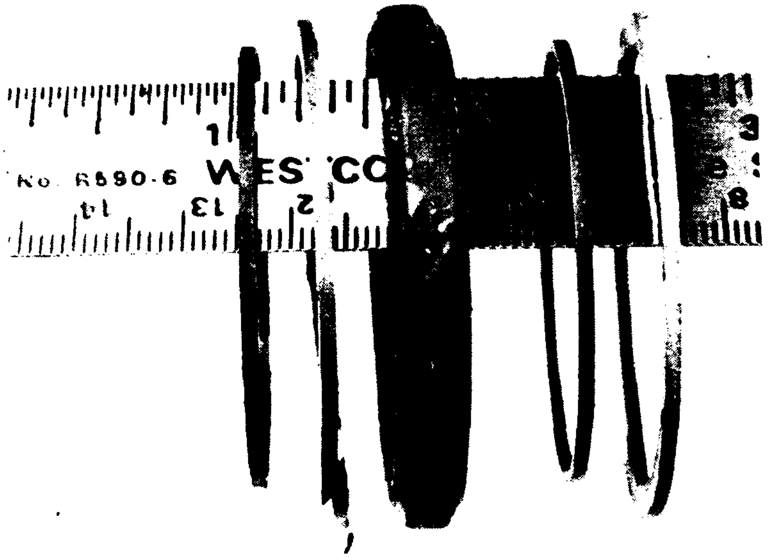


ACTUATOR #5
SECONDARY ROD SEAL
C.E. CONOVER CEC5056C-326-D8

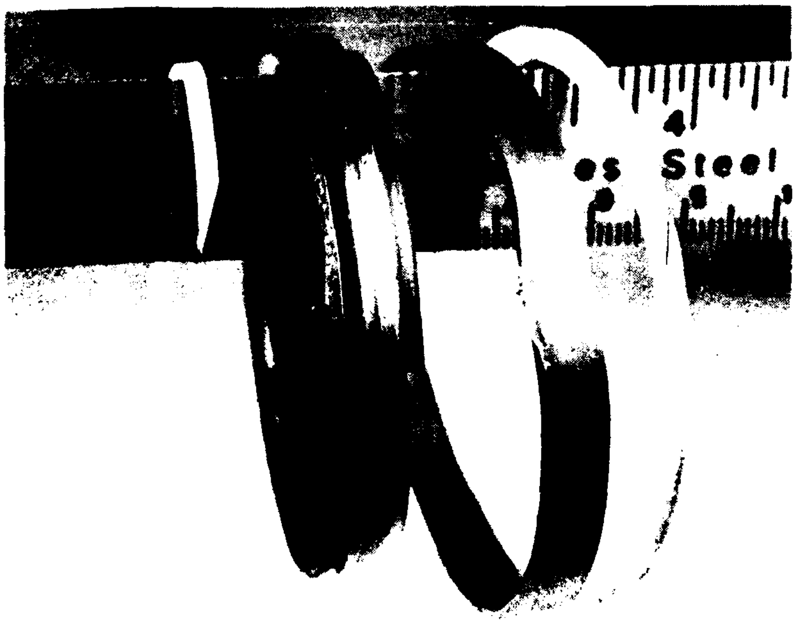


ACTUATOR #5
PISTON SEAL
SHAMBAN S35985

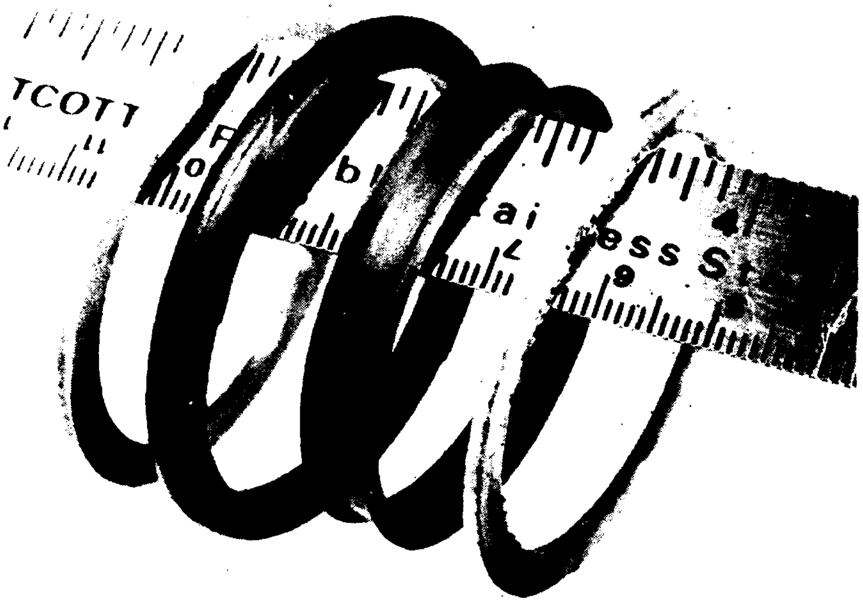
ACTUATOR #6
PRIMARY ROD SEAL
SHAMBAN S35971



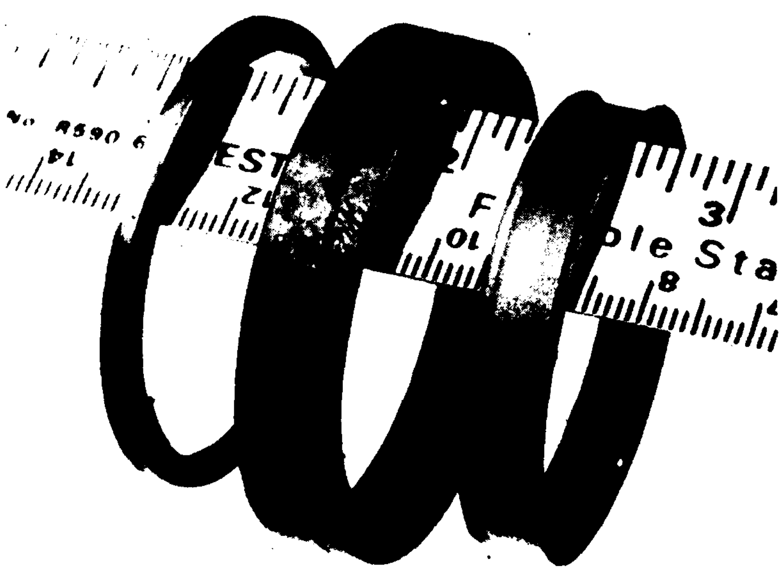
ACTUATOR #6
SECONDARY ROD SEAL
SHAMBAN S35968



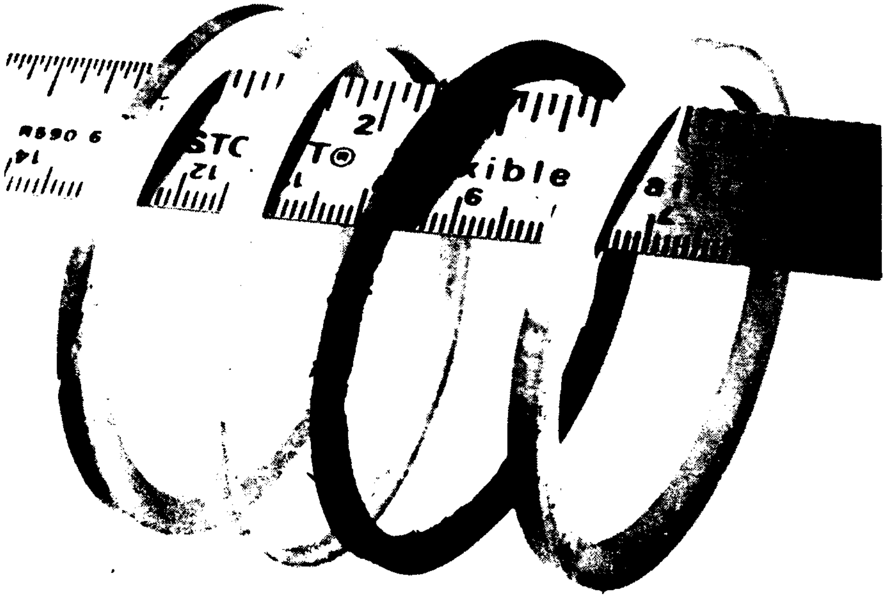
ACTUATOR #6
PISTON SEAL
GREENE TWEED 266-32900-818-1160



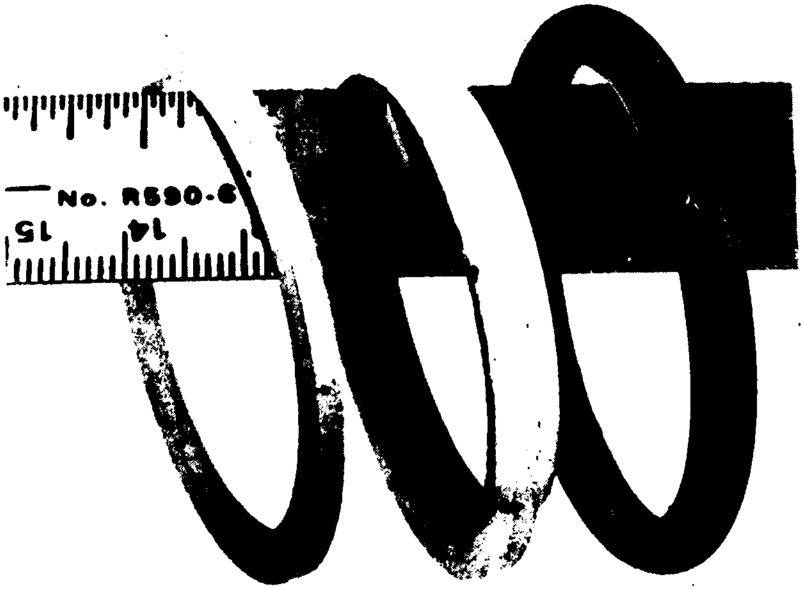
ACTUATOR #7
PRIMARY ROD SEAL
PARKER GNP ML1851/V835-75/XP2714-2



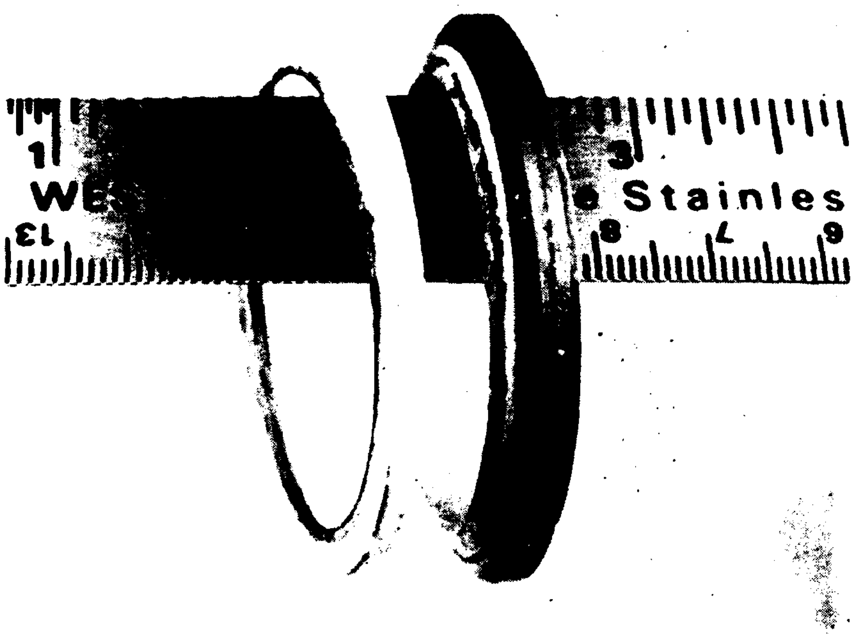
ACTUATOR #7
SECONDARY ROD SEAL
GREENE TWEED 265-32600-818-1160



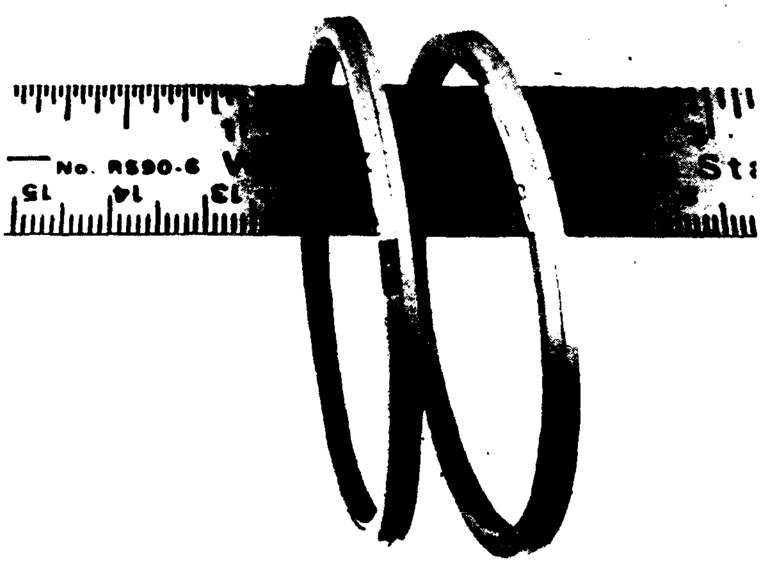
ACTUATOR #7
PISTON SEAL
TETRAFLUOR SD851212-2-2
SD851212-2-1
M83485/1-226 SQUARE RING



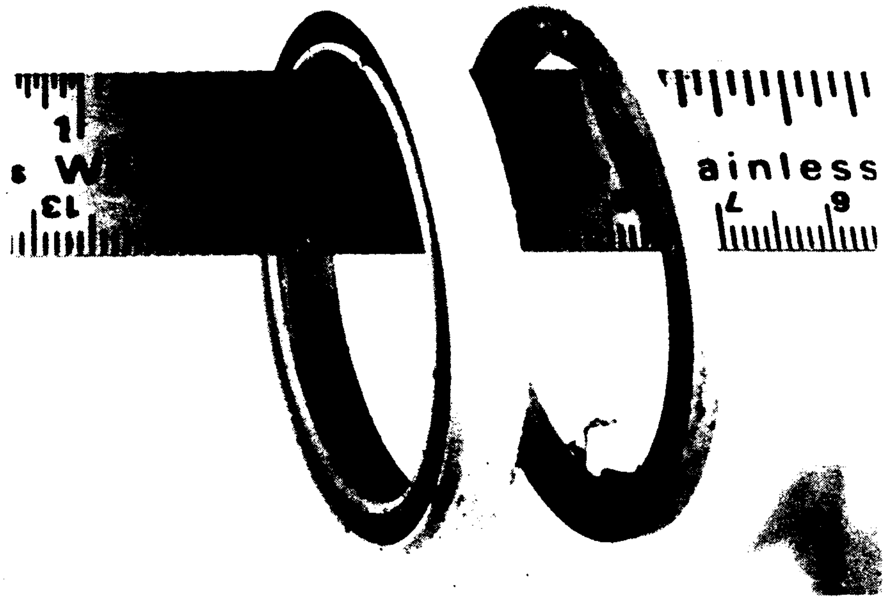
ACTUATOR #10
PRIMARY SEAL
TETRAFLUOR TF456-7326
TF1097M7326
M83485/1-326



ACTUATOR #10
SECONDARY ROD SEAL
C.E. CONOVER CEC6001C-326-D8

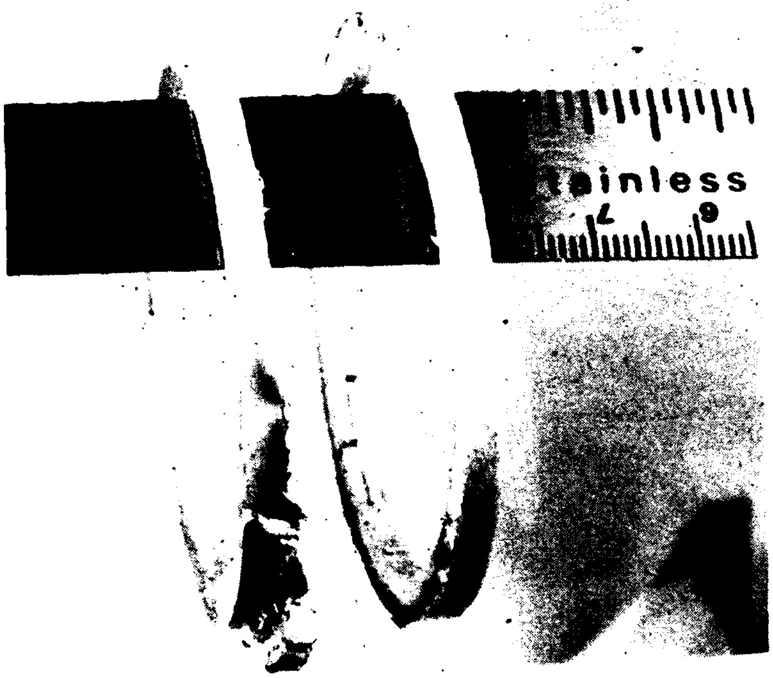


ACTUATOR #10
PISTON SEAL
PARKER BERTEA 301641ADP-1 (2)

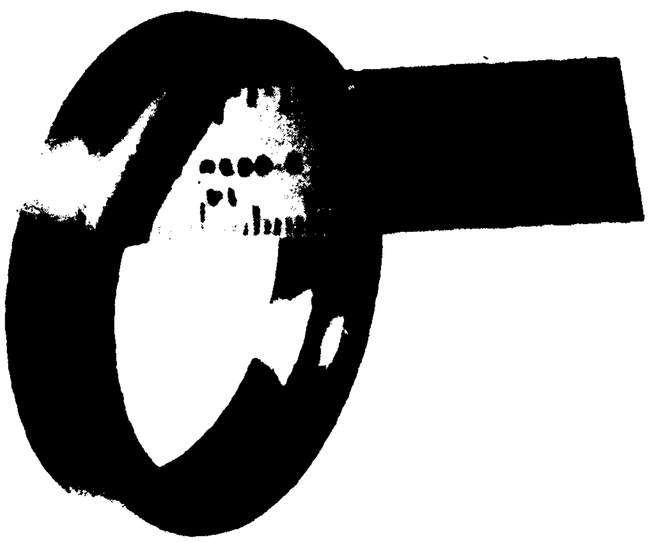


ACTUATOR #13 -
PRIMARY ROD SEAL
TETRAFLUOR TF851216-6
TF888S121685-4

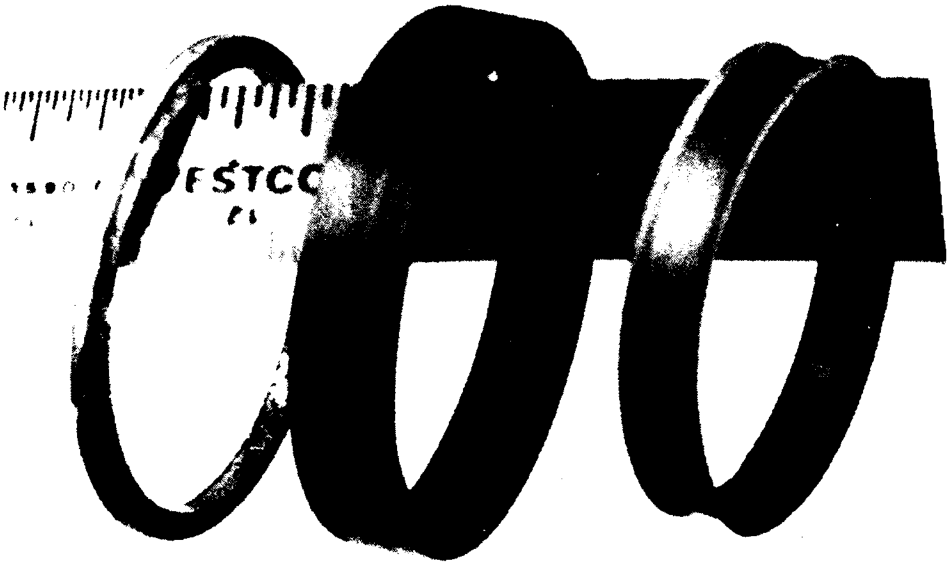
ACTUATOR #13
SECONDARY ROD SEAL
TETRAFLUOR TF456-7326
TF1097M-7326



ACTUATOR #13
PISTON SEAL
TETRAFLUOR TF500A-329 (2)



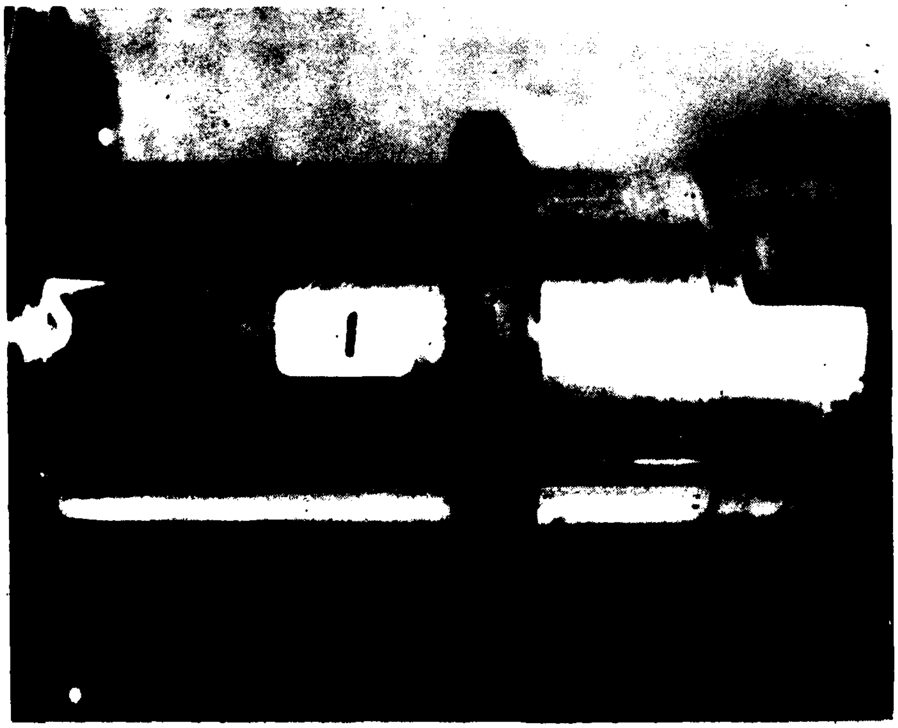
ACTUATOR #15
PRIMARY ROD SEAL
AMERICAN VARISEAL AS-1316



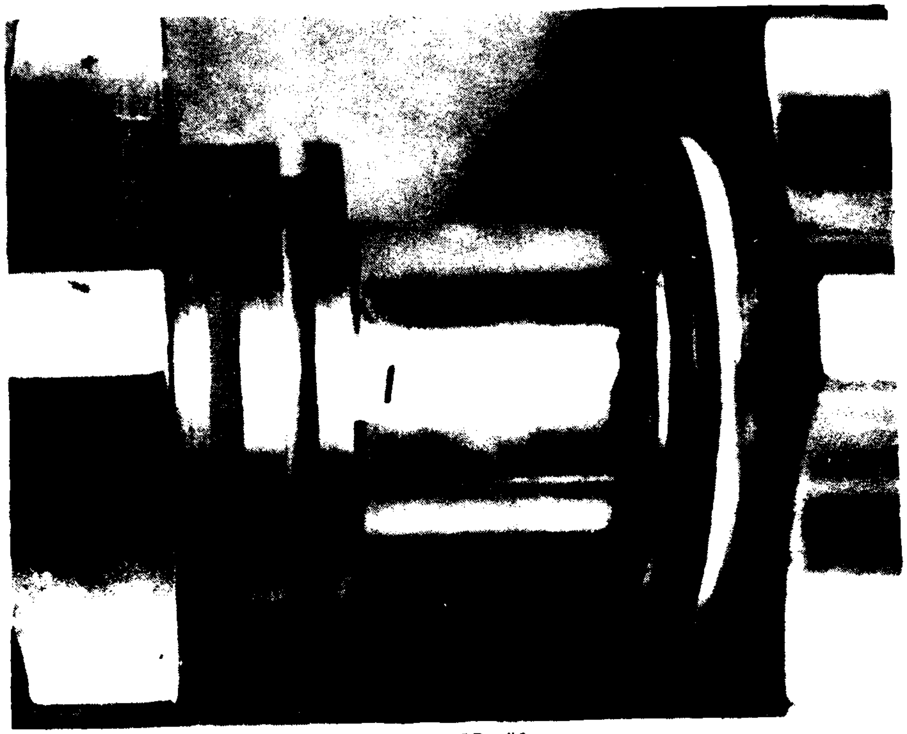
ACTUATOR #15
SECONDARY ROD SEAL
GREENE TWEED 265-32600-818-1160

ACTUATOR #15
PISTON SEAL
PARKER CSD 301641ADP-1

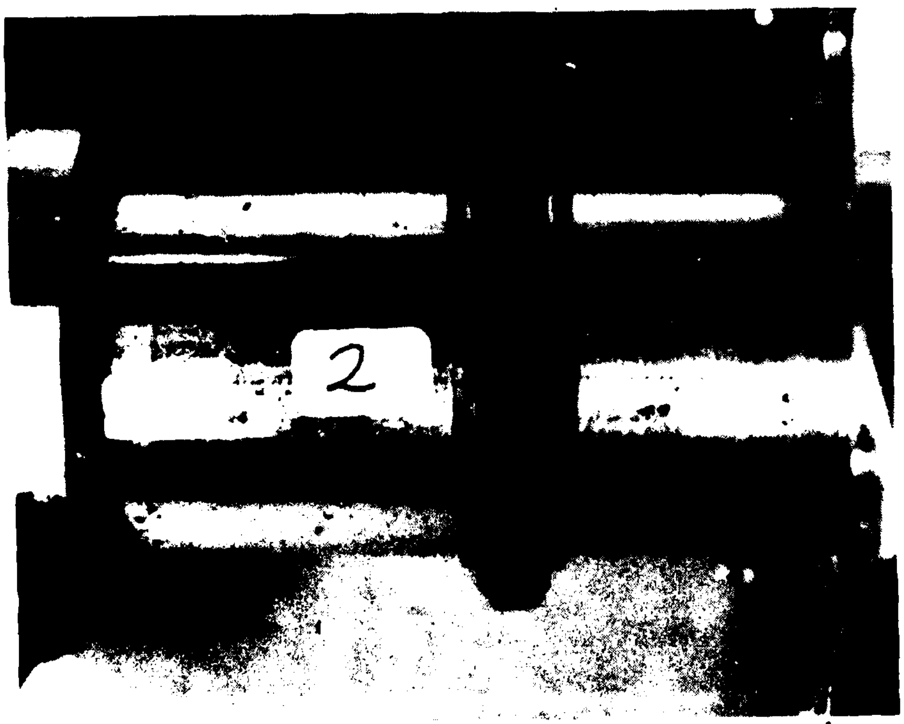
ACTUATOR #1
PRIMARY ROD SEAL
BAL SEAL X6789



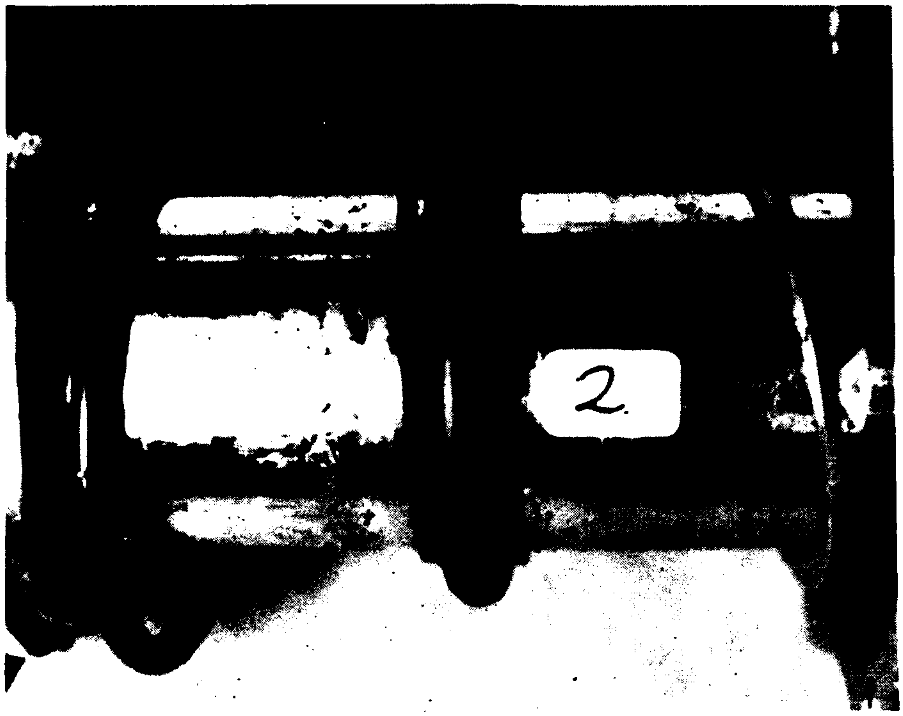
ACTUATOR #1
SECONDARY ROD SEAL
C.E. CONOVER CEC6001C-326-D8



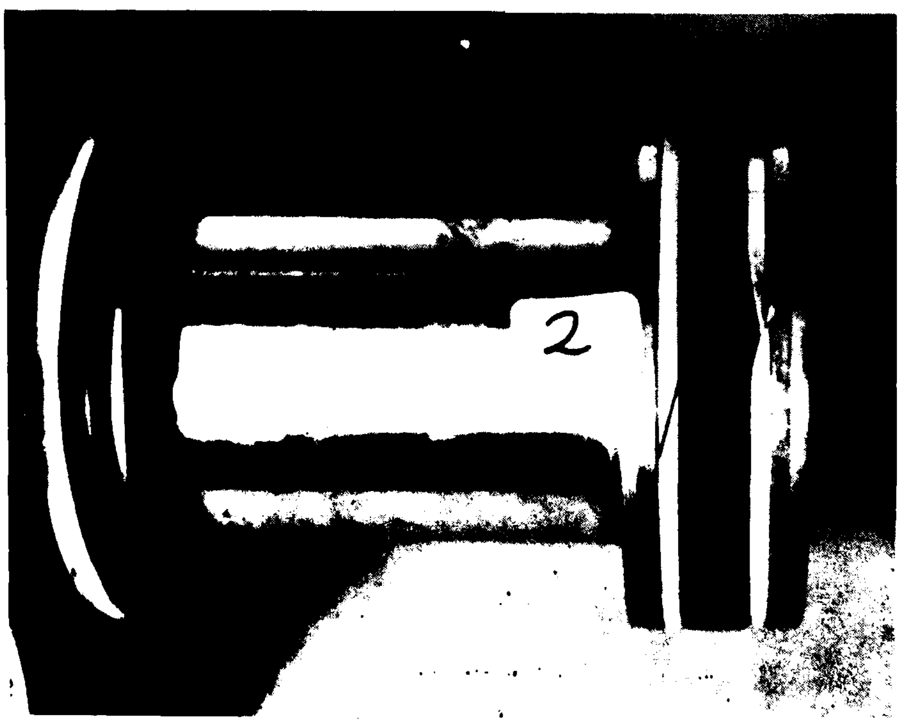
ACTUATOR #1
PISTON SEAL
PARKER CSD 301641ADP-1



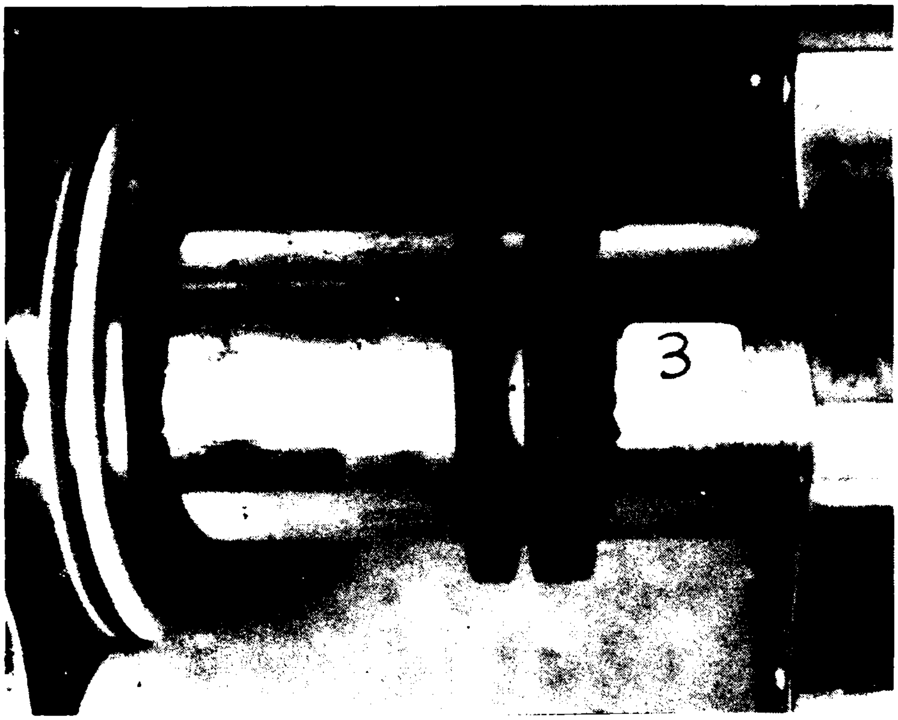
ACTUATOR #2
PRIMARY ROD SEAL
SHAMBAN S35968



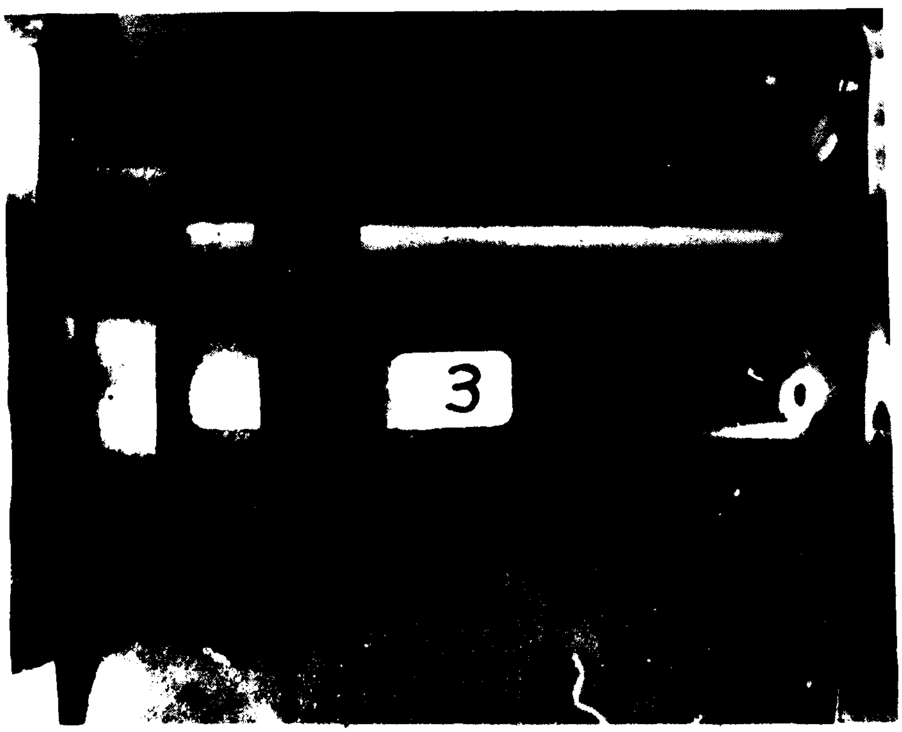
ACTUATOR #2
SECONDARY ROD SEAL
SHAMBAN S35971



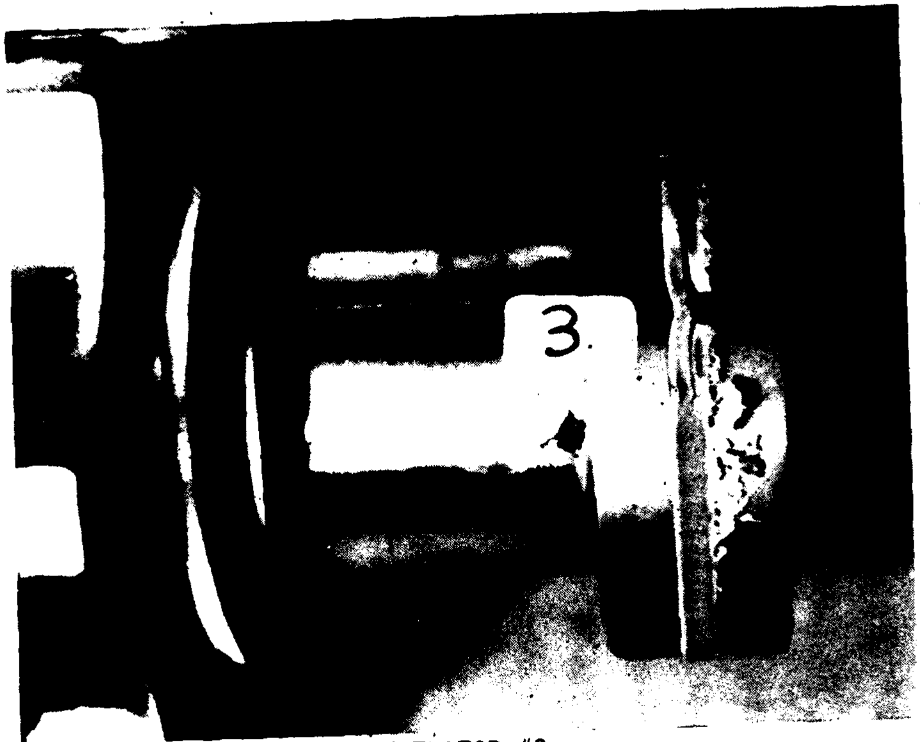
ACTUATOR #2
PISTON SEAL
GREENE TWEED 266-32900-818-1160



ACTUATOR #3
PRIMARY ROD SEAL
BAL SEAL X15033

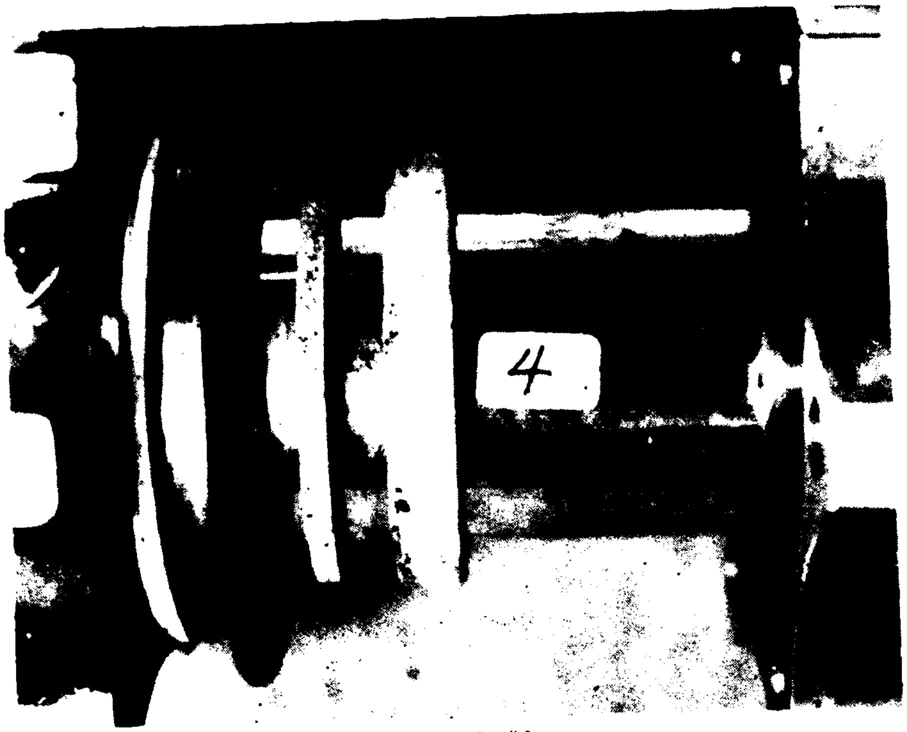


ACTUATOR #3
SECONDARY ROD SEAL
GREENE TWEED 265-32600-818-1200

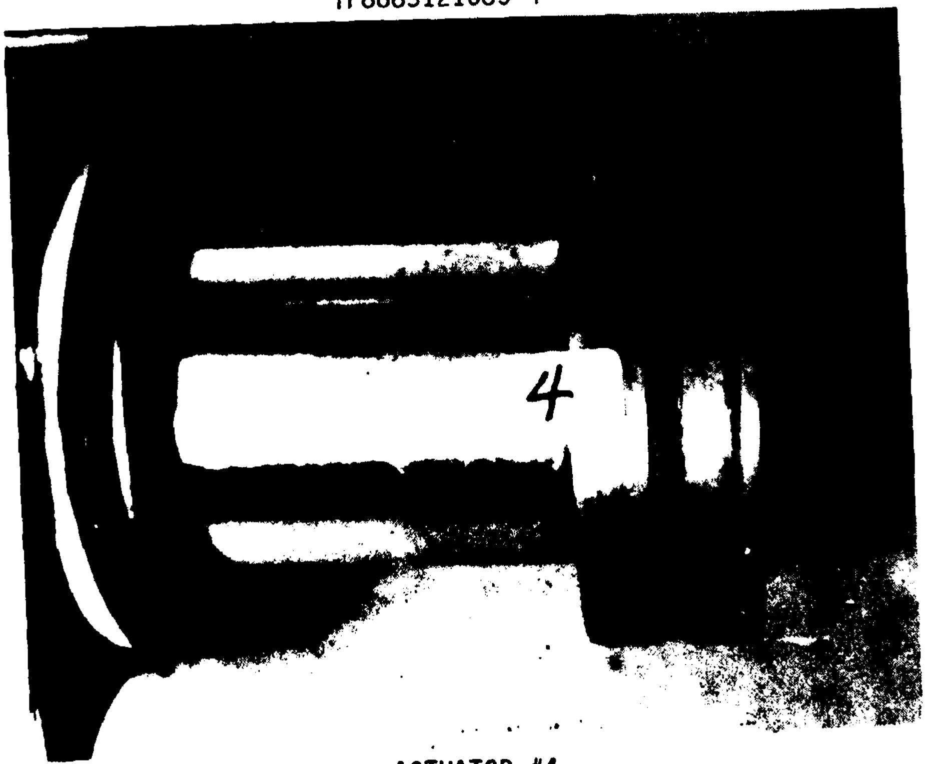


ACTUATOR #3
PISTON SEAL
TETRAFLUOR TF500A-329 (592)

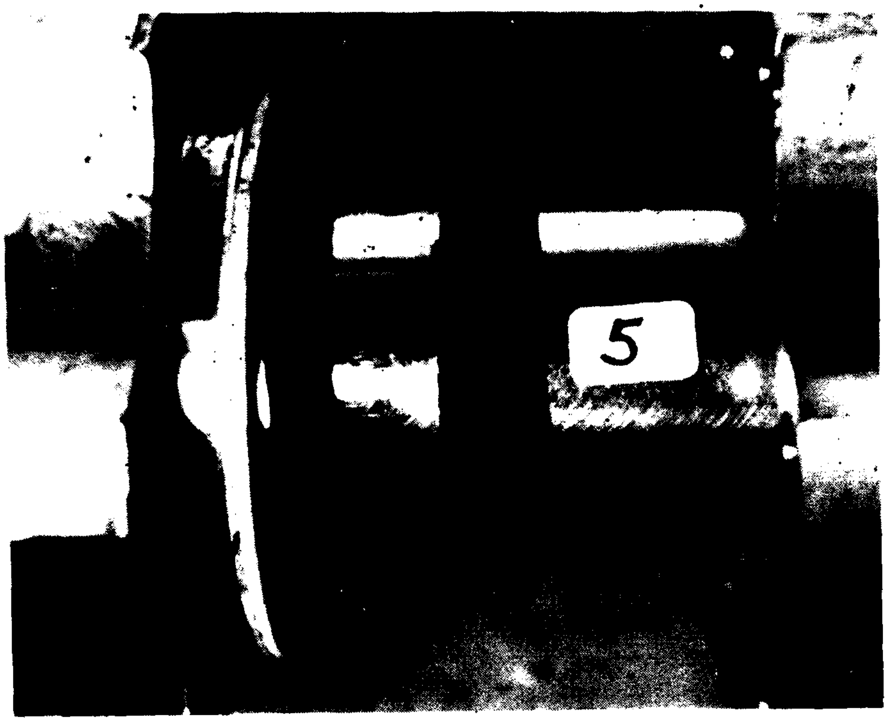
ACTUATOR #4
PRIMARY ROD SEAL
PARKER GNP ML1851/V1098-85/XP27414-4



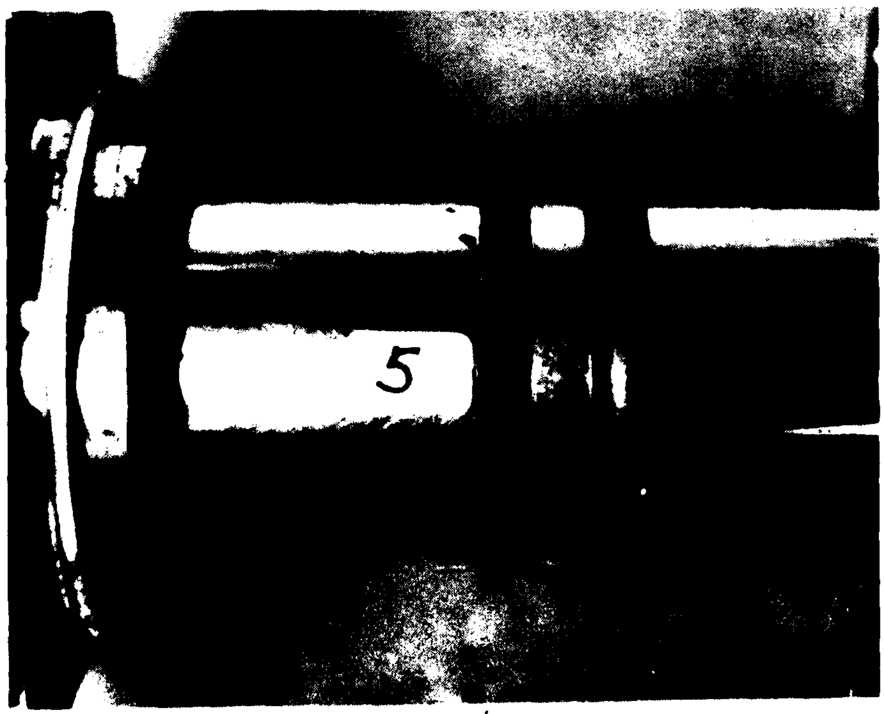
ACTUATOR #4
SECONDARY ROD SEAL
TETRAFLUOR SD851216-6
TF888S121685-4



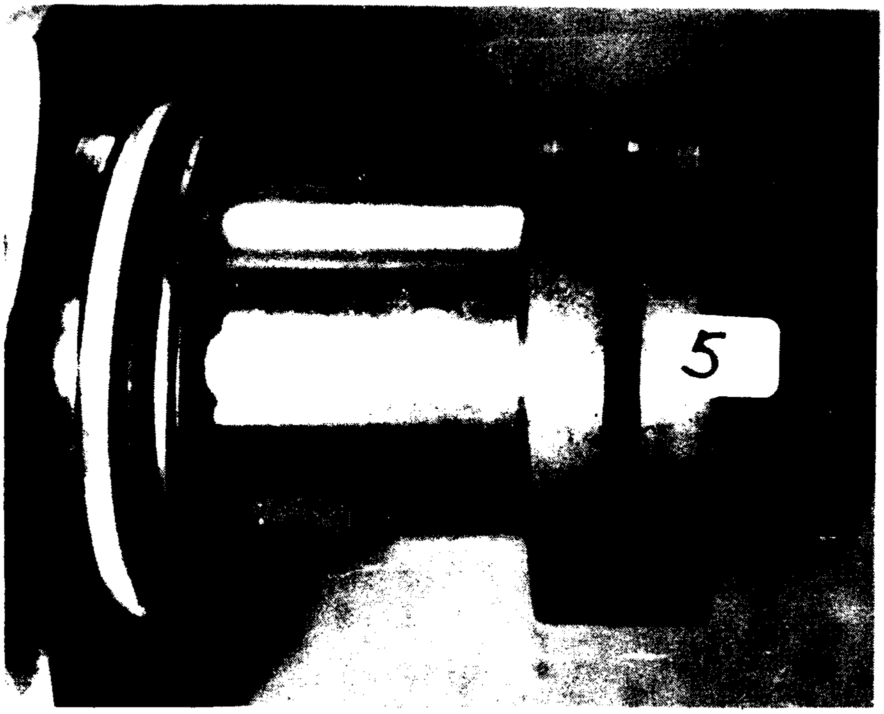
ACTUATOR #4
PISTON SEAL
PARKER CSD 301641ADP-1



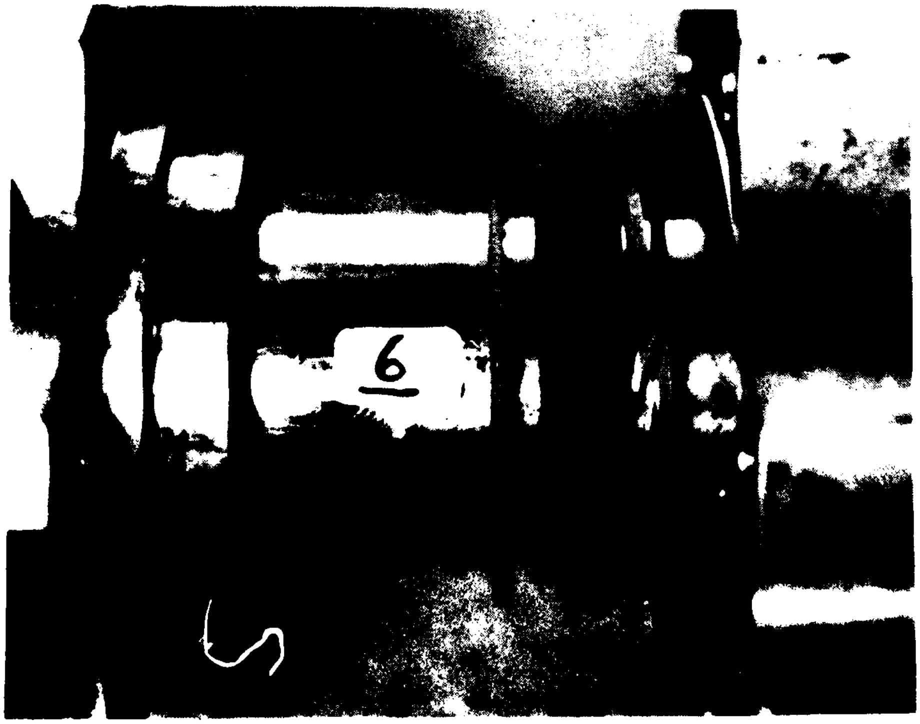
ACTUATOR #5
PRIMARY ROD SEAL
SHAMBAN S35968



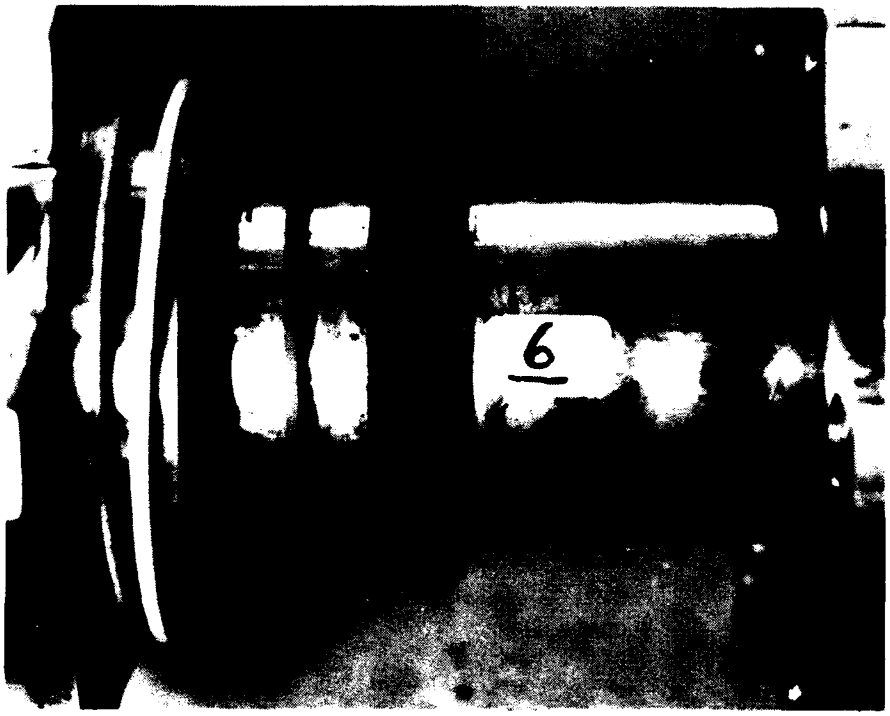
ACTUATOR #5
SECONDARY ROD SEAL
C.E. CONOVER CEC5056C-326-D8



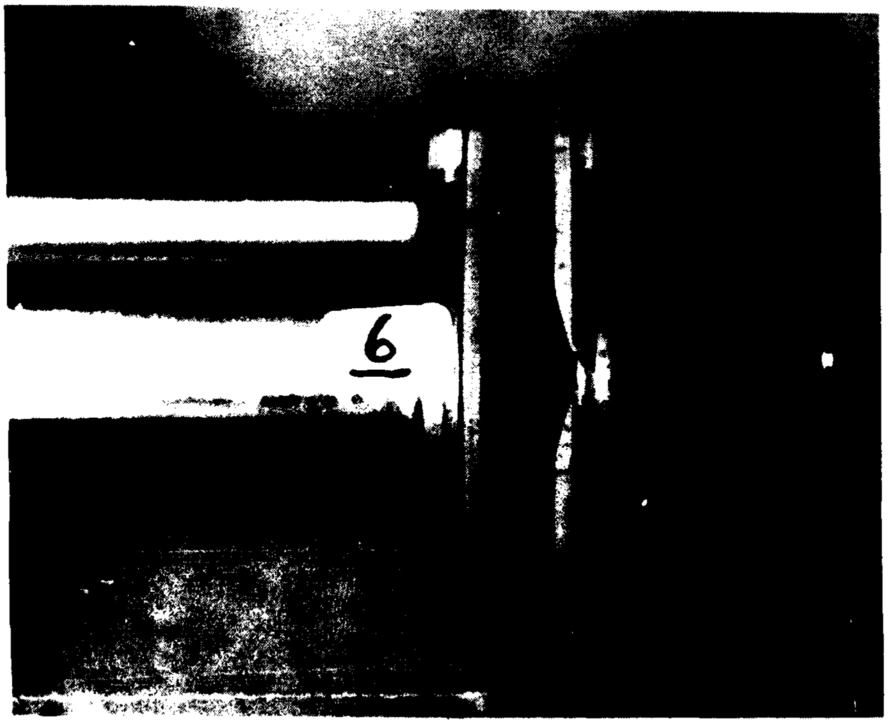
ACTUATOR #5
PISTON SEAL
SHAMBAN S35985



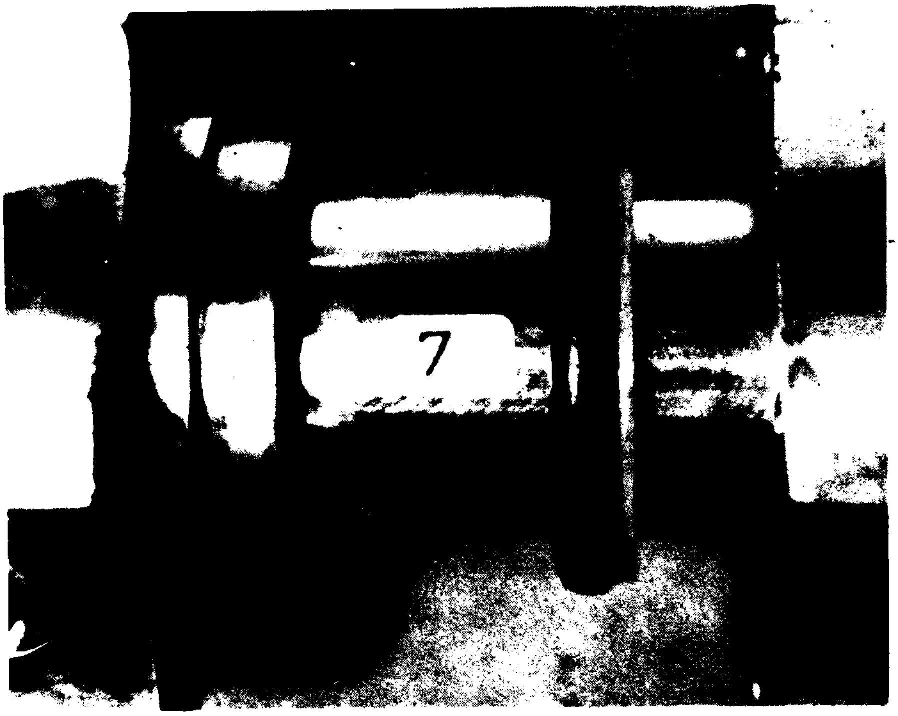
ACTUATOR #6
PRIMARY ROD SEAL
SHAMBAN S35971



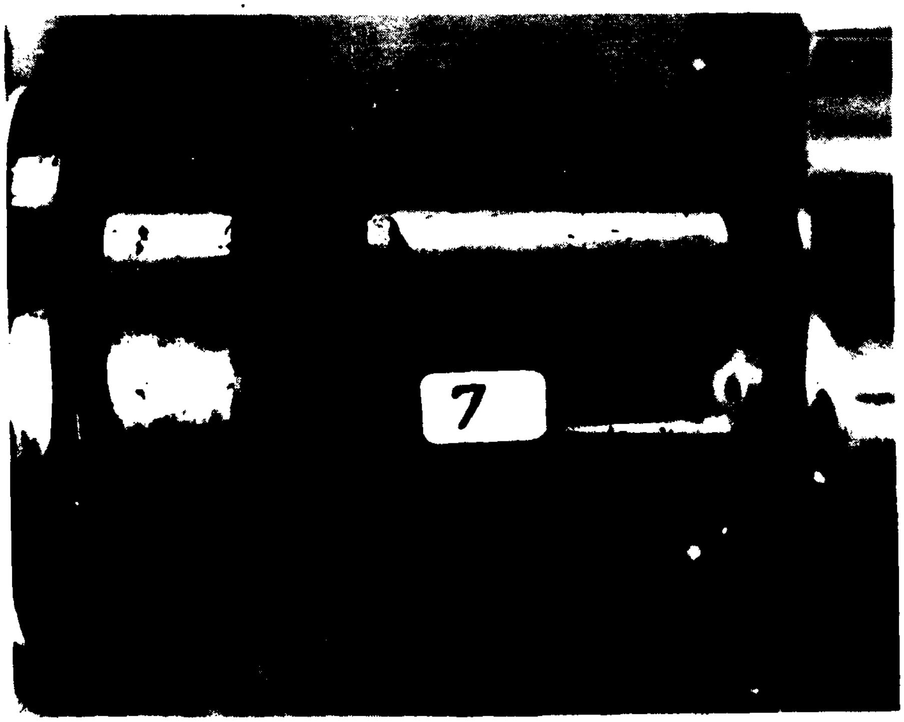
ACTUATOR #6
SECONDARY ROD SEAL
SHAMBAN S35968



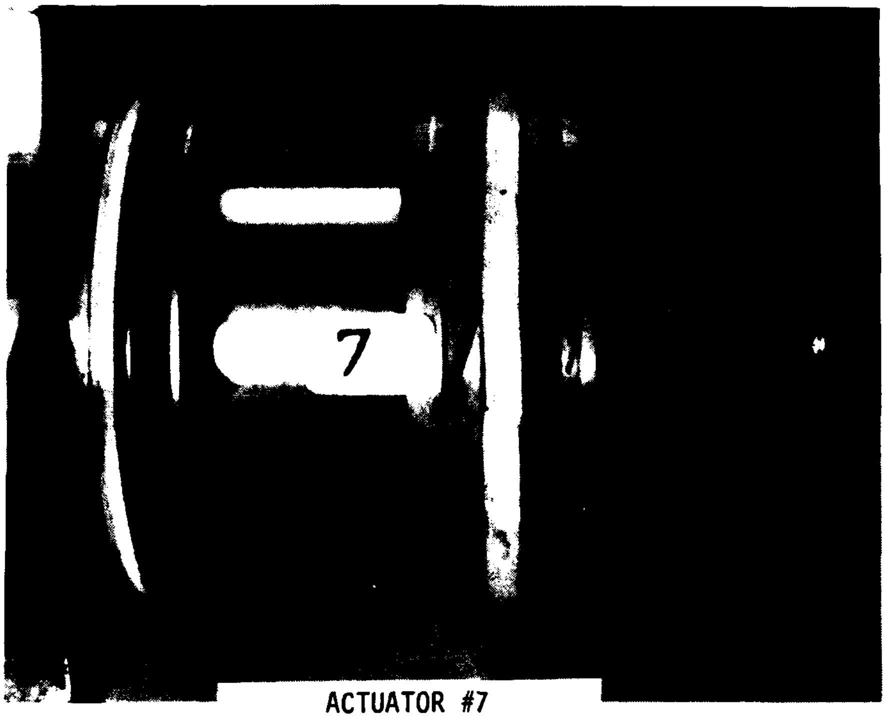
ACTUATOR #6
PISTON SEAL
GREENE TWEED 266-32900-818-1160



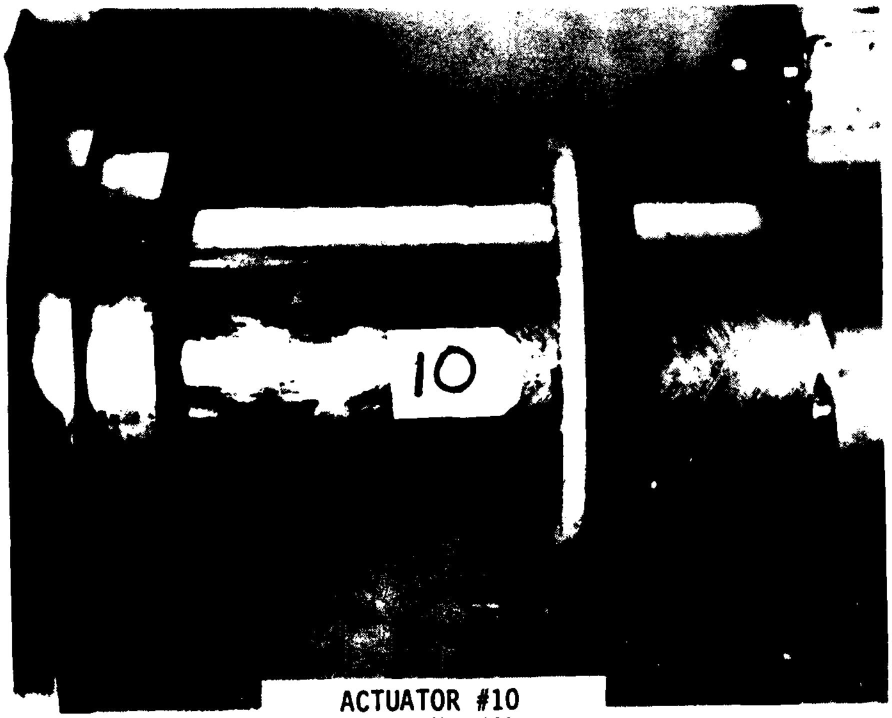
ACTUATOR #7
PRIMARY ROD SEAL
PARKER GNP ML1851/V835-75/XP2714-2



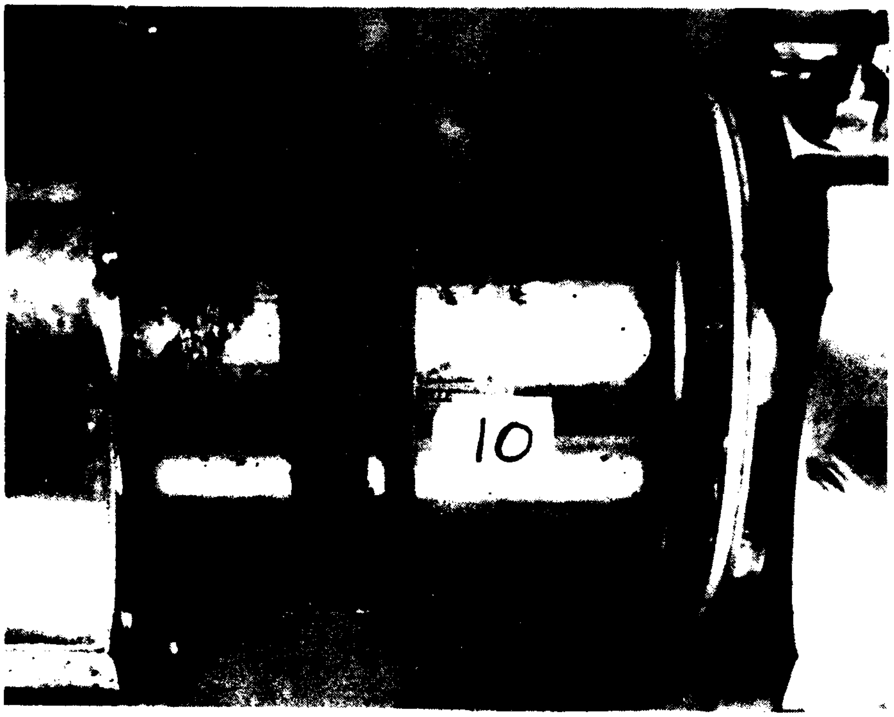
ACTUATOR #7
SECONDARY ROD SEAL
GREENE TWEED 265-32600-818-1160



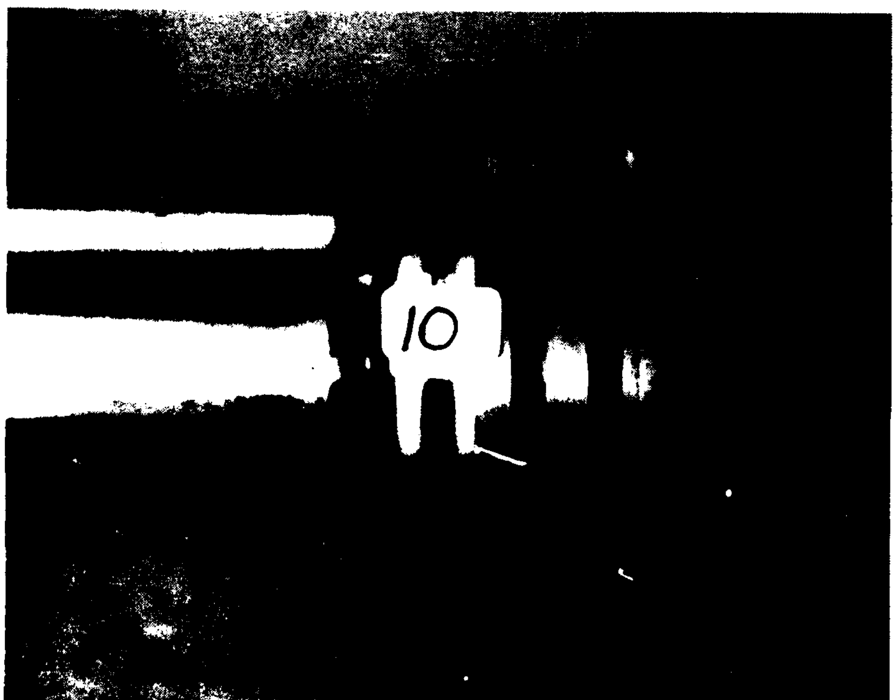
ACTUATOR #7
PISTON SEAL
TETRAFLUOR SD851212-2-2
SD851212-2-1
M83485/1-226 SQUARE RING



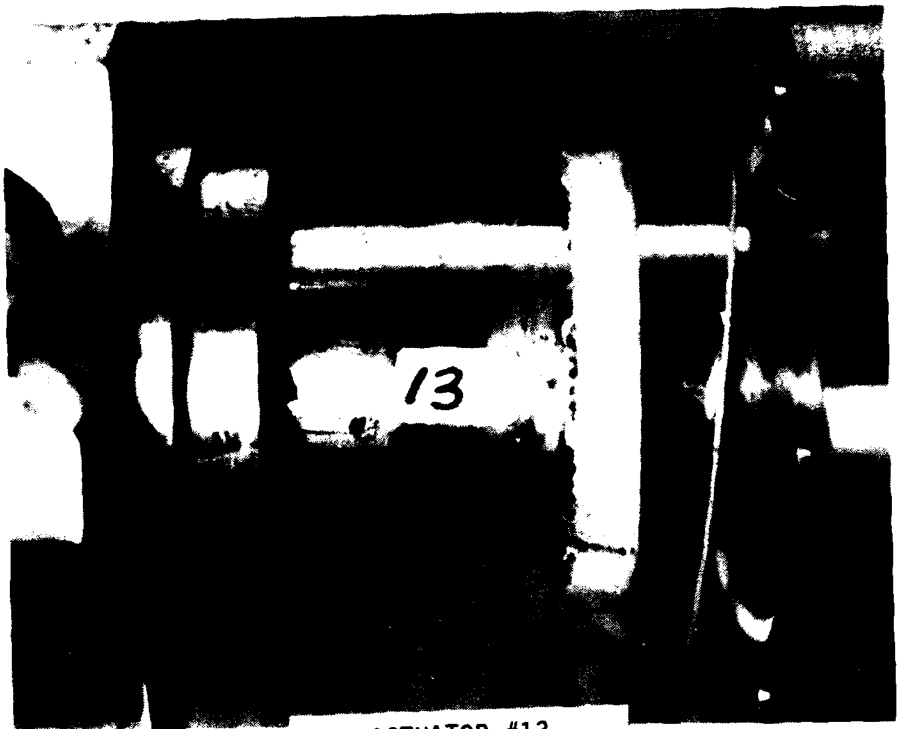
ACTUATOR #10
PRIMARY SEAL
TETRAFLUOR TF456-7326
TF1097M7326
M83485/1-326



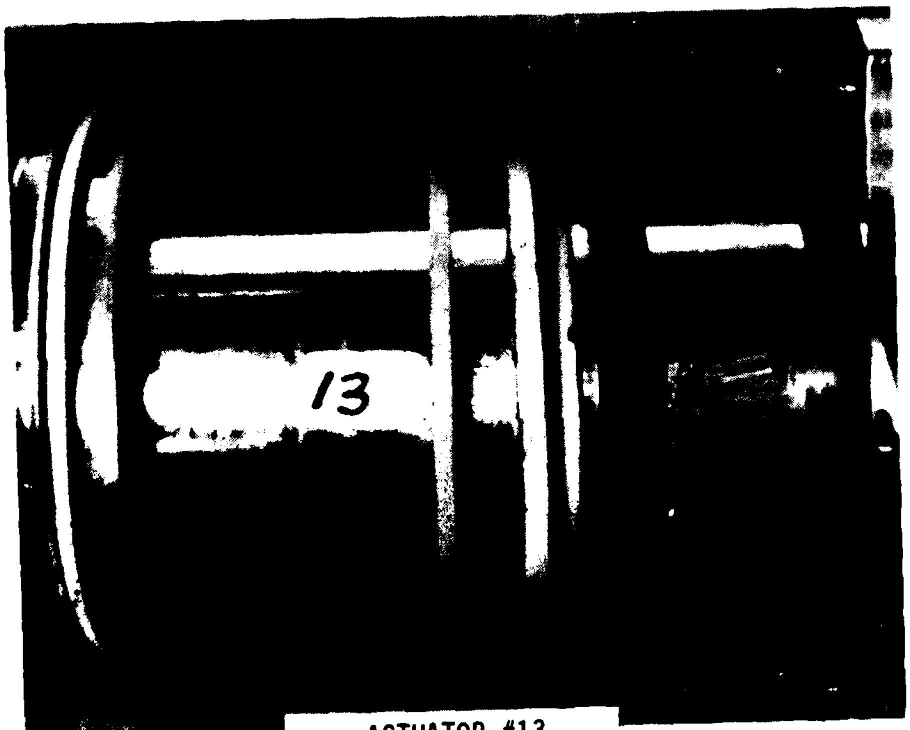
ACTUATOR #10
SECONDARY ROD SEAL
C.E. CONOVER CEC6001C-326-D8



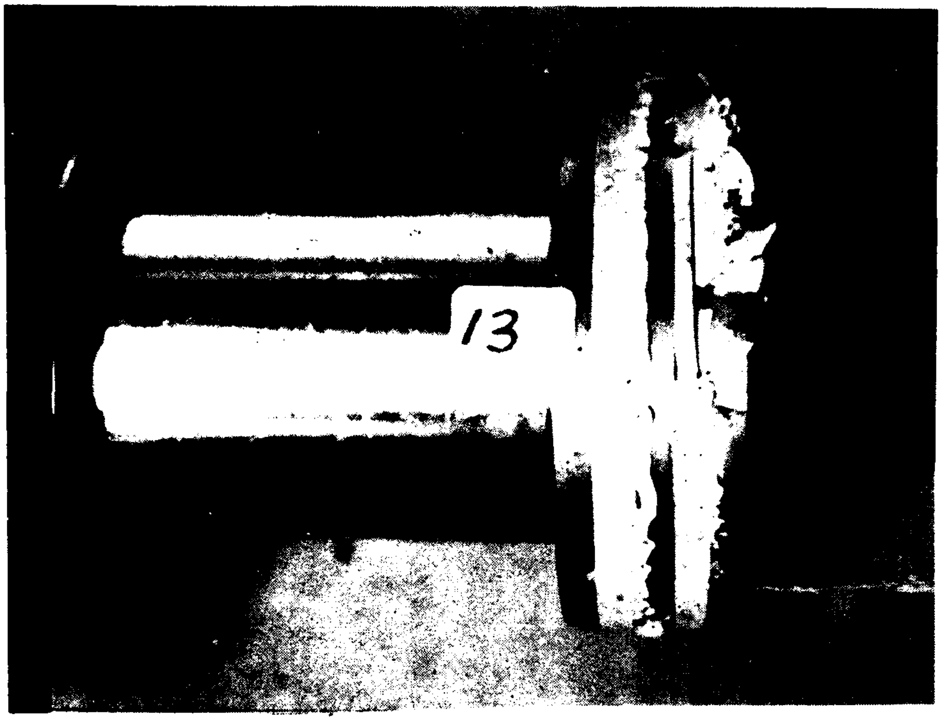
ACTUATOR #10
PISTON SEAL
PARKER BERTEA 301641ADP-1 (2)



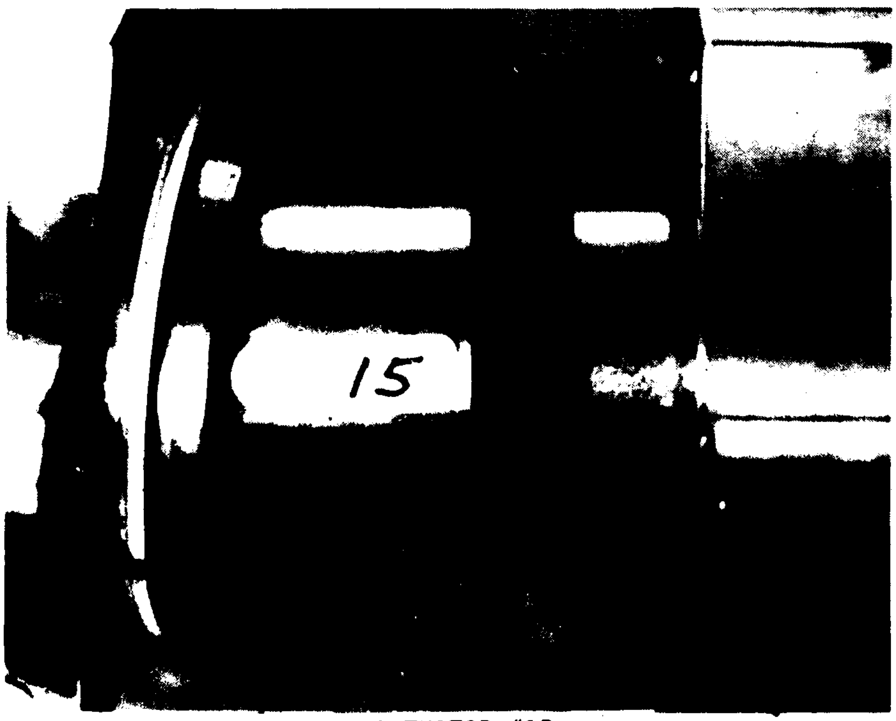
ACTUATOR #13
PRIMARY ROD SEAL
TETRAFLUOR TF851216-6
TF888S121685-4



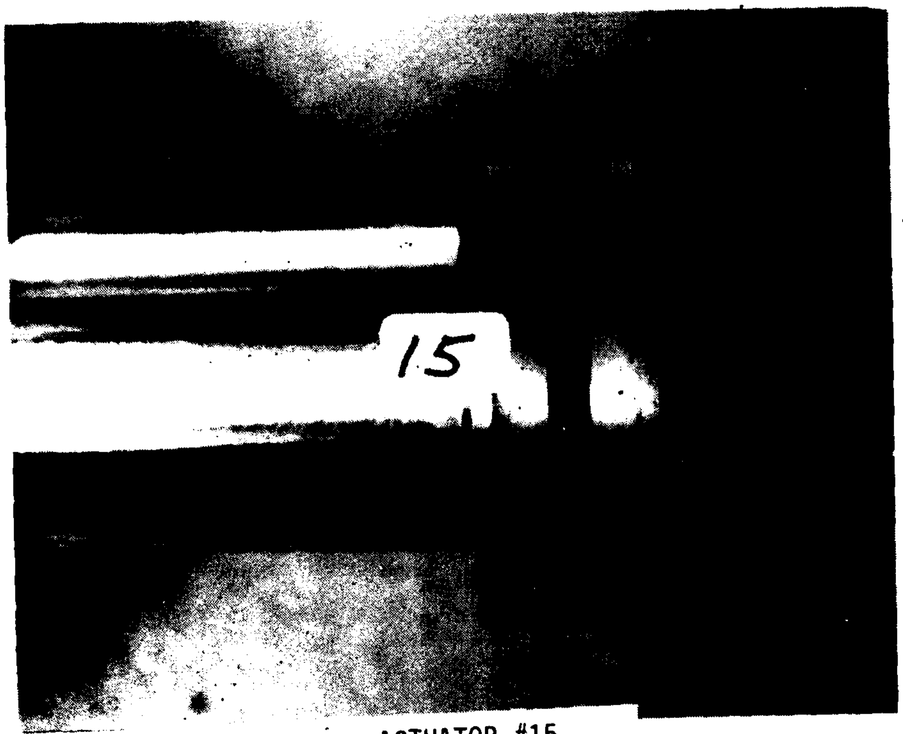
ACTUATOR #13
SECONDARY ROD SEAL
TETRAFLUOR TF456-7326
TF1097M-7326



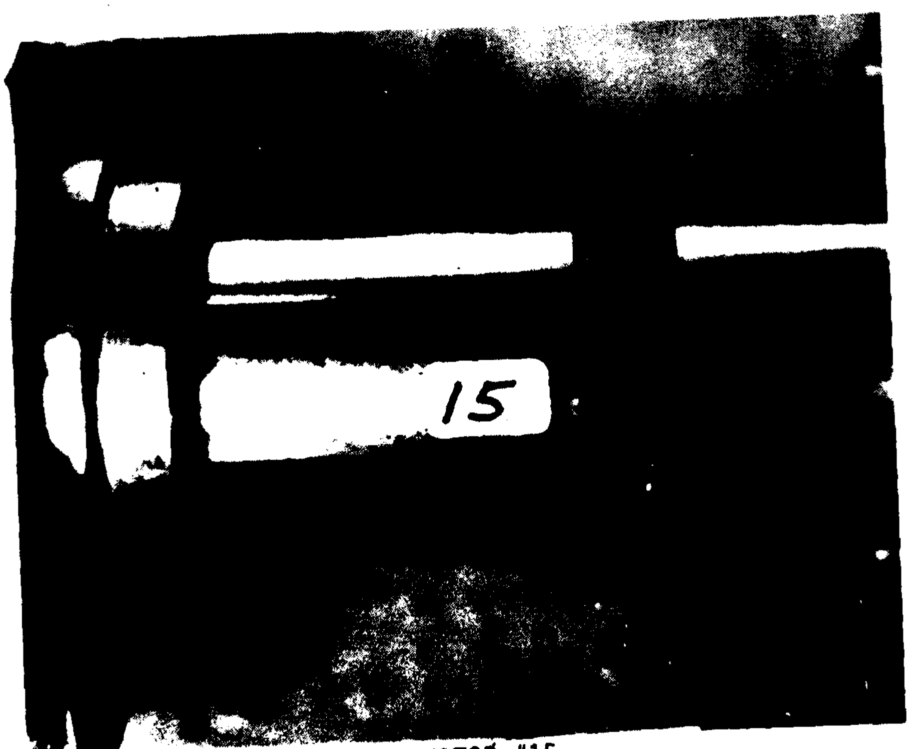
ACTUATOR #13
PISTON SEAL
TETRAFLUOR TF500A-329 (2)



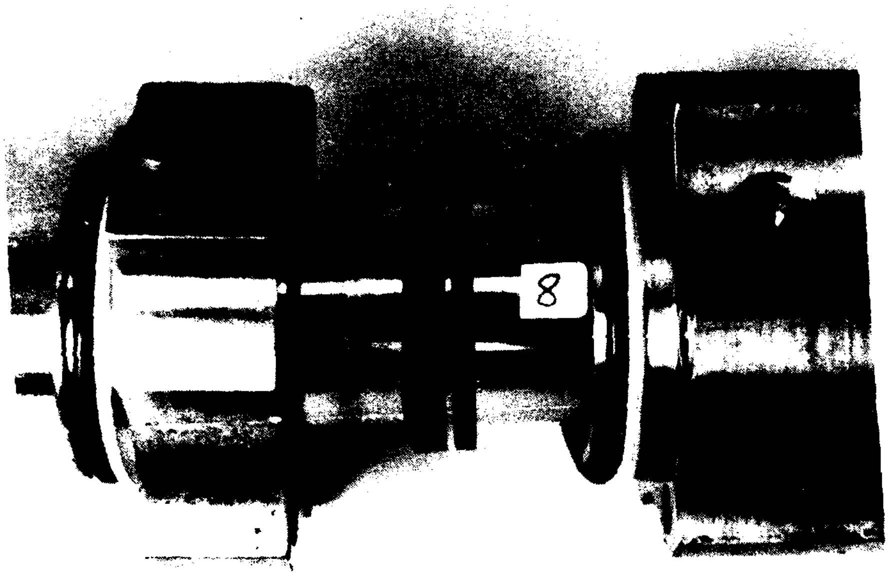
ACTUATOR #15
PRIMARY ROD SEAL
AMERICAN VARISEAL AS-1316



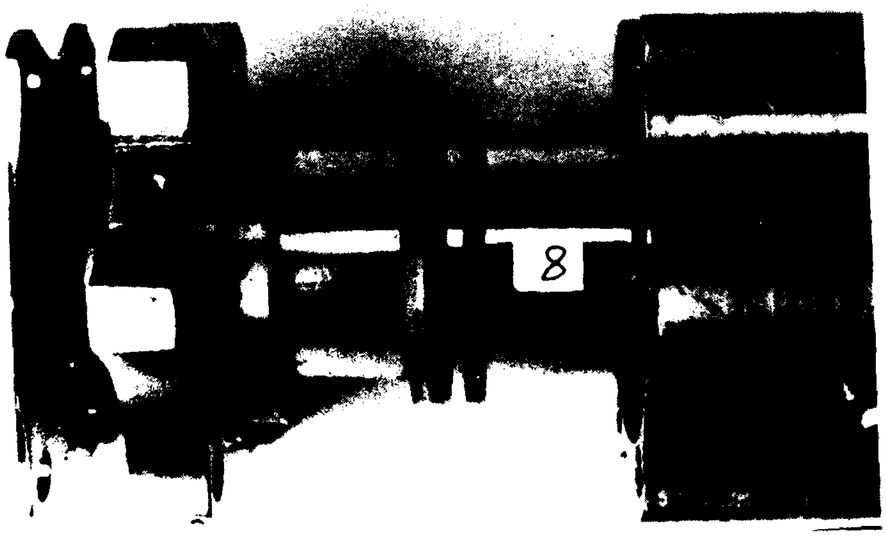
ACTUATOR #15
PISTON SEAL
PARKER CSD 301641ADP-1



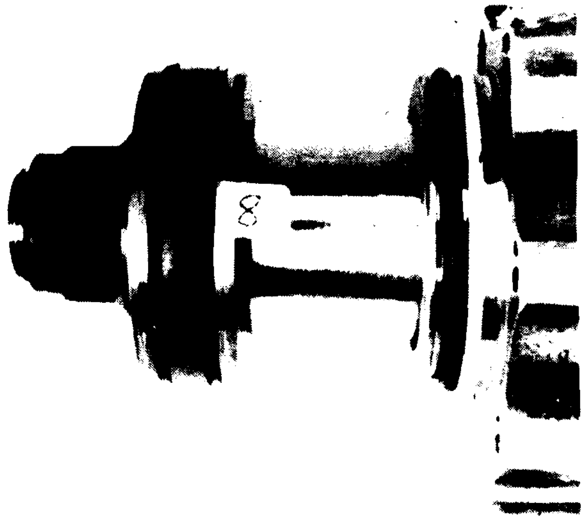
ACTUATOR #15
SECONDARY ROD SEAL
GREENE TWEED 265-32600-818-1160



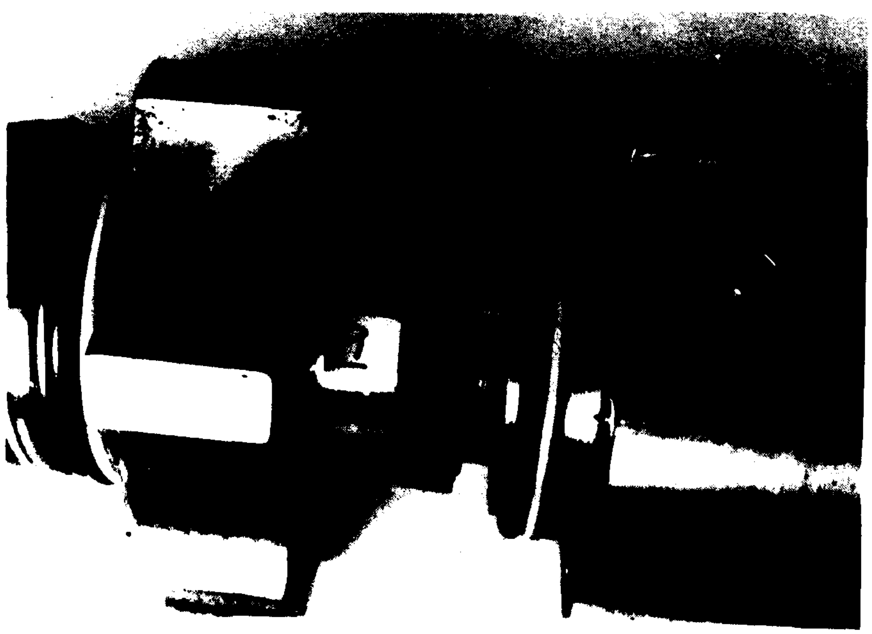
ACTUATOR #8
PRIMARY ROD SEAL
BAL SEAL X15033



ACTUATOR #8
SECONDARY ROD SEAL
ADVANCED PRODUCTS 46194/46195

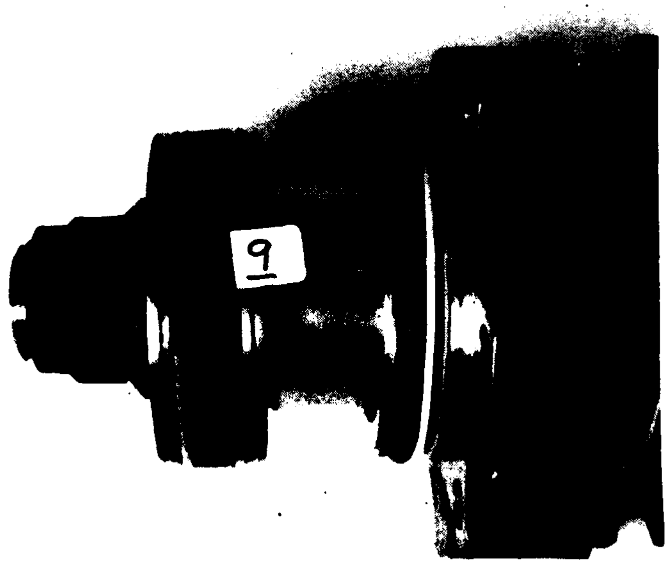


ACTUATOR #8
PISTON SEAL
SHAMBAN S35979

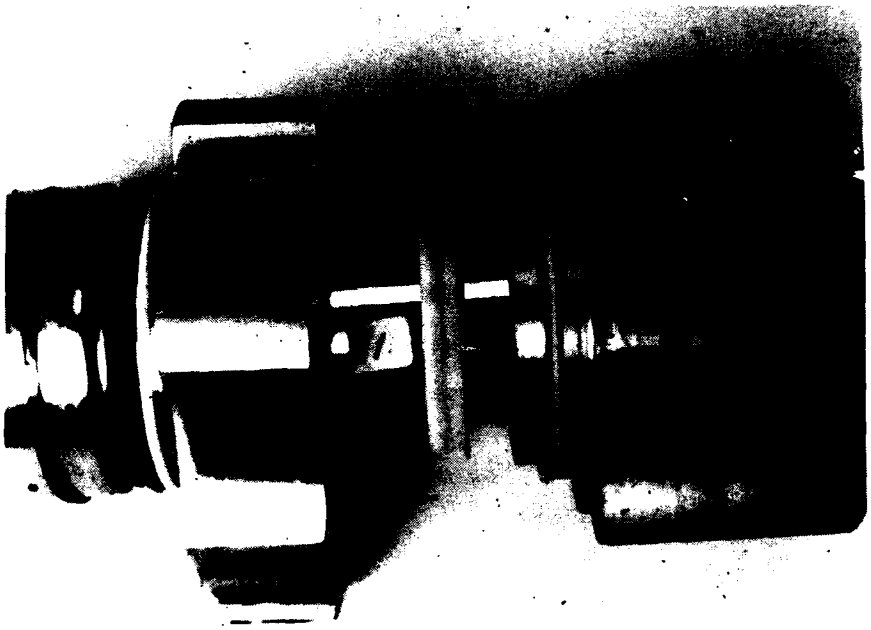


ACTUATOR #9
PRIMARY ROD SEAL
KOPPERS C5267A60

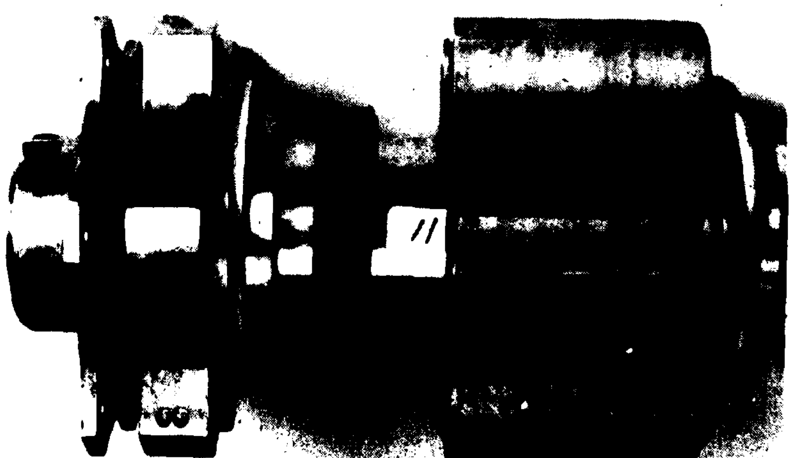
ACTUATOR #9
SECONDARY ROD SEAL
C.E. CONOVER CEC6001C-326-D8



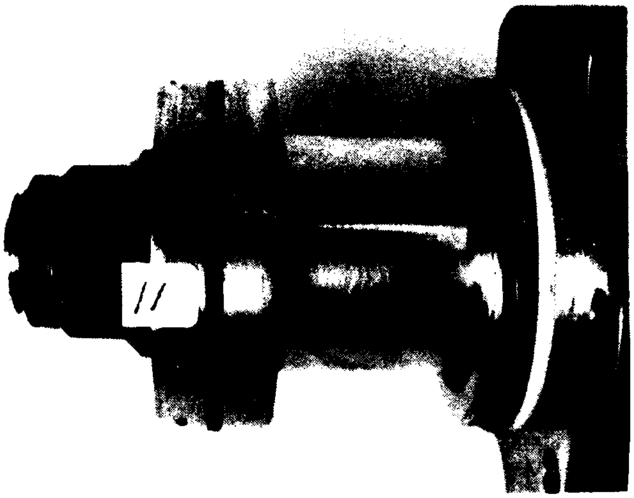
ACTUATOR #9
PISTON SEAL
GREENE, TWEED 5979A32900P001
NOTE: THIS SEAL REPLACED FAILED ORIGNAL
GREENE, TWEED 5979A32900P001
PISTON SEAL



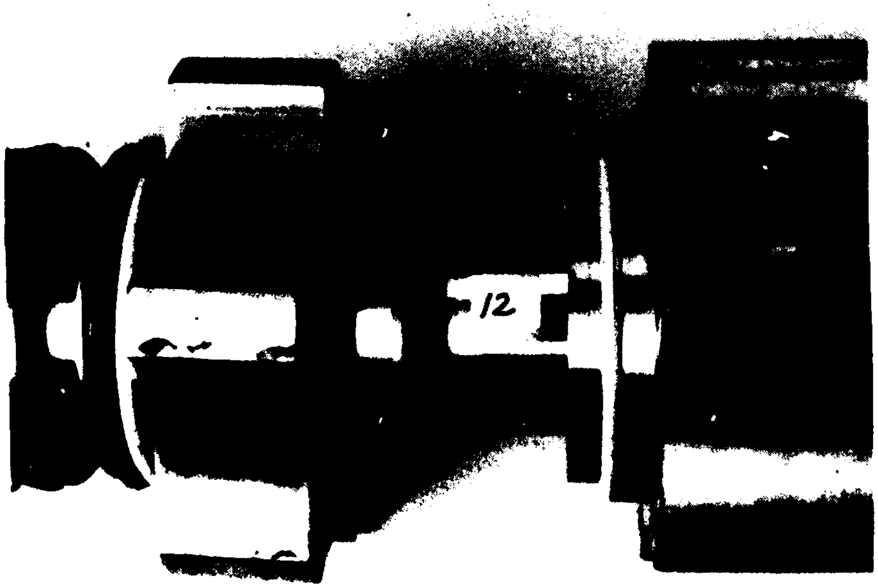
ACTUATOR #11
PRIMARY ROD SEAL
TETRAFLUOR TF888S121685-41
SD851216-61



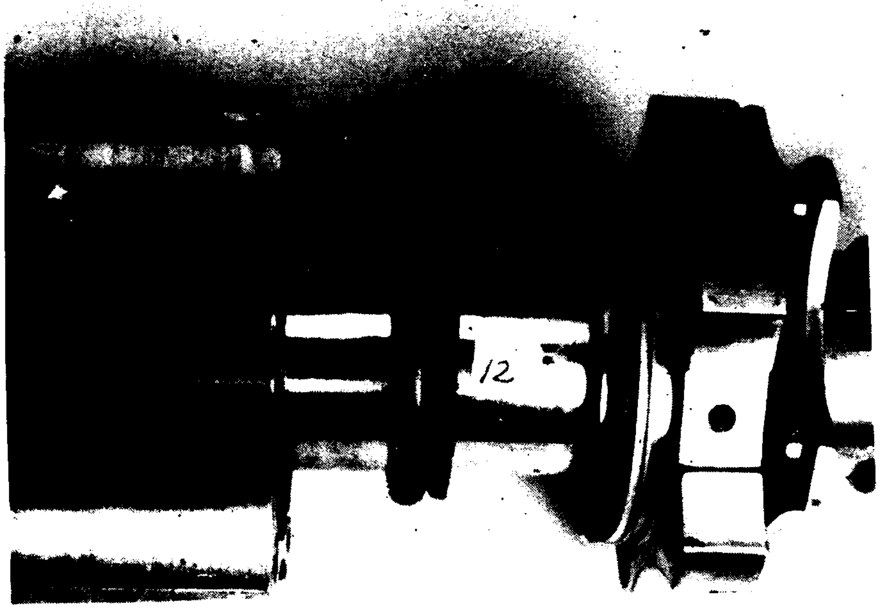
ACTUATOR #11
SECONDARY ROD SEAL
GREENE, TWEED 265-32600-777-1160



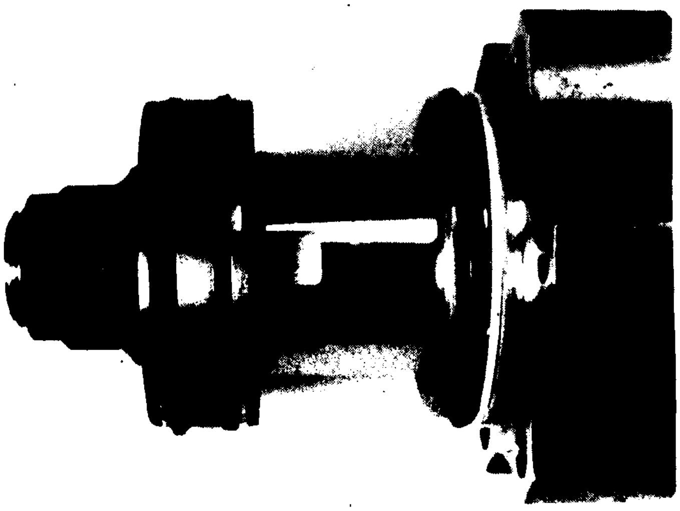
ACTUATOR #11
PISTON SEAL
DOVER ABP17573



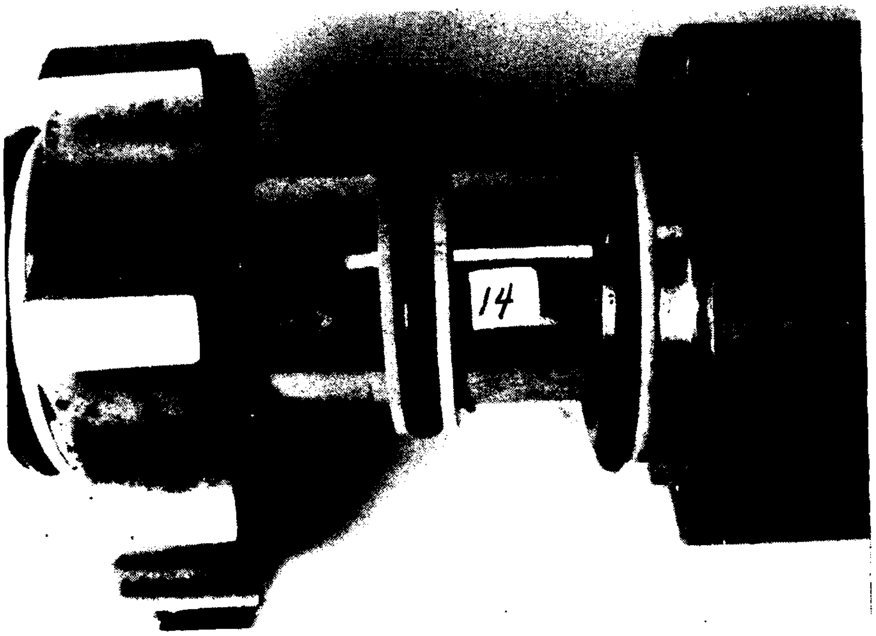
ACTUATOR #12
PRIMARY ROD SEAL
FLUOROCARBON AR104974



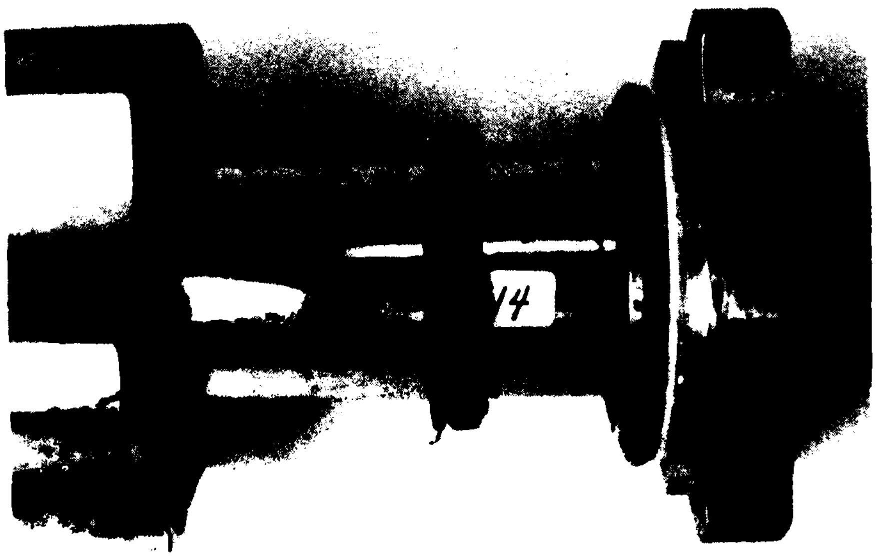
ACTUATOR #12
SECONDARY ROD SEAL
C.E. CONOVER CEC5056-326-D8



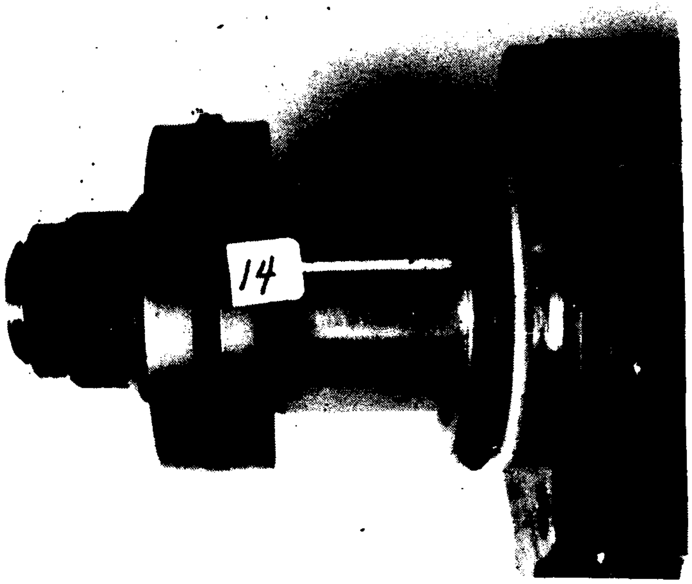
ACTUATOR #12
PISTON SEAL
DOVER ABP17573 (2 ea)



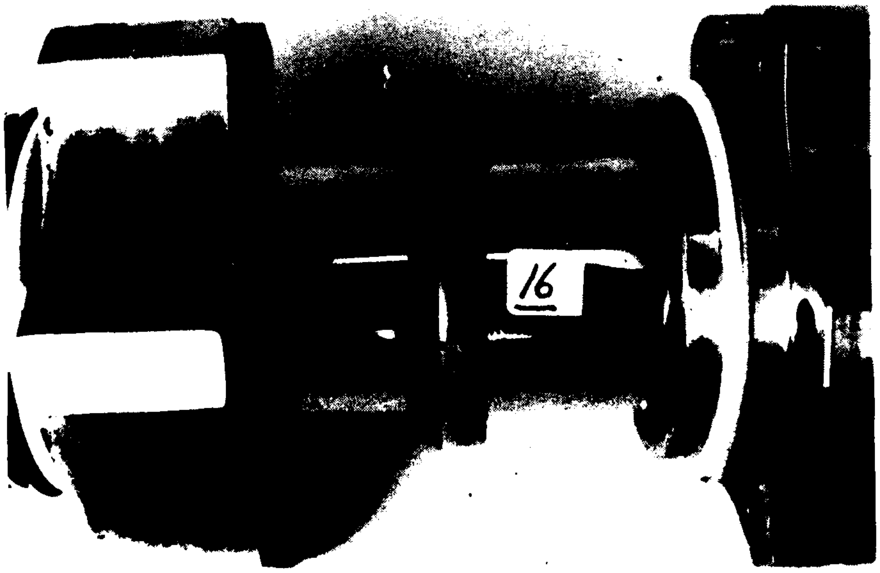
ACTUATOR #14
PRIMARY ROD SEAL
TETRAFLUOR TF1097M-7326(582)
TF456-7326(801)



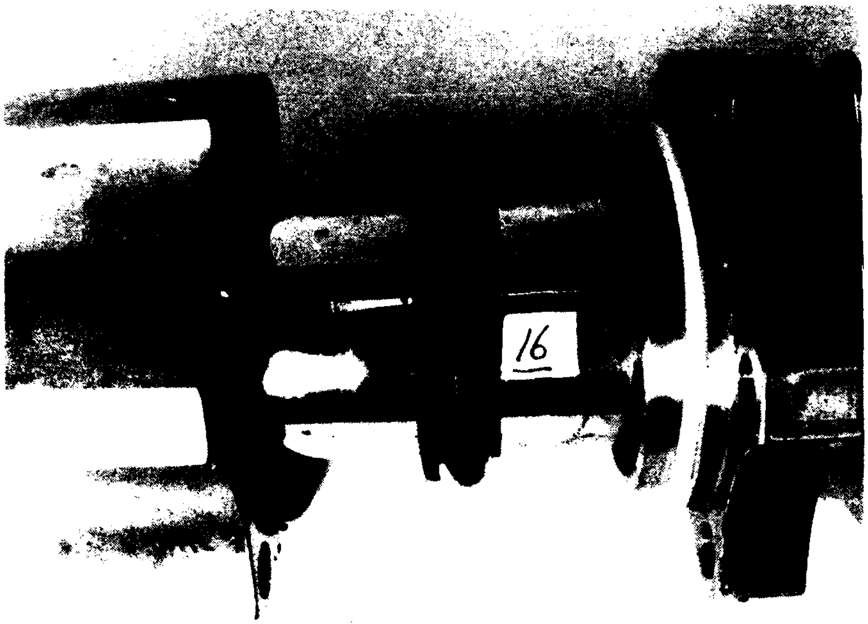
ACTUATOR #14
SECONDARY ROD SEAL
SHAMBAN S35968



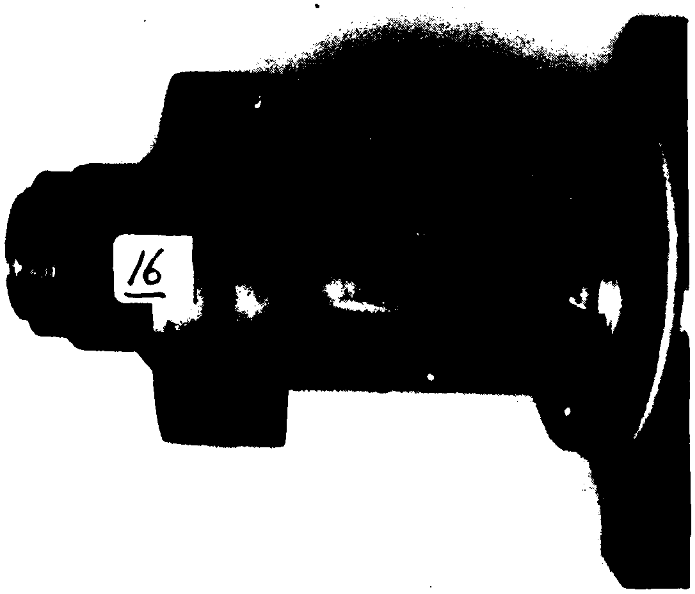
ACTUATOR #14
PISTON SEAL
PARKER CSD 330446ADP-5



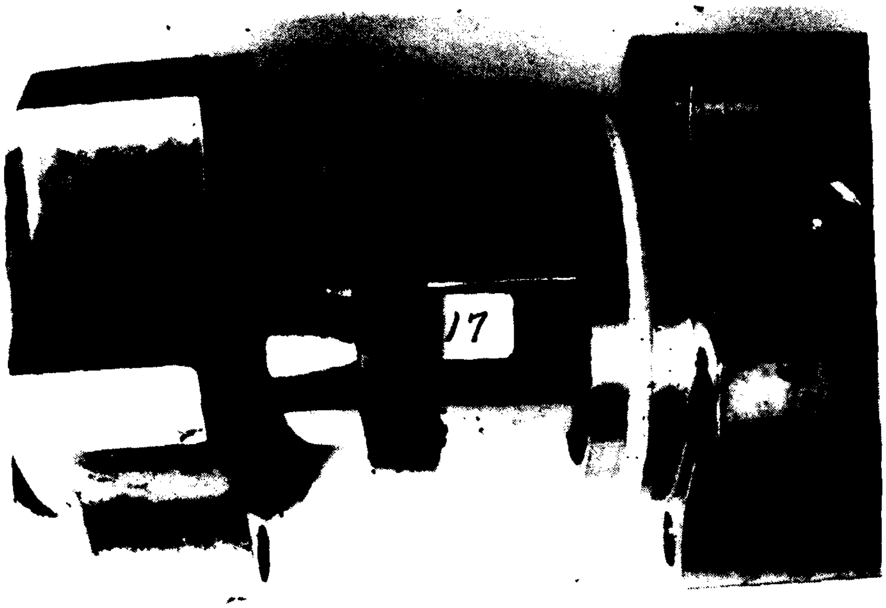
ACTUATOR #16
PRIMARY ROD SEAL
ADVANCED PRODUCTS 46194/46195



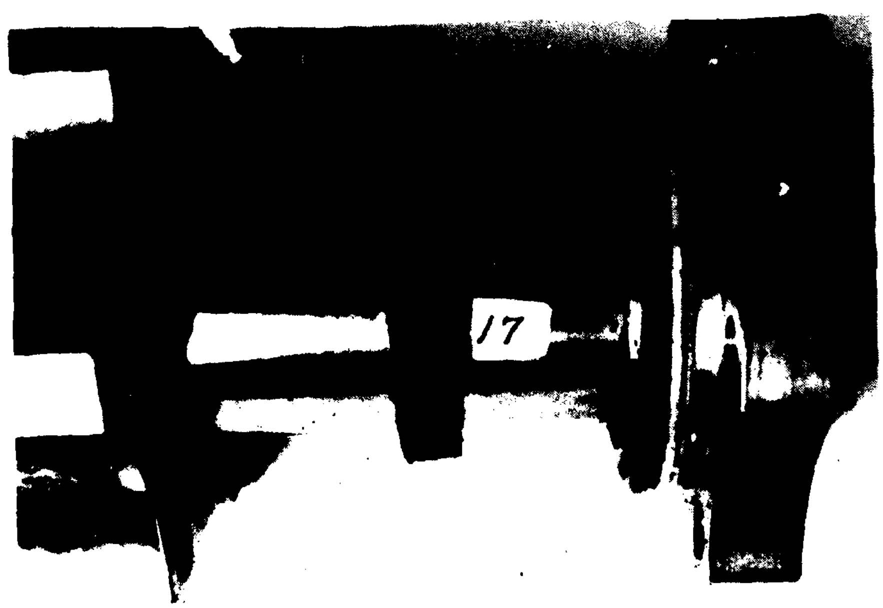
ACTUATOR #16
SECONDARY ROD SEAL
SHAMBAN S35971



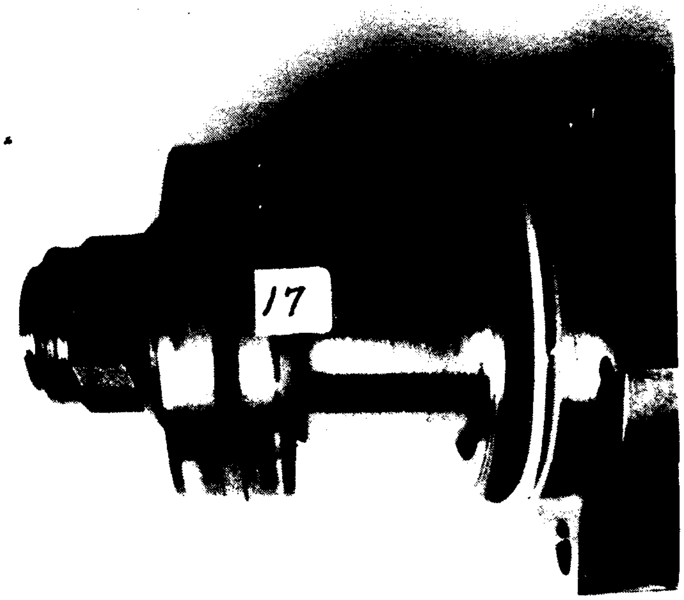
ACTUATOR #16
PISTON SEAL
PARKER CSD 301641ADP-1
NOTE: THIS SEAL REPLACED FAILED ORIGINAL
KOPPERS C5816A60 PISTON SEAL



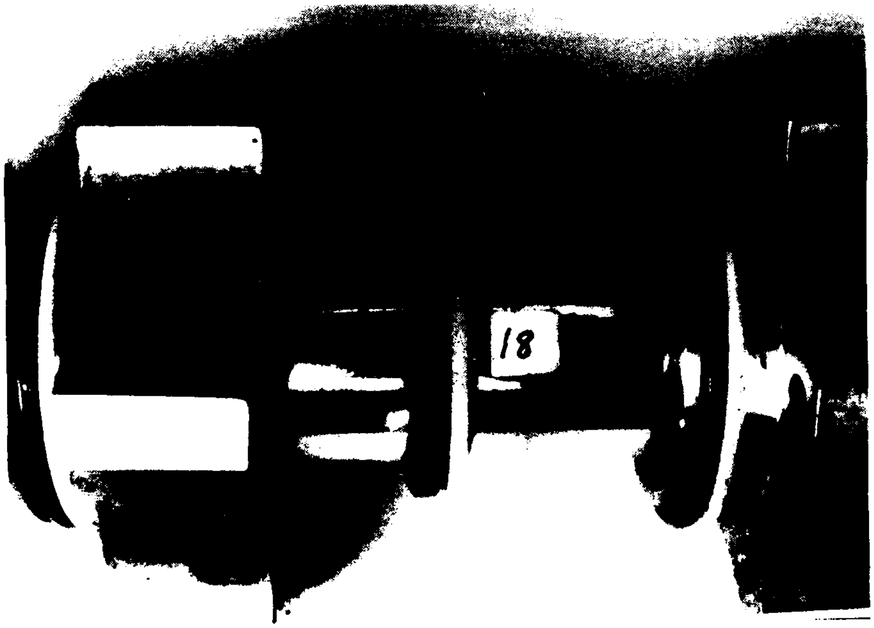
ACTUATOR #17
PRIMARY ROD SEAL
GREEN, TWEED 265-3260-818-1160



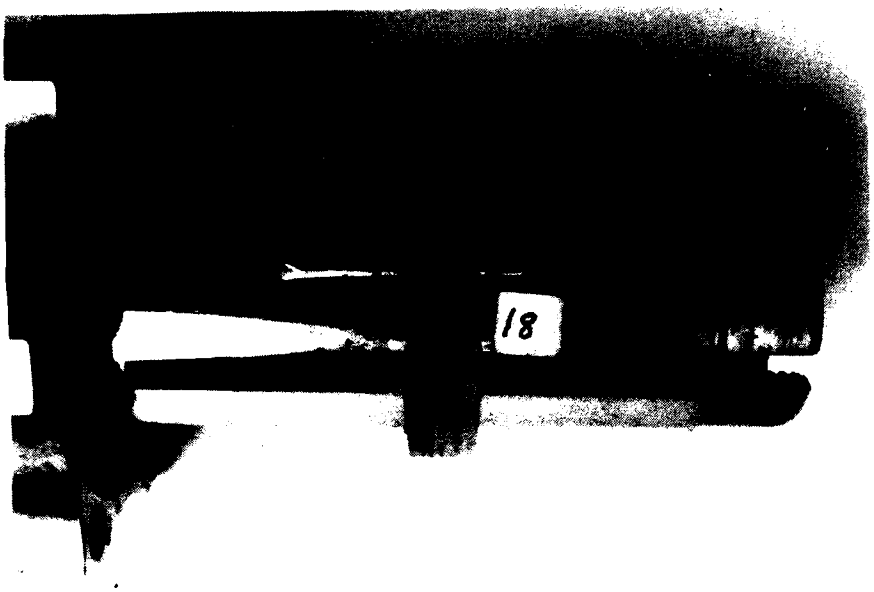
ACTUATOR #17
SECONDARY ROD SEAL
BAL SAL X6789



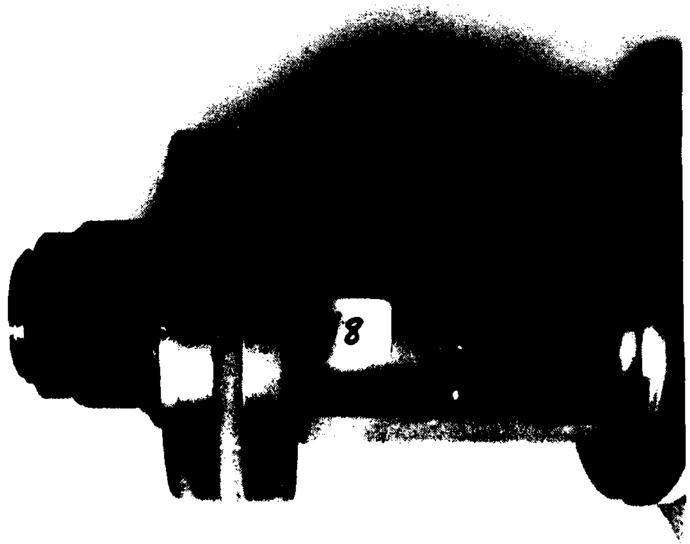
ACTUATOR #17
PISTON SEAL
PARKER CSD 301641ADP-1
NOTE: THIS SEAL REPLACED FAILED ORIGINAL
KOPPERS C5816A60 PISTON SEAL



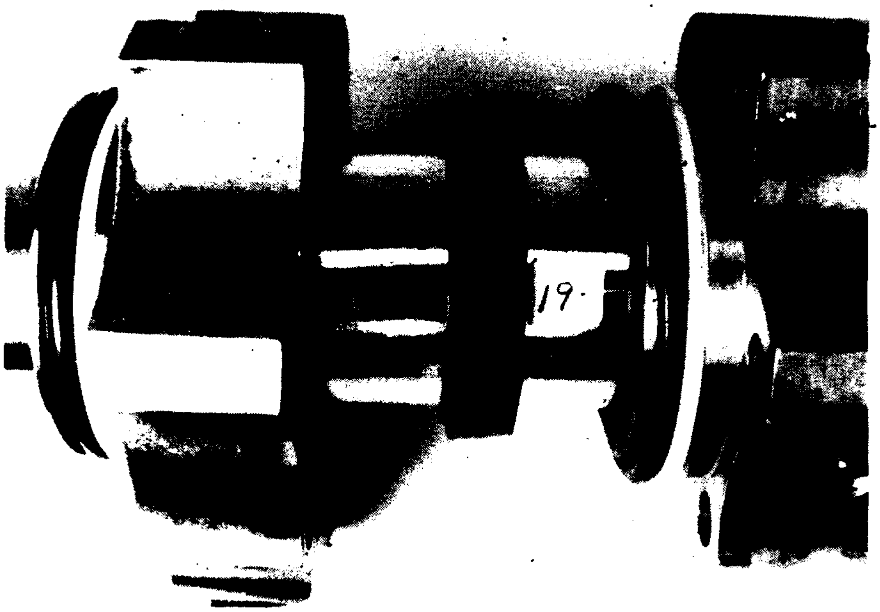
ACTUATOR #18
PRIMARY ROD SEAL
CONOVER CEC6001C-326-D8



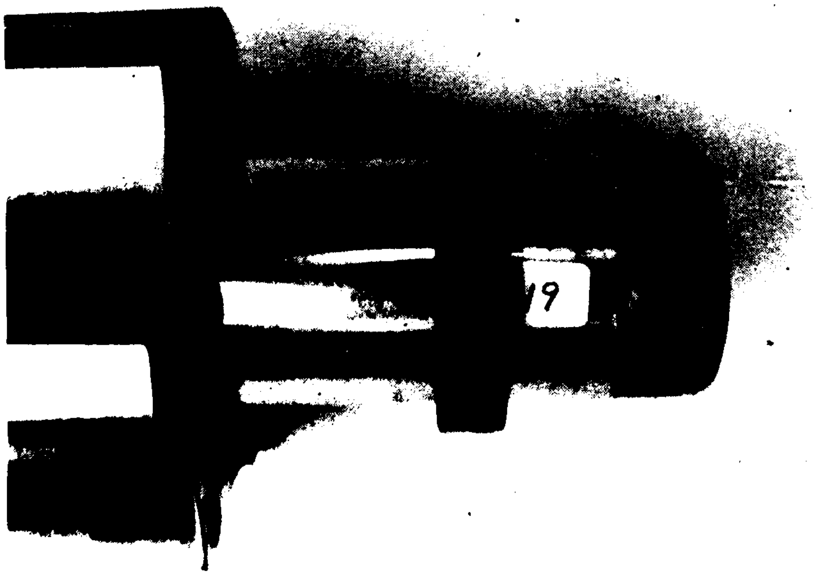
ACTUATOR #18
SECONDARY ROD SEAL
ADVANCED PRODUCTS



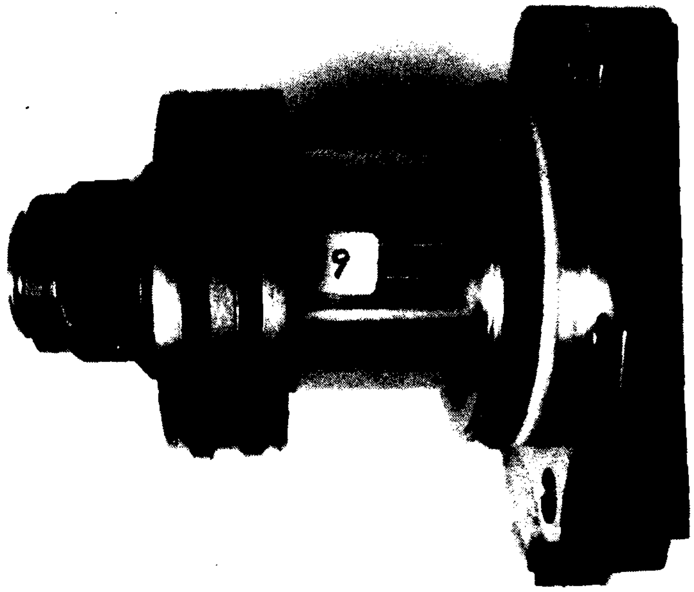
ACTUATOR #18
PISTON SEAL
PARKER CSD 330446ADP-3



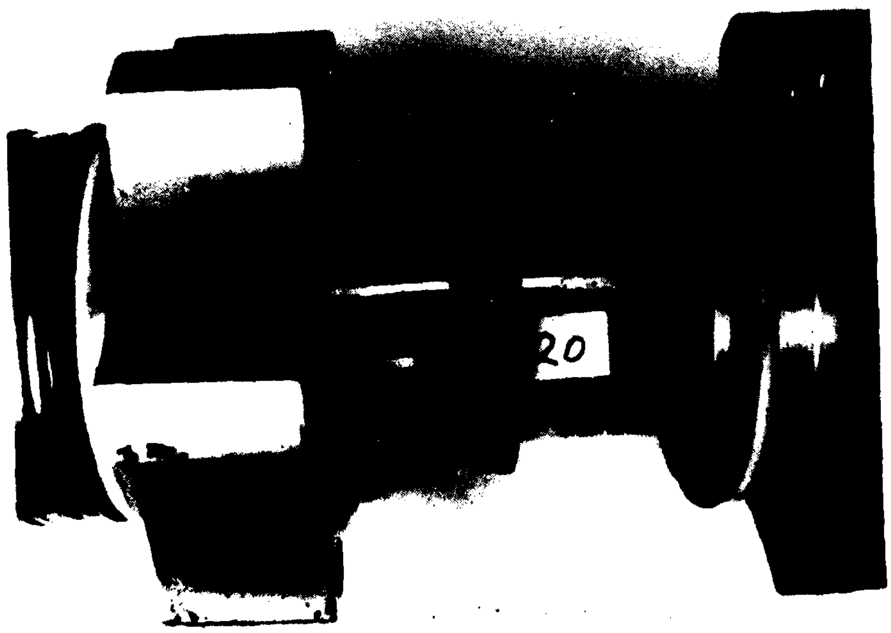
ACTUATOR #19
PRIMARY ROD SEAL
GREENE, TWEED 265-32600-818-1200



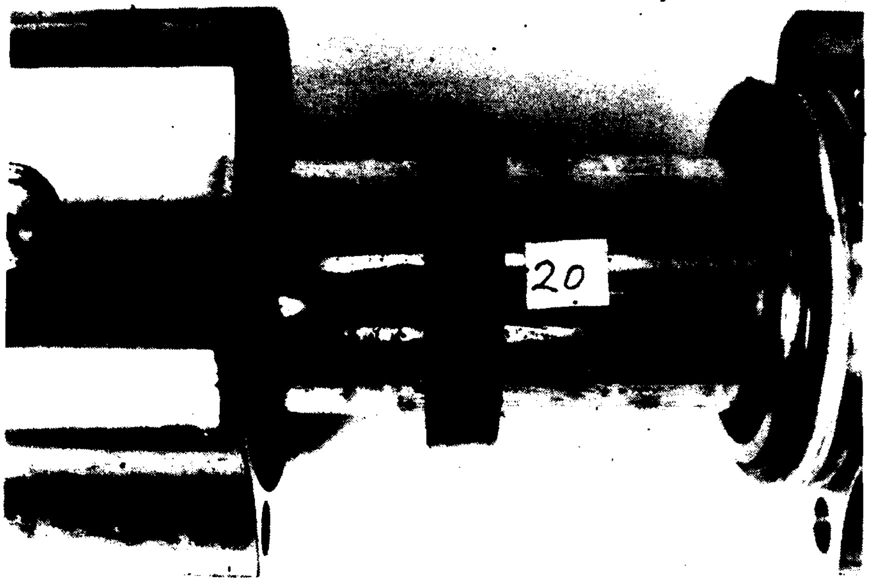
ACTUATOR #19
SECONDARY ROD SEAL
AMERICAN VARISEAL AS1316



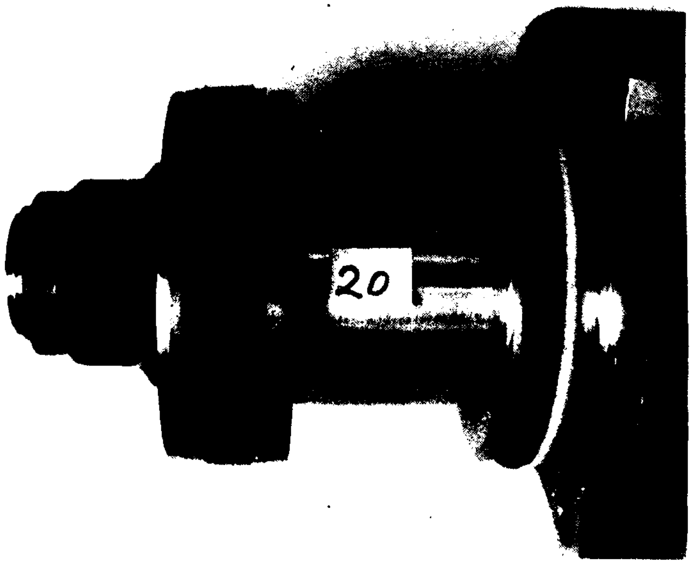
ACTUATOR #19
PISTON SEAL
PARKER CSD 330446ADP-5



ACTUATOR #20
PRIMARY ROD SEAL
FLUOROCARBON AR104974



ACTUATOR #20
SECONDARY ROD SEAL
GREENE, TWEED 265-32600-777-1160

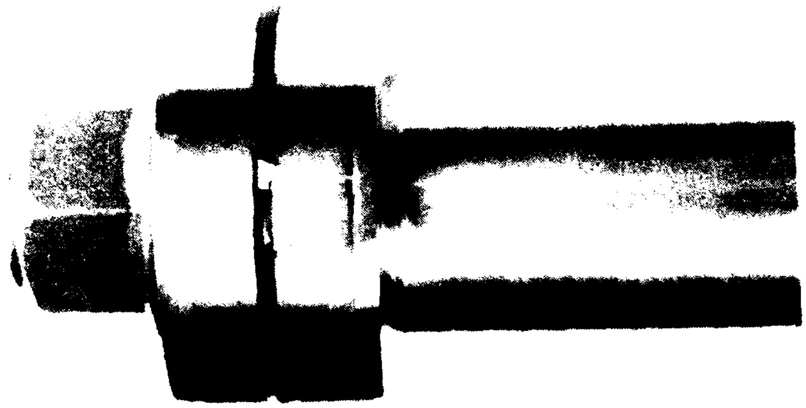


ACTUATOR #20
PISTON SEAL
GREENE, TWEED 59794A32900P001

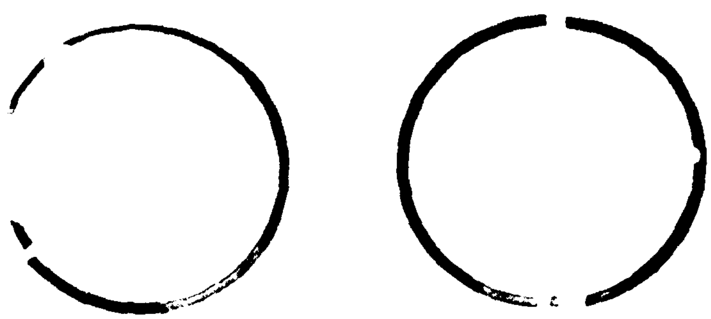
NOTE: THIS SEAL REPLACED FAILED ORIGINAL
GREENE, TWEED 5979A32900P001
PISTON SEAL

APPENDIX F

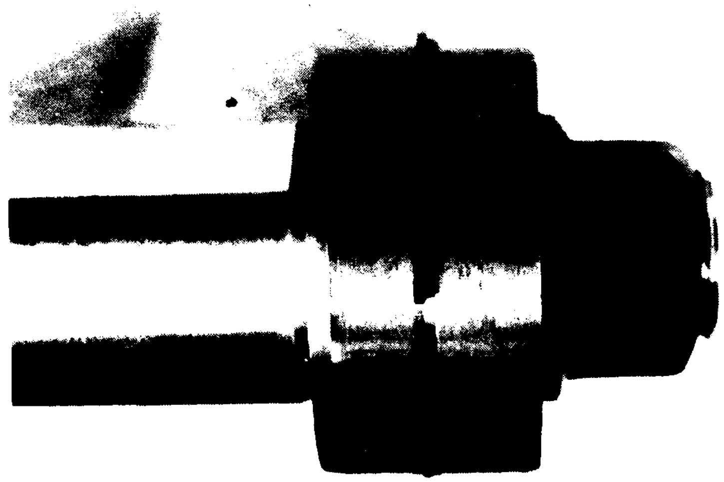
PHOTOS OF THE LONG LIFE TEST SEALS



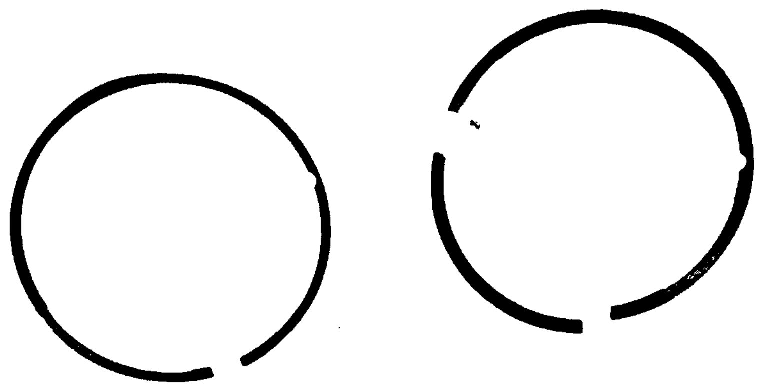
SMALL ACTUATOR 1
DOVER PISTON RING P/N ABP 17572
469,000 CYCLES



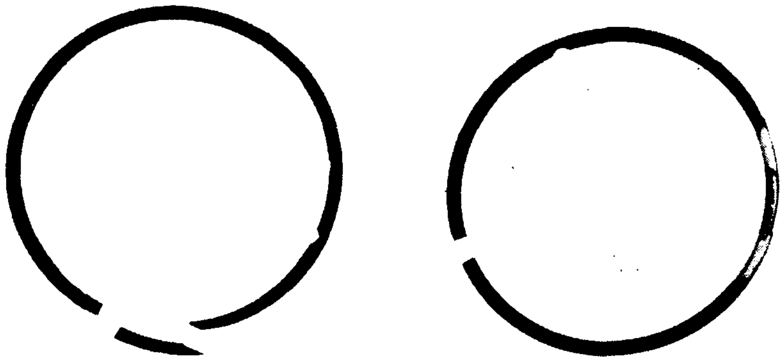
SMALL ACTUATOR 1
DOVER PISTON RING P/N ABP 17572
469,000 CYCLES
NOTE: INNER RING NOT SHOWN



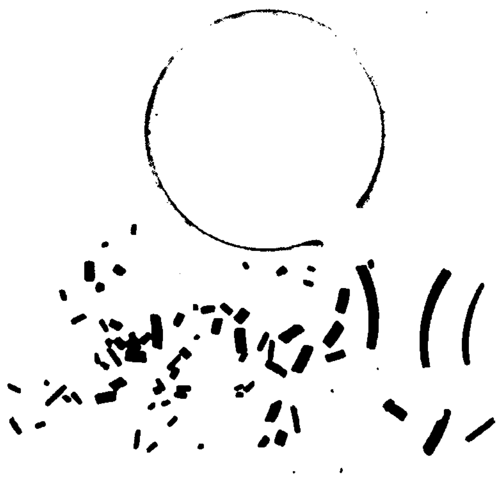
SMALL ACTUATOR 2
DOVER PISTON RING P/N ABP 17572
469,000 CYCLES



SMALL ACTUATOR 2
DOVER PISTON RING P/N ABP17572
469,000 CYCLES
NOTE: INNER RING NOT SHOWN

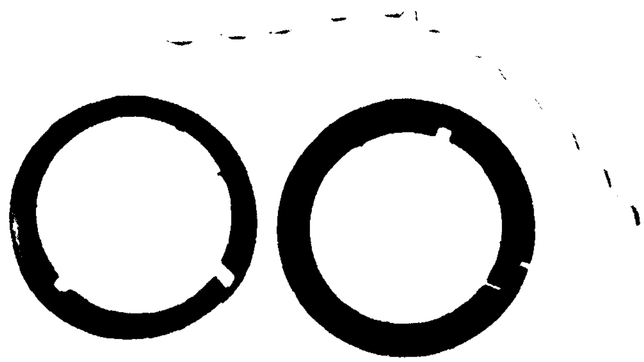


SMALL ACTUATOR 3
DOVER PISTON RING P/N ABP17572
704,000 CYCLES
NOTE: INNER RING NOT SHOWN

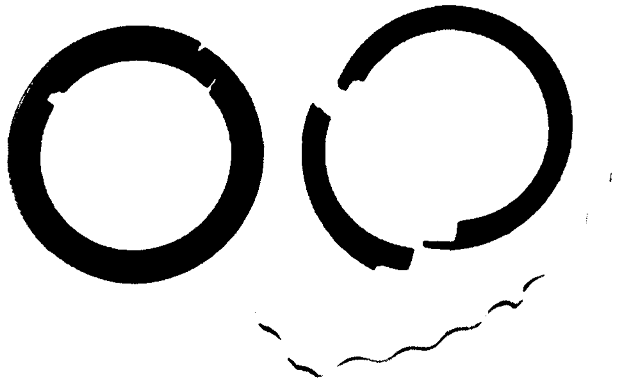


SMALL ACTUATOR 1
DOVER PISTON RING P/N ABP17572
938,000 CYCLES TO FAILURE
RING REMOVED AFTER 4,695,000 CYCLES

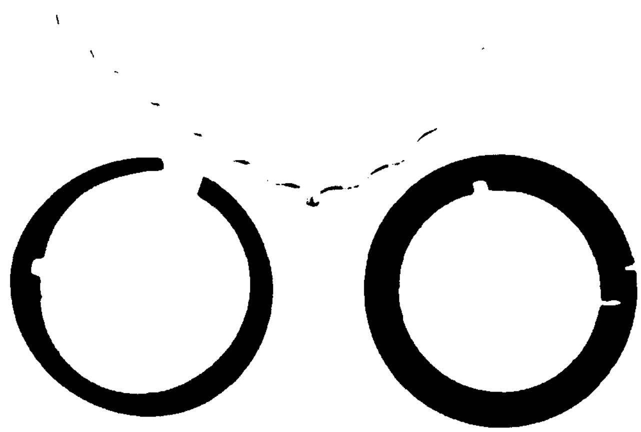
SMALL ACTUATOR 3
DOVER PISTON RINGS P/N ABP 17572 (2 SETS)
704,241 CYCLES TO FAILURE
RINGS REMOVED AFTER 4,695,000 CYCLES



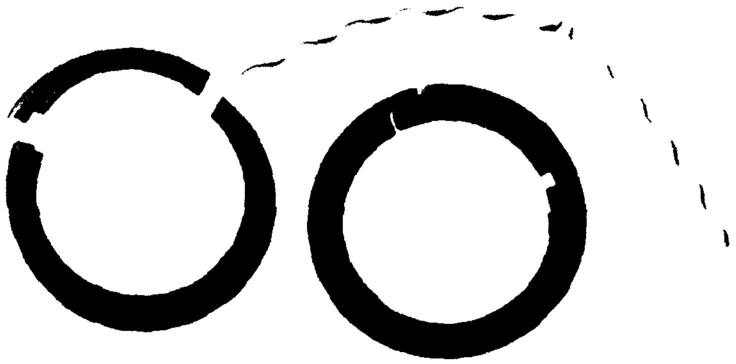
SMALL ACTUATOR 6
SHAMBAN PISTON RING P/N S35982 (SET 2)
1,643,000 CYCLES TO FAILURE
RING REMOVED AFTER 4,929,000 CYCLES



SMALL ACTUATOR 6
SHAMBAN PISTON RING P/N S35982 (SET 1)
1,643,000 CYCLES TO FAILURE
RING REMOVED AFTER 4,929,000 CYCLES
NOTE: RING BROKEN DURING REMOVAL

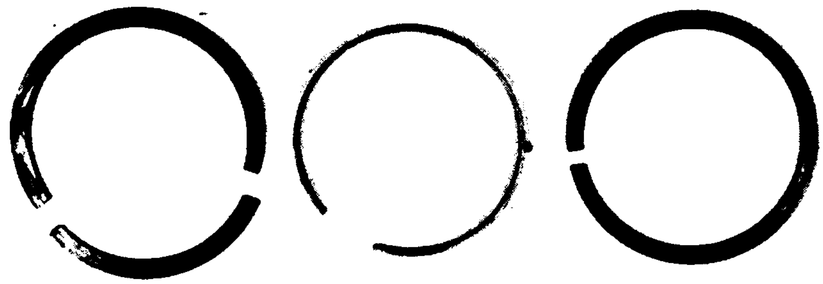


SMALL ACTUATOR 4
SHAMBAN PISTON RING P/N 35982
1,643,000 TO FAILURE
REMOVED AFTER 4,929,000 CYCLES

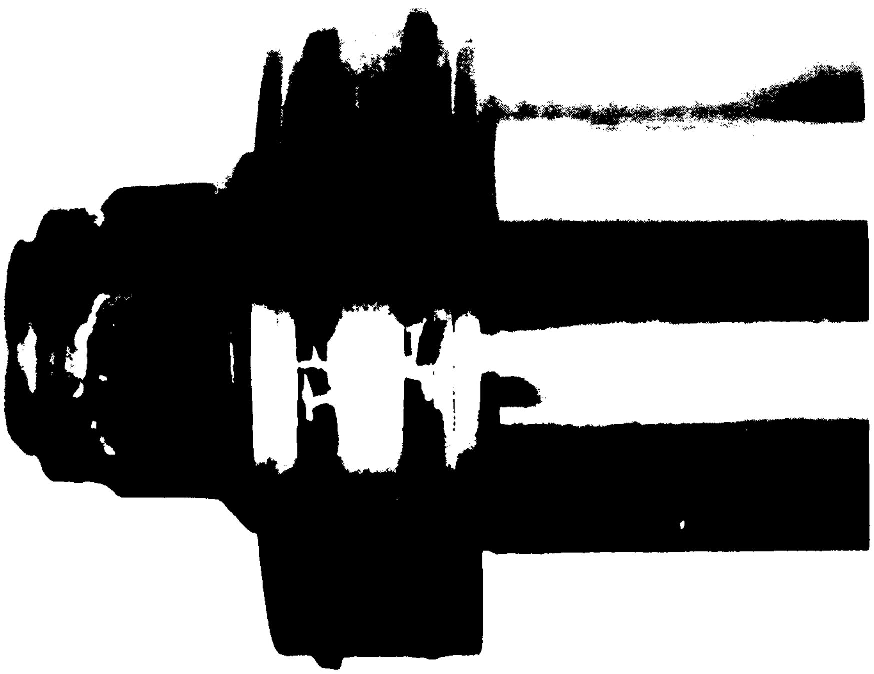


SMALL ACTUATOR 5
SHAMBAN P/N S35982
2,582,000 CYCLES TO FAILURE
RING REMOVED AFTER 4,929,000 CYCLES
NOTE: RING BROKEN DURING REMOVAL

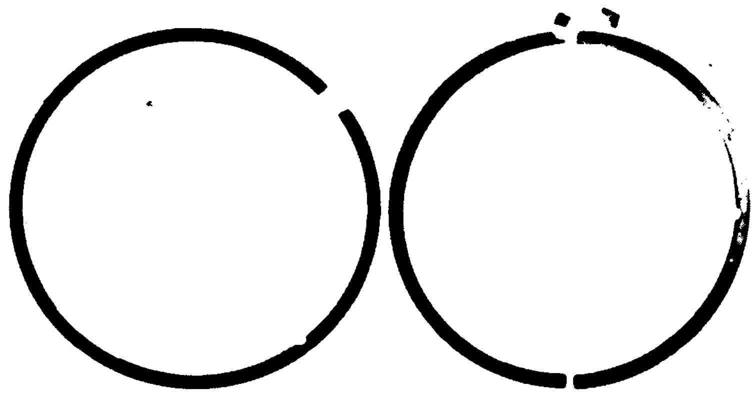
SMALL ACTUATOR 10
PARKER CSD PISTON RING P/N 301641ADP-7
3,990,000 CYCLES TO FAILURE



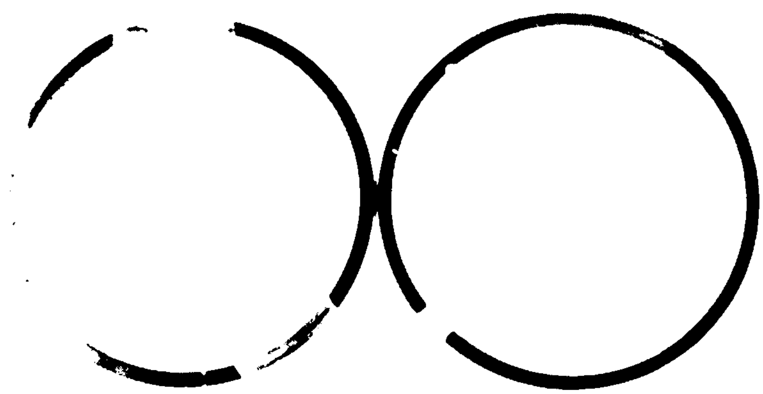
SMALL ACTUATOR 8
PARKER CSD PISTON RING P/N 301641-7
4,695,000 CYCLES TO FAILURE



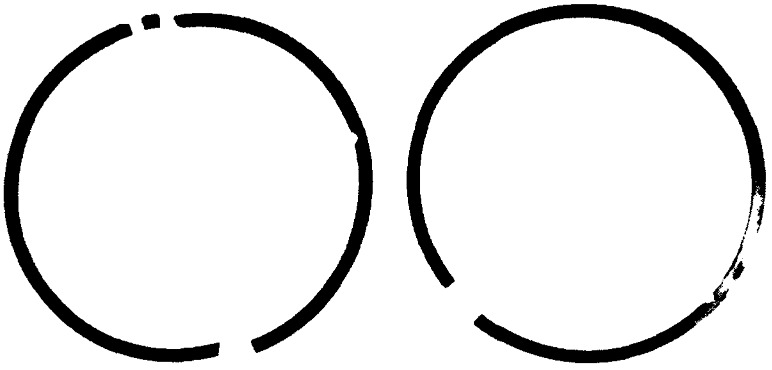
LARGE ACTUATOR 3
DOVER PISTON RINGS P/N ABP 17573
469,000 CYCLES



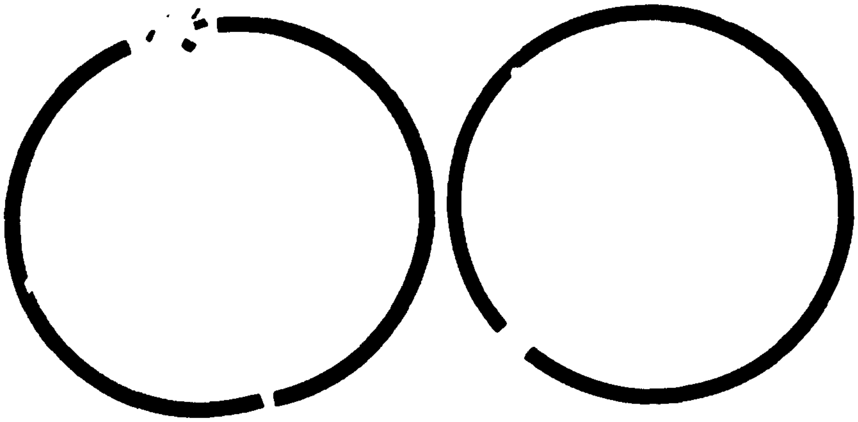
LARGE ACTUATOR 3
DOVER PISTON RING P/N ABP 17573
469,000 CYCLES
NOTE: INNER RING NOT SHOWN



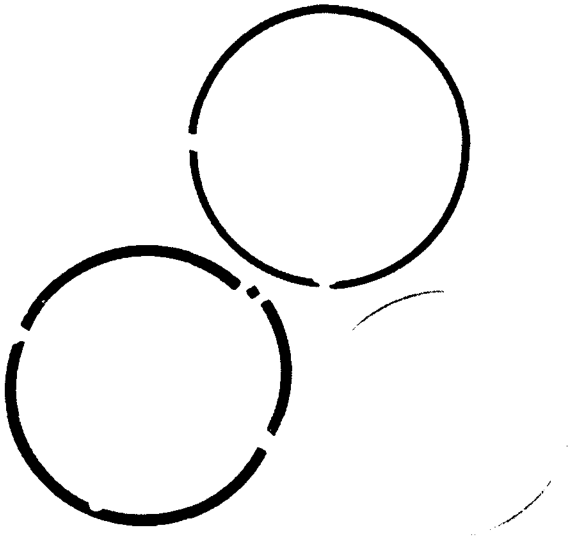
LARGE ACTUATOR 3
DOVER PISTON RING P/N ABP27673
469,000 CYCLES
NOTE: INNER RING NOT SHOWN



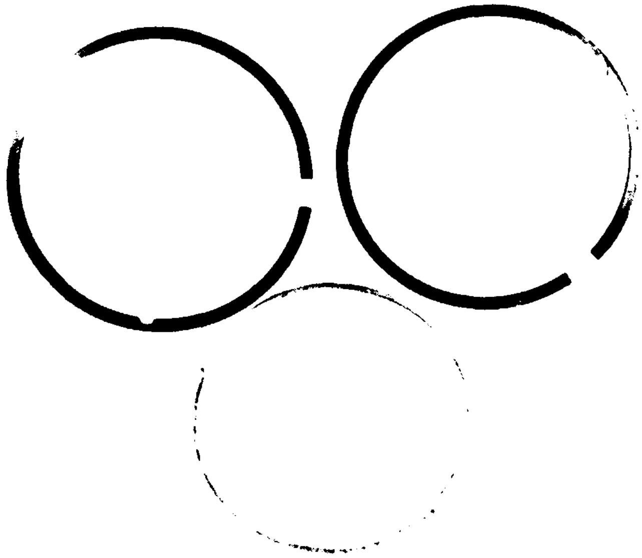
LARGE ACTUATOR 1
DOVER PISTON RING P/N ABP17573
938,000 CYCLES
NOTE: INNER RING NOT SHOWN



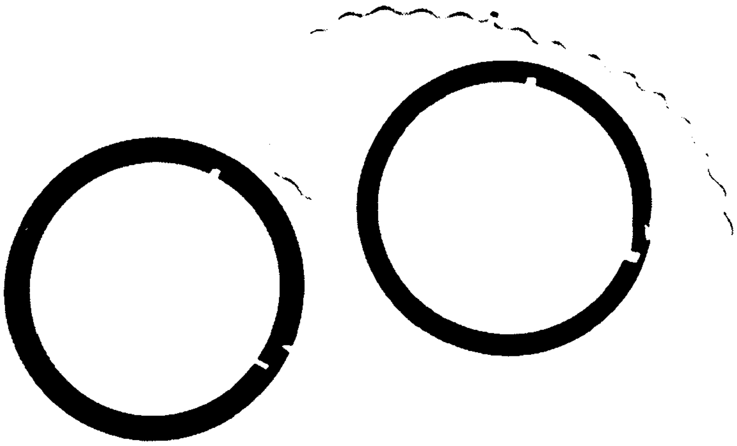
LARGE ACTUATOR 2
DOVER PISTON RING P/N ABP17573
1,173,000 CYCLES
NOTE: INNER RING NOT SHOWN



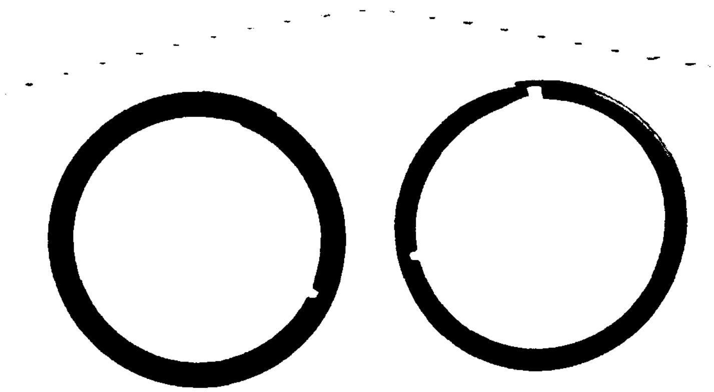
LARGE ACTUATOR 1
DOVER PISTON RING P/N ABP17573
704,000 CYCLES TO FAILURE
REMOVED AFTER 1,408,000 CYCLES



LARGE ACTUATOR 2
DOVER PISTON RING P/N ABP17573
938,000 CYCLES TO FAILURE
REMOVED AFTER 1,173,000 CYCLES

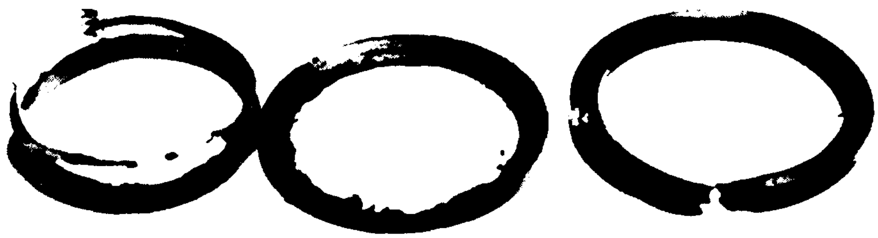


LARGE ACTUATOR 4
SHAMBAN PISTON RING P/N S35985
1,643,000 CYCLES TO FAILURE
RING REMOVED AFTER 2,816,000 CYCLES

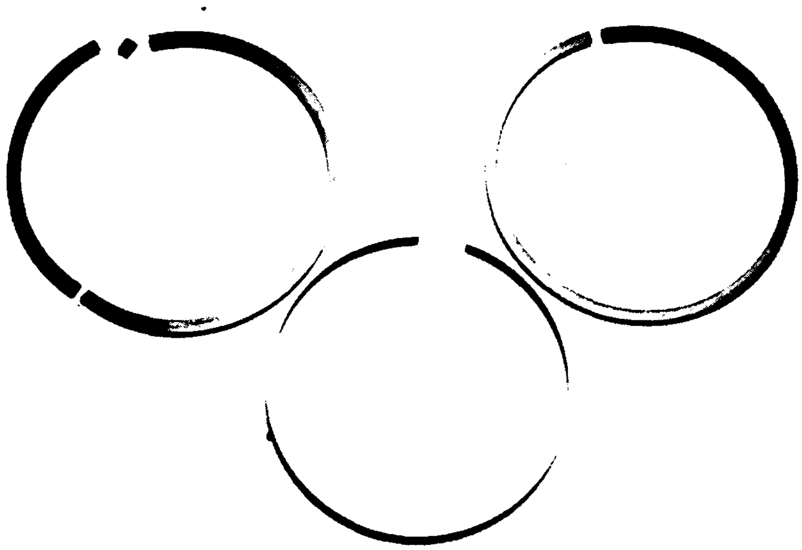


LARGE ACTUATOR 5
SHAMBAN PISTON RING P/N S35985
2,112,000 CYCLES TO FAILURE
RING REMOVED AFTER 2,816,000 CYCLES

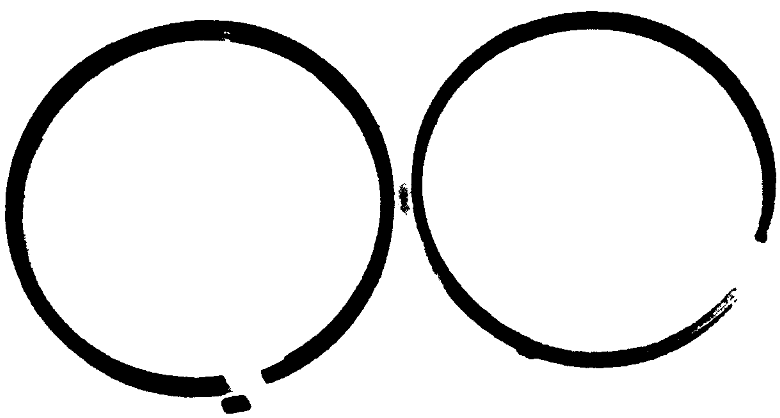
SMALL ACTUATOR 8
CONOVER SECONDARY ROD SEAL
P/N CEC 6001-214-L9
PRIOR TO REMOVAL FROM THE GLAND



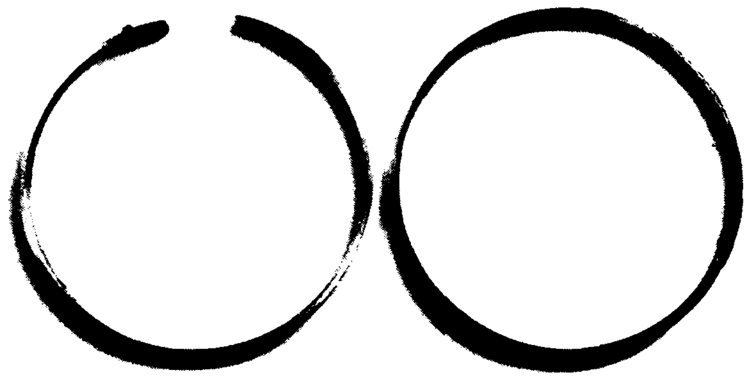
SMALL ACTUATOR 8
CONOVER SECONDARY ROD SEAL
P/N CEC 6001-214-L9
5,868,600 CYCLES



SMALL ACTUATOR 7
PARKER CSD PISTON SEAL
P/N 301641ADP-7
5,868,600 CYCLES

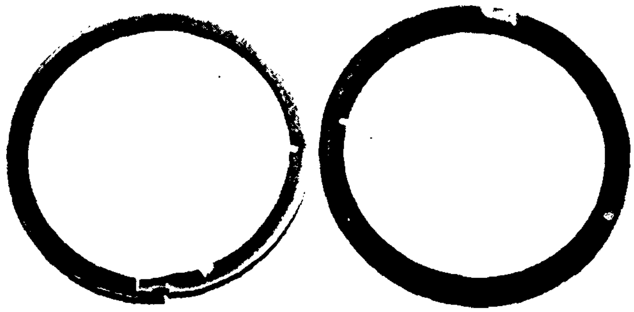


SMALL ACTUATOR 1
DOVER PISTON SEAL
P/N ABP19340
469,000 CYCLES

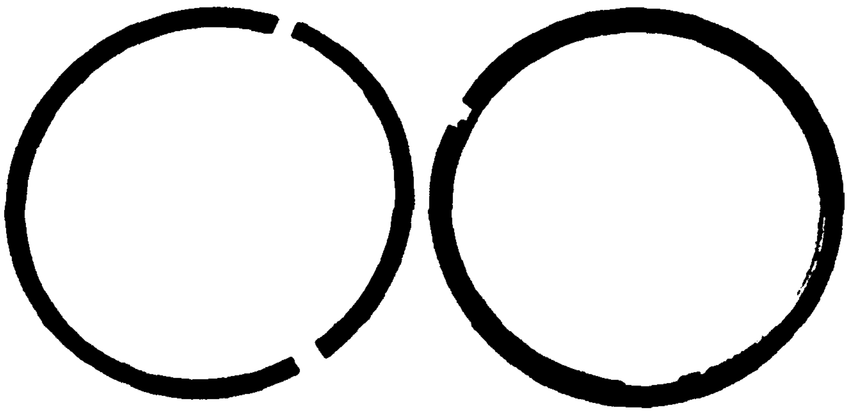


SMALL ACTUATOR 4
KOPPERS PISTON SEAL
P/N C6000-60
234,000 CYCLES TO FAILURE
REMOVED AFTER 938,000 CYCLES

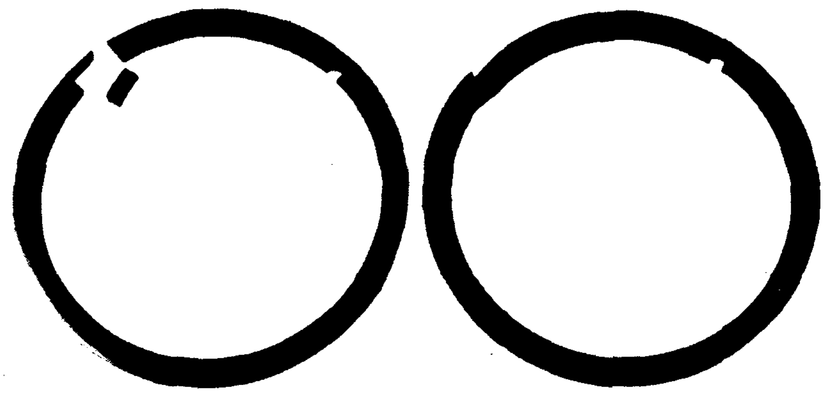
LARGE ACTUATOR 1
ADVANCED PRODUCTS SECONDARY ROD SEAL
P/N 46194/46195
3,652,000 CYCLES
NOTE: 46195 RING NOT SHOWN



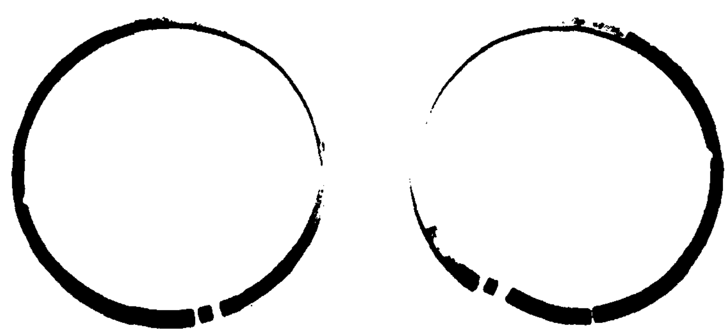
LARGE ACTUATOR 4
SHAMBAN PISTON SEAL
P/N S35985
469,000 CYCLES



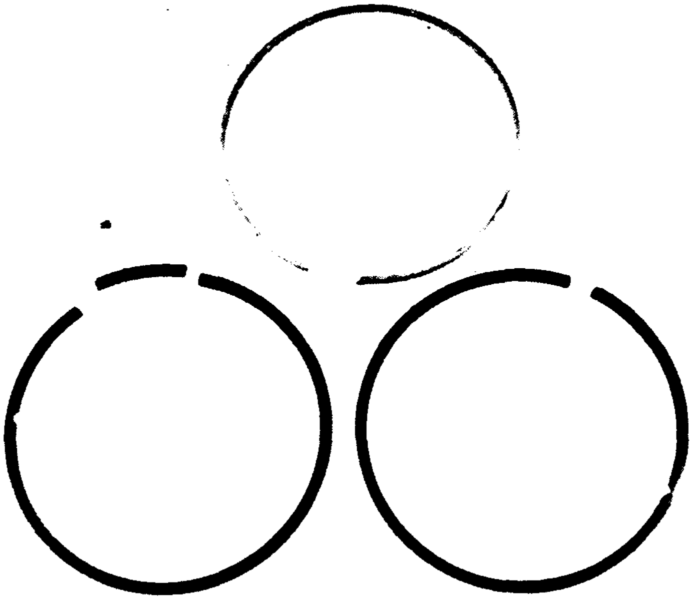
LARGE ACTUATOR 8
PARKER CSD PISTON SEAL
P/N 301641ADP-1
4,694,000 CYCLES



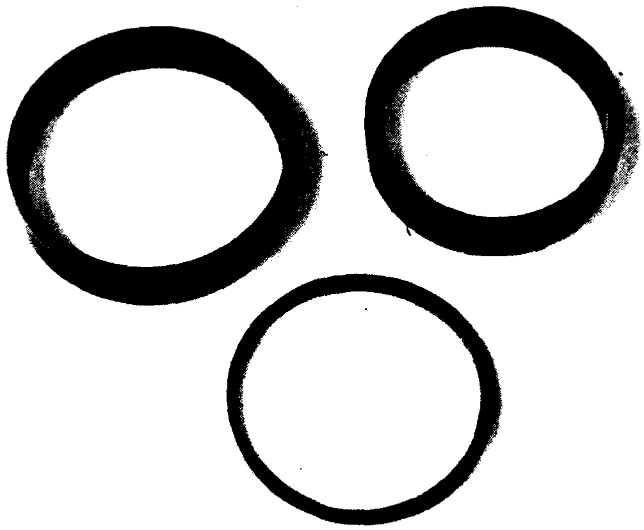
LARGE ACTUATOR 6
SHAMBAN PISTON SEAL
P/N S35985
3,286,000 CYCLES



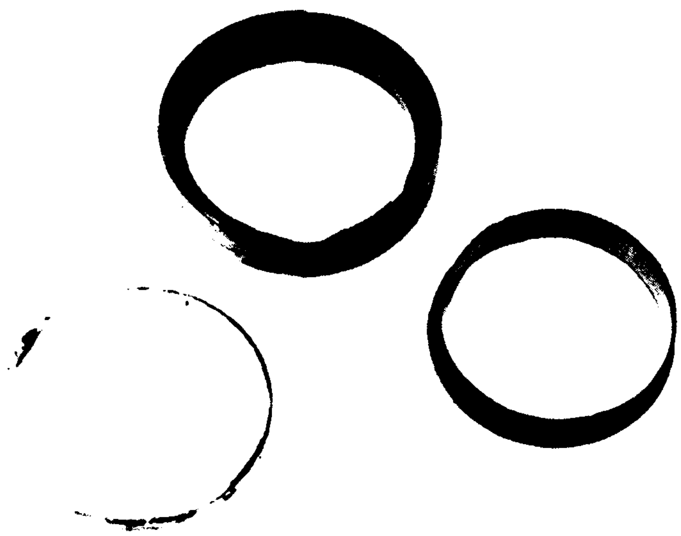
LARGE ACTUATOR 2
DOVER PISTON SEAL
P/N ABP17573
469,000 CYCLES



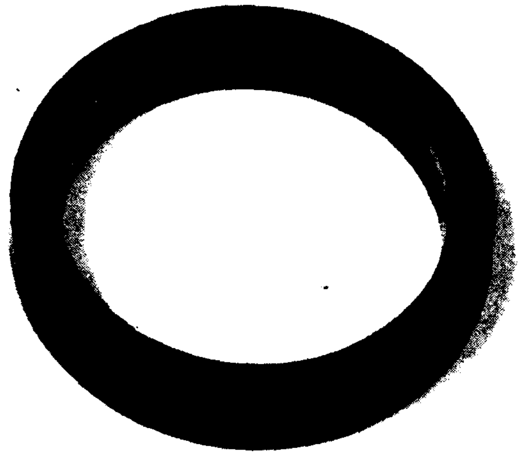
LARGE ACTUATOR 2
DOVER PISTON SEAL
P/N ABP17573
234,000 CYCLES



SMALL ACTUATOR 3
KOPPERS PRIMARY ROD SEAL
P/N C5270B60
6,807,660 CYCLES

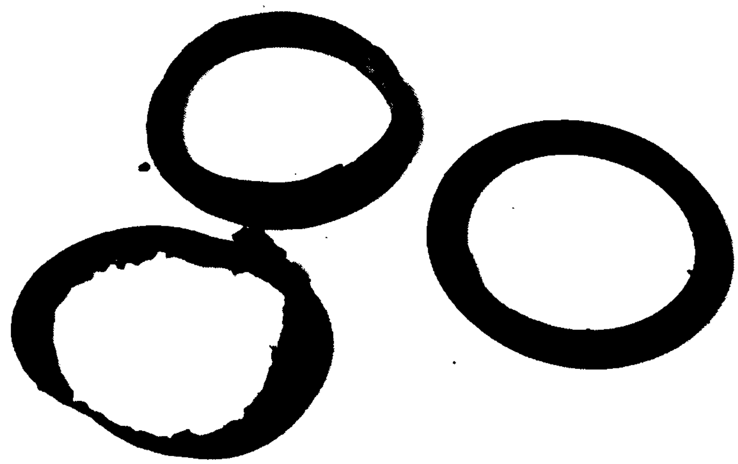


SMALL ACTUATOR 2
GREENE TWEED SECONDARY ROD SEAL
P/N 265-21400-777-1160
9,389,880 CYCLES



SMALL ACTUATOR 2
AMERICAN VARISEAL PRIMARY ROD SEAL
P/N AS 1272
9,389,880 CYCLES

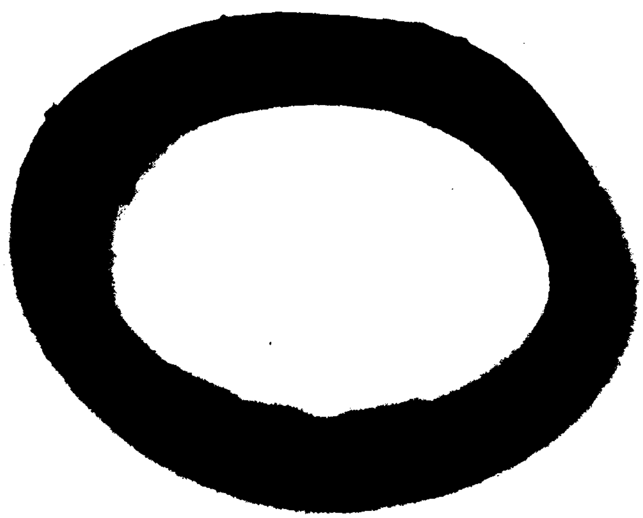
SMALL ACTUATOR 10
PARKER GNP PRIMARY ROD SEAL
P/N ML 1839-2/KLON833
ML 1854/V1098-85
ML 1841-XP2714-2
8,920,386 CYCLES



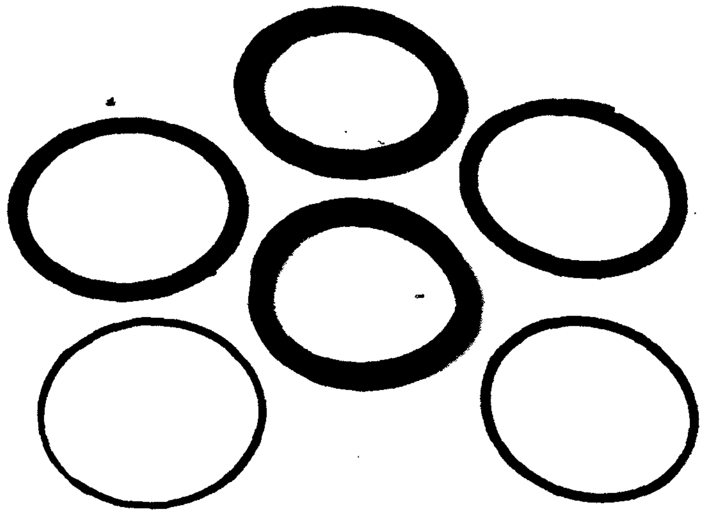
SMALL ACTUATOR 3
C.E. CONOVER SECONDARY ROD SEAL
P/N CEC 6001-214-L9
9,389,880 CYCLES

LARGE ACTUATOR 6
FLUOROCARBON PRIMARY ROD SEAL
P/N AR104974
6,338,170 CYCLES

LARGE ACTUATOR 1
ADVANCED PRODUCTS SECONDARY ROD SEAL
P/N 46194/46195
4,094,700 CYCLES



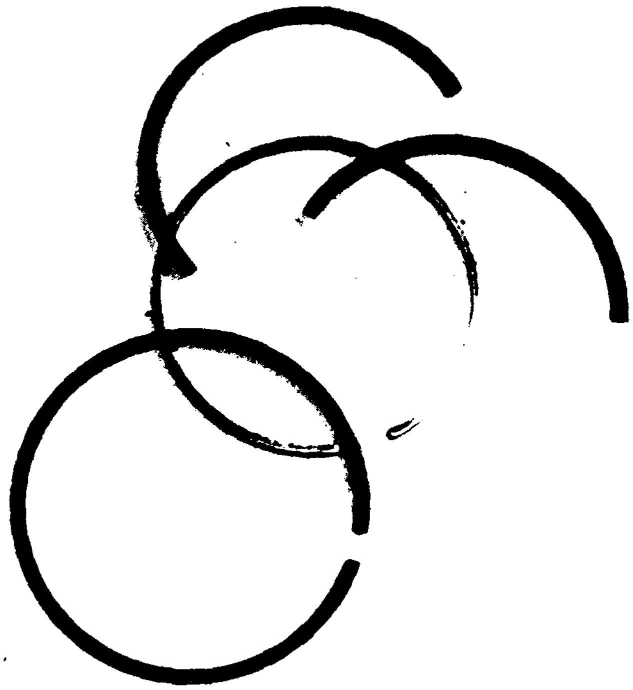
LARGE ACTUATOR 1
ADVANCED PRODUCTS SECONDARY ROD SEAL
P/N 46194/46195
4,094,700 CYCLES



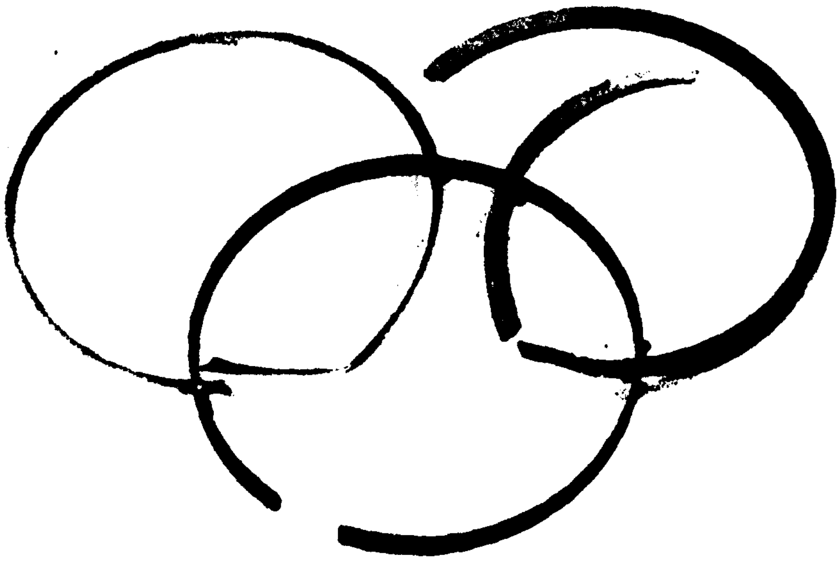
LARGE ACTUATOR 7
SHAMBAN PRIMARY ROD SEAL
P/N 535968
6,338,170 CYCLES

LARGE ACTUATOR 1
ADVANCED PRODUCTS SECONDARY ROD SEAL
P/N 46194
3,286,460 CYCLES

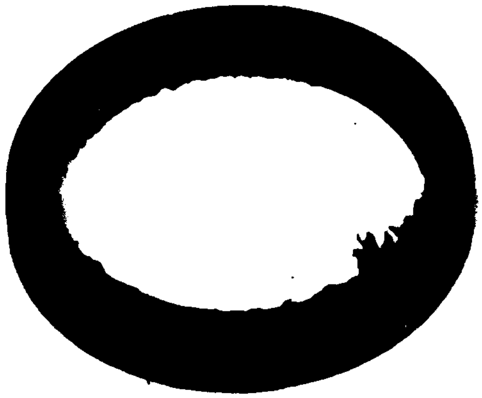
LARGE ACTUATOR 6
GREENE TWEED SECONDARY ROD SEAL
P/N 265-32600-777-1160
11,033,110 CYCLES



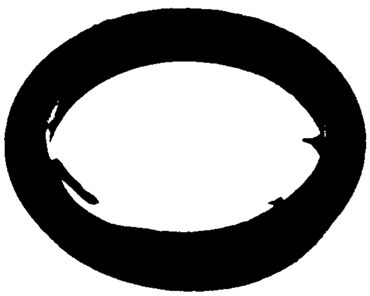
LARGE ACTUATOR 1
DOVER PISTON SEAL P/N ABP17573 REV 3
1,643,230 CYCLES



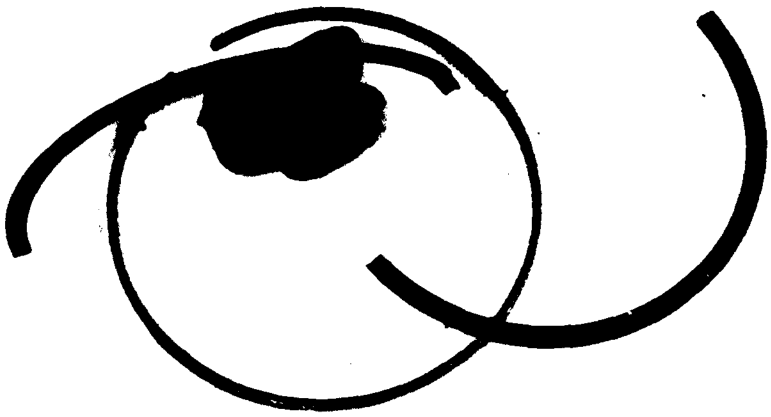
LARGE ACTUATOR 8
PARKER CSD PISTON SEAL P/N 301641SK5
938,000 CYCLES



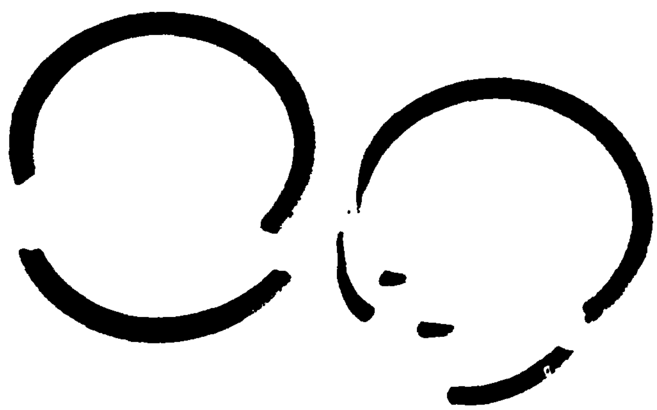
LARGE ACTUATOR 1
BAL SEAL PRIMARY ROD SEAL
P/N X15033
7,277,150 CYCLES



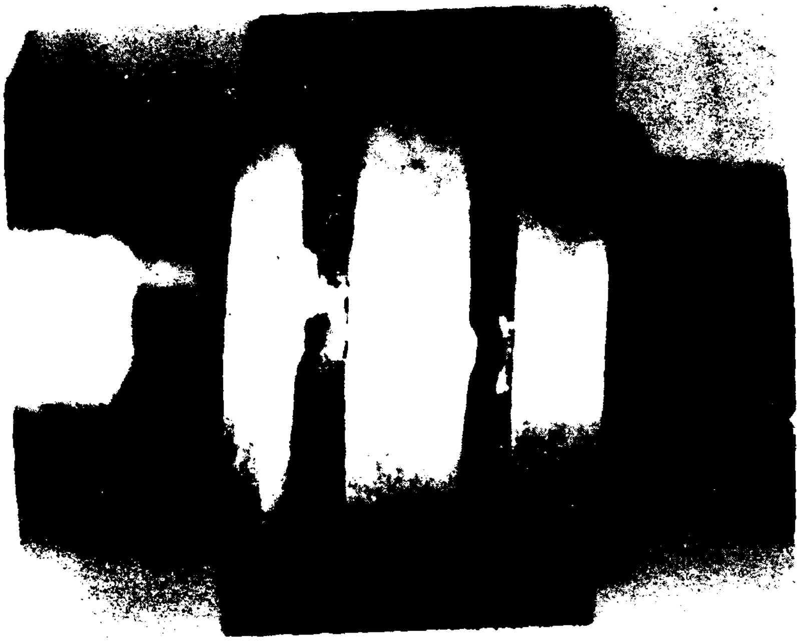
SMALL ACTUATOR 5
PARKER GNP PRIMARY ROD SEAL
P/N ML189-2/KLON 833
ML1854/V1098-85
9,624,630 CYCLES



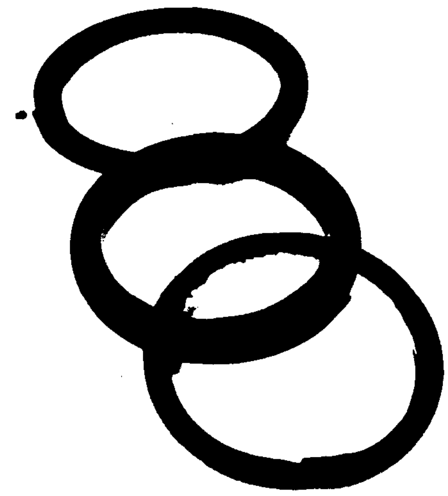
SMALL ACTUATOR 1
DOVER PISTON SEAL P/N ABP17572 REV 2
1,173,730 CYCLES



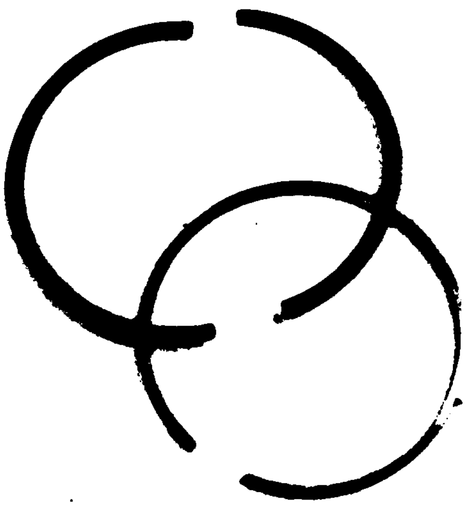
SMALL ACTUATOR 7
PARKER CSD PISTON SEAL
P/N 301641SK4
469,490 CYCLES



SMALL ACTUATOR 3
DOVER PISTON SEAL P/N ABP17572 REV 2
1,643,230 CYCLES

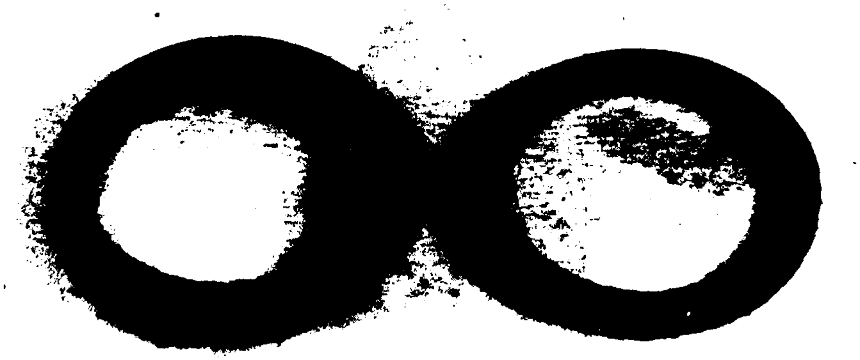


SMALL ACTUATOR 7
SHAMBAN PRIMARY ROD SEAL
P/N S36470
11,033,110 CYCLES

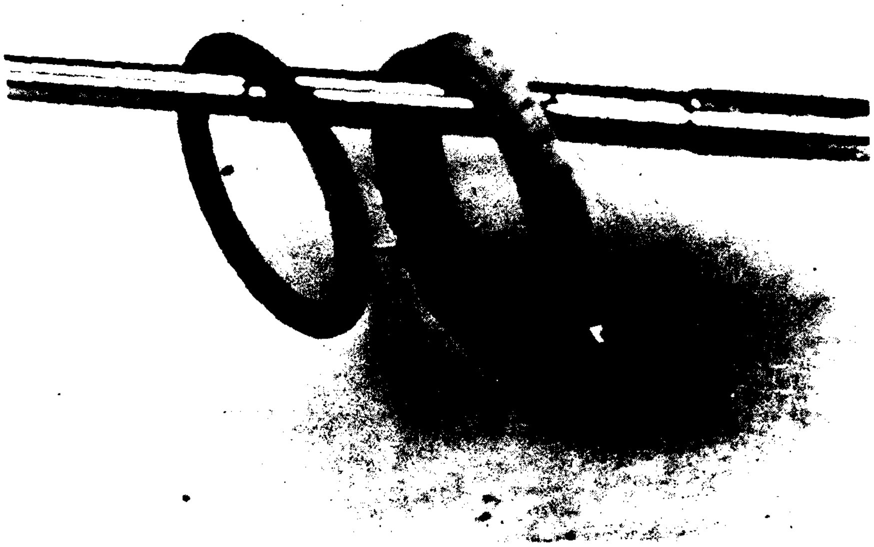


SMALL ACTUATOR 3
DOVER PISTON SEAL P/N ABP17572 REV 2
1,643,230 CYCLES

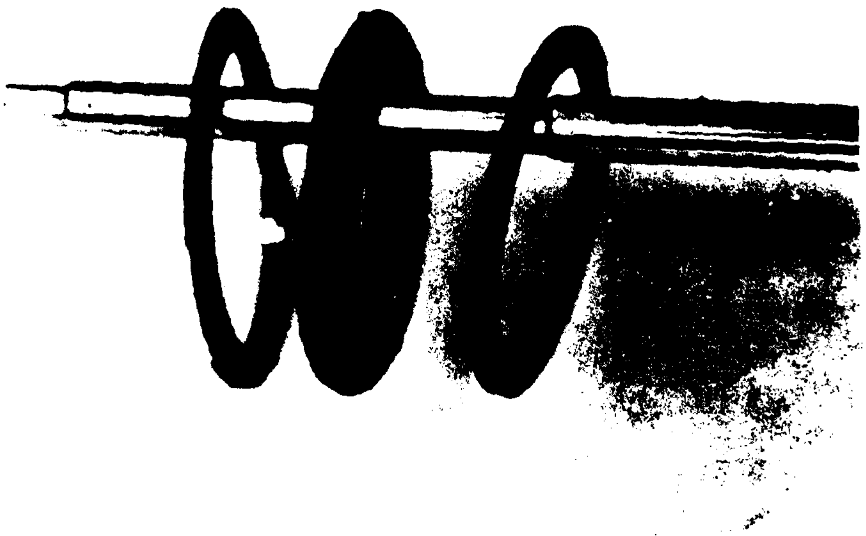
SMALL ACTUATOR # 1
BALSEAL X10243
PRIMARY ROD SEAL
12,200,000 CYCLES-NO FAILURE



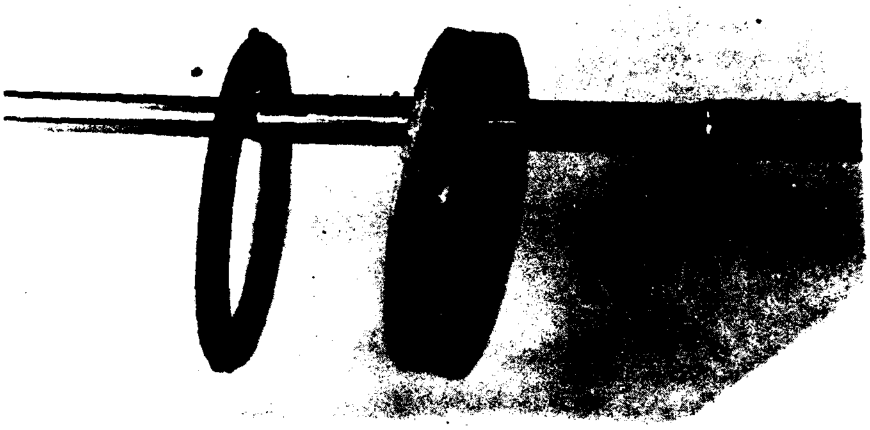
SMALL ACTUATOR # 1
ADVANCED PRODUCTS 46203146204
SECONDARY ROD SEAL
12,200,000 CYCLES-NO FAILURE



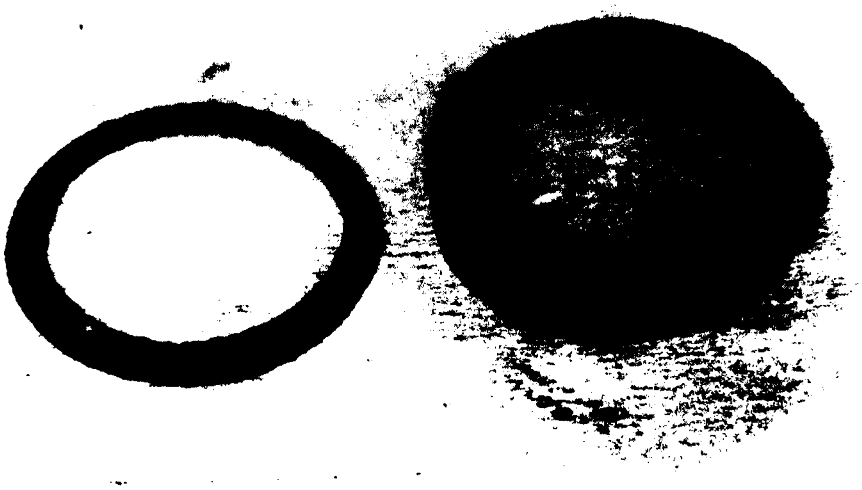
SMALL ACTUATOR # 4
TETRAFLUOR TF888S121685-31/SD851216-51
PRIMARY ROD SEAL
12,200,000 CYCLES-NO FAILURE



SMALL ACTUATOR # 4
SHAMBAN S36471
SECONDARY ROD SEAL
12,200,000 CYCLES-NO FAILURE



SMALL ACTUATOR # 5
TETRAFLUOR TF888S121685-31/SD851216-51
SECONDARY ROD SEAL
12,200,000 CYCLES-NO FAILURE

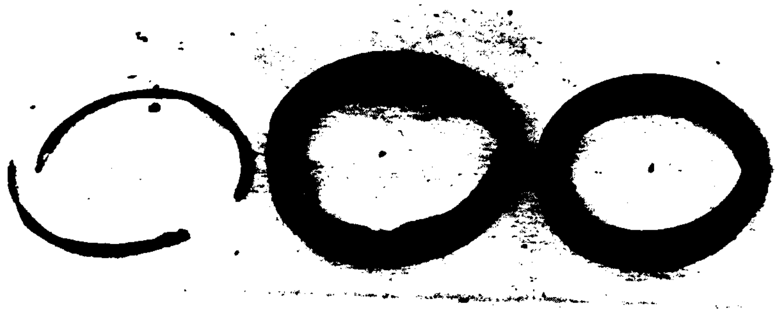


SMALL ACTUATOR # 6
FLUOROCARBON
PRIMARY ROD SEAL
12,200,000 CYCLES-NO FAILURE

SMALL ACTUATOR # 6
GREENE TWEED 265-21400-177-1160
SECONDARY ROD SEAL

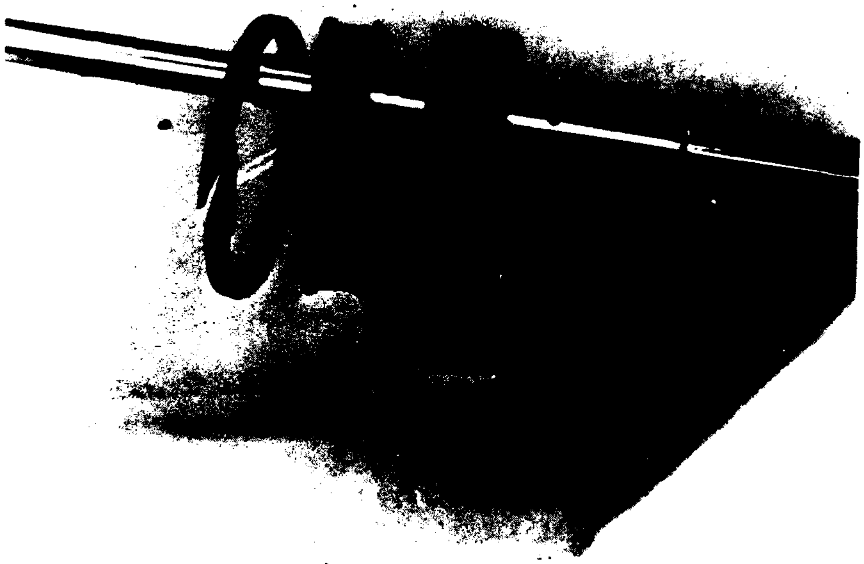
12,200,000 CYCLES-SEAL DID NOT LEAK

SMALL ACTUATOR # 6
SHAMBAN S35982
PISTON SEAL
3,521,000 CYCLES TO FAIL

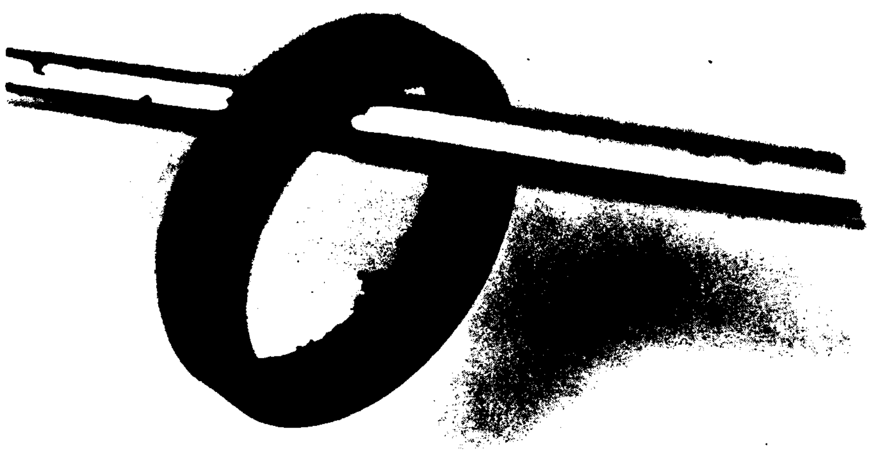


SMALL ACTUATOR # 8
KOPPERS C5270B60
PRIMARY ROD SEAL
1,878,000 CYCLES-SEAL DID NOT LEAK

SMALL ACTUATOR # 8
CONOVER CEC6001-214-L9
SECONDARY ROD SEAL
5,399,000 CYCLES-SEAL DID NOT LEAK

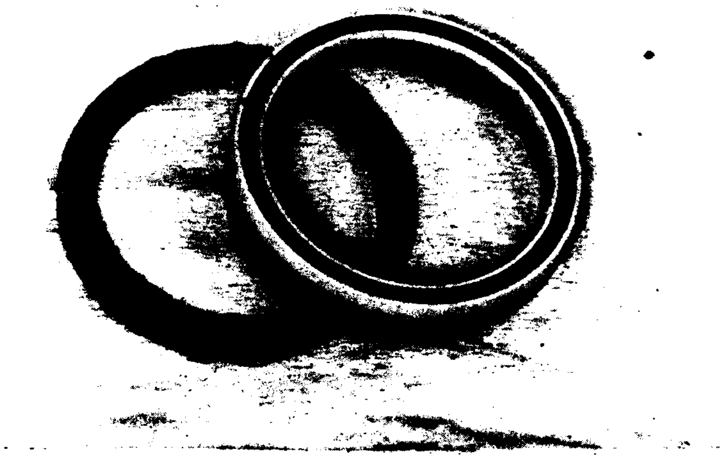


SMALL ACTUATOR # 9
GREENE TWEED 265-21400-777-1160
SECONDARY ROD SEAL
10,329,000 CYCLES TO FAILURE

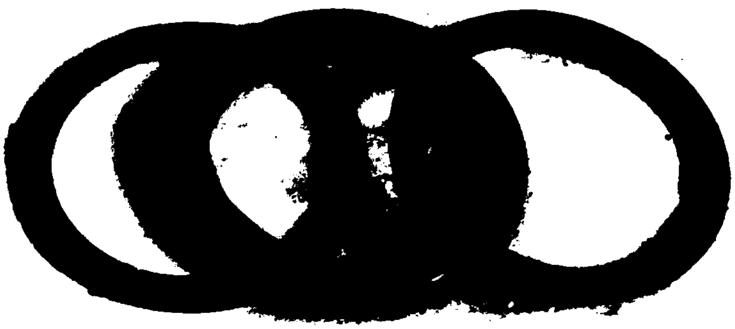


SMALL ACTUATOR # 10
BALSEAL X26266 (LESS BACKUP)
PRIMARY ROD SEAL
3,286,000 CYCLES-NO FAILURE

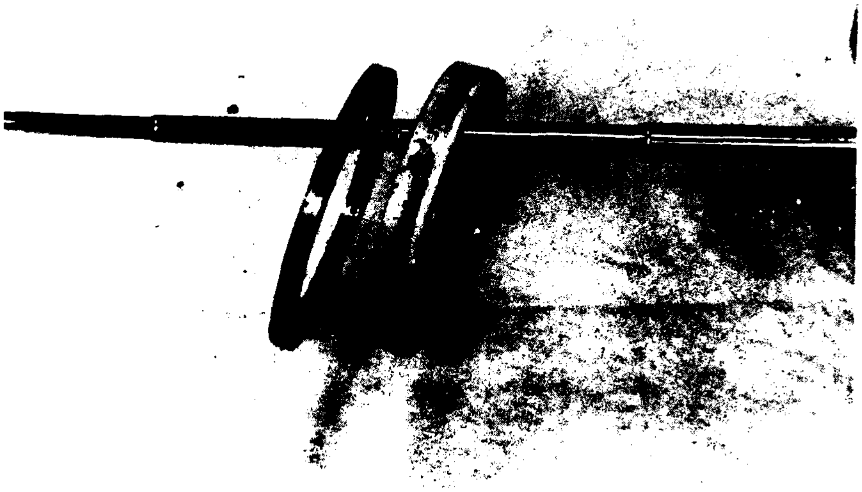
SMALL ACTUATOR # 10
PARKER CSD 301641SK3
PISTON SEAL
2,817,000 CYCLES-NO FAILURE



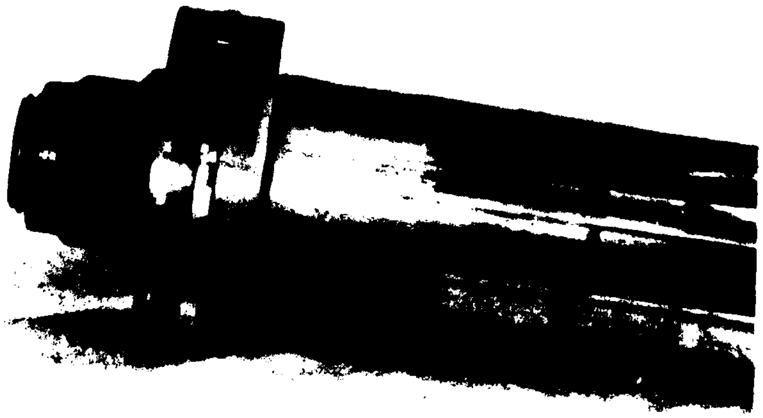
LARGE ACTUATOR # 4
TETRAFLUOR TF888S121685-41
& SD851216-61
PRIMARY ROD SEAL
12,200,000 CYCLES-NO FAILURE



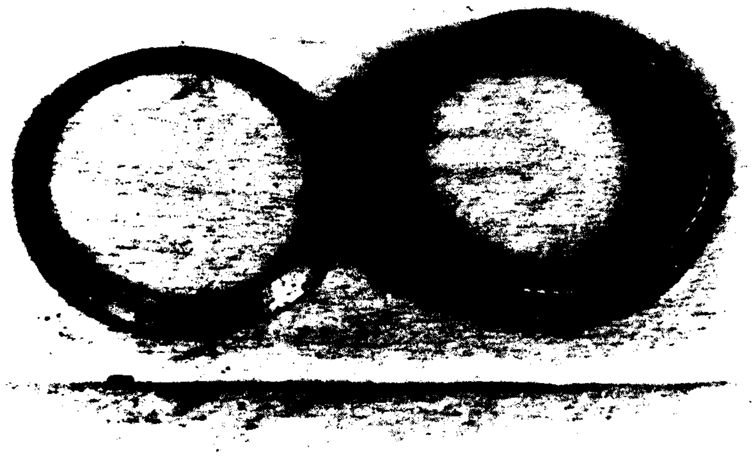
LARGE ACTUATOR # 4
SHAMBAN S35971
SECONDARY ROD SEAL
12,200,000 CYCLES-NO FAILURE



LARGE ACTUATOR # 5
TETRAFLUOR TF888S121685-41
& SD851216-61
SECONDARY ROD SEAL
12,200,000 CYCLES-NO FAILURE



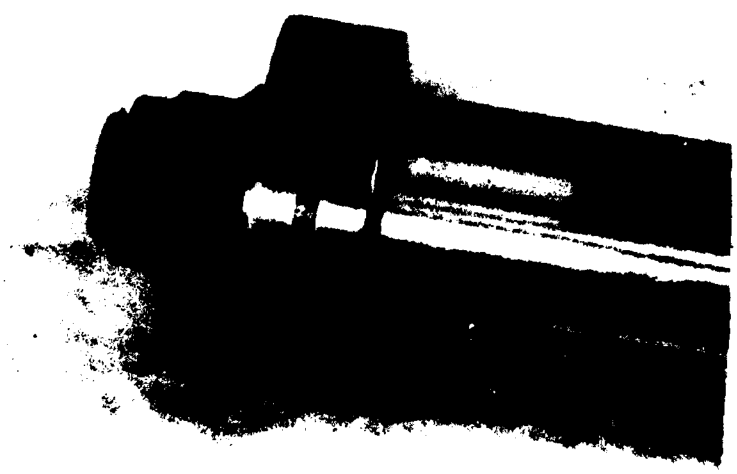
LARGE ACTUATOR # 5
KOPPERS C5980A60
PISTON SEAL
9,390,000 CYCLES-NO FAILURE



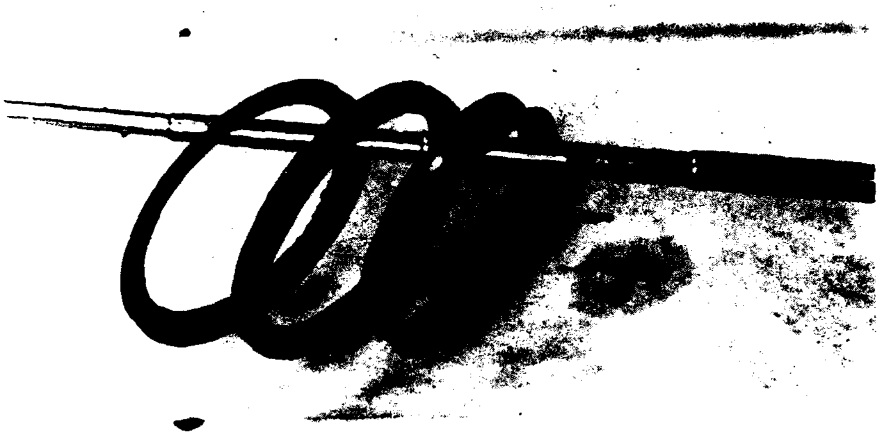
LARGE ACTUATOR # 6
FLUOROCARBON AR104974
PRIMARY ROD SEAL
12,200,000 CYCLES-NO FAILURE

LARGE ACTUATOR # 6
SHAMBAN S35985 PISTON SEAL
6,573,000 CYCLES-NO FAILURE

LARGE ACTUATOR # 10
PRIMARY ROD SEAL
PARKER GNP ML1851/V1098-85/XP2714-4
12,200,000 CYCLES-NO FAILURE



LARGE ACTUATOR # 10
PARKER CSD 301641SK1
PISTON SEAL
6,573,000 CYCLES-NO FAILURE



LARGE ACTUATOR # 3
CONOVER CEC 6001-326-D8
SECONDARY ROD SEAL
12,200,000 CYCLES-NO FAILURE

LARGE ACTUATOR # 7
SHAMBAN S35968
PRIMARY ROD SEAL
8,920,000 CYCLES-NO FAILURE

LARGE ACTUATOR # 2
SECONDARY ROD SEAL
GREENE TWEED 265-32600-818-1200
11,268,000 CYCLES-NO FAILURE

APPENDIX G

INDUSTRY SURVEY

INDUSTRY SURVEY

Parker Hannifin Corporation
Bertea Control Systems Division
18001 Von Karman Avenue
Irvine, CA 92715 USA
Phone (714) 833-3000
Telex 67-8427

September 11, 1984

Gentlemen:

In connection with an Air Force contract for actuator dynamic seal development for 8000 psi CTFE fluid systems and to provide a realistic approach to our test program we are respectfully seeking expert technical opinion from major system users. Specifically, your response to the questions contained in this survey will be appreciated.

Parker Bertea believes that fire proof hydraulic fluids pressurized to 5000-8000 psi will probably become an operational reality in next generation air vehicles. Accordingly, over the past two years, we have devoted design and test activities toward the generation of suitable hydraulic components. Our tested hardware includes solenoid valves, direct drive valves and actuators of the single and tandem variety. Test experiences to date, although somewhat limited in scope, have produced encouraging results particulary when benefits of safety and weight savings are considered. However, the Air Force test program plan now warrants simulated life cycle testing, using aircraft quality actuators, fabricated from high strength, fracture tough materials operating under fly-by-wire aircraft environment and duty cycle. Our plan includes testing of multiple actuators operating with CTFE nonflammable hydraulic fluid at 8000 psi system pressure. Your input to the following will assist our program efforts.

1. Considering an 8000 psi system pressure and fly-by-wire actuator application suggest the size of two surface actuators that may be considered representative for future aircraft.

   Actuator A - Bore ...., piston rod ......, stroke .....
   Actuator B - Bore ...., piston rod ......, stroke .....

2. Assuming the load stroke schedule noted and an aircraft life of 15 years suggest the total number of duty cycles required of the fly-by-wire actuator and approximate cyclic rate.

Percent Stroke Load	Test Duty Cycles	Cyclic Rate
1.0	———	———
2.0	———	———
10.0	———	———
50.0	———	———
100.0	———	———

3. What operating temperatures do you forsee for future fly-by-wire actuators?

   Ambient - From ———°F to ———°F
   Oil - From ———°F to ———°F

4. Assuming that low temperature testing will take place at suitable intervals throughout life testing at what temperature should the test duty cycles be carried out?

   -----% test duty cycles carried out with ----°F
   Oil temperature and ambient temperature of -----°F
   Balance of cycles with ----°F oil and ----°F ambient

5. Based on your test experience to date, using CTFE hydraulic fluid can you offer any comment relative to actuator wearing surface materials and finishes?

6. Based on test experience to date, using 8000 psi hydraulic fluid can you offer any comment relative to allowable static and dynamic fluid seal extrusion gaps?

7. What would be representative actuator output force requirement?

   Small Actuator ------lbs

   Large Actuator ------lbs

8. What would be representative equivalent structural mounting spring rates?

   Small Actuator ------lbs/in
   Large Actuator ------lbs/in

9. What system pressure pulsation range and frequency is considered normal?

   -----psi maximum -----psi minimum Hz.

10. How many no load bottoming cycles would occur in the life of these actuators?

    -----cycles

11. Any Other Comments

Sincerely,

PARKER HANNIFIN CORPORATION
BERTEA CONTROL SYSTEMS DIVISION

Z.J. Janczur
Senior Project Engineer
714/851-3568

INDUSTRY SURVEY RECIPIENT LIST

Wright-Patterson AFB
Department of the Air Force
Wright-Patterson AFB, OH 45433

Attention: K.E. BINNS, AFWAL/POOS

Grumman Aerospace Corporation
Plant 35, B15-35
Bethpage, Long Island, New York 11714

Attention: E.A. ANDERSON

Rockwell International Corporation
4300 E. 5th Avenue
Columbus, OH 43216

Attention: WILLIAM BICKEL

Air Force Wright Aeronautical Labs
Flight Dynamics Laboratory
AFWAL/FIGL
Wright-Patterson AFB, OH 45433

Attention: GREGORY J. CECERE
NAVAL AIR DEVELOPMENT CENTER
ACSTD 60611
Warminster, PA 18974

Attention: J.H. DEVER

VOUGHT CORPORATION
P.O. Box 225907
MS 220-80
Dallas, TX 75222

Attention: G.K. FLING

LOS ANGELES DIVISION, INT'L AIRPORT
ROCKWELL INTERNATIONAL CORPORATION
P.O. Box 92098, MS GC03
Los Angeles, CA 90009

Attention: WILLIAM FRANTZ

MCDONNELL AIRCRAFT COMPANY
Box 516, Lambert Field
St. Louis, MO 63166

Attention: R.J. LEVEK

NAVAL AIR ENGINEERING CENTER
DEPARTMENT OF THE NAVY
Bldg 120, Code 9311
Lakehurst, NJ 08733

Attention: J.A. MARINO

DOUGLAS AIRCRAFT COMPANY
MCDONNELL DOUGLAS CORPORATION
3855 Lakewood Blvd, MS 36-94
Long Beach, CA 90846

Attention: L.S. MCBEE

WRIGHT-PATTERSON AFB
ASD/AEMOF (RA)
Dayton, OH 45433

Attention: GENE POAST

September 11, 1984

BOEING MILITARY AIRPLANE COMPANY
P.O. Box 3707, MS 41-23
Seattle, WA 98124

Attention: E.T. RAYMOND

September 11, 1984

BOEING MILITARY AIRPLANE COMPANY
P.O. Box 3707, MS 41-23
Seattle, WA 98124

Attention: E.T. RAYMOND

September 11, 1984

LOCKHEED
Staff Engineering - Hydraulics
P.O. Box 551
Burbank, CA 91520

Attention: C.S. RHEES

GENERAL DYNAMICS CORPORATION
P.O. Box 748, MS 2604
Fort Worth, TX 76101

Attention: W.M. ROWELL

INDUSTRY SURVEY RECIPIENT LIST

LOCKHEED-GEORGIA CO.
86 South Cobb Drive
Dept 72-20, Mail Zone 419
Marietta, GA 30063

Attention: EDWIN WESLEY RUMRILL JR.

U.S. AIR FORCE
ASD/ENFEM
Wright-Patterson AFB, OH 45433

Attention: F. STRAUS

BOEING MILITARY AIRPLANE COMPANY
ORGN 3-75420, MS-K 75-78
3801 S. Oliver
Wichita, KS 67210

Attention: ERNEST C. WAGNER, Principal Engineer
SEC PWR & MECH

SIKORSKY AIRCRAFT DIVISION
UNITED TECHNOLOGIES CORPORATION
Main Street
Stratford, CT 06497

Attention: KARL H. WALLISCHECK, Supervisor,
Hydraulics/Control

NAVAL AIR SYSTEMS COMMAND
Code Air 53031B
Washington, DC 20361

Attention: E.N. WEBB, Aerospace Engineer

NORTHROP CORPORATION
AIRCRAFT GROUP
One Northrop Avenue
Hawthorne, CA 90250

Attention: JOSEPH P. YAKAL, Hydraulics Engineer
Dept 3252/52

David Roy Bentley
3 Leaf Court
Baden, PA 15005

BOEING MILITARY AIRPLANE COMPANY
P.O. Box 3707
Seattle, WA 98124

Attention: NARINDER AFRI

Northrop Aircraft Division
1 Northrop Avenue
Organization 2520/52
Hawthorne, California 90250

Attention: J. Stalony Dobrzanski

General Dynamics
Fort Worth Division
P.O. Box 748
Fort Worth, Texas 76101

Attention: Darwin White

Lockheed California Company
P.O. Box 551
Burbank, California 91520

Attention: B. N. Rosenbaum

Lockheed California Company
P.O. Box 551
Burbank, California 91520

Attention: O. A. Knuusi

Lockheed California Company
P.O. Box 551
Burbank, California 91520

Attention: J. LeBold

Lockheed California Company
P.O. Box 551
Burbank, California 91520

Attention: W. E. Ripper

Lockheed California Company
P.O. Box 551
Burbank, California 91520

Attention: K. Luminello

INDUSTRY SURVEY RECIPIENT LIST

Rockwell International Corporation
North American Aircraft Operation
P.O. Box 92098
Downey, California 90009

Attention: J. L. Schmidt

Grumman Aerospace
Bethpage
Long Island, New York

Attention: F. Wakefield

Grumman Aerospace
Bethpage
Long Island, New York

Attention: G. Castellano

McDonnell Aircraft
St. Louis, Missouri

Attention: Ralph Hertemark

McDonnell Aircraft
St. Louis, Missouri

Attention: Jack Snyder

McDonnell Aircraft
St. Louis, Missouri

Attention: Neil Pierce

Northrop Aircraft Division
Organization 2520
1 Northrop Avenue
Hawthorne, California 90250

Attention: Wally Nelson

USER SURVEY

Parker Hannifin Corporation
Bertea Control Systems Division
18001 Von Karman Avenue
Irvine, CA 92715 USA
Phone (714) 833-3000
Telex 67-8427

Attention:

October 5, 1984

Gentlemen:

In connection with an Air Force contract for actuator dynamic seal development for 8000 psi CTFE fluid systems and to provide realistic approach to our test program, we are respectfully asking your organization to share with us the experiences (good and bad) with seal configurations and materials already tested and those undergoing development.

The results of our seal develpopment program will be distributed to the industry for application in future generic fighter aircraft.

BACKGROUND

The 8000 psi hydraulic systems are being considered by the United States Navy and Air Force as potential candidates from the weight and required space aspects. The development of the nonflammable hydraulic fluid systems is the result of the concern regarding military aircraft hydraulic fluid fires. A number of aircraft fires, approximately ten (10) per year over the recent past fifteen (15) year period involved the petroleum-base hydraulic fluid in general use in Air Force aircraft. The Air Force development program has identified the CTFE polymer based fluid as the main candidate nonflammable fluid. The high density of this fluid led to a search for weight reduction means, with 8000 psi operating pressure as a potential candidate of this search.

At present, all prime contractors are actively engaged in design and development of 8000 psi systems using CTFE and MIL-H-83282 hydraulic fluids for powering controls of the future generation of aircraft.

Your response to the questions listed below will be helpfull in preparing the screening procedures for the seal configurations proposed by various seal manufacturers.

October 5, 1984
Page 2

QUESTIONNAIRE

Elastomers Tested

Seal Configurations Tested

Test Fluids Used

Test Conditions

Operating pressures
Operating temperatures
External loads
Cycle schedules and rates
Piston rod and cylinder bore finishes
Extrusion gaps
Gland configurations

Problems Experienced

Incompatibility with fluid
Excessive swell
Excessive softening
Loss of strength
Becoming brittle
Abrasiveness
Corrosiveness
Any other problems

Sincerely,

PARKER HANNIFIN CORPORATION
BERTEA CONTROL SYSTEMS DIVISION

Z.J. Janczur
Senior Project Engineer
714/851-3568

National Water Lift Company
2220 Palmer Ave.
Kalamazoo, Michigan 49001

Attention: Richard A. Harlow, Chief Engineer

Martin Marietta Aerospace
P.O. Box 179, M.S. 4011
Denver, Colorado 80201

Attention: D.G. Macumber, Sr. Staff Engineer

E-Systems - Montek Division
2268 S. 3270 W. 127
Salt Lake City, Utah 84119

Attention: Herb C. Friess

Vickers, Inc.
P.O. Box 10177
5353 Highland Drive
Jackson, Mississippi 39206-1177
Attention: Frederic W. Perian, Chief Engineer R&D

TRW Inc.
Defense & Space Systems Group
1 Space Park
Redondo Beach, Calif. 90278
Attention: John Martin

AFWAL/MLBT
Wright Patterson AFB
Ohio, 45433

Attention: Tom Graham

Naval Air Development Center
Aircraft and Crew Systems Technology Directorate
Warminster, Pennsylvania 18974

Attention: John Olsen

Bendix Corp.
Fluid Power Div.
211 Seward Ave.
Utica, NY 13501
Attention: Director of
Research & Devel

Grumman Aerospace Corp.
Grumman Corp.
Plant 35, B15-35
Bethpage, L.I. NY 11714

Attention: E.A. Anderson

MOOG Inc.
E. Aurora. NY 14127

Attention: Kenneth Garnjost

ABEX, Corp.
Aerospace Division
3151 W. 5th St.
Oxnard, Calif. 93030

Attention: Charles A. Kubilos

Hydraulic Research, Controls
Division of Textron Inc.
25200 W. Rye Canyon, Calif. 91355

Attention: Manfred A. Runkel

SUPPLIER SURVEY

Parker Hannifin Corporation
Bertea Control Systems Division
18001 Von Karman Avenue
Irvine, CA 92715 USA
Phone (714) 833-3000
Telex 67-8427

Gentlemen:

In connection with an Air Force contract for actuator dynamic seal development for 8000 psi CTFE fluid systems, we are inviting your participation in the program by recommending seal configurations, being produced or developed by your company, suitable for use in future aircraft nonflammable hydraulic fluid (CTFE) systems.

The evaluation/test program is outlined below. Multiple seals will be required for testing. It is not Parker Bertea's intention to request your contribution of the seal materials.

Your comments, suggestions, ideas and any reference materials and reports will be welcome.

BACKGROUND

The 8000 psi hydraulic systems are being considered by the United States Navy and Air Force as potential candidates from the weight and required space aspects. The development of the nonflammable hydraulic fluid systems is the result of the concern regarding military aircraft hydraulic fluid fires. A number of aircraft fires, approximately ten (10) per year over the recent past fifteen (15) year period involved the petroleum-base hydraulic fluid in general use in Air Force aircraft. The Air Force development program has identified the CTFE polymer based fluid as the main candidate nonflammable fluid. The high density of this fluid led to a search for weight reduction means with 8000 psi operating pressure as a potential candidate of this search.

At present, all prime contractors are actively engaged in design and development of 8000 psi systems using CTFE and MIL-H-83282 hydraulic fluids for powering controls of the future generation of aircraft.

POTENTIAL REQUIREMENTS

Operating Fluid:	Chlorotrifluoroethylene (CTFE) hydraulic fluids. For basic properties of the fluid, see Appendix 1.
Operating Pressure Range:	0 to 8000 psi
Proof Pressure	0 to 12000 psi
Burst Pressure	0 to 18000 psi
Operating Temperature Range:	-65°F to +275°F steady state
Ambient Temperature Range:	-65°F to +275°F steady state with growth potential to +350°F
Δ Pressure across the seal:	Operating 0 to 8000 psi Proof 0 to 12000 psi Burst 0 to 18000 psi
Decompression rate:	8000 psi to 0 psi: 10 msec
Gland Design:	In accordance with MIL-G-5514 (preferred), MIL-G-5514 modified to supplier suggestions
Life Expectancy:	Operational - 40,000,000 mixed (load stroke) cycles Storage - TBD

DESIGN AND DEVELOPMENT PROGRAM

The program will consist of two parts:

(i) Design Study - mostly analytical (Suppliers and Parker Bertea)

(ii) Development Test (Parker Bertea only)

DESIGN STUDY

The seals submitted for evaluation shall be:

(i) Compatible with CTFE polymer-base hydraulic fluids.

(ii) Designed to work in the existing standard gland configurations in accordance with MIL-G-5514, or in the seal supplier modified MIL-G-5514 glands.

Note: Alternate gland configurations will be evaluated.

(iii) Compatible with materials commonly used in the design of the flight controls e.g. low alloy steels, corrosion resistant steels, aluminum alloys, titanium alloys.

(iv) Supported by analysis underlining seal design features.

(v) Not affected by sudden decompression.

DEVELOPMENT TEST - PARKER BERTEA RESPONSIBILITIES

The seals/seal configurations selected on the basis of the design studies submitted by the supplier and those conducted by Parker Bertea will be subjected to a dynamic screening test amounting to 10% of the required life test. Finally, the most promissing seals/seal sets will be subjected to full 40,000,000 mixed cycle life test.

The dynamic test fixture will be designed to represent actual flight hardware. The magnitude of side loads will be determined at a later date. The fixture will permit the measurement of seal friction by means of load cells.

Testing will be conducted under maximum and minimum extrusion gap conditions to be defined at a later date, and with several surface finishes also to be defined at a later date.

Sincerely,

PARKER HANNIFIN CORPORATION
BERTEA CONTROL SYSTEMS DIVISION

Z.J. Janczur
Senior Project Engineer
714/851-3568

SEAL SUPPLIER SURVEY RECIPIENT LIST

Dover Corporation/Cook Airtomic Div.
P.O. Box 1038
Louisville, Kentucky 40201

B.F. Goodrich Co.
Fabricated Polymer Division
500 S. Main Street
Akron, Ohio 44318

Selastomer Chicago
A Microdot Company
347 E. Green Street
Bensenville, IL 60106

W. S. Shamban & Company
1855 Centinela Avenue
Santa Monica, CA 90404

Phelps Packing & Rubber Co., Inc.
One Montgomery Road
Baltimore, Maryland 21227

Sargent Industries
Seal Division
6020 Avinada Encinas
Carlsbad, CA 92008

The Fluorocarbon Company
1754 S. Clementine Street
Anaheim, CA 92803

Tetrafluor, Inc.
2051-53 E. Maple Avenue
El Segundo, CA 90245

Porter Seal Co.
1837 Victory Blvd
Glendale, CA

Bal-Seal Engineering Co.
620 W. Warner Avenue
Santa Ana, CA 92707

The Advanced Product Co.
33 Defco Park Road
North Haven, CN 06473

Parco
2152 Parco Avenue
Ontario, CA 91761

Accratronics of California
2211 Holywood Way
Burbank, Ca. 91505

C.E. Conover & Co., Inc.
333 Passaic Avenue
Fairfield, NJ 07006

Greene Tweed & Co.
Department 62
North Wales, PA 19454

Raybestos-Manhattan, Inc.
P.O. Box 5205
North Charleston, SC 29406

Dowty Corporation
Seal Division
P.O. Box 5000
Sterling, VA 22170

Sterling Plastic & Rubber Products, Inc.
548 Rte 35, P.O. Box 697-T
South Amboy, NJ 08879

Kirkhill Rubber Company
Cypress Court
Brea, CA 92621

National O-Rings
A Division of Federal Mogue
11634 Patton Road
Downey, CA 90241

Disogrin Industries Corporation
Grenier Industrial Airpk
Manchester, NH 03103

Precision Rubber Products Corporation
Hartmann Drive
Lebarron, TN 37087

Minnesota Rubber Company
3628 Woodale Avenue
Minneapolis, MN 55416

Parker Hannifin Corporation
Seal Group
10567 Jefferson Blvd
Culver City, CA 90230

APPENDIX H

8,000 PSI TEST LITERATURE

LIST OF PAPERS AND REPORTS ON
HIGH PRESSURE AIRCRAFT HYDRAULIC SYSTEMS AND
NONFLAMMABLE HYDRAULIC FLUID SYSTEMS

Reports on High Pressure Systems

1. THEORETICAL STUDY OF VERY HIGH PRESSURE FLUID POWER SYSTEMS, 10/15/66, AD 803 870

2. LIGHTWEIGHT HYDRAULIC SYSTEM DEVELOPMENT, 5/83, AD 911 672L

3. PREPARATIONS FOR LIGHTWEIGHT HYDRAULIC SYSTEM HARDWARE ENDURANCE TESTING, 12/73, AD B-001 857L

4. LIGHTWEIGHT HYDRAULIC SYSTEM HARDWARE ENDURANCE TEST, 3/75, AD A-013 244

5. DESIGN AND TEST OF AN LHS LATERAL CONTROL SYSTEM FOR A T-2C AIRPLANE, 5/76, AD A-032 677

6. FLIGHT TEST OF AN 8000 PSI LIGHTWEIGHT HYDRAULIC SYSTEM, 4/77, AD A-039 717/4GA

7. LIGHTWEIGHT HYDRAULIC SYSTEM EXTENDED ENDURANCE TEST, 9/78, AD A062 749

8. Navairsyscom N R72H-20, APPLICATION OF VERY HIGH PRESSURE HYDRAULIC SYSTEMS TO AIRCRAFT, 3/72

9. Navairdevcen 75085-30, LIGHTWEIGHT HYDRAULIC SYSTEM HARDWARE ENDURANCE TEST 3/75

10. Navairdevcen 76166-30, DESIGN AND TEST OF AN LHS LATERAL CONTROL SYSTEM FOR A T-2C AIRPLANE, 5/76

11. Presentation at Meeting No. 82 SAE A-6 Committee, LHS ADVANCED DEVELOPMENT PROGRAM AND FLIGHT TEST OF A LIGHTWEIGHT HYDRAULIC SYSTEM, 4/77

12. Navairdevcen 77098-30, FLIGHT TEST OF AN 8000 PSI LIGHTWEIGHT HYDRAULIC SYSTEM, 4/77

13. SAE Report 771007, FLIGHT TESTING AN 8000 PSI LIGHTWEIGHT HYDRAULIC SYSTEM, 11/77

14. Navairdevcen 77218-30, LIGHTWEIGHT HYDRAULIC SYSTEM EXTENDED ENDURANCE TEST, 9/78

15. Presentation at Meeting No. 85 SAE A-6 Committee, FLIGHT VERIFICATION OF THE ADVANCED FLIGHT CONTROL ACTUATION SYSTEM IN THE T-2C AIRCRAFT, 10/78

16. Presentation at Meeting No. 85 SAE A-6 Committee, LIGHTWEIGHT HYDRAULIC SYSTEM ADVANCED DEVELOPMENT PROGRAM, 10/78

17. SAE Committee G-3 Report Col 17757A, LIGHTWEIGHT HYDRAULIC SYSTEM DEVELOPMENT AND FLIGHT TEST, 2/80

18. Vickers 27th Fluid Power Conference, HIGH PRESSURE HYDRAULIC SYSTEMS, 11/80

19. DESIGN, DEVELOPMENT, AND EVALUATION OF LIGHTWEIGHT HYDRAULIC SYSTEM HARDWARE - PHASE I, 1/81, NADC-77108-30

20. HYDRAULIC ADVANCED TECHNOLOGY PROGRAM, 12/81, NADC 80247-60

21. APPLICATION STUDY OF VERY HIGH PRESSURE HYDRAULIC SYSTEMS TO THE F-14 AIRCRAFT, 12/71, MD-864082-V1

22. EVALUATION OF MS-6 FIRE RESISTANT FLUID FOR 8000 PSI LIGHTWEIGHT HYDRAULIC SYSTEMS, 10/81, NADC 79120-60

23. DYNAMIC SEAL FOR ADVANCED HYDRAULIC SYSTEM, 8/81, AFWAL-TR-81-2066

24. HYDRAULIC SYSTEM SEAL DEVELOPMENT, 6/81, USAAVRADCOM TR-81-D-17

Reports on Nonflammable Hydraulic Systems

1. AFAPL-TR-79-2055, 7/79, ASSESSMENT OF THE FLAMMABILITY OF AIRCRAFT HYDRAULIC FLUIDS

2. AFML-TR-79-4143, 1/80, DEVELOPMENT OF SEALS FOR NONFLAMMABLE HYDRAULIC FLUIDS

3. Journal of the American Society of Lubrication Engineers, Vol 36, No. 8, 8/80, DEVELOPMENT OF A NONFLAMMABLE HYDRAULIC FLUID FOR AEROSPACE APPLICATIONS OVER A -54° TO 135°C TEMPERATURE

4. AFAPL-TR-79-2095, 10/80, DYNAMIC, HOT SURFACE IGNITION OF AIRCRAFT FUELS AND HYDRAULIC FLUIDS

5. AIAA-81-1716-1721, 8/13/81, (American Institute of Aeronautics and Astronautics) NONFLAMMABLE AIRCRAFT HYDRAULIC SYSTEM DEVELOPMENT

6. AFWAL-TR-80-2111, 3/82, DESIGN GUIDE FOR AIRCRAFT HYDRAULIC SYSTEMS AND COMPONENTS FOR USE WITH CHLOROTRIFLUOROETHYLENE NONFLAMMABLE HYDRAULIC FLUIDS

7. AFWAL-TR-80-2112, 7/82, FIRE RESISTANT AIRCRAFT HYDRAULIC SYSTEM

8. AFWAL-TR-81-2080, 9/81, FIREPROOF BRAKE HYDRAULIC SYSTEM

9. SAE Technical Paper No. 821566, 10/13/82, NONFLAMMABLE AIRCRAFT HYDRAULIC SYSTEMS DEVELOPMENT

10. Technical Paper ASD832159, NONFLAMMABLE HYDRAULIC SYSTEM DEVELOPMENT FOR AEROSPACE

APPENDIX I

MTI REPORT

MTI 85TR61

EVALUATION OF SEALING MATERIALS AND SEAL DESIGN FOR HIGH PRESSURE CTFE NON-FLAMMABLE HYDRAULIC SYSTEMS

Prepared by:

J. Giordano
C. Lee
L. Winn

Prepared for:

Parker Hannifin Corporation
Control Systems Division
Irvine, CA

September, 1985

MECHANICAL TECHNOLOGY INC.
968 Albany-Shaker Road
Latham, New York 12110

ACKNOWLEDGEMENT

The authors wish to acknowledge the valuable contributions made by Mr. M. Eusepi in designing the test vehicle and Mr. D. Kubish in carrying out the tests. Special thanks are due to Dr. E. Zorzi for his guidance in the finite element modeling of the seal configuration.

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1.0 INTRODUCTION

This report describes the work performed by Mechanical Technology Incorporated (MTI) as a subcontractor to Parker Hannifin Corporation, Bertea Control Systems Division (BERTEA) under Purchase Order Number R70064. The work was carried out within the framework of Bertea's program with the United States Air Force, Air Systems Command, Contract Number F33615-84-C-2416, entitled "High Pressure Hydraulic Seals".

MTI's contribution to this program consisted of:

- Seal material wear and evaluation tests in fluid.
- Analyses and design of an actuator piston ring set.
- Analyses and design of an actuator rod seal.

The seal materials to be evaluated were selected by Bertea. Chlorotrifluoroethylene (CTFE-A02) fully formulated hydraulic fluid was supplied by A.F.A.P.L. The sealing concepts for the hydraulic rod seals and piston rings capable of operation at 8,000 psi were developed by M.T.I. Out of a number of concepts considered, one rod and one piston ring configuration was picked for detailed analyses and design. A summary of the work performed, together with the conclusions and recommendations are given in Section 2 of this report.

2.0 SUMMARY

Evaluation of potential seal material candidates for use in the new generation of non-flammable chlorotrifluoroethylene (CTFE) hydraulic fluids was performed. Studies were also carried out of new or improved sealing devices capable of operating in CTFE at pressures up to 8,000 psi.

Out of a number of potential material candidates, three materials were selected for evaluation on a new test vehicle specifically designed to simulate conditions of rod seal operation in CTFE fluids.

The selected materials were:

- Green & Tweed's Arlon 1,000 (PEEK)
- Dupont's VESPEL SP1
- Bal-Seal's GFD (PTFE plus graphite)

Coefficients of friction, wear and resistance to "cold flow" (extrusion) under pressure and at temperatures of 275°F served as the main criteria for material ranking.

Current hydraulic seal designs were reviewed and new concepts studied. The high pressures and reduced lubricity expected in CTFE Systems necessitates an engineering approach to seal design. It was found that for PEEK and VESPEL, currently available finite element structural programs can be employed in the design process to calculate stresses and deflections, although the long-term effect of pressure, temperature and fluid on the structural integrity of the materials are as yet unknown. PTFE, however cannot be handled with a linear code because of its apparent visco-elastic behavior. Utilizing a different modeling technique, the linear program employed predicts that with proper confinement, materials such as PTFE could possibly be used at the conditions anticipated in hydraulic applications using CTFE fluids.

A simple, one-piece rod seal configuration, was selected for analyses and design. This configuration employs an "O"Ring for secondary sealing. The seal is pressure-balanced so as to reduce the radial load acting on the rod. This reduces the neat generated at the seal-to-rod interface and indirectly aids in the improvement of wear and leakage characteristics. Most of the currently employed hydraulic seals put little emphasis on this aspect of seal design.

The piston ring represents a less critical component because excessive leakage does not result in loss of hydraulic fluid from the system and is noticed only in the deterioration of actuator performance. For this application, a three-piece piston ring design is suggested. The central ring is solid and made of filled PTFE. Split rings on each side provide the confinement required to avoid extrusion.

2.1 Conclusions

The results of the work reported upon in this report indicate that:

- PEEK was least affected by CTFE soaks.
- The lowest friction was produced by GFD.
- Both PEEK and VESPEL retained their shape during wear tests. GFD did extrude.
- The lowest wear was registered with PEEK.
- No significant differences were observed between chrome plate and tungsten carbide coatings in the wear tests, with the exception of GFD whose wear rate against tunsgten carbide was high.
- A comparison in wear factors between Dupont's wear test results and MTI's using graphite filled PTFE shows good agreement.
- Current linear programs can be used in the design of seals made with modern plastics such as PEEK which exhibit a low degree of visco-elastic behavior.
- More data on the mechanical properties of modern plastics is needed to gain a higher degree of confidence in the analyses.
- Materials exhibiting a high degree of visco-elasticity require improved non-linear codes to enhance the design process.

2.2 Recommendations

1. Most modern plastic materials (exception, PTFE) are poorly character-

ized. New work must be initiated by the manufacturers or users to obtain good, complete data on mechanical and thermal properties.

2. The designs recommended in this report should be subjected to a thorough evaluation on component tests before committing to system use.

3. The state-of-art in finite element codes for structural non-linear visco-elastic systems should be reviewed and if need be advanced.

4. The lubricity of CTFE leaves a lot to be desired. Operation with viscosities less than one centipoise falls at best in the regime of boundary lubrication. This is shown by the increase in coefficients of friction at 275°F, although plastic materials may be made to perform, the performance of steel components in sliding or rolling motion in high temperature CTFE must be watched for wear.

3.0 SEAL MATERIAL TESTS AND EVALUATION

This section describes and identifies the materials selected for test, the evolution of the test vehicle to render it compatible with CTFE (A02) fluids, the instrumentation employed to measure friction and wear, and the data reduction process.

One of the problems encountered early in the material testing process was the volatility of A02. Based upon data on A08, the volatility of CTFE was expected to be close to that of MIL-H-5606, and no serious problems were originally anticipated with an open sump system. Following the first set of soak tests where almost all fluid evaporated in open beakers after 72 hours of exposure to 275°F, special precautions were taken to keep the test fluid at above ambient pressures.

3.1 Selection of Seal Material

Hydraulic seal materials for the high pressure CTFE applications were selected by Bertea. These materials were subjected to soak tests in CTFE at 275°F for 72 hours, and friction and wear tests. The original list contained:

- General Electric's ULTEM 1000 (an amorphous thermoplastic polyether-imide).
- Green and Tweed's ARLON 1000 (a polyether-etherketone, PEEK).
- DART AND KRAFTS XYDAR (an aromatic polyester liquid crystal polymer)
- Dupont's VESPEL SP.1 (high performance polyimide resin)
- Bal-Seal's GFD (PTFE filled with graphite fibers).

Upon closer examination, XYDAR and ULTEM were eliminated from the evaluation procedure; XYDAR because of the still unresolved un-isotropic properties of the material and ULTEM because of the suspected incompatibility with CTFE. The other three materials were subjected to the full wear test procedure.

3.2 Test Rig Description

An oscillating friction test rig was designed, procured and fabricated to conduct the required tests. The rig was designed to measure friction coefficients and wear of test specimens running on disks with different coating and surface finishes. The test rig was designed to have the following capabilities:

- Interchangeability of plastic test specimens
- Utilization of disks with different coating and surface finishes
- Testing with specimens submerged in CTFE
- Operate with a nominal CTFE temperature of 275°F
- Apply known normal load between test specimen and disk
- Impose oscillatory sliding motion between test specimens and disk
- Measure friction force
- Measure overall wear and wear rates

3.2.1 Test Rig Mechanical Hardware

Details of the test rig are shown in Figures 1 and 2. The spindle is driven by a rotary actuator on one end and the test disk attaches to the other end. The spindle is supported on a pair of ball bearings on the actuator end, and a roller bearing on the disk end. The ball bearing pair restrains the shaft axially whereas the roller bearing provides radial support. This arrangment results in high radial rigidity near the test disk and allows for differential thermal expansion of the spindle. The bearings are supported in a housing which provides a rigid support structure for the spindle/bearing assembly. The spindle has a key-way on the actuator end to transmit torque from the actuator.

The test disks are shown in the schematic in Figure 3. The disks are equipped with a 3/8 inch wide coating located on each disk face 1/8 inch from the outside rim edge. Either disk can be attached to the spindle using a three-pin "dutchman". In addition, there is a light interference (≈0.5 mil) between the disk and the spindle. As shown in Figure 1, there is a spacer inboard of the disk to maintain perpendicularity of the disk face and a nut/jam nut arrangement which secures the disk to the spindle.

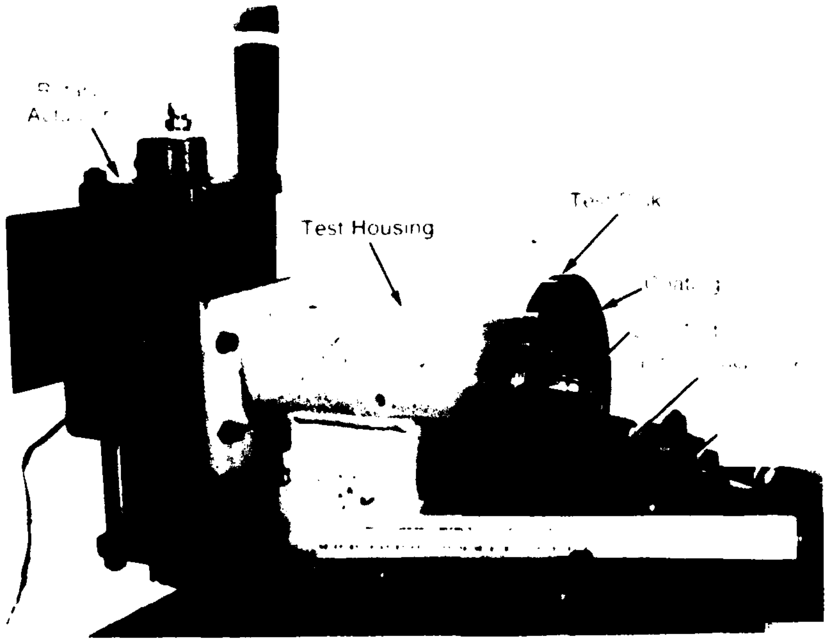


FIGURE 1

PICTURE OF ASSEMBLED TEST RIG

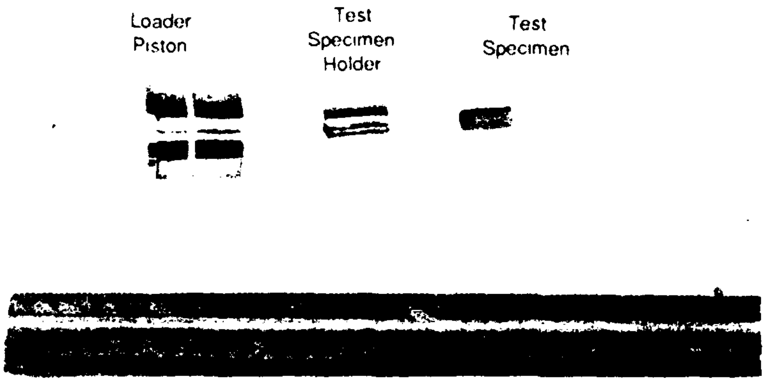


FIGURE 2

TEST SPECIMEN ASSEMBLY COMPONENTS

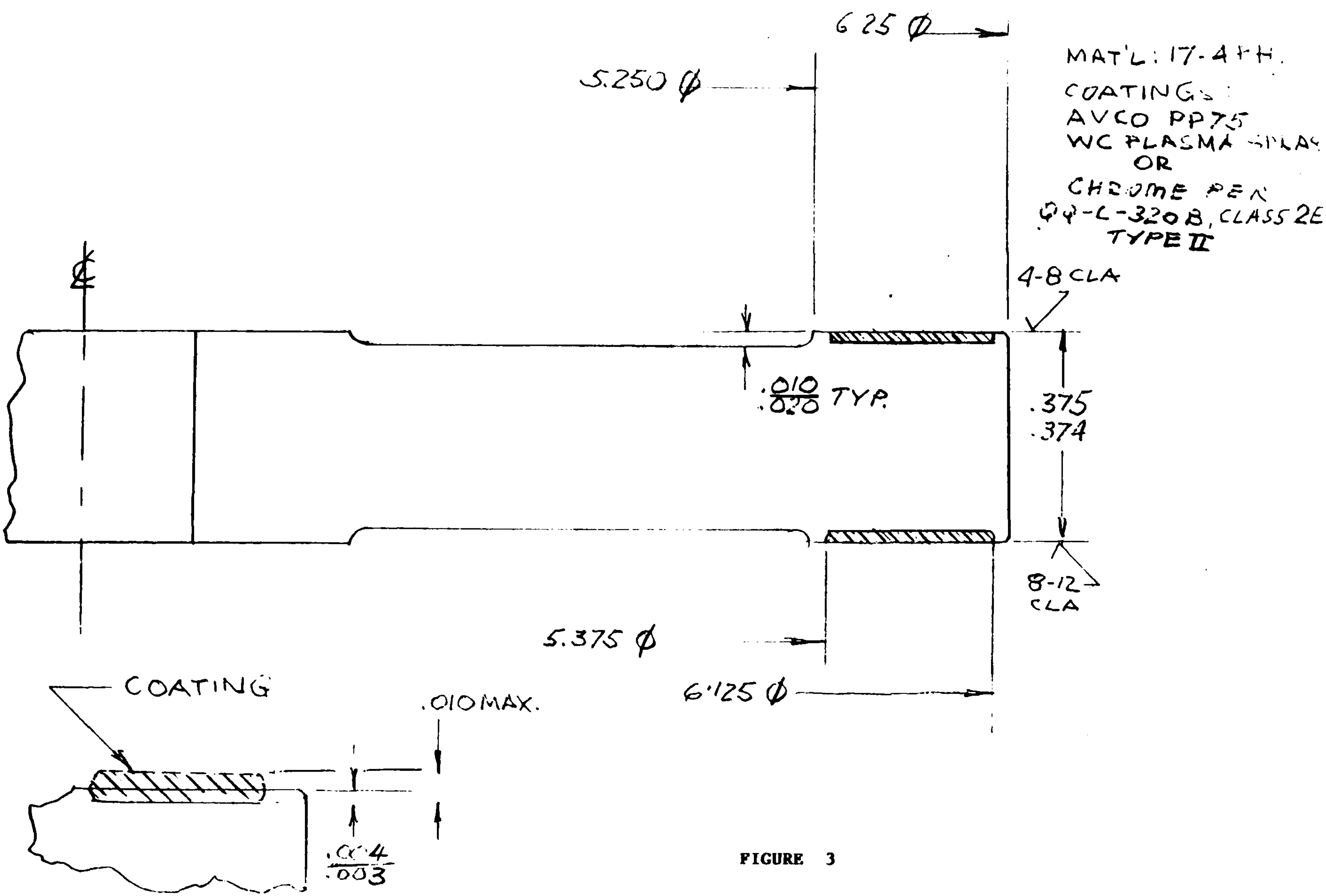


FIGURE 3

TEST DISK COATING SKETCH

The fluid reservoir, which houses the test specimens assembly, is also shown in Figure 1. Since these components were to be in continuous contact with the CTFE, they were made from 17-4PH. The reservoir has two cylindrical ports, one for each of the specimen holder assemblies. The specimen holder assembly consists of a load piston and specimen holder. Test specimens are inserted in the holder which in turn is inserted in the piston (see Figure 2 for additional details). The piston fits in the reservoir port with a seal. Also, the piston has a lip which hits a shoulder in the reservoir to provide a positive stop (referred to as "bottomed out" position). The caliper chamber behind the piston is covered with a cover plate and seal. The chamber can be pressurized to provide normal load between the specimen and the disk. The axial stack up for this assembly is nominally as follows:

1. Specimen sticks out beyond its holder by ≃ 10 mils

2. With no specimen in holder, clearance between disk and holder is ≃ 3 mils when the piston is bottomed out.

Based on the first condition, when a specimen is installed and the caliper chamber is pressurized, a normal load between the specimen and the disk develops. The normal load is varied by changing the pressure. The chamber is pressurized with bottled nitrogen and the pressure is maintained with an in-line regulator. The magnitude of the normal load is calculated using the caliper chamber pressure and the area of the piston. Furthermore, if there is significant specimen wear, there is no risk of damaging the disk. That is, based on Item 2 above, when sufficient specimen material wears away, the piston bottoms out before the specimen holder can contact the disk. Note that there are two specimens, one on each side of the disk. This ensures that no extraneous bending moments are imposed on the spindle and it implies that torque in the spindle is due to the friction of both test specimens. As described later, spindle torque is used to measure friction force.

3.2.2 Oscillation Control

Oscillatory motion between the disk and the test specimens is imposed using a rotary actuator on the spindle shaft, as shown in Figure 1. The actuator is bolted to a flange on the spindle housing and transmits torque through a key. The actuator is operated by alternately supplying pressure to the two ports.

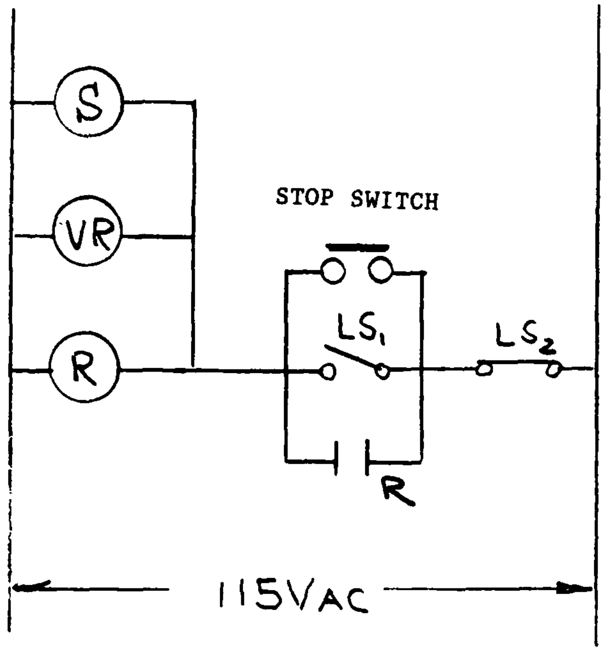
The actuator is controlled using the circuit shown in Figures 4 and 5. The four-way valve alternately pressurizes the two actuator ports. This valve is controlled by two microswitches and a relay in the circuit. The microswitches change from their normal position (i.e., normally opened to closed and vice-versa) when contacted by a lever on the spindle. The microswitches are physically installed on a plate mounted to the actuator housing. Key parameters which control sliding motion between the disk and specimen are the frequency and amplitude of the actuator stroke. Amplitude is controlled by the location of the microswitches (i.e., the arc through which the lever travels between contacting the two switches). Frequency is controlled by varying supply pressure to the actuator. The velocity profile achieved on this apparatus was close to a square wave.

3.2.3 Temperature Control

The reservoir is heated by five (5) Chromalox circular heaters installed in holes in its base. These heaters are installed with a foil wrap and heat conducting grease to ensure good thermal conduction between them and the reservoir. The heaters are wired in parallel and powered with 220 vac through a variac. A temperature controller is used to power a relay which turned the heaters on and off as required. A thermocouple inserted in the fluid bath was used as input to the controller.

3.2.4 Instrumentation

The test rig is instrumented so that friction force, normal load, specimen movement due to wear and temperature can be measured. To measue friction force,



S = 4 WAY SOLENOID VALVE

VR = VEEDER ROOT COUNTER

R = GRANGER 5 x 812 RELAY

LS_1 = NORMALLY OPEN MICROSWITCH

LS_2 = NORMALLY CLOSED MICROSWITCH

FIGURE 4

ACTUATOR CIRCUIT (ELECTRIC)

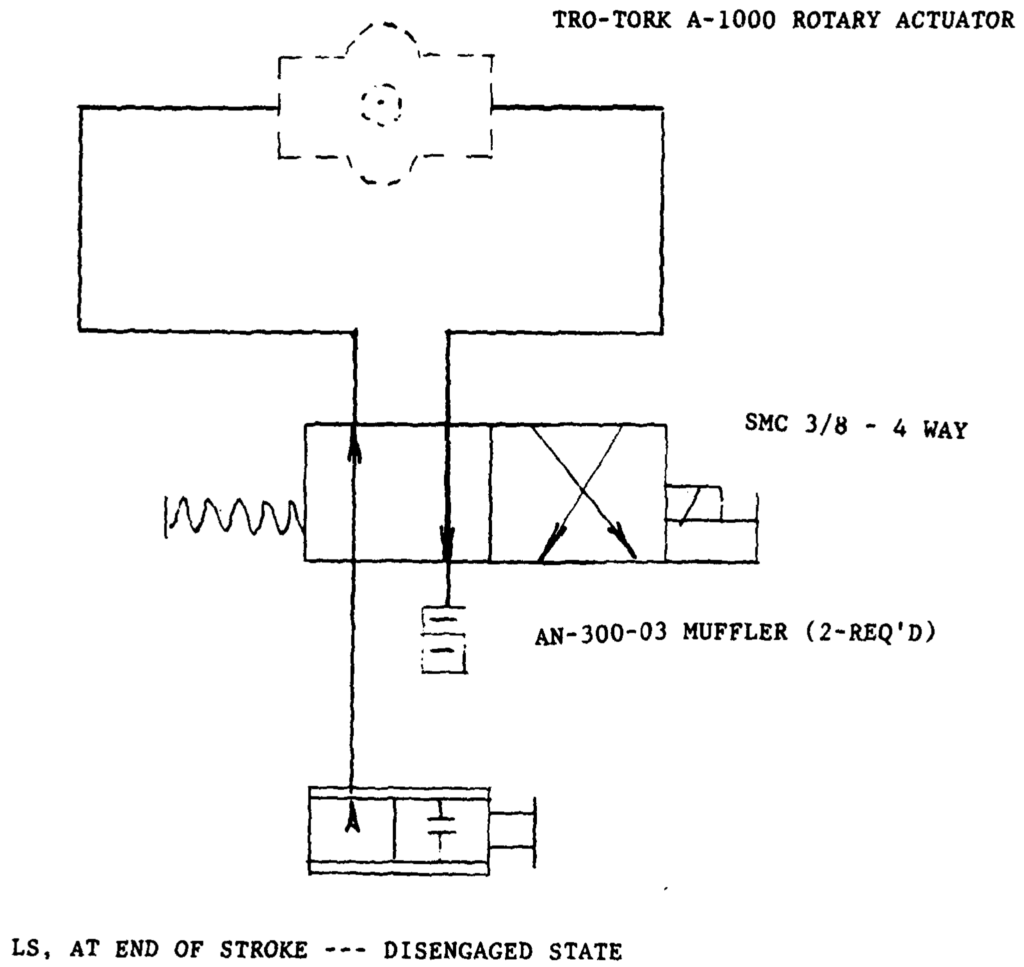


FIGURE 5

ACTUATOR CIRCUIT (PNEUMATIC)

strain gages are installed on the spindle between the disk and the roller support bearing. In this location, the primary torque in the spindle is due to friction between the disk and the specimens. As noted before, this torque is due to the friction force of both specimens, therefore, it must be halved to obtain the torque (i.e., friction force) for one specimen. A full Wheatstone bridge is used on the spindle and it is wired so that bending strain and strain due to axial thermal growth are cancelled. Details of the strain gage installation and calibration are given in Appendix I.

Normal load is measured by measuring the pressure in the caliper chamber. This pressure is measured with a transducer in the bottled nitrogen supply line (Gulton model with a 500 psi maximum range). The pressure transducer was calibrated and set to a sensitivity of 50 psi/volt. Thus, since the cylinder diameter is 1.19 inch, the normal load calibration factor is 56 lbs/volt.

Motion of each piston is monitored using a capacitance probe installed in the reservoir cover plate (See Figure 6). These probes were calibrated and had a linear range of approximately 15 mils. The calibration factor is nominally 10.0 mils/volt.

Thermocouples were installed so that specimen and fluid bath temperature could be continually monitored. To measure specimen temperature, thermocouples are inserted in each specimen in holes which were 35 to 40 mils shorter than the specimen. The thermocouple wires are fed through a slot in the specimen holder and out through the reservoir, thus eliminating the need for penetration through the seal plate. In addition, a thermocouple was placed in the fluid bath to monitor the bath temperature. This thermocouple was placed in the center of the reservoir, away from the walls.

Instrumentation was read and logged using the following devices:

- Strain gage bridge amplifier
- Digital storage scope for strain gage output
- Chart recorder for permanent record of strain output
- Digital thermocouple read-out
- Digital voltmeter to measure:
  - caliper chamber supply pressure

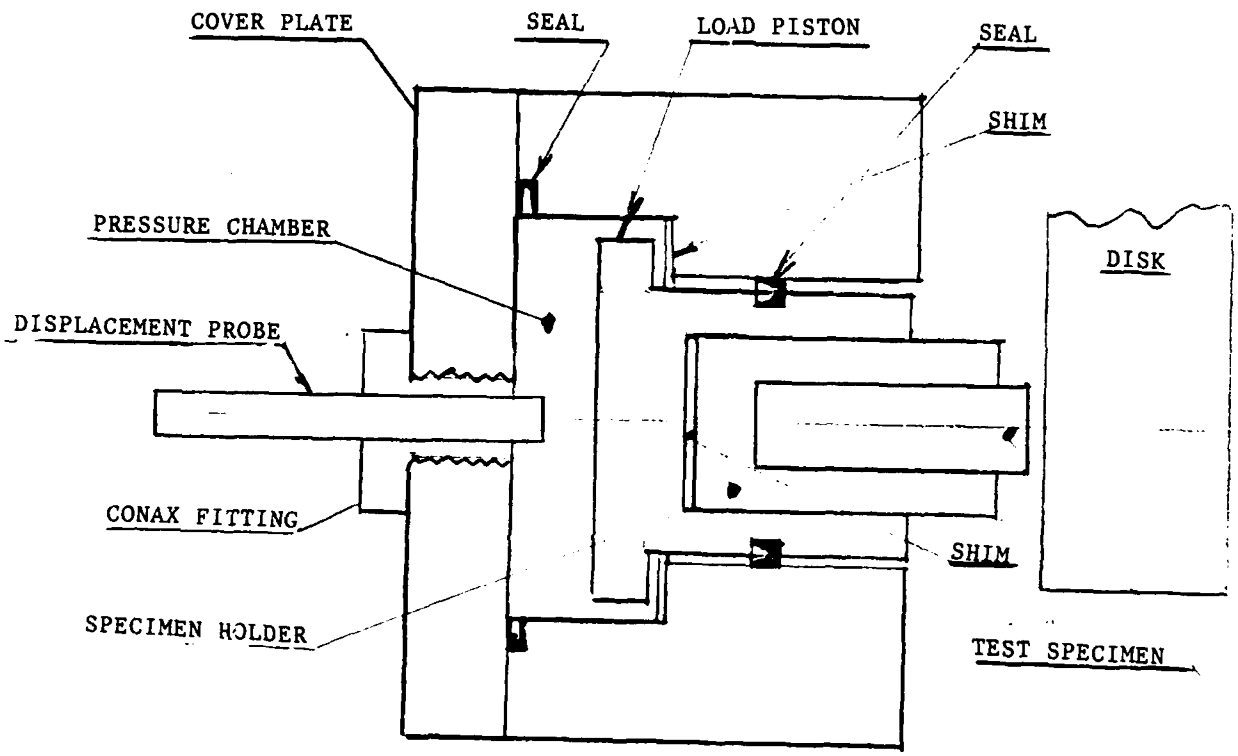


FIGURE 6

TEST PIN ASSEMBLY

- capacitance probe output

During test, rig performance was continually monitored and log sheets were kept to tabulate the required data.

3.2.5 Test Rig Assembly and Debug

Test rig hardware was manufactured, procured and assembled according to the following procedures:

1. Install ball bearings on the shaft in the DB configuration per manufacturer instructions (i.e., outer race samplings facing each other).

2. Use bear hug nut (with Loctite) to secure ball bearings on the shaft.

3. Heat roller bearing inner race to ≃ 275°F, cool shaft with LN_2 and install inner race on shaft.

4. Let shaft/bearings come to room temperature.

5. Apply grease to roller bearings and bore of outer race, and press into housing.

6. Pack shaft in area between bearings and ball bearings with grease.

7. Slide shaft into housing from actuator end until ball bearings are seated.

8. Install retainer plates.

The rig was installed on a bed plate (≃ 24 in. x 24 in. x 2 in.) set on rubber pads on laboratory table. The spindle housing was installed on the bed plate using four (4) bolts and two (2) dowel pins to ensure repeatable positioning. The reservoir was held to the bed plate using four (4) clamps. The reservoir was not doweled since adjustments for different tests were required.

The actuator was installed and the control circuit components were assembled according to Figures 4 and 5. The rig was initially run without any test specimens. The control circuit operated properly.

A gear was installed on the disk end of the spindle and a proximity probe was used to observe the gear. With this arrangement the velocity profile of the spindle motion can be determined because the frequency of the proximity probe signal due to the gear teeth is related to the tangential spindle velocity. This frequency was found to be essentially constant between the start and stop point of the spindle stroke. This indicates that the velocity is nearly constant.

Following this debug effort,the reservoir was installed with a set of (sacrificial) test specimens. The rig was operated in this condition with different values of caliper supply pressures, actuator supply pressures and microswitch locations. The following test rig performance was observed:

- Frequency could be maintained at 1 Hz
- Minimum stroke amplitude at 1 Hz was approximately 120° (apparently due to inertia of the actuator components)
- For GFD test specimen material (softest of the ones to be tested) a 3 mil stick-out could not be maintained with any significant normal load.
- For GDF, a 10 mil stick-out could be used at normal loads up to ≈ 56 lbs. (1140 psi) without bottoming out.

Based on the above rig performance, it was decided to conduct tests under the following nominal conditions:

- Test Frequency: 1 Hz
- Test Amplitude: 12.5 in. peak-peak
- Normal load : 56 lbs.

These test rig conditions result in the following:

- Sliding Velocity: 12.5 in/sec
- Contact Stress : 1140 psi

- PV Value : 71,250 (psi x ft/min)

3.2.6 Test Specimens - Soak Tests in CTFE

Preliminary soak tests were performed for test specimen materials. These tests were conducted so that swelling characteristics could be established and used to size the actual test specimens for the friction and wear tests. Test specimens were soaked in CTFE at 275°F for 72 hours. At this temperature, the fluid evaporation rate was significant and the specimens had to be placed in covered containers. Furthermore, the materials floated in the CTFE (except for GFD), therefore weights were placed on the specimens to ensure that they stayed covered with fluid. One test tube was used for each test specimen material and the test tubes were placed in a thermostatically controlled electric resistance oven. A shield was placed over the oven heating element to ensure uniform temperature distribution around the test tubes (i.e., eliminate radiation heating of the test tubes).

The materials subjected to the soak tests were:

- VESPEL
- PEEK
- GFD

The results of the soak tests are summarized in Table 1 . Vespel lost about 1.2% of its weight and slightly decreased in length. The color of the fluid was amber. Apparently CTFE has managed to penetrate this material and interact with some of its content. GFD which is a carbon graphite fiber filled PTFE gained in weight and size, indicating considerable swelling when exposed to CTFE although the color of the fluid did not appear to appreciably differ from a baseline fluid sample introduced into the oven together with the soal samples. PEEK seemed to be least affected by exposure to CTFE. The color of the fluid, again matched the color of the baseline sample.

TABLE 1

SOAK TEST RESULTS

72 HOURS AT 275°F
IN CFTE (A02)

MATERIAL	CHANGE IN WEIGHT IN MG. (%)	DIMENSIONAL CHANGE MILS		COMMENTS
		DIAMETER	LENGTH	
VESPEL	-8.2 (-1.2%)	0	-0.9	COLOR-AMBER
PEEK	-1.0 (-0.2%)	0	+2.3	COLOR-GOLD
GFD	+25.9 (+2.4%)	+2.8	+3.0	COLOR-GOLD

3.2.7 Test Procedure

Test procedures were established for rig assembly/testing. The procedures consisted of the following major steps:

1. Assemble disk and align with respect to test specimen holders.

2. Measure and record specimen pre-test dimensions and weights

3. Install specimens in rig and install instrumentation

4. Conduct tests and record data for three conditions:
   - Dry (i.e. no CTFE in reservoir) for ≈ 200 cycles.
   - With CTFE at room temperature for ≈ 200 cycles.
   - With CTFE at 275°F until there is 3 mils of wear or for 25,000 cycles.
   - Remove specimens.
   - Measure and record specimen dimensions and weights.

A detailed test procedure is contained in Appendix II.

3.2.8 Discussion of Friction and Wear Tests

The procedure, loading and speeds applied has been described in detail in Sections 3.2.1 through 3.2.7. The materials were tested in the following sequence:

- Test No.2, VESPEL on hard Chrome
- Test No.3, PEEK on hard Chrome
- Test No.4, GFD on hard Chrome
- Test No.5, GFD on Tungsten Carbide
- Test No.6, VESPEL on Tungsten Carbide
- Test No.7, PEEK on Tungsten Carbide

Test No.1 was carried out primarily to debug and calibrate the test vehicle and equipment. No data was taken with the exception of the verification of the calibration constants and checkouts. The results of the other tests are summarized in the form of sets of tables and figures, each set consisting of:

a. A Summary Table

b. Friction Trace

c. Wear Rate Curves

Two samples of the same material were run simultaneously on the same disc. The disc side facing the spindle was designated as Side Number 1 and the outward facing side as Side Number 2. The surface finish as new was,

HARD CHROME PLATE
Side No.1 - 2 CLA (microinches)
Side No.2 - 7 CLA

TUNGSTEN CARBIDE COATING
Side No.1 - 7 CLA
Side No.2 - 14 CLA

The original aim of obtaining the same surface finishes on the hard chrome plate as on the tungsten carbide coating could not be met because of the slight porosity of the latter. This fact does not detract from the overall value of the test results.

The details of the results achieved on each test are presented in Appendix III, where a summary sheet and a full set of data is presented for each material combination tested in conjunction with each surface finish. A summary of the most pertinent test results is hereby presented.

3.2.8.1 Friction.

The coefficient of friction at static conditions (i.e., 200 cycles at 1140 psi) in dry air was highest for VESPEL and lowest for GFD. This is to be expected. PEEK exhibited friction somewhere between the above two materials.

As shown in Table 2, the frictional values run anywhere between 0.26 and .16. The values obtained for GFD are in good agreement with those cited in Reference 2. No appreciable difference was noted between the break-away (Coulomb) friction and sliding friction. This is indicative of materials with good dry lubricating properties. The difference in friction between Tungsten carbide and chrome plate is not substantial enough to be of any great significance.

The coefficient of friction does drop quite significantly when CTFE at room temperature is added to the reservoir. Two frictional components, a static and dynamic are now apparent. The static component stands out at the points of stroke reversal where the velocity goes through zero. The dynamic coefficient goes through some type of an unstable stick-slip action, but its average is much lower than that of the Coulomb or static component. In general, the room temperature lubricated friction is not appreciably different for all three materials operating in the dynamic mode. Apparently, some type of boundary lubrication is present when the CTFE is at room temperature and possesses a viscosity of about five centipoises. This becomes more apparent when the CTFE temperature is raised to 275°F. Now the viscosity of CTFE is below one centipoise and lubrication is extremely marginal. The net outcome is a higher coefficient of friction which in its magnitude approaches that of the static friction registered in CTFE at lower temperatures.

The general conclusions to be drawn from Table 2 are:

1. The coefficient of friction does not differ significantly when the same material is run against chrome plate or tungsten carbide.

2. Coulomb friction shows up only in CTFE runs.

3. CTFE has the potential to enhance cr create some form of hydrodynamic lubrication. This potential however decreases at high temperatures of operation.

4. The lowest friction obtained was with GFD. The friction of PEEK is in most cases, close to that of VESPEL.

TABLE 2

SUMMARY OF FRICTION COEFFICIENTS

MATERIAL	DRY		IN CTFE AT ROOM TEMP		CTFE @ 275°F	
	Sliding	Static	Sliding	Static	Sliding	Static
VESPEL						
Hard Chrome	0.25	N/O	0.04	0.16	0.15	0.20
Tungsten Carbide	0.26	N/O	0.044	0.15	0.10-0.13	0.14-0.18
PEEK						
Hard Chrome	0.21	N/O	0.06	0.15	0.16	0.19
Tungsten Carbide	0.18	N/O	0.064	0.18	0.12-0.14	0.16-0.20
GFD						
Hard Chrome	0.19	N/O	0.06	0.12	0.063	0.095
Tungsten Carbide	0.16		0.04	0.11	0.056-0.06	0.072

N/O Not Observed

Following the tests, each track was examined for changes in surface finish and indications of wear. All materials tested seemed to exercise a similar effect on the disc or track material. Thus, the finely finished side of tungsten carbide initially at 7 CLA roughened to about 12 CLA. The rougher side of that same disc originally at 14 CLA improved to 10 CLA. On the chrome plated disk, the smoother side (originally 2 CLA) changed to 3 CLA, and the rougher side originally at 7 CLA stayed about the same. It seems that a value of 8-12 CLA should satisy most rod seal applications.

3.2.8.2 Wear.

Wear of the specimen was measured in three ways:

1. Difference in length before and after test measured with micrometer.

2. Difference in weight before and after test. Measured on fine scale.

3. Continuous measurement of approach between specimen and disc. Measured with capacitance probe.

When little or no mushrooming (cold flow) took place at the point of contact, the wear calculations between methods one and two above should be in good agreement. When flow occurs, then the true wear can be measured by the weight loss, but should be substantially different than the apparent volume lost based on the length and weight measurements. A comparison of the loss in specimen length as measured with a micrometer, before and after test, and the in-situ capacitance probe measurements is shown in Table 3.

The same table also shows a comparison between weight loss as measured before and after test with weight loss calculated on the basis of the in-situ capacitance measurement at the start and end of test. Note that the weight loss thus calculated represents a secant rather than tangent loss. The tangent weight loss presented later eliminates the high wear at break-in and concentrates on the final wear rate only. The data in Table 3 indicates that the comparison of the probe versus micrometer readings on Specimen No. 1's smooth side is better than that on the rough side, although even on the later, the scatter is accepta-

TABLE 3

OVERALL WEAR DATA

	SPECIMEN LENGTH		CHANGE (MIL)		SPECIMEN WEIGHT		CHANGE (MG)	
	Specimen #1 (Smooth)		Specimen #2 (Rough)		Specimen #1 (Smooth)		Specimen #2 (Rough)	
	ΔL*	ΔProbe*	ΔL*	ΔProbe*	ΔW_1*	ΔVxρ*	ΔW_1*	ΔVxρ*
VESPEL								
Hard Chrome	5.3	5.5	4.5	3.3	7.8	6.2	6.3	3.7
Tungsten	5.5	5.6	2.8	3.2	8.1	6.3	4.5	3.6
PEEK								
Hard Chrome	3.0	3.7	3.0	3.2	3.6	3.9	3.7	3.4
Tungsten	3.9	3.6	2.3	1.9	3.6	3.7	2.1	1.9
GFD								
Hard Chrome	4.3	4.2	4.7	5.7	7.6	7.0	8.2	9.5
Tungsten	7.6	8.8	12.1	11.7	9.7	14.3	15.9	18.9

ΔL = Change in specimen length

ΔProbe = Motion measured by probe from start to finish

ΔW_1 = Change in specimen weight

ΔV = ΔProbe x area by ρ

ρ = Density mg/in^3

ble. A substantial difference is noticable with GFD as run against chrome plate and tungsten carbide. An examination of the GFD versus tungsten carbide wear plot in Appendix III, Page III-13, shows a distinct leveling of the curves slope at about 15,000-16,000 feet of travel. The measured loss in length is about 8 mils on Specimen No.1 and about 12 mils on Specimen No.2. It is this apparent shortening of both specimens caused by a combination of wear and cold flow that resulted in the stopping of the sample holder against the shoulder prior to test termination, hence the straight line in the latter part of the test. Stopping distance was predetermined through the introduction of shims to prevent rubbing of the sample holder metal against the disk, as explained in Section 3.2.1.

The wear of GFD against tungsten carbide was higher than that of any other material combination. Similarly, a comparison between direct weight measurement and calculated weight loss based upon the capacitance probes indicates the presence of 3-4 mg of displaced rather than worn material. For instance, in the last row of Table 3, the difference between the weighed and calculated weight loss for GFD against the smooth tungsten carbide coating is 14.3 - 9.7 or 4.6 miligrams. On the rough disk end, the difference is 18.9-15.9 or only 3 miligrams. These values can be attributed to cold flow. The difference between 4.6 and 3 cannot be merely explained by the differences in roughness of the surfaces in the GFD run. It is more likely that this difference represents the sum total of inaccuracies inherent in both measuring systems.

Table 4 summarizes the wear rates based upon the slope of the wear curve following initial break-in. The wear rate, given in inches cubed per inch of travel, is highest for VESPEL and lowest for PEEK when the materials are run against chrome plate. With tungsten carbide as the mating surface, the wear rate is lowest for PEEK and highest for GFD. Apparently the porosity of tungsten carbide and the cold flow charactristics of GFD combined to yield high wear rates. Perhaps even of greater interest is the fact that in CTFE at 275°F, the wear rates of all materials tested are of the same magnitude, or of the order of 10^{-9} in.^{3}/inch.

3.2.8.3 Comparison With DuPont Data.

To establish the validity of the friction and wear rates obtained in these

TABLE 4

AVERAGE VOLUMETRIC WEAR RATES

(Based On Slope Of Travel Vs. Wear Curve)

	AVERAGE WEAR RATE (in^3/in)	
	SPEC #1 (Smooth)	SPEC #2 (ROUGH)
VESPEL		
Hard Chrome	0.952×10^{-9}	0.613×10^{-9}
Tungsten Carbide	0.857×10^{-9}	0.607×10^{-9}
PEEK		
Hard Chrome	0.469×10^{-9}	0.432×10^{-9}
Tungsten Carbide	0.558×10^{-9}	0.347×10^{-9}
GFD		
Hard Chrome	0.387×10^{-9}	0.561×10^{-9}
Tungsten Carbide	1.32×10^{-9}	2.38×10^{-9}

tests, a comparison was drawn with data produced by Dupont, as presented in Reference (2).

The coefficients of friction quoted in Reference [2] for a 15% graphite filled teflon falls between 0.16 and 0.20 for sliding at PV values of about 10,000 at room temperature with velocities of about 60 ft/min. the values obtained in this test are 0.16 to 0.19.

Wear is measured in Reference [2] with the aid of a wear factor K defined as:

$$K = t/PVT \qquad (2.1)$$

Where t is wear in inches

P - Pressure in psi

V - Velocity in ft/,min

T - Time in hours

The wear factor for Teflon with 15% graphite is given as 34×10^{-10}. The maximum PV limit for this material is given as 28,000. The test described in this report was run at a PV of 71,250.

From Table 3, the average wear for GFD against hard chrome is about 4.5 mils. The total test time is 7 hours. Substituting the above values in Equation 2.1

$$K = .0045 / 71{,}250 (7) = 90 \times 10^{-10}$$

This value is of the same order of magnitude as that quoted in Reference 2. Considering the inherent differences in sample geometry and test conditions, the K values are remarkably close.

4.0 SEAL DESIGN

The design of high pressure hydraulic seals requires knowledge of the material properties, novel design ideas, and tools in the form of computer codes to aid in the design effort.

The guidelines for the seal design included:

- Mechanical Integrity
- CTFE compatibility
- Operation at pressures up to 8,000 psi and temperatures of 275°F.
- Low Leakage
- Low Friction
- Rod seal per MIL-G-5514-214 Specification ("O"Ring Gland without back-up).
- Piston ring to fit 2-inch diameter bore.

Mechanical integrity and compatibility are in a large measure a function of the material properties. Mechanical integrity in addition to structural soundness includes also, wear resistance and time dependent effects of environment on the seal materials.

As it is, hydraulic seals have traditionally been developed by trial and error methods primarily because of lack of reliable information on the mechanical thermal and physical properties of the materials. These methods have, with time, proven remarkably effective. However, the advent of new materials, new fluids, and new, more severe conditions of operation anticipated in advanced hydraulic aircraft control systems leaves little time for the tedious, brute force approach, and necessitates the development of engineering tools which would aid in the design process.

4.1 Analytical Considerations

The network of traditional equations involving Hook's Law, yield stress, fatigue stress, etc., around which most of the current ate-of-art computer codes are constructed breaks down in the face of the new requirements. New and improved tools are needed to handle the complexities introduced by the visco-elastic behavior of the new elastomeric and plastic materials.

Within the framework of this contract, MTI engineers have attempted to explore the readiness and applicability of finite element non-linear elastic plastic programs such as NEPSAP. Unfortunately, neither time nor finances permitted a thorough exploration. Consequently the program employed in the analytical design effort was selected from MTI's computer library. The program designated as ISOPDQ was originally developed by Garrett for WPAFB, and subsequently modified by MTI to include orthotropic and anisotropic material characteristics and color graphics. Upon examination of the available plastic materials, only the structural-linear, isotropic, thermal, and displacement features were used. As it turned out, PEEK, ULTEM, and VESPEL characteristically exhibit low extrusion levels and small deflections at temperature, so that the use of ISOPDQ in these cases was justified. Teflon--in any neat or filled form will exhibit viscoelastic behavior at 8,000 psi and 275°F and the ISOPDQ program set-up had to be manipulated to obtain any reasonable indications of distortion at the given conditions.

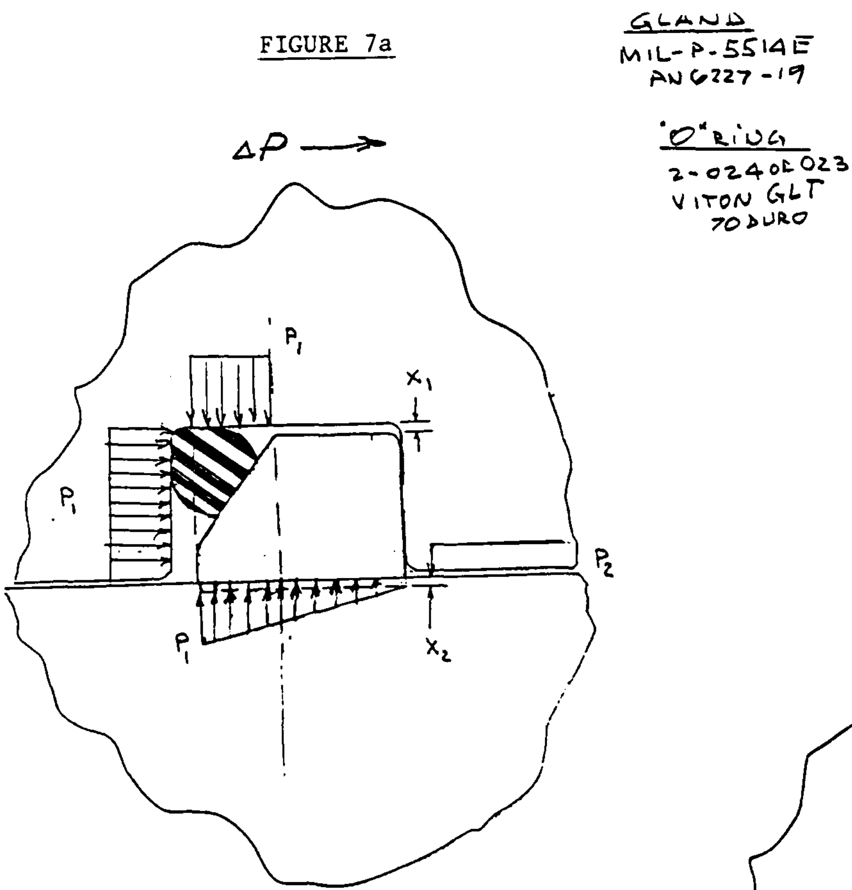
4.2 Rod Seal Design

The guidelines for the rod seal design were given in the introduction to this section. Because of the enormous multitude of rod seal shapes and systems currently on the market, a brief review of the available designs was performed with the objective of avoiding duplication of existing seals. Simplicity of design, low radial load, and minimized distortions under load served as additional criteria in the conceptualizing process.

4.2.1 Rod Seal Concept

A schematic of a baseline design and its evolution is shown in Figure 7. The rod seal (7) consists of a simple ring which is shrunk onto the shaft to provide initial sealing at room temperature and compensates for differential thermal expansion between shaft and seal at higher temperatures. The elastomer "O"Ring shown does not require any specific structural strength, nor does it need to

FIGURE 7a



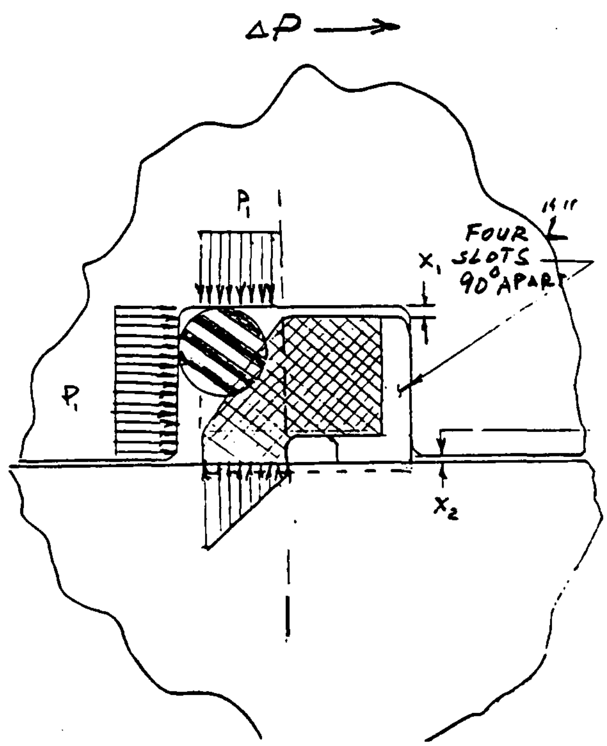
HIGH PRESSURE

HYDRAULIC ROD

SEAL CONCEPT

SCALE APPROX. 20:1

FIGURE 7b



HIGH PRESSURE

HYDRAULIC ROD

SEAL CONCEPT

FIGURE 7

exhibit good wear characteristics since its only function is to seal the gap formed between the ring outside diameter and stationary gland inside diameter. Any extrusion into the gap should be of no great consequence. As long as the gap is small, the extruded material should not interfere with the seal's performance.

The seal is pressure-balanced to reduce the radial forces acting on the rod and minimize friction and wear.

As shown in Figure 7a, "x_1" represents the cold clearance at the seal outside diameter, and "x_2" the cold interference between the seal bore and rod.

The pressure profiles in the axial and radial directions are denoted with arrows. Because of the low Poisson's Ratio of the "O"Ring, it may be assumed that when pressurized, the ring will not interfere with the pressure pattern shown.

Referring to Figure 7a, the vertical line establishes the limit of radial pressure action on the seal. Since $P_1 > P_2$, the seal will become pressurized as soon as P_1 is built up and its compressive hoop stress around the rod will increase only in the section left of the line. In the absence of leakage, the full pressure will act radially downward against the rod; in the presence of leakage a counteracting linear pressure drop develops. In the absence of balance grooves the pressure drop may extend over the full seal width as shown in Fig. 7a and the seal may lift-off causing excessive leakage. The pressure P_1 acts also axially pushing the seal against the wall.

Figure 7b shows a slight refinement of the original concept. To prevent seal lift-off, a circumferential groove "A" is machined at the end of the sealing section in the seal's bore. Four (4) axial slots are then introduced to vent the non-sealing bore section to ambient P_2. Furthermore, to avoid seal "shuttling" from end-to-end during the reciprocating stroke four (4) radial slots "C" are introduced in the back face. These slots will vent any secondary leakage, thus, assuring the seal's seating against one wall when pressurized and actuated.

Another important aspect of the seal design is the initial interference to be introduced between seal and rod. Because most plastic materials exhibit high coefficients of thermal expansion in comparison to that of steel, the initial interference should be high enough to prevent any creation of a clearance path between rod and seal at higher temperatures.

Materials such as PEEK, ULTEM, and VESPEL do have high coefficients of thermal expansion and require high interference fits. Table 5 lists the material characteristics used in the analyses of the seals.

4.2.2 Interference Fit Study

Excessive interference fits between rod and seal bore make for a difficult, and in some cases, impractical assembly.

To determine what the current fits should be, a study was performed using at first, ULTEM 1000 and TORLON SP1 as materials. The results of this study are summarized in Figure 8 and Table 5. Details are given in Appendix 3.

Figure 8 shows two different approaches that one may utilize to mount the seal with low interference and maintain sealing capability at all temperatures with or without pressure. TORLON has a low coefficient of thermal expansion in comparison to ULTEM. As shown in Figure 8, one can assemble the TORLON seal (Model C) with only 0.002 inches of radial interference and still maintain a 0.0013 inch interference at 275°F. To arrive at a similar interference fit at 275°F with ULTEM, an original interference of 0.004 inches is required. This level of radial interference is extremely high for a one inch nominal shaft diameter. To reduce the required interference at high temperatures, one may select Model B (Figure 8). Here, limited space is provided in the gland for outward seal expansion. As the seal expands, it makes contact with the gland diameter, and any further expansion results in compression of the seal against the rod. This compression at higher temperatures permits the reduction of the interference fit at room temperature. The reduction can be substantial as one can deduce from a comparison of Model A with Model B. The room temperature fit can now be reduced to 0.002 inches, a number similar to that of TORLON. As the computer data listed in Appendix II indicates, the pressure profiles at the rod do not significantly change the radial stress distribution. The freely expanding ring data is very similar to that of the ring with restricted expansion. Plots of this data are shown in Figures 9-11 for models A, B and C respectively.

TABLE 5

MECHANICAL PROPERTIES OF SEAL MATERIALS*

PROPERTY	MATERIAL				
	ULTEM 1,000	PEEK ARLON 1,000	VESPEL SP-1	TORLON 4235	GRAPHITE FILLED PTFE
MODULUS OF ELASTICITY, PSIx10^{-4}					
70°F	45	40	45	1.06	0.6
275°F	35	24	35	0.81	0.3
POISSON'S RATIO	.42	.40	.41	.39	.48
THERMAL EXPANSION					
75°F -300°F	31	26	30	14	75
-65°F - 75°F (in/in x 10^6)	N/A	N/A	25	N/A	70

* The values quoted in these tables are approximate and are based upon extrapolation of what appeared in most instances to be insufficient data.

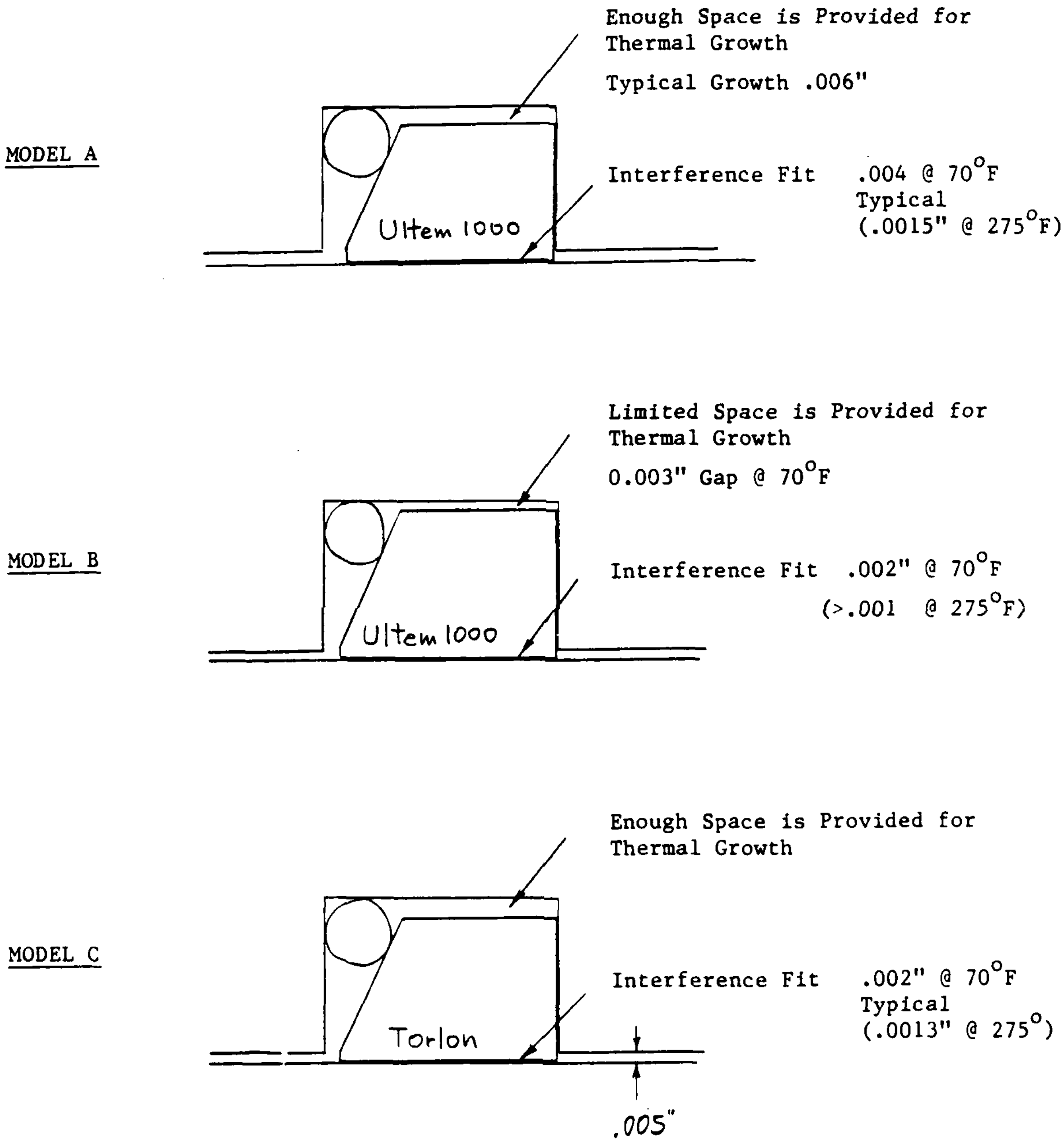


FIGURE 8

RESULTS OF THERMAL STUDY

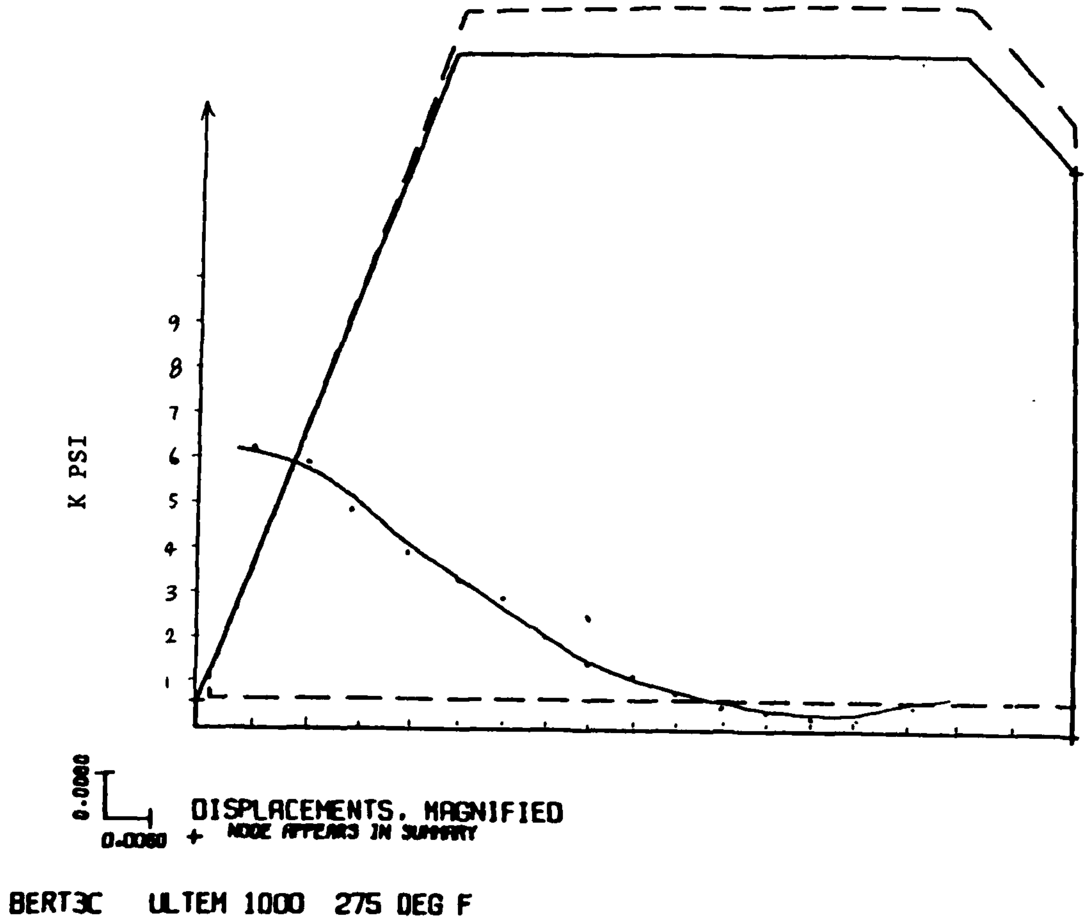
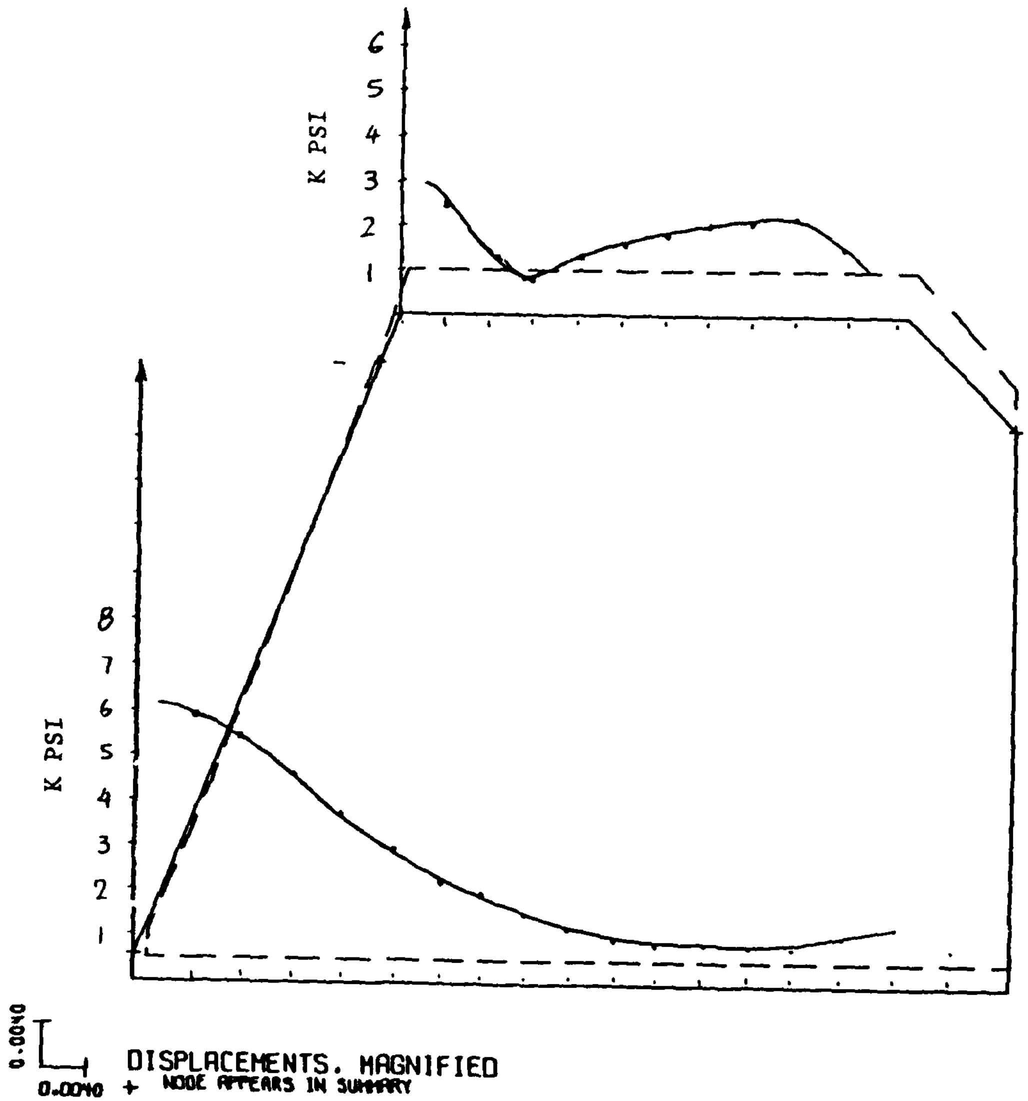


FIGURE 9

MODEL A RADIAL STRESS



BERT506 ULTEM 1000 275 DEG F

FIGURE 10

MODEL B RADIAL STRESS AT CONTACT

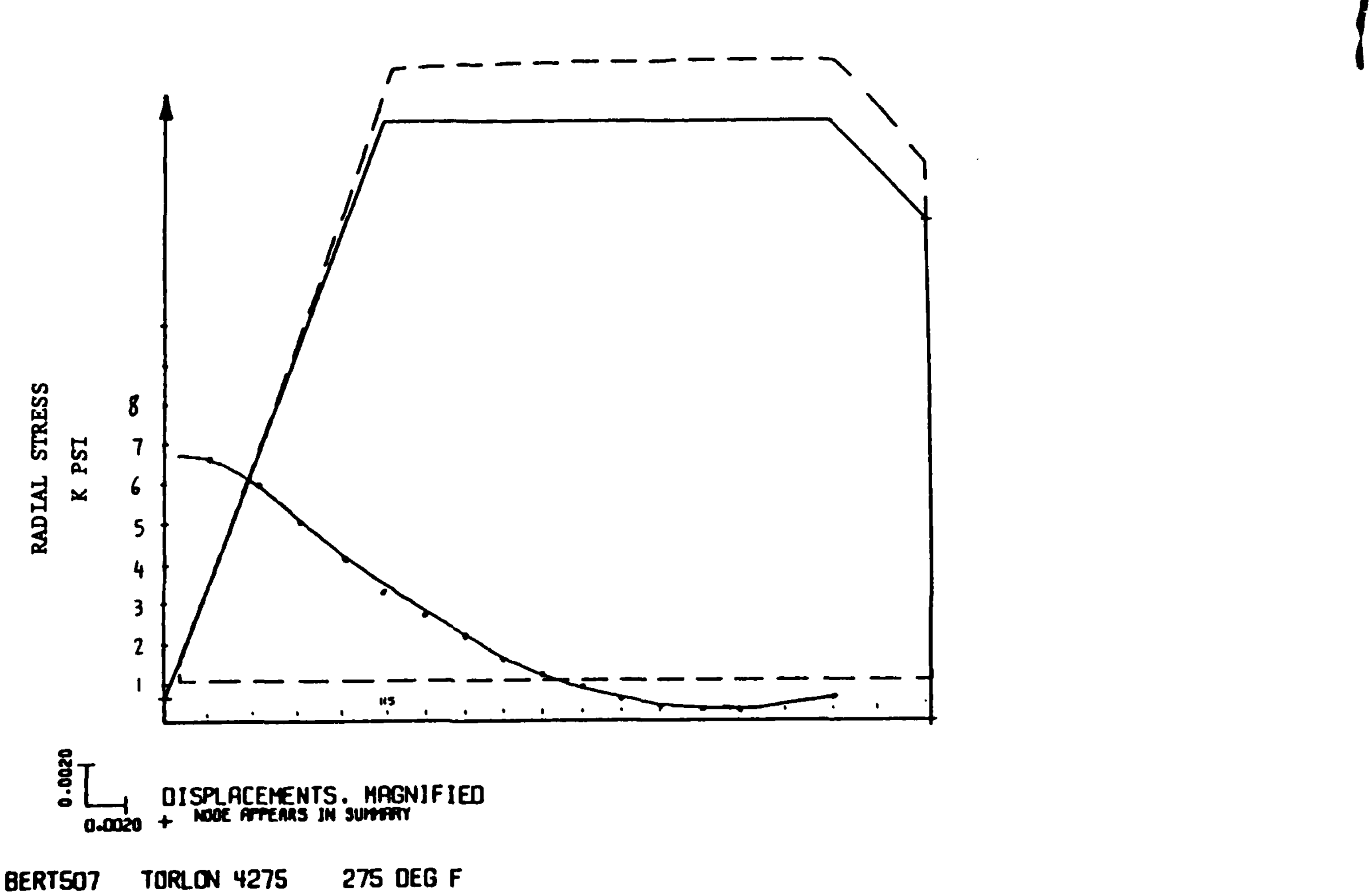


FIGURE 11

MODEL C RADIAL STRESS

Note that the radial stresses at the seal-to-rod contact are not appreciably different regardless as to what material or what method is employed, as long as we are dealing with materials exhibiting similar properties. As noted in Table 5, the properties of ULTEM 1000, PEEK (ARLON 1000), VESPEL SP-1, and TORLON 4275 are not appreciably different.

4.2.3 Rod Seal Design Details

The evolution of the seal concept has been discussed in Section 4.2.1. Following the testing of the materials it became clear that PEEK represents, at least at this stage, the most attractive material from the standpoint of strength, low wear and low coefficient of friction. A set of production runs with PEEK used in two seal designs, one with full and one with limited thermal expansion at the outer diameter was performed. The plain and interference induced radial compressive stresses are listed as a function of temperature in Table 6. Model D uses the interference and limited expansion approach. Model E emphasizes interference only to affect a tight seal on the shaft at all conditions. The final computer code model and detailed outputs and plots for the PEEK seals are given in Appendix V.

Although from a theoretical standpoint, both of these designs are feasible, from a practical standpoint, the 0.004 inch radial interference required to maintain contact on the Model E is much too high, and Model D is recommended for test.

The final design is shown in Figure 12. The machining tolerance of ± .001 inches on the bore and seal outside diameter will have to be maintained in view of the rod seal and gland dimensions given. The latter comply with MIL-E-5514-214 specifications. The "O"Ring should be made of Viton GLT - 70 . The "O"Ring size is 024.

4.3 Piston Ring Design

As was the case with the rod seals, a number of different concepts were considered for the piston ring. To avoid duplication of designs, (many a rod seal can

TABLE 6

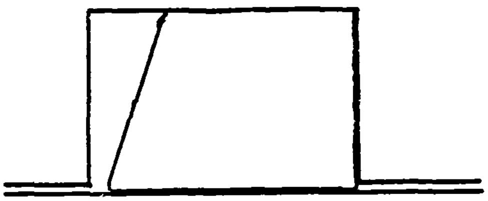
PEEK ROD SEAL

DESIGN DATA

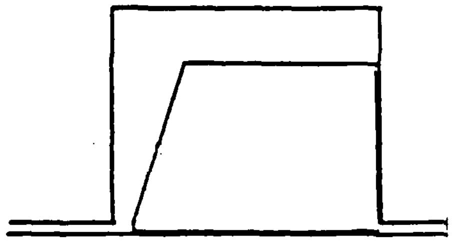
$E = 242 \times 10^3$ PSI

$\nu = 0.4$

MODEL D



MODEL E



NOTE: ALL STRESSES ARE IN PSI-INTERFERENCE IN INCHES

.001"	Interference at 70°F	.004"
.001	Gap	Enough Space For Thermal Growth
	1. 70°F No Pressure	
---	σZmax	---
-100.	σRmax	-300.
---	σTmax	---
	2. 275°F No Pressure	
-600.	σZmax	---
-1500.	σRmax	-100.
-1400.	σTmax	---
	3. 275° + Pressure	
-10,000*	σZmax - axial	-10,000*
-8,000	σRmax - axial	-6,000
-8,000	σTmax - tangential	-6,000

*Includes Stresses At Edges

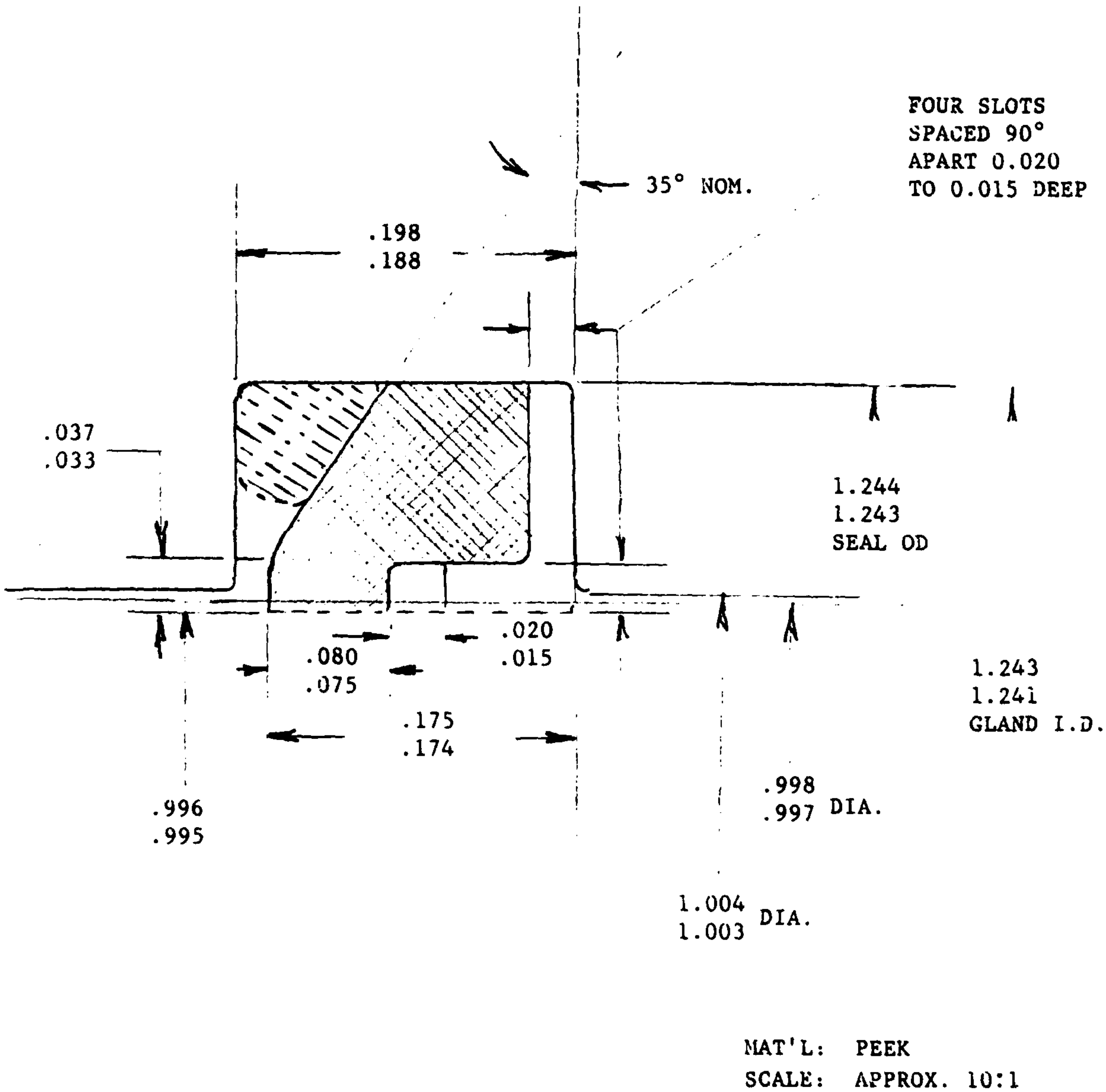


FIGURE 12

ROD SEAL DESIGN

be used as a piston ring and visa versa), the approach finally settled upon a design which utilizes PTFE or a filled version thereof such as Rulon J (polyimide filled PTFE), and consists of three pieces.

4.3.1 Piston Ring Concept

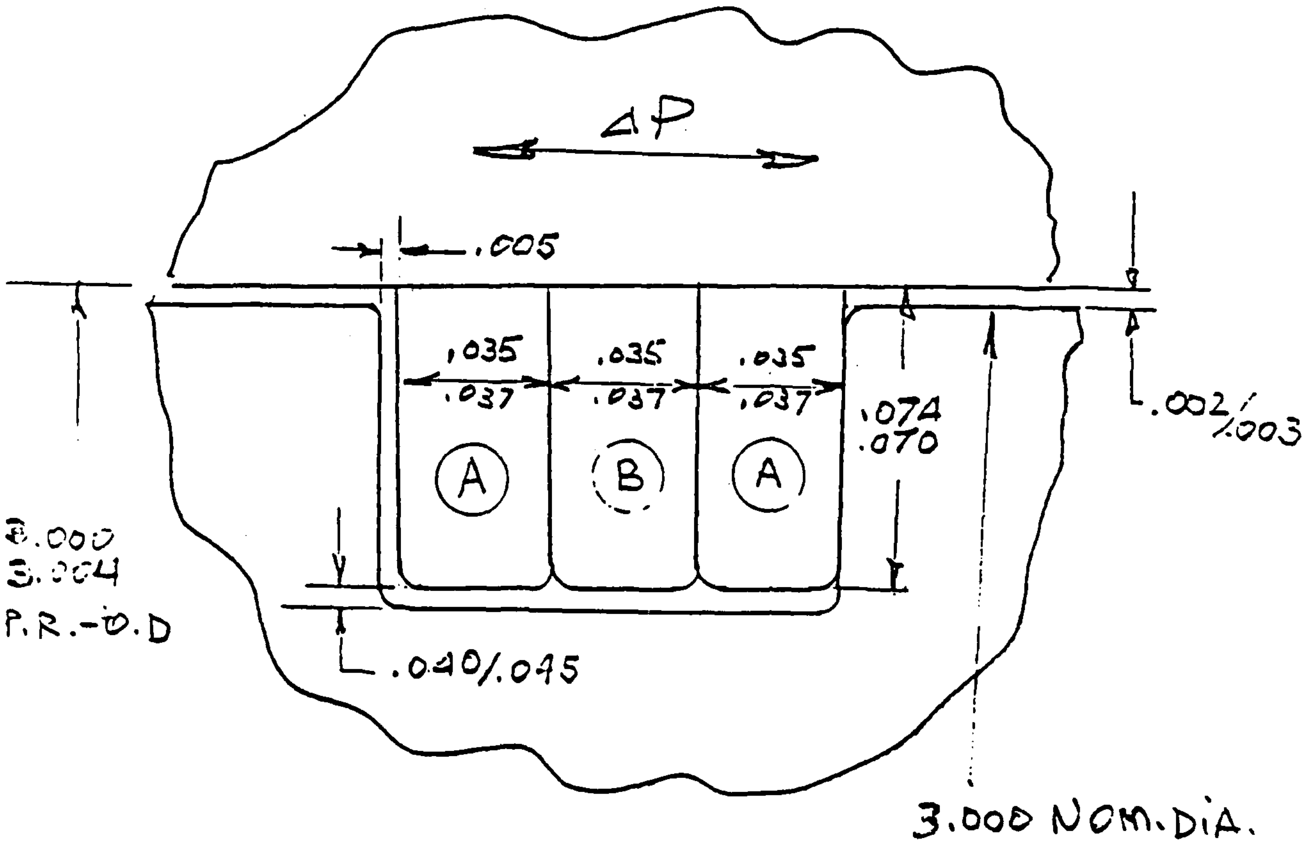
The piston ring design is somewhat less critical than the rod seal design in that a much larger amount of leakage can be tolerated. The leakage does not escape outward, hence the system does not suffer from fluid depletion. The ultimate failure is one of lack of response as reflected by poor performance.

Piston rings traditionally consist of cut rings with scarf cut butted or lap joints. Under pressure, these joints produce a seal. Positive sealing is difficult to achieve because of piston ring shuttling from wall-to-wall during pressure reversals and the sensitivity to internally generate (wear) or externally introduce contamination. When acted upon by high pressure differentials and at high piston speeds, wear may also become a problem, in particular when the hydraulic fluid has poor lubricity.

The concept finally arrived at consists of a triple ring arrangement as shown in Figure 13. The central ring consists of a solid, non-cut ring. The two side rings are typical of piston ring design and may contain scarf, butt or lap joints. One of the major advantages of this design lies in the fact that the solid central ring once pressurized can affect a good positive seal. The design also permits the use of PTFE filled materials since the central ring is trapped and cannot extrude because of the retentive action of the side rings. Secondary surface sealing along the groove wall may be somewhat more problematic but should not be less effective than that of a standard piston ring.

4.3.2 Piston Ring Analyses

The aspect of piston ring analyses was perhaps the most problematic one. Only a PTFE ring, according to MTI's experience can be made to stretch over a piston skirt so that it can be installed without cuts into a piston groove. The strength of PTFE, even in the filled state, is below that required to carry the pressures in the CTFE hydraulic application. As a consequence at the given pressures and temperatures, the material behaves almost like an incompressible



MATERIALS: A = PEEK OR OTHER PLASTIC

B = RULON "J"

FIGURE 13

HIGH PRESSURE PISTON
RING SET

fluid. Consequently, the structural linear element programs cannot be expected to yield an exact solution. Following a series of trial and error attempts, it was possible to at least affect a partial solution which indicates that with appropriate surface tension, PTFE can be made to work in this arrangement.

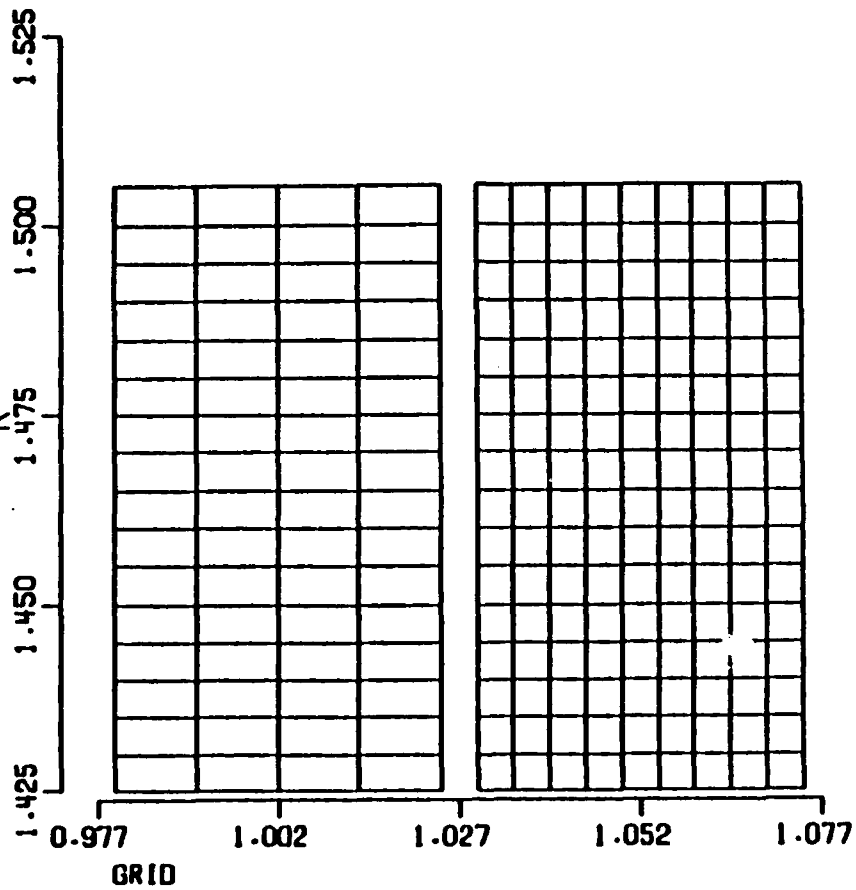
The algorithm arrived at utilizes a thin skin membrane around the PTFE seal which possesses slightly different properties from the PTFE material. The skin contains the PTFE material, limits its deflection, and permits ISOPDQ to obtain a solution.

To analyze the piston ring set only, two rings were required. The third ring can be ammended to be part of the groove wall. The model network for the two rings is shown in Figure 14. The first, coarsely divided ring represents the split PEEK piston ring. The second piston ring is the solid PTFE central ring. Figure 15 shows the hypothetical membrane wrapped around the PTFE model. In Figure 16, the full pressure of 8000 psi is applied in the axial direction only. Note, that a bulge occurs at the rings inside diameter. The "buldging" is a time, temperature pressure dependent phenomenon, and creep may continue until the material has almost fully extruded. The interesting part of it is shown in Figure 17. Here the pressure is applied in the axial and radially outward direction. The buldge is greatly reduced and the material appears to be almost fully contained. Although this scenario presented by the alterations in boundary conditions seems realistic, it is nevertheless imperative to have this behavior confirmed on test. The stress distribution at 8000 psi is shown in Figures 18, 19, and 20 for the side ring and central ring, in the axial, radial and tangential directions at the 8000 psi pressure. The stresses are all at 8000 psi levels.

4.3.3 Piston Ring Design Details

Figure 13 shows a sketch and the most pertinent dimensions of the piston ring set. Each one of the rings is 0.035 inches wide and of 0.070 inch cross-section. The design shown applies to a 2.00 inch piston diameter but could be used without any changes in cross-section up to four inches in piston diameter.

The solid ring, when installed, should have a line-to-line to 0.003 inches diametral interference with the cylinder bore. The side rings are designed using standard open ring machining practice to assure a spring pre-load. An alternate



RING

FIGURE 14

PISTON RING MODEL NETWORK

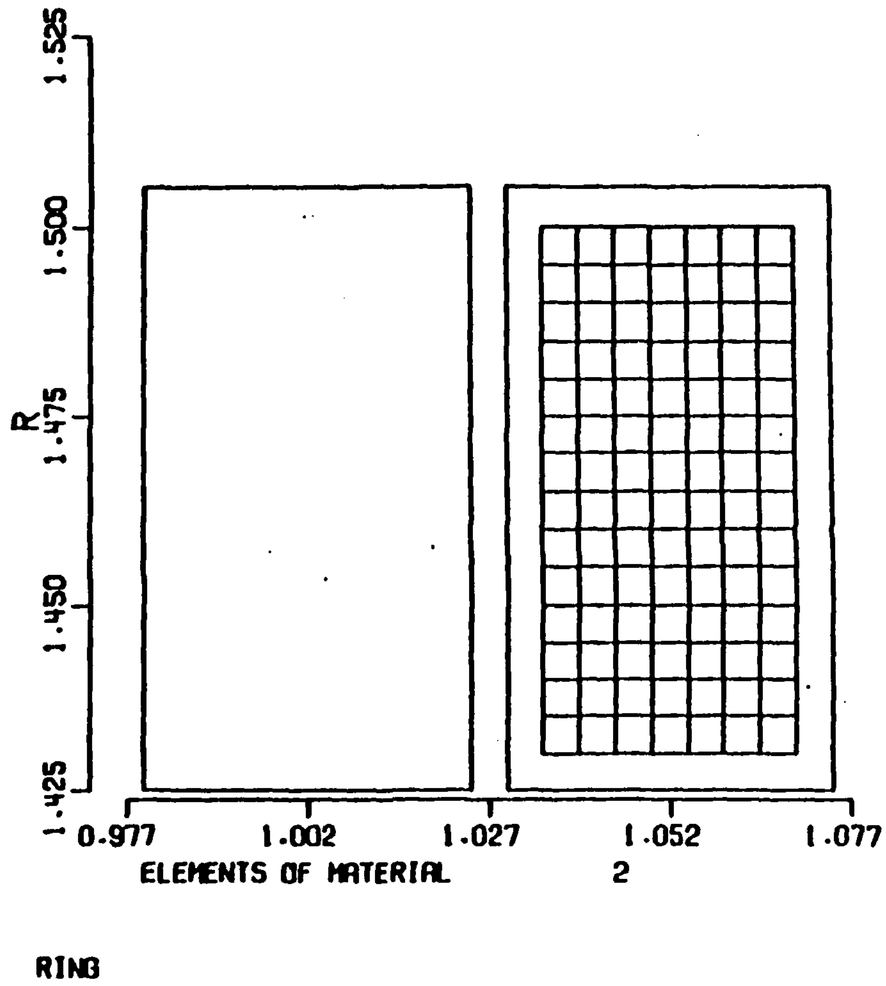


FIGURE 15

MEMBRANE WRAPPED PTFE MODEL

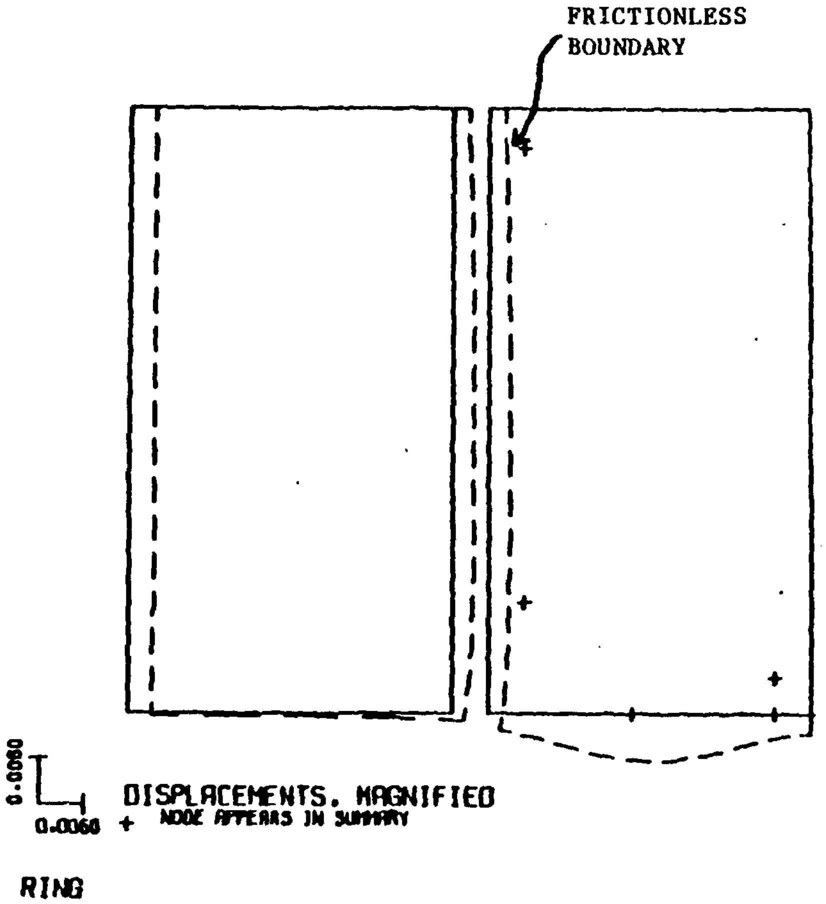


FIGURE 16

AXIALLY LOADED RINGS
P = 8000 psi

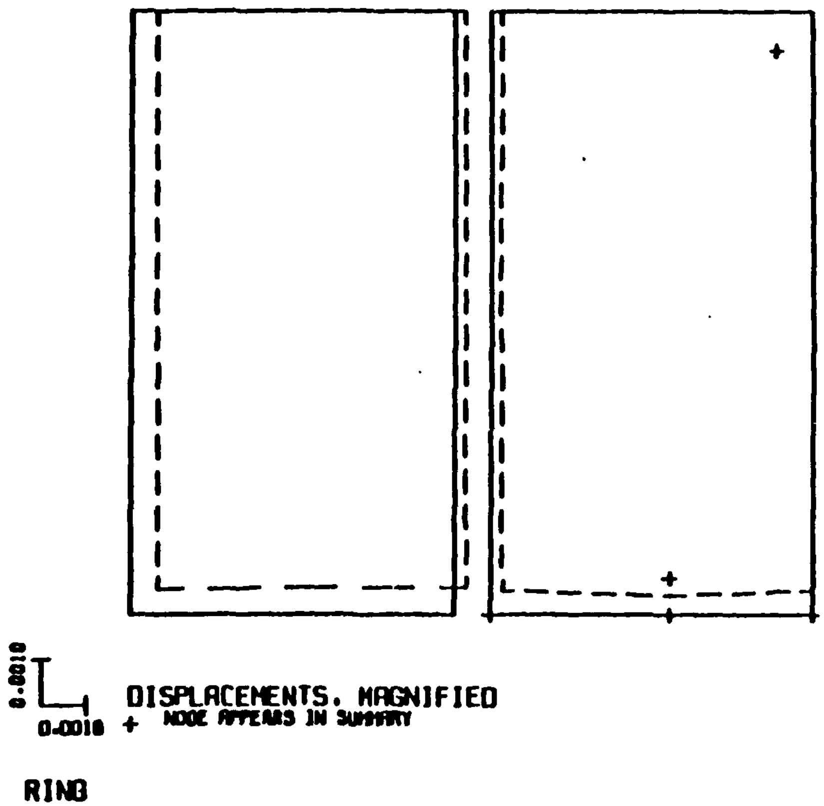


FIGURE 17

PISTON RINGS UNDER COMBINED
AXIAL AND RADIAL PRESSURE

FIGURE 8

RESULTS OF THERMAL STUDY

4-7

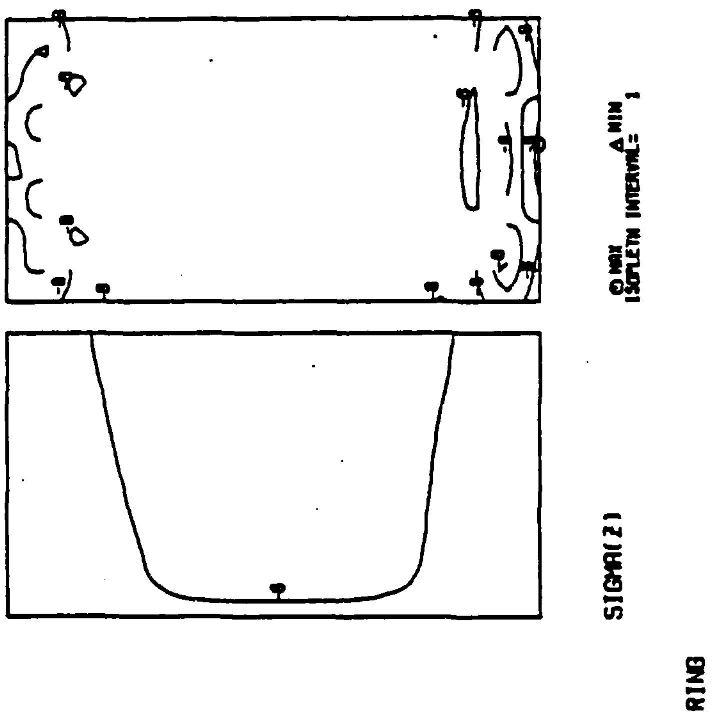


FIGURE 18

AXIAL STRESS DISTRIBUTION

PISTON RINGS

P = 8000 psi

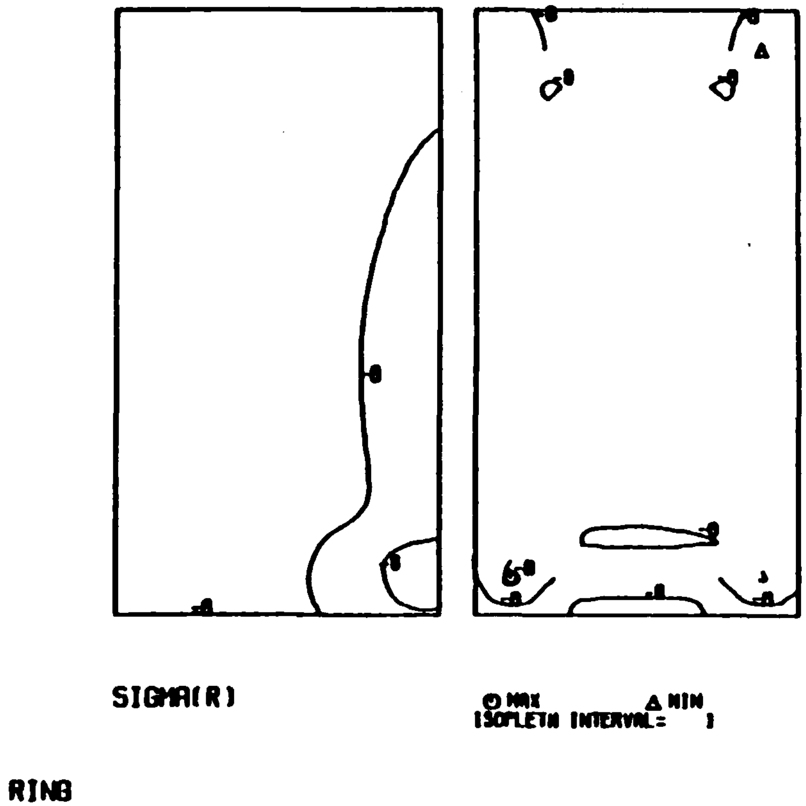


FIGURE 19

RADIAL STRESS DISTRIBUTION
PISTON RINGS
P = 8000 psi

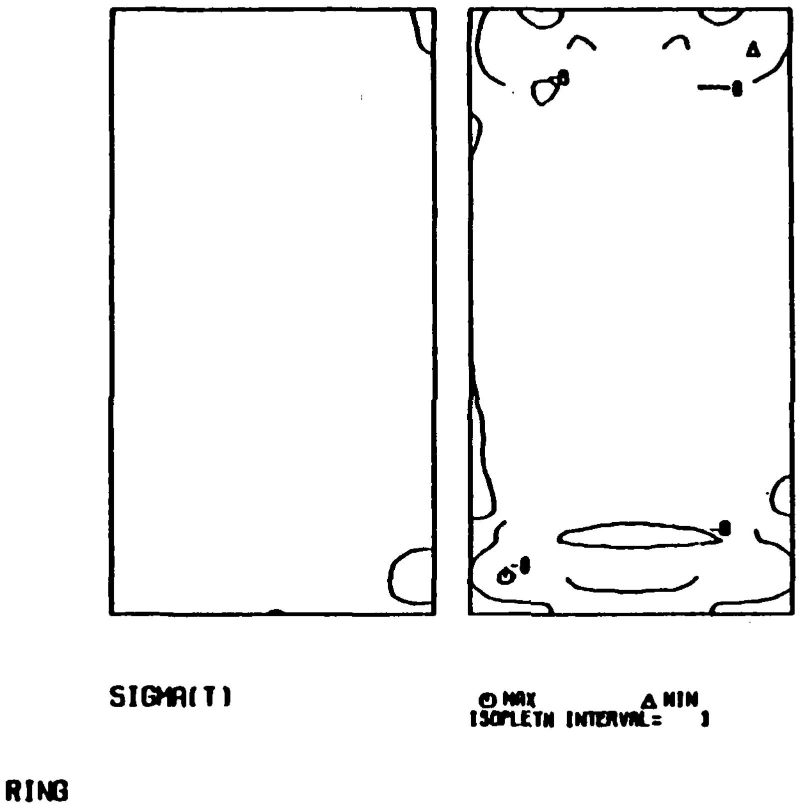


FIGURE 20

TANGENTIAL STRESS DISTRIBUTION
PISTON RINGS
P = 8000 psi

version of this seal could use a deeper groove equipped with an elastomer seal under the PTFE ring to provide for secondary sealing. In this case the two PEEK side rings woud act only as extrusion limiting devices.

4.4 Summary of Seal Designs

Two seals were designed, one for a one (1) inch diameter rod and the other for a two (2) inch piston diameter. The rod seal as designed is made of Arlon 1000 (PEEK) and assembled with an interference fit on the shaft. This seal requires a split housing. The "O"Ring is used to provide secondary sealing at the seal outside diameter. Two seals in tandem can be used to provide for redundance in safety. The seal design with limited thermal expansion is preferred because it uses a lower interference fit.

The rod seal provides the following advantages:

- Seal is rendered flexible by virtue of small cross-section.
- Direct "lip-type" pressurization at contact.
- Can be run in tandem for delta P control across each seal.
- Low frictional load.
- Overload is controlled by grooving.

On the negative side of the ledger, most of the disadvantages are associated with unknowns connected with the material and with the fact that the seal shall, at least in part, act as a rod bearing. The disadvantages thus are:

- Stresses and loads; can the materials take them?
- High wear may induce higher leakage.
- Lack of experience - novel idea.

The three-piece piston ring represents a new idea although the central ring made of PTFE has been used before at MTI with good results.

The advantages of the three-piece piston ring are:

- The scarf cut rings provide initial sealing required to energize central seal and add to the sealing capability of the tri-ring.

- Central ring when energized provides sealing and supplies low friction material to the end rings.
- Under pressure the friction coefficient of PTFE is very low, (0.04) resulting in low frictional force.

The disadvantages are centered around:

- Wear and "cold flow" of the center ring cannot be reliably estimated.
- End rings will be of the split self-energized design. The ease of manufacture must be investigated.
- Lack of experience at high CTFE pressures.

Both of these designs, the rod and piston ring, represent somewhat different and unconventional approaches to sealing. Thorough testing and evaluation, accompanied, if need be, by further development shall be required before these designs can be committed to actual CTFE hydraulic hardware.

The compatibility tests consisted of soaks of candidate plastic materials in CTFE at 275°F for 72 hours. The friction and wear test conditions are given in Section 2.2.5.

5.0 REFERENCES

1. Handout prepared by W.B. Campbell, PSB, APD, APL, dated 4 September, 1984.

2. "Teflon-Mechanical Design Data", E.I. Dupont Nemours and Company (Inc.), Polymer Products Department, Willmington, Delaware.

APPENDIX I

STRAIN GAGE INSTALLATION

The type of gages used on the spindle and the basic installation are shown in the sketch you prepared (Figure AI-1). The gages were first bonded to the shaft (which had been sand blasted) and allowed to cure. Following application of the gages, a calibration fixture was made as shown in Figure AI-2. This fixture allowed for applying a maximum moment of 1200 in-lbs in either a clockwise or counter clockwise direction. During calibration, a known static moment was applied to the shaft and strain readings were made. To make the strain readings, MTI's SR4 strain indicator was used. During calibration, the indicator was set up as follows:

Range Extender: 0
Range: 10
Gain Factor: 2.00
Terminal Connections:
- B: red lead wire to strain gage bridge
- W: white lead wire to strain gage bridge
- R: green lead wire to strain gage bridge
- G: black lead wire to strain gage bridge

Data for clockwise and counter clockwise applied moments is shown in Tables AI-1 and AI-2 respectively. In addition, this data has been plotted and shown in Figure AI-3.

The linear and repeatable behavior of the data indicate that both the strain gage application and the calibration were of good quality. In addition, the strain gage bridge showed virtually no sensitivity to bending loads. Based on the measured data, the calibration factor is 1.80 in-lb/micro strain.

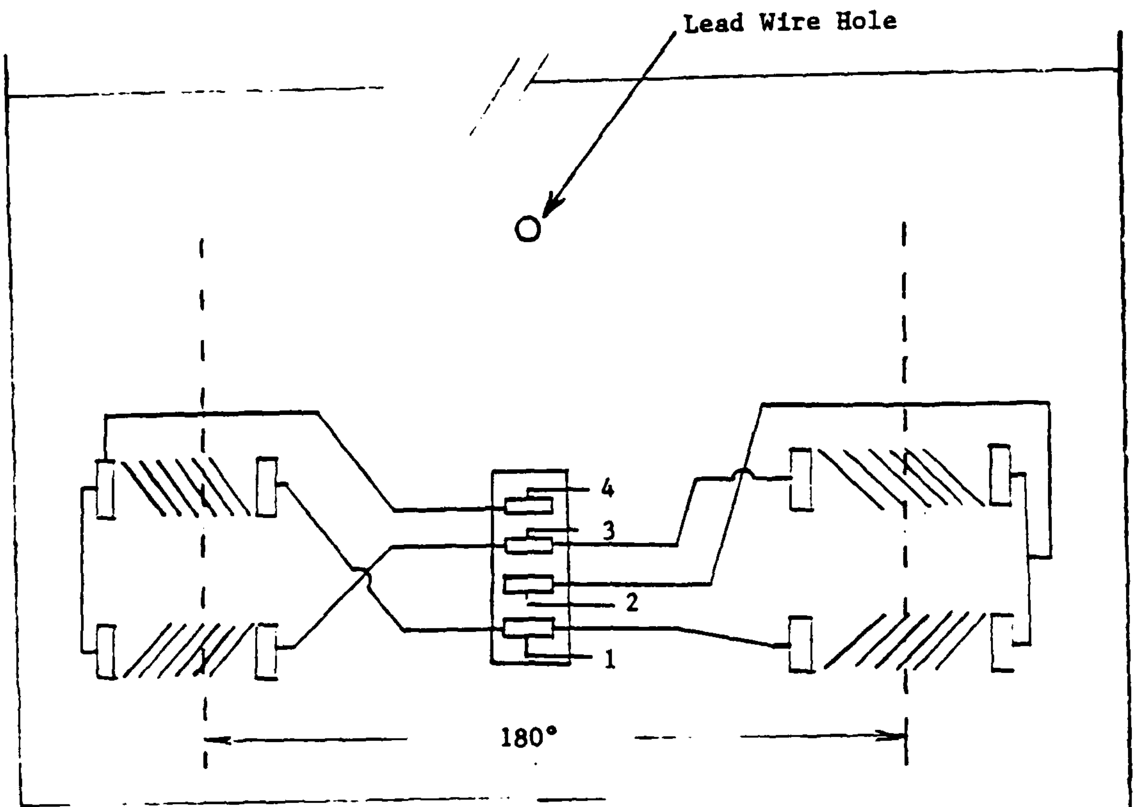
Calibration resistors were sized and checked so that bridge calibration could be easily checked during the test period. Calibration resistor results are summarized in Table AI-3.

FIGURE 1

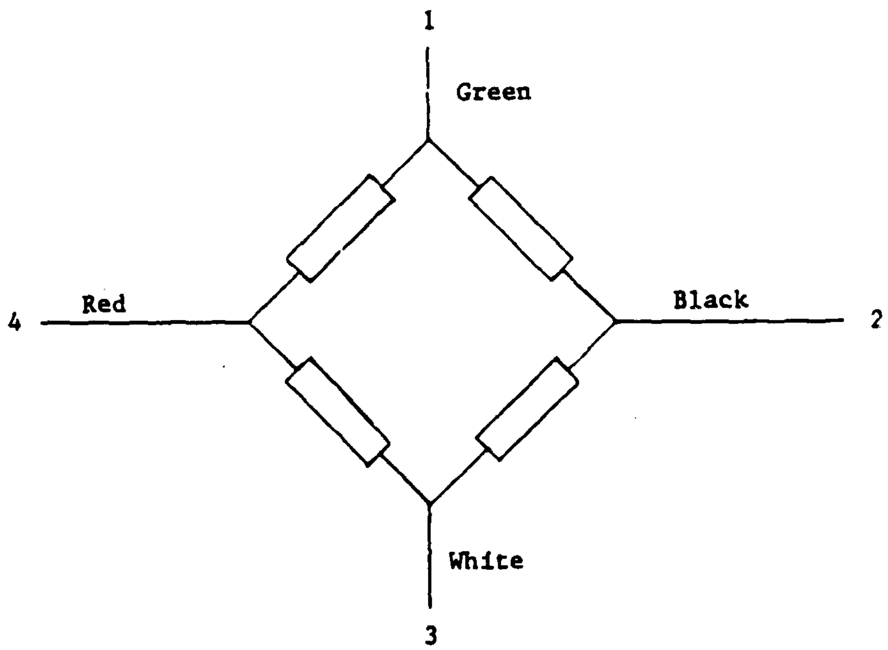
STRAIN GAGE APPLICATION DATA

GAGE TYPE: EA-06-125TK-350 (Micro-Measurement)

GAGE FACTOR: 2.025 ± 0.5% + 0.2



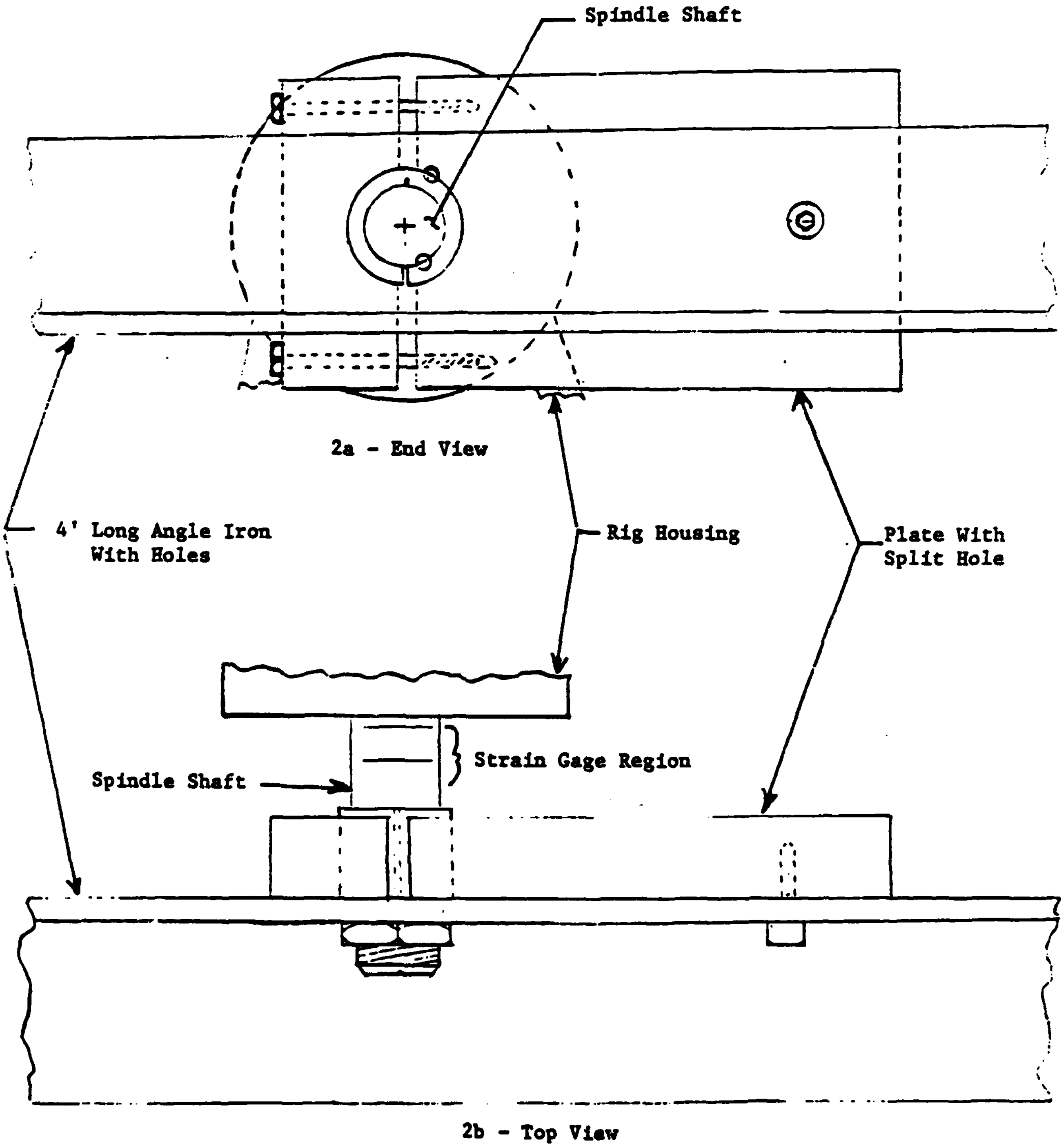
1a - Shaft Developed Surface



1b - Strain Gage Bridge

FIGURE 2

CALIBRATION SET-UP



STRAIN GAGE CALIBRATION

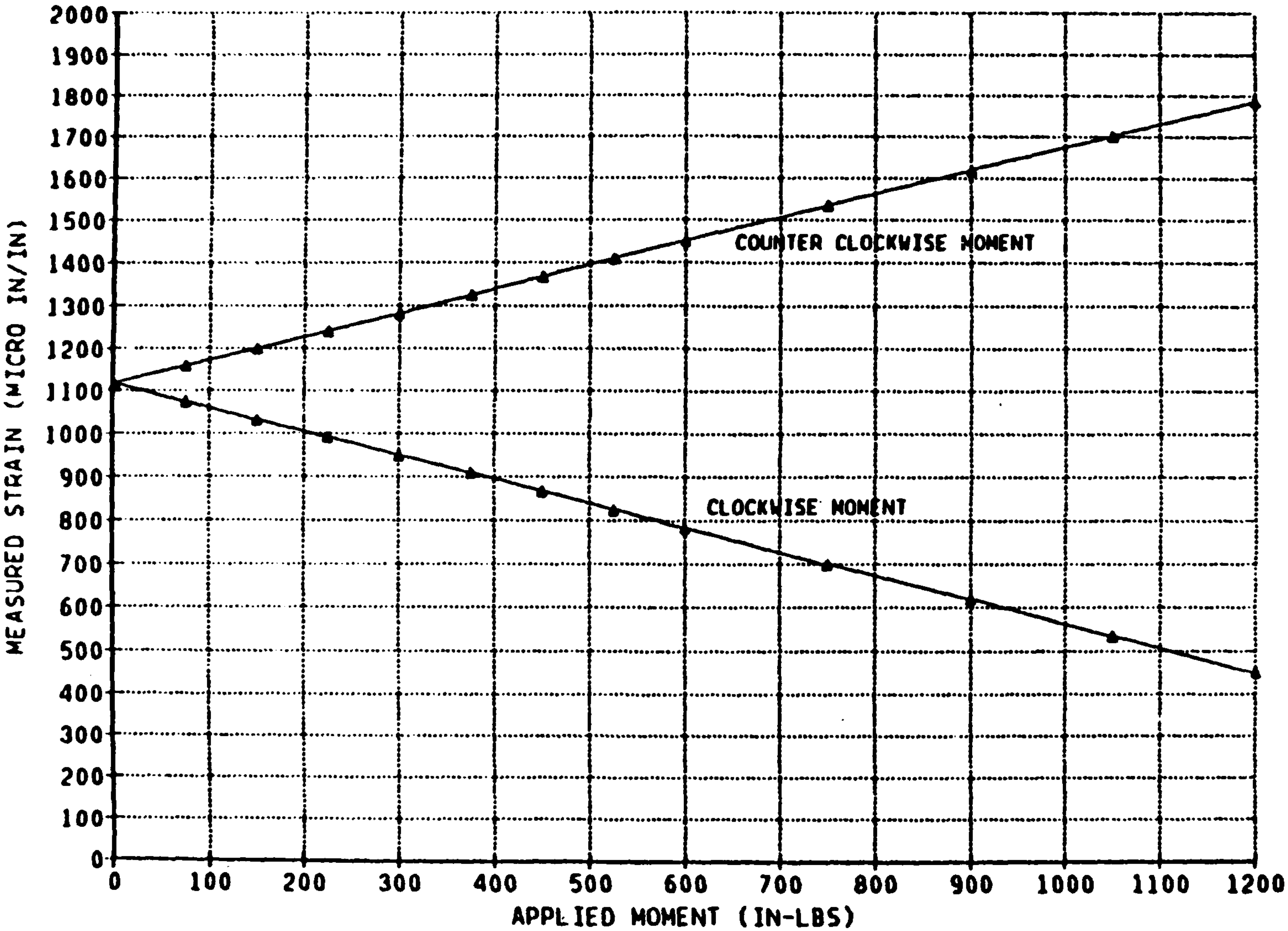


FIGURE 3

TABLE 1

DATA FOR ↻ MOMENT LOOKING AT DISK END

NOMINAL WEIGHT (lbs.)	MOMENT ARM (in.)	NOMINAL APPLIED TORQUE (in. lbs.)	MEASURED (MICRO in/in)
0	0	0	1118
25*	3	75	1075
25	6	150	1032
25	9	225	992
25	12	300	950
25	15	375	910
25	18	450	868
25	21	525	826
25	24	600	782
50*	24	1200	451
50	21	1050	535
50	18	900	620
50	15	750	700
50	12	600	786

*all 25 lb. weights are 25 lbs. + 107.5 gm

**all 50 lb. weights are 50 lbs. + 138.5 gm

$$K = \frac{1200}{1118-451} = 1.80 \text{ in-lb/microstrain}$$

TABLE 2

DATA FOR ↶ MOMENT LOOKING AT DISK END

NOMINAL WEIGHT (lbs.)	MOMENT ARM (in)	NOMINAL APPLIED TORQUE (in. lbs.)	MEASURED STRAIN (MICRO in/in)
0	0	0	1118
25*	3	75	1160
25	6	150	1200
25	9	225	1241
25	12	300	1282
25	15	375	1325
25	18	450	1368
25	21	525	1410
25	24	600	1452
50**	24	1200	1786
50	21	1050	1702
50	18	900	1620
50	15	750	1535
50	12	600	1450

*all 25 lb. weights are 25 lbs. + 107.5 gm

**all 50 lb. weights are 50 lbs. + 138.5 gm

$$K = \frac{1200}{1786-1118} = 1.80 \text{ in-lb/micro strain}$$

TABLE 3

CALIBRATION RESISTOR DATA

RESISTOR VALUE*	STRAIN READING (MICRO-STRAIN)	DELTA STRAIN (MICRO-STRAIN)	EQUIVALENT TORQUE (IN LB)
0	1118	-	-
281 KΩ	501	617	1110
559 KΩ	802	316	568
1179 KΩ	958	160	288

*Resistors placed between red and white lead wires

APPENDIX II

TEST PROCEDURE

1.0 SOAK TESTS

1.1 Preliminary Test

1. Prepare 0.25 in diameter samples (check for appropriate length) of applicable plastic materials. Record length and diameter.

2. Weigh each sample after air blast cleaning and deburring. Make sure air is dry. If need be, use bottled N_2.

3. Prepare a bath filled with CTFE fluid. Immerse sample into bath. Cover bath to keep fluid clean.

4. Place sample and bath into 275°F oven and keep for 72 hours. To save on time, use six containers, one for each material.

5. Following soak, cool off baths, remove samples being careful not to contaminate them. Blot off extra fluid with lint-free paper.

6. Weigh each sample and measure its cold (68°F) dimensions.

7. Record data for comparison with (1).

8. Check sample versus holder dimension. Determine amount of swelling in each material type. Use this data to determine the pre-soak dimensions of test samples to be used for conducting tests taking into account 0.010 - 0.005 in stick-out and a line-fit in the sample holder.

1.2 Test Sample Soak Tests

1. Prepare four samples of each material type using diameters and lengths determined from step (8) in the preliminary tests. Record length and diameter.

2. Weigh each sample after air blast cleaning and deburring. Make sure air is dry. If need be, use bottled N_2.

3. Prepare a bath filled with CTFE fluid. Immerse sample into bath. Cover bath to keep clean.

4. Place sample and bath into 275°F oven and keep for 72 hours. To save on time, use six containers, each one with at least two (2) samples of the same material.

5. Following soak, cool off baths, remove samples being careful not to contaminate them. Blot off extra fluid with lint-free paper.

6. Weigh each sample and measure its cold (68°F) dimensions.

7. Record data for comparison with (1).

8. Check sample versus holder dimensions. Allowing for fit and 0.010 stick-out of plastic beyond sample holder at 275°F. Final size adjustments may be required.

9. Install samples into holders for test. Samples not used should be preserved in separate covered glass dishes.

2.0 TESTING

1. Install disk on shaft:
   - heat disk to 375 - 400°F
   - place collar and one (1) washer on shaft
   - place disk on shaft so that an unused portion of the disk will be contacted by test specimen
   - install one (1) or more anti-rotation pins
   - install washer and nut
   - tighten nut
   - place assembled unit in front of fan (to minimize strain gage heating) and allow to cool

2. Connect strain gage leads to strain gage read out instrument and check using calibration resistor.

3. Install holder in cylinder and insert cylinder in reservoir - DO NOT INSTALL TEST SPECIMENS

4. Install reservoir seal plates, seals, displacement probes and caliper pressure hoses.

5. Place spindle on bed plate dowel pins (with disk in reservoir). Check alignment and make adjustments to satisfy the following:
   - disk face run-out at contact region (0.0005 in. TIR)
   - reservoir face run-out with respect to disk (0.0005 in. TIR)
   - clearance between disk and specimen holder with cylinder in bottomed out position (i.e., 2-5 psi caliper pressure) and equal on each side ≈ 1-2 mil.

6. With cylinder in "bottomed out" position, adjust probe gap to allow for specimen stick-out and thermal growth of specimen. Record bottomed out position.

FOR EXAMPLE

- 10 mil stick-out
- thermal growth (VESPEL):
  $0.62 \times 30 \times 10^{-6} \times 200^{o}F$ in/in/$^{o}F = 3.72$ mil
- minimum gap: 13.7 mil

7. Remove spindle, seal plates and specimen holder assembly

SPECIMEN PREPARATION AND INSTALLATION

8. Remove specimen from fluid. Dry specimen with lint-free paper and then blow with air or dry gas (e.g., nitrogen) for several minutes.

9. Measure and record length, diameter (to the nearest 0.0001") and weight (to the nearest 0.0001 g) of each specimen.

10. Install specimens in holders and shim as required tc get 0.010" stick-out. Measure and record weight of specimen holder and shim (to the nearest 0.0001 g).

11. Install thermocouples in specimens, and reassemble specimen holder assemblies in reservoir housing.

12. Reassemble caliper seal plates and re-install spindle.

13. Install strain gage, displacement probe leads and connect all instrumentation.

14. Record cylinder displacement (with spindle shaft at known location) with caliper pressure at two values:
    V = 0.075 volts
    V = 1.00 volts (test pressure)

15. Set caliper pressure to test pressure (1.0 volt) operate rig at 1 Hz for 100-200 cycles and take strain gage data. Read caliper position and then remove caliper pressure.

16. Install fluid in reservoir, install reservoir cover, and repeat step 14 and 15.

17. Turn on temperature controller and heater. Increase temperature to 275^{o}F and allow to stabilize. (No caliper pressure during this time).

18. When temperature has stabilized, repeat step 14.

19. Leave caliper pressure at 1.0 volts, set test frequency to 1 Hz.

20. Record strain, displacement, temperature, cycle count and displacement data at 15 minute intervals for the first hour.

21. Repeat step 20 at 1 hour intervals until end of test. End of test occurs at 25,000 cycles or to failure. Failure is defined as loss of stick-out to the point where friction force is no longer generated.

22. Shut down rig and repeat step 14.

23. Turn off heater and allow to cool.

24. When rig has cooled to room temperature repeat step 14.

25. Remove fluid from reservoir.

26. Remove spindle housing and disassemble specimen holders.

27. Remove specimens from holders, dry specimens with lint-free paper and then blow dry.

28. Measure and record length, diameter (to nearest 0.0001 in.) and weight (to nearest 0.0001 g) of each specimen.

29. Clean specimen holders and shims. Put specimen in holders with shims used for test.

30. Measure and record weight of specimen, holder and shims to nearest 0.0001 g) and measure specimen stick-out.

To repeat test with different specimen or contact zone on disk, repeat test procedure.

APPENDIX III

TEST DATA SUMMARY

By John Giordano

TABLE 1

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TEST RESULT SUMMARY

TEST NUMBER: 2

Nominal Test Conditions:

Frequency: 1 Hz
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: VESPEL
Disk coating: Hard Chrome

Actual Test Parameters

Total cycles: 26,268
Total distance: 27,360 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

PV: 71,250 (psi x ft/min)

Measured Coefficient of Friction

Dry (room temperature): 0.25
In CTFE (room temperature) 0.04/0.16 (sliding/static)
In CTFE (275°F) at start: 0.15/0.20 (sliding/static)
In CTFE (275°F) at finish:

Measured Wear Data (in CTFE at 275°F)

Cycles: 24,856
Distance: 25,890 ft.

Wear data for 2 CLA disk surface finish

Specimen length change: 5.5 mil
Specimen weight change: 0.0078 gm

Average Wear rate: 0.952×10^{-9} in^3/in

Wear data for 7 CLA disk surface finish

Specimen length change: 3.3 mil
Specimen weight change: 0.0063 g

Average Wear rate: 0.613×10^{-9} in^3/in

FIGURE 1

HIGH PRESSURE - CTFE SEAL DEVELOPMENT PROGRAM
TYPICAL FRICTION FORCE DATA

TEST NUMBER: 2

Nominal Test Conditions:

Frequency: 1 hz
Av. Velocity: 12.5 in/sec

Actual Test Parameters

Total cycles: 26,268
Total distance: 27,360 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

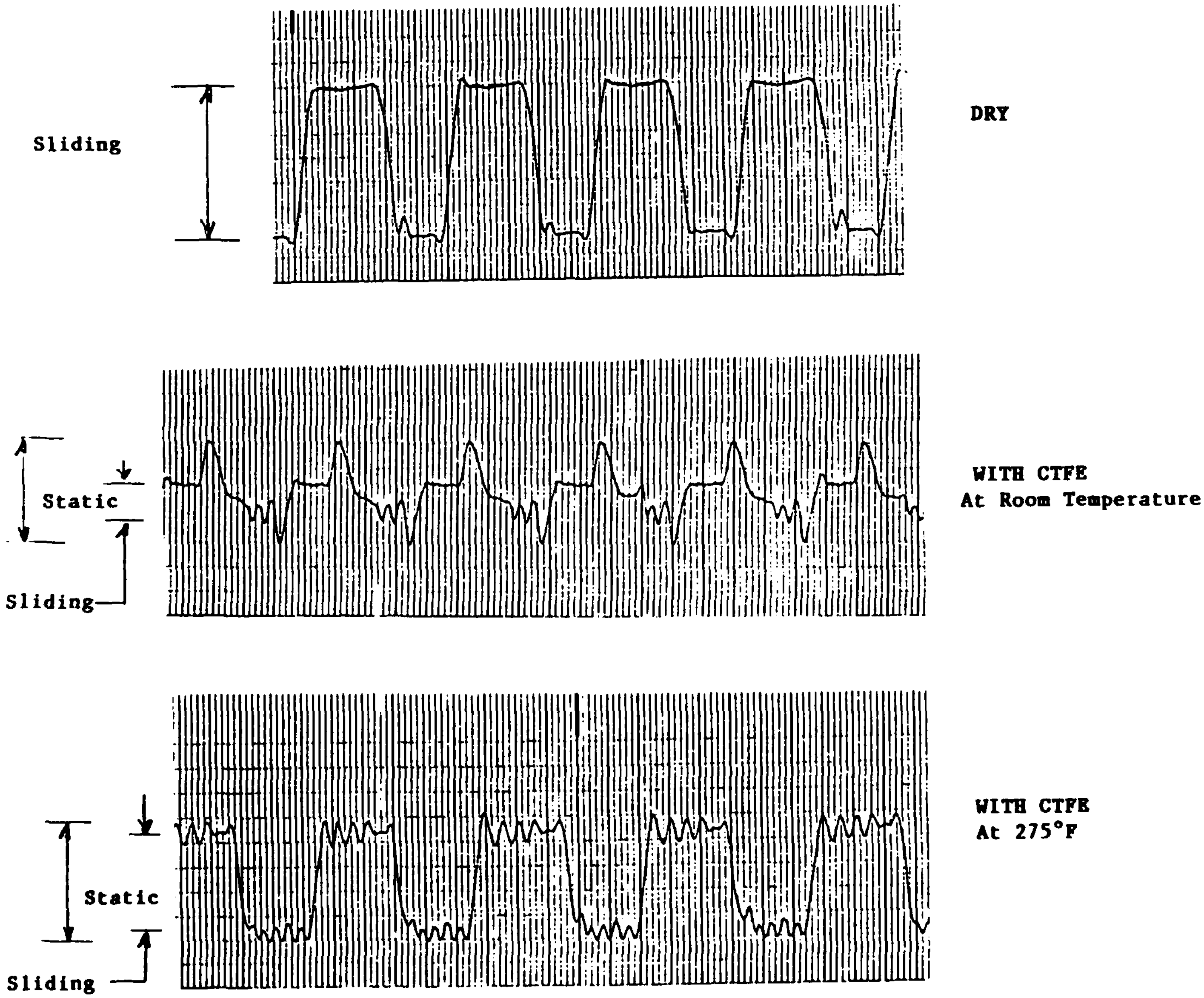
PV: 71,250 (psi x ft/min)

Test Material Summary:

Specimen: VESPEL
Disk coating: Hard Chrome

Chart Calibration

4.47lbs/spec/large div



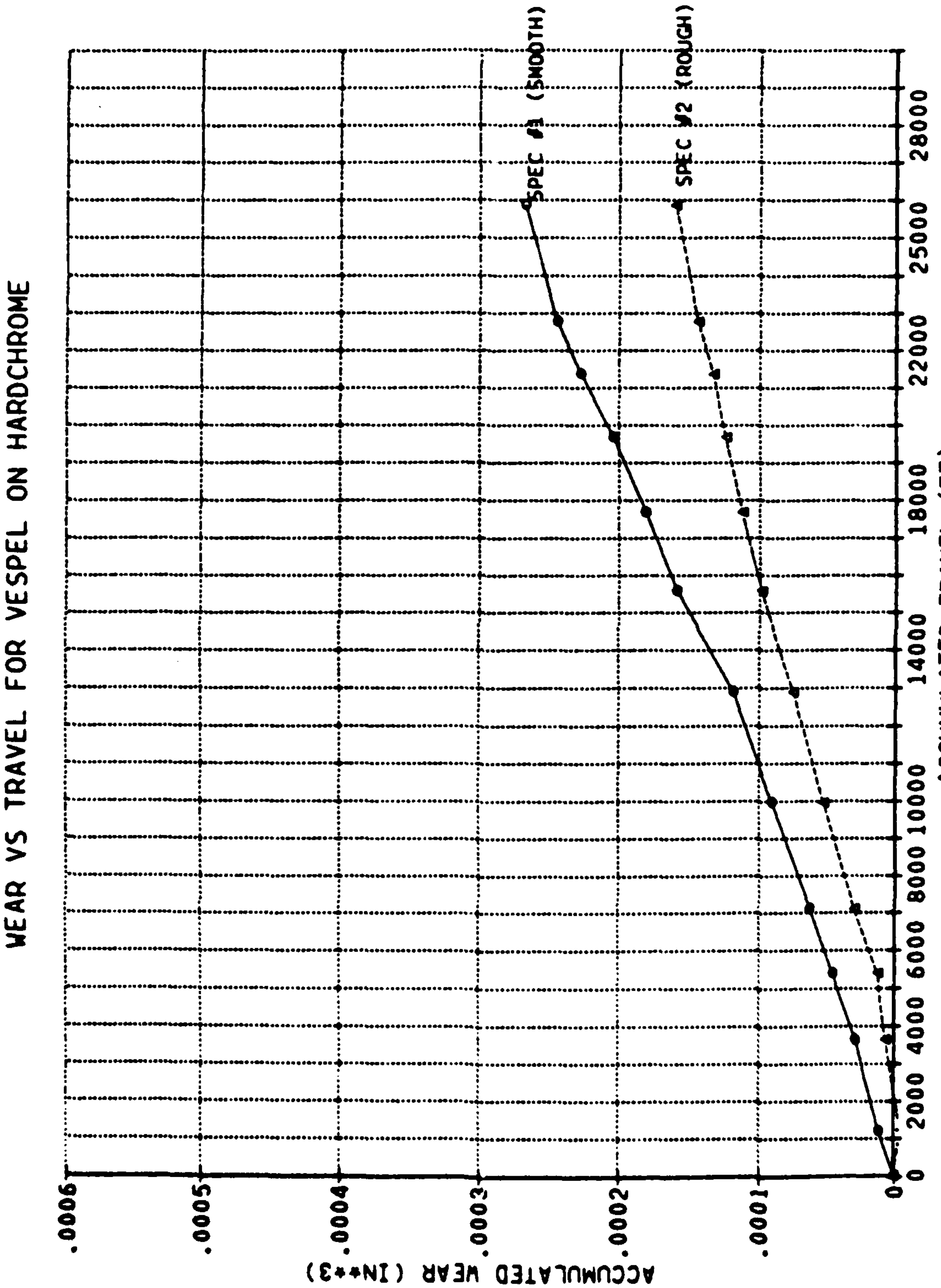

WEAR VS TRAVEL FOR VESPEL ON HARDCHROME
SPEC #1 (SMOOTH)
SPEC #2 (ROUGH)
ACCUMULATED TRAVEL (FT)
0
2000
4000
6000
8000
10000
14000
18000
22000
25000
28000
ACCUMULATED WEAR (IN**3)
0
.0001
.0002
.0003
.0004
.0005
.0006

FIGURE 2

TABLE 2

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TEST RESULT SUMMARY

TEST NUMBER: 3

Nominal Test Conditions:

Frequency: 1 Hz
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: PEEK
Disk coating: Hard Chrome

Actual Test Parameters

Total cycles: 25,960
Total distance: 27,040 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

PV: 71,250 (psi x ft/min)

Measured Coefficient of Friction

Dry (room temperature): 0.21
In CTFE (room temperature) 0.06/0.15 (sliding/static)
In CTFE (275°F) at start: 0.16/0.19 (sliding/static)
In CTFE (275°F) at finish: 0.15/0.17

Measured Wear Data (in CTFE at 275°F)

Cycles: 25,282
Distance: 26,335 ft.

Wear data for 2 CLA disk surface finish

Specimen length change: 3.7 mil
Specimen weight change: 0.0035 g

Average Wear rate: 0.464×10^{-9} in^3/in

Wear data for 7 CLA disk surface finish

Specimen length change: 3.2 mil
Specimen weight change: 0.0037 g

Average Wear rate: 0.432×10^{-9} in^3/in

FIGURE 3

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TYPICAL FRICTION FORCE DATA

TEST NUMBER: 3

Nominal Test Conditions:

Frequency: 1 hz.
Av. Velocity: 12.5 in/sec

Actual Test Parameters

Total cycles: 25,960
Total distance: 27,040 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

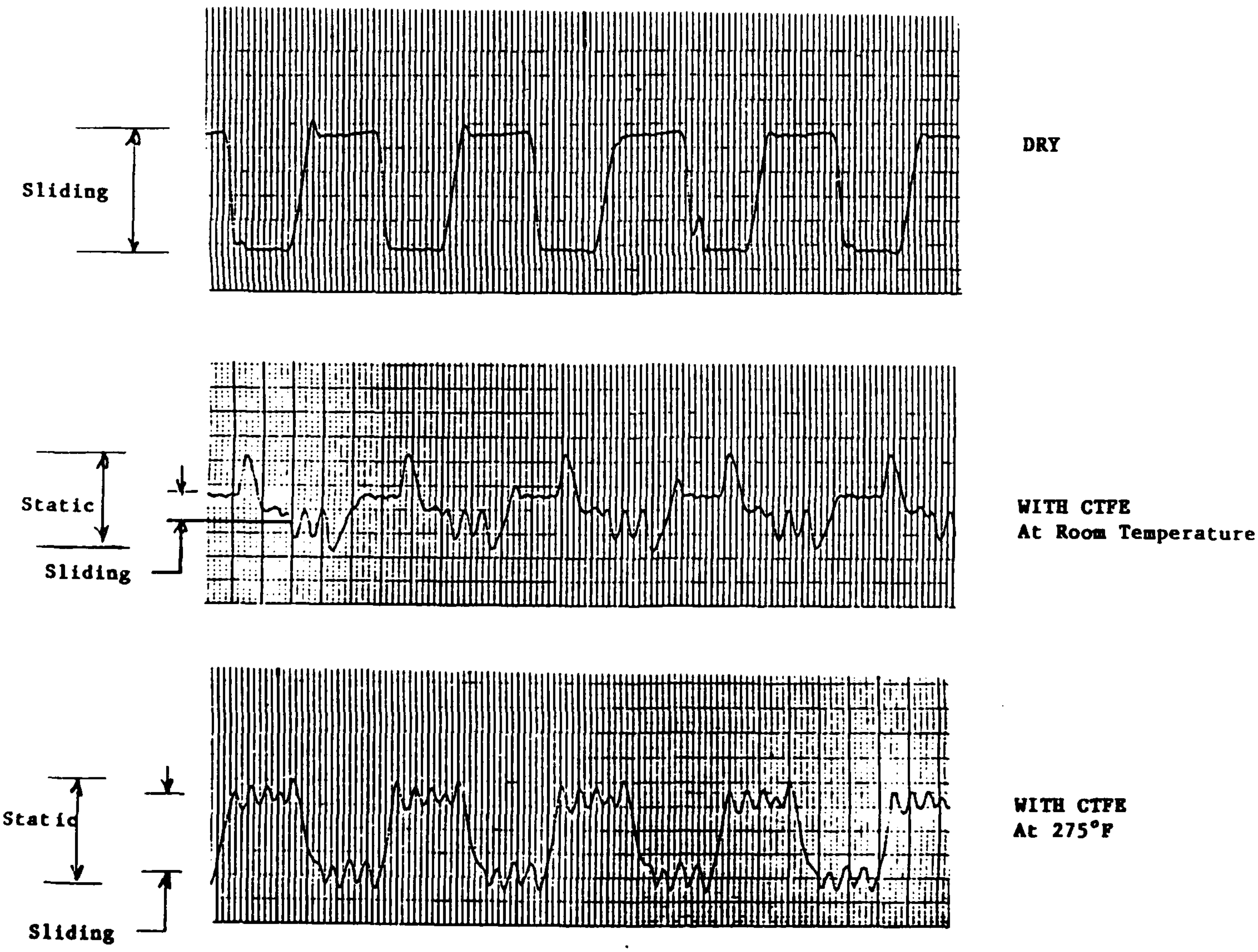
PV: 71,250 (psi x ft/min)

Test Material Summary:

Specimen: PEEK
Disk coating: Hard Chrome

Chart Calibration

4.47lbs/spec/large div



WEAR VS TRAVEL FOR PEEK ON HARDCHROME

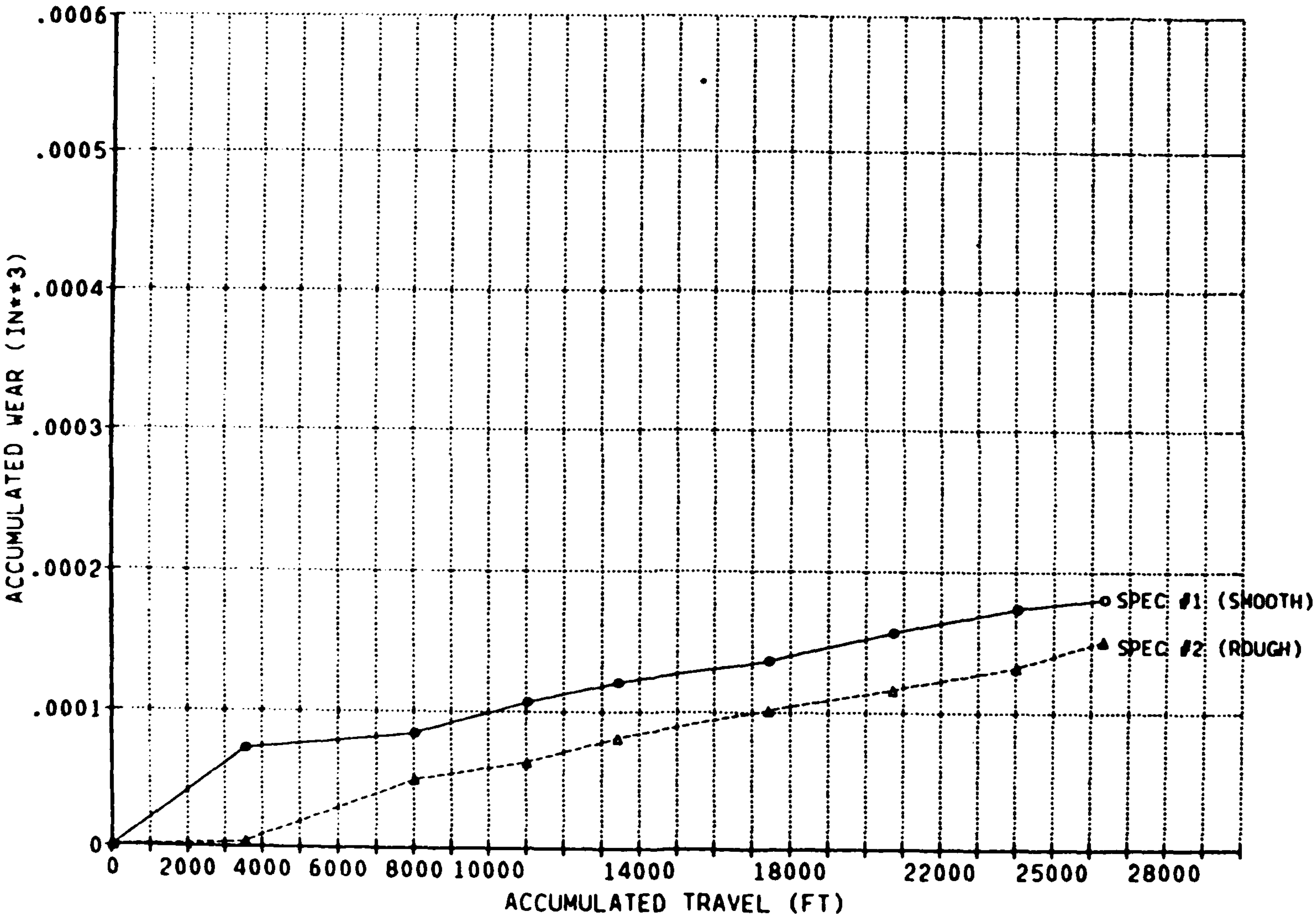


FIGURE 4

TABLE 3

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TEST RESULT SUMMARY

TEST NUMBER: 4

Nominal Test Conditions:

Frequency: 1 Hz
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: GFD
Disk coating: Hard Chrome

Actual Test Parameters

Total cycles: 25,786
Total distance: 26,860 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

PV: 71,250 (psi x ft/min)

Measured Coefficient of Friction

Dry (room temperature): 0.19
In CTFE (room temperature) 0.06
In CTFE (275°F) at start: 0.063/0.095 (sliding/static)
In CTFE (275°F) at finish: 0.08/0.10 (sliding/static)

Measured Wear Data (in CTFE at 275°F)

Cycles: 25,007
Distance: 26,048 ft.

Wear data for 2 CLA disk surface finish

Specimen length change: 4.2 mil
Specimen weight change: 0.0076 g

Average Wear rate: 0.387×10^{-9} in^3/in

Wear data for 7 CLA disk surface finish

Specimen length change: 5.7 mil
Specimen weight change: 0.008 g

Average Wear rate: 0.561×10^{-9} in^3/in

FIGURE 5

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TYPICAL FRICTION FORCE DATA

TEST NUMBER: 4

Nominal Test Conditions:

Frequency: 1 hz.
Av. Velocity: 12.5 cm/sec.

Actual Test Parameters

Total cycles: 25,786
Total distance: 26,860

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

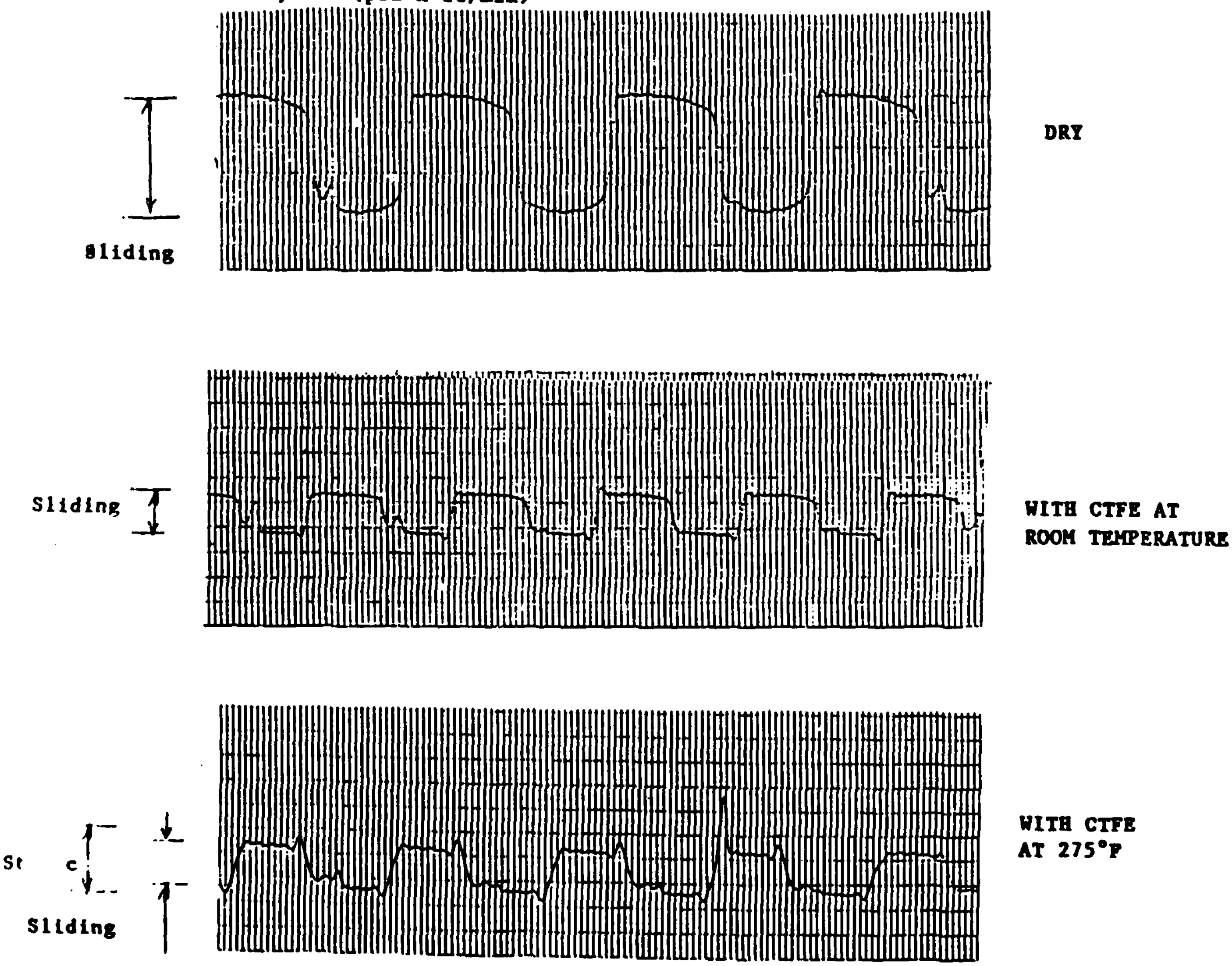
PV: 71,250 (psi x ft/min)

Test Material Summary:

Specimen: GFD
Disk coating: Hard Chrome

Chart Calibration

4.47lbs/spec/large div



WEAR VS TRAVEL FOR GFD ON HARDCHROME

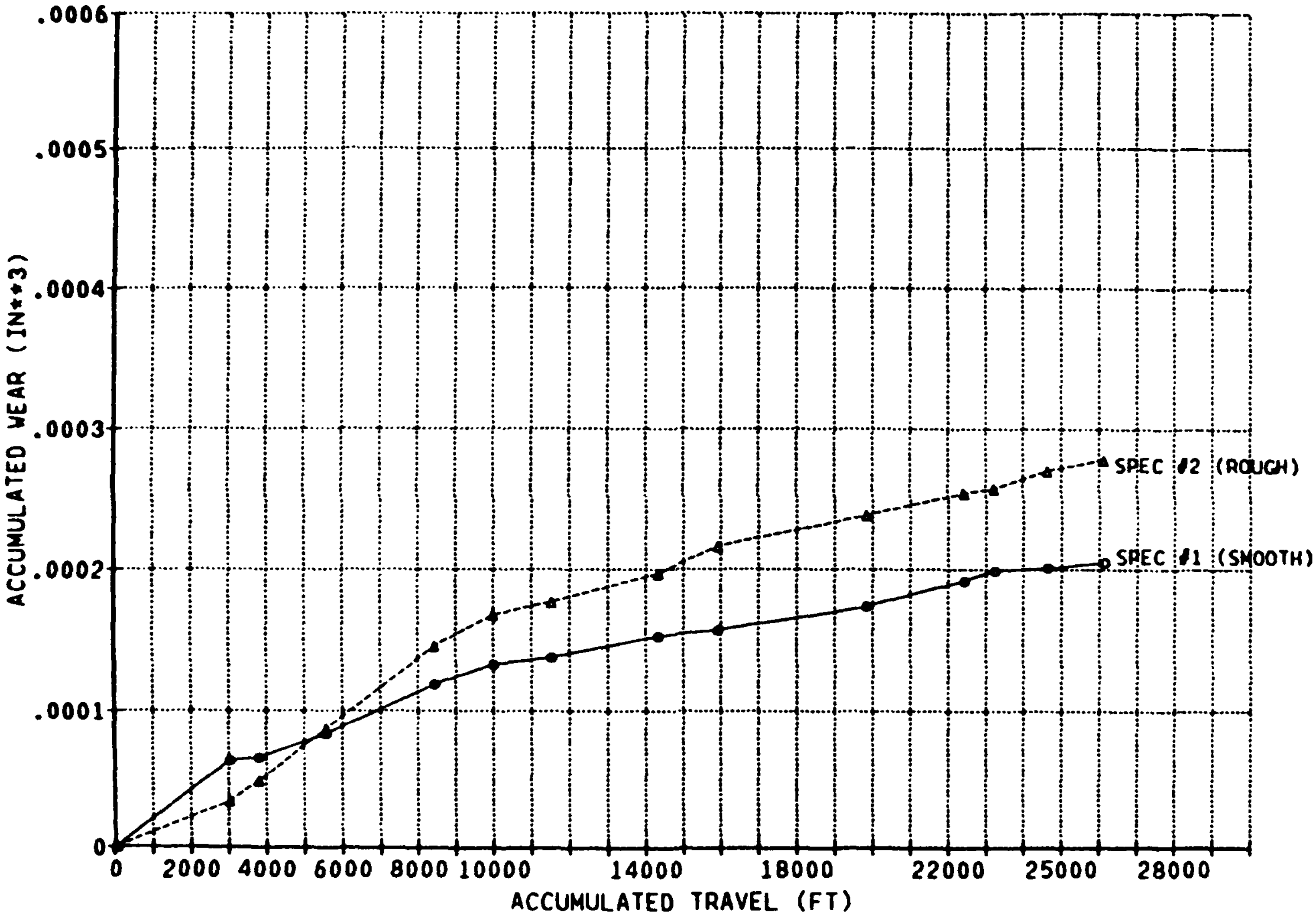


FIGURE 6

TABLE 4

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TEST RESULT SUMMARY

TEST NUMBER: 5

Nominal Test Conditions:

Frequency: 1 Hz
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: GFD
Disk coating: Tungsten Carbide

Actual Test Parameters

Total cycles: 25,474
Total distance: 26,535 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

PV: 71,250 (psi x ft/min)

Measured Coefficient of Friction

Dry (room temperature):	*0.16		
In CTFE (room temperature)	*0.04/0.11	(sliding/static)	(25 mv p-p/70 mv p-p)
In CTFE (275°F) at start:	0.060	(sliding/static)	(75 mv p-p/N/O)
In CTFE (275°F) at finish:	0.056/0.072	(sliding/static)	(70 mv p-p/90 mv p-p)

Measured Wear Data (in CTFE at 275°F)

Cycles: 25,053
Distance: 26,096 ft.

Wear data for 7 CLA disk surface finish

Specimen length change: 8.8 mil
Specimen weight change: 0.0097 g

Average Wear rate: 1.32×10^{-9} in^3/in

Wear data for 14 CLA disk surface finish

Specimen length change: 11.7 mil
Specimen weight change: 0.0159 g

Average Wear rate: 2.38×10^{-9} in^3/in

* Run @ reduced pressure since GFD was very compliant
  Load/specimen = 23 lbs.
  Contact stress = 570 psi

FIGURE 7

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TYPICAL FRICTION FORCE DATA

TEST NUMBER: 5

Nominal Test Conditions:

Frequency: lh3
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: GFD
Disk coating: Tungsten Carbide

Actual Test Parameters

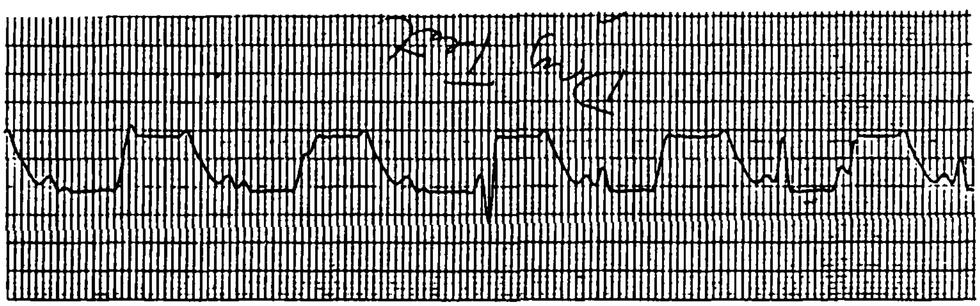
Total cycles: 25,474
Total distance: 26,535 ft

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

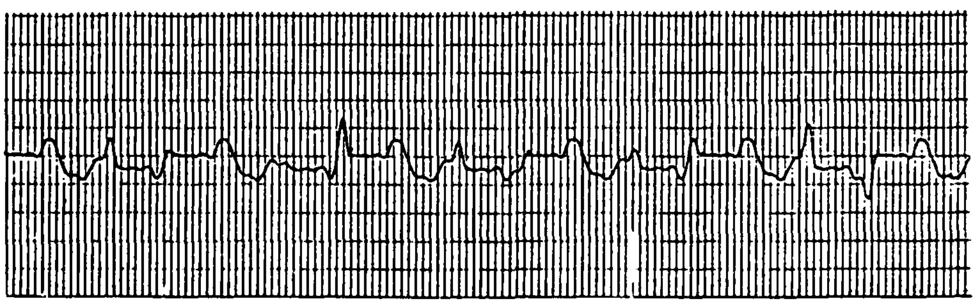
PV: 71,250 (psi xft/min)

Chart Calibration

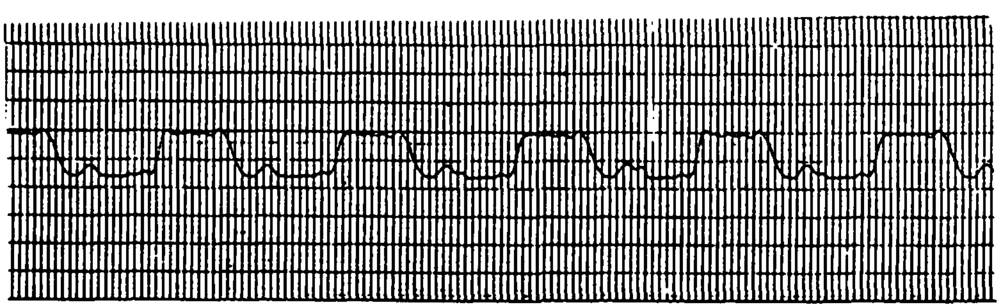
4.47lbs/spec/large div



DRY



WITH CTFE AT ROOM TEMPERATURE



WITH CTFE AT 275°F

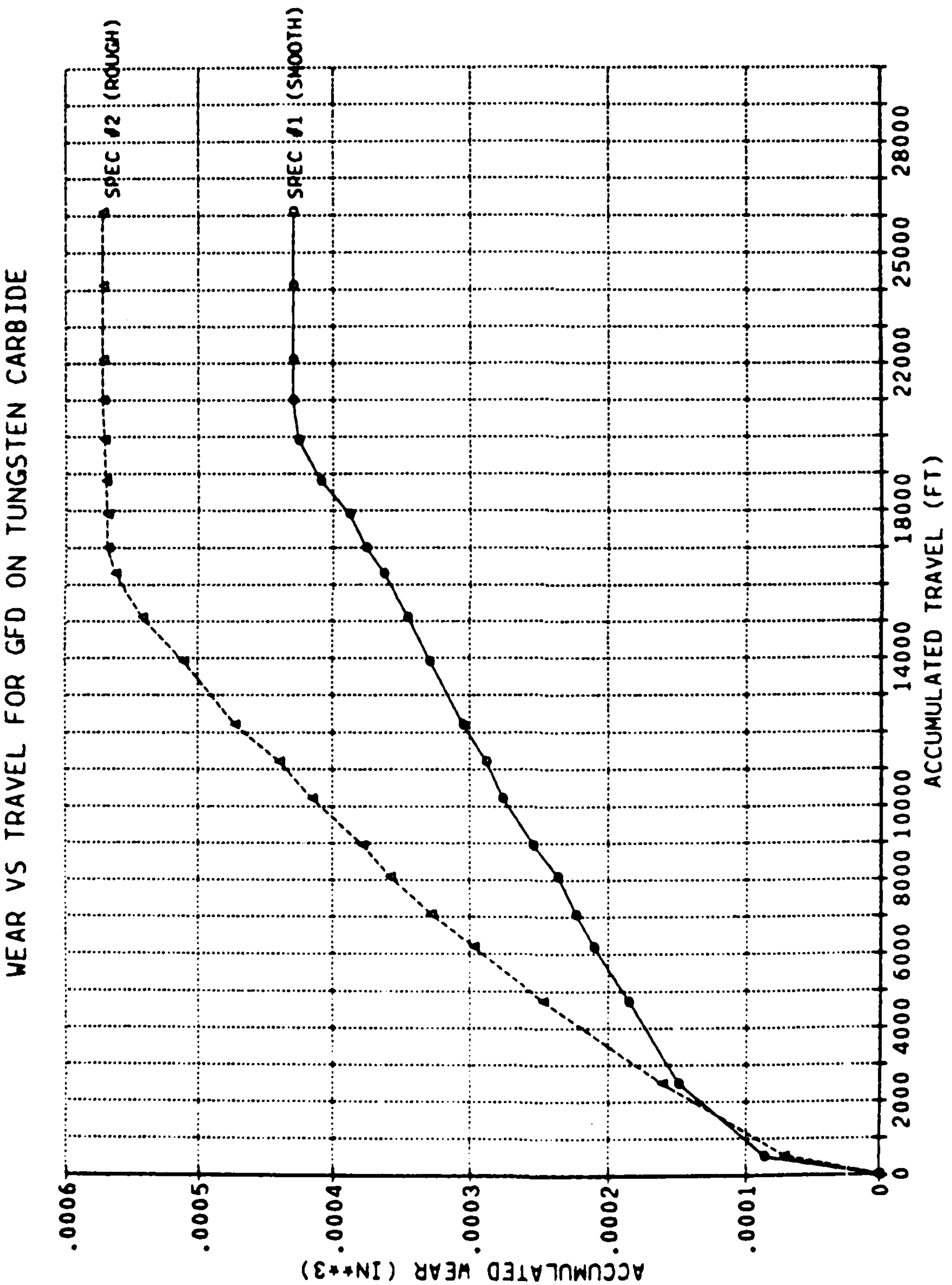

WEAR VS TRAVEL FOR GFD ON TUNGSTEN CARBIDE
SPEC #2 (ROUGH)
SPEC #1 (SMOOTH)
ACCUMULATED WEAR (IN**3)
.0006
.0005
.0004
.0003
.0002
.0001
0
ACCUMULATED TRAVEL (FT)
0
2000
4000
6000
8000
10000
14000
18000
22000
25000
28000

FIGURE 8

TABLE 5

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TEST RESULT SUMMARY

TEST NUMBER: 6

Nominal Test Conditions:

Frequency: 1 Hz
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: VESPEL
Disk coating: Tungsten Carbide

Actual Test Parameters

Total cycles: 26,658
Total distance: 26,727 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

PV: 71,250 (psi x ft/min)

Measured Coefficient of Friction

Dry (room temperature):	0.26	(320 mv p-p)	
In CTFE (room temperature)	0.044/0.15	(sliding/static)	(50-60 mv p-p/190 mv p-p)
In CTFE (275°F) at start:	0.10/0.14	(sliding/static)	(120 mv p-p/180 mv p-p)
In CTFE (275°F) at finish:	0.13/0.18	(sliding/static)	(160 mv p-p/220 mv p-p)

Measured Wear Data (in CTFE at 275°F)

Cycles: 25,128
Distance: 26,175 ft.

Wear data for 7 CLA disk surface finish

Specimen length change: 5.6 mil
Specimen weight change: 0.0081 g

Average Wear rate: 0.857×10^{-9} in^3/in

Wear data for 14 CLA disk surface finish

Specimen length change: 3.2 mil
Specimen weight change: 0.0045 g

Average Wear rate: 0.607×10^{-9} in^3/in

FIGURE 9

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TYPICAL FRICTION FORCE DATA

TEST NUMBER: 6

Nominal Test Conditions:

Frequency: lh3
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: Vespel
Disk coating: Tungsten Carbide

Actual Test Parameters

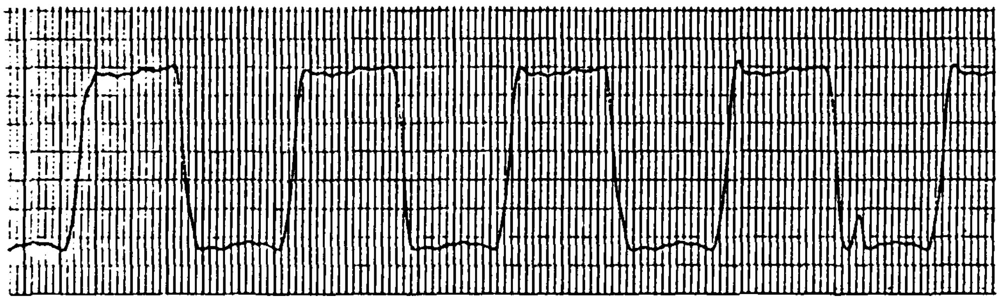
Total cycles: 26,268
Total distance: 27,360 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

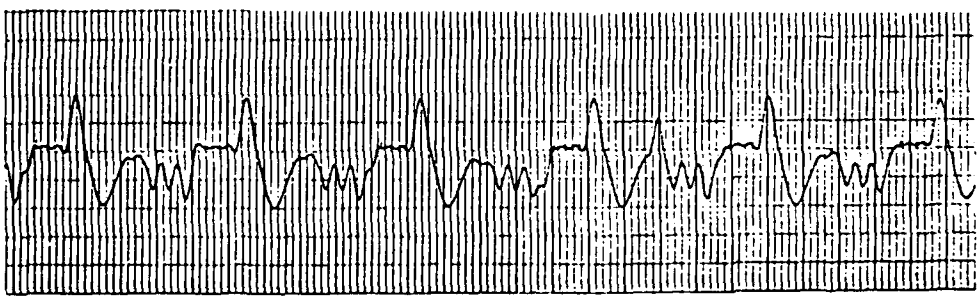
PV: 71,250 (psi xft/min)

Chart Calibration

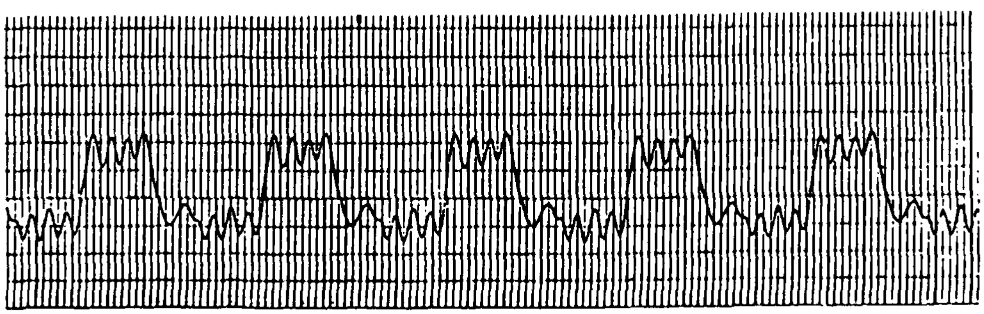
4.47lbs/spec/large div



DRY



CTFE AT ROOM TEMPERATURE



CTFE AT 275°F

WEAR VS TRAVEL FOR VESPEL ON TUNGSTEN CARBIDE

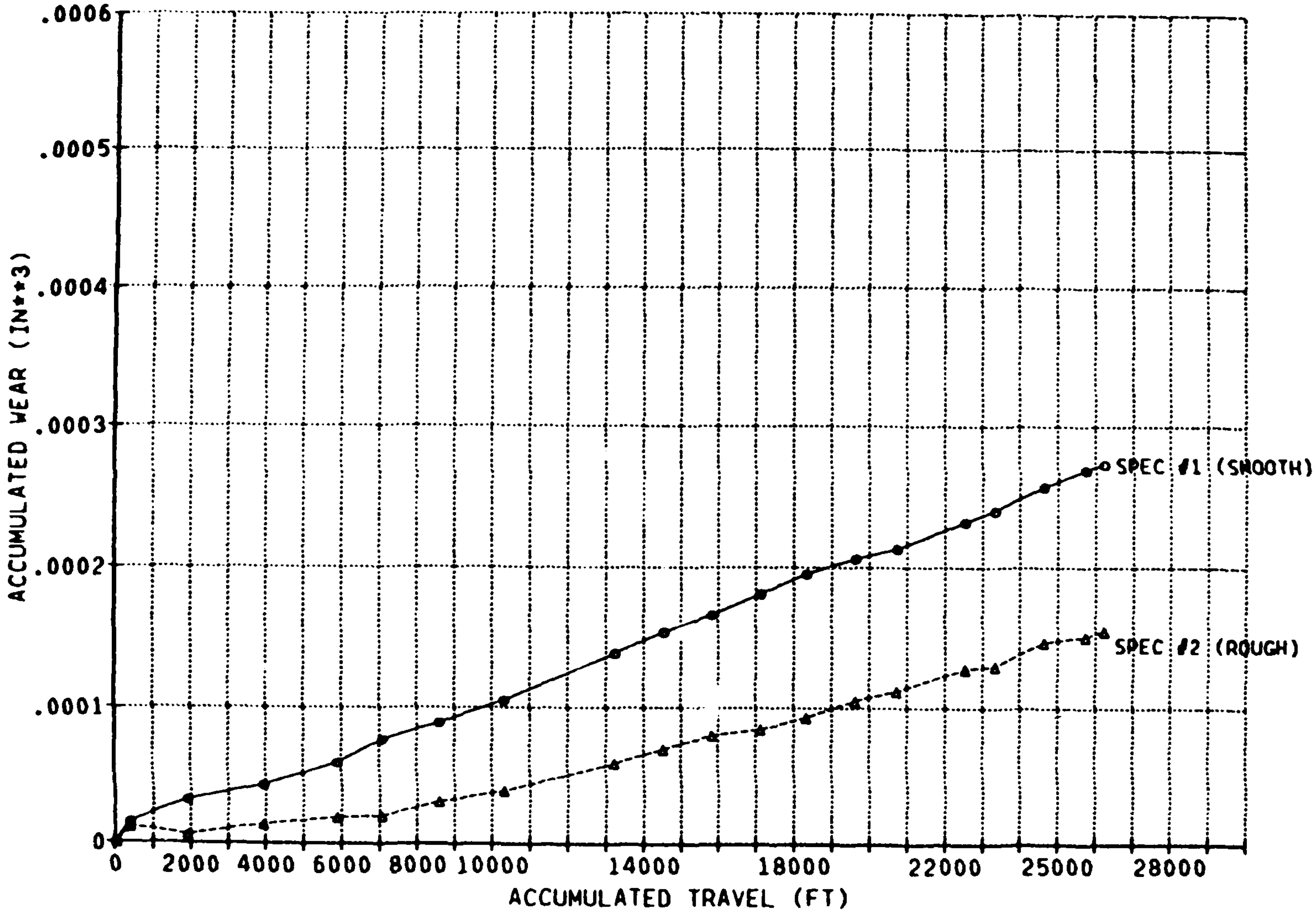


FIGURE 10

TABLE 6

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TEST RESULT SUMMARY

TEST NUMBER: 7

Nominal Test Conditions:

Frequency: 1 Hz
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: PEEK
Disk coating: Tungsten Carbide

Actual Test Parameters

Total cycles: 25,615
Total distance: 26,682 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

PV: 71,250 (psi x ft/min)

Measured Coefficient of Friction

Dry (room temperature):	0.18/0.22	(sliding/static)	(230 mv p-p/270 mv p-p)
In CTFE (room temperature)	0.064/0.18	(sliding/static)	(80 mv p-p/220 mv p-p)
In CTFE (275°F) at start:	0.12/0.16	(sliding/static)	(150 mv p-p/200 mv p-p)
In CTFE (275°F) at finish:	0.14/0.20	(sliding/static)	(170 mv p-p/250 mv p-p)

Measured Wear Data (in CTFE at 275°F)

Cycles: 25,126
Distance: 26,173 ft.

Wear data for 7 CLA disk surface finish

Specimen length change: 3.6 mil
Specimen weight change: 0.0036 g

Average Wear rate: 0.558×10^{-9} in^3/in

Wear data for 14 CLA disk surface finish

Specimen length change: 1.9 mil
Specimen weight change: 0.0021 g

Average Wear rate: 0.347×10^{-9} in^3/in

FIGURE 11

HIGH PRESSURE CTFE SEAL DEVELOPMENT PROGRAM
TYPICAL FRICTION FORCE DATA

TEST NUMBER: 7

Nominal Test Conditions:

Frequency: lh3
Av. Velocity: 12.5 in/sec

Test Material Summary:

Specimen: Peek
Disk coating: Tungsten Carbide

Actual Test Parameters

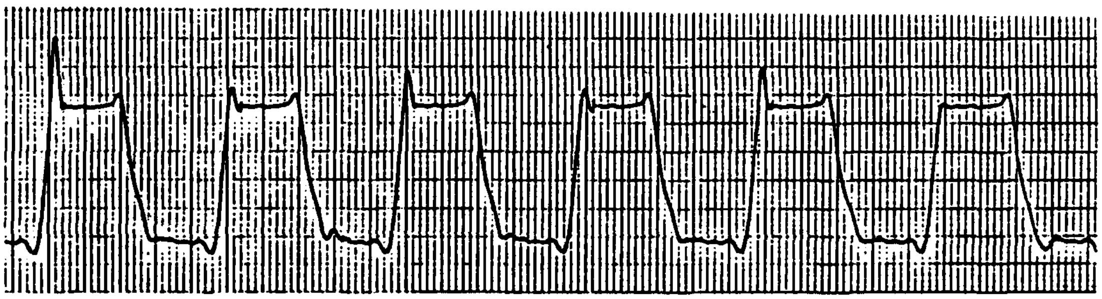
Total cycles: 25,615
Total distance: 26,682 ft.

Normal load/specimen: 56 lbs.
Normal contact stress: 1140 psi

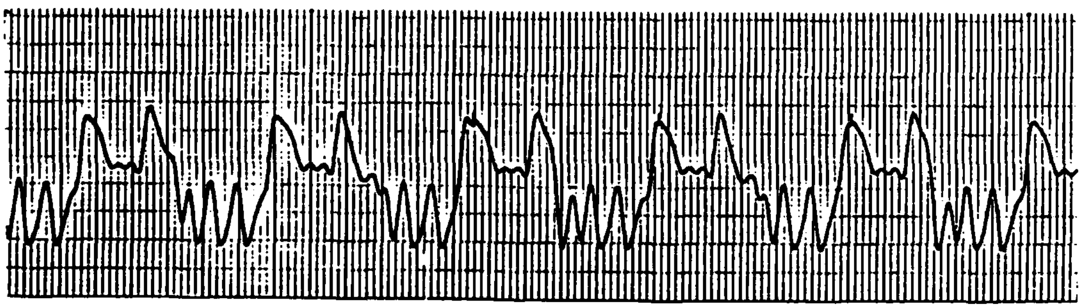
PV: 71,250 (psi xft/min)

Chart Calibration

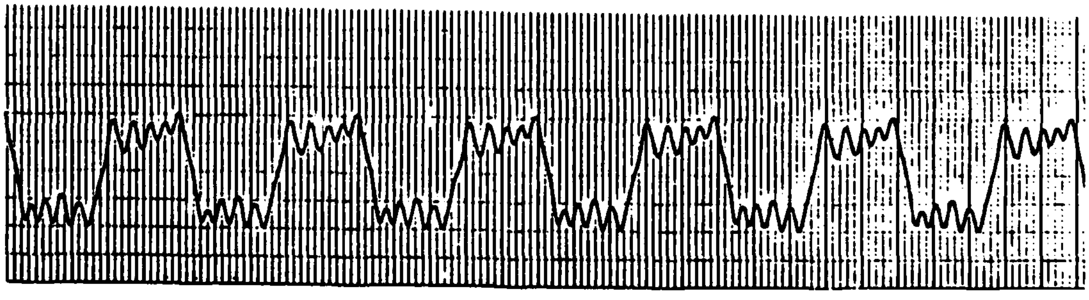
4.47lbs/spec/large div



DRY



CTFE AT ROOM TEMP.



CTFE AT 275°F

WEAR VS TRAVEL FOR PEEK ON TUNGSTEN CARBIDE

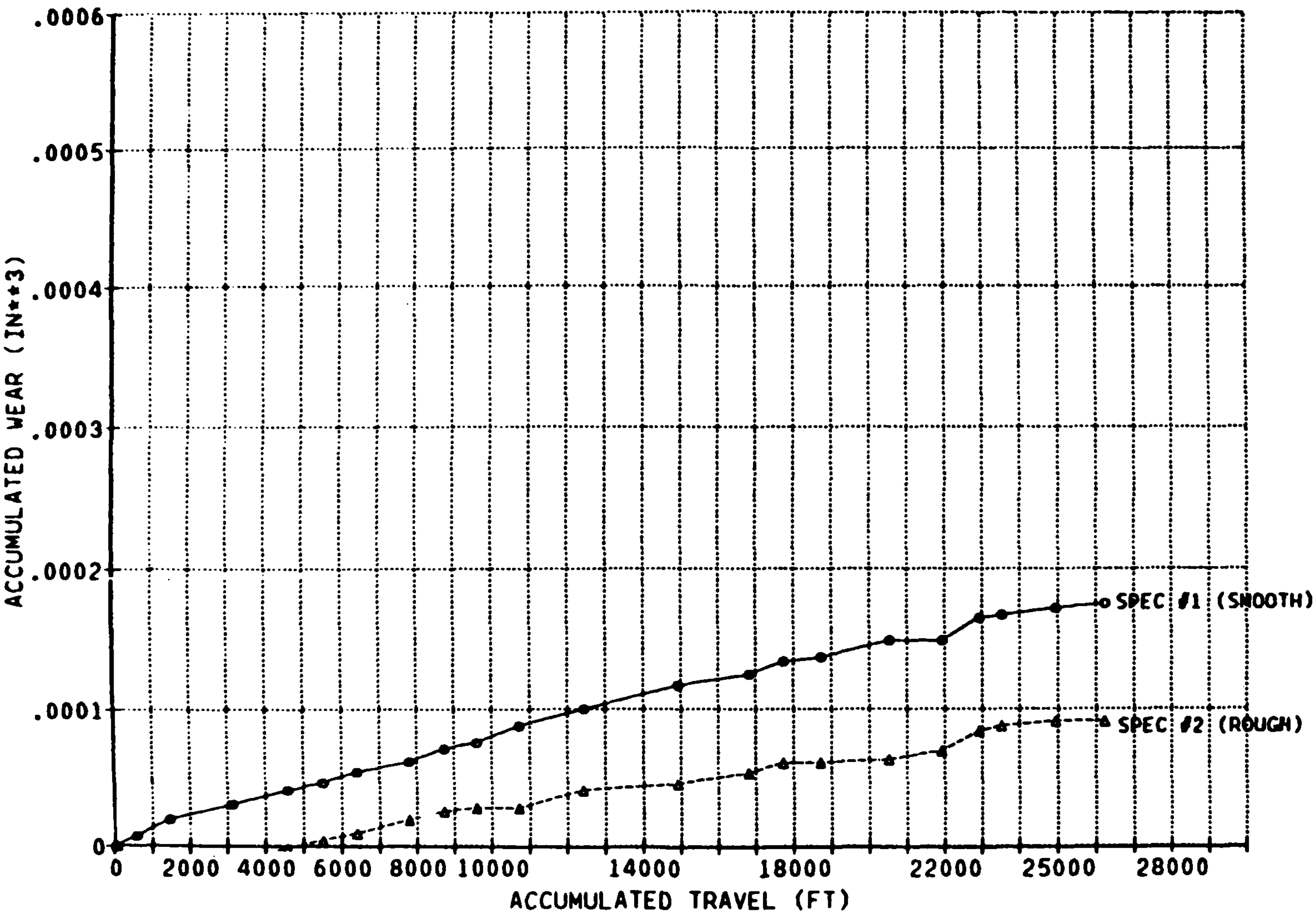


FIGURE 12

APPENDIX IV

PRELIMINARY DESIGN ROD SEAL STUDIES

By Chester Lee

ROD SEAL INTERFERENCE STUDY

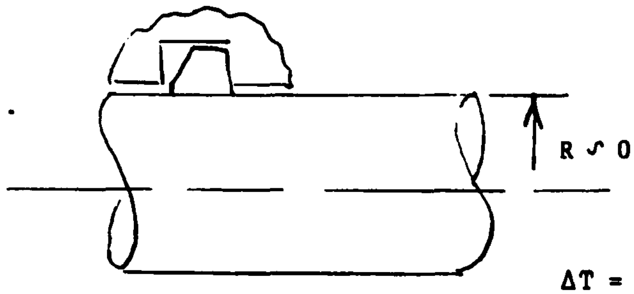
A simple thermal growth calculation shown on the next page indicated that a high interference fit is required (at room temperature 70°F) in order to compensate for the thermal growth of the seal at 275°F. Due to the differences in thermal expansion rate of the two materials, at least 0.00246 inches difference should be imposed to start with. This means that if 0.002 inches INT is desired at 275°F, it should start with a 0.002 + 0.00246 = 0.00446 inches at 70°F. This inference is high and two alternatives were considered.

1. Material of low thermal expansion

2. Limited seal outside diameter expansion

The results of utilization of either or a combination of these methods are shown in Figure A3-1. A tabulation of those studies are summarized in Table A3-1.

Thermal Growth Calculation



$\Delta T = 275-70 = 205°F$

a. Thermal growth of shaft
   205 x 0.5 x (7 x 10-6) = 0.72 mils

b. Thermal growth of ULTEM 1000

$205 \times 0.5 \times 31 \times 10^{-6} = 3.18$ mils

c. Thermal growth of TORLON

$205 \times 0.5 \times 14 \times 10^{-6} = 1.44$ mils

Compensation required:

ULTEM - Steel - 2.46 mils

TORLON - Steel - 0.72 mils

MODEL 3C

Two cases were analyzed:

1. 0.004 inches growth @ 275°F

2. 0.006 inches growth @ 275°F

Take Case 1 for example. A 0.004 inch growth at 275°F will yield 0.004 inches - 0.00246 = 0.00154 inches INT at 275°F. The overall stesss level is within the limit of the material (ULTEM 1,000). Radial stress is compressive throughout the contact starting at 8,500 psi at the H.P. end tapering to about 300 psi at the LP end. When fractional force is included in the model (assume coefficient of friction = 0.1) no significant change of the stress levels is observed as seen in Figure A3-2. Figures A3-3 and A3-4 show the distribution of streses in the radial and axial directions.

MODEL 506

If only limited space is provided for the thermal growth, smaller INT can be used. Two cases were analyzed:

1. 0.002 inch growth and 0.002 inch space

2. 0.002 inch growth and 0.004 inch space

Radial stress is compressive throughout the contact. For Case 1, the stress maintained at about 8,000 psi from the high pressure (HP) to the low pressure (LP) end. This is due to the limited radial growth at 0.002 inches (calculated growth is 0.00318 inches). When this limitation is relieved to 0.004 inches, radial stresses at the contact are much lower. Starting at about 5600 psi at the HP end, the radial stress at the contact tapered to about 1,000 psi towards the LP end. On the top of the seal where growth is limited, the stress at the contact is generally in about 1,000-2,000 psi range. The radial pressure distribution is shown in Figure A3-5. The radial and axial stress distribution is shown in Figures A3-6 and A3-7.

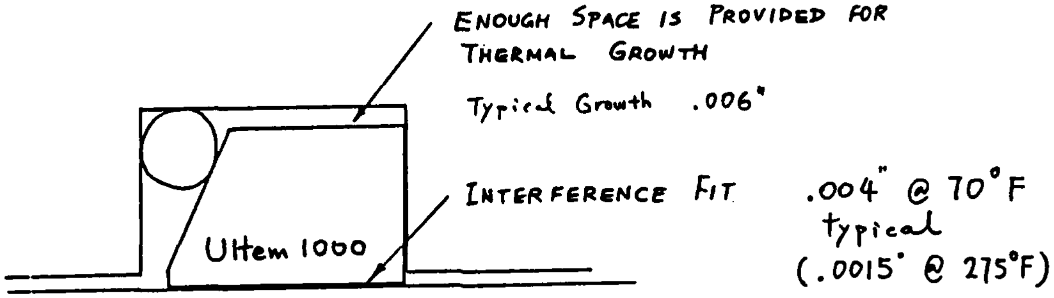
MODEL 507

Since the thermal expansion rate of TORLON is much smaller than that of ULTEM 1,000, smaller INT is needed at room temperature. The case analyzed here, 0.002 inches growth at 275°F, indicated that an INT of 0.002 - 0.00144 = 0.00056 inches can be maintained. Radial stress distribution is plotted as shown in Figure A3-8. The overall stress level is within the limits of the material. The radial and axial stresses are given in Figure A3-9 and A3-10.

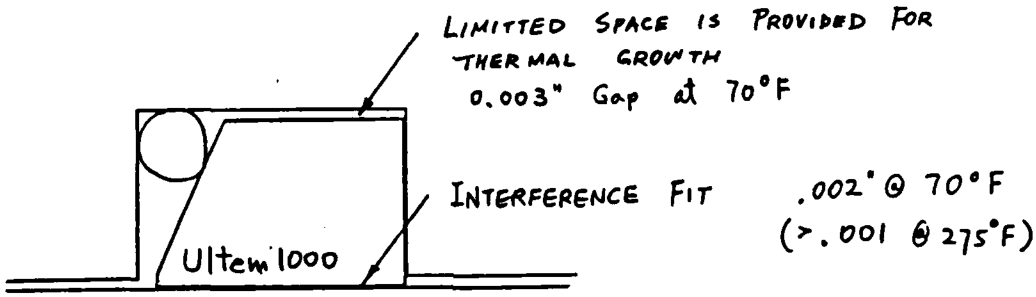
It should be noted that in the figures depicting the stress isobars, high stress concentration is indicated on the axial contact fact between seal and gland wall. This is primarily due to the sharp corners put into the model. In a real design, these corners should be replaced by radii which blend in with the seal profile.

FIGURE 1

Model 3C



Model 506



Model 507

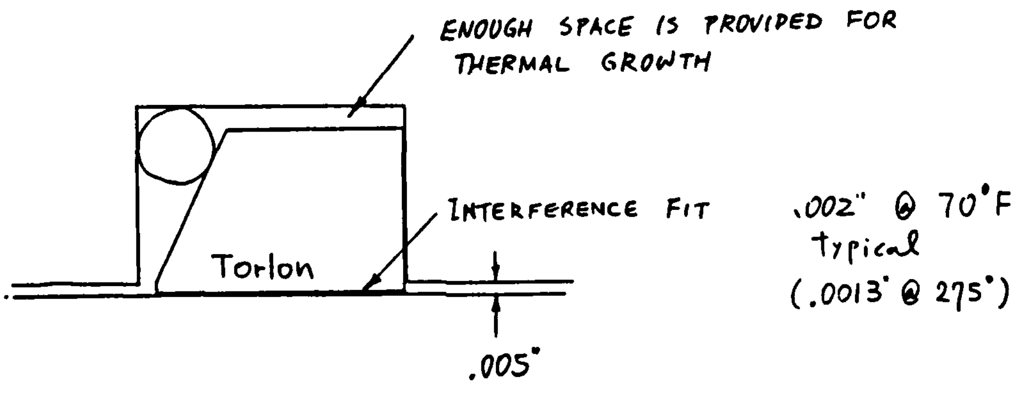
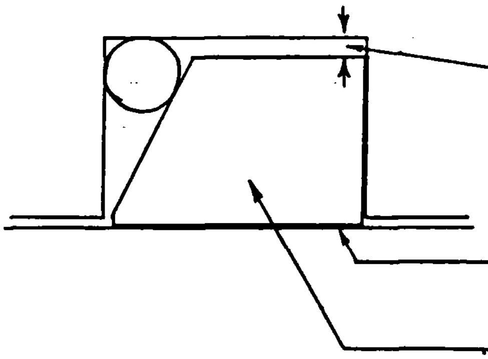


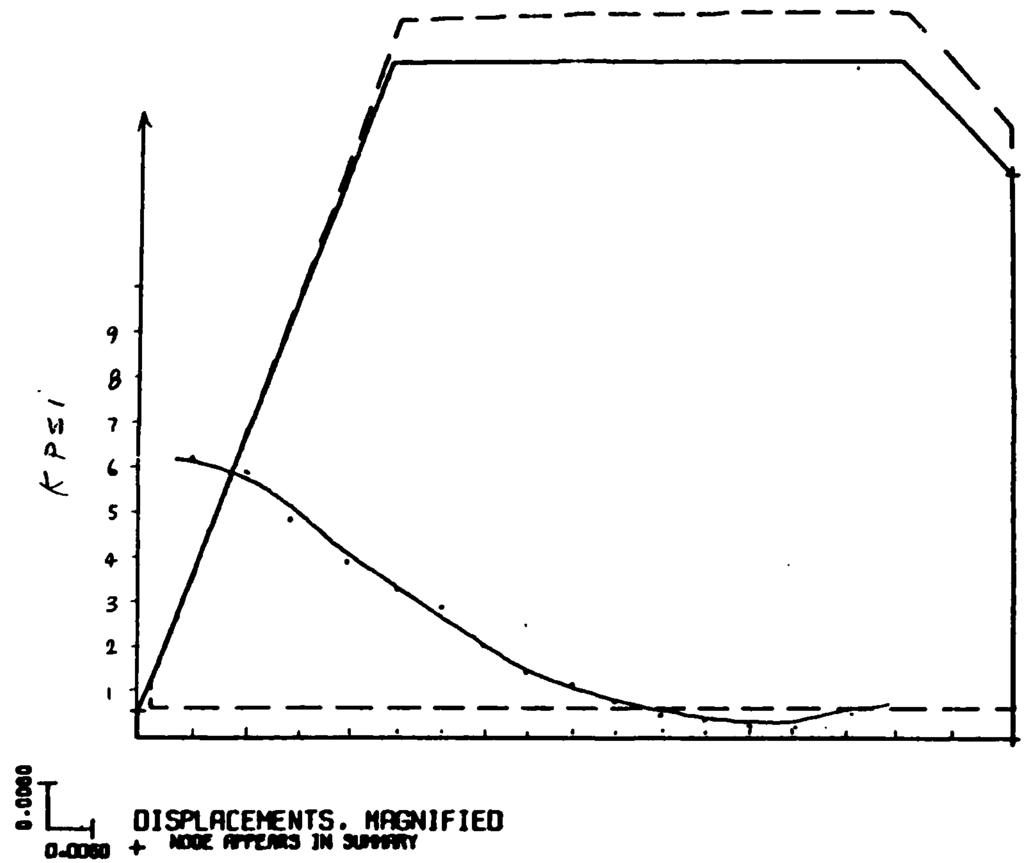
TABLE 1

INTERFERENCE STUDY RESULTS



	Model 3C	Model 506	Model 507
GAP REQUIRED	> 0.006"	= 0.003"	> 0.004"
INT 70° 275°	0.004" 0.0015"	0.002" > 0.001	0.002" 0.0013"
Material	ULTEM 1000	ULTEM 1000	TORLON 4275

- All three cases have similar stress profiles.
- All three cases show similar radial stress distribution at contact.



BERT3C ULTEM 1000 275 DEG F

FIGURE 2 MODEL 3C, RADIAL STRESS

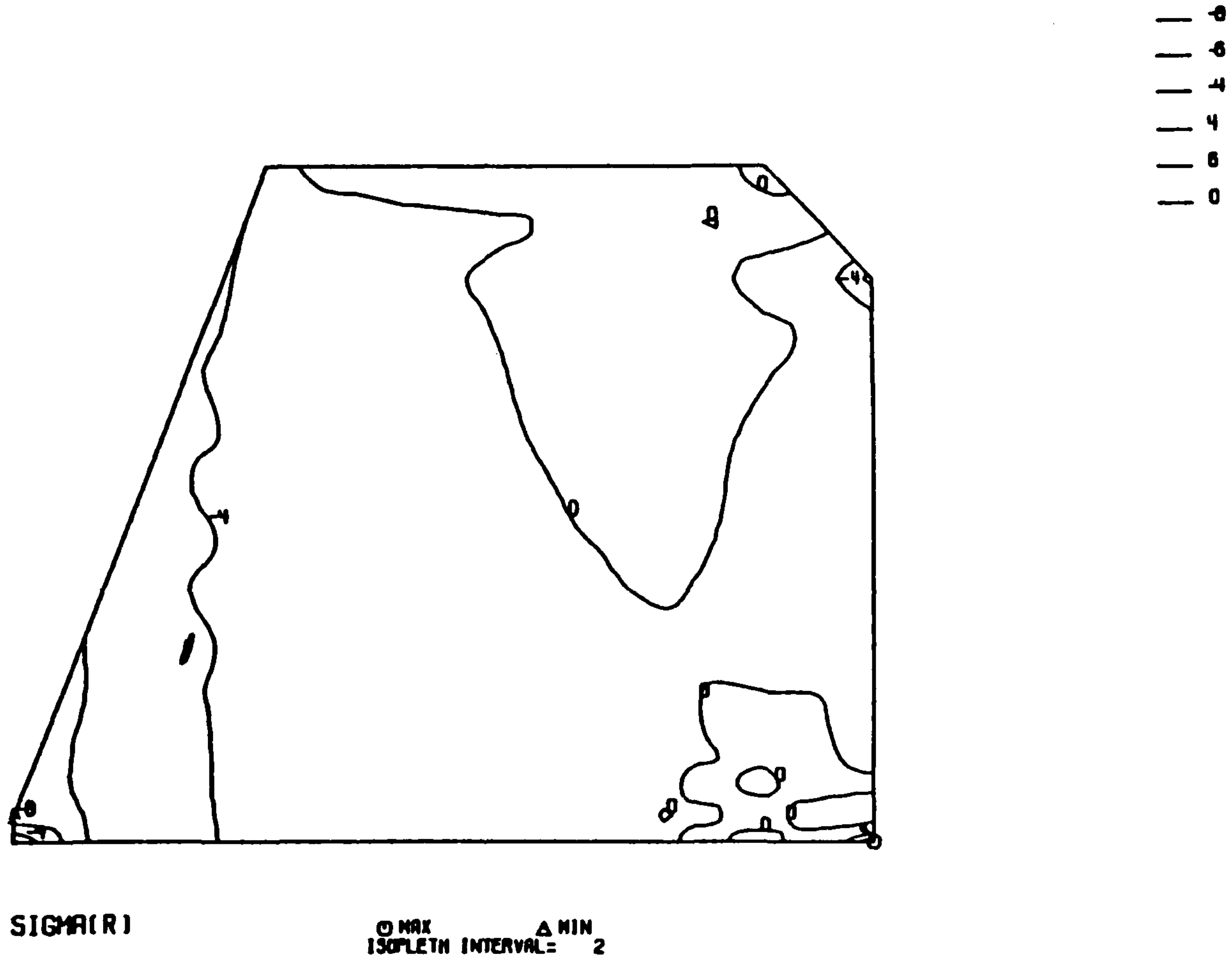
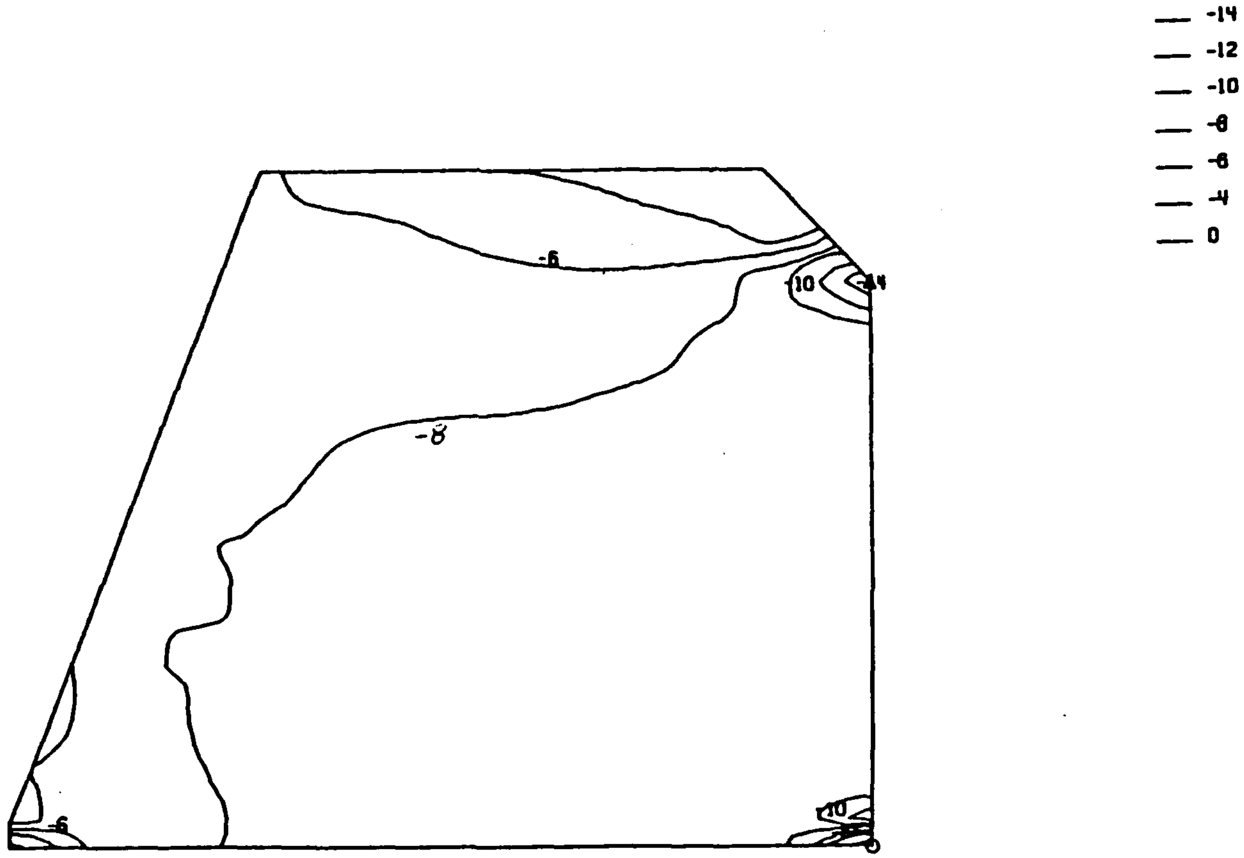


FIGURE 3 CASE 3C, RADIAL STRESS



SIGMA(Z)

⊙ MAX △ MIN
ISOPLETH INTERVAL= 2

BERT3C ULTEM 1000 275 DEG F

FIGURE 4 CASE 3C, AXIAL STRESS

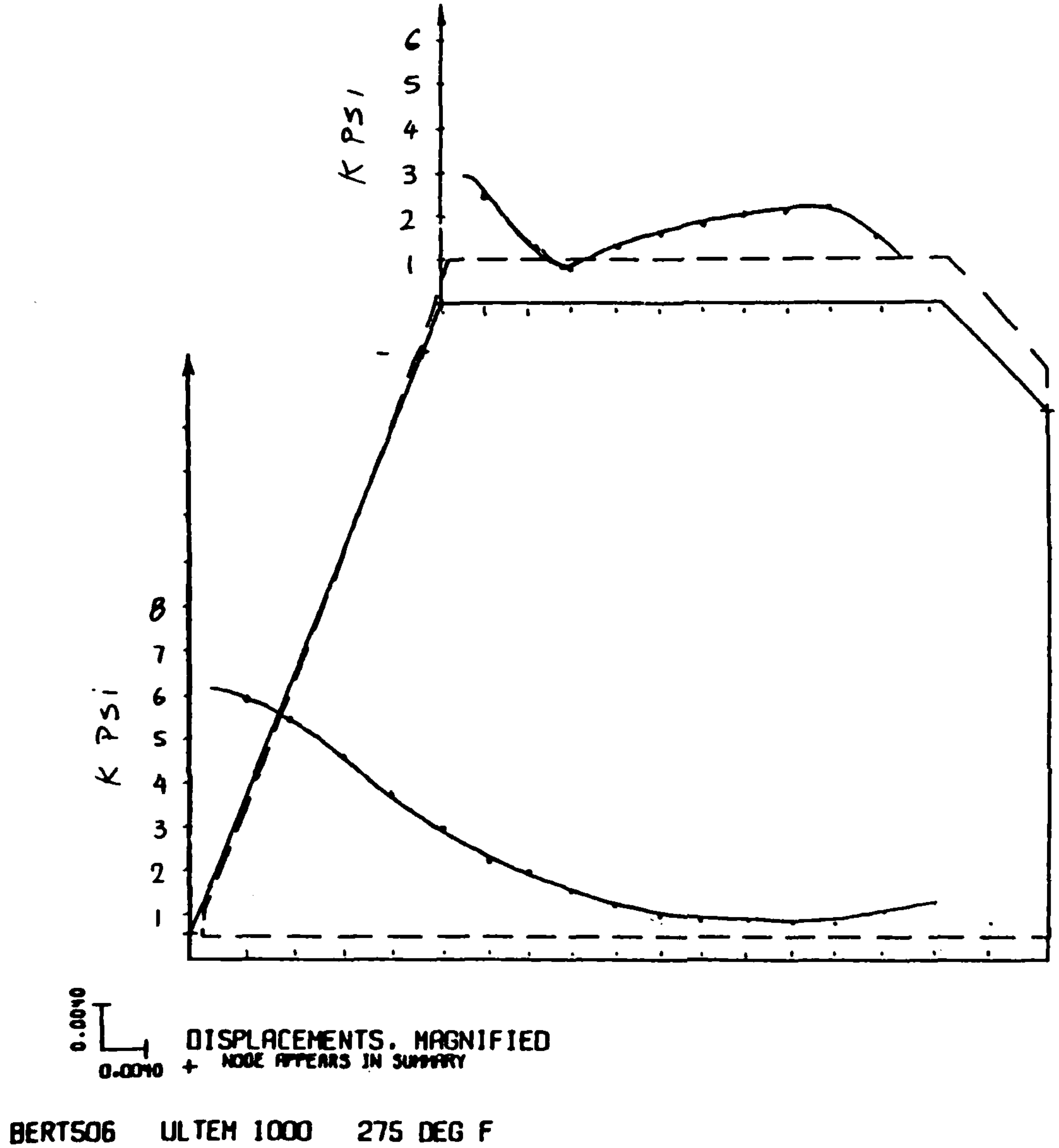
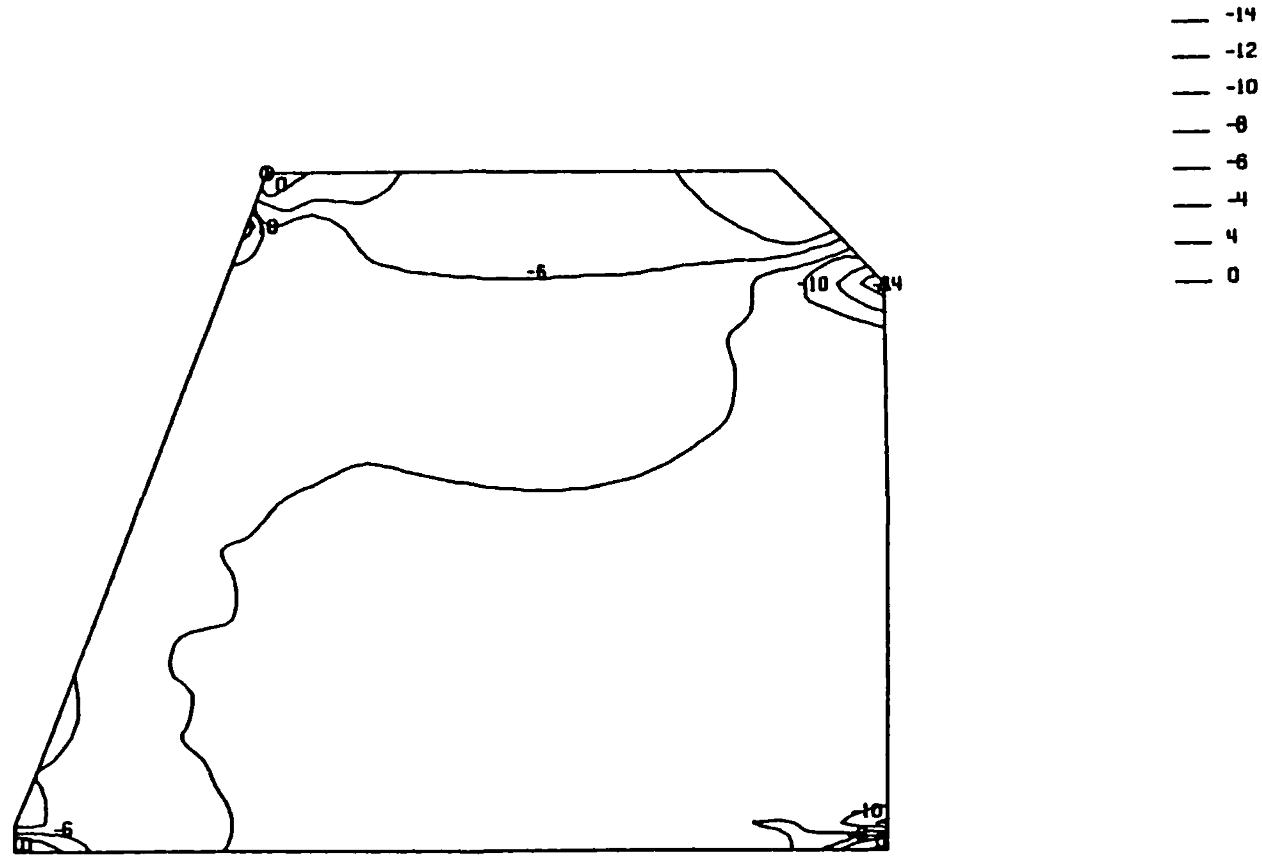


FIGURE 5 MODEL 506, RADIAL STRESS AT CONTACT



SIGMA(Z)

MAX MIN
ISOPLETH INTERVAL= 2

BERT506 ULTEM 1000 275 DEG F

FIGURE 6 MODEL 506, AXIAL STRESS

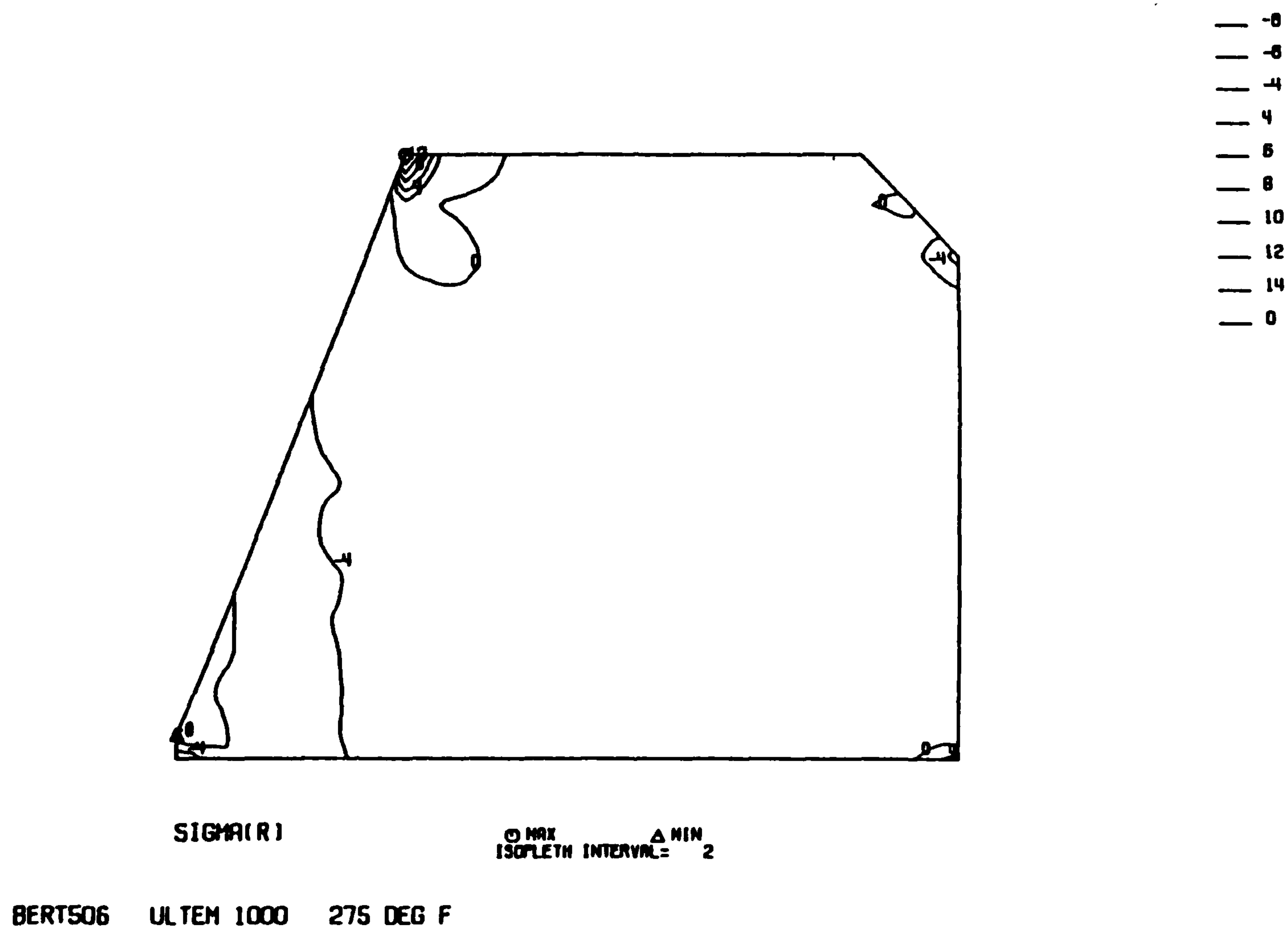
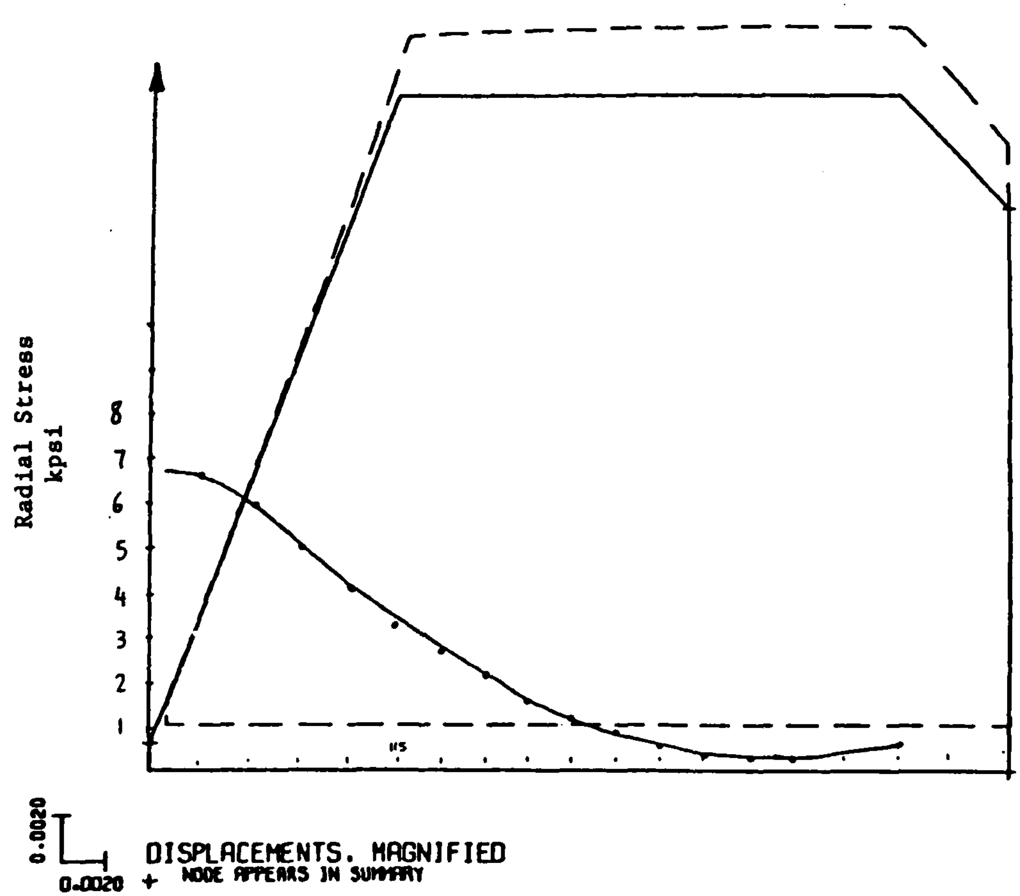


FIGURE 7 MODEL 506, RADIAL STRESS



BERT507 TORLON 4275 275 DEG F

FIGURE 8 MODEL 507

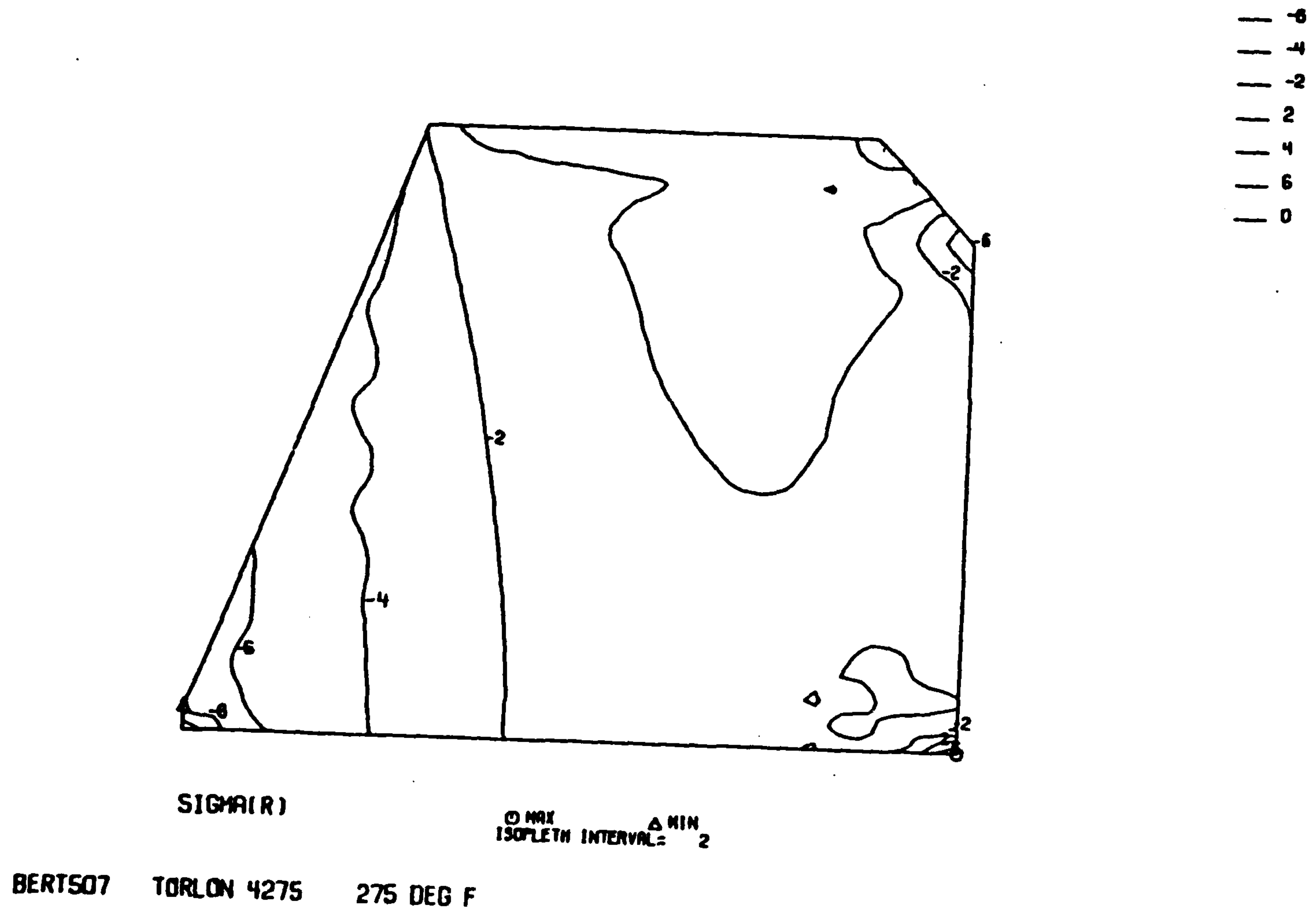


FIGURE 9 CASE 507, RADIAL STRESS

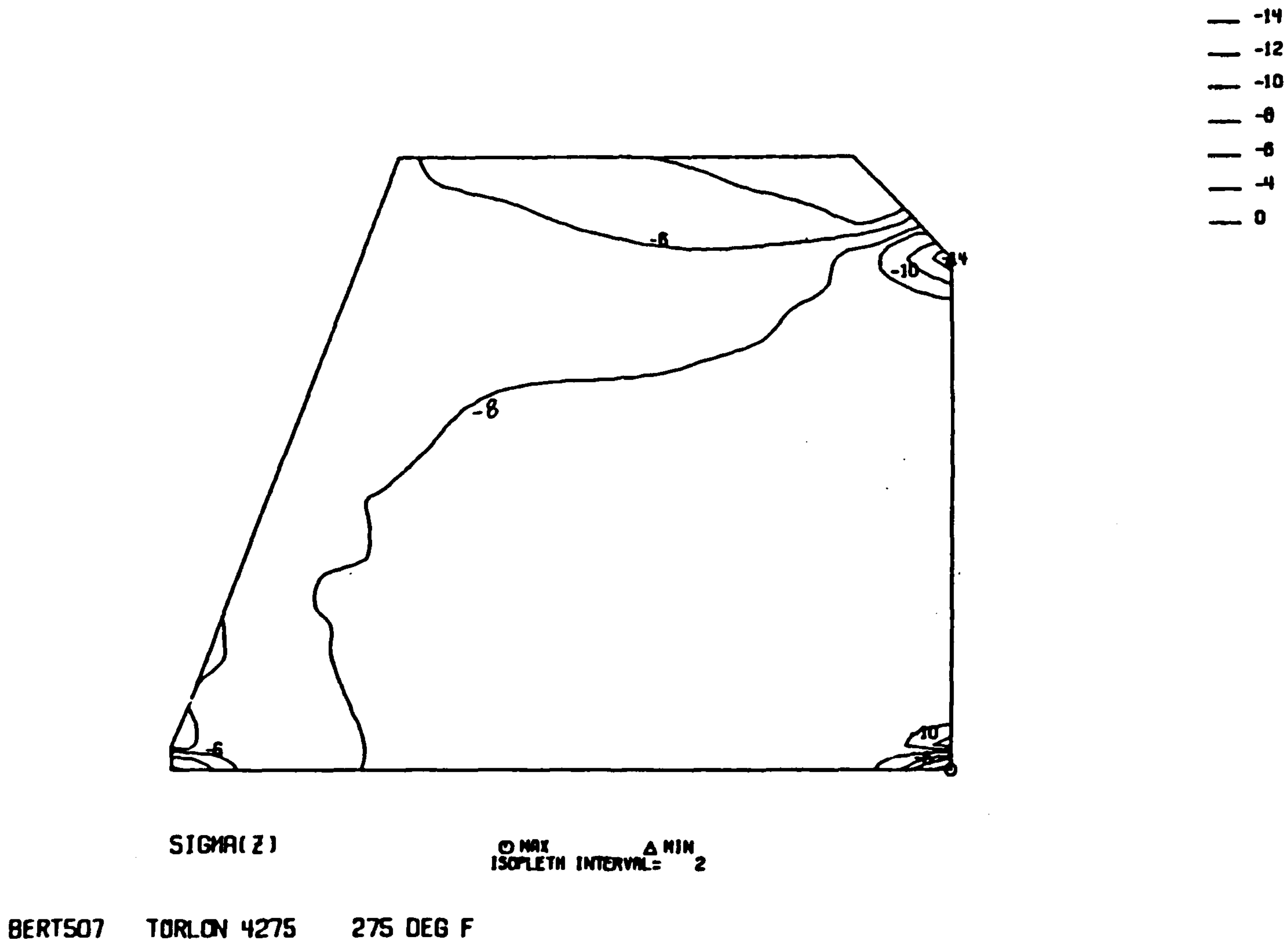


FIGURE 10 CASE 507, AXIAL STRESS

APPENDIX V

PEEK ROD SEAL ANALYSES

This Appendix presents the results obtained with PEEK under different conditions of operation. Specifically, the following plots are presented:

Case 1: Interference - .001" (radial)
Gap on top - .001"
Temperature - .275°F
Pressure - 8000 psi

(See Figures V-1 through V-5 for stresses and deflections)

Case 2. Interference - .004" (radial)
Gap on top - infinite
Temperature - 275°F
Pressure - 8000 psi

(See Figure V-6 through V-10 for stresses and deflections)

Case 3. Interference - .004"
Gap on top - infinite
Temperature - 275°F
Pressure - 0 psi
Max radial stress = -100 psi
Max axial stress = 0 psi
Max tengential stress = 800 psi

Case 4. Interference - .004"
Gap on top - infinite
Temperature - 70°F
Max radial stress = -300 psi
Max axial stress = 0 psi
Max tengential stress = 1700 psi

Case 5: Interference - .001"

Gap on top - >.001"

Temperature - 70°F

Max radial stress = -100 psi

Max axial stress = 0 psi

Max tangential stress = 400 psi

Case 1 is representative of the suggested design. This Case together with Case 5 show the stresses developed at assembly (Case 5) and operation (Case 1). Case 2 depends upon a high interference fit which in conjunction with Case 4 presents the operational and assembly conditions. Case 3 shows the stresses developed at full temperature in absence of pressure when the initial interference is 0.004" on the radius.

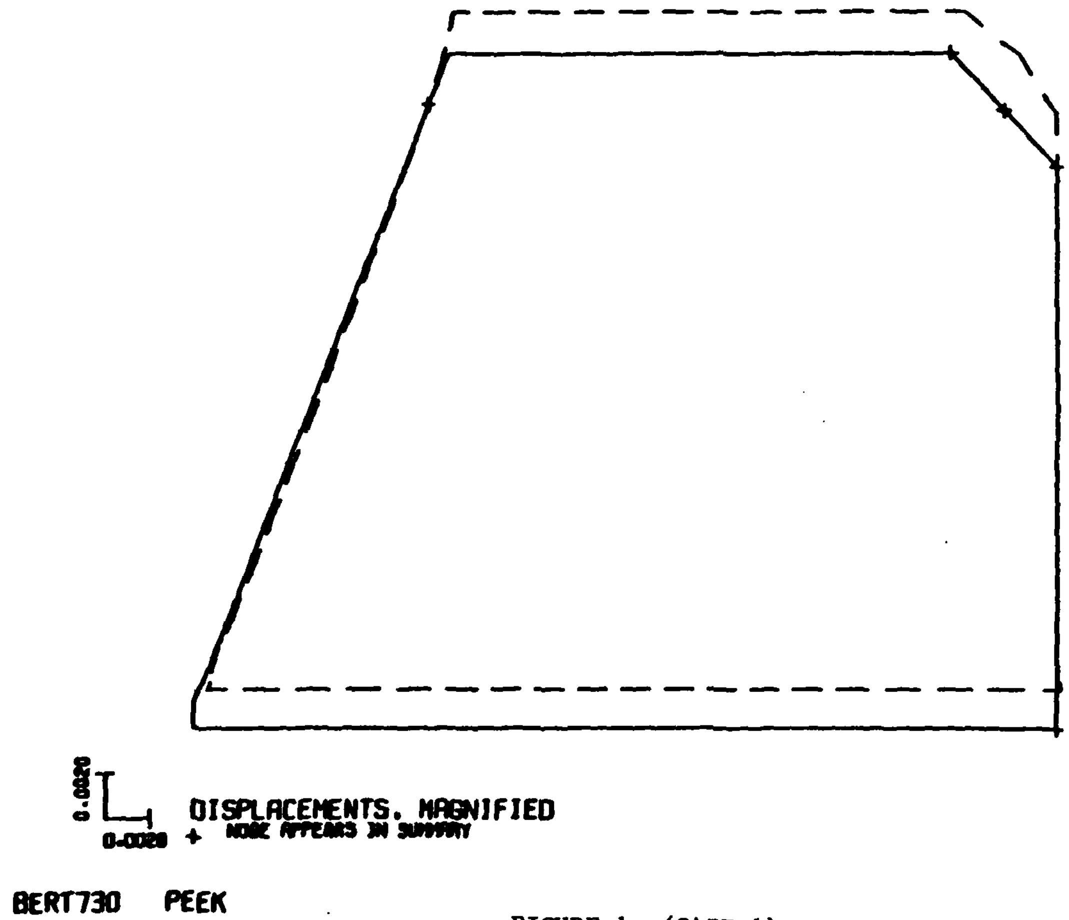


FIGURE 1 (CASE 1)

DISPLACEMENT AT PRESSURE AND TEMPERATURE

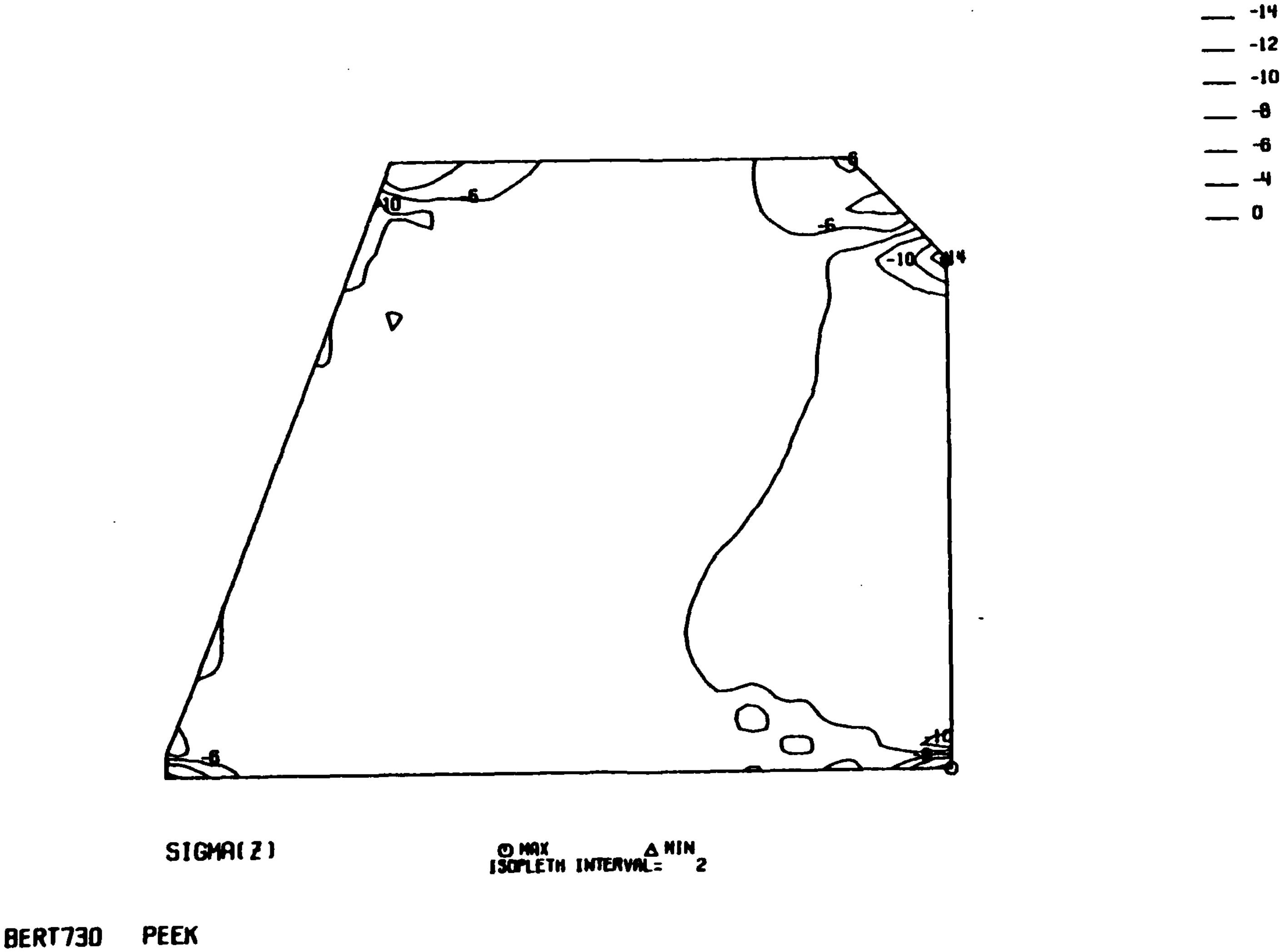


FIGURE 2 (CASE 1)

AXIAL STRESS

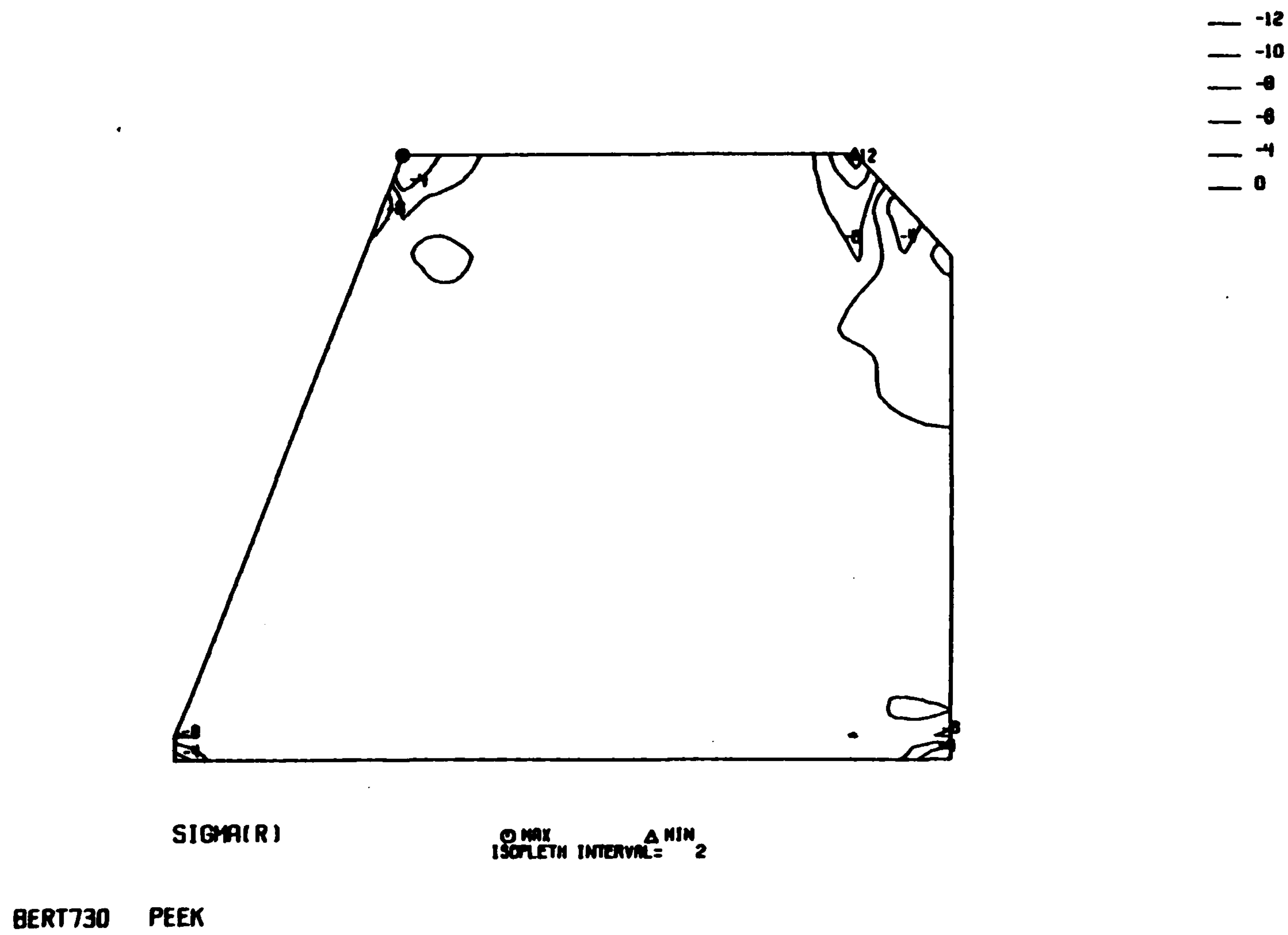


FIGURE 3 (CASE 1)

RADIAL STRESS

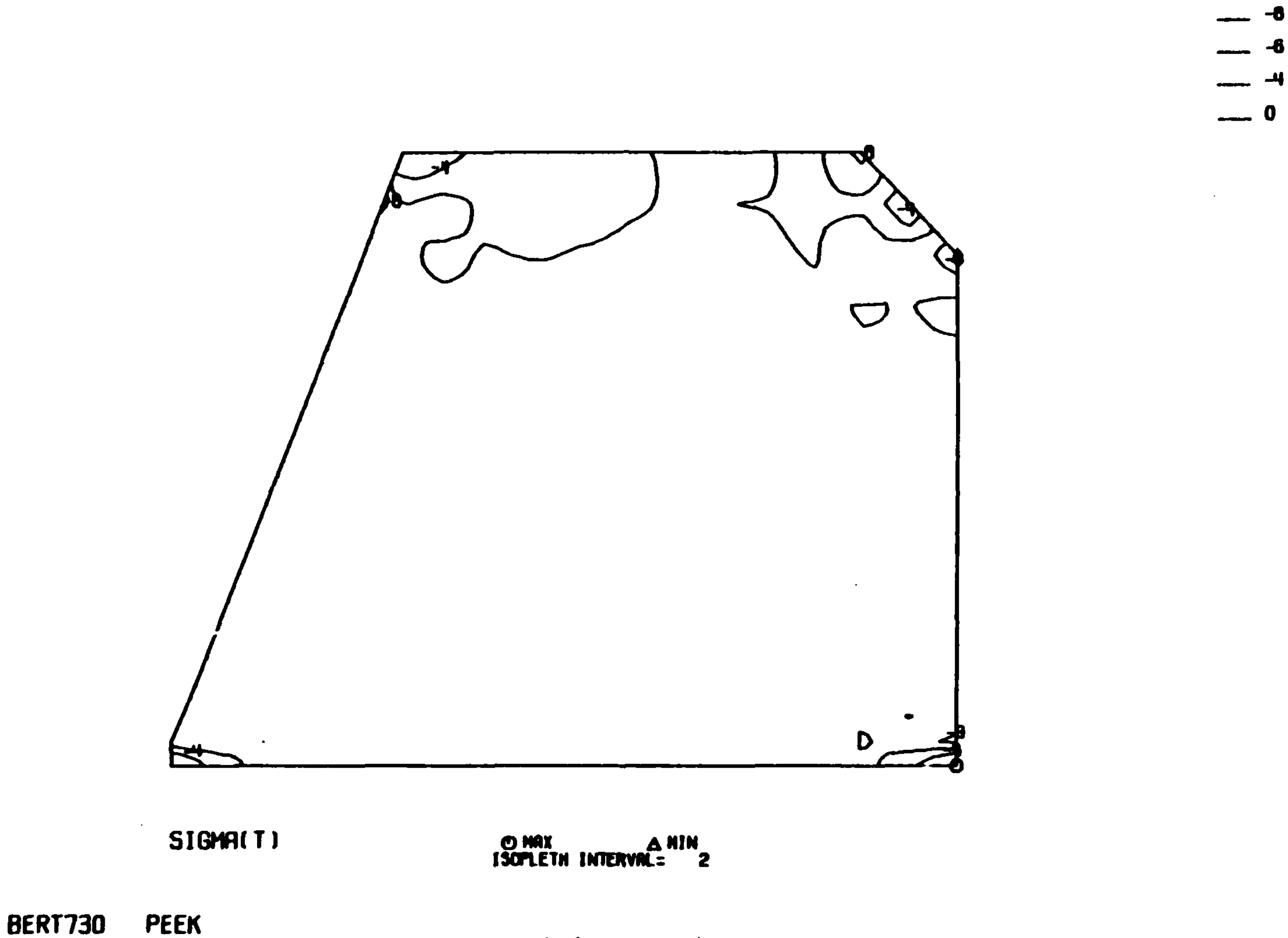


FIGURE 4 (CASE 1)

TANGENTIAL STRESS

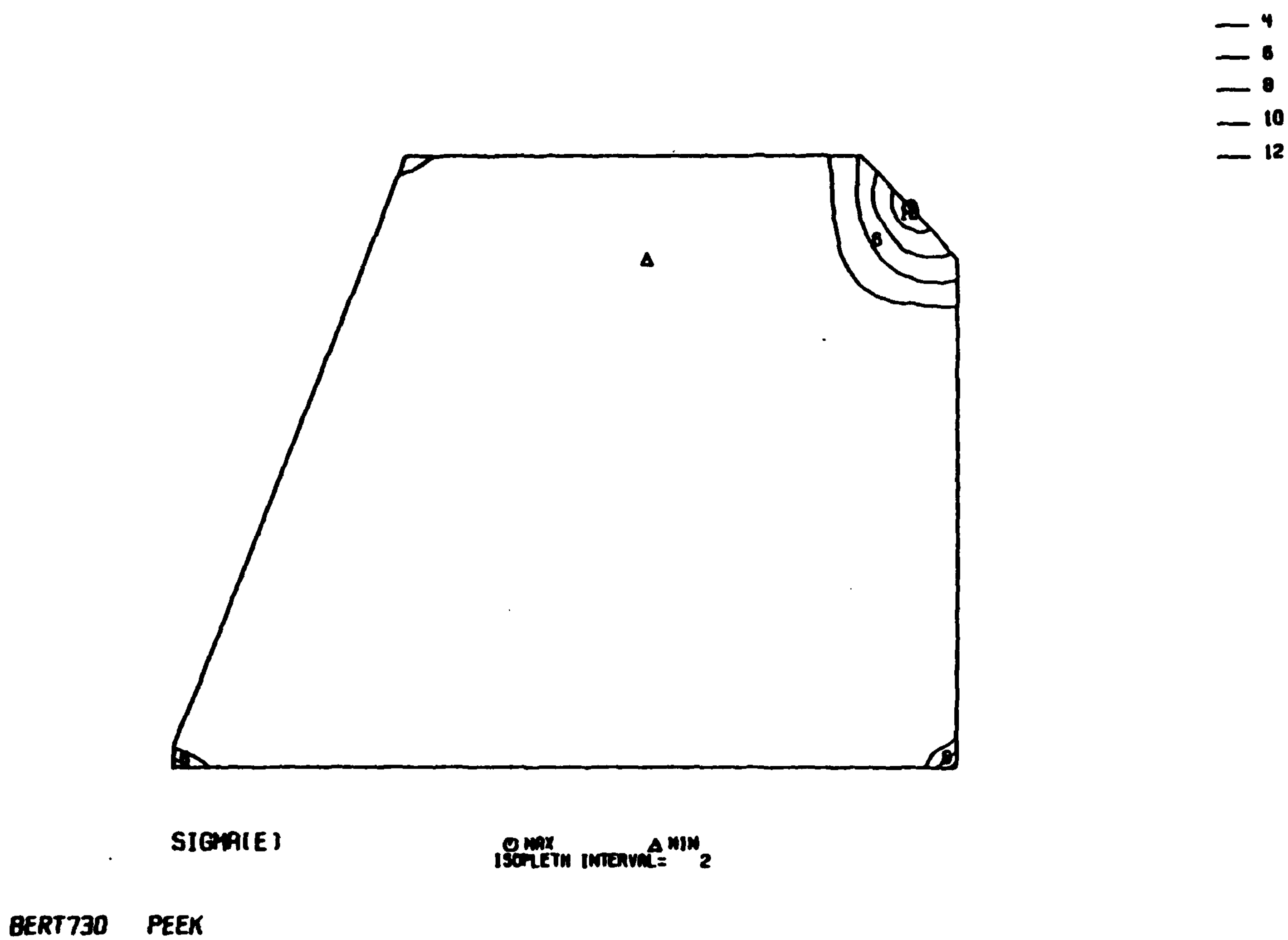


FIGURE 5 (CASE 1)

TOTAL STRESS

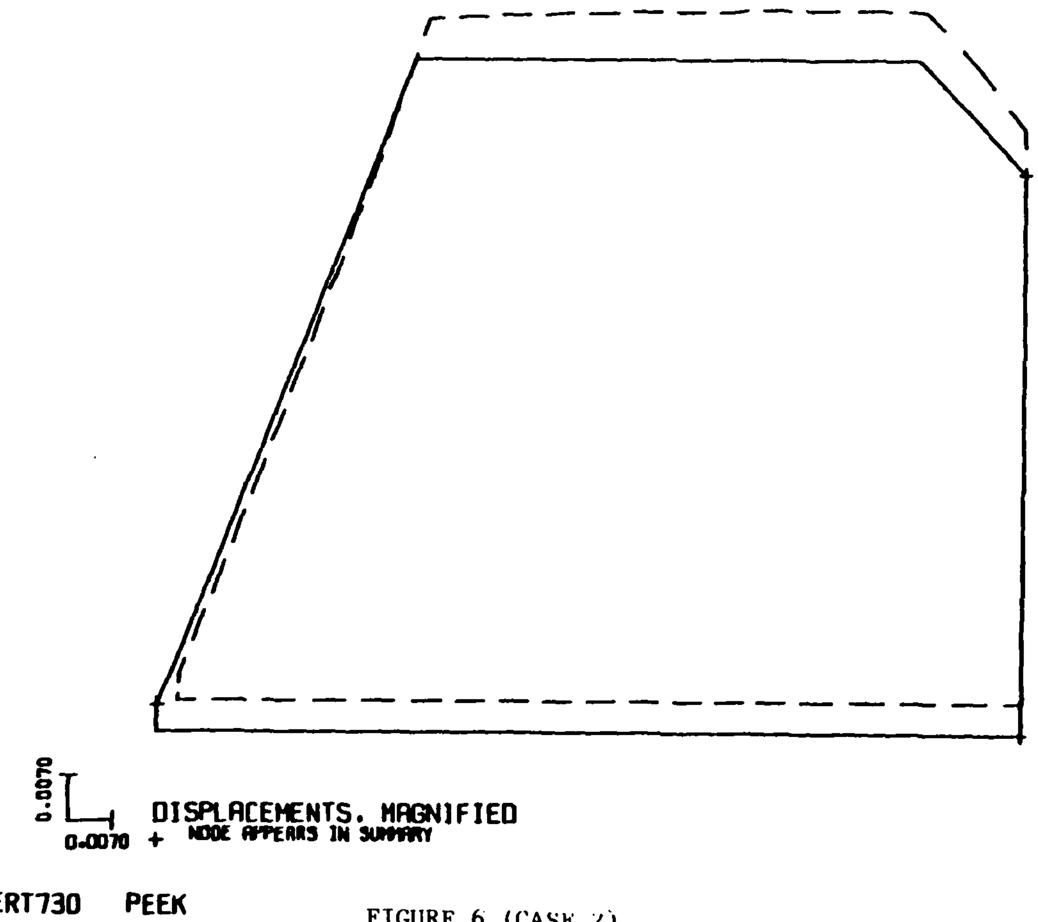


FIGURE 6 (CASE 2)

DISPLACEMENT AT PRESSURE AND TEMPERATURE

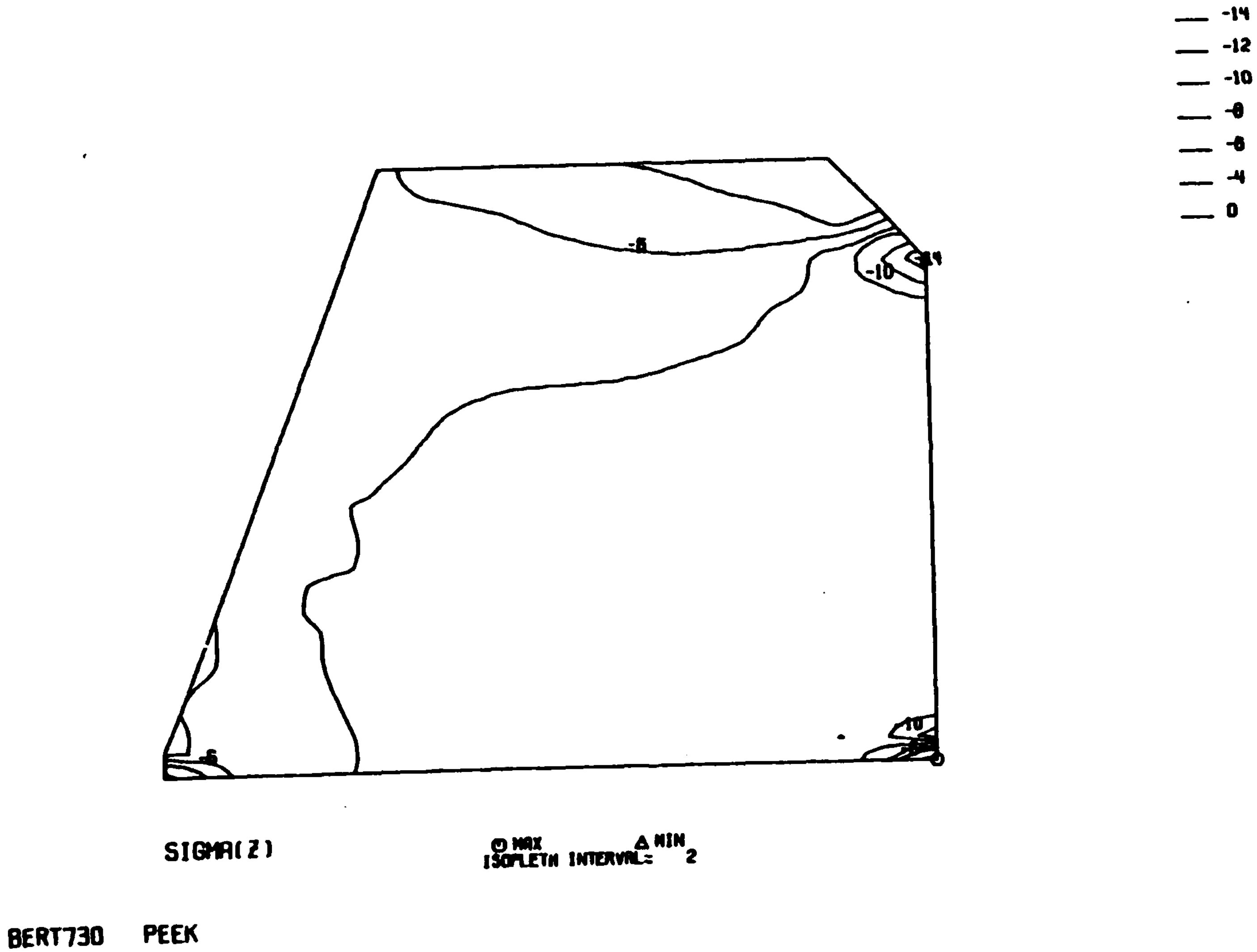
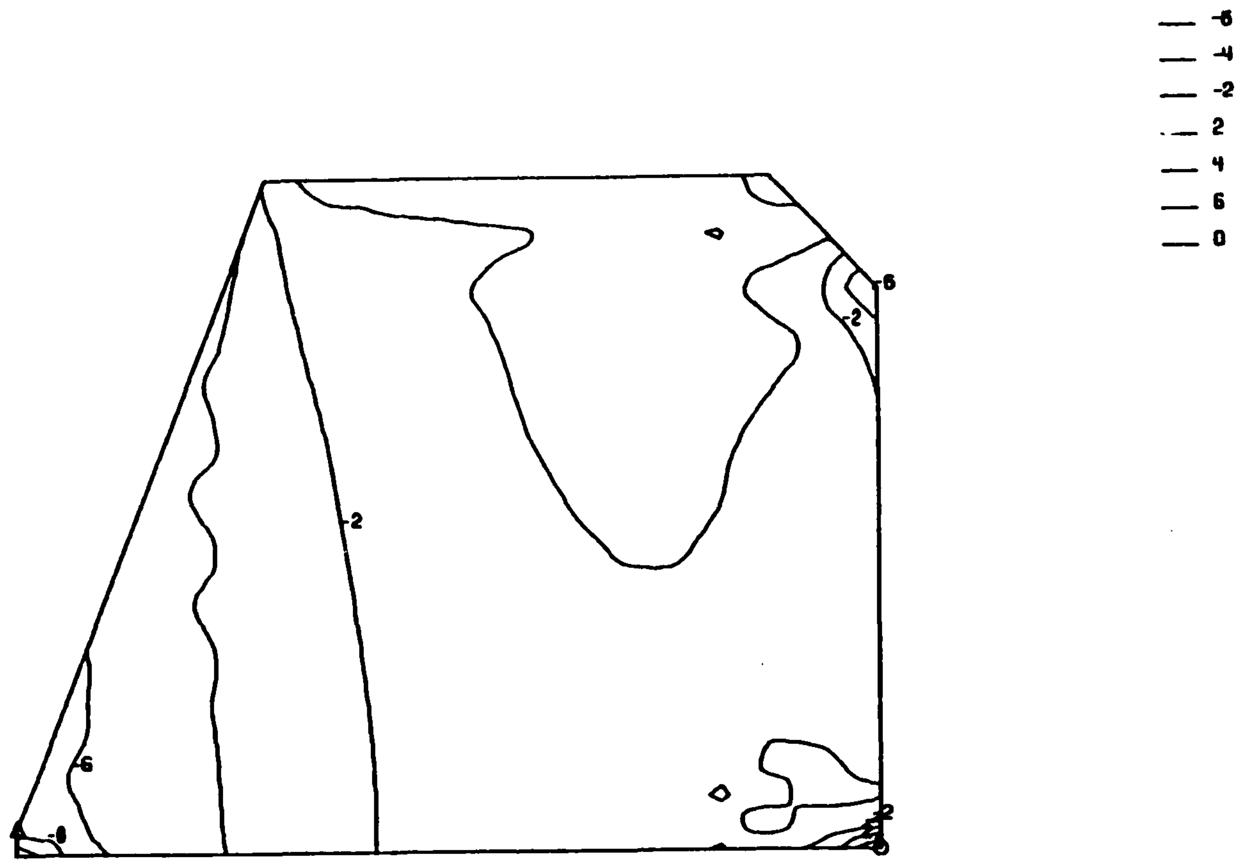


FIGURE 7 (CASE 2)

AXIAL STRESS



SIGMA(R)

⊙ MAX △ MIN
ISOPLETH INTERVAL= 2

BERT730 PEEK

FIGURE 8 (CASE 2)

RADIAL STRESS

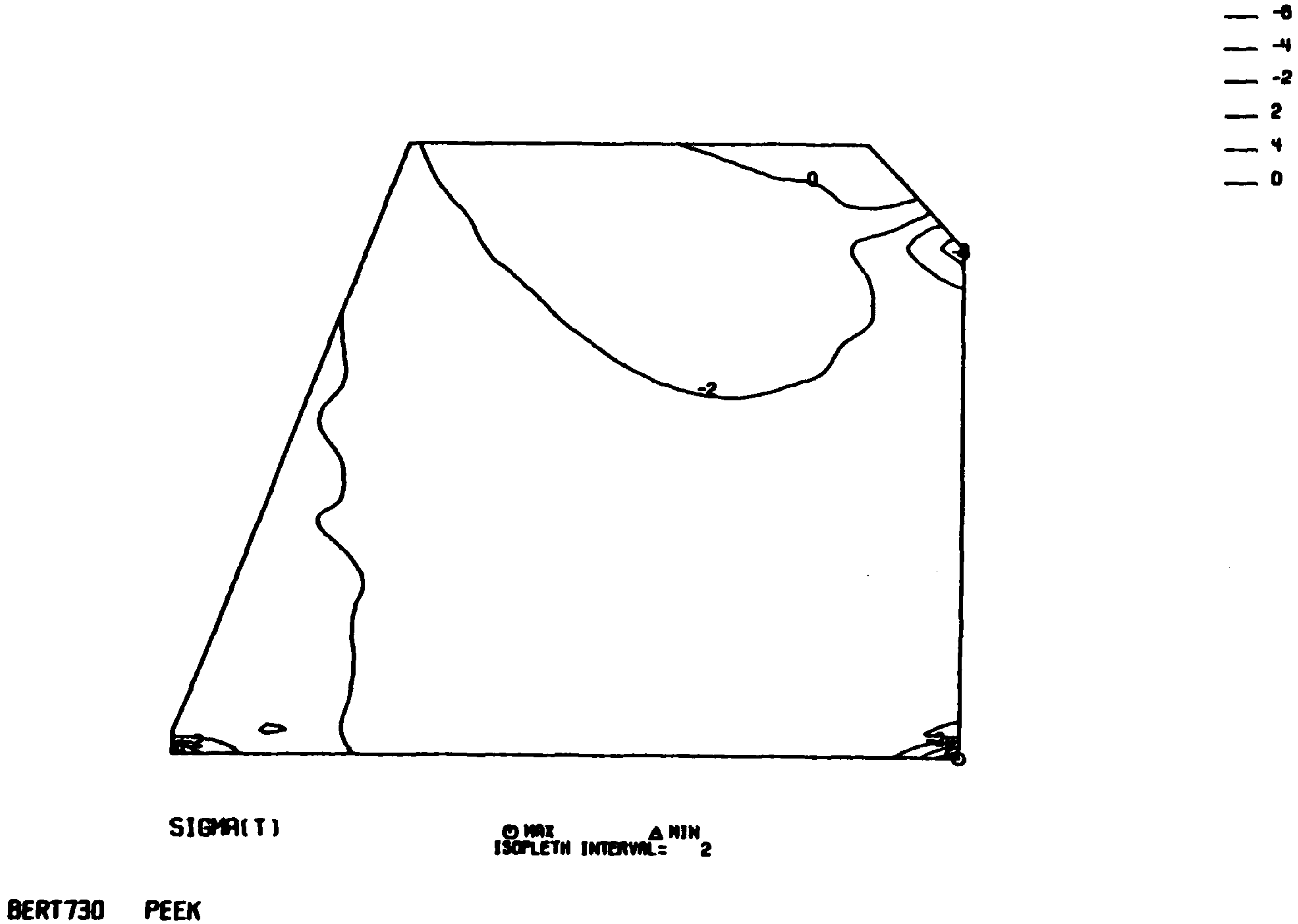


FIGURE 9 (CASE 2)

TANGENTIAL STRESS

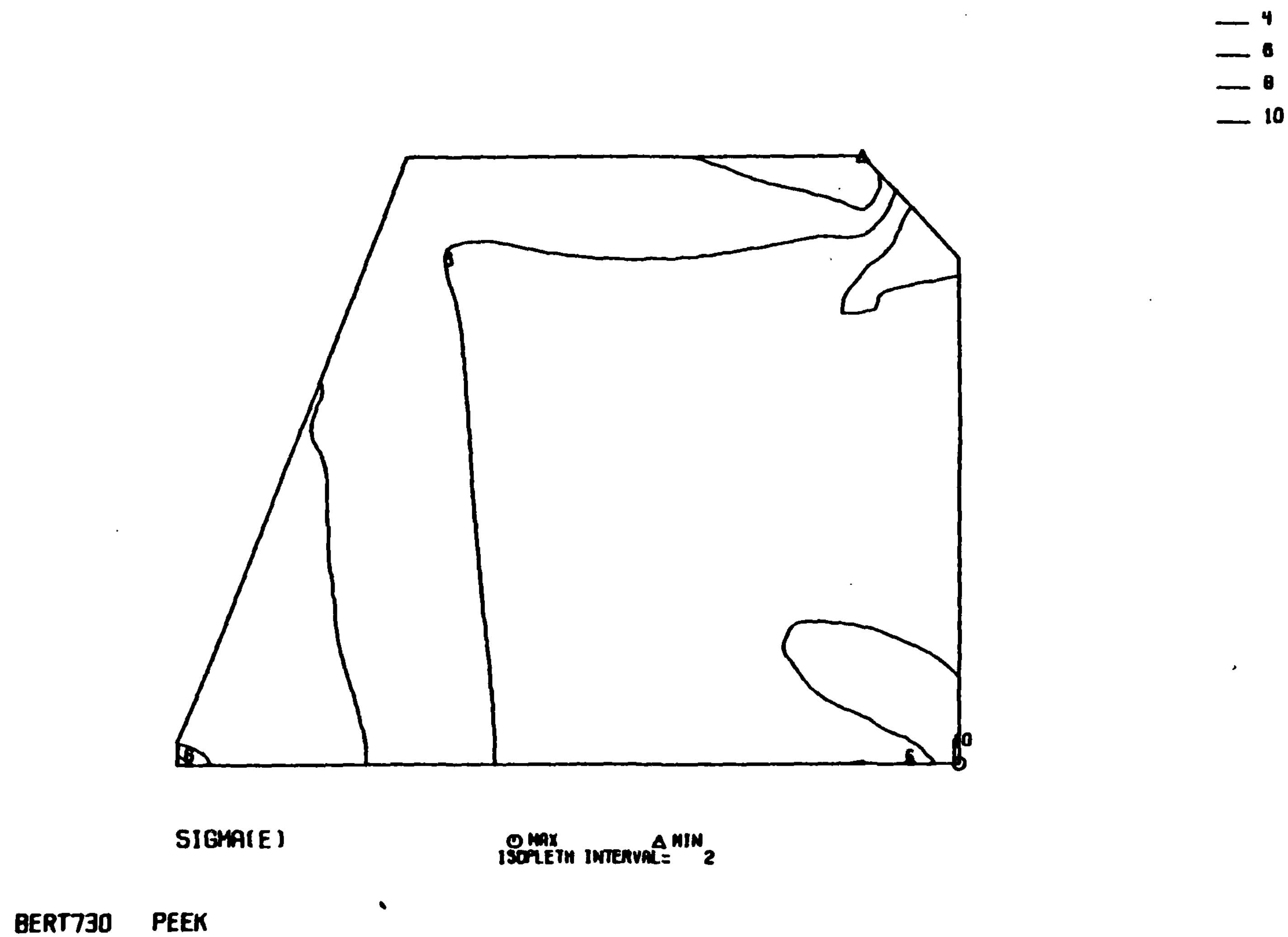


FIGURE 10 (CASE 2)

TOTAL STRESS