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Ship Systems and Equipment—Hydraulic Systems—Filter Selection Parameters

Foreword—This SAE Recommended Practice is based to a large extent on a paper prepared by Wayne K. Wilcox of the Naval Sea Systems Command titled "Selection Parameters for Hydraulic System Filters with a Comparison of Aircraft and Marine Applications" which was published in the September 1987 issue of the Naval Engineers Journal. Much of the material in this document has been extracted directly from the paper with the permission of the author.

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1. Scope—This SAE Recommended Practice identifies and examines the various parameters which must be considered in selecting hydraulic system filters, their locations within the system and the dirt capacity of the filter elements.

1.1 Field of Application—This document is generally applicable to all ship hydraulic systems but does not apply to personal or recreational watercraft.

2. References

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 SAE Publications—Available from Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pa 15096.

SAE AIR 887—Liquid Filter Ratings, Parameters and Tests
SAE J1778—Hydraulic Fluids For Marine Vehicles
SAE J1779—Hydraulic System Design Criteria for High-Performance Marine Surface Vehicles and Small Submersible Vehicles
SAE J2321—Ship Systems and Equipment—Filter Elements—Hydraulic and Lube Oil Service (Document under development)

2.1.2 NFPA Publications—Available from National Fluid Power Association, 3333 North Mayfair Road, Milwaukee, WI 53222.

T3.10.8.8—Multi-Pass Method for Evaluating the Filter Performance (Note: Expected to be replaced with ISO 16889.)

2.1.3 ISO Documents—Available from International Organization for Standardization, 1 rue de Varembe, 1211 Geneva 20, Switzerland or from the National Fluid Power Association (NFPA).

ISO 4406—Hydraulic fluid power—Fluids—Codes for defining the level of contamination of solid particles
ISO 4572—Hydraulic fluid power—Filters—Multipass method for evaluating filtration performance of a fine filter element (Note: Expected to be replaced with ISO 16889.)
ISO 12103-1—Road vehicles—Test dust for filter evaluation—Part 1: Arizona test dust
ISO 11171—Hydraulic fluid power—Calibration of liquid automatic particle counters

2.1.4 Department of Defense Publications—Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-F-5504—Filter and Filter Elements, Fluid Pressure, Hydraulic Micronic Type
MIL-H-5606—Hydraulic Fluid, Petroleum Base, Aircraft and Ordnance
MIL-F-8815—Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems, General Specification for
MIL-F-17111—Fluid, Power Transmission
MIL-L-17331—Lubricating Oil, Steam Turbine and Gear, Moderate Service
MIL-PRF-17672—Hydraulic Fluid, Petroleum, Inhibited
MIL-H-19457—Hydraulic Fluid, Fire-Resistant, Non-Neurotoxic
MIL-H-22072—Hydraulic Fluid, Catapult, NATO Code Number H-579

MIL-F-24402—Filter (Hydraulic), Filter Elements (High Efficiency) and Filter Differential Pressure Indicators
MIL-F-24402/4—Filter Elements, Hydraulic, Disposable (Expected to be replaced by SAE J2321)
MIL-F-24702—Filter Elements, Hydraulic, Disposable, General Specification for (Expected to be replaced by SAE J2321 when issued)
MIL-PRF-83282—Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft, Metric, NATO Code Number H-537

2.2 Other Publications

Downs, David C., "Clean hydraulics cuts downtime," Machine Design, Dec. 14, 1995, pg. 113-119
Needleman, W. M., "Filtration," STLE Handbook of Lubrication and Tribology, E. R. Booser, Ed., CRC Press, 1994
Pall Industrial Hydraulics Corporation, "Contamination Control and Filtration Fundamentals," 1993, 2200 Northern Blvd., East Hills, NY 11548-1289
Parker Hannifin Corporation, "The Handbook of Hydraulic Filtration," Hydraulic Filter Division, 16810 Fulton County Road #2, Metamora, OH 43540
Vickers, Incorporated "Vickers Guide to Systemic Contamination Control, 12/1992. P.O. Box 302, Troy, MI 48007-302
Wilcox, Wayne K., "Selection Parameters for Hydraulic System Filters with a Comparison of Aircraft and Marine Applications," Naval Engineers Journal, Sept. 1987, Vol. 99, No. 5, pp. 62-70
Zingaro, A. "Walking the fluid cleanliness tightrope, Part 5: Fluid cleanliness standards, the Multipass Test, Beta Ratios, Contaminant loading, particle capture efficiency, and filter selection and location," Hydraulic & Pneumatics, March 1996. (Reprint of entire series available from Parker Hannifin Corporation, Filtration Group, Cleveland, Ohio 44112.)

3. Definitions

3.1 Filtration Efficiency—Efficiency ratings measure the ability of a filter element to remove contaminants. Various efficiency ratings are described as follows:

3.2 Absolute Rating—The diameter of the largest hard spherical particle (usually a glass bead) which will pass through the filter medium under specified conditions. (Since contaminants are rarely spherical, the absolute rating cannot be correlated with efficiency rating and is usually less significant in defining filter performance than is the efficiency rating. When using a multi-pass test to determine efficiency, the particle size at which the filtration ratio is 75 or 100 is sometimes referred to as the "absolute" rating).

3.3 Filtration Ratio (Beta Ratio)—A numerical rating which is the ratio of particles greater than a given size entering a filter divided by the number of particles larger than the same size simultaneously leaving the filter. A Beta rating means that AC fine test dust was the contaminant used for the test. (AC fine test dust is no longer available and is being replaced by ISO 12103-1 A3 Medium Test Dust). A rating, $\beta = 50$ at 10 μ, means that for particles 10 µm and larger, the upstream count is 50 times the downstream count. The Beta rating, or Filtration Ratio, can be converted to an efficiency rating by Equation 1:

$$\text{Efficiency}\ (\%) = (1 - 1/\ \text{Beta Ratio}) \times 100 \qquad \text{(Eq. 1)}$$

Therefore, a filter with a rating, $\beta = 50$ at 10 μ, will remove 98% of fine test dust particles larger than 10 µm. The same filter might have a rating, $\beta = 10$ at 5 μ, meaning that the element will remove 90% of the fine test dust particles larger than 5 µm. The filtration ratio is often determined for a number of particle sizes and at differential pressures up to at least the terminal pressure drop of the element.

3.4 Nominal (Size) Rating—This is an obsolete rating term used in the past to indicate removal of certain percentage of particles greater than a certain size. To be meaningful, the percentage removal (90, 95, or 98%) needs to be identified along with the test contaminant and the test procedure.

3.5 Percentage by Weight—Some older military specifications have required that a filter element remove a certain percentage by weight of a contaminant (glass beads or test dust of a specific size distribution). This test basically provides a measure of the efficiency of a new element but provides little information as to how the efficiency changes as differential pressure increases across the element.

4. Filter Selection Guidelines

4.1 Background—Many times the filtration installed for ship hydraulic systems has been inadequate. Common deficiencies have been:

a. Short element life
b. Bypass relief valves lift even with new elements installed
c. Excessive pressure drop across the filter
d. Element collapse
e. Low-filtration efficiency
f. Element media incompatible with water in the fluid

4.2 Causes of Past Deficiencies—Some of the past deficiencies in ship hydraulic filtration have resulted from the utilization of aircraft filters and design practices without careful evaluation of the differences in the applications.

4.3 Selection Parameters—In order to provide effective filtration for ship hydraulic systems, a number of parameters must be considered. The parameters identified and discussed in this document include the following:

a. Fluid viscosity and flow rate
b. Location of filter assemblies
c. Essentiality of system operation
d. Duration of system operation
e. Required filtration level (efficiency)
f. Maintenance philosophy
g. Logistic support requirements
h. Initial and operating costs
i. Filter size and weight

Most of these parameters are interdependent and while each will be discussed separately, one must not neglect their interdependence.

4.4 Fluid Viscosity and Flow Rate

4.4.1 ELEMENT SIZING—One of the most important considerations in filter selection is assuring that the filter elements are sized to handle the flow and viscosity of the fluid to be filtered at the desired dirt capacity of the element. The differential pressure across a filter element is a function of the flow rate and the fluid viscosity. Almost all losses across the element are viscous losses directly proportional to fluid viscosity. Therefore, the safest practice is to assume that pressure losses are proportional to absolute fluid viscosity and flow rate. Flow rates are usually relatively easy to determine. (Absolute viscosity equals kinematic viscosity times the mass density. For commonly used hydraulic fluids, the absolute viscosity in centipoises is usually within 15% of the kinematic viscosity in centistokes.) However, fluid viscosity varies with the type of fluid, fluid temperature, and pressure.

4.4.2 VISCOSITY OF HYDRAULIC FLUIDS—Because of cold ambient temperatures for start-up and operation, aircraft hydraulic fluids have a relatively low viscosity. One low viscosity hydraulic fluid, MIL-H-5606, is often used for testing of filter elements for ship hydraulic applications as well as aerospace and industrial applications. However, the fluids used in most ship hydraulic systems tend to be considerably more viscous than MIL-H-5606. See SAE J1778 for characteristics of ship hydraulic fluids and their selection parameters. Table 1 summarizes the viscosity of MIL-H-5606 and other fluids commonly used in ship hydraulic systems. Note that the viscosity of some hydraulic fluids at 40 °C are five to seven times that of the MIL-H-5606 fluid commonly used to test filter elements. At 0 °C, the viscosity of these fluids may be 30 or more times the viscosity of MIL-H-5606 at 40 °C which is the temperature most often used for filter element testing.

TABLE 1—VISCOSITY OF COMMONLY USED SHIP HYDRAULIC FLUIDS

Fluid Symbol of Designation	Military Specification	Kinematic Viscosity in Centistokes 40 °C	Kinematic Viscosity in Centistokes 0 °C
Petroleum Base			
	MIL-H-5606	14	45
NATO H-575	MIL-F-17111	27–30	
ISO VG 32	MIL-PRF-17672, 2075-TH	32% ± 10%	150–200
ISO VG 46	MIL-PRF-17672, 2110-TH	46% ± 10%	275–300
ISO VG 68	MIL-PRF-17672, 2135-TH	68% ± 10%	475–525
	MIL-L-17331, 2190TEP	74–97	1000–2000
Synthetic Hydrocarbon			
NATO H-537	MIL-PRF-83282	14 (Min.)	90
Triaryl Phosphate Ester			
NATO H-580	MIL-H-19457	43–50	
Water-glycol			
NATO H-579	MIL-H-22072	36–43	

4.4.3 OPERATING TEMPERATURE RANGE—Filters must be designed and sized to perform over the operating temperature range of the system. If the systems must start at cold ambient temperatures, this must be considered. Generally, fluids in aircraft systems must operate over a wider temperature range than fluids in ship hydraulic systems. This is the primary reason that a low viscosity fluid is selected. While ship hydraulic systems operate in a narrower temperature range, the higher viscosity fluids with lower viscosity indexes may result in even greater viscosity variations than found in aircraft systems. Only the lower temperature of the operating range is important in sizing filter elements. If the filter elements are not designed for the viscosity at the coldest temperature, excessive pressure losses across the filter will be experienced, bypass relief valves may lift or the element may collapse due to excessive differential pressure.

4.4.4 CHANGE OF VISCOSITY WITH PRESSURE—Designers often are unaware of and ignore the change of viscosity with pressure although this can be a significant factor with most fluids. Fluids whose viscosity varies significantly with temperature are subject to viscosity change with pressure. The viscosities of water-base fluids change relatively little with pressure, but these fluids are seldom used in ship systems since they are not suitable for cold temperatures. For MIL-H-5606 aircraft hydraulic fluid at 40 °C, the increase in viscosity at 20 MPa (2900 psi) is approximately 30% compared to the viscosity at atmospheric pressure and 40 °C, increasing by nearly 75% at –40 °C a typical temperature requirement for cold start of aircraft systems in cold climates. For the more viscous fluids normally used in ship hydraulic systems, the increase is even greater. For example, the viscosity of 2135TH fluid (ISO viscosity grade 68) increases by factors of 1.65 and 3.0 at pressures of 20 MPa (2900 psig) and 60 MPa (8700 psig) respectively. For phosphate-ester base fluids, the increase in viscosity with pressure is even greater than with petroleum fluids. (See SAE J1778 for additional data on viscosity change with pressure.)

4.5 Filter Location

4.5.1 NUMBER AND LOCATION OF FILTERS—The number and location of filters within a system are dependent to a large degree on the size of the system, the number of actuators and pumps, and of the sensitivity of the components to contamination. Generally filters are installed in one or more of the following locations:

a. Pump suction
b. Pump discharge
c. Pump case drain
d. Upstream of contamination sensitive components
e. Return lines

SAE J1779 provides guidance on hydraulic system design criteria, including filtration requirements, for high-performance surface vehicles and small submersible vehicles. SAE J1779 contains the following recommendations:

a. Pump discharge filters for all pumps with the possible exception of hand pumps
b. Return line filters for systems serving more than 5 actuators or more than one compartment
c. Case drain or return line filters for flow from pump and motor case drains
d. Last chance (secondary) filters as necessary to protect contamination sensitive components

4.5.2 PUMP SUCTION VERSUS RETURN LINE FILTERS—Both pump suction and return line filters are used primarily to protect pumps. Pump suction filters are located closer to the pumps and can compensate for poor tank design, but that is about their only advantage. Pump suction filters must operate at very low differential pressures. Consequently, they must be of relatively large size compared to return line filters of the same flow and dirt capacity. In addition, bypass relief valves are almost mandatory to prevent starvation and damage to the pump when the differential pressure becomes excessive due to contamination or cold fluid during system start-up. Return line filters can accommodate higher differential pressures than suction filters. Bypass relief valves in return lines can be set at higher pressure than in suction filters. Accordingly, higher dirt capacities can be obtained in return line filters compared to suction filters of the same size and weight. However, in sizing return line filters, the designer must consider the peak flow rates that may occur, not just system pumping capacity.

4.5.3 CASE DRAIN FILTERS—For pumps with case drains, a case drain filter should be considered. A considerable amount of the contamination generated by the pump passes through the case drain. A case drain filter can provide warning of incipient pump failure. In some systems, use of a case drain filter versus a return line filter can be considered. If the system is small and contamination generation within the system minor, the use of a pump discharge filter and a pump case drain filter can provide sufficient filtration. A case drain filter can be much smaller than a return line filter because of the much lower flow rate. However, case drain filters are often used with return line filters for the following reasons:

a. Identification of incipient pump failures with case drain filters
b. Inability of pump shaft seals to withstand the higher differential pressures at which return line filters operate

In selecting case drain filters, particular attention must be given to the maximum pressure that will be present at the case of the pump or motor. Pump and motor cases often are not designed for the pressures that may be generated by the installation of a case drain filter. To protect the cases of pumps and motors, the case drain filter must generally be equipped with a bypass relief valve. Indicators on the case drain filter must actuate at relatively low pressures so that the elements can be changed before bypass flow occurs.

4.5.4 Pump Discharge Filters—A pump discharge filter should be installed in the discharge of each system pump. Return line filters are generally sufficient to maintain system cleanliness levels; however, they cannot protect system components from a catastrophic pump failure. In systems with multiple pumps, a separate discharge filter is recommended for each pump.

4.5.5 Filters Upstream of Contamination Sensitive Components—Filters should be installed immediately upstream of critical and contamination sensitive components, such as electro-hydraulic servo valves, particularly in large systems where the servo is located a considerable distance from the pump discharge filter. When such filters are installed, it is generally not a good practice to select a filter with finer filtration than the pump discharge or return line filter or they are apt to have a short service life as they become the primary system filter. Filters in these locations should be minimized. For high flow rate servo valves, filtration of only the pilot stage supply is usually sufficient.

4.5.6 Partial Flow Filtration—In some applications, the use of partial flow filtration should be considered. In partial flow filtration, only a portion of the fluid is subject to filtration. This may result in smaller and less costly filtration equipment. In a system which has large but infrequent demands, it may be possible to install partial flow filtration unit which operates continuously. Partial flow filtration may also be considered for a pump/motor transmission system where make up and control flow is provided by a separate small pump. Filtration may be provided only for the make up/control flow. However, this should only be considered where experience indicates that satisfactory contamination control of the primary system can be maintained by filtering the smaller circuit. Partial flow filtration may be considered with coarser (less efficient) system filters when system limitations preclude using full flow filters of sufficient efficiency. Certain types of partial flow filtration, such as those employing electrostatic precipitators, may be particularly suitable for such applications.

4.5.7 Hydrostatic Transmissions—It may not be necessary to provide filters in the closed transmission loop when the pump and motor are located in close proximity to each other and there is sufficient leakage flow that the transmission loop is kept clean by replenishment with clean fluid. However, in many cases, additional filtration will be required to keep the system clean. This usually requires installing a filter in each line of the transmission loop. The filter installed must be equipped with check valves so that the flow is always in the same direction across the filter element. With two check valves per filter, filtration in only one direction is possible. By using four check valves with the filter, it is possible to obtain filtration regardless of the direction of flow within the line.

4.5.8 Minimizing the Number of Filters—In weight critical applications, efforts to minimize the number of filters to minimize weight is a consideration. Minimizing filters is easier in small systems than in large systems with several pumps and many actuators. A single pump discharge filter may be adequate in a small system.

4.6 Filter Bypass Relief Valves

4.6.1 The Influence of Mission Essentiality and Maintenance Practices—A bypass relief valve jeopardizes the very protection which a filter provides. On the other hand, a bypass relief may be necessary to prevent serious system malfunctions. Therefore, system or mission essentiality and maintenance practices are important considerations in determining whether a bypass relief valve should be provided. The need for a bypass relief valve needs to be specifically evaluated for each filter location.

4.6.2 Pump Discharge Filters—One purpose of a pump discharge filter is to protect the system components from a catastrophic pump failure. With a bypass relief, the filter may become loaded upon a pump failure and permit contamination to circulate through the entire system. To solve this problem, a two-stage filtration system may be used in which bypass flow around the primary filter flows through a reserve secondary filter.

4.6.2.1 *Single Pump Systems*—In an essential system with a single pump, it may be acceptable to provide a bypass relief. Failure of the pump basically means failure of the system whether or not the filter has a bypass relief. However, with a bypass relief, cleaning of the system after a pump failure can be costly and time consuming.

4.6.2.2 *Multiple Pump Systems*—In a multiple pump system, it is usually important that the pump casualty be limited to the failed pump and contamination isolated to prevent causing subsequent failure of other system components including the remaining pumps. Therefore, in multiple pump systems, pump discharge filters should not be provided with relief valves.

4.6.3 SYSTEM RELIEF REQUIREMENTS—When a bypass relief is not installed, the effect of increasing differential pressure on system operation and maintenance philosophy must be considered. Filter elements must be able to withstand the differential pressure which may be developed. Since pressure in excess of system pressure may result if maintenance is neglected, a pump discharge relief valve should be located between the pump and the filter to protect the pump, piping and the filter from excess pressure. As this relief lifts, less flow passes through the filter to the system. With proper maintenance this relief should lift only in event of a catastrophic pump failure occurring when the filter is nearing its terminal dirt capacity. If this is a multiple pump system, the relief valve should discharge into a return line upstream of any return line filter, not directly to tank.

4.6.4 MAINTENANCE PRACTICES FOR PUMP DISCHARGE FILTERS—Under normal circumstances, immediate change of a filter element is not required when the replacement differential pressure is reached. However, good maintenance practice is necessary since the rate of pressure build-up increases with time. Devices indicating the need for element replacement must be monitored frequently enough that element replacement can be scheduled before system operation and mission completion are jeopardized. Unlike aircraft applications in which the elements are replaced only at the completion of a mission, the length of ship missions sometimes requires element replacement during the mission. In cases of a single pump system, this may require the installation of multiple filters so that system operation may continue while one filter is being changed. When periodic maintenance inspection for excessive pressure differential is infrequent, it may be necessary to have a remotely operated panel light to warn when element replacement is necessary.

4.6.5 BYPASS RELIEF VALVE REQUIREMENTS FOR RETURN LINE FILTERS—For return line filters, a bypass relief valve is usually recommended. First, without a bypass relief, the danger of excessive return line pressure causing inadvertent actuator operation must be considered. Secondly, without a relief valve, it may be necessary to design the return line piping for greater pressures, adding to the weight and cost of the system. An alternative to a built-in bypass relief in the filter, is a return line relief which will open when the differential pressure across the filter becomes excessive. Even when relief protection is provided, frequent monitoring of filter condition is necessary and the use of remote warning lights should be considered.

4.6.6 BYPASS RELIEF VALVE REQUIREMENTS FOR CASE DRAIN FILTERS—Case drain filters can be installed with or without bypass relief valves. If the filter discharge is directly to tank, a bypass relief should be avoided. If discharge flow also passes through a return line filter, the use of a bypass relief is acceptable. The pressure rating of pump shaft seals may dictate the use of a bypass relief.

4.6.7 BYPASS RELIEF REQUIREMENTS FOR COMPONENT FILTERS—Where filters are provided for specific components, the recommended practice is to avoid bypass relief valves. U.S. submarine steering and diving system hydraulic servo valves were originally designed with pilot stage filters with bypass relief valves. Sailors often ignored maintenance and contaminants bypassing the filters resulted in degraded servo valve performance. Corrective action required both filter element and servo valve replacement. The bypass relief valves were later eliminated. Neglect of maintenance now results in high differential pressure across the filter and eventually degraded performance of the servo valve similar to that experienced with contamination. However, corrective action now requires only replacement of the filter element.

4.7 Filter Element Efficiency and Dirt Capacity

4.7.1 FILTER EFFICIENCY RATINGS—Although improved methods of specifying filtration efficiency (Beta ratios or percentage removal by weight) have been established, too often filter efficiency has been specified by relatively meaningless absolute or nominal ratings. (In addition to the definitions in Section 3, see SAE AIR 887 for a detailed description of liquid filter ratings.) NFPA T3.10.8.8 and ISO 4572 are multipass test procedures to determine the efficiency and dirt capacity of fine filter elements.

4.7.2 FILTER MEDIA INFLUENCE ON EFFICIENCY AND DIRT CAPACITY—Many different types of media are employed for filters. Over the years there has been a general trend from the use of cleanable metal elements to the use of cellulose and fiber-glass disposable elements. This trend may change due to environmental concerns with the disposal of elements. In general, the disposable media tends to offer greater efficiency and more dirt capacity when elements of equal volume are compared.

4.7.3 RECOMMENDATIONS FOR ELEMENT EFFICIENCY—To a large degree, the filter efficiency selected should depend upon the contaminant sensitivity of components. Procedures have been developed to determine the contamination sensitivity of system components. Using finer filters than necessary decreases filter life and increases filter element costs. On the other hand, failure to provide adequate filtration can result in increased component wear and even malfunction. For systems where operation is critical, it is better to error by provided finer filtration than needed than to risk component malfunction due to contamination. While filter element efficiency as determined by a multipass test, such as ISO 4572, provides a means of comparing filter elements, it does not directly correlate with the system cleanliness which will be achieved. This is because the test procedures cannot duplicate field conditions. The contaminants in the field differ from test contaminant as do their levels. The multipass tests are generally run with a higher level of contamination than is present in the system. When the contaminant levels are reduced, as in actual service, the efficiency of the elements tends to be lower than under normal multi-pass test conditions. Also the multi-pass test does not subject the element to pressure pulses, variations in flow rate, cold start and shock, vibration, and other conditions which may degrade filter element performance. See 4.12 for recommended system cleanliness levels.

4.7.3.1 Efficiency of Pump Suction Strainers—Generally pump suction strainers are preferred to filters and the fineness of filtration provided should consider the contamination sensitivity of the pump. In general suction strainers with apertures 300 µm square (50 mesh/linear inch) are adequate.

4.7.3.2 Efficiency of Filter Elements—While selecting filter efficiency, the contaminant sensitivity of system components needs to be considered. However, experience has shown that elements with a $Beta_{10}$ rating of 75 or higher are generally adequate for most components. Filter elements to MIL-F-24702 generally have a Beta rating of 75 or higher at 10 µm. MIL-F-24402 and MIL-F-8815 (15 µm absolute) elements usually have a Beta rating of about 200 at 10 µm, although the Beta rating tests are not required by the specifications. When issued, SAE J2321 is expected to replace MIL-F-24402/4 and MIL-F-24702 and its associated specification sheets. If elements of different efficiencies are used in a system, the element with the highest efficiency will tend to be subject to the greatest dirt loading. Therefore, the filter providing the finest, most efficient filtration should have a large capacity. For this reason, it is recommended that return line filters be the ones with the highest efficiency. Dirt capacity can be obtained at lower cost and minimum weight in low-collapse pressure elements and low-pressure assemblies.

4.7.4 DIRT CAPACITY CONSIDERATIONS—Little guidance for determining the dirt capacity of filters in marine applications has been available. Similarly, no general system dirt capacity requirements have been established by the aircraft industry where the need for adequate filtration has long been recognized. However, it has been reported (see 2.2, Wilcox) that in many cases airlines are achieving up to 5000 operating hours before element replacement. It is difficult to establish specific requirements which can be universally applied because of differences in system design, components, environmental, and other operating conditions. However, the following guidelines are applicable:

a. The more locations in which filters are installed, the less dirt capacity required for each element.
b. When return line filters are used, the elements in these filters generally require a higher dirt capacity per unit of flow than do pump discharge filters.
c. Pump and motor case drain filters are downstream of primary contaminant generators and require the largest dirt capacity per unit of flow. Fortunately, flow rates in case drain filters are relatively low and adequate dirt capacities can be achieved with reasonable size filters.
d. In specifying dirt capacity, consideration must be given to system operating time. A component filter that operates infrequently does not need as much capacity as a pump discharge filter which will see continuous flow. (An extreme example is a hydraulic system on a missile which operates for only a very short time and where weight, space and cost considerations dictate that the element be of minimum size.)
e. The initial cost penalty for oversize elements must be compared with the lower cost per gram of dirt removal possible with the larger element.

NOTE—Many hydraulic filter elements are designed for aircraft systems and even those that are not, are very often rated based on MIL-H-5606 aircraft hydraulic fluid. On ships, when the weight penalty is not significant, elements with larger dirt capacity not only have significantly lower costs per gram of contaminant removal but can contribute to lower manning requirements due to fewer maintenance man-hours. Since spare elements must normally be carried on ships, smaller elements do not always result in space and weight savings as on aircraft.

4.7.5 Dirt Capacity Recommendations—Mission requirements, maintenance requirements, weight, and space restrictions should all be considered in the selection of the dirt capacity of system elements along with standardization and minimization of element configurations. However, experience indicates that providing 0.25 g of dirt capacity for each liter per minute of flow (1 g per gpm) will usually provide sufficient dirt capacity.

4.8 Cost Factors In Filter Selection

4.8.1 Cost Per Gram of Element Dirt Capacity—A comparison (see 2.2, Wilcox) between filter elements designed specifically for aircraft and those designed for ships showed that the larger size elements had a much lower cost per gram of dirt capacity. Cleanable elements had a much lower cost per gram of dirt capacity. Cleanable elements had the highest cost per gram of dirt removal. For elements of the same configuration and essentially identical requirements, the disposable elements had a dirt capacity about three times as high as the cleanable elements. The cost per gram of dirt capacity for the cleanable elements was about eight times that for the comparable disposable element. Elements with a higher collapse pressure tended to have a higher cost per gram of dirt capacity than low-collapse pressure elements; the high-collapse elements requiring a more costly support structure.

NOTE—The larger procurement quantity required for disposable elements is a factor in the lower procurement cost for disposable elements.)

4.8.2 Maintenance Costs—In addition to lower costs per gram of dirt removal, large elements reduce the frequency of maintenance. Therefore, large dirt capacity elements should be used where feasible to minimize the introduction of contamination during maintenance and to reduce manpower requirements and associated costs.

4.8.3 LOGISTIC SUPPORT COSTS—Logistic support costs shall be considered in the selection of filter elements for an application. Costs can be reduced by minimizing the number of different elements which must be logistically supported. This concept has been used on DC-9 and DC-10 aircraft and on the SSBN 726 Class of submarines. In each case, the system was designed to use a single configuration element with multiple elements being used in applications with high flow rates. One airline was impressed that an inventory of only $200 dollars in filter elements was required to support a DC-9 versus several thousand dollars for a foreign competitor. For aircraft, spare elements are stocked at maintenance bases, whereas for ships, spare elements must normally be carried onboard. Without the severe weight penalties for oversize filter assemblies on aircraft, ship designers can standardize on large dirt capacity filters that will minimize both maintenance and logistic support costs. Using a minimum number of elements sizes also reduces the storage space for spare elements.

4.8.4 LIFE CYCLE COSTS—Life cycle costs include the initial cost of the filter assembly, cost of replacement elements, the man-power costs to change the element, and element disposal costs. A comparison between the life cycle costs for a servo pilot stage filter on a class of submarines which used a small MIL-F-8815/2 filter and the use on a later class of a MIL-F-24402 filter with a large Size B element indicated that the life cycle costs were 9 times greater when the smaller element was used. (Reference 2.2, Wilcox) This comparison ignored certain logistic support factors, such as the need for fewer configurations of elements, which would result in even greater savings. However, larger assemblies can pose arrangement problems and increase design costs.

4.9 Selection of Maintenance Practices

4.9.1 GENERAL—There are several general practices that can be employed with regard to filter maintenance, i.e., element replacement/renewal:

a. Replacement at specific intervals, (i.e., six months, one year)
b. Replacement based on operating hours
c. Replacement (based on differential pressure)
d. Some combination of two or more of the previous practices

The advantages and disadvantages of these practices will be covered in the following paragraphs.

4.9.2 PERIODIC ELEMENT REPLACEMENT—Monthly, semi-annual, or yearly replacement of filter elements is a relatively easy practice to implement. However it is often difficult to determine the proper replacement frequency. If elements are replaced too early, element and manpower costs are increased. If the interval between replacement is too long, the build-up of differential pressure may cause filter bypass relief valves to open. This permits contaminants to reach components, causing wear, jeopardizing component performance and life. If bypass relief valves are not installed, performance may degrade. If slightly degraded performance is acceptable and it will signal the need for filter maintenance which can be accomplished within a relatively short period, then this may be acceptable. In most applications, periodic replacement alone is not a satisfactory maintenance practice. However, for systems or portions of systems that operate very infrequently and for which dirt capacity is more than adequate, periodic replacement may be suitable. For example, in a system where hand pumps are used only for emergency, replacement of hand pump discharge filter elements every few years may be completely adequate. In most cases, a periodic element replacement practice usually needs to be combined with replacement based on differential pressure across the element.

4.9.3 Element Replacement Based on Operating Hours—This maintenance practice presents some improvement over simple periodic replacement of elements since it is based on operating hours, not just elapsed time. However, if this is the sole maintenance practice it suffers from many of the same disadvantages as periodic element replacement. Replacement based on operating hours combined with replacement based on differential pressure is a very good maintenance practice which is used extensively on commercial aircraft. Replacement of elements is accomplished during scheduled major maintenance and overhaul periods based on operating hours. Unlike, aircraft, the operating hours for various ship systems are often not the same as ship operating hours. System operating hours are not currently recorded for most ship hydraulic systems, although this could be accomplished relatively easily.

4.9.4 Element Replacement Based on Differential Pressure—The most widely used maintenance practice for the replacement of filter elements is replacement based on the differential pressure across the element. This requires the filter or filter installations to be equipped with indicators for monitoring the differential pressure. The practice results in maximum filter life. However, the selection of proper indicators is important for monitoring the differential pressure as filter maintenance needs to be accomplished relatively soon after the need for replacement is identified as the pressure differential across the filter will continue to increase at an exponential rate.

4.10 Selection of Element Condition Indicators

4.10.1 Indicator Types—The type of indicator selected must be matched to the application. The filter indicators most often used in ship systems consist of the following types:

a. Mechanical Pop-Up
b. Mechanical Pop-Up with Switch for Remote Indication
c. Gage type
d. Continuously Indicating, Mechanical Type
e. Electrical Indicator Type

The MIL-F-24402 specification provides for the first three types listed previously and has standardized the porting configuration so that the three types are interchangeable. Therefore, initial selection of the wrong type can be remedied with relative ease and minimum cost. In the follow paragraphs the advantages and disadvantages of the generic type of indicators listed previously are identified.

4.10.2 Mechanical Pop-Up Indicators—A widely used indicator for element replacement is the mechanical pop-up indicator. As differential pressure increases to a predetermined value, an indicator button (usually red in color) pops up. Mechanical pop-up indicators require periodic visual inspection to determine if they have been activated, since, once activated they remain in the pop-up condition until reset.

4.10.2.1 Advantages of Pop-Up Indicators—The advantages of this type of indicator are its compact size and relatively low cost. The fact that the indicator remains actuated even after system shut down can be an advantage in applications where the indicator can be monitored only periodically.

4.10.2.2 Disadvantages of Pop-Up Indicators—A major problem with pop-up differential indicators is that they may be actuated on cold system start-up when differential pressure can be high. This problem is sometimes solved by equipping the pop-up indicator with a thermal lock-out, which prevents actuation until the fluid reaches a warmer temperature. Another problem is that pop-up indicators may be actuated by short duration flow surges. Again, some indicators are designed so that they will not actuate for flow surges of very short duration, for example, 0.1 s. Another problem is that the indicators are sensitive to changes in fluid viscosity. This is particularly a problem with many of the fluids used in ship hydraulic systems. Therefore, indicators with mechanical pop-up indicators are not recommended for use in applications where fluid viscosity will vary significantly. See additional discussion under 4.10.2.3.

4.10.2.3 Thermal lockouts on MIL-F-8815 Pop-Up Indicators—Thermal lockouts on MIL-F-8815 pop-up indicators prevent actuation of the pop-up until fluid temperature reaches 38 °C ± 8 °C (100 °F ± 15 °F). For MIL-H-5606 fluid used in aircraft, the viscosity varies from approximately 17 cst at 29 °C (85 °F) to 14 cst at 46 °C (115 °F), a change of 20%. On the other hand, MIL-L-17331 fluid used in submarine hydraulic systems varies from 150 to 60 cst over this same temperature range. This large viscosity change at atmospheric pressure is even greater at system operating pressure. One problem is that indicators with thermal lock-outs must not be used in applications where the fluid temperature is not sufficient to disengage the lockout. The filter can become excessively dirty but the thermal lockout may prevent the pop-up from actuating. MIL-F-24402 mechanical pop-up indicators are not equipped with thermal lock-outs.

4.10.3 MECHANICAL POP-UPS WITH SWITCH FOR REMOTE INDICATION—For some applications, filters may be located in areas which must be opened for access or in applications where it is necessary to know filter status at a remote location. In these applications, the mechanical indicator may be combined with a remote indicating device, usually a light. A single light may be used for a group of filters in a particular area of application to decrease space and installation cost requirements. On-site inspection is then required to determine the specific filter requiring service.

4.10.4 DIFFERENTIAL PRESSURE GAGES—Differential pressure gages can be integral with the filter housing or may be mounted at some distance from the filter by using runs of tubing. The MIL-F-24402 gage type indicators are relatively compact and are designed so that the gage face may be rotated to face in a direction convenient for monitoring. An alternative is to install pressure test stations upstream and downstream of the element where a differential pressure gage can be installed with quick disconnect fittings and hoses that can be connected and disconnected under pressure. However, for ease of use and to encourage proper maintenance, an installed indicator is recommended although the installation of test points for validation of installed indicators is encouraged.

4.10.4.1 Advantages of Differential Pressure Gages—For conditions in which viscosity and flow vary considerably, the differential pressure gage can be used in conjunction with a chart which indicates the differential pressure at which the element should be changed for various temperature and flow conditions. In addition, gages give an indication of remaining element life, whereas pop-up indicators do not.

4.10.4.2 Disadvantages of Differential Pressure Gages—Differential pressure gages are relatively expensive particularly if a high degree of accuracy is required. The MIL-F-24402 gages have a reasonable accuracy and are relatively inexpensive though more costly than pop-up indicators. Gage type indicators are suitable only for monitoring current conditions. They may not be suitable for use in a return line application where high flow rates occur only infrequently. In such an application, a pop-up indicator may be more appropriate. The gage type is an alternative if high flow rates can be induced for the specific purpose of monitoring filter condition.

4.10.5 MECHANICAL DIFFERENTIAL PRESSURE INDICATORS—These indicators are similar to pressure gages in that a mechanical pointer is actuated by differential pressure to indicate filter condition. These indicators are integral with the housing and usually part of a bypass relief assembly. The following words and colors are usually used to indicate element condition:

a. Clean or OK—Green
b. Caution—Yellow
c. Change or Bypassing—Red

Mechanical differential pressure indicators of this type are suitable for use where the indicator may be observed during system operation. However, at least one manufacturer makes an indicator which not only indicates current differential pressure but also indicates the highest differential pressure experienced since the indicator was last reset.

4.10.5.1 Advantages of Mechanical Differential Pressure Indicators—The advantages are similar to differential pressure gages. These indicators may be more rugged and less expensive than gages.

4.10.5.2 Disadvantages of Mechanical Differential Pressure Indicators—These indicators have disadvantages similar to differential pressure gages. If operating temperatures and fluid viscosity vary significantly, this type of indicator may not be suitable.

4.11 Selection of Standardized Elements and Assemblies

4.11.1 Use of Standard Configuration Elements—Whenever possible, standard elements to an industry or military specification should be used. The advantages of using standardized element configuration are:

a. Multiple sources. Increased competition results in lower costs for elements and eliminates dependency upon a single source.
b. The performance parameters are adequately identified. Problems often occur when a user goes to an alternate source without adequate specifications. In such cases, element performance may not meet that of the original source.
c. Elements are more readily available and tend to be less expensive because of increased demand.

4.11.2 Use of Standard Housings—The use of standard housings is not as important as the use of standard elements. The advantages of standard housings are similar to those for filter elements. Another advantage is that replacement housings from other manufacturers will interchange without piping and foundation modifications.

4.11.3 Reasons for Using Non-Standard Housings—In applications where weight or space are critical, the use of a non-standard housing may have benefits. By having the filter element integral with other components it may be possible to obtain significant weight or space savings.

4.12 Determining System Cleanliness Requirements.

4.12.1 Contamination Sensitivity of System Components—The cleanliness level of the system generally must be satisfactory to provide the cleanliness required for the most contaminant sensitive component in the system. Normally, the most contaminant sensitive components are pumps, motors, and valves. Variable volume piston pumps are usually more sensitive to contamination than other types. For valves, servo valves are usually the most contaminant sensitive followed by proportional valves. Most manufacturers of hydraulic components will identify the fluid cleanliness required for satisfactory operation of their equipment. Major component manufacturers and major filter suppliers have published general cleanliness requirements for components. (See all 2.2 references, except Wilcox.) The cleanliness levels in Table 2 are based to a large extent on these recommendations. The recommended cleanliness levels in Table 2 can be used where test data and manufacturer's recommendations are not available. The levels in Table 2 are general recommendations and the sensitivity of specific components may vary.

4.12.2 Adjustments to Table 2 Cleanliness Levels—When cleanliness levels based on component contamination sensitivity tests or the manufacturer's recommendations are not available, use Table 2 to find the cleanliness level based on the most contamination sensitive component (i.e., the lowest range numbers.) Adjust these numbers one range lower if two or more of the operating conditions identified as follows are applicable:

a. Water-base fluids (including water-oil emulsions and water-glycol) are used. (Also applies if system is likely to be contaminated with water)
b. Operation at fluid temperatures above 70 °C
c. Frequent cold starts with fluid temperature below 0 °C
d. System is critical to mission
e. System malfunction could endanger personnel or ship safety