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Hydraulic fluid power contamination control — General principles and guidelines for selection and application of hydraulic filters

Vérification de la contamination des transmissions hydrauliques — Principes généraux et lignes directrices pour l'application et la sélection des filtres hydrauliques

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Contents

Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 15640 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 6, *Contamination control*.

Introduction

Hydraulic systems transmit power by means of a pressurized liquid in a closed circuit. Foreign materials or contaminants present in the fluid can circulate around the system, cause damage to the component surfaces, and reduce the efficiency, reliability and useful life of the system. Hydraulic filters are provided to control the number of particles circulating within the system to a level that is commensurate with the degree of sensitivity of the components to the contaminant, and the reliability and durability objectives of the hydraulic system.

The selection and application of filters takes into account the filter design and performance, the system design and function, the required cleanliness level (RCL), the severity of the system operation and the standard of maintenance. The only way to confirm whether the correct filter has been selected is to monitor the cleanliness level in the fluid, and the reliability and durability of the system.

These guidelines are intended to introduce the concepts of cleanliness management and filter selection and application to both system designers and users. Although this guide cannot make one an expert on filter selection and use, it does seek to educate and thereby assist the reader in making informed decisions about filtration, and to improve the communication process.

Hydraulic fluid power contamination control — General principles and guidelines for selection and application of hydraulic filters

1 Scope

This Technical Report is applicable to contamination control principles for hydraulic fluid power systems and includes guidelines for the selection and application of hydraulic filters. Although control of non-particulate contamination, e.g. air, water and chemicals, is important, and is briefly discussed, the primary focus of this Technical Report is the control of particulate contamination and the selection and application of filters for that function.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5598, *Fluid power systems and components — Vocabulary*

NOTE The other documents mentioned and referenced in this document in a non-normative way are listed in the Bibliography.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following apply.

3.1
contaminant
any material or combination of materials (solid, liquid or gaseous) that can adversely affect the system

3.2
ingression
introduction of environmental contamination into the system

NOTE Contamination introduced through ingression is referred to as ingressed contamination.

3.3
filter medium
part of the filter structure that removes and retains contaminant

3.4
filter media
collective layers that make up a filter element

4 Types and sources of contamination

4.1 General

Contaminants in a hydraulic fluid are any material or combination of materials (solid, liquid or gaseous) that can adversely affect the system.

4.2 Solid contaminants

4.2.1 General

Solid contaminant particles come from four main sources as shown in Table 1 and can vary considerably in material, hardness, shape and size from sub-micrometre to millimetres.

Contaminant shape varies widely and debris can appear as granular (cube-shaped), acicular (rod-shaped), platelets (very thin, nearly two dimensional), irregular fragments and fibres. Shape affects the way that particles are aligned in the moving fluid and thus the likelihood of the particles becoming lodged in a small clearance or trapped within the filter medium. Although quite important, particle shape is rarely reported because of the difficulties involved in its determination.

Table 1 — Primary sources of particulate contamination

Built-in (manufacturing debris)	Ingressed		Generated		Maintenance (service debris)
	Process	Atmosphere	Surfaces	Fluid	
– burrs – machining swarf – weld spatter – abrasives – drill turnings – filings – dust – contaminated components – dust from grinding – incompatible fluids – paint chips	– initial fluid fill – addition of incorrect fluid – compressed air or gas – pulp – pulverized coal – ore dust – aggregates – cement – catalysts – clays – process chemicals	– ingestion via reservoir breather – ingestion via seals – reservoir opening – rock dust – mill scale – quarry dust – foundry dust – slag particles – dust from welding and grinding	– mechanical wear – corrosive wear – cavitation – exfoliation – hose materials – filter fibres – break-in debris – elastomers	– re-entrainment – filter desorption – additive precipitation – sludge – insoluble oxides – carbonisation – coke – aeration – varnishes	– repairs – preventive maintenance – new filter – new fluid – dirty hose, connector, components – top-up containers – incorrect fluid – cleaning rags – dust from welding and grinding – dust from atmosphere and workplace

4.2.2 Built-in contaminant

All new systems contain some contaminant left during manufacture and assembly. This can consist of fibres (from rags, etc.), casting sand, pipe scale, cast iron or other metal particles, jointing material or loose paint. When a system is operated at an unusual load or if there are high pulsations in the flow, it is likely that built-in contaminant becomes dislodged.

4.2.3 Ingressed contaminant

Systems can also be contaminated during normal operation, through openings in the reservoir, inadequate air breather filters, through worn seals in vacuum conditions and by intrusion through the fluid film on piston rods. Worn seals increase the likelihood of ingression. These ingressed contaminants can be highly abrasive.

4.2.4 Generated contaminant

When a normal system has been run for a reasonable period of time, a quantity of solid contaminant can be present in the form of small metallic platelets, created by the normal wear process. For correctly designed systems, which are provided with suitable filtration, the majority of these particles are smaller than 15 µm. If a filter blockage indicator is ignored, previously retained contaminant can be dislodged from the filter element (see 10.4.1). However, if abnormal wear occurs, both the size and quantity of particles increase and, if not detected by monitoring, wear rates can accelerate and the wear mode can change from benign fatigue wear to abrasive wear. With abrasive wear, substantial amounts of surface material can be removed.

4.2.5 Maintenance-induced contaminant

Contaminants can easily be introduced during routine system maintenance unless the maintenance is performed in a clean environment, and precautions are taken to prevent contaminant from getting on serviced items. For example, topping up the system with new fluid can add contaminants unless the fluid is filtered upon addition.

4.3 Liquid contaminants

After damage caused by solid particulate contamination, damage caused by the presence of liquid contamination is the next highest cause of contamination-related problems. This damage is caused either directly through corrosion or indirectly through the interaction of the liquid contamination with the hydraulic fluid. This either reduces the fluid’s effectiveness and thereby increases component wear rates, or reacts with it to produce insoluble products that can block filters, clearances, etc. Blockage under these circumstances is often rapid and unless it is detected and rectified, filtration ceases.

Water is the most common liquid contaminant in systems using mineral or synthetic fluids. Water can enter the system from the atmosphere, leaking coolers and condensation. Although most hydraulic fluids are formulated to cause water to separate so that it can settle in the reservoir and be drawn off, it is essential that the water content is maintained at levels well below the solubility or saturation level of the fluid used, at the minimum operating temperature.

Contamination by even small amounts of water in the fluid significantly lowers the load-sustaining capabilities of the fluid. This deterioration of lubrication ability is of great importance to many components in hydraulic systems. One example is that of rolling-element bearings, in which very high pressures are generated. If water is present in the hydraulic fluid, even in dissolved form, the viscosity increase required for the form of lubrication required in the bearing might not be achieved, and wear can result.

4.4 Gaseous contaminants

Nearly all fluids contain some dissolved gases. At atmospheric pressure, hydraulic fluids normally contain about 8 % of their volume as dissolved air, which, at this pressure, causes no problem. Increasing the pressure in the hydraulic fluid causes an increase in the amount of air that can be dissolved, and in low-pressure parts of the system, some of this dissolved air can be liberated in the form of bubbles, a situation frequently found downstream of pressure relief valves.

The presence of air bubbles in a system almost always causes erratic operation of the system, as it affects the stiffness (bulk modulus) of the fluid and thereby system response. Air bubbles in an inlet (suction) line of a pump reduce the volumetric efficiency and cause damage to most kinds of pumps through cavitation. Another effect often seen in high performance systems is the sudden compression of the fluid in the high pressure section of the pump, which causes the air bubbles to implode, and causing the vapour to ignite momentarily. The very high temperatures generated cause thermal stress on the fluid, leading to oxidation and nitration. A similar condition can exist downstream of metering valves; the process is known as “dieseling” and leads to the formation of gums, varnishes and even microscopic “coke” particles. These in turn can lead to lacquering of valves and plugging of filters.

5 Effects of particulate contamination and the benefits of its removal

5.1 General

It has been demonstrated that, in the majority of hydraulic systems, the presence of solid contaminant particles is the main cause of failure and reduced reliability. The sensitivity of components to these particles depends on the internal working clearances in these components, the system pressure levels and the quantity, size and hardness of the contaminants.

5.2 Failures caused by particulate contamination

Failures arising from contamination fall into three main categories:

a) sudden or catastrophic failure, which occurs when a few large particles or a very large number of small particles enter a component and cause seizure of moving parts (e.g. pumping elements or valve spools);

b) intermittent or transient failure, which is caused by contamination momentarily interfering with the function of a component. The particle(s) can be washed away during the next cycle of operation. For example, particles can prevent a valve spool from moving in one of its positions but are washed away when the valve spool is moved to a new position; or a particle can stop a poppet valve from closing properly but is washed clear during the next operation; and

c) degradation failure, which generally happens over time and shows up as a gradual loss of performance. The main causes are abrasive wear inside a component and erosion caused either by cavitation or by impingement of contaminated fluid at high velocity, all of which can cause increased internal leakage. If degradation failure is allowed to continue, it can eventually lead to catastrophic failure.

5.3 Benefits of filtration to reduce solid particulate contamination

The objective of filtration is to reduce the level of solid particulate contamination present in a system and maintain an acceptable level of cleanliness, no matter what contamination is being generated and ingressed into the system. Maintaining an acceptable level of contamination achieves the following benefits:

a) extended component life — the wear in components is reduced thus extending the useful life of the system;

b) enhanced system reliability (see 8.1) — maintaining fluid cleanliness minimises intermittent failures caused by particles jamming in critical components;

c) reduced downtime and servicing costs — the cost of replacing components is often far outweighed by lost production time and servicing costs. By increasing component life and reliability, contamination control contributes to production efficiency and reduced maintenance costs;

d) safety of operation — safety of operation results from consistent and predictable performance. Contamination control ensures that the conditions that lead to inconsistent and unpredictable operation are greatly reduced; and

e) extended fluid life — by minimizing the number of particles in the system, operating with a clean fluid can extend the life and serviceability of the system fluid by reducing oxidation, which is catalyzed by the presence of reactive particles. For example, it has been shown that the catalytic effect of a mixture of copper particles and water results in 47 times more oxidation (ageing) of the oil. This is of considerable importance when the lifecycle costs of fluid (initial, operational and disposal) are significant.

6 Evaluation of cleanliness

6.1 General

The level of cleanliness in a system varies depending on its design, assembly and operation. Later clauses describe the control necessary to maintain acceptable cleanliness levels. However, it is important to know what level of contamination is reasonable for the required reliability and life of the particular system and how these levels can be categorized.

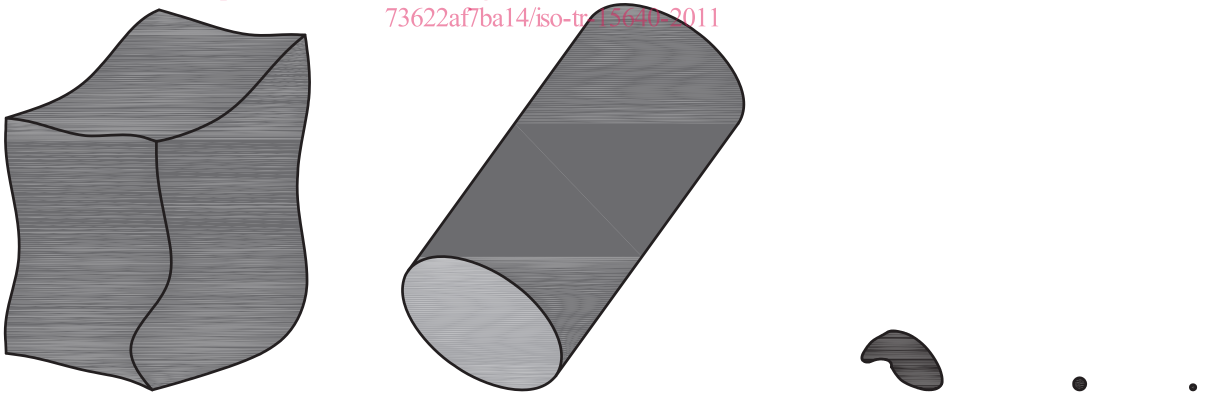
6.2 Particle size range of interest

A wide range of particle sizes can affect the performance of hydraulic components and systems. The smallest size of concern can range from 1 µm or smaller, when considering particles that cause wear by penetrating the clearances of components, to well over 1 000 µm (1 mm) in the case of large particles jamming the moving parts of components. Table 2, which is adapted from the American Society of Mechanical Engineers (ASME) Wear Control Handbook (see Bibliography), shows typical dynamic operating clearances for common hydraulic components.

Table 2 — Typical dynamic operating clearances

Component	Clearance	Component	Clearance
piston pump		servo valve	
piston to bore:	5-40 µm	spool to sleeve:	1-4 µm
valve plate to cylinder:	0,5-5 µm	orifice:	130-450 µm
gear pump		flapper wall:	18-63 µm
tooth to side plate:	0,5-5 µm	roller element bearings:	0,1-1 µm
tooth tip to case:	0,5-5 µm	journal bearings:	0,5-25 µm
vane pump		hydrostatic bearings:	1-25 µm
vane sides:	5-13 µm	gears:	0,1-1 µm
vane tip:	0,5-1 µm	dynamic seal:	0,05-0,5 µm
		actuators:	5-250 µm

The particle size range of interest presents some difficulties in perceiving and understanding the size of these particles. For most of the sizes, scientific instruments are needed to both size and count particles, as the smallest particle that can be seen with the unaided human eye is about 40 µm; see Figure 1.



Grain of salt
≈ 100 µm on each side

Diameter of a human hair
≈ 75 µm

Limit of human
vision ≈ 40 µm

5 µm
wear
particles

2 µm
wear
particles

Figure 1 — Relative sizes (diameter or longest dimension) of common particles and objects

6.3 Methods of measuring and monitoring solid particulate contaminants

Several analytical methods are commonly used to measure and describe solid particulate contaminants. Each technique produces a different piece of information about the contaminant. None produces a complete description nor is there a convenient way to translate data of one type into another. These principal methods are:

a) gravimetric concentration: determines contaminant mass per volume of fluid; ISO 4405 provides a method;

NOTE The inaccuracies inherent in this method make it unsuitable for evaluating the fluid cleanliness of modern hydraulic systems. It is more suited to analyze samples in which relatively large weights are involved, for example, the evaluation of component cleanliness.

b) optical particle counting (automatic or manual): determines size and number; ISO 11500 and ISO 4407 provide methods;

c) ferrography: primarily indicates the magnetic metal content of the contaminant;

d) spectroscopy: determines elemental composition of the contaminant;

e) filter blockage: semi-quantitative determination of size and number of particles; ISO 21018-3 provides a method.

ISO 21018-1 provides a more comprehensive list of contaminant monitoring techniques and the advantages and limitations of each method.

7 Coding systems for expressing level of solid particulate contamination

7.1 General

The output of most of the particle monitoring instruments is the number of particles at certain sizes. In hydraulic systems, these can vary considerably from single figure values in the case of larger particle sizes in very clean systems to many millions in the case of dirty systems. The communication of these varied numbers at the different sizes is often confusing, and to overcome this, several coding systems have been developed to simplify the reporting of contamination data. The basis of these codes is the sub-division of the counts into broad based bands and assigning a code number to each band. The most commonly-used methods currently in use in industry are described in the following subclauses.

7.2 ISO 4406 coding system

For industrial applications, the ISO 4406 coding system for expressing the level of contamination by solid particles is the preferred method of quoting the number of solid contaminant particles in a fluid sample. The code is constructed from the combination of three scale numbers representing the concentration of particles at three specific particle sizes.

The unit of particle size depends on the sizing parameter used in the analysis, whether it is the longest dimension (optical microscopic method) or equivalent spherical diameter (automatic particle counter method). In the ISO 4406 coding system, particle sizes expressed in µm indicates that the particle size distribution was determined using a microscope, and particle sizes expressed in µm(c) indicates that the particle size distribution was determined using an automatic particle counter (APC) calibrated in accordance with ISO 11171. In the ISO 4406 coding system:

a) the first scale number represents the number of particles in a millilitre sample of the fluid that are larger than 4 µm(c);

b) the second number represents the number of particles larger than 5 µm or 6 µm(c); and

c) the third number represents the number of particles that are larger than 15 µm or 14 µm(c).

Because not every application requires that all three sizes be specified, or in those cases where the contamination monitor is unable to provide this information, there are three variants on the three-number code, in accordance with the following examples:

a) 22/19/14, which indicates that all three particle sizes are have been counted;

b) */19/14, which indicates that there are too many particles equal to or larger than 4 µm(c) to count; and

c) -/19/14, which indicates that the application does not require that particles equal to or larger than 4 µm(c) be counted.