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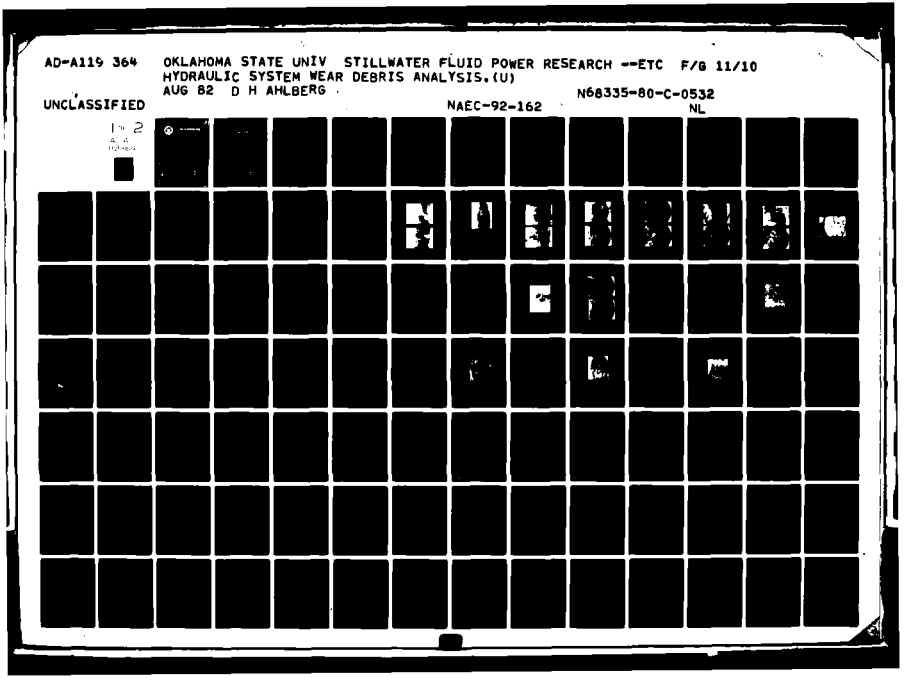

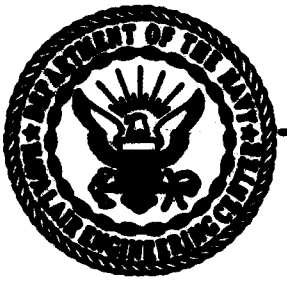

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NAVAL AIR ENGINEERING CENTER
REPORT NAEC-92-162

HYDRAULIC SYSTEM WEAR DEBRIS ANALYSIS

Advanced Technology Office
Support Equipment Engineering Department
Naval Air Engineering Center
Lakehurst, New Jersey 08733

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Final Report for Period September 1980 to September 1981
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Commander, Naval Air Systems Command
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HYDRAULIC SYSTEM WEAR DEBRIS ANALYSIS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The use of Ferrography as a means to detect elastomer wear in aircraft hydraulic systems is explored. A method is described which increases the deposition of elastomer material on the Ferrogram. Nine distinct seal wear mechanisms are identified. Metallic wear debris from different sample points is compared

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SUMMARY

A new sample pretreatment, which increases the effectiveness of the Ferrograph in capturing elastomer wear debris, has been developed. A solution containing the rare earth metal of holmium is added to a sample prior to the making of a Ferrogram. The solution effects a minimum increase in elastomer deposition of 10 percent.

Five categories of seal wear debris have been discovered for linear motion seals and four for rotary motion seals. Only one category is unique, and it is the result of linear motion seal wear. Therefore, at present, it is not possible to categorize a given particle of elastomer wear debris as to its mode of wear except for one case, which is undoubtably one associated with linear motion.

Metallic debris contained in samples supplied by the Naval Air Engineering Center appeared quite similar. Further work in this area will be necessary before any definite conclusions may be reached concerning the feasibility of using Ferrography to detect wear from specific hydraulic components. It is recommended that a program of carefully contrived testing of individual components be undertaken to determine conclusively whether or not specific and distinguishable types of wear are generated by each component.

The use of a scanning electron microscope (SEM) equipped with an X-ray analyzer has demonstrated the ability to determine the predominant elements constituting the individual wear particles deposited on Ferrograms. It is recommended that further work be carried out in this area to determine the feasibility of using X-ray analysis as a method of detecting wear from specific hydraulic components.

PREFACE

This report was prepared by the staff of the Fluid Power Research Center of the Division of Engineering, Technology, and Architecture, Oklahoma State University. The study was initiated by the Naval Air Engineering Center at Lakehurst, New Jersey. Authorization for the effort reported herein was granted under Contract No. N68335-80-C-0523.

The study was conducted under the general guidance of Mr. D. H. Ahlberg, Senior Project Engineer at Fluid Power Research Center. The ferrographic elastomer wear debris capture technique was developed by Mr. D. Walley, Center Project Assistant. The visual characterization of metallic wear debris was performed by Mr. F. D. Norvelle, Center Assistant Director. The overall direction of this study was carried out by Dr. E. C. Fitch, Center Director. The findings and conclusions are presented in this final report.

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT.)

I. INTRODUCTION

A. This report describes the results of an experimental effort having three main thrust areas. Those areas were to characterize the metallic wear debris of individual hydraulic components, to affect the deposit of elastomer debris on Ferrograms, and to characterize elastomer wear debris as to wear mode, material, and source.

B. In the matter of characterizing the metallic wear debris of individual hydraulic components, the analyses and comments cited in this report are made purely on the basis of the samples received. The Fluid Power Research Center (FPRC) had no information concerning system design, component location or material content, filtration level, or maintenance history.

C. An experimental program was undertaken to achieve the goal of effectively increasing the deposition of elastomer debris on Ferrograms by means of sample pretreatment. The pretreatments investigated were the addition of solutions containing the perchlorate or chloride salts of lanthanide series metals. Lanthanide series metals become magnetized in the presence of a strong magnetic field. It was expected that elastomer debris would absorb the solutions, become magnetized when passing over the ferrographic magnet, and more readily deposit on the Ferrogram. This work is being presented in a paper entitled: "A New Sample Pretreatment for Increasing the Effectiveness of the Ferrograph in Capturing Elastomer Wear Debris," which will be presented at the Annual Meeting of the American Society of Lubricating Engineers in May 1982.

D. In order to characterize wear debris by material, the use of a scanning electron microscope (SEM) equipped with an X-ray analyzer was investigated. Extremely small particles were located visually by the SEM, whose powerful electron beam excited the electrons of the particles of debris into emitting X-rays. The X-rays were read by the X-ray analyzer which, by noting their strength and quantity, was able to determine the predominant elements present.

II. EQUIPMENT

A. THE FERROGRAPH

1. The analytical Ferrograph system consists of three components: the Ferrograph analyzer, the Ferroscope, and the densitometer. The Ferrograph analyzer is used to make Ferrograms. The Ferroscope is used to visually analyze individual particles on Ferrograms. The densitometer is used to indicate at various locations along the Ferrogram the percent of area, which is covered by debris, of that region which is contained in a 150-micrometer field of view.

2. The procedures governing all aspects of Ferrogram preparation and analysis, as well as more detailed descriptions of equipment, are outlined in reference (a).

B. THE SCANNING ELECTRON MICROSCOPE (SEM) AND X-RAY ANALYZER

1. A JEOL JSM 35 SEM was used along with a Tractor Northern TN-2000 X-ray analyzer. The SEM was used to visually locate individual particles on Ferrograms. The X-ray analyzer was used to determine the predominant chemical composition of individual wear particles. Figure 1 shows the function of the X-ray analyzer.

2. Some particles, particularly elastomer particles, tend to absorb a static charge from the electron beam. This lessens the visual clarity on the SEM cathode ray tube screen and leads, in some cases, to particles jumping off the Ferrogram. To control this problem, carbon may be sputtered onto the surface of poor conducting particles. This reduces charge buildup. A Technics Hummer II plasma coater was used to sputter carbon onto the Ferrograms.

Ref: (a) Dobson, J. D., "The FPRC Recommended Ferrographic Procedure," The BFPR Journal, 1982, Vol. 15, No. 4, pp. 437-444.

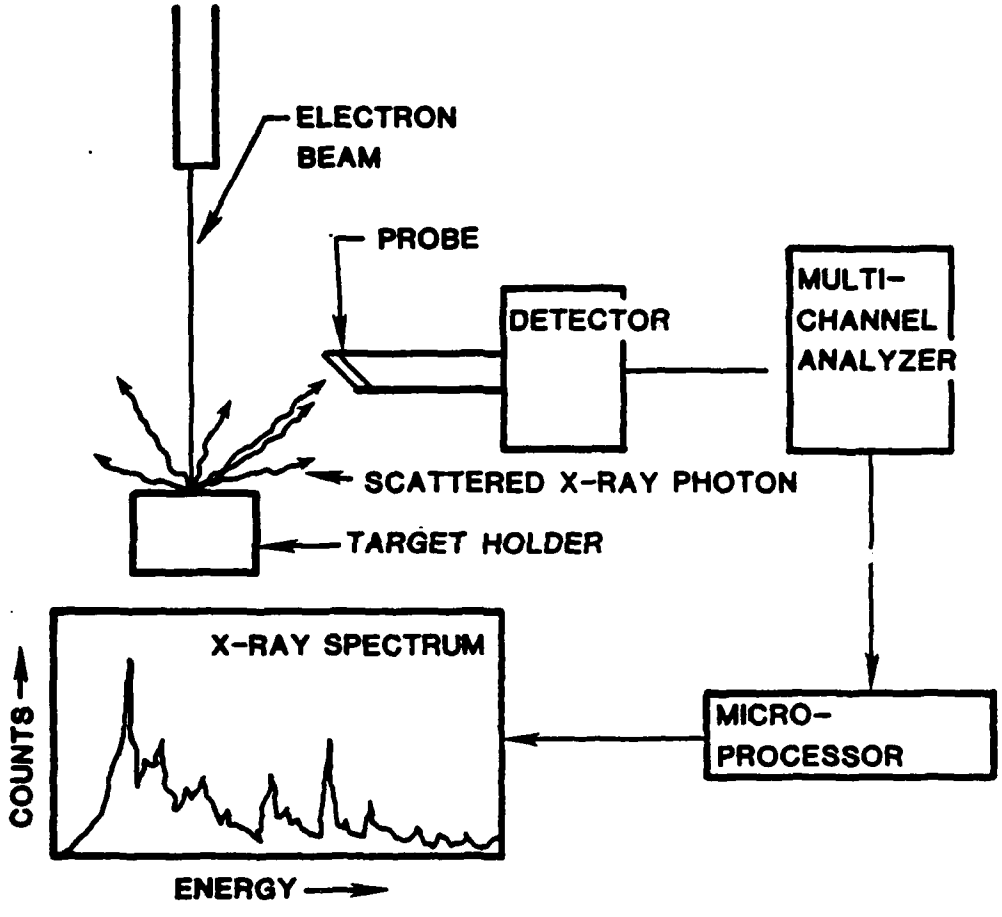

Figure 1 - Function of the X-Ray Analyzer

III. ELASTOMER WEAR DEBRIS CHARACTERIZATION

A. INTRODUCTION

1. An experimental effort, whose objective was to develop a method for increasing the deposition of elastomer debris on Ferrograms, has been performed. Samples of oil containing nitrile elastomer debris were pretreated with solutions containing a perchlorate or chloride salt of a lanthanide series metal. Pretreatment with a solution containing the perchlorate salt of holmium resulted in a significant increase in debris deposition. A minimum increase of 10 percent was effected. Pretreatments with solutions containing the perchlorate salts of gadolinium, dysprosium, and thulium and the chloride salt of erbium did not effect significant increases in particle deposition.

2. Linear-motion-generated seal wear debris has been classified into five groupings, while that for rotary motion has been classified into four groupings. Only one grouping has been observed to be unique to linear motion generated wear. It is not, therefore, possible at present to assign to an individual wear particle its mode of wear, except in the one case found to be unique to linear motion generated wear.

B. SAMPLE PRETREATMENT

1. This part of the report is a presentation of the results of an experimental effort, whose objective was to increase the deposition of elastomer debris by means of sample pretreatments. The pretreatments investigated were the addition of solutions containing the perchlorate or chloride salts of lanthanide series metals. Lanthanide series metals become magnetized in the presence of a strong magnetic field. It was expected that elastomer debris would absorb the solutions, become magnetized when passing over the ferrographic magnet, and more readily deposit on the Ferrogram.

2. EXPERIMENTS

a. Thirty Ferrograms were prepared from samples of oil (SX-100 motor oil) containing nitrile elastomer debris. The debris came from the seal and shaft of a radial lip seal test stand on site at the FPRC. The samples were divided into six groups. Each of the five groups were pretreated with one of five different solutions containing the soluble chloride or perchlorate salt of lanthanide series metal. One group was pretreated with a solution devoid of any lanthanide series metal. The lanthanide chloride and perchlorate salts used were those of gadolinium ($Gd(ClO_4)_3$), dysprosium ($Dy(ClO_4)_3$), holmium ($Ho(ClO_4)_3$), thulium ($Tm(ClO_4(_3$), and erbium ($ErCl_3$).

b. The 30 one-mL samples of oil, from which one Ferrogram per sample was made, were drawn from one source. Approximately 10 percent of the source was drawn as samples.

c. One of the authors drew all the samples and applied the pretreatments. One technician made all the Ferrograms in the usual way with the exceptions of placing the glass substrate directly on the Ferrograph magnet and elevating the back of the Ferrograph to a height of 12.7 mm. One of the

authors counted the particles on each Ferrogram 5 micrometers in size of larger, which were contained in six fields of view. Each field of view was 150 micrometers in diameter. The fields were centered over the entrance point of the Ferrogram and at five subsequent locations spaced 10 mm apart.

d. Pretreatment Solution Preparation

(1) Saturated aqueous solutions of the four perchlorate salts and one chloride salt were prepared. One drop of a different solution was added at 20°C to each of five containers that each contained 10 mL of n-butanol (ACS grade). These were shaken until the aqueous solutions were completely dissolved. To each container was added 100 mL of toluene (ACS grade). These were shaken until they were completely mixed.

(2) Lanthanide perchlorates exhibit great oxidizing potential along with explosive characteristics when anhydrous. However, their hygroscopic character to readily absorb moisture from the environment desensitizes them tremendously.

e. Ferrogram Sample Preparation

(1) The elastomer-debris-bearing oil source was shaken for 15 minutes in a paint shaker and deaerated in an ultrasonic bath. Ten one-mL samples were drawn at one time. The next day the procedure was repeated, and 15 one-mL samples were drawn. Each one-mL sample was drawn with a clean plastic pipette of one-mL capacity. The samples were placed in clean Ferrogram preparation bottles.

(2) One 3-mL dose of each pretreatment solution was added to one each of five bottles. Each bottle was shaken and then heated at 54°C for 15 minutes. This was followed by Ferrogram preparation.

(3) Five additional one-mL samples were drawn from the source after it had been shaken and deaerated. Each sample was pretreated with 3 mL of toluene diluent to achieve a viscosity that was approximately equal to that of the other samples. The toluene contained no lanthanide chloride or perchlorate.

3. RESULTS AND DISCUSSION

a. Table 1 is a listing of the particle counts for each Ferrogram. The count averages and variances are included. The counts for each pretreatment were assumed to be approximately normally distributed. To test this assumption, the counts were plotted on normal probability plotting paper. Straight lines were fitted to the plots, and 80 percent confidence bands were added. These plots are shown in Figure 2. None of the plotted points lie outside of the confidence bands. This may be thought of as being like a hypothesis where it was not possible to reject at the 0 to 20 percent level of significance the assumption of an approximate normal distribution for the counts. Thus, the assumption of the counts being approximately normally distributed was maintained in all data analyses.

TABLE 1 - THE NUMBER OF PARTICLES PER FERROGRAM CONTAINED IN SIX 150-MICROMETER FIELDS OF VIEW

The Lanthanide in the Pretreatment Solution	The Number of Particles Per Ferrogram - Five Ferrograms Per Treatment	Count Average	Count Variance
No Lanthanide	132 138 179 227 267	189	3,369
Gadolinium	149 171 172 201 482*	173	455
Dysprosium	175 197 206 209 210	199	212
Erbium	187 195 205 213 224	205	212
Thulium	145 167 181 313 438	249	15,495
Holmium	216 316 365 398 +	324±	6,295±

* This value was not used in computing the count average nor the count variance.
\+ This count has been lost.
± This value was computed with the four counts listed.

b. Hypothesis Testing

(1) A null hypothesis, which states the particle deposition was not affected by any of the pretreatments, was tested against an alternative hypothesis, which states that one or more of the pretreatments effected an increase in particle deposition. The significance level for this test was chosen to be 5 percent, which means that if it is concluded that one or more of the pretreatments effected an increase in particle deposition, there is a probability of 5 percent that such a conclusion is incorrect.

(2) Table 2 is a listing of the values of the T-statistic and the corresponding critical value for the test arranged by pretreatment. Only the holmium-containing pretreatment solution resulted in a value for the T-statistic that lies in the critical rejection region. The pretreatment solution containing holmium was concluded, therefore, to have effected an increase in particle deposition. At the 5 percent level of significance, it was not possible to reject the hypothesis that the other pretreatment solutions had no effect in increasing particle deposition.

TABLE 2 - VALUES OF THE T-STATISTIC AND THE CRITICAL VALUE FOR TESTING PRETREATMENT EFFECTS ON PARTICLE DEPOSITION

The Lanthanide in the Pretreatment Solution	T-Statistic	Critical Value
Gadolinium	-0.57	2.00
Dysprosium	0.61	2.05
Erbium	0.61	2.05
Thulium	0.98	1.98
Holmium	2.85	1.96

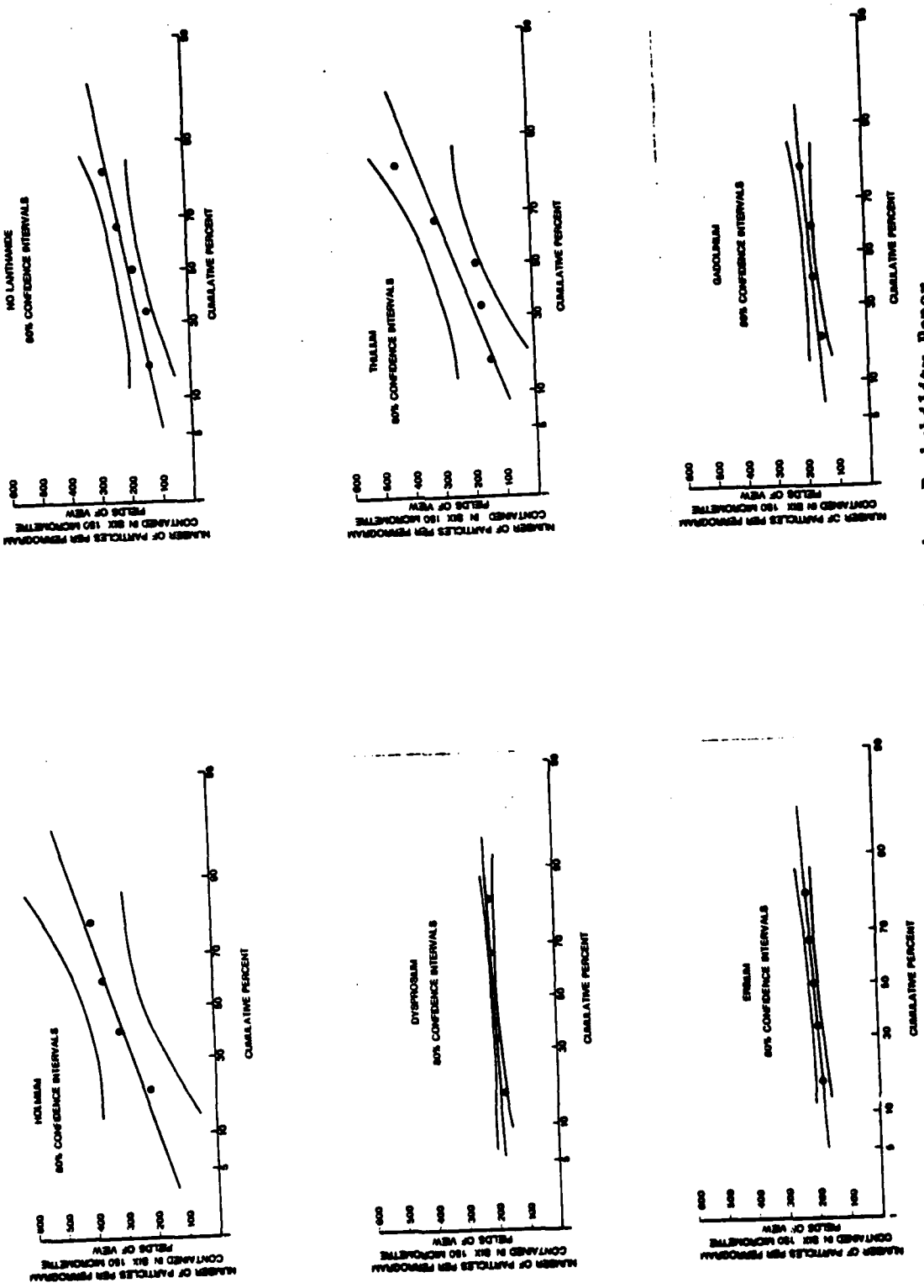

Figure 2 - Particle Counts Plotted on Probability Paper With 80 Percent Confidence Bands

c. The Effectiveness of Pretreatment with Lanthanide Holmium

(1) In determining the effectiveness of the holmium perchlorate salt solution, the count variances for this pretreatment and for nonpretreatment with a lanthanide were assumed to be equal. A 95 percent confidence interval for the difference between the mean particle counts for pretreatment with the lanthanide holmium and nonpretreatment with a lanthanide is (27, 242). A 95 percent confidence interval for the mean particle count for nonpretreatment with a lanthanide is (17, 261). Thus, the statement, which has a 5 percent probability of being incorrect, can be made that pretreatment with the solution containing the lanthanide holmium effected at least a 27/671 or a 10 percent increase in particle deposition.

4. CONCLUSIONS

a. Pretreatment of nitrile elastomer debris bearing oil with a solution containing holmium resulted in an increase in the deposition of the elastomer debris on Ferrograms. At least a 10-percent increase in deposition occurred.

b. It was inconclusive whether pretreatments with solutions containing other lanthanide metals of gadolinium, dysprosium, thulium, and erbium resulted in any increase in particle deposition.

C. WEAR MODE CHARACTERIZATION

1. INTRODUCTION

a. Elastomer seal wear is caused by the wearing action of some surface, which moves relative to the sealing surface of the elastomer. It is generated during the linear reciprocating motion of cylinder rods and pistons and during the rotational motion of the shafts on rotary machinery. The severity of the wear could be dependent on many things, some of which may be pressure, seal material, shaft or barrel material and finish, fluid, operating speed, and clearances.

b. Several Ferrograms were made from samples of fluid containing elastomer wear generated during reciprocating motion and during rotational motion. The wear debris was washed from the shafts of rotational seals, from the seals themselves, and from cavities in a block which held linear seals into sampling bottles. Several photographs of this debris, which was deposited on Ferrograms, are shown in order to contrast wear that is generated during reciprocating and rotational motion.

2. LINEAR MOTION GENERATED SEAL DEBRIS. In observing the seal wear debris generated by linear motion, it appears possible to classify it into five groups. The groupings are gross extrusion, secondary extrusion, rolling, chunking, and film transfer wear.

a. During gross extrusion wear, seal elastomers extrude under pressure into clearances. The extruded portion is more strained than the bulk of the elastomer and wears preferentially. Large chunks of the extruded elastomer may

be detached from the seal. Figure 3 presents photographs at 1000X magnification of long, thin elastomer particles. The particles are approximately 100 micrometers long and are thick enough to block the background light. They are somewhat jagged in appearance.

b. Secondary extrusion wear is illustrated in Figure 4, a photograph at 1000X magnification of a particle approximately 40 micrometers long. It is wider, thinner, and less jagged than the gross extrusion wear particles. The particle appears to have been rubbed smooth and thin before being detached from the seal. It was thought that this particle could be from additional extrusion following the detachment of a gross extrusion wear particle.

c. Rolling wear is illustrated in Figure 5 which shows cigar-shaped particles. The photographs are at 1000X magnification, and the particles are approximately 30 micrometers long. The particles appear to be rolled up in a twisted fashion.

d. Chunking wear is illustrated in Figure 6, a photograph at 1000X magnification of a chunk approximately 15 micrometers in size. The particle looks as if it could have been a chunk off the end of a cigar-shaped rolling wear particle in the process of separating from the parent particle.

e. Film transfer wear is illustrated in Figure 7 which is a photograph at 1000X magnification of a large, flat, thin particle approximately 80 micrometers long. A lot of background light can be seen through the particle, especially at the edges. The edges are cracked in many places. It was thought that such a particle could have been generated by a thin film of elastomer transferring to the shaft and subsequently detaching.

3. ROTARY MOTION GENERATED SEAL DEBRIS. In observing the seal wear debris generated by rotary motion, it appears possible to classify it into four groupings. The groupings are fatigue, abrasion, rolling, and film transfer wear.

a. Fatigue wear is illustrated in Figure 8 which is a photograph at 1000X magnification of a ragged chunk approximately 60 micrometers in size. Because of its appearance, it was thought to have been pulled out of the elastomer surface by a fatiguing action.

b. Abrasion wear is illustrated in Figure 9, which is a photograph at 1000X magnification of a thin, flat particle approximately 40 micrometers in size. The thinness and flatness of the particle are thought to be the result of abrasion.

c. Rolling wear is illustrated in Figure 10, which presents photographs at 1000X magnification of cylindrical particles. The particles in Figure 10A are definitely twisted. It is thought likely that the twisted cylinders are a secondary occurrence following fatigue and abrasion wear.

d. Film transfer wear is illustrated in Figure 11 which presents photographs at 40X magnification of extremely thin "particles." A great

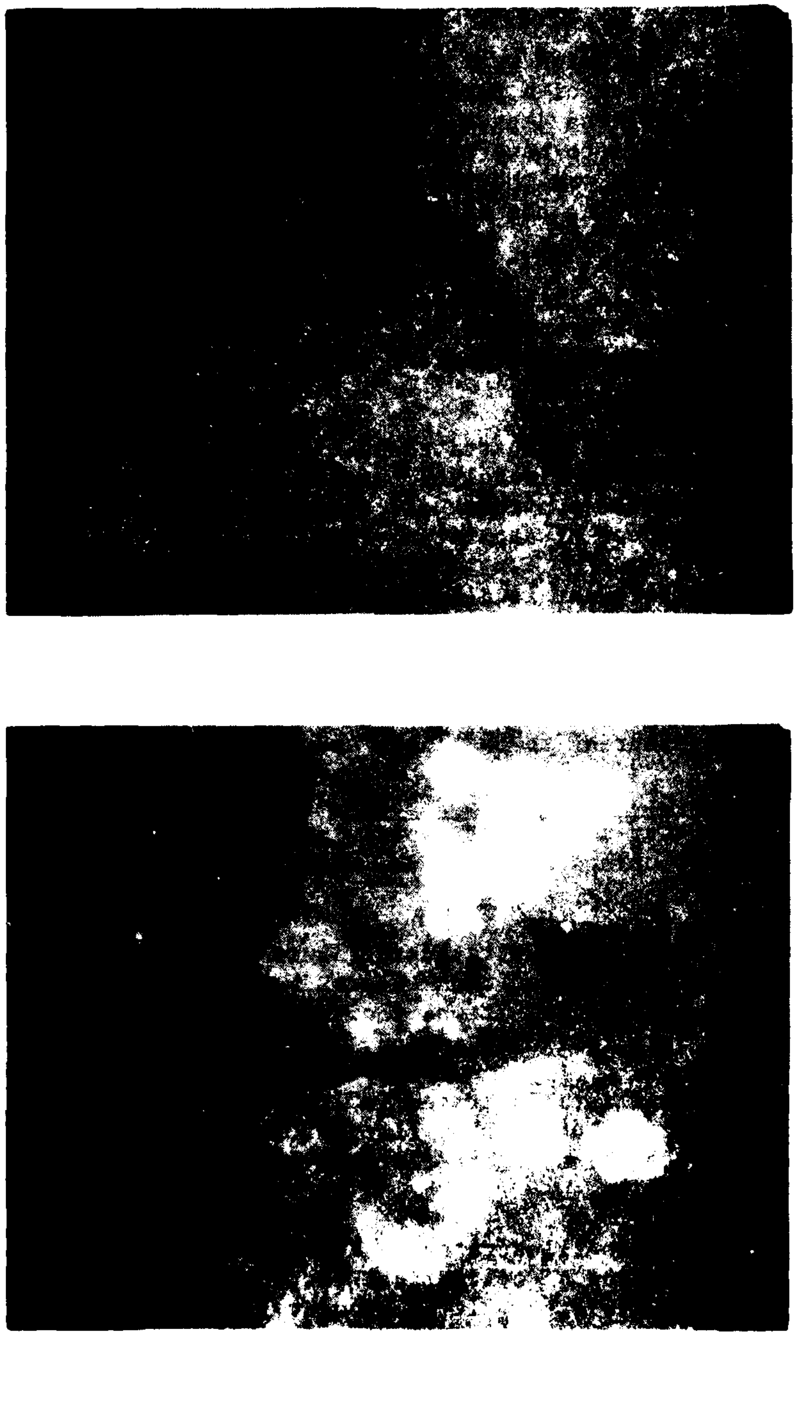

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Figure 3 - Photographs of Long, Thin Extruded Elastomer Particles at 1000X

Figure 4 - Photograph of a Secondary Extrusion Wear Particle at 1000X

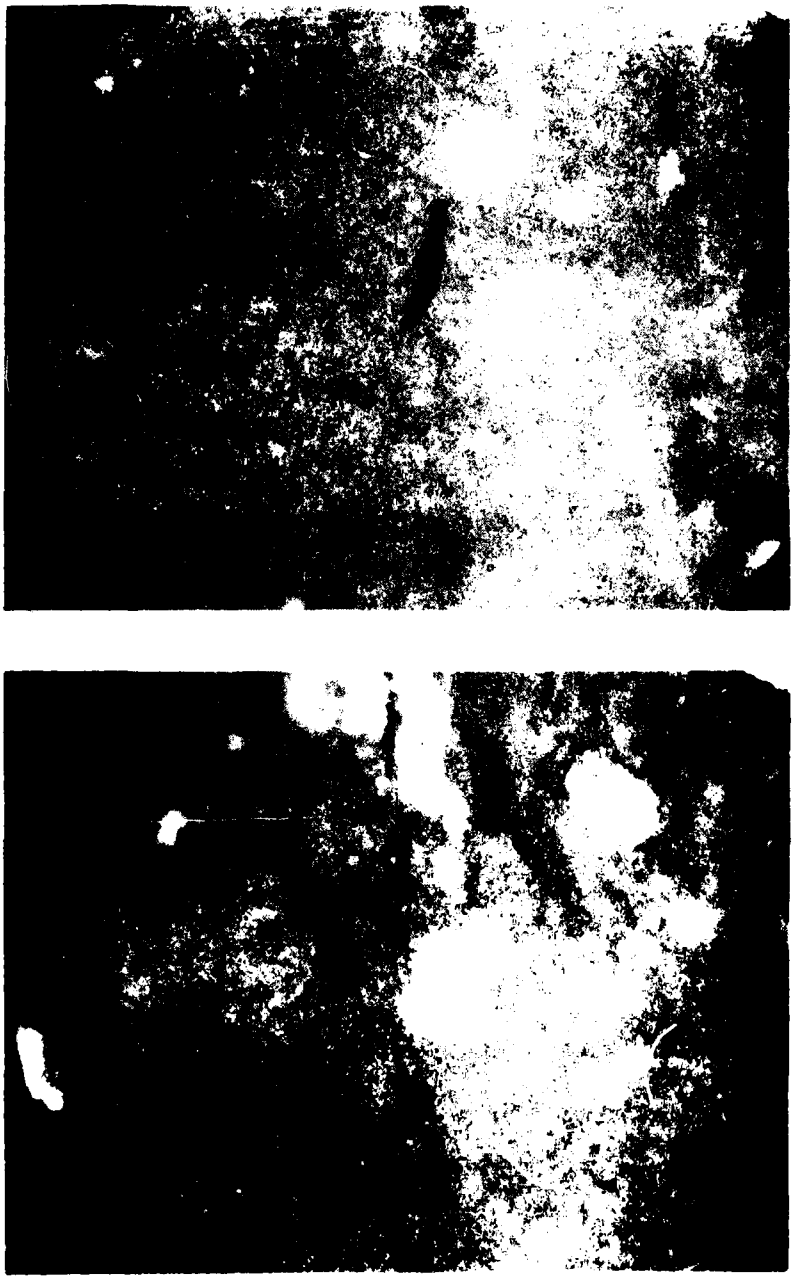

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Figure 5 - Photographs of a Cigar-Shaped Rolling Wear Particle at 1000X

Figure 6 - Photograph of Chunking Wear Particle at 1000X

Figure 7 - Photograph of Film Transfer Wear Particles at 1000X

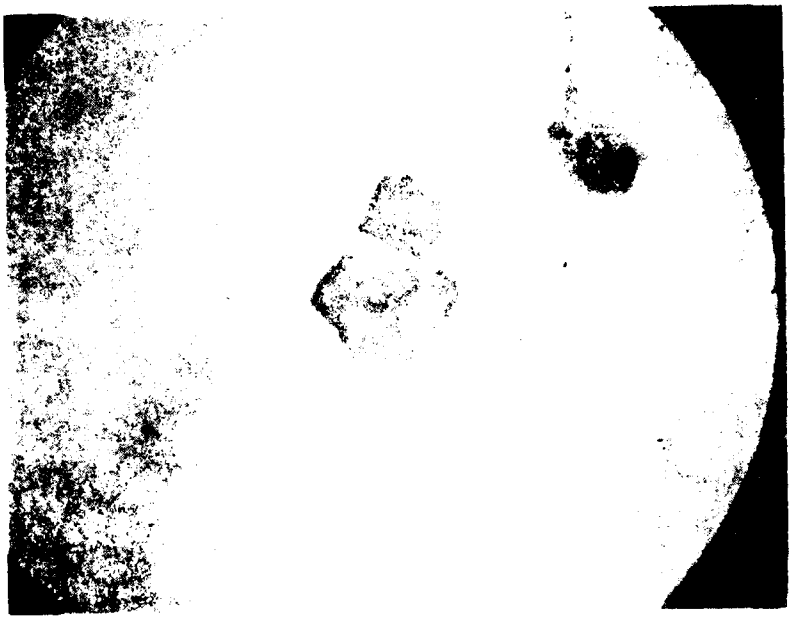

Figure 9 - Photograph of Abrasion Wear Particle at 1000X

Figure 8 - Photograph of Fatigue Wear Particle at 1000X

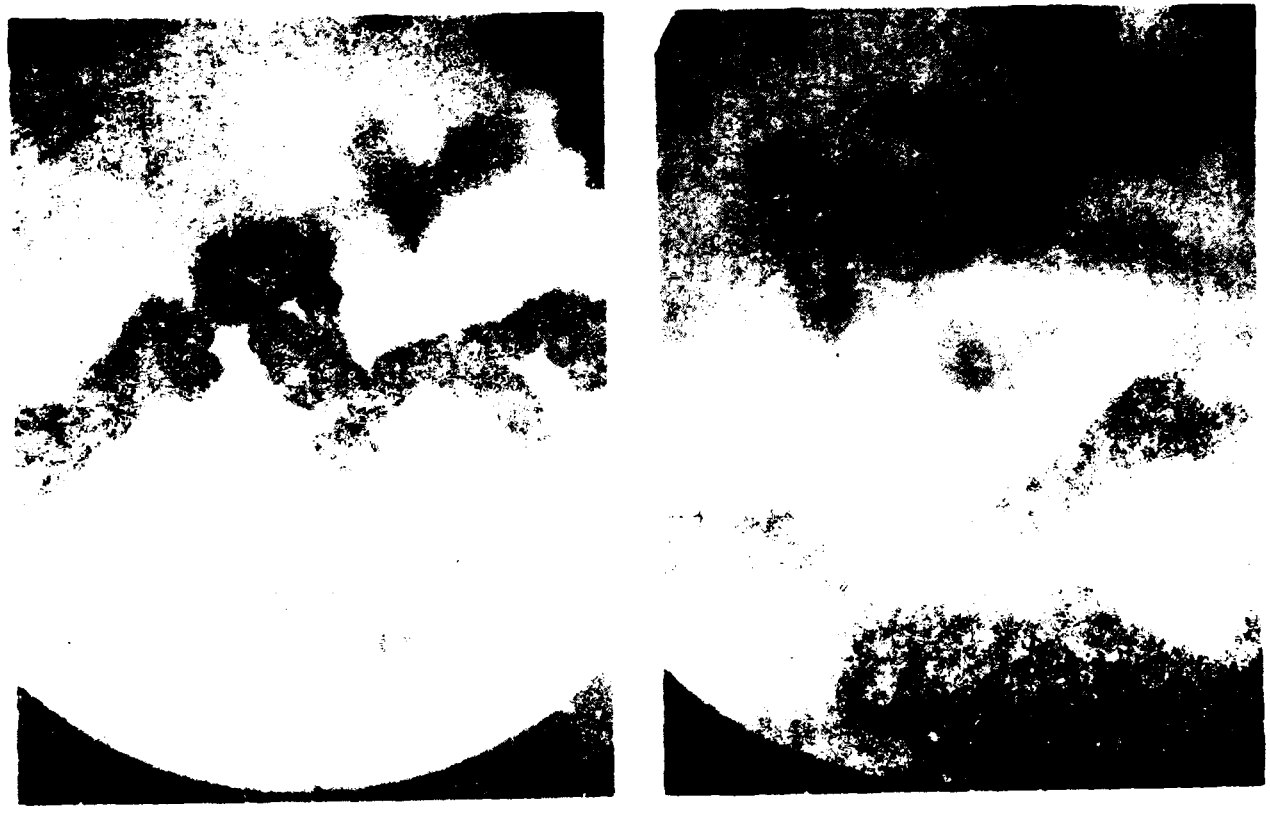

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Figure 10 - Photographs of Rolling Wear Particles at 1000X

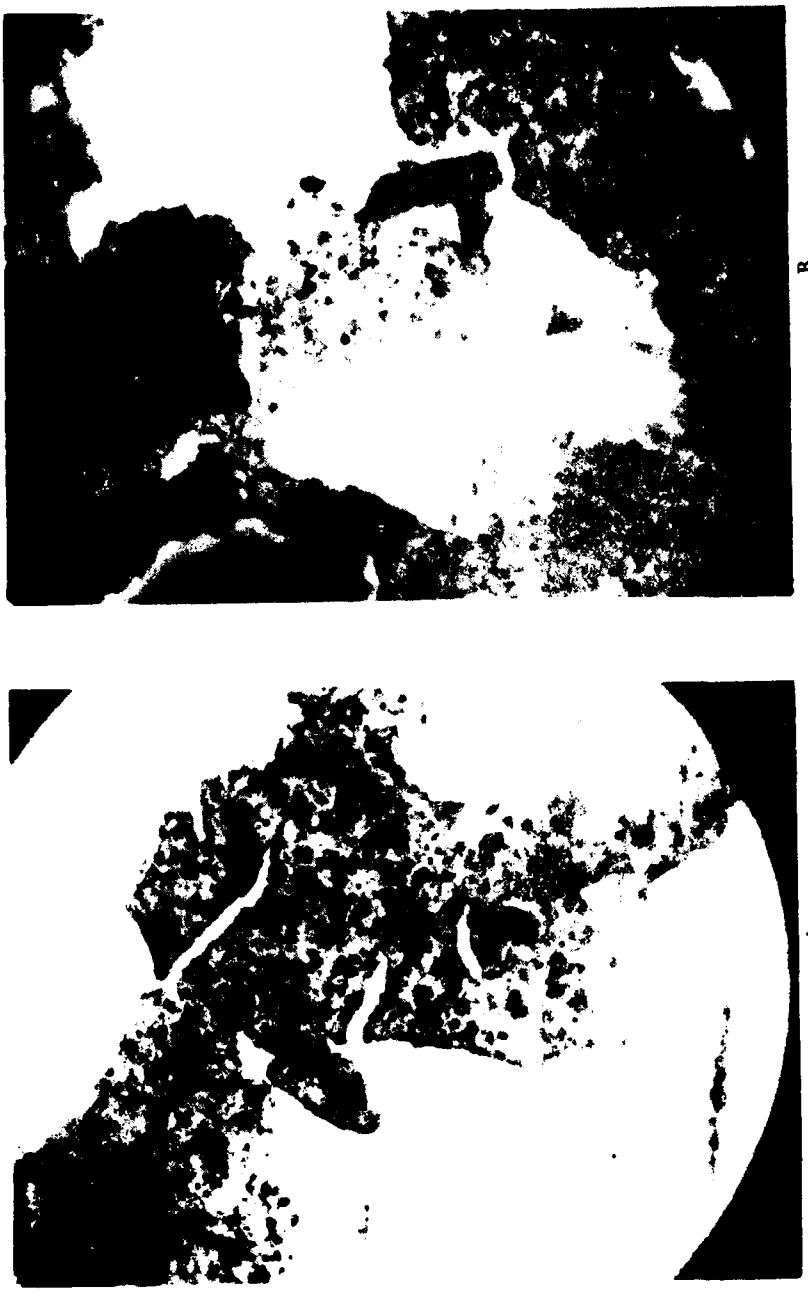


Figure 11 - Photographs of Film Transfer Wear Particles at 40X (Sheet 1 of 2)

C

Figure 11 - Photographs of Film Transfer Wear Particles at 40X (Sheet 2 of 2)

deal of background light appears through the elastomer wear. This debris is thought to be the result of the transfer of a thin polymer film from the seal to the shaft.

4. RECIPROCATING/ROTARY MOTION GENERATED SEAL DEBRIS.

a. Seal wear generated during reciprocating and rotary motion has classifications, one of which is unique to reciprocating motion and one of which seems to predominate in rotating motion. Gross extrusion, not noticed in rotary motion wear generation, was observed in reciprocating motion wear generation. Film transfer, very evident in rotating motion wear generation, was seldom observed in reciprocating motion wear generation. The secondary extrusion wear observed in reciprocating motion wear generation was similar to the abrasion wear observed in rotating motion wear generation. The rolling wear observed for both modes of generation was similar. The chunking wear observed in reciprocating motion wear generation was similar to the fatigue wear observed in rotary motion wear generation.

b. To conclude, although seal wear debris may be assigned to a classification if the mode, rotary or reciprocating motion, is known, it is more difficult to assign the wear mode for an arbitrary wear particle. Here, unless the particle fits the gross extrusion classification, it could not be determined by which mode it was generated.

IV. METALLIC WEAR DEBRIS CHARACTERIZATION

A. BACKGROUND

1. The analyses and comments reported in this section are made purely on the basis of the samples received. The FPRC had no information concerning system design, component location or material content, filtration level, or maintenance history.

2. Each of the Ferrography reports in Appendix A is marked according to the analyst's opinion of the severity of the wear debris viewed on the Ferrogram. As with most other aspects of analytical Ferrography, this is a somewhat subjective evaluation. The subjectivity of this analysis is increased in this particular study by the fact that no maintenance information was provided for the analyst.

3. It is known that the severity of wear depends on many factors, including internal clearances, allowable leakage, the mass of various component parts, and the contaminant tolerance of the component. It has been shown that different systems are characterized by different "normal" contamination levels. For instance, in aircraft gas turbine engines, the TF-30 is a characteristically "dirty" engine, while the TF-33 is a characteristically "clean" engine. Thus, a sample that would be considered normal for a TF-30 would probably be considered critical for a TF-33 (reference (b)).

4. Because no such information was available for the system from which these samples were taken, the classifications of the severity of the wear debris are somewhat arbitrary. They do offer, however, a pseudo-quantitative method for comparing the data from the various sample points.

B. RESULTS

1. The wear debris severity indexes of the pump case drain filter, dual yaw control filter, reservoir return line filter, and the actuators' system circuit were plotted against operating hours. The plots are shown in Figures 12 through 15. These plots indicate that wear debris severity is highest for the pump case drain filter, followed by the dual yaw control filter, the reservoir return line filter, and the actuators' system circuit. The average wear debris severity indexes are 4.3 for the pump case drain filter, 3.7 for the dual yaw control filter, 3.3 for the reservoir return line filter, and 2.6 for the actuators' system circuit.

2. The plots of Figures 12 through 15 provide a method of trending the overall health of the system. The wear debris severity indexes for all four plots begins decreasing significantly between 476.5 and 533.5 hours. Figure 16 is a plot of the average wear debris severity indexes for the composite system, and Figure 17 is a plot of the running average of the last five average wear debris severity indexes. These two plots clearly reveal the decreases in the wear debris severity indexes that occur at 476.5 hours.

Ref: (b) Fluid Power Research Center, "PRAM Ferrography Final Engineering Report," FPRC Report No. T51980, USAF Contract No. F34650-78-V-0351, 15 Apr 1980.

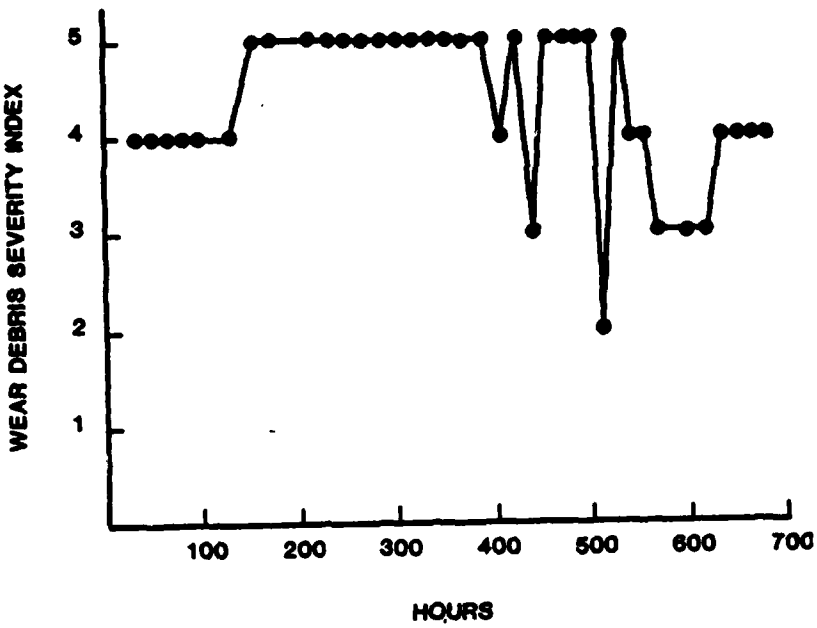


Figure 12 - Plot of Wear Severity for Pump Case Drain Filter

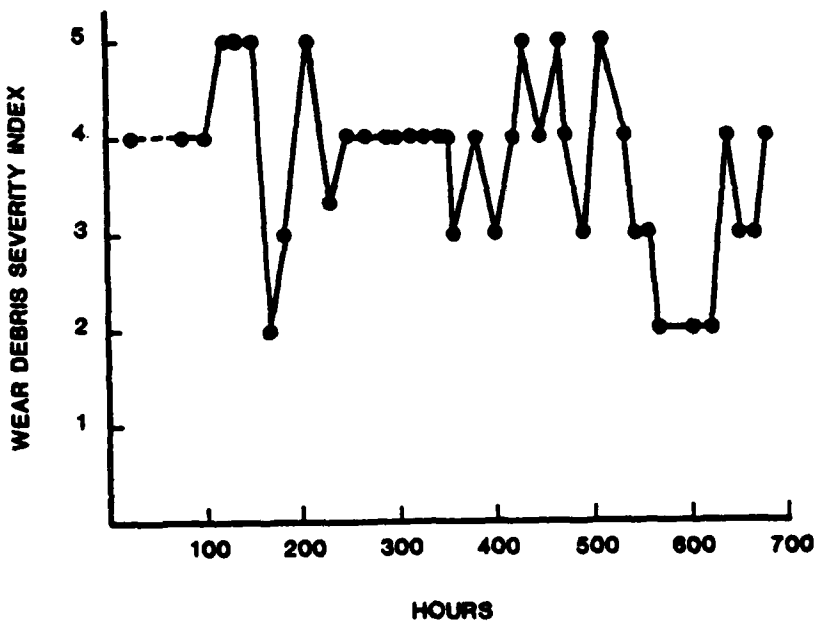


Figure 13 - Plot of Wear Severity for Dual Yaw Control Filter

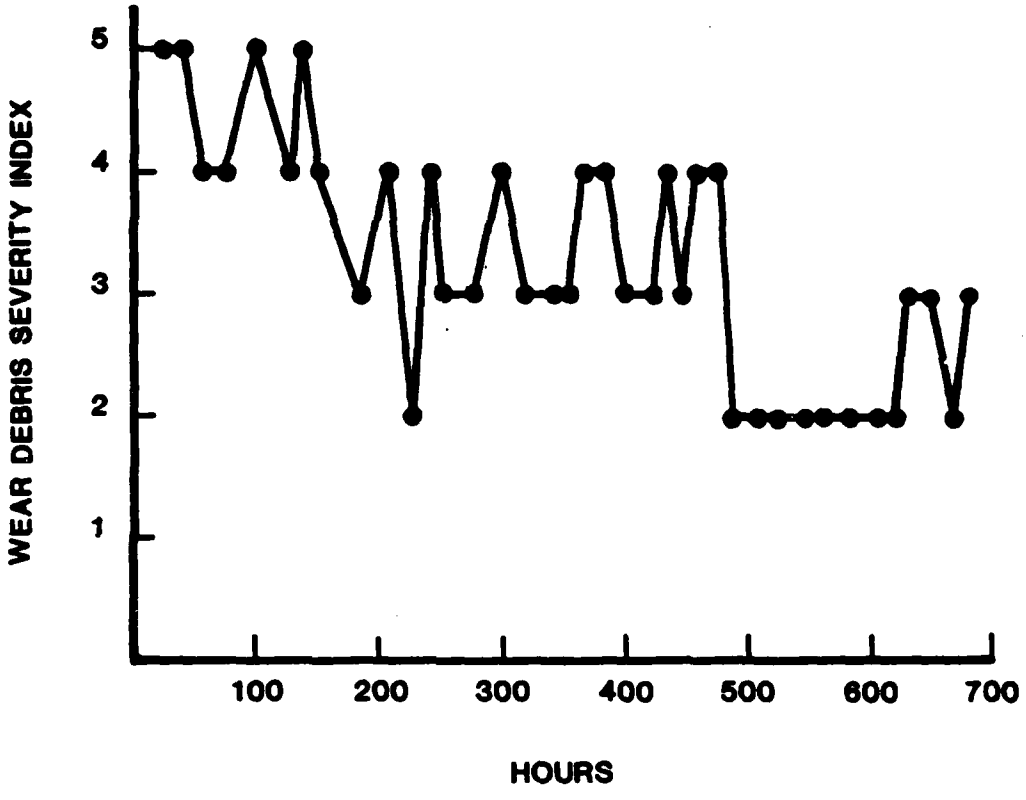


Figure 14 - Plot of Wear Severity for Reservoir Return Line Filter

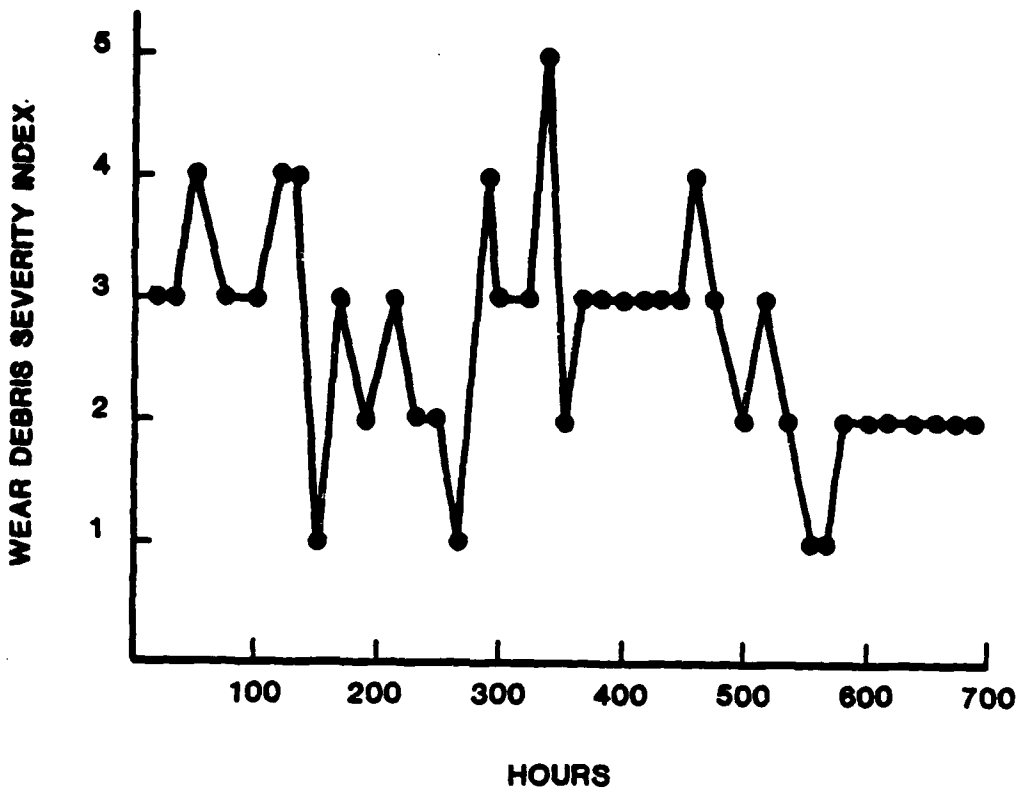


Figure 15 - Plot of Wear Severity for Actuator System Circuit

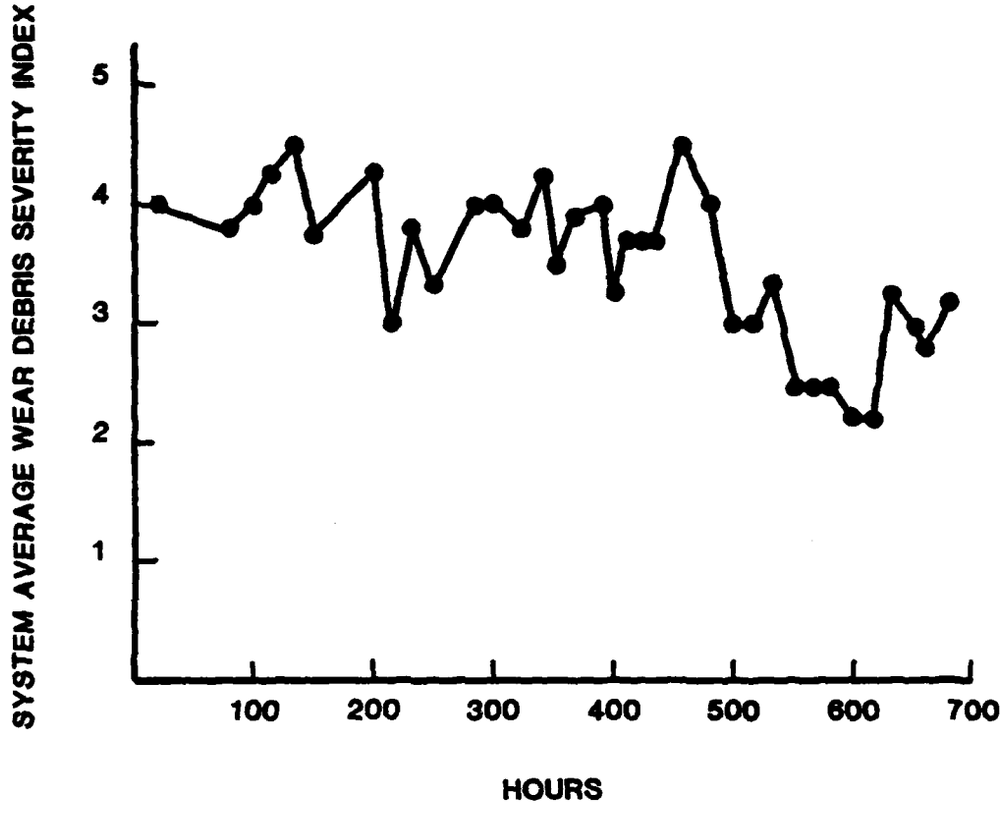


Figure 16 - Plot of System Average Wear Debris Severity

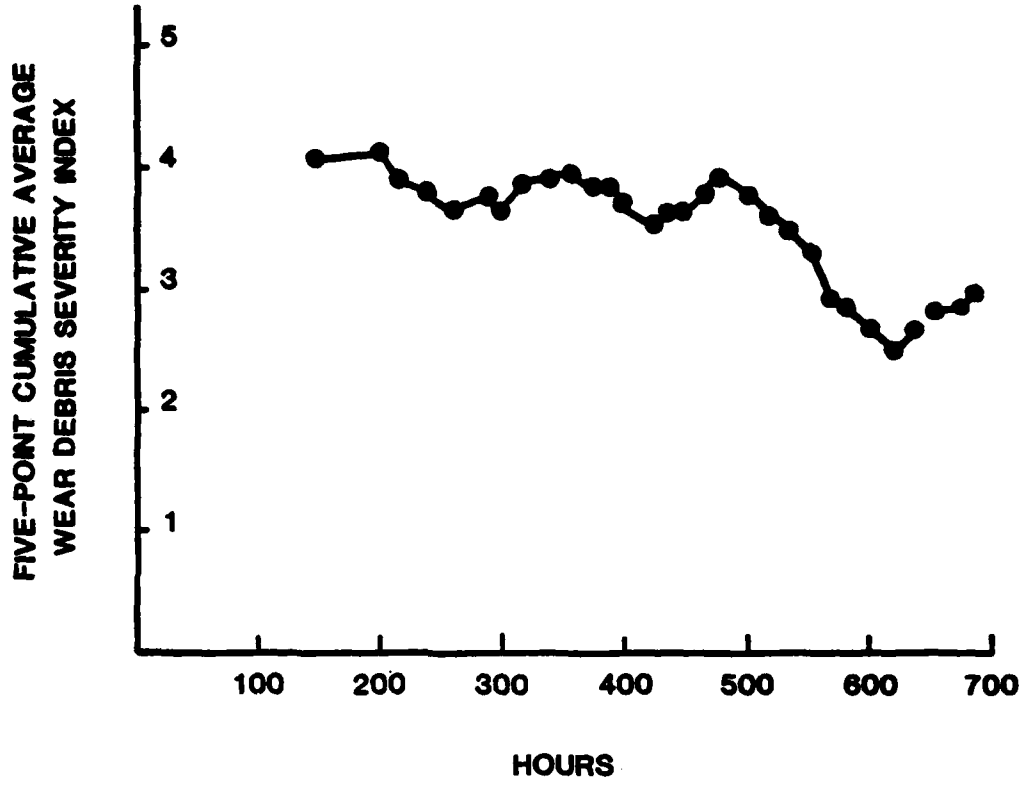


Figure 17 - Plot of Five-Point Cumulative Average of Wear Debris Severity

3. DISCUSSION.

a. While no maintenance records are available, this sudden and overall improvement in the system's level of debris suggests the possibility of either an oil change, a filter change, or both. This thinking is reinforced by the fact that after the 618.5-hour sample, the system's average level of debris begins to increase again.

b. The fact that the pump case drain filter was ranked worst is not surprising. It is generally understood that highly loaded rotating components such as pumps are both the most contaminant sensitive (from a wear aspect) and the highest particle generators in a hydraulic system. Because the case drain fluid is used to lubricate the loadbearing surfaces within the pump, a large portion of the internally generated wear debris is found in that fluid.

c. It was somwhat unexpected that the dual yaw control filter samples were worse than the reservoir return line filter. The relative locations of these filters would have a major influence on this. However, such a situation may not be abnormal with this system.

C. VISUAL CHARACTERIZATION OF METALLIC DEBRIS

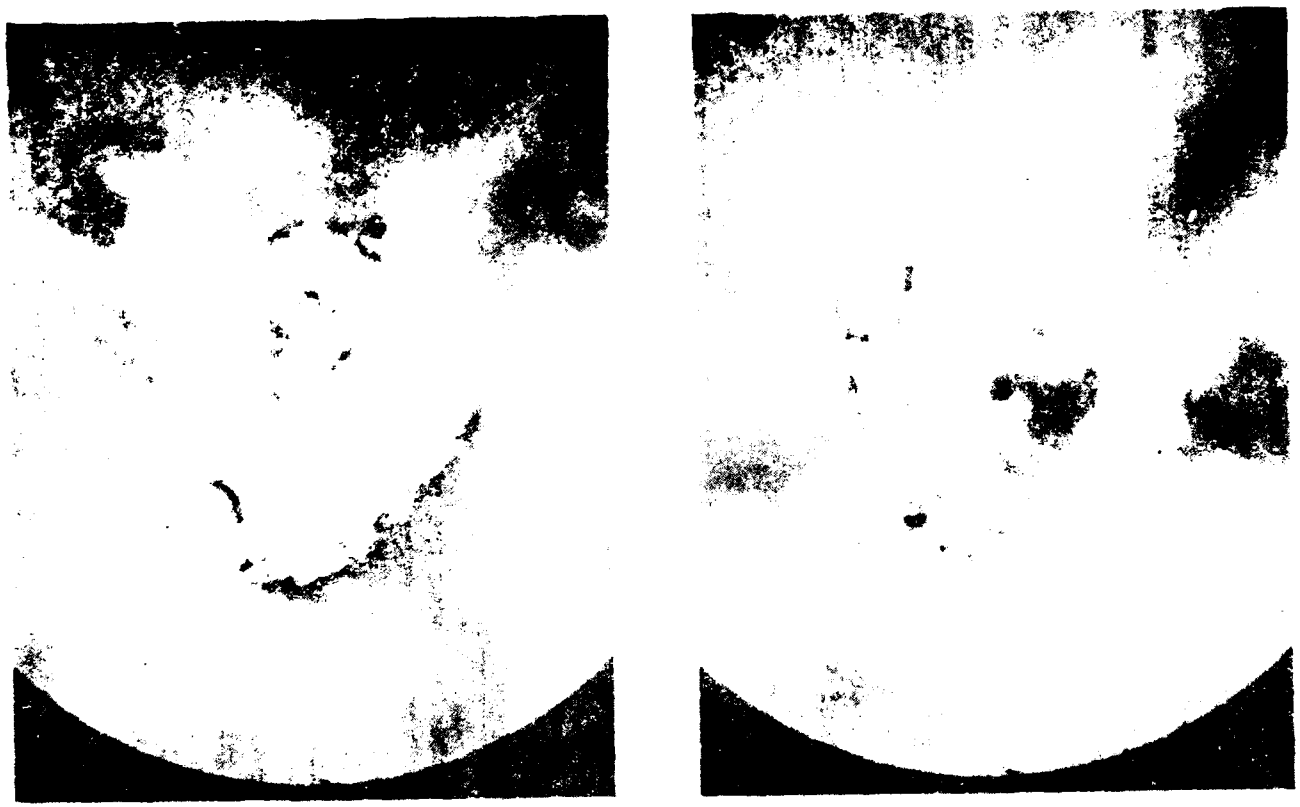
1. Only the pump case drain filter samples demonstrated uniquely characteristic wear debris. Each of the other samples contained very similar types of ferrous wear debris, with a great deal of oxidation evident. The majority of the large debris (greater than 25 micrometers) in all of the samples were bright white in color and had a very rough surface texture similar to cast aluminum.

2. In addition to the ferrous wear debris that appeared in the other samples, the samples from the case drain filter contained large, white, metallic chunks with curved striations, Figures 18 and 19. This material was bright white but had a very different surface texture than the white material found in the other samples. By heating the material to temperatures in excess of 650°F, it was determined that it was a high quality stainless steel. Based on the material, striations, and the point from which the samples were taken, it seems very likely that the particles were wear debris from the swash plate of an axial piston pump.

3. The fact that the debris from all of the samples was similar indicates that either the wear modes experienced in all portions of the system were actually the same (as would be expected if the components were all similar, for example, linear actuators) or the filters were allowing the characteristic particles from each portion of the system to pass through a mix with those from other portions of the system. Which of these is actually the case can be determined either by installing extremely fine, nonbypass-type filters in each portion of the system or by carefully contrived testing of individual components. The latter of these is preferable.

D. Further work in this area will be necessary before any definite conclusions can be reached concerning the feasibility of using Ferrography to detect wear from specific hydraulic components.

Figure 18 - Photograph of Sample from Case Drain Filter Containing Large, White, Metallic Chunks at 400X



A B

Figure 19 - Photographs of Sample from Case Drain Filter at 1000X

V. WEAR DEBRIS MATERIAL CHARACTERIZATION

A. BACKGROUND. Wear debris was analyzed spectroscopically by placing Ferrograms into the chamber of a SEM. The high energy beam of the SEM was sufficient to excite the electrons of the elements which make up the debris. The excited electrons, in decaying from their excited state to their normal state, emit an X-ray photon. Each element, when excited, will emit uniquely characteristic X-rays. By analyzing the X-rays, the predominant elements present in a wear debris particle may be discovered.

B. EXPERIMENTS

1. Several of the prepared Ferrograms were placed in the SEM chamber. Various particles of interest, which had been photographed through the bichromatic microscope of the analytical Ferrograph, were located on the cathode ray tube of the SEM with the help of the photographs. The X-ray analyzer then counted the number of X-rays of various strengths emitted by the debris. The X-ray analyzer could distinguish between elements whose atomic number was greater than that of NEON: 10.

2. The glass substrates of the Ferrograms proved to be a hindrance in the X-ray analysis. The silicon in the glass overshadowed the elements of the wear debris. To overcome this difficulty, the Ferrogram should be prepared on a carbon-filled substrate to reduce the background X-rays. A Ferrogram was prepared on a film of plastic and this proved to significantly reduce the background X-rays.

C. RESULTS

1. METALLIC DEBRIS

a. Figure 20A shows the counts, which were counted in 60 seconds, of X-ray photons at various energy levels coming from the entry point of Ferrogram 3635. The SEM photograph, Figure 20B, is at a magnification of 100X. The silicon appears to dominate the count due to the excessive background X-rays caused by the glass slide of the Ferrogram.

b. Figure 21 shows the counts for the same Ferrogram as in Figure 20B, but at a new magnification of 2200X. The ordinate was shifted to coincide with the silicon count. The counting was continued for 472 seconds. By shifting the ordinate, all elements emitting X-rays of energy greater than 2 kev are easily distinguished; those emitting X-rays of energy less than 2 kev are not observed.

2. PLASTIC SUBSTRATE FERROGRAM. A Ferrogram was made on a plastic film from a sample of fluid taken from a dual yaw control after 172 hours of operation. Figure 22 is a photograph of the Ferrogram entry location at 1000X. Four different regions were analyzed by the SEM. Figure 23 shows the counts for the A-region; the count was conducted for 20 seconds. Figure 24 shows the counts for the brass region; the count was carried on for 20 seconds. Figure 25 shows the counts for C-region; counting was performed for 40 seconds. Figure 26 shows the counts for the center of the entry location; the counting

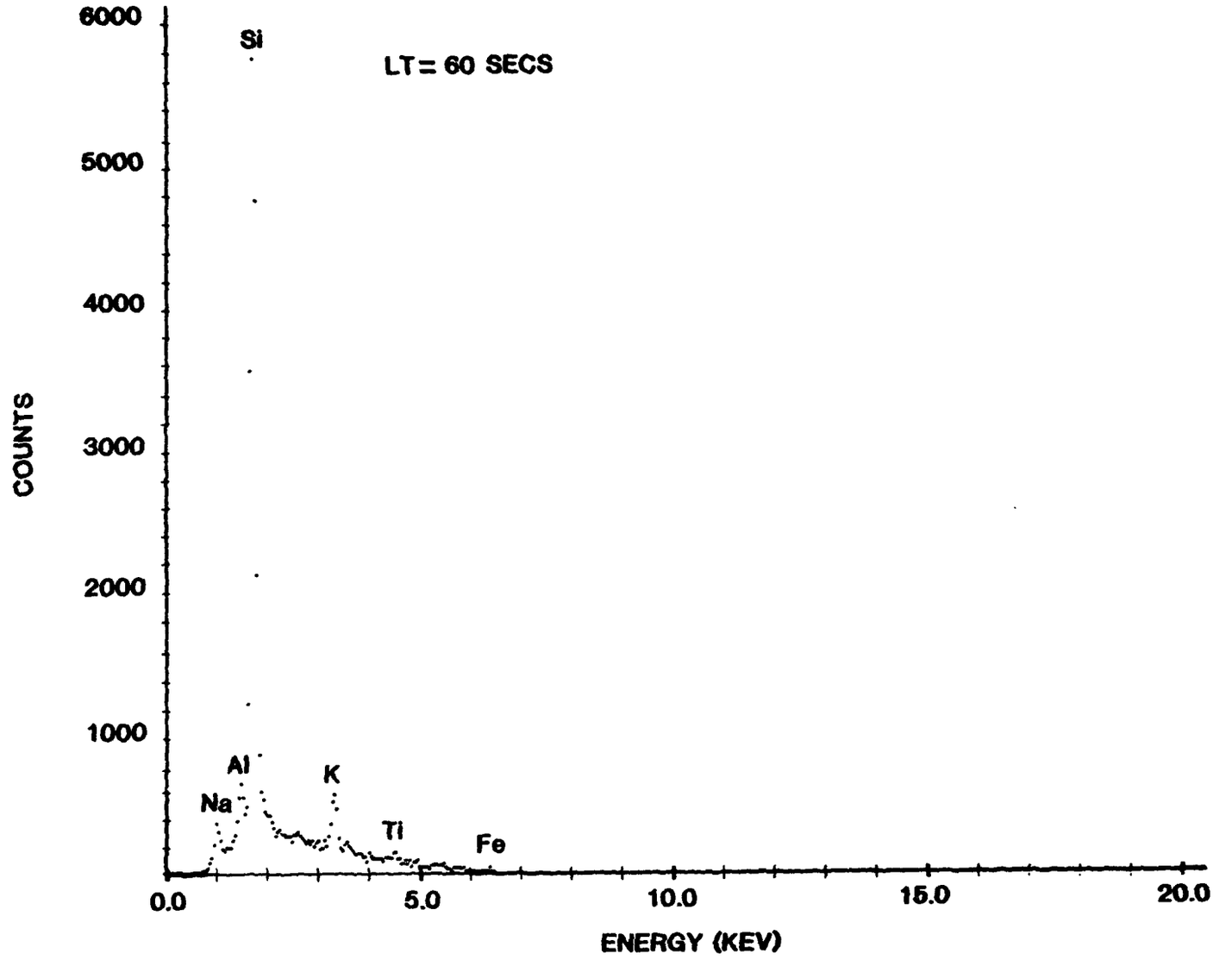


Figure 20A - Counts of Ferrogram 3635

Figure 20B - Photograph of Ferrogram 3635 at 100X

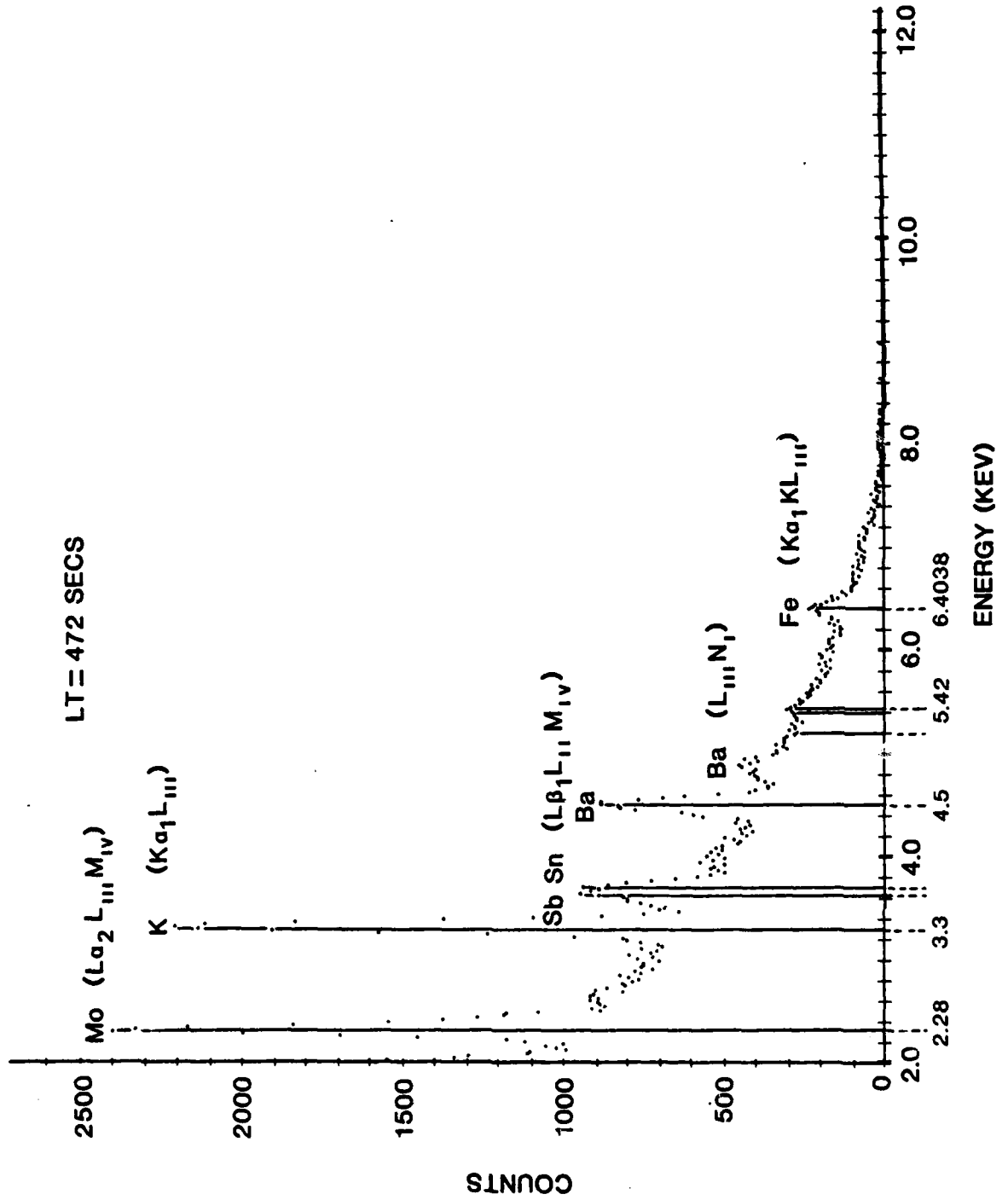


Figure 21 - Counts of Ferrogram 3635 at 2200X

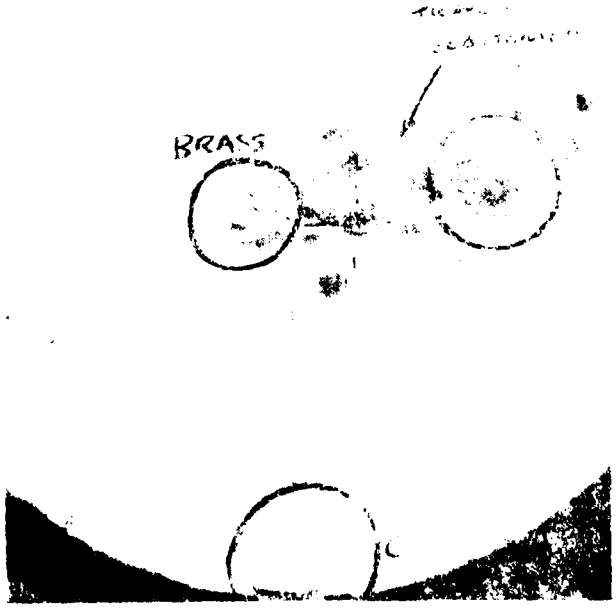


Figure 22 - Photograph of Ferrogram Entry Location at 1000X

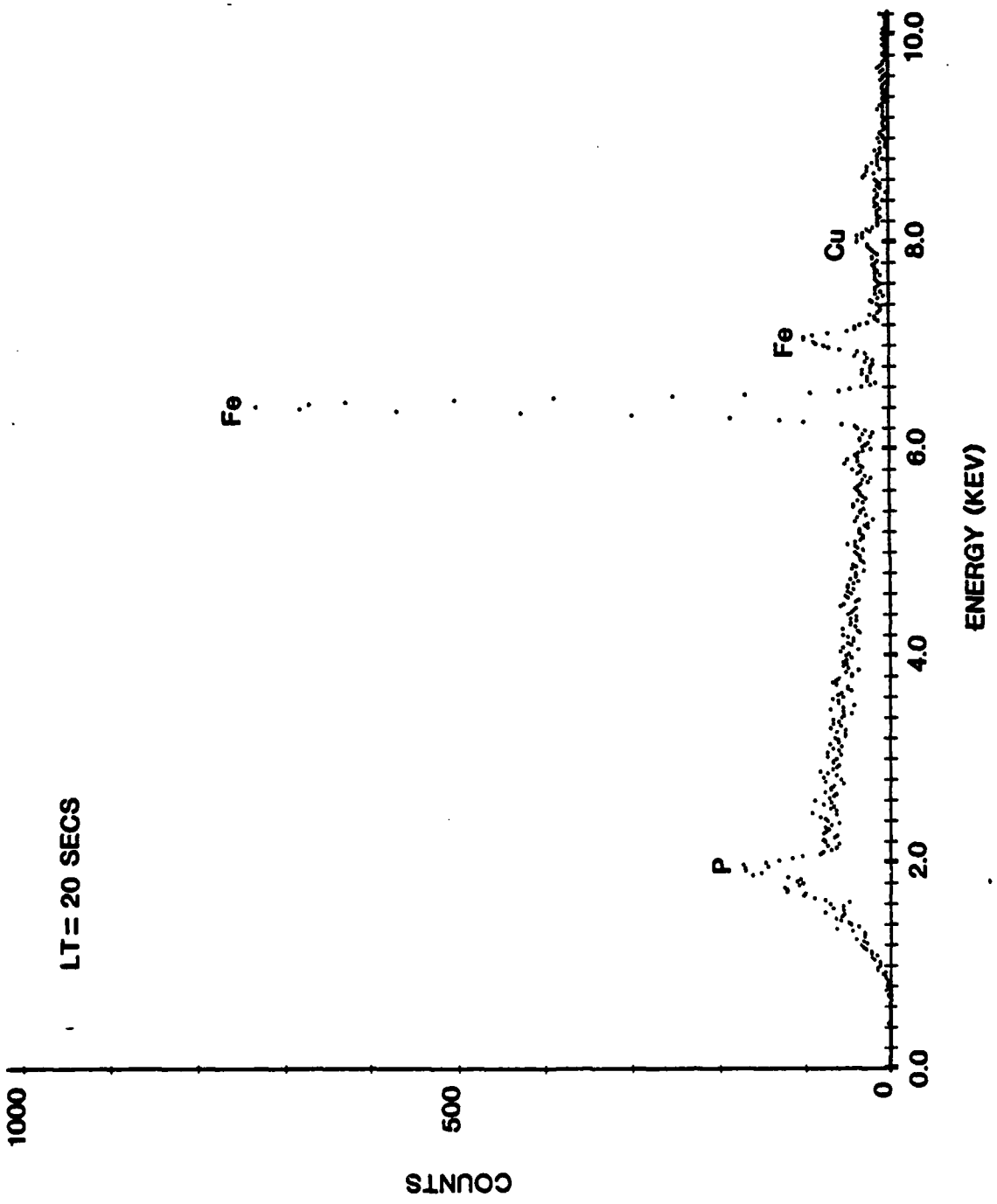


Figure 23 - Counts for the A-Region

Figure 24 - Counts for the Brass Region

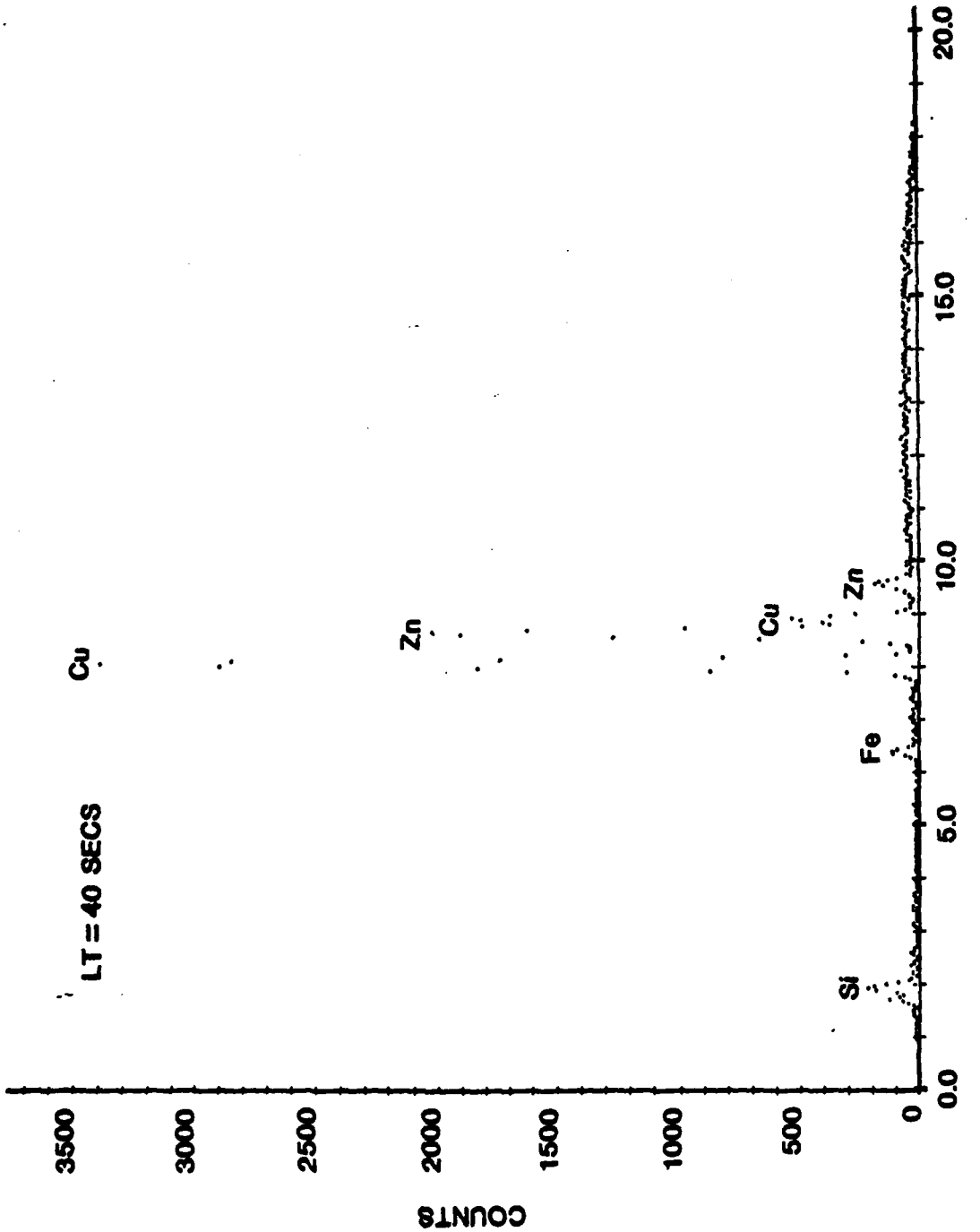


Figure 25 - Counts for the C-Region

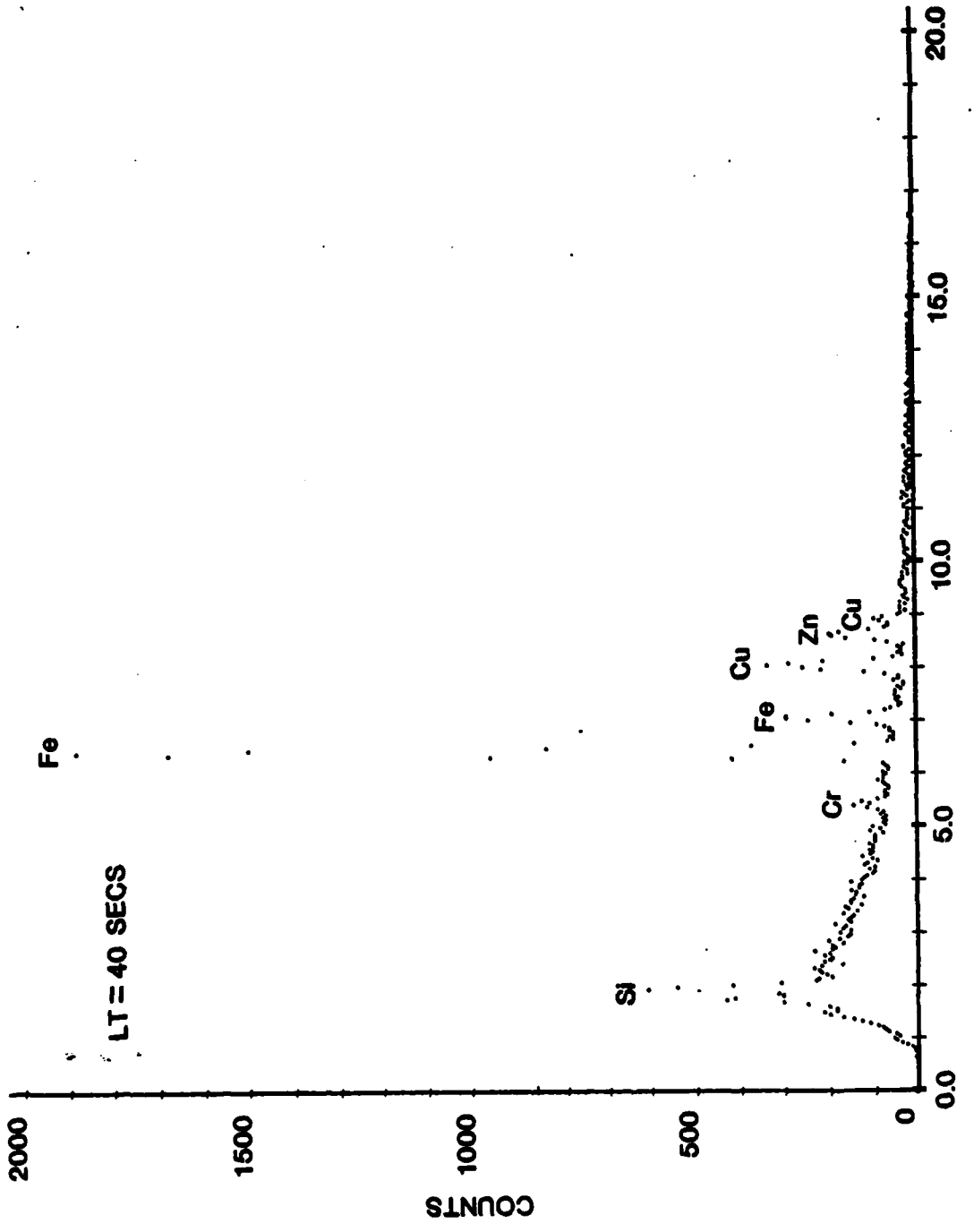


Figure 26 - Counts for Center of Entry Region

was continued for 40 seconds. The background X-rays of silicon have been greatly reduced. This permits the predominant element present in the debris to stand out.

3. NONMETALLIC DEBRIS

a. With the ability to now affect the capture of elastomer and other nonmetallic debris on a Ferrogram, the analysis of nonmentallic debris becomes possible. The visual analysis of such debris may become as important as the visual analysis of metallic debris. The X-ray analysis of elastomer wear debris has, however, not proved to be a very significant analysis. This is because most elastomers are compounded of elements having an atomic number less than 10. Thus, the X-ray analyzer cannot distinguish between elastomer types except for the trace quantities of cross-linking agents and other agents added to the elastomer to improve its formulation. Thus, sulfur, a common cross-linking agent, can be detected but carbon and hydrogen cannot.

b. Figure 27A shows the counts for the elastomer debris, which are shown at magnification of 5000 X in Figure 27B. The silicon background X-rays of the glass Ferrogram substrate dominate the counts; however, sulfur is also observed.

c. Figure 28A shows the counts for the elastomer debris, which are shown at a magnification of 6500X in Figure 28B. Sulfur is observed.

d. Figure 29A shows the counts for the fabric debris, which are shown at a magnification of 1100X in Figure 29B. No sulfur is observed.

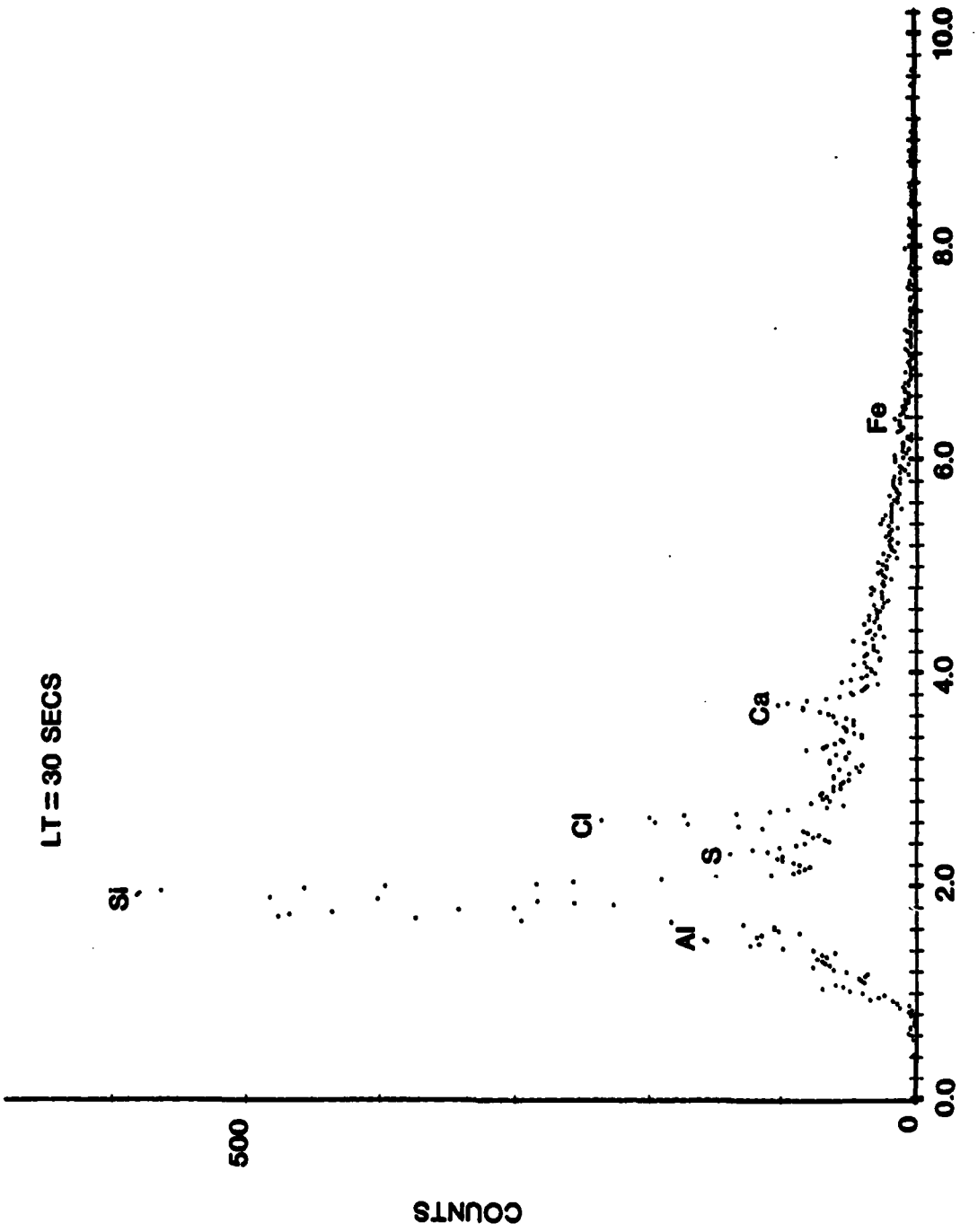


Figure 27A - Counts of Elastomer Debris

Figure 27B - Magnification of Elastomer Debris at 5000X

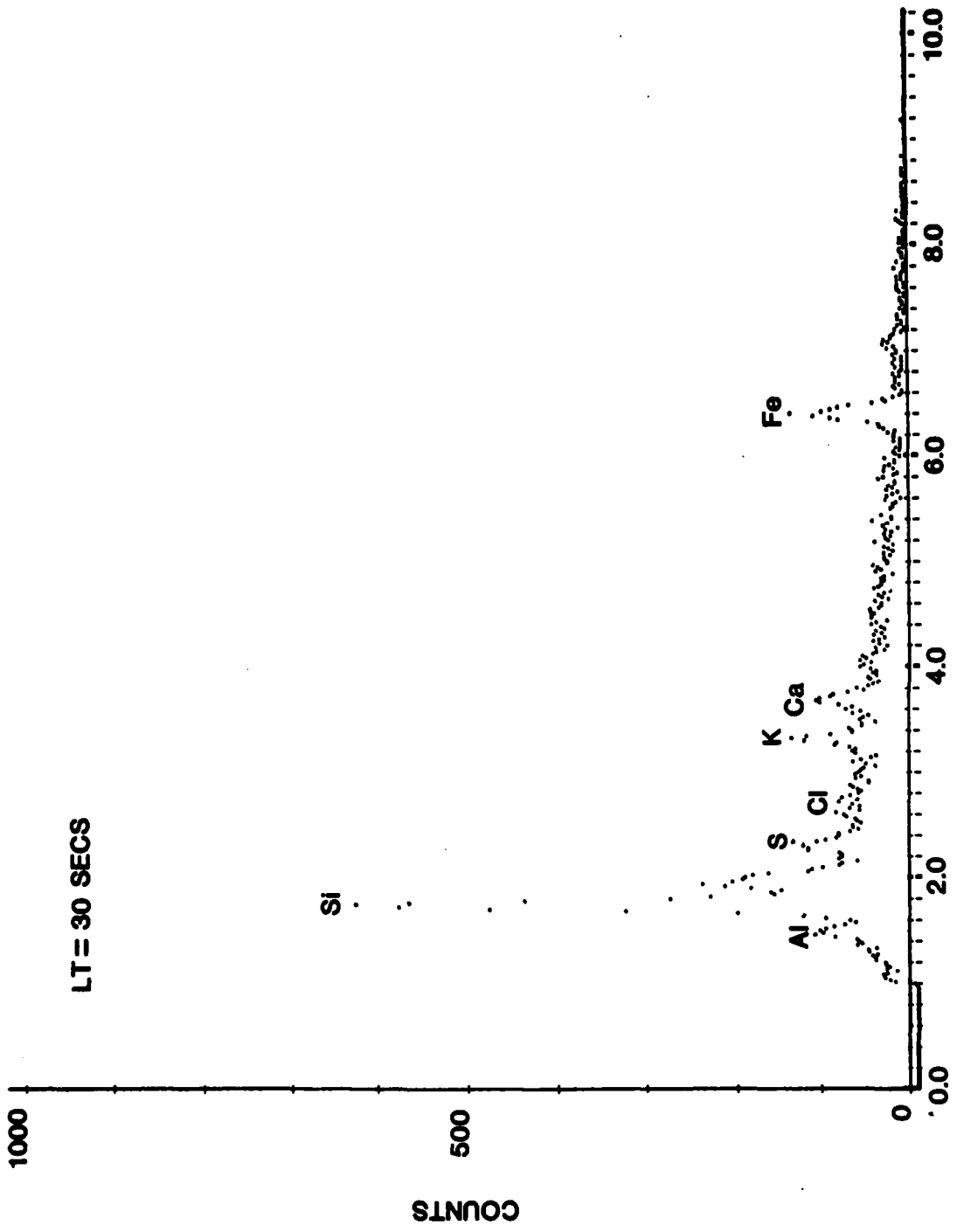


Figure 28A - Counts of Elastomer Debris

Figure 28B - Magnification of Elastomer Debris at 6500X

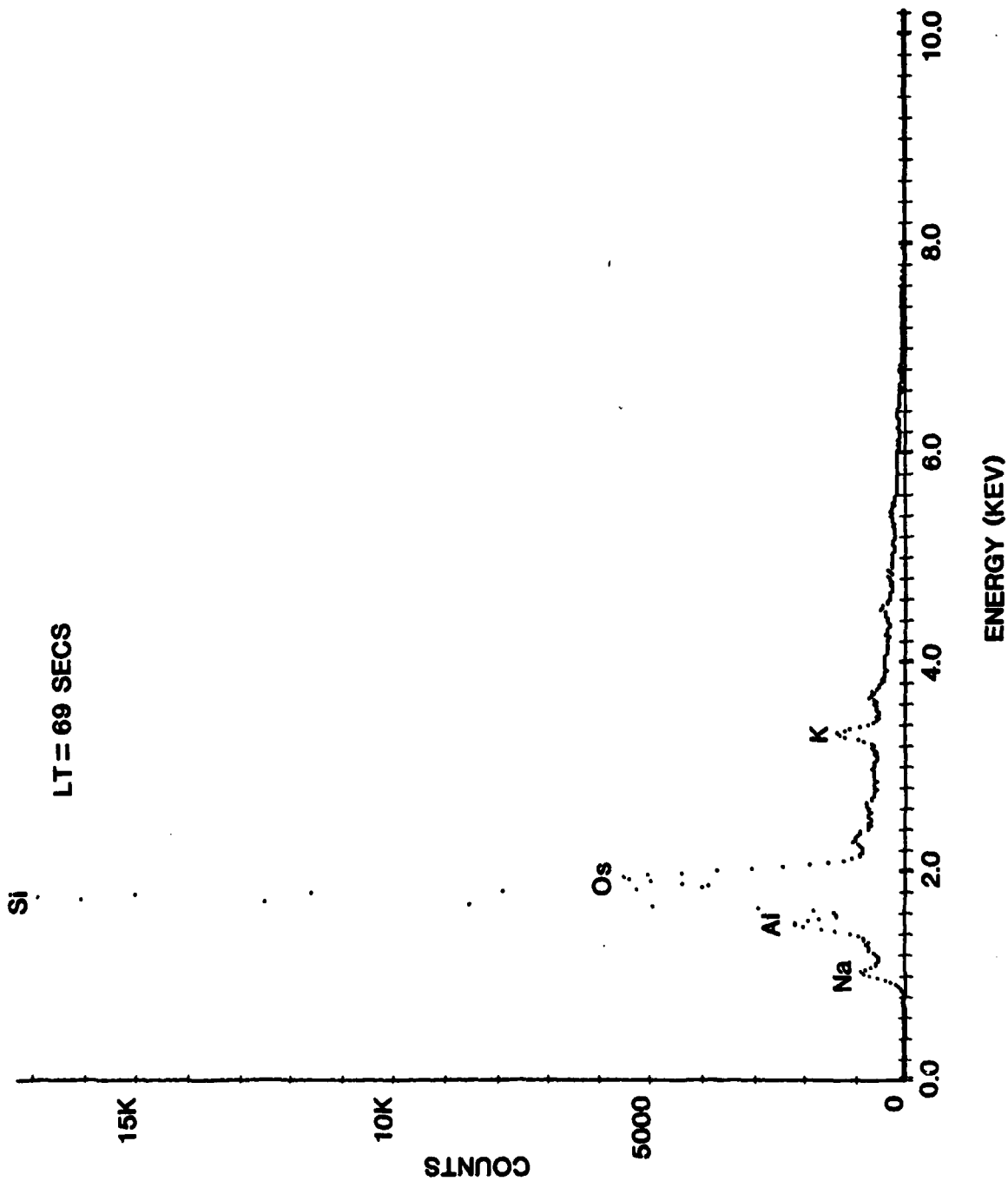


Figure 29A - Counts for Fabric Debris

Figure 29B - Magnification of Fabric Debris at 1100X

VI. RECOMMENDATIONS

A. It has not been demonstrated with this pioneering effort that a given Ferrographically deposited particle of elastomer wear debris may be classified as to wear mode. It has been shown that in only one instance, that of the linear motion seal wear mode, can one particular type of particle be definitely assigned a wear mode. It is recommended that an extension of this pioneering effort be undertaken in order to develop methods for determining the wear mode of a given particle.

B. Metallic debris, which was contained in the samples supplied by the Naval Air Engineering Center, appeared quite similar, regardless of sampling location. Further work in this area will be necessary before any definite conclusions may be reached concerning the feasibility of using Ferrography to detect wear from specific hydraulic components. It is recommended that a program of carefully contrived testing of individual components be undertaken to determine conclusively whether specific and distinguishable types of wear are generated by each component.

C. The use of a SEM, which was equipped with an X-ray analyzer, has demonstrated the ability to determine the predominant elements constituting the individual wear particles, which have been deposited on the Ferrograms. It is recommended that further work be carried out in this area to determine the feasibility of using X-ray analysis as a method of detecting wear from specific hydraulic components.

VII. REFERENCES

(a) Dobson, J. D., "The FPRC Recommended Ferrographic Procedure," The BFPR Journal, 1982, Vol. 15, No. 4, pp. 427-444.

(b) Fluid Power Research Center, "PRAM Ferrography Final Engineering Report," FPRC Report No. T51980, USAF Contract No. F34650-78-C-0351, 15 Apr 1980.

APPENDIX A - FERROGRAPHY REPORTS

A. This appendix contains the Ferrography reports for the samples sent to the FPRC by Naval Air Engineering Center. The Ferrography reports are grouped by sampling location as follows:

Each set of reports is arranged in order of increasing hours of operation.

B. The wear debris severity index is a number from 1 to 5 (1 is least severe, and 5 is most severe) and is the analyst's opinion of the severity of the wear debris viewed on the Ferrogram. The debris gravity index is a number from 1 to 3 and is the result of the analyst's visual judgment as to the amount of debris observed. A debris gravity index of 1 indicates that little debris of the indicated type was observed on the Ferrogram; a debris gravity index of 3 indicates very much debris was observed.

Ferrogram No. 3635	Sample No. A-1	Ferrogram No. 3639	Sample No. B-1
Sample Description Filter, Reservoir Return Line		Sample Description Filter, Reservoir Return Line	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL	Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours 25	Wear Debris Severity Index 5	Operating Hours 42	Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	110 micrometers	Fatigue Chunks.....	3	30 micrometers
Spheres.....	1	8-10 micrometers	Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	1	40 micrometers	Cutting Wear.....	0	
Corrosive Wear.....	3		Corrosive Wear.....	3	
Oxides (rust).....	2-3		Oxides (rust).....	3+	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	3+	
Nonferrous Metallic.	3+	200 micrometers bright white chunk/striations	Nonferrous Metallic.	2	190 micrometer bright white chunk
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	3	Orange, flat, square edges
Amorphous.....	3+		Amorphous.....	0	
Additional Comments: Moderate amount of elastomer debris. Transfer films and cylinders were observed. A few particles have been oxidized and appear black, blue, and bronze in color.			Additional Comments:		

Ferrogram No. 3642 Sample No. C-1	Ferrogram No. 3645 Sample No. D-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 61.5 Wear Debris Severity Index 4	Operating Hours 82 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3		Fatigue Chunks.....	3	90 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	1	
Cutting Wear.....	1		Cutting Wear.....	1	80 micrometers
Corrosive Wear.....	3		Corrosive Wear.....	0	
Oxides (rust).....	3		Oxides (rust).....	3	
Dark Metallo-Oxides.	3		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	2		Nonferrous Metallic.	1	90 micrometers bright white chunk
Nonmetallic:			Nonmetallic:		
Crystalline....	3		Crystalline....	2-3	Orange, flat, square edges
Amorphous.....	0+	Several	Amorphous.....	2	

Additional Comments: A few oxidized particles are present.	Additional Comments: A few particles have been oxidized, orange and black in color.

Ferrogram No. 3649	Sample No. E-1
Sample Description Filter, Reservoir Return Line	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours 102	Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3+	60 micrometers with striations
Spheres.....	0	
Severe Wear.....	3	
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	3	
Dark Metallo-Oxides.	3	
Nonferrous Metallic.	1	60 micrometers
Nonmetallic:		
Crystalline....	3	Orange, flat, square edges
Amorphous.....	3	

Additional Comments:
A few fibers are present.
Several elastomer cylinders are present.
A few severely oxidized particles were observed.

Ferrogram No. 3653	Sample No. F-1
Sample Description Filter, Reservoir Return Line	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours 122	Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	30 micrometers
Spheres.....	0	
Severe Wear.....	1	20 micrometers
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	3	
Nonferrous Metallic.	3	30 micrometers white to to bright white chunk
Nonmetallic:		
Crystalline....	2	Some orange, flat, square edges
Amorphous.....	3	

Additional Comments:
A moderate amount of elastomer cylinder and transfer films were observed. A few oxidized particles were observed.

Ferrogram No. 3657 Sample No. G-1	Ferrogram No. 3661 Sample No. H-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 132 Wear Debris Severity Index 5	Operating Hours 149 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	90 micrometers	Fatigue Chunks.....	3	40 micrometers
Spheres.....	1		Spheres.....	0	
Severe Wear.....	3	50 micrometers	Severe Wear.....	3	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	2		Oxides (rust).....	2	
Dark Metallo-Oxides.	3		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	3		Nonferrous Metallic.	2	
Nonmetallic:			Nonmetallic:		
Crystalline....	1	Orange, flat, square edges	Crystalline....	1	Orange, flat, square edges
Amorphous.....	3		Amorphous.....	3	

Additional Comments: Several elastomer spheres and some cylinders and chunks were observed. A few particles tempered blue and dark bronze were observed.	Additional Comments: Many small elastomer wear particles were observed. A few oxidized particles were observed.

Ferrogram No. 3681 Sample No. J-1	Ferrogram No. 3648 Sample No. K-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 187.5 Wear Debris Severity Index 3	Operating Hours 205 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	15 micrometers	Fatigue Chunks.....	3	80 micrometers, oxidized orange and black
Spheres.....	0		Spheres.....	1	Not polished, oxidized, ferrous & nonferrous
Severe Wear.....	0		Severe Wear.....	2	18-20 micrometers
Cutting Wear.....	?		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	3	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	1	Bright white	Nonferrous Metallic.	2	40 micrometers, bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	2-3	Orange, flat, square edges	Crystalline....	3	Orange, flat, square edges
Amorphous.....	0		Amorphous.....	3	
Additional Comments:			Additional Comments: Many elastomer particles were observed. One metallic rod, which was nonferrous and 270 micrometers long, was observed.		

Ferrogram No. 3688 Sample No. L-1	Ferrogram No. 3692 Sample No. M-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 223.5 Wear Debris Severity Index 2	Operating Hours 241 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	1	20 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1-2	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	3	Flakes and chunks, bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	1	Orange, flat, square edges	Crystalline....	1	Orange, flat, square edges
Amorphous.....	3		Amorphous.....	3	

Additional Comments:	Additional Comments:
Several elastomer particles were observed.	A few elastomer particles were observed.

Ferrogram No. 3696	Sample No. N-[illegible]	Ferrogram No. 3700	Sample No. 0-1
Sample Description Filter, Reservoir Return Line		Sample Description Filter, Reservoir Return Line	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL	Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours 258.5	Wear Debris Severity Index 3	Operating Hours 285.5	Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	25 micrometers, torn with striations	Fatigue Chunks.....	1	20 micrometers
Spheres.....	0		Spheres.....	1	
Severe Wear.....	1	20 micrometers	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	2	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	0		Nonferrous Metallic.	2-3	
Nonmetallic:			Nonmetallic:		
Crystalline....	1	Orange, flat, square edges	Crystalline....	1	Orange, flat, square edges
Amorphous.....	1		Amorphous.....	1	
Additional Comments:			Additional Comments: The particles were observed to be highly tempered because of extreme heat.		

Ferrogram No. 3774	Sample No. P-1	Ferrogram No. 3778	Sample No. Q-1
Sample Description Filter, Reservoir Return Line		Sample Description Filter, Reservoir Return Line	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL	Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours -	Wear Debris Severity Index 4	Operating Hours -	Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	18-20 micrometers	Fatigue Chunks.....	2-3	
Spheres.....	1	3-8 micrometers, nonferrous and ferrous	Spheres.....	0	
Severe Wear.....	2	20-25 micrometers	Severe Wear.....	1	
Cutting Wear.....	1-2		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	2-3	Bright white chunks	Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	0		Crystalline....	1	
Amorphous.....	3		Amorphous.....	2	

Additional Comments:	Additional Comments:
A few elastomer particles were observed. The metallic particles were observed to be tempered to a dark bronze color.	The particles were observed to have been tempered and the ferrous particles appeared to have been pitted.

Ferrogram No. 3782 Sample No. R-1	Ferrogram No. 3786 Sample No. S-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours - Wear Debris Severity Index 3	Operating Hours - Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0	
Spheres.....	1	One sphere was observed
Severe Wear.....	0	
Cutting Wear.....	0	
Corrosive Wear.....	0	
Oxides (rust).....	3	
Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1	30 micrometers white chunk
Nonmetallic:		
Crystalline....	3	Orange, flat, square edges
Amorphous.....	3	

Additional Comments:

A few elastomer particles were observed.

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	30 micrometers
Spheres.....	1	5-8 micrometers
Severe Wear.....	1	
Cutting Wear.....	0	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1	
Nonmetallic:		
Crystalline....	2	
Amorphous.....	0	

Additional Comments:

A few elastomer particles were observed.
The metallic particles have been oxidized.

Ferrogram No. 3819 Sample No. T-1	Ferrogram No. 3823 Sample No. U-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 364 Wear Debris Severity Index 4	Operating Hours 386 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	20 micrometers	Fatigue Chunks.....	3	30 micrometers
Spheres.....	0		Spheres.....	1	
Severe Wear.....	3	20 micrometers	Severe Wear.....	2	20 micrometers
Cutting Wear.....	0		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	3		Oxides (rust).....	3+	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	0		Nonferrous Metallic.	1	2 were observed
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	3	Fibers were present
Amorphous.....	3		Amorphous.....	3	

Additional Comments:	Additional Comments:
Many elastomer particles were observed. The metallic particles have been tempered.	Many elastomer particles were observed. The ferrous particles have been tempered.

Ferrogram No. 3827 Sample No. V-1	Ferrogram No. 3831 Sample No. W-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 402.5 Wear Debris Severity Index 3	Operating Hours 420 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	30 micrometers	Fatigue Chunks.....	1	
Spheres.....	0		Spheres.....	1	
Severe Wear.....	2	20 micrometers	Severe Wear.....	1	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	2		Oxides (rust).....	0	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	2	50 micrometers, bright white chunk
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	1	
Amorphous.....	3		Amorphous.....	3	

Additional Comments: A few elastomer particles were observed. The metallic particles have been tempered.	Additional Comments: A few elastomer particles were observed.

Ferrogram No. 3835	Sample No. X-1
Sample Description Filter, Reservoir Return Line	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours 431.5	Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	2 chunks were observed
Spheres.....	0	
Severe Wear.....	1	1 particle observed
Cutting Wear.....	1	Large
Corrosive Wear.....	0	
Oxides (rust).....	3	
Dark Metallo-Oxides.	3	
Nonferrous Metallic.	0	
Nonmetallic:		
Crystalline....	3	
Amorphous.....	3	

Additional Comments:

Several elastomer particles were observed.
The ferrous particles have been highly tempered.

Ferrogram No. 3839	Sample No. Y-1
Sample Description Filter, Reservoir Return Line	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours 445.5	Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2-3	20 micrometers
Spheres.....	1	
Severe Wear.....	0	
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	2	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	2-3	25 micrometers, bright white
Nonmetallic:		
Crystalline....	3	Fibers were observed
Amorphous.....	3	

Additional Comments:

Many elastomer particles were observed.

Ferrogram No. 3843 Sample No. Z-1	Ferrogram No. 3847 Sample No. AA-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 459.5 Wear Debris Severity Index 4	Operating Hours 476.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	20 micrometers	Fatigue Chunks.....	3	40 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	2	20 micrometers	Severe Wear.....	3	18 micrometers
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	2	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	2	90 micrometers	Nonferrous Metallic.	3	30 micrometers
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	1	
Amorphous.....	3		Amorphous.....	3	
Additional Comments:			Additional Comments: Several elastomer particles were observed. The metallic particles have been tempered to dark gold or orange in color.		

Ferrogram No. 3851 Sample No. BB-1	Ferrogram No. 3855 Sample No. CC-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 497.5 Wear Debris Severity Index 2	Operating Hours 515.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	0	
Spheres.....	1		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	1	1 long (90 micrometers) and slender particle
Cutting Wear.....	0		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	2		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	1	1 particle	Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	3		Crystalline....	1	
Amorphous.....	3		Amorphous.....	2	
Additional Comments:			Additional Comments:		

Ferrogram No. 3859 Sample No. DD-1	Ferrogram No. 3863 Sample No. EE-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 533.5 Wear Debris Severity Index 2	Operating Hours 551.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	1 particle	Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	0	
Severe Wear.....	1	1 particle	Severe Wear.....	1	one 20 micrometer particle
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	2		Oxides (rust).....	2	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	1		Nonferrous Metallic.	1	35 micrometers
Nonmetallic:			Nonmetallic:		
Crystalline....	3		Crystalline....	3	
Amorphous.....	3		Amorphous.....	0	
Additional Comments:			Additional Comments:		

Ferrogram No. 3867 Sample No. FF-1	Ferrogram No. 3871 Sample No. GG-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 567.5 Wear Debris Severity Index 2	Operating Hours 584.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	1	20 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	1	one 20 micrometer particle	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	0		Nonferrous Metallic.	1	One cutting wear 190 micrometers
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	2	
Amorphous.....	0		Amorphous.....	0	
Additional Comments:			Additional Comments:		

Ferrogram No. 3875 Sample No. HH-1	Ferrogram No. 3879 Sample No. II-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 601.5 Wear Debris Severity Index 2	Operating Hours 618.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	One 20 micrometer particle	Fatigue Chunks.....	1	One 19 micrometer particle
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	2		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	0	
Nonmetallic: Crystalline....	2		Nonmetallic: Crystalline....	1	
Amorphous.....	0		Amorphous.....	0	
Additional Comments:			Additional Comments:		

Ferrogram No. 3883 Sample No. JJ-17 Sample Description Filter, Reservoir Return Line Sample Fluid: Description MIL-H-83282A Volume 3 mL	Ferrogram No. 3887 Sample No. KK-1 Sample Description Filter, Reservoir Return Line Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 637.5 Wear Debris Severity Index 3	Operating Hours 649.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	20 micrometers	Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	1	
Severe Wear.....	2	20 micrometers	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	2		Oxides (rust).....	3	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	1	20 micrometers	Nonferrous Metallic.	1	One 100 micrometer chunk
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	3	Some fibers
Amorphous.....	0		Amorphous.....	0	
Additional Comments:			Additional Comments:		

Ferrogram No. 3891 Sample No. LL-1	Ferrogram No. 3895 Sample No. MM-1
Sample Description Filter, Reservoir Return Line	Sample Description Filter, Reservoir Return Line
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 667.5 Wear Debris Severity Index 2	Operating Hours 681.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	1	20 micrometers
Spheres.....	1		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	1-2	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	0		Nonferrous Metallic.	1	One 80 micrometer chunk
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	2	
Amorphous.....	0		Amorphous.....	0	
Additional Comments:			Additional Comments:		

Ferrogram No. 3636 Sample No. A-2	Ferrogram No. 3646 Sample No. D-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 1.5 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 25 Wear Debris Severity Index 4	Operating Hours 82 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	25 micrometers	Fatigue Chunks.....	3	40 micrometers
Spheres.....	0		Spheres.....	1.5	3 - 8 micrometers
Severe Wear.....	0		Severe Wear.....	3	25 micrometers
Cutting Wear.....	1		Cutting Wear.....	0	
Corrosive Wear.....	2		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	1	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	3	90 micrometer, bright white chunks.	Nonferrous Metallic.	0	
Nonmetallic: Crystalline....	1		Nonmetallic: Crystalline....	2	
Amorphous.....	2		Amorphous.....	3	
Additional Comments: A moderate amount of elastomer debris was observed. The ferrous particles had been oxidized.			Additional Comments: Not much elastomer debris was observed.		

Ferrogram No. 3654 Sample No. F-2	Ferrogram No. 3650 Sample No. E-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 122 Wear Debris Severity Index 5	Operating Hours 102 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	100 micrometers	Fatigue Chunks.....	3	30 micrometers
Spheres.....	1		Spheres.....	0	
Severe Wear.....	3	25 micrometers	Severe Wear.....	3	20 micrometers
Cutting Wear.....	0		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	3		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	30 micrometers, bright white	Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	0		Crystalline....	2	
Amorphous.....	3		Amorphous.....	3	

Additional Comments: A moderate amount of elastomer debris was observed.	Additional Comments: The elastomer debris appeared as cylinders and chunks. Some ferrous particles had been oxidized.

Ferrogram No. 3658 Sample No. G-2	Ferrogram No. 3678 Sample No. I-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 132 Wear Debris Severity Index 5	Operating Hours 167.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	60 micrometers	Fatigue Chunks.....	0	
Spheres.....	1		Spheres.....	0	
Severe Wear.....	3	20 micrometers	Severe Wear.....	0	
Cutting Wear.....	1.5		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	one laminar observed, bright white	Nonferrous Metallic.	3	80 micrometers, bright white, chunks & flakes
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	0	
Amorphous.....	3		Amorphous.....	3	
Additional Comments: A moderate amount of elastomer debris were observed. The ferrous particles had been oxidized. Several glass-like fibers were observed.			Additional Comments: Much elastomer debris was observed.		

Ferrogram No. 3662 Sample No. H-2 Sample Description Filter, Dual Yaw Control Sample Fluid: Description MIL-H-83282A Volume 1.5 mL	Ferrogram No. 3682 Sample No. J-2 Sample Description Filter, Dual Yaw Control Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 149 Wear Debris Severity Index 5	Operating Hours 187.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	30 micrometers
Spheres.....	0	
Severe Wear.....	2	20 micrometers
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	one laminar 180 micrometers, bright white was observed
Nonmetallic:		
Crystalline....	3	gray chunks
Amorphous.....	2	

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	30 micrometers
Spheres.....	1	
Severe Wear.....	2	20 micrometers
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	2.5	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	1	85 micrometers, bright white
Nonmetallic:		
Crystalline....	2	
Amorphous.....	0	

Additional Comments: Many small particles of elastomer debris were observed. The ferrous particles had been tempered to a lightly bronze color.	Additional Comments:

Ferrogram No. 3685 Sample No. K-2	Ferrogram No. 3689 Sample No. L-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 205 Wear Debris Severity Index 5	Operating Hours 223.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	90 micrometers	Fatigue Chunks.....	1	120 micrometer chunk
Spheres.....	1		Spheres.....	0	
Severe Wear.....	3	30 micrometers	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	Bright white and lightly straw colored	Nonferrous Metallic.	2	one 30 micrometer laminar
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	2	
Amorphous.....	3		Amorphous.....	2	
Additional Comments: Much elastomer debris was observed. Ferrous chunks appeared rough and irregular in shape. The ferrous particles had been tempered and were somewhat pitted.			Additional Comments: Not much elastomer debris was present.		

Ferrogram No. 3693 Sample No. M-2	Ferrogram No. 3697 Sample No. N-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 241 Wear Debris Severity Index 4	Operating Hours 258.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	30 micrometers	Fatigue Chunks.....	3	50 micrometers, torn
Spheres.....	0		Spheres.....	0	
Severe Wear.....	2	18-20 micrometers	Severe Wear.....	1	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	2.5	one 25 micrometers, most 18 micrometers	Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	1	fibers were present	Crystalline....	2	Fibers were present
Amorphous.....	2		Amorphous.....	2	

Additional Comments: Not much elastomer debris was observed. One 30 micrometer laminar ferrous particle was observed.	Additional Comments: The ferrous particles had been tempered and oxidized.

Ferrogram No. 3791 Sample No. O-2	Ferrogram No. 3775 Sample No. P-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 285.5 Wear Debris Severity Index 4	Operating Hours ? Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1		Fatigue Chunks.....	3	40 micrometers
Spheres.....	0		Spheres.....	1	3-10 micrometers
Severe Wear.....	2	20 micrometers	Severe Wear.....	1	20 micrometers, some pitting
Cutting Wear.....	1	one was darkly colored	Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	1	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	3	20 micrometer laminars, 50 micrometer chunks and flakes	Nonferrous Metallic.	2	20 micrometers, bright white chunks
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	some fibers
Amorphous.....	1		Amorphous.....	3	
Additional Comments: Not much elastomer debris was observed. The ferrous particles had been somewhat tempered.			Additional Comments: Not much elastomer debris was observed.		

Ferrogram No. 3779 Sample No. Q-2	Ferrogram No. 3783 Sample No. R-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours ? Wear Debris Severity Index 4	Operating Hours ? Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	20 micrometers	Fatigue Chunks.....	3	30 micrometers
Spheres.....	0		Spheres.....	1	2-5 micrometers
Severe Wear.....	1	20 micrometers	Severe Wear.....	3	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	180 micrometers, silver, torn	Nonferrous Metallic.	3	bronze, blue and bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	1	three carbon chunks were observed	Crystalline....	0	
Amorphous.....	2		Amorphous.....	3	
Additional Comments: Not much elastomer debris was observed. The ferrous particles had been tempered by extreme heat.			Additional Comments:		

Ferrogram No. 3787 Sample No. S-2	Ferrogram No. 3820 Sample No. T-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours ? Wear Debris Severity Index 4	Operating Hours 364 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	30 micrometers, bright white	Fatigue Chunks.....	2.5	20 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	2	20 micrometers	Severe Wear.....	1	18 micrometers
Cutting Wear.....	0		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	2	30 micrometers, bright silver	Nonferrous Metallic.	2	75 micrometer, silver flakes
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	0	
Amorphous.....	3		Amorphous.....	3	

Additional Comments: Much elastomer debris was observed. One brass colored chunk was observed.	Additional Comments: Not much elastomer debris was observed. The particles had been highly tempered.

Ferrogram No. 3824 Sample No. U-2	Ferrogram No. 3828 Sample No. V-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 386 Wear Debris Severity Index 4	Operating Hours 402.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	50 micrometers	Fatigue Chunks.....	1	
Spheres.....	1	8-15 micrometers	Spheres.....	0	
Severe Wear.....	2	20 micrometers	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	30 micrometers, bright white	Nonferrous Metallic.	1	40 micrometers, bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	3	fibers were observed	Crystalline....	2	
Amorphous.....	3		Amorphous.....	3	
Additional Comments: A moderate amount of elastomer debris was observed.			Additional Comments: A moderate amount of elastomer debris was observed. The particles had been tempered.		

Ferrogram No. 3832 Sample No. W-2	Ferrogram No. 3836 Sample No. X-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 420 Wear Debris Severity Index 4	Operating Hours 431.5 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	40 micrometers	Fatigue Chunks.....	3	120 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	3	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	1.5	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1	140 micrometers, bright white	Nonferrous Metallic.	3	60 micrometers, bright white, chunks, and cutting wear
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	0	
Amorphous.....	3		Amorphous.....	3	fibrous
Additional Comments: The particles had been tempered.			Additional Comments: Much elastomer debris was observed. The ferrous particles had been tempered.		

Ferrogram No. 3840 Sample No. Y-2	Ferrogram No. 3844 Sample No. Z-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 445.5 Wear Debris Severity Index 4	Operating Hours 459.5 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	35 micrometers, rough	Fatigue Chunks.....	3	30 micrometers, with striation
Spheres.....	0		Spheres.....	0	
Severe Wear.....	3	20 micrometers	Severe Wear.....	3	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	60 micrometers, bright white and tempered	Nonferrous Metallic.	3	80 micrometers, bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	0	
Amorphous.....	3		Amorphous.....	3	

Additional Comments: The ferrous and non-ferrous particles had been highly tempered to blue and orange colors.	Additional Comments: Not much elastomer debris was observed. The particles had been oxidized and tempered.

Ferrogram No. 3848 Sample No. AA-2

Sample Description Filter, Dual Yaw Control

Sample Fluid:
Description MIL-H-83282A Volume 3 mL

Operating Hours 476.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	40 micrometers
Spheres.....	0	
Severe Wear.....	2	18 micrometers
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	bright white
Nonmetallic:		
Crystalline....	2	
Amorphous.....	3	

Additional Comments: Not much elastomer debris was observed. The particles had been highly tempered and oxidized.

Ferrogram No. 3852 Sample No. BB-2

Sample Description Filter, Dual Yaw Control

Sample Fluid:
Description MIL-H-83282A Volume 3 mL

Operating Hours 497.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0	
Spheres.....	3	numerous "chains"
Severe Wear.....	0	
Cutting Wear.....	0	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1	one 200 micrometer, bright white, with striations
Nonmetallic:		
Crystalline....	1	
Amorphous.....	0	

Additional Comments: The spheres may have been the result of welding debris.

Ferrogram No. 3856 Sample No. CC-2

Sample Description Filter, Dual Yaw Control

Sample Fluid:
Description MIL-H-83282A Volume 3 mL

Operating Hours 515.5 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	35 micrometers
Spheres.....	1	
Severe Wear.....	3	20 micrometers
Cutting Wear.....	1.5	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	bright white chunks
Nonmetallic: Crystalline....	1	
Amorphous.....	3	some fibrous debris

Additional Comments: Much elastomer debris was observed. The particles had been tempered.

Ferrogram No. 3860 Sample No. DD-2

Sample Description Filter, Dual Yaw Control

Sample Fluid:
Description MIL-H-83282A Volume 3 mL

Operating Hours 533.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	50 micrometers
Spheres.....	1	
Severe Wear.....	0	
Cutting Wear.....	0	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	80 micrometers, bright white
Nonmetallic: Crystalline....	3	
Amorphous.....	0	

Additional Comments: The particles had been tempered and oxidized.

Ferrogram No. 3864 Sample No. EE-2	Ferrogram No. 3868 Sample No. FF-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 551.5 Wear Debris Severity Index 3	Operating Hours 567.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	two 60 micrometers	Fatigue Chunks.....	2	40 micrometers, torn
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	0		Nonferrous Metallic.	2	50 micrometers, bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	0	
Amorphous.....	0		Amorphous.....	3	some fibrous debris
Additional Comments:			Additional Comments: One non-ferrous chunk indicated that surface adhesion had taken place.		

Ferrogram No. 3872 Sample No. GG-2	Ferrogram No. 3876 Sample No. HH-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 584.5 Wear Debris Severity Index 2	Operating Hours 601.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	0	
Severe Wear.....	1	20 micrometers	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	1	one 30 micrometer chunk	Nonferrous Metallic.	1	50 micrometers, white chunks
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	2	
Amorphous.....	2	Fibrous	Amorphous.....	0	

Additional Comments:	Additional Comments:

Ferrogram No. 3880 Sample No. II-2	Ferrogram No. 3884 Sample No. JJ-2
Sample Description Filter, Dual Yaw Control	Sample Description Filter, Dual Yaw Control
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 618.5 Wear Debris Severity Index 2	Operating Hours 637.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	one 20 micrometer chunk	Fatigue Chunks.....	3	30 micrometers
Spheres.....	1	one sphere	Spheres.....	1	
Severe Wear.....	1		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1	20 micrometer chunks	Nonferrous Metallic.	1	70 micrometer chunks
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	0		Amorphous.....	1	
Additional Comments:			Additional Comments: The particles had been tempered orange and blue.		

Ferrogram No. 3888 Sample No. KK-2

Sample Description Filter, Dual Yaw Control

Sample Fluid:
Description MIL-H-83282A Volume 3 mL

Operating Hours 649.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	20 micrometers
Spheres.....	0	
Severe Wear.....	0	
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	1	
Nonferrous Metallic.	2	one 40 micrometer brass colored chunk, white chunks
Nonmetallic:		
Crystalline....	1	
Amorphous.....	2	fibrous

Additional Comments:

Ferrogram No. 3892 Sample No. LL-2

Sample Description Filter, Dual Yaw Control

Sample Fluid:
Description MIL-H-83282A Volume 3 mL

Operating Hours 667.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	45 micrometers
Spheres.....	0	
Severe Wear.....	1	
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	1	
Nonferrous Metallic.	1	30 micrometers, bright white
Nonmetallic:		
Crystalline....	0	
Amorphous.....	1	fibrous

Additional Comments: The particles had been tempered bronze and blue.

Ferrogram No. 3896 Sample No. MM-2	Ferrogram No. _____ Sample No. _____
Sample Description Filter, Dual Yaw Control	Sample Description _____
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 681.5 Wear Debris Severity Index 4	Operating Hours _____ Wear Debris Severity Index _____

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	35 micrometers	Fatigue Chunks.....		
Spheres.....	0		Spheres.....		
Severe Wear.....	1		Severe Wear.....		
Cutting Wear.....	1		Cutting Wear.....		
Corrosive Wear.....	0		Corrosive Wear.....		
Oxides (rust).....	0		Oxides (rust).....		
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.		
Nonferrous Metallic.	3	145 micrometers, bright white	Nonferrous Metallic.		
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....		
Amorphous.....	3	fibrous	Amorphous.....		

Additional Comments: A moderate amount of elastomer debris was observed.	Additional Comments:

Ferrogram No. 3637 Sample No. A-3	Ferrogram No. 3640 Sample No. B-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 1.5 mL	Sample Fluid: Description MIL-H-83282A Volume 1.5 mL
Operating Hours 25 Wear Debris Severity Index 4	Operating Hours 42 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	25 micrometers	Fatigue Chunks.....	2	30 micrometers
Spheres.....	1		Spheres.....	1	8-10 micrometers
Severe Wear.....	1		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	0	
Corrosive Wear.....	3		Corrosive Wear.....	3	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	3	50 micrometers, white	Nonferrous Metallic.	3	60 micrometer white chunk
Nonmetallic:			Nonmetallic:		
Crystalline....	2	fibers present	Crystalline....	2	
Amorphous.....	1		Amorphous.....	0	

Additional Comments: Several particles of elastomer debris were present. The ferrous particles had been oxidized to a blue and bronze color.	Additional Comments: A moderate amount of elastomer debris was observed. The ferrous particles had been oxidized.

Ferrogram No. 3643 Sample No. C-3	Ferrogram No. 3647 Sample No. D-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 61.5 Wear Debris Severity Index 4	Operating Hours 82 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	75 micrometers	Fatigue Chunks.....	3	30 micrometers
Spheres.....	0		Spheres.....	1	
Severe Wear.....	1	25 micrometers	Severe Wear.....	1	20 micrometers
Cutting Wear.....	0		Cutting Wear.....	1.5	
Corrosive Wear.....	3		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	2.5	
Nonferrous Metallic.	3	100 micrometers, bright white	Nonferrous Metallic.	3	145 micrometers, bright white chunk
Nonmetallic:			Nonmetallic:		
Crystalline....	0		Crystalline....	2	
Amorphous.....	1		Amorphous.....	2	

Additional Comments: A few particles had been oxidized and appeared to be pitted.	Additional Comments: A few elastomer particles were present. A few particles had been 'somewhat' oxidized.

Ferrogram No. 3651 Sample No. E-3	Ferrogram No. 3655 Sample No. F-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 102 Wear Debris Severity Index 4	Operating Hours 122 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	20 micrometers
Spheres.....	1	
Severe Wear.....	3	20 micrometers
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	130 micrometer white chunk
Nonmetallic: Crystalline....	2	
Amorphous.....	3	

Additional Comments: Several elastomer debris parti- the ferrous particles had been

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	50 micrometers
Spheres.....	0	
Severe Wear.....	3	15-20 micrometers
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	0	Bright white and white
Nonmetallic: Crystalline....	2	
Amorphous.....	3	

Additional Comments: A moderate amount of elastomer chunks and rolls were observed. The ferrous particles had been severely tempered to a blue or dark bronze color.

AD-A119 364 OKLAHOMA STATE UNIV STILLWATER FLUID POWER RESEARCH --ETC F/6 11/10
HYDRAULIC SYSTEM WEAR DEBRIS ANALYSIS.(U)
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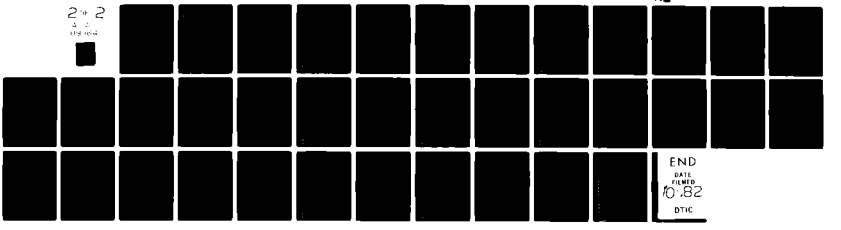

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Ferrogram No. 3659 Sample No. G-3	Ferrogram No. 3663 Sample No. H-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 1.5 mL
Operating Hours 132 Wear Debris Severity Index 4	Operating Hours 149 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	Type	Debris Gravity Index	Comments
Fatigue Chunks.....	?	Too many fibers at entry	Fatigue Chunks.....	3	30 micrometers
Spheres.....	1		Spheres.....	1	
Severe Wear.....	0		Severe Wear.....	3	
Cutting Wear.....	1		Cutting Wear.....	1.5	with striations
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	3		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	75 micrometers, bright white and off-white	Nonferrous Metallic.	3	bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	0	
Amorphous.....	3	very fibrous	Amorphous.....	3	
Additional Comments: The non-ferrous particles, which were off-white, were pitted.			Additional Comments: Very many elastomer particles were present. The ferrous particles had been severely oxidized.		

Ferrogram No. 3679 Sample No. I-3	Ferrogram No. 3686 Sample No. K-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 1.5 mL
Operating Hours 167.5 Wear Debris Severity Index 5	Operating Hours 205 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	20 micrometers	Fatigue Chunks.....	3	50 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	0		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	3		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	3	190 micrometers, bright white, some had striations	Nonferrous Metallic.	3	90 micrometers, bright white chunks
Nonmetallic:			Nonmetallic:		
Crystalline....	3		Crystalline....	0	
Amorphous.....	3		Amorphous.....	3	fibrous

Additional Comments: Numerous particles of elastomer debris were present. The ferrous particles had been tempered blue and gold.	Additional Comments: Numerous elastomer particles were present. The ferrous particles had been oxidized.

Ferrogram No. 3690 Sample No. L-3	Ferrogram No. 3694 Sample No. M-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 223.5 Wear Debris Severity Index 5	Operating Hours 241 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	30 micrometers	Fatigue Chunks.....	3	80 micrometers
Spheres.....	0		Spheres.....	1	
Severe Wear.....	3		Severe Wear.....	3	
Cutting Wear.....	1		Cutting Wear.....	1.5	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	3		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	3	50 micrometers, bright white and off-white	Nonferrous Metallic.	3	80 micrometers, (1) laminar, (2) bronze color
Nonmetallic:			Nonmetallic:		
Crystalline....	0		Crystalline....	2	
Amorphous.....	3		Amorphous.....	3	
Additional Comments: Numerous elastomer particles were observed. The ferrous particles had been tempered.			Additional Comments: Numerous elastomer particles were present. Some of the ferrous particles had been tempered. Many of the chunks were rectangular in shape, had flat surfaces, and had square edges.		

Ferrogram No. 3698 Sample No. N-3	Ferrogram No. 3702 Sample No. 0-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 1.5 mL	Sample Fluid: Description MIL-H-83282A Volume 1.5 mL
Operating Hours 258.5 Wear Debris Severity Index 5	Operating Hours 285.5 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	40 micrometers, with striations	Fatigue Chunks.....	3	20 micrometers
Spheres.....	1		Spheres.....	0	
Severe Wear.....	3	20 micrometers	Severe Wear.....	3	20 micrometers
Cutting Wear.....	1.5		Cutting Wear.....	1.5	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	3		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	3	some galled, bright white chunks	Nonferrous Metallic.	3	bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	3	fibers were present	Amorphous.....	2	

Additional Comments: Several elastomer particles were present. The ferrous particles had been tempered to a gold and blue color.	Additional Comments: Many elastomer particles were observed. Many fibers were present. The non-ferrous particles had been galled and torn. The ferrous particles had been tempered to a dark bronze and blue color. They had been somewhat pitted.

Ferrogram No. 3776 Sample No. P-3	Ferrogram No. 3780 Sample No. Q-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours ? Wear Debris Severity Index 5	Operating Hours ? Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	with striations	Fatigue Chunks.....	3	30 micrometers
Spheres.....	0		Spheres.....	1	5-8 micrometers
Severe Wear.....	0		Severe Wear.....	3	20 micrometers
Cutting Wear.....	2	ferrous and non-ferrous	Cutting Wear.....	2	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	3	with striations	Nonferrous Metallic.	3	70 micrometers, bright white chunks
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	0	
Amorphous.....	3	fibers were also present	Amorphous.....	3	fibrous

Additional Comments: There was a heavy deposit of elastomers. The ferrous particles had been oxidized and somewhat tempered. This may have been due to surface adhesion and extreme heat.	Additional Comments: There was a heavy concentration of elastomer debris. The particles had been tempered and it appears to have been done by extreme heat. The particles had been pitted.

Ferrogram No. 3784 Sample No. R-3	Ferrogram No. 3788 Sample No. S-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours ? Wear Debris Severity Index 5	Operating Hours ? Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	50 micrometers with striations
Spheres.....	1	2-5 micrometers
Severe Wear.....	3	20 micrometers
Cutting Wear.....	1.5	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	50 micrometers, bright silver, with striations
Nonmetallic:		
Crystalline....	0	
Amorphous.....	3	fibrous

Additional Comments: Many elastomer particles were observed. Some particles had been tempered to a blue and gold color.

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	30 micrometers
Spheres.....	0	
Severe Wear.....	3	20 micrometers
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	90 micrometers, bright white chunks
Nonmetallic:		
Crystalline....	1	
Amorphous.....	3	fibrous

Additional Comments: Many elastomer particles were observed. Some particles had been tempered light gold in color.

Ferrogram No. 3821 Sample No. T-3	Ferrogram No. 3825 Sample No. U-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 364 Wear Debris Severity Index 5	Operating Hours 386 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	90 micrometers	Fatigue Chunks.....	3	100 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	3	40 micrometers	Severe Wear.....	3	
Cutting Wear.....	2		Cutting Wear.....	1.5	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	2		Oxides (rust).....	1	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	180 micrometers bright white chunk, with striations	Nonferrous Metallic.	3	180 micrometers, bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	0		Crystalline....	0	
Amorphous.....	3	fibrous	Amorphous.....	3	fibrous
Additional Comments: Many elastomer particles were present. The particles had been highly tempered.			Additional Comments: Much elastomer debris was present. The ferrous particles had been tempered.		

Ferrogram No. 3829 Sample No. V-3	Ferrogram No. 3833 Sample No. W-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 402.5 Wear Debris Severity Index 4	Operating Hours 420 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	100 micrometers, with striations	Fatigue Chunks.....	3	
Spheres.....	1		Spheres.....	1	
Severe Wear.....	0		Severe Wear.....	2	
Cutting Wear.....	1		Cutting Wear.....	2	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	3	Bright white, chunks and cutting wear debris	Nonferrous Metallic.	3	100 micrometers, chunks and cutting
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	1	
Amorphous.....	3	fibrous	Amorphous.....	3	
Additional Comments: Much elastomer debris was present. The particles had been highly oxidized and tempered.			Additional Comments: The particles had been highly tempered.		

Ferrogram No. 3837 Sample No. X-3	Ferrogram No. 3841 Sample No. Y-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 431.5 Wear Debris Severity Index 3	Operating Hours 445.5 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	18-20 micrometers	Fatigue Chunks.....	3	80 micrometers, with striations
Spheres.....	1	5-8 micrometers	Spheres.....	1	one present
Severe Wear.....	1	18 micrometers	Severe Wear.....	3	30 micrometers
Cutting Wear.....	1		Cutting Wear.....	2	with striations
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	3	
Nonferrous Metallic.	2	silver chunks	Nonferrous Metallic.	3	bright white chunks and cutting wear debris
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	0	
Amorphous.....	3		Amorphous.....	3	fibrous

Additional Comments: Much elastomer debris was present.	Additional Comments: Much elastomer debris was present. The particles had been tempered.

Ferrogram No. 3845 Sample No. Z-3	Ferrogram No. 3849 Sample No. AA-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 459.5 Wear Debris Severity Index 5	Operating Hours 476.5 Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	35 micrometers
Spheres.....	1	
Severe Wear.....	3	20 micrometers
Cutting Wear.....	1.5	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	1	
Nonferrous Metallic.	3	225 micrometers, bright white, chunks and cutting wear
Nonmetallic:		
Crystalline....	2	
Amorphous.....	3	fibrous

Additional Comments: Several elastomer particles were present. Many particles had been tempered. Many particles appear to be the result of break-in.

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	
Spheres.....	0	
Severe Wear.....	2	
Cutting Wear.....	2	
Corrosive Wear.....	0	
Oxides (rust).....	1.5	
Dark Metallo-Oxides.	1	
Nonferrous Metallic.	3	chunks and cutting, with striations
Nonmetallic:		
Crystalline....	0	
Amorphous.....	3	fibrous

Additional Comments: Much elastomer debris was present. The ferrous particles had been tempered.

Ferrogram No. 3853 Sample No. BB-3	Ferrogram No. 3857 Sample No. CC-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 497.5 Wear Debris Severity Index 5	Operating Hours 515.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	100 micrometers	Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	0	
Severe Wear.....	3	20 micrometers	Severe Wear.....	1	one 20 micrometer particle
Cutting Wear.....	1.5		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	200 micrometers, cutting wear and chunks	Nonferrous Metallic.	1	one bright white chunk
Nonmetallic:			Nonmetalli		
Crystalline....	1		Cryst.....	1	
Amorphous.....	3	fibrous	Amorphous.....	3	
Additional Comments: Several elastomer particles were present. Particles had been oxidized and tempered. Some non-ferrous particles had been tempered blue in color. One bronze colored chunk, which was not tempered, was present.			Additional Comments:		

Ferrogram No. 3869 Sample No. FF-3	Ferrogram No. 3873 Sample No. GG-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 567.5 Wear Debris Severity Index 4	Operating Hours 584.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	60 micrometers	Fatigue Chunks.....	2	30 micrometers
Spheres.....	1		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	0		Nonferrous Metallic.	3	white chunks, one 30 micrometer laminar
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	3		Amorphous.....	3	fibrous
Additional Comments: The particles appeared to have been very torn.			Additional Comments: Much elastomer debris was present.		

Ferrogram No. 3861 Sample No. DD-3	Ferrogram No. 3865 Sample No. EE-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 533.5 Wear Debris Severity Index 5	Operating Hours 551.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	18 micrometers	Fatigue Chunks.....	3	30 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	1	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	forty-nine bright white particles	Nonferrous Metallic.	3	twenty-five particles, chunks and cutting wear
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	0	
Amorphous.....	3	fibrous	Amorphous.....	3	fibrous
Additional Comments: Much elastomer debris was present. Some particles had been tempered.			Additional Comments: Much elastomer debris was present. The particles had been tempered.		

Ferrogram No. 3877	Sample No. HH-3
Sample Description Filter, Pump Case Drain	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours 601.5	Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	20 micrometers
Spheres.....	0	
Severe Wear.....	0	
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	90 micrometers, chunks and cutting wear
Nonmetallic:		
Crystalline....	0	
Amorphous.....	2	

Additional Comments:

Ferrogram No. 3881	Sample No. II-3
Sample Description Filter, Pump Case Drain	
Sample Fluid: Description MIL-H-83282A	Volume 3 mL
Operating Hours 618.5	Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	30 micrometers
Spheres.....	0	
Severe Wear.....	0	
Cutting Wear.....	1.5	
Corrosive Wear.....	0	
Oxides (rust).....	0	
Dark Metallo-Oxides.	1	
Nonferrous Metallic.	2.5	90 micrometers, chunks and cutting wear
Nonmetallic:		
Crystalline....	0	
Amorphous.....	2	fibrous

Additional Comments: Several elastomer particles were present.

Ferrogram No. 3885 Sample No. JJ-3	Ferrogram No. 3889 Sample No. KK-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 637.5 Wear Debris Severity Index 4	Operating Hours 649.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	90 micrometers	Fatigue Chunks.....	2	20 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	1	
Cutting Wear.....	1	with striations	Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	1	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	160 micrometers, cutting wear	Nonferrous Metallic.	3	190 micrometers, bright white, chunks and cutting wear
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	3		Amorphous.....	2	fibrous

Additional Comments: Much elastomer debris was present.	Additional Comments: Several elastomer particles were present. The metal particles had been tempered bronze and blue in color.

Ferrogram No. 3893 Sample No. LL-3	Ferrogram No. 3897 Sample No. MM-3
Sample Description Filter, Pump Case Drain	Sample Description Filter, Pump Case Drain
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 667.5 Wear Debris Severity Index 4	Operating Hours 681.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	20 micrometers	Fatigue Chunks.....	2	30 micrometers
Spheres.....	1		Spheres.....	1	
Severe Wear.....	1	20 micrometers	Severe Wear.....	1	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	3	100 micrometers, bright white chunks	Nonferrous Metallic.	3	90 micrometers, bright white, chunks and cutting wear
Nonmetallic: Crystalline....	1		Nonmetallic: Crystalline....	1	
Amorphous.....	3		Amorphous.....	2	fibrous
Additional Comments: Much elastomer debris was present.			Additional Comments: Several elastomer particles were observed. The ferrous particles had been tempered.		

Ferrogram No. 3638 Sample No. A-4	Ferrogram No. 3641 Sample No. B-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 1.5 mL	Sample Fluid: Description MIL-H-83282A Volume 1.5 mL
Operating Hours 25 Wear Debris Severity Index 3	Operating Hours 42 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	20 micrometers	Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	0	
Severe Wear.....	2		Severe Wear.....	1	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	0	
Corrosive Wear.....	2		Corrosive Wear.....	3	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	0		Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	2	
Amorphous.....	2		Amorphous.....	0	
Additional Comments: A moderate amount of elastomer debris was observed.			Additional Comments: Not much elastomer debris was observed. The ferrous particles had been oxidized.		

Ferrogram No. 3644 Sample No. C-4	Ferrogram No. 3648 Sample No. D-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 61.5 Wear Debris Severity Index 4	Operating Hours 82 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	30 micrometers	Fatigue Chunks.....	2	20 micrometers
Spheres.....	0		Spheres.....	1	
Severe Wear.....	2	20 micrometers with striations	Severe Wear.....	1	20 micrometers
Cutting Wear.....	0		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	2	
Nonferrous Metallic.	1		Nonferrous Metallic.	1	80 micrometers
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	2	
Amorphous.....	2		Amorphous.....	0	

Additional Comments: A moderate amount of elastomer debris was observed. The ferrous particles had been oxidized. Several fibers were observed.	Additional Comments: A moderate amount of elastomer debris was observed.

Ferrogram No. 3652 Sample No. F-4	Ferrogram No. 3656 Sample No. F-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 102 Wear Debris Severity Index 3	Operating Hours 122 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	30 micrometers	Fatigue Chunks.....	3	30 micrometers, with striations
Spheres.....	0		Spheres.....	1	
Severe Wear.....	1	20 micrometers	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1		Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	2	
Amorphous.....	3		Amorphous.....	0	

Additional Comments: A moderate amount of small elastomer debris was observed. The ferrous particles had been somewhat oxidized.	Additional Comments:

Ferrogram No. 3660 Sample No. G-4	Ferrogram No. 3664 Sample No. H-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 1.5 mL
Operating Hours 132 Wear Debris Severity Index 4	Operating Hours 149 Wear Debris Severity Index 1

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	3	20 micrometers
Spheres.....	1.5	2-3 micrometers
Severe Wear.....	3	20 micrometres
Cutting Wear.....	1.5	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	2	
Nonferrous Metallic.	3	30 micrometers, bright white chunks
Nonmetallic:		
Crystalline....	2	
Amorphous.....	3	

Additional Comments: Much elastomer debris was observed. The ferrous particles had been tempered bronze and blue. They may have been cast iron or stainless steel.

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0	
Spheres.....	0	
Severe Wear.....	0	
Cutting Wear.....	0	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	1	
Nonferrous Metallic.	1	
Nonmetallic:		
Crystalline....	1	
Amorphous.....	2	

Additional Comments: Much elastomer debris was observed. A 75 micrometer bronze colored chunk may consist of a crystalline base with a thin coating of bronze or brass.

Ferrogram No. 3680 Sample No. I-4	Ferrogram No. 3683 Sample No. J-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 167.5 Wear Debris Severity Index 3	Operating Hours 187.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	20 micrometers	Fatigue Chunks.....	2	20 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	1	18 micrometers.	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	1	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	1	bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	2	fibers were present	Crystalline....	0	
Amorphous.....	2		Amorphous.....	3	
Additional Comments: A moderate amount of elastomer debris was observed. The ferrous particles had been oxidized.			Additional Comments:		

Ferrogram No. 3687 Sample No. K-4	Ferrogram No. 3691 Sample No. 1-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 205 Wear Debris Severity Index 3	Operating Hours 223.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	25 micrometers	Fatigue Chunks.....	0	
Spheres.....	1		Spheres.....	1	one sphere was observed
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	2		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	2	20 micrometers, bright white chunk	Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	2		Amorphous.....	2	
Additional Comments: Not much elastomer debris was observed. One lightly strawcolored particle was observed.			Additional Comments: A moderate amount of elastomer debris was observed.		

Ferrogram No. 3695 Sample No. M-4	Ferrogram No. 3699 Sample No. N-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 241 Wear Debris Severity Index 2	Operating Hours 258.5 Wear Debris Severity Index 1

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2.5	18 micrometers	Fatigue Chunks.....	1	two were observed
Spheres.....	0		Spheres.....	0	
Severe Wear.....	1	one was observed	Severe Wear.....	0	
Cutting Wear.....	0		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	0		Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	1	
Amorphous.....	2		Amorphous.....	2	
Additional Comments: Not much elastomer debris was observed.			Additional Comments: Not much elastomer debris was observed.		

Ferrogram No. 3703 Sample No. O-4	Ferrogram No. 3777 Sample No. P-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 285.5 Wear Debris Severity Index 4	Operating Hours ? Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	20 micrometers	Fatigue Chunks.....	1	
Spheres.....	0		Spheres.....	1	3-18 micrometers
Severe Wear.....	1	20 micrometers	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	3		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	3	30 micrometers, bright white chunks	Nonferrous Metallic.	1	white
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	3		Amorphous.....	3	
Additional Comments: Much elastomer debris was observed.			Additional Comments: Not much elastomer debris was observed. The ferrous particles had been tempered by extreme heat.		

Ferrogram No. 3781 Sample No. O-4

Sample Description Actuators, System Circuit

Sample Fluid:
Description MIL-H-83282A Volume 3 mL

Operating Hours ? Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	20 micrometers
Spheres.....	1	one observed
Severe Wear.....	1	20 micrometers
Cutting Wear.....	1	one observed
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1	95 micrometers, bright white
Nonmetallic:		
Crystalline....	1	
Amorphous.....	3	

Additional Comments: Not much elastomer debris was observed. Some particles had been tempered lightly gold and blue.

Ferrogram No. 3785 Sample No. R-4

Sample Description Actuators, System Circuit

Sample Fluid:
Description MIL-H-83282A Volume 3 mL

Operating Hours ? Wear Debris Severity Index 5

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	20 micrometers
Spheres.....	3	2-8 micrometers, bright white
Severe Wear.....	1	20 micrometers
Cutting Wear.....	1	
Corrosive Wear.....	0	
Oxides (rust).....	1	
Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1	three 180 micrometer particles observed, torn
Nonmetallic:		
Crystalline....	1	
Amorphous.....	2	

Additional Comments: The spheres were both ferrous and non-ferrous.

Ferrogram No. 3789 Sample No. S-4 Sample Description Actuators, System Circuit Sample Fluid: Description MIL-H-83282A Volume 3 mL	Ferrogram No. 3822 Sample No. T-4 Sample Description Actuators, System Circuit Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours ? Wear Debris Severity Index 2	Operating Hours 364 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	1	20 micrometers
Spheres.....	1	one was observed	Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	2	20 micrometers
Cutting Wear.....	0		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	1	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1		Nonferrous Metallic.	1	one observed
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	2	
Amorphous.....	2		Amorphous.....	3	
Additional Comments:			Additional Comments: Much elastomer wear was observed.		

Ferrogram No. 3826 Sample No. U-4	Ferrogram No. 3830 Sample No. V-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 386 Wear Debris Severity Index 3	Operating Hours 402.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	30 micrometers	Fatigue Chunks.....	2	20 micrometers
Spheres.....	1		Spheres.....	0	
Severe Wear.....	1	20 micrometers	Severe Wear.....	1	
Cutting Wear.....	0		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	2	50 micrometers, bright white	Nonferrous Metallic.	2	
Nonmetallic:			Nonmetallic:		
Crystalline....	0		Crystalline....	1	
Amorphous.....	3		Amorphous.....	3	
Additional Comments: A moderate amount of elastomer debris was observed. The particles had been tempered.			Additional Comments: Not much elastomer debris was observed. The particles had been tempered.		

Ferrogram No. 3834 Sample No. W-4	Ferrogram No. 3838 Sample No. X-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 420 Wear Debris Severity Index 3	Operating Hours 431.5 Wear Debris Severity Index 3

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	20 micrometers	Fatigue Chunks.....	1	20 micrometers
Spheres.....	1	seventeen were observed in clusters	Spheres.....	1	
Severe Wear.....	0		Severe Wear.....	1	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	1	bright white	Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	3		Amorphous.....	3	
Additional Comments:			Additional Comments: The particles had been highly tempered.		

Ferrogram No. 3842 Sample No. Y-4	Ferrogram No. 3846 Sample No. Z-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 445.5 Wear Debris Severity Index 3	Operating Hours 459.5 Wear Debris Severity Index 4

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	3	30 micrometers
Spheres.....	1		Spheres.....	1	one was observed
Severe Wear.....	1		Severe Wear.....	3	20 micrometers
Cutting Wear.....	1		Cutting Wear.....	1.5	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	1	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	0		Nonferrous Metallic.	3	bright orange chunks, 50 micrometers, bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	1	fibers were observed	Crystalline....	0	
Amorphous.....	3		Amorphous.....	3	
Additional Comments: A moderate amount of elastomer debris was observed.			Additional Comments:		

Ferrogram No. 3850 Sample No. AA-4	Ferrogram No. 3854 Sample No. BB-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 476.5 Wear Debris Severity Index 3	Operating Hours 497.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	2	18 micrometers	Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	1.5	
Severe Wear.....	1	18 micrometers	Severe Wear.....	1	one observed
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	1	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	1	
Nonferrous Metallic.	2	chunks and cutting wear	Nonferrous Metallic.	2.5	40 micrometers, bronze and bright white
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	3		Amorphous.....	3	
Additional Comments:			Additional Comments:		

Ferrogram No. 3858 Sample No. CC-4	Ferrogram No. 3862 Sample No. DD-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 515.5 Wear Debris Severity Index 3	Operating Hours 533.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	20 micrometers	Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	0	
Severe Wear.....	1	20 micrometers	Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	3		Oxides (rust).....	0	
Dark Metallo-Oxides.	3		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	3		Crystalline....	1	
Amorphous.....	2		Amorphous.....	2	
Additional Comments:			Additional Comments:		

Ferrogram No. 3866 Sample No. EE-4	Ferrogram No. 3870 Sample No. FF-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 551.5 Wear Debris Severity Index 1	Operating Hours 567.5 Wear Debris Severity Index 1

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	0		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	0		Amorphous.....	0	
Additional Comments:			Additional Comments:		

Ferrogram No. 3874 Sample No. GG-4	Ferrogram No. 3878 Sample No. HH-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 584.5 Wear Debris Severity Index 2	Operating Hours 601.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	0	
Spheres.....	1	one observed	Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	0		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	1	one 145 micrometer chunk
Nonmetallic:			Nonmetallic:		
Crystalline....	2		Crystalline....	1	
Amorphous.....	3		Amorphous.....	0	
Additional Comments:			Additional Comments:		

Ferrogram No. 3882 Sample No. II-4	Ferrogram No. 3886 Sample No. JJ-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 618.5 Wear Debris Severity Index 2	Operating Hours 637.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	1	20 micrometers
Spheres.....	0		Spheres.....	0	
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	1		Cutting Wear.....	1	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	0		Oxides (rust).....	0	
Dark Metallo-Oxides.	0		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	0		Amorphous.....	1	
Additional Comments:			Additional Comments:		

Ferrogram No. 3890 Sample No. KK-4	Ferrogram No. 3894 Sample No. LL-4
Sample Description Actuators, System Circuit	Sample Description Actuators, System Circuit
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 649.5 Wear Debris Severity Index 2	Operating Hours 667.5 Wear Debris Severity Index 2

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	0		Fatigue Chunks.....	0	
Spheres.....	0		Spheres.....	1	one was observed
Severe Wear.....	0		Severe Wear.....	0	
Cutting Wear.....	0		Cutting Wear.....	0	
Corrosive Wear.....	0		Corrosive Wear.....	0	
Oxides (rust).....	1		Oxides (rust).....	0	
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.	0	
Nonferrous Metallic.	0		Nonferrous Metallic.	0	
Nonmetallic:			Nonmetallic:		
Crystalline....	1		Crystalline....	1	
Amorphous.....	1		Amorphous.....	0	

Additional Comments: Not much elastomer debris was observed.	Additional Comments:

Ferrogram No. 3898 Sample No. MM-4	Ferrogram No. _____ Sample No. _____
Sample Description Actuators, System Circuit	Sample Description _____
Sample Fluid: Description MIL-H-83282A Volume 3 mL	Sample Fluid: Description MIL-H-83282A Volume 3 mL
Operating Hours 681.5 Wear Debris Severity Index 2	Operating Hours _____ Wear Debris Severity Index _____

ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments	ANALYSIS OF DEBRIS Type	Debris Gravity Index	Comments
Fatigue Chunks.....	1	19 micrometers	Fatigue Chunks.....		
Spheres.....	1		Spheres.....		
Severe Wear.....	0		Severe Wear.....		
Cutting Wear.....	1		Cutting Wear.....		
Corrosive Wear.....	0		Corrosive Wear.....		
Oxides (rust).....	1		Oxides (rust).....		
Dark Metallo-Oxides.	1		Dark Metallo-Oxides.		
Nonferrous Metallic.	0		Nonferrous Metallic.		
Nonmetallic:			Nonmetallic:		
Crystalline....	0		Crystalline....		
Amorphous.....	0		Amorphous.....		

Additional Comments:	Additional Comments:

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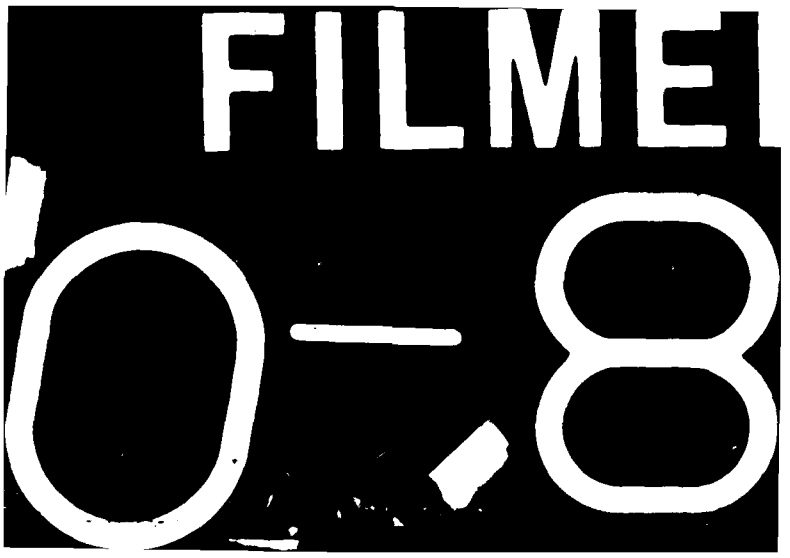
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