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A SUMMARY OF CONTAMINATION IN HYDRAULIC FLUID SYSTEMS OF USAF AND SUPPORT SYSTEMS

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JAMES W. PARKER

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by the Aeronautical Systems Division (ASD), Air Force Systems Command, United States Air Force as an in-house effort. No formal project for this work exists. The effort was initiated by the Directorate of Aerospace Ground Equipment Engineering with Mr. James W. Parker as project engineer.

The studies initiated in August 1959, and not yet completed,were begun on the informal request of the Strategic Air Command, Capt Kenneth W. Hendricks, B-52/KC-135 Operational Engineering Section, Castle Air Force Base, California.

The information contained in this report was collected from many sources including presentations, papers, discussions and reports by industry and Government. Many of these reports and papers are listed in the reference section for the information of those readers who desire to become more familiar with specific details that are not within the scope of this document.

ABSTRACT

The purpose of this Technical Note is to summarize hydraulic fluid contamination experience, problems, and possible solutions that relate to Air Force weapon and support systems. No attempt is made to present the detail necessary for the reader to become minutely familiar with the many and varied technical aspects of fluid particle separation and related fields; it is written rather to convey a general knowledge to management personnel for use in Air Force planning in the field of hydraulic fluid particle separation.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Paul E. Beck

PAUL E. BECK
Chief, Checkout & Test Equipment Division
Directorate of Aerospace Ground Equipment
Engineering
Deputy for Engineering

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SECTION I

GENERAL INTRODUCTION

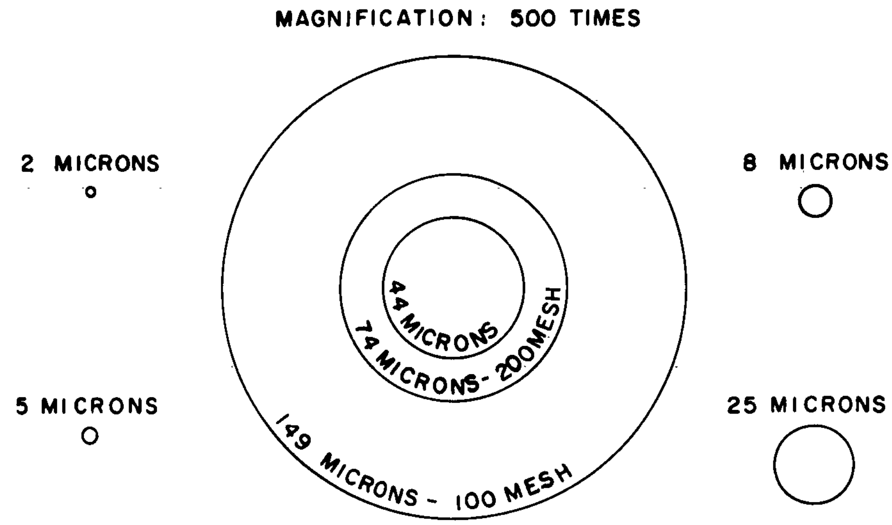
The majority of today's high performance weapon systems depend upon hydraulics for control and other important powered functions. These systems are highly susceptible to binding and lagging when supplied with fluid that contains even minute particles of solid contaminants. New hydraulic fluid, as received from fluid manufacturers, does not meet the cleanliness requirements of many systems.

Fluid contamination is also cited as one of the contributing factors in premature hydraulic pump failures. It appears, however, that pumps will tolerate more contaminants than will many other components in the systems.

Future weapon systems, because of the precise control and reliability will require considerably lower levels of fluid contamination than any attainable at present.

This technical note outlines the problems encountered, the present approximate state of the art, and future planned efforts.

Manuscript released 16 October 1961 for publication as an ASD Technical Note.



LINEAR EQUIVALENTS

1 INCH	25.4 MILLIMETERS	25.400 MICRONS
1 MILLIMETER	.0394 INCHES	1000 MICRONS
1 MICRON	$\frac{1}{25,400}$ OF AN INCH	.001 MILLIMETERS
1 MICRON	3.94×10^{-5}	.000039 INCHES

RELATIVE SIZES

LOWER LIMIT OF VISIBILITY (NAKED EYE)	40 MICRONS
WHITE BLOOD CELLS	25 MICRONS
RED BLOOD CELLS	8 MICRONS
BACTERIA (COCCI)	2 MICRONS

SCREEN SIZES

MESHES PER LINEAR INCH	U.S. SIEVE NO.	OPENING IN INCHES	OPENING IN MICRONS
52.36	50	.0117	297
72.45	70	.0083	210
101.01	100	.0059	149
142.86	140	.0041	105
200.00	200	.0029	74
270.26	270	.0021	63
323.00	325	.0017	44

Figure 1. Relative Size of Particles

SECTION II

MATERIALS, SOURCE AND PROBLEMS ASSOCIATED WITH SOLID PARTICLE CONTAMINANTS

Contaminants

The most prevalent and the most troublesome hydraulic fluid contaminants are solid particles which range in size from one-half to several hundred microns. Particle sizes are defined and measured as the largest dimension of the particle. Fibers are those particles having a length to diameter ratio of 10 to 1 or greater. Table 1 shows the common contaminants and probable sources:

TABLE I

ELEMENT	PROBABLE SOURCE
IRON OXIDE	RUST (CANS)
SILICA	CLAY (DUST)
CALCIUM	RED DYE
LEAD	SOLDER (CAN)
TIN	PLATING (CAN)
LINT FIBERS	WIPING RAGS
WATER	CONDENSATION
PAINT	CANS, GSE UNITS, ETC.
MAGNETIC METALS	MACHINING
NON-MAGNETIC METALS	WEAR
LAPPING COMPOUNDS	MACHINING
PIPE SEAL COMPOUNDS	THREADS
RUBBER	HOSES AND SEALS
BACTERIA	GROWTH

Sources of Contaminants

The sources of contaminants are as many and varied as the multiple system components and paths the fluid must follow in a dependable hydraulic power system.

As noted in table 1, one source of hydraulic fluid contamination is the fluid itself. In the manufacture of hydraulic fluid small amounts of color dyes, oxidation inhibitors, viscosity improvers, and other additives may exist in particle sizes (one-half to three microns) that classify them as contaminants. Fluid in storage, especially that subjected to the vibrations of truck or rail transportation, is more contaminated than new fluid. This is due in part to the phenomenon of agglomeration, wherein numerous small particles are attracted and attached one to the other to form single larger particles. Fluid stored for long periods of time is susceptible also to bacterial growth, which is a contaminant.

The containers in which the fluid is packaged are themselves inherent sources of contamination. The manufacturing processes of mass produced cans make it impractical to produce an absolutely clean container. To clean these cans contaminated with plating, solder, paint, rust, etc., is in itself a major effort, and is seldom 100 percent effective.

The transfer of fluid from the hermetically sealed container to the operating system involves the addition of undesirable contaminants. Normally, the container is punctured with a service station pouring spout, a beverage can opener, or a screwdriver. These tools collect dirt when not in use, and various amounts of this dirt are added to the fluid. This transfer of fluid from the can to a hydraulic test stand, hydraulic service cart, or directly to the reservoir of a system often occurs on a ramp or other places exposed to floating dust particles. Also, these test stands or service cart systems are in many cases already grossly contaminated.

There are numerous sources of contamination in test stands or service carts: carelessness, failure to change filters at prescribed intervals, leaving connecting hoses uncapped, allowing uncapped hose ends to contact concrete ramps, and many other ways. The filters in these equipments are in most cases inadequate. These filters are (AN 6235 elements) nominally rated to remove 10-micron size particles. There are instances however where these elements have passed particles up to 100 microns in size. Other deficiencies of these paper element filters are: they collapse at low differential pressures, becoming ineffective; paper fibers continually break loose from the filter and pass downstream into the fluid, in what is known as media migration. It has been shown that storage time directly affects the capabilities of the filter elements to withstand their rated differential pressure; therefore, differential pressure indicators across the filters that indicate a clogged condition are practically useless. Frequently, replacement filter elements are not available at the using activities when needed because of logistics problems.

Hydraulic test stands are particularly prone to contamination through daily use on aircraft systems. The test stand may be connected to a hydraulic system in which a pump has failed and been replaced. A large part of the contamination caused by the failure of the pump is transferred to the test stand system. Subsequent servicing of aircraft with the same test stand transfers the contaminant to them possibly causing other pump or component failures and therefore producing a growing pyramid of contamination.

The control of contamination in missile hydraulic systems is usually easier than in aircraft hydraulic systems due to the improved filters that are usually provided in the ground hydraulic equipment; the long periods of time available to recirculate fluid through the system thereby flushing out the contaminants; and finally the extreme care that is usually exercised by the maintenance personnel. Since long periods of time are available for recirculation, low flow depth type filters are used in the ground support equipment.

Fluid in any operating hydraulic system is susceptible to a continual buildup of contaminant level. The residual contamination in new systems, the never ending wear of pumps, and valves, and the continual "flaking off" from seals and flexible hoses, all contribute to the gradual buildup of contaminant levels.

Failure of a pump or major component in a hydraulic system contributes catastrophically to the contamination level of that system. The immeasurable contamination is distributed throughout the system in which the failure occurs. Its removal is practically impossible because of the many dead end lines and actuators. Major disassembly and cleaning of individual components and lines are necessary. The time involved often runs into hundreds of manhours and is prohibitive when weighed against operational schedules.

Problems Created by Contaminants

Contaminants in hydraulic systems create problems of varying degrees. The problems caused by contamination are not, however, necessarily proportional to the amount of contaminant in that system. Some systems are more tolerant than others. The degree of tolerance of the system to contaminants is a function of the design of the system, and the design is in turn dictated by the performance requirements of the weapon system. In general, supersonic and ultrasonic weapon systems require the most precise control; therefore, they require the closest clearances in servo-valves and other components of the control system. The close-clearance servo-valve is most affected by minute solid particle contaminants.

Figure 1 presents the details of the internal workings of a typical control servo-valve. Within the servo-valve there are four areas which are susceptible to dirt particles. These areas are:

1. The nozzles and flapper clearances
2. The orifices
3. The spool clearances in the second stage
4. The filters in both the first and second stages (some valves have filters in only the first stage).

The diameter of the nozzle is approximately 0.032 inch, or 800 microns and the clearance between the nozzle and flapper is approximately 15 microns, or 0.00059 inch. The presence of a particle of contaminant large enough to plug the nozzle or lodge between the nozzle face and the flapper would render the valve inoperative. One might think that the nozzle hole, which is 0.032 inch in diameter is too large to become plugged by particles, however, if a long sliver of material or a machined metal turning finds its way into the nozzle it can become lodged across the diameter. These particles will then begin to build up across the nozzle opening until the passage is completely blocked, and the valve becomes inoperative.

The diameter of the orifices is approximately 0.005 inch or 124 microns. Here again if the orifices become plugged the valve will either behave sluggishly or will not operate.

The diametral clearance between the spool and bushing assembly is approximately 0.0002 inch or 5 microns. Particles of contaminant 2.5 microns in size will find their way into this clearance and tend to increase hysteresis and decrease the response of the servo-valve. The amount of this degradation is a function of the size, concentration and the types of contaminants present.

The above mentioned critical areas: the nozzle flapper clearance, the orifices, and the spool and bushing diametral clearances (in some valves) are for the most part protected during operation in a servo-valve by the use of filters, as shown in figure 1.

These filters in servo-valves are necessarily very tiny and may become clogged by very few particles. The flow then is restricted and the valves sluggish. Unless they are cleaned they will become inoperative. When the filters become clogged particles may pass but the results are the same: lagging, sluggish operation.

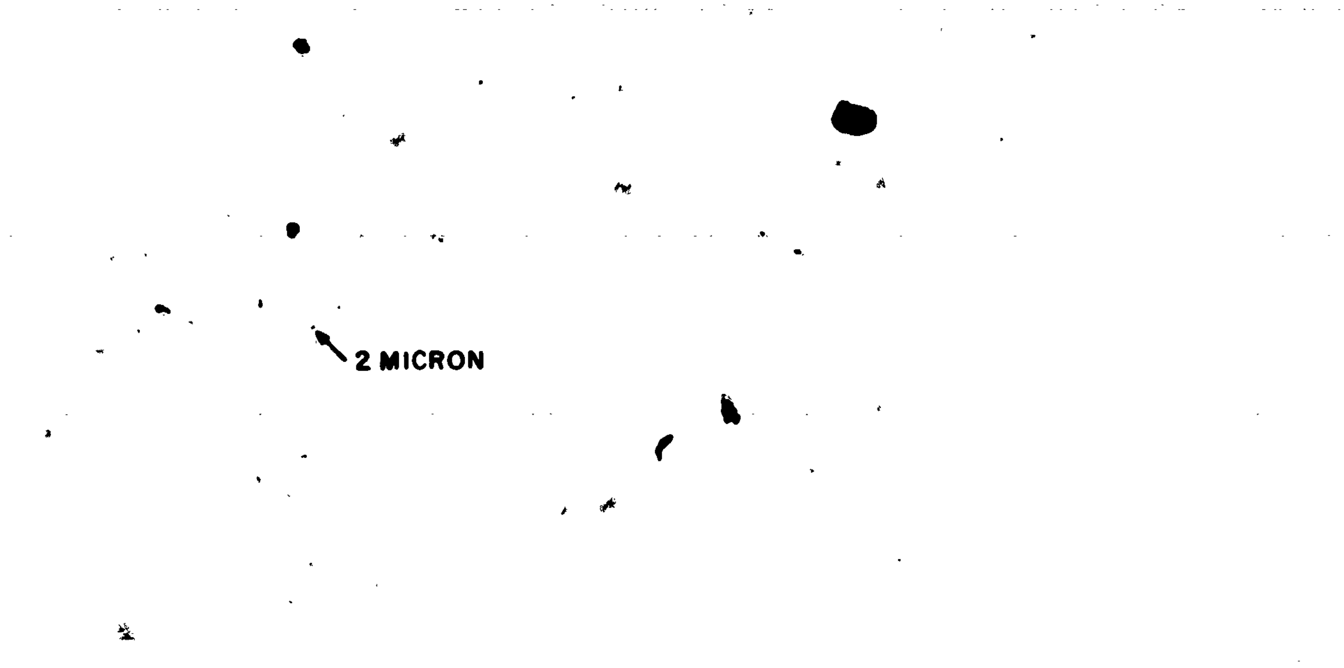


Figure 2A. Unfiltered MIL-H-5606 Fluid

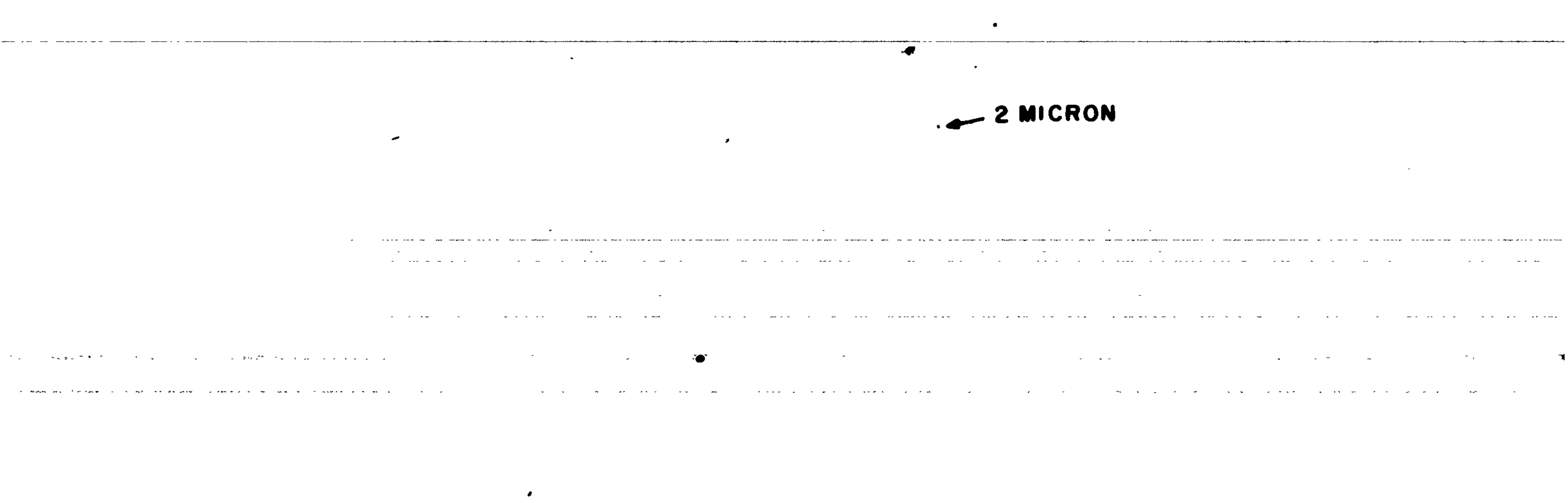


Figure 2B. MIL-H-5606 Fluid Filtered to the Degree Necessary for F-105 Aircraft

TABLE 2

UNFILTERED MIL-H-5606 FLUID FROM SEALED CAN

JULY 29, 1958

LABORATORY NO. 40139

COUNT: 5 FIELDS UNDER MAGNIFICATION OF 400

$$\text{FACTOR} = \frac{1010\ \text{mm}^2}{0.0625 \times 5} = 3232$$

FIELD	PARTICLE SIZE IN MICRONS 0-2	2-5	5-10	10-20	20-44	ABOVE 44
1	384	36	27	10	1	—
2	405	31	31	11	1	—
3	350	35	23	8	—	1
4	398	29	25	9	1	—
5	411	21	19	11	1	1
TOTAL	1984	152	125	49	4	2
PARTICLES PER 100 ML	6,412,228	491,264	404,000	158,368	12,928	6,464
				TOTAL = 7,485,252		
%	85.7	6.6	5.4	2.1	0.1	0.1

NOTE: THERE ARE MANY AMORPHOUS PARTICLES, AND MEASUREMENTS OF THESE PARTICLES ARE DIFFICULT

Silting may occur in these valves. Silting is a build-up of small particles (2 to 5 micron sizes) that occurs in the spool and bushing clearance when the valve is not moved for several seconds. During static conditions, fluid under pressure on one band of the spool continually bleeds through to the low-pressure side carrying with it small particles of contaminants. The contaminants build up causing the spool to bind. When the spool is then required by the control stage to move in one direction the unbalance of pressure suddenly breaks the spool free, causing erratic, unsteady movement of the control actuator.

Figure 2 presents the details of the internal parts of a typical high pressure, high speed hydraulic pump commonly used in airborne and ground equipment. In these pumps the critical parts affected by contamination are the contacting faces between the cam plate and the piston shoes, and between the valve plate and the cylinder body. Particles may break the lubricating film between these sliding surfaces allowing direct metal-to-metal contact. The high operational speeds of the pumps (upward from 4,000 RPM) and the lack of the lubricating film very quickly cause failure.

The main hydraulic filter elements in aerospace weapon systems are of two basic types; cleanable and noncleanable. Cleanable elements are usually sintered bronze or woven wire mesh. Sintered bronze types are highly susceptible to media migration and require unusually refined manufacturing techniques and quality control. Woven wire mesh elements are the most common cleanable ones, and are not as susceptible to media migration. The merits of each type will be discussed later in this report. No equipment is available to using personnel that will adequately clean the cleanable type elements; they are either discarded, or rinsed in fluid and returned to service. The latter procedure adds to the contamination in the element and usually leads to a clogged and by-passing filter.

Noncleanable filter elements are the least desirable of the available elements. They are usually made of pressed paper and are susceptible to media migration, aging embrittlement and collapse. Collapsed paper element filters are responsible for much of the contamination in hydraulic systems.

Naturally, the ideal hydraulic system would be one containing no contamination. It is impossible to achieve such a system. It is necessary therefore to compromise, and settle upon a contaminant level for each system that will provide it with reasonable, trouble-free life. This level has not been determined for most existing systems, and a concerted effort will be required to establish the contamination level for future systems.

Missile and aircraft hydraulic systems are becoming more and more intolerant of contaminants. Levels are building up through normal operation and maintenance to catastropic failures in some cases. Once a failure occurs in a system, the only completely satisfactory way to return it to service is to disassemble, clean and reassemble. On the other hand, minute solid particles in a system probably shorten its useful life. The degree to which the life of the system is shortened by contamination is dependent upon the design of that system, and is not known.

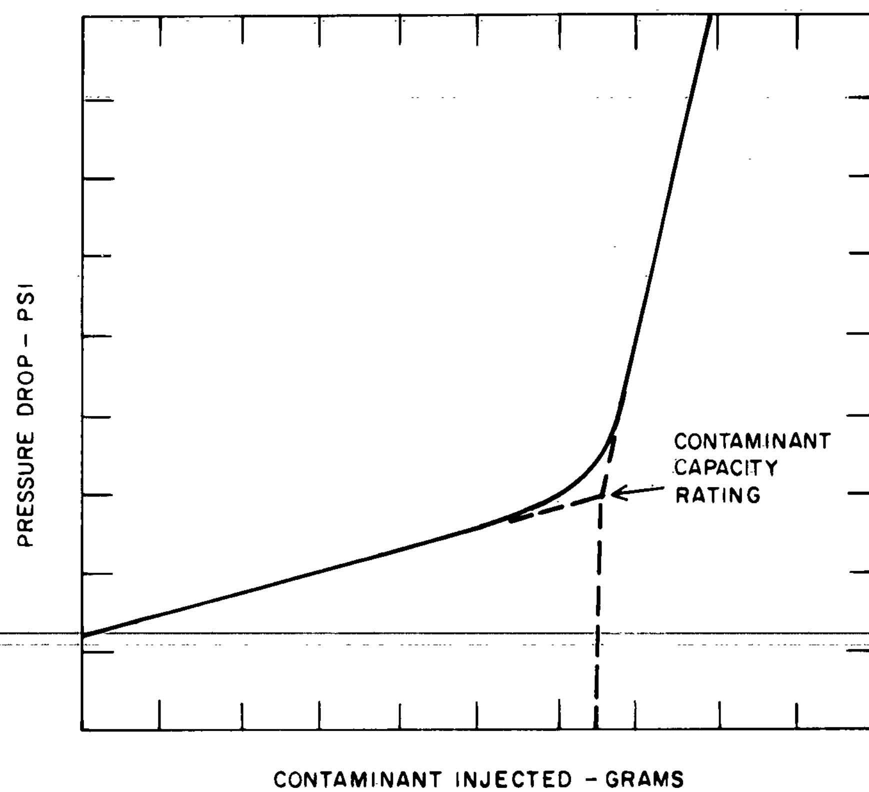


Figure 3. Filter Contaminant Capacity

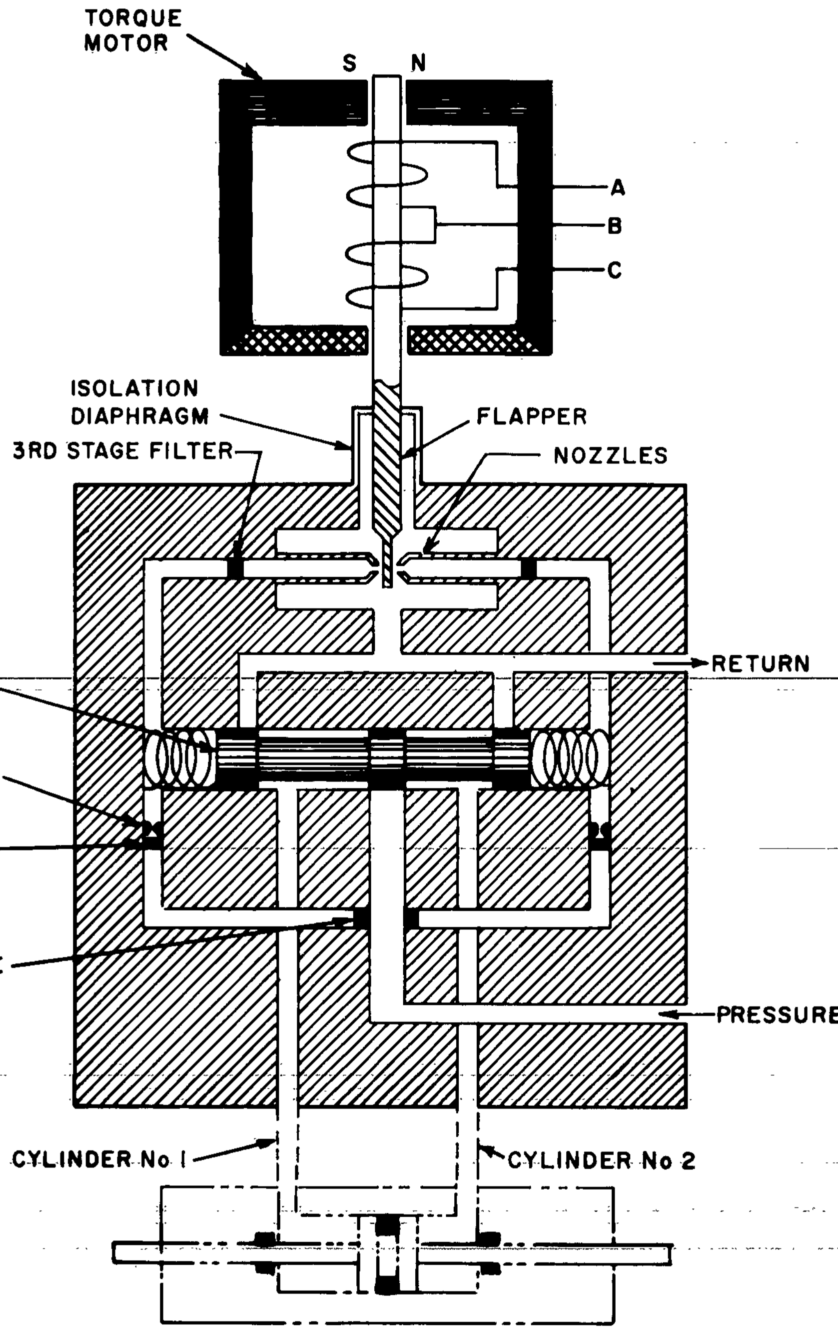


Figure 4. Typical Hydraulic Servo Valve

SECTION III

FLUID PARTICLE SEPARATION TECHNIQUES

Numerous methods of separating particles from fluid are available. Many are adaptions of old principles; some are new. Discussion here will be limited to four of the more promising, namely, mechanical, centrifugal, chemical, and electrostatic. The merits of each are discussed at the conclusion of this section.

Mechanical Filters

Mechanical filter media are, in essence, strainers; however, the problems involved in the fabrication of a strainer that will consistently separate 2- and 3-micron-size particles from fluid belies this simple definition. There are many configurations, materials, types and models of filters available.

The most commonly used are fabricated of woven steel wire mesh and these have many advantages. They are classed as cleanable and are extensively used in ultrasonic aircraft and missile systems. Wire mesh filters are fabricated of extremely fine wire (usually stainless steel) woven with an interlocking cloth weave. This material is then corrugated and fabricated into the desired shape and size.

Sintered metal, usually bronze, is also used for mechanical filters. This material is formed by the sintering process wherein extremely small spheres of bronze are heated to the critical temperature under pressure and formed thereby into a porous material.

Pressed paper filter elements have been used almost exclusively in the past. Many subsonic aircraft flying today are equipped with paper filters. However, these filters are not considered adequate for high performance systems.

Matted fibers, paper, fiberglass, and membranes are used in a few ground test hydraulic systems.

Each of the above mechanical type filter media has definite limitations. Table 3 illustrates the comparative merits of each.

Other Means of Fluid Particle Separation

Centrifugal, chemical, and electrostatic fluid particle separation techniques have been studied by industry to the point of feasibility. Each of these methods promises to further the state of the art. Each, if successfully followed through to completion, might provide distinct advantages for specific applications.

Determination of Degree of Contamination

A deterring factor in the advancement of the state of the art of fluid particle separation has been the inability to make accurate counts of the particles. Several methods are available, each with advantages and disadvantages.

Most widely used of the available counting methods is Aeronautical Recommended Practice No. 598, a method recommended by the Society of Automotive Engineers. It involves taking a sample of fluid from the system into a precleaned bottle. The fluid is then passed through a grid type membrane filter rated at one-half micron absolute. The membrane filter is then viewed through a microscope with calibrated eyepieces. Size of particals is estimated and counted. Results of this method of particle counting are accurate to approximately ±20 percent under normal conditions.

Another method of determining the degree of contamination of a fluid is commonly referred to as the gravimetric method. With this method the fluid sample is passed through a pre-weighed membrane filter which is then reweighed, thus the weight of contaminant in the original sample of fluid may be determined. This method gives only the weight and not the size of the particles of the contaminant.

Various commercial equipments are available for counting and sizing contaminant particles. Two of them are promising. In one case an interrupted light beam and light sensing cells are employed; the other makes use of the differing electrical resistances between fluid and contaminant. Correlation of results between the various methods of particle counting has not been accomplished.

TABLE 3
COMPARATIVE MERITS OF COMMONLY USED FILTER MEDIA

	ABILITY FOR ABSOLUTE CUT - OFF RATING	FILTERING ABILITY		CLEAN-ABILITY	MECHANICAL STRENGTH	DIFF PRESS RATING [1]	DIRT CAPACITY	MEDIA MIGRATION
		PARTICLES	FIBERS					
WOVEN WIRE MESH	GOOD	GOOD	FAIR	GOOD	GOOD	GOOD	POOR	GOOD
SINTERED METAL	FAIR	GOOD	GOOD	FAIR	GOOD	FAIR	FAIR	FAIR [2]
PRESSED PAPER	POOR	POOR	FAIR	NIL	POOR	FAIR	FAIR	POOR
MATTED FIBERS	POOR	FAIR	GOOD	NIL	POOR	POOR	GOOD	POOR
MEMBRANES	GOOD	GOOD	FAIR	NIL	POOR	FAIR	POOR	GOOD

1. DIFF PRESS RATING — PRESSURE DROP ACROSS A UNIT AREA VERSUS FILTERING ABILITY
2. MEDIA MIGRATION OF SINTERED METAL DEPENDS UPON MANUFACTURING TECHNIQUES

SECTION IV

CONCLUSIONS

From the data presented a conclusion can be drawn that contamination in many hydraulic systems is, and will remain, at levels beyond the limits of reliable performance unless a concerted effort is made to provide cleaner systems.

a. Hydraulic fluid as received does not meet the cleanliness requirement of many systems.

b. Maintenance techniques are inadequate for transferring fluid from the can to the systems.

c. Hydraulic test stands do not provide adequate filtration of the fluid.

d. No means are provided to clean a system after it has become contaminated.

SECTION V

RECOMMENDATIONS

a. That effort be expended to provide the means of transferring fluid from a can to a system without adding to the contamination of the fluid.

b. That a standard method be developed for sampling and counting particulate contamination in hydraulic systems.

c. That an effort be made to control the design of future aircraft and missile components that will be more tolerant of contaminants.

d. No effective means other than disassembly are provided to clean a system after it has become contaminated.

e. That new fluid particle separation techniques be investigated for all hydraulic ground support equipment. The ground equipment should provide better filtration than that in the airborne system and should be able to retain large amounts of contaminants before becoming clogged.

f. That ground support equipment systems be designed to provide turbulent flow with fewer static flow areas and contaminant traps.

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2. Ground Support System Contamination

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