Troubleshooting Hydraulic System Problems

Introduction to Hydraulic Systems

In 1650, French scientist, mathematician and philosopher Blaise Pascal discovered the fundamental law of physics that forms the basis of all hydraulic systems. Pascal's Law states, "Pressure applied to a confined fluid is transmitted undiminished throughout the confining vessel or system."

In practical terms, if we apply this law to a hydraulic cylinder or motor, any oil pressure applied to the pistons will be transmitted equally in all directions within the fluid filled cylinder or motor.

Hydraulic systems may be very complex, but **every system,** no matter how basic, **must contain** a reservoir, a pump, various valves to control oil flow, direction and pressure and a hydraulic cylinder or motor to move the load applied by oil under pressure. **(SEE FIGURE 1.)**

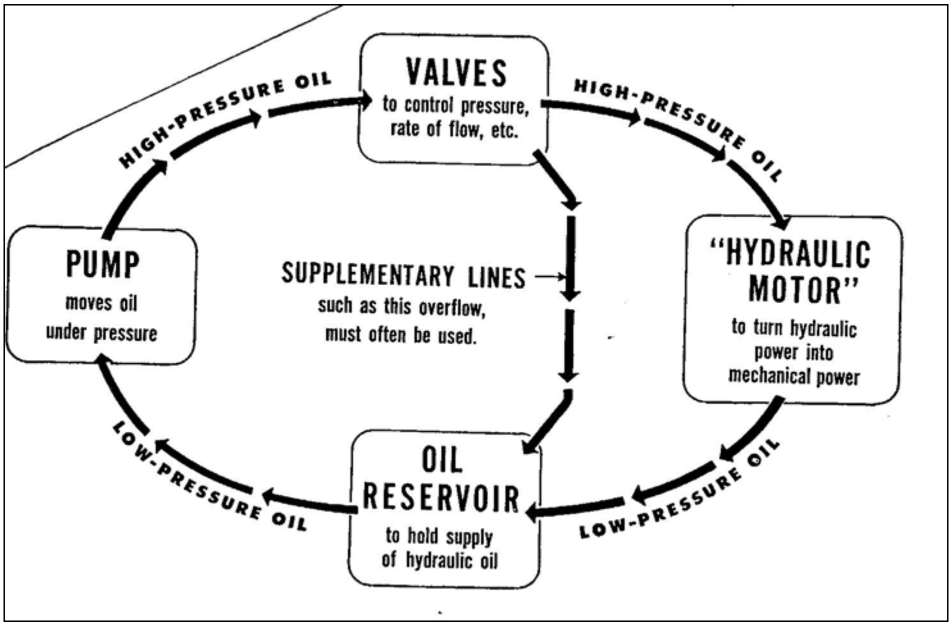


FIGURE 1. A basic hydraulic system.

Hydraulic System Operating Principles

There are two fundamental principles that must be understood when troubleshooting hydraulic system problems.

1. Pumps (which may be vane, gear, or piston types) are used in hydraulic systems to **produce sufficient flow** to obtain the speed required from cylinders or motors. This speed (oil flow) can be increased or decreased by using a pump of higher or lower capacity, or by changing the relative size of the cylinder or motor, but the flow of oil (speed of the cylinder) will not be significantly increased or decreased by altering system pressures.

2. The resistance to oil flow is directly related to the load which the cylinder is carrying or lifting, therefore **resistance to oil flow results in pressure.** The heavier the load, the higher the resulting pressure (subject to the maximum pressure setting of the pressure relief valve).

   If a system is not maintaining correct pressures while the pump is maintaining its specified flow rate, then only two conditions may exist; either an external leak is occurring, which should be obvious by the oil spill, or an internal leak is occurring which may not be so obvious.

   If on the other hand, the system is developing excessive pressures during operation, the cause is excessive resistance to flow. This may be the result of excessive load, restricted components, such as plugged filters or hoses, or some mechanical problem such as a bent cylinder rod.

   Technicians and troubleshooters would be well advised to remember these two principles and learn to correctly use flow meters and pressure gauges during their diagnostic procedures.

   Today, this lack of understanding the principles and/or an unwillingness or inability to use the necessary diagnostic tools, cannot be tolerated. How many times have we heard a plant manager or production supervisor suggest that no repair action is necessary because a “hydraulic leak is not serious.” This is a huge error in judgment.

   If a cylinder is leaking even a small amount of oil, the result may be the equivalent amount of air and dust particles entering the cylinder as it retracts, resulting in an unacceptable level of internal contamination or spongy action of components.

If the hydraulic pump is the heart of the system, then the hydraulic oil is the life blood and the functions of hydraulic oil can be summarized:

a) Transmit power from one point to another,
b) Lubricate system components,
c) Transfer and dissipate heat,
d) Provide a seal to maintain pressure.

Hydraulic Oil Selection Is of Critical Importance

Hydraulic fluids must contain rust and oxidation inhibitors, exhibit hydrolytic stability, resistance to foaming and the ability to release air and should contain an anti-wear additive, particularly where vane type pumps are used. They must also be compatible with hose and seal materials.

The viscosity of hydraulic oil changes in relationship to changes in temperature and pressure. As a result, these fluids should also have a high viscosity index, particularly where the system is subjected to dramatic changes in ambient temperatures.

Perhaps the most important consideration in selecting hydraulic fluids is the viscosity. Because the fluid itself is the power transmission medium, the oil viscosity in hydraulic systems **may be more important than in any other type of lubricated machine.**

If the viscosity is too high (thick), internal fluid friction will increase, reduced flow may occur, pump cavitation could result particularly in cold operating conditions, all of which could cause metal to metal contact (boundary lubrication) in some or all system components, such as valves and pumps.

If the viscosity is too low (thin), internal and external leakage may increase and pump slippage will increase, both of which will reduce flow rates and increase oil temperature causing oxidation and varnish deposits if severe.

In addition, boundary lubrication may also occur within valves, pumps and other lubricated components, all of which in turn, may cause an overall pressure loss within the system.

Hydraulic System Maintenance

Once correctly selected, hydraulic fluids and the systems in which they are used must be adequately maintained, in order to ensure their long life and reliability. The most important maintenance recommendations include:

1. Keep hydraulic fluids cool. The bulk oil temperature at the exterior of the reservoir should not exceed 140ºF (60ºC) and the exterior of all components must be kept scrupulously clean to ensure that no hot spots develop as a result of accumulated dust and dirt. Remember, mineral base oils begin to oxidize at around 160ºF (71ºC). Where water base fire resistant fluids are used, it is recommended that operating temperatures be

maintained at not more than 122ºF (50ºC) to minimize the loss of water through evaporation.

2. Keep hydraulic fluids dry. Water content generally should never exceed 1000 ppm (.1%) in hydraulic systems using mineral base or synthetic fluids. Biodegradable hydraulic fluids with vegetable or canola oil base are extremely susceptible to degradation caused by water. Water content should not exceed 500 ppm (.05%) if long service life is to be achieved.

3. Repair fluid leaks immediately. If oil can escape, dirt, dust and air can re-enter the system. Inspect the system periodically for the causes of leaks, such as scored cylinder rods or pump vibrations causing seal wear or damage.
   Pump vibration is frequently caused by unbalanced pumps or misaligned shafts. Hot spots at seals or valves can reduce oil viscosity causing leaks. Inspect pipe joints and fittings for looseness causing leaks.
   Ensure that pump inlets are located below the reservoir outlet to ensure that the pump is continually "flooded" with fluid. This will reduce cavitation and the possibility of air being drawn into the system by the action of the pump. **When any entrained air bubbles become compressed, they dramatically increase in temperature, causing the oil surrounding the bubbles to also increase in temperature.**
   In addition, air bubbles trapped in the fluid may vaporize and implode at valve or pump surfaces causing cavitation erosion,

which in turn causes internal leaks resulting in hot spots near the damaged surface and the conditions worsen.

Finally, keep in mind that **an external leak of one drop of oil per second is equal to 400 gallons in a 12 month period.** If an operator wants to know how much more the re-supply of oil costs, he only needs to count the plant's oil leaks. **(SEE FIGURE 2.)**

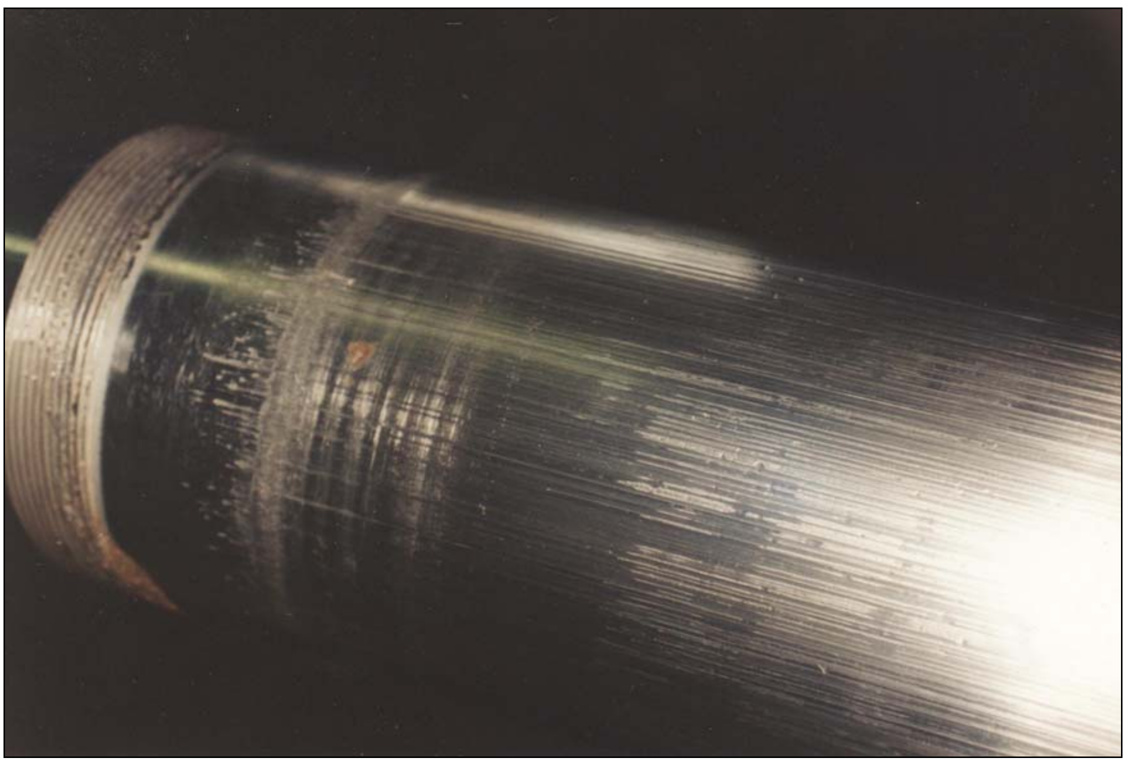


FIGURE 2. Severe scoring, evidence of rust and a circumferential seal lip wear pattern are clear indications of water and hard particle contamination on this cylinder rod. External fluid leaks past the seal were continuous during operation.

4. Keep hydraulic fluid clean. There is general agreement among hydraulic system experts that 75–80% of hydraulic component

failures are caused by fluid contamination with dirt, water, wear particles and other foreign material. In today's systems, frequently with pressures exceeding 5000 psi, clearances between lubricated surfaces are very small, making contamination control critical. **(SEE TABLE 1.)**

Table 1

Typical critical clearances—fluid system components

Item	**Typical Clearance** Micrometres	Inches
Gear Pump (Pressure Loaded)		
Gear to Side Plate	1/2—5	0.000,02—0.000,2
Gear Tip to Case	1/2—5	0.000,02—0.000,2
Vane Pump		
Tip of Vane	1/2—1*	0.000,02—0.000,04
Sides of Vane	5—13	0.000,2 —0.000,5
Piston Pump		
Piston to Bore (R)†	5—40	0.000,2 —0.001,6
Valve Plate to Cylinder	1/2—5	0.000,02—0.000,2
Servo-Valve		
Orifice	130—450	0.005 —0.40
Flapper Wall	18—63	0.000,7 —0.002,5
Spool-Sleeve (R)†	1—4	0.000,04—0.000,16
Control Valve		
Orifice	130—10,000	0.005 —0.40
Spool-Sleeve (R)†	1—23	0.000,04—0.000,90
Disc Type	1/2—1*	0.000,02—0.000,04
Poppet Type	13—40	0.000,5 —0.001,5
Actuators	50—250	0.002 —0.010
Hydrostatic Bearings	1—25	0.000,04—0.001
Anti-Friction Bearings	1/2*—	0.000,02—
Sleeve Bearings	1/2*—	0.000,02—

* Estimate for thin lubricant film
† Radial clearance

Ref. *Machine Design* May 25, 1967

TABLE 1.

The critical clearances shown clearly illustrate the importance of maintaining clean fluid in all hydraulic and

recirculating systems. For instance, the piston to cylinder bore clearances of 5–40 microns in hydrostatic transmission systems are highly susceptible to abrasive wear caused by silt sized particles. These particles cannot be effectively monitored using wear metals analysis alone, nor will they be effectively removed by applying standard full flow filtration systems.

In hydraulic systems using servo control valves, contamination in the 5 micron range can cause intermittent spool jamming, slow response or instability and eventually cause spool valve surface erosion and solenoid burnout.

Contamination in gear and vane pumps will cause scoring of gear teeth, housings, vane tips and cam rings respectively. In piston pumps, contamination will cause severe scoring on valve port plates, pump barrel assembly housing ends, pistons and piston slipper faces. **(SEE FIGURES 3, 4, 5.)**

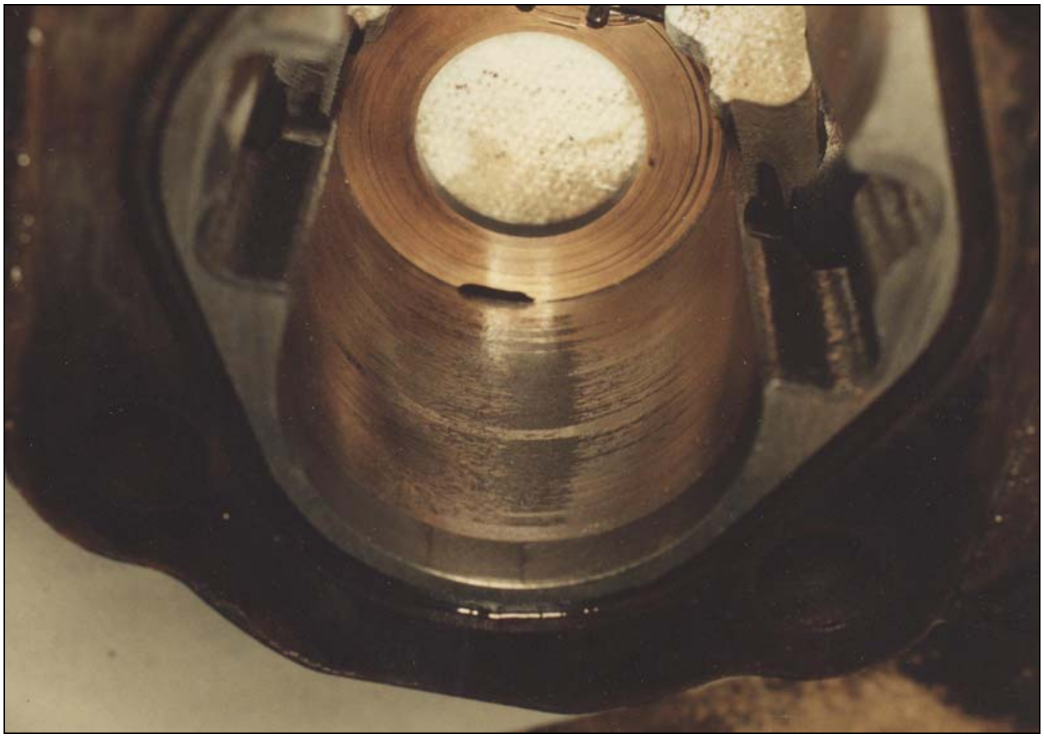


FIGURE 3. Scored gear pump housing and scored bronze pressure plate.

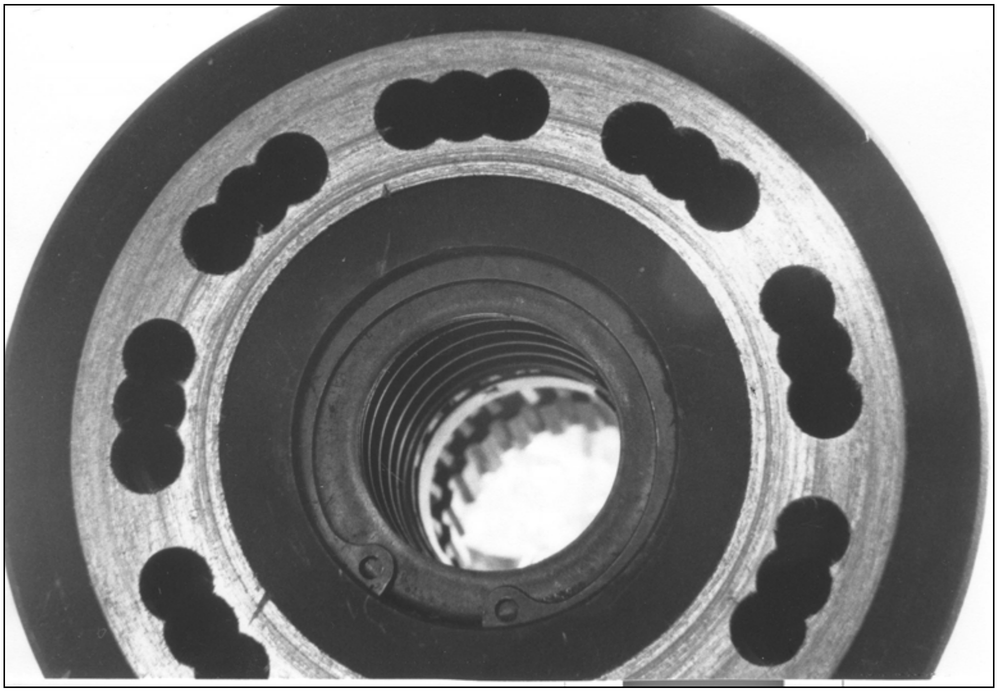


FIGURE 4. Scored piston pump barrel assembly. The standard clearance between the barrel assembly and valve port plate is .5–5 microns.

FIGURE 5. A piston pump assembly illustrating the severe scoring visible on the piston slipper faces. Note the mushroomed edges of some of the slipper faces. This is indicative of a lack of sufficient lubricant film between the slipper face and swash plate and suggests that the drilled lubricant passage in the piston was plugged with contaminants.

5. Establish an effective oil analysis program. The fluid used in a hydraulic system is a critical component of that system and its condition should be monitored as part of an effective maintenance and reliability program.

   The first consideration that must be implemented is the process for obtaining fluid samples, which is frequently neglected or misunderstood. In order to obtain repeatable and accurate data from oil samples, the following process **must** be implemented.

a) Samples must be obtained on a regularly, scheduled basis. In a 24/7 operation, sample intervals should initially be set at 300 hours until contamination levels and other problems are resolved, after which sample intervals may be extended.

b) Samples must be taken at the same location each time, preferably at a location after the oil has circulated through the system, but before the filter.

c) Samples must be taken using the same method, preferably from a sampling valve installed in the system using a proper container designed for the purpose. **(SEE FIGURE 6.)**

d) Samples must be drawn when the oil is hot and well circulated, preferably while the machine is in operation after reaching its operating temperature. This will ensure that the sample is representative of the condition of the oil.

e) Always compare the used oil analysis with the record of an analysis of the **new oil**, so that comparisons can be made.

FIGURE 6.

As noted earlier, contamination can be a serious problem in any hydraulic system and contrary to current practices and popular opinion, monitoring contamination levels is very often much more important than measuring wear rates using spectroscopic analyses. The reasons should be obvious, but are often not well understood as the following graphic illustrates. **(SEE FIGURE 7.)**

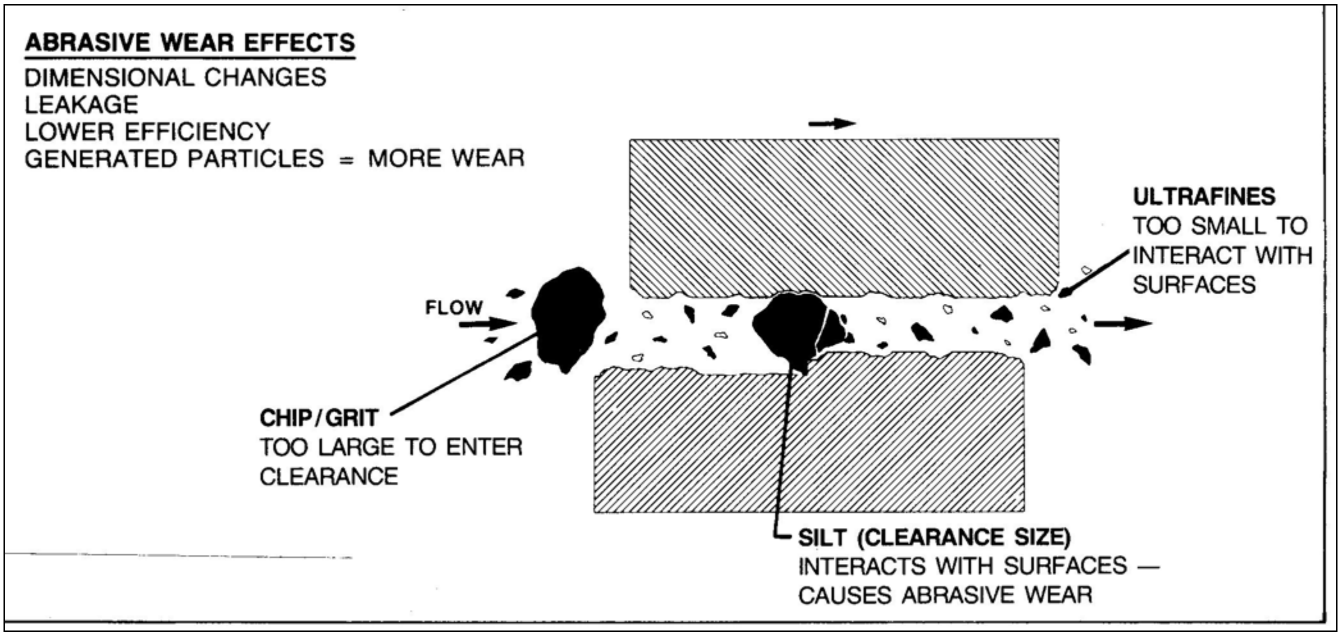


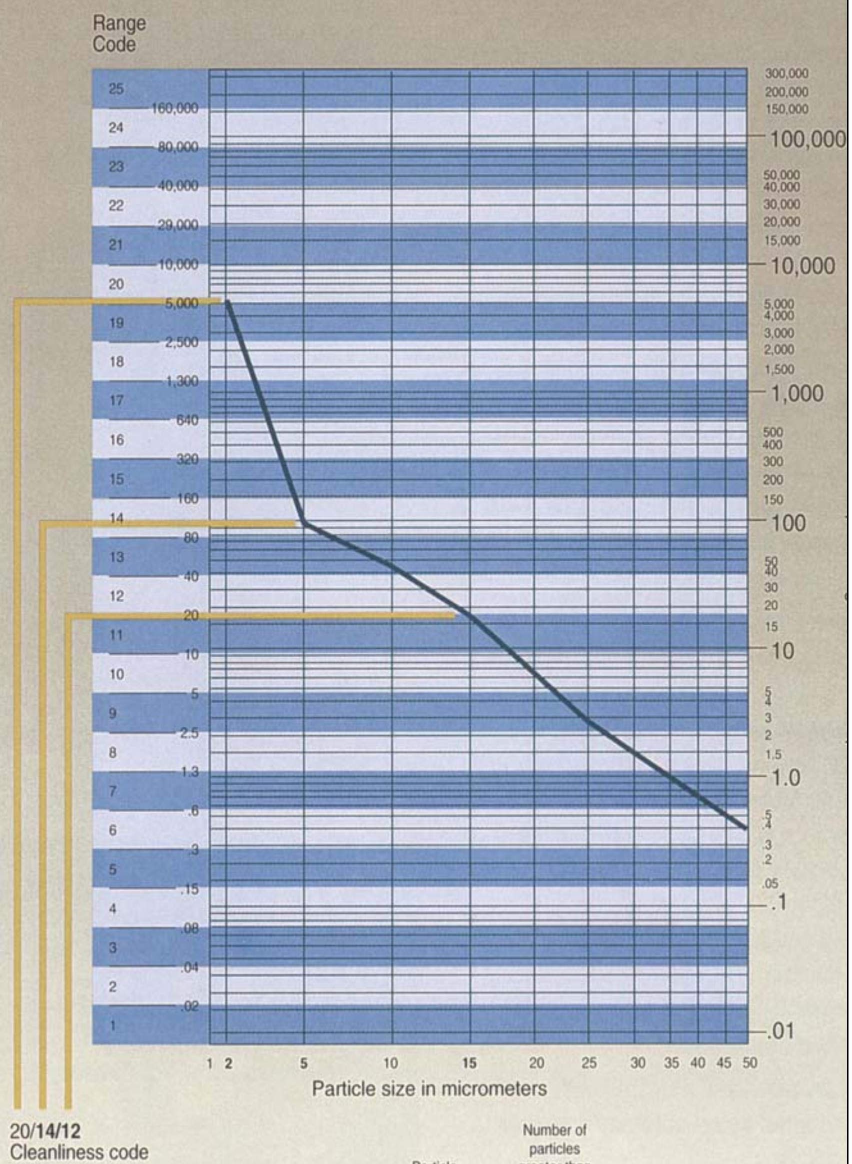
FIGURE 7.

Ultra-fine particles are those particles, usually wear metals, which are **most often the result of wear, but not the cause of wear,** yet these are the particles most often measured regularly using spectroscopic analyses. Most spectrometers are limited to the measurement of particles in the submicronic to 5 micrometer size range and the result is that silt or clearance size particles are **not monitored** when using only spectroscopic analyses.

On the other hand, silt sized particulate in the size range of 2–15 micrometers are those which cause the most abrasive wear. In addition, if a hydraulic system is equipped with only standard 10 micron filters, much of this contaminant is **never** removed by the full flow filter. It is critical therefore that the larger and more abrasive silt particulate be monitored and particle counting techniques must be used for this purpose.

6. Apply the Fluid Cleanliness Code Standard ISO 11171 to all hydraulic equipment. After a particle counting procedure is carried out by an oil analysis laboratory, the results are most often converted to the ISO fluid cleanliness code. In 1999, the ISO (International Standards Organization) fluid cleanliness code 11171 replaced the older standard ISO cleanliness code 4406. ISO 4406 measured and monitored >2, >5, and > 15 micrometer particulate in hydraulic and recirculating fluid systems. ISO 11171 changes the particle size the code represents. The newer ISO code measures particle size ranges of >4, >6, and >14 micrometer, respectively. **(SEE FIGURE 8.)**

Cleanliness Code Chart



Example

Particle size "X" in micrometer	Number of particles greater than "X" size in one ml of test fluid	Range code
2	5120	20
5	89	14
10	43	X
15	20	12
25	3	X
50	.4	X

FIGURE 8.

7. Implement the following preventive maintenance and condition monitoring techniques for hydraulic machinery.

    a) Minimum oil analyses testing should include; spectroscopic elemental analysis to monitor wear rates and measure viscosity at 40ºC and 100ºC to determine thickening, thinning or shearing of the fluid, particularly when using multigrade fluids. Water content should be measured using an accurate test, such as the Karl Fischer analysis, which reports water content in ppm or percentage. Measure ISO cleanliness levels and the acid number, which will provide a guide to the remaining life of the hydraulic fluid. In all cases, AN will increase as weak acids accumulate or oxidation occurs in the fluid. Compare these test results with new oil test results for comparison purposes and **always** act on the oil analysis laboratory's recommendations.

    b) Whenever an oil analysis report indicates high levels of contamination or wear rates, consider carrying out a ferrographic analysis of the hydraulic fluid. This test will provide additional and very useful information on the type of wear or contaminant and its probable or possible source.

    c) If contamination by dirt, water or wear metals remains a problem, consider the installation of additional side stream, absorbent filtration systems capable of removing solids and water. **These filters should be rated in absolute terms at a micron rating lower than the smallest clearance in the system**. For example, if the system uses servo valves with clearances of 2 microns, the side stream or kidney filters should be rated at a minimum of 2 microns or lower and **always pre-filter** new oil prior to topping up or filling the reservoir.

In addition, reservoirs should be fitted with access plates to allow periodic interior cleaning and all reservoir air breathers should be fitted with 2 micron filters. **(SEE FIGURE 9.)**

FIGURE 9. Good quality filters with absolute micron ratings, such as Pall or Harvard filters, are recommended for use in all hydraulic applications.

Improper lubricant storage and careless dispensing practices are two of the major causes of contaminated lubrication systems, including hydraulics; the following sight is all too common in many production facilities and manufacturing plants. **(See Figure 10).**

Figure 10.

Clean, cool, well-ventilated storage facilities are required for lubricants and industrial fluids. Clean hands, clean and clearly marked containers used for specific lubricants and clean, pre-filtered lubricant application practices are essential requirements for the initial control of hydraulic system contamination. Even new lubricants may contain some contamination as is illustrated below **(See Figure 11.)**

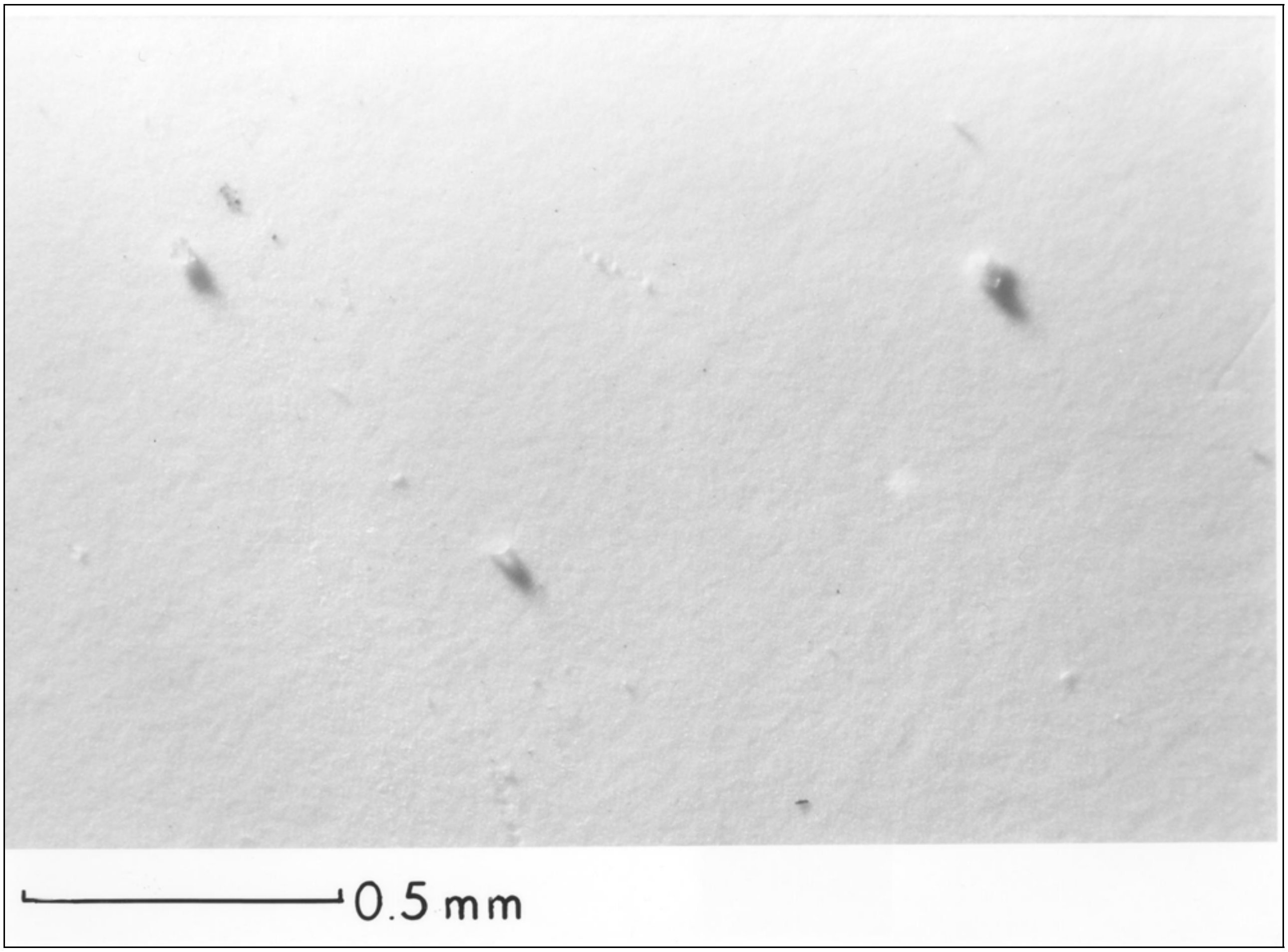


FIGURE 11. This contaminant was discovered in a sample of new oil after a gravimetric particle analysis was carried out.

Tips For Troubleshooting Hydraulic Systems

When hydraulic system degradation is obvious or suspected, there are many cost effective inspection methods and testing techniques to aid the troubleshooter in locating the cause or causes of the problem.

Generally, improper hydraulic system operation can be traced to one of the following deficiencies:

a) Insufficient fluid level.
b) The presence of air in the system.
c) Contamination by foreign material.
d) Incorrect adjustment of components.
e) Internal or external fluid leakage.
f) Mechanical damage to components.
g) Wrong fluid type or viscosity.
h) Excessive temperatures.

The following tips, tools and techniques should be considered for appropriate use whenever any of these operating conditions develop.

1. **The contaminant test; obtain** an oil sample in a clean, clear jar and let it sit overnight. Any contamination will settle to the bottom of the container and will remain attracted to the bottom surface for viewing even when the container is turned over.

2. **The crackle test;** If water is suspected but not obvious, obtain an oil sample and place two or three drops of the oil on a hot plate. The drops will crackle, pop or sizzle if any water is present. Remember that **any** water may be harmful depending upon the equipment type or process.

3. **The “poor man’s” particle count;** is a simple inspection of the machine’s filter. Cut the filter open, spread the media out on a bench and view any contaminant with a magnifying glass or microscope. Run a magnet under the filter media. Any ferrous material will move with the magnet. This should immediately call for a ferrographic analysis of an oil sample. **(SEE FIGURE 12.)**

FIGURE 12.

4. **The color test;** Any brownish or darkening discoloration of the oil which is an obvious change, suggests that oxidation has begun. Any discoloration should be immediately investigated by sending an oil sample for a minimum of viscosity and acid

number analysis. If the viscosity has increased by 10% or more of new oil and the acid number has increased substantially, the fluid may have reached the end of its service life.

5. **The high temperature test;** Dark discoloration of the hydraulic fluid suggests that oxidation is occurring. If high temperatures are suspected, they could be caused by external leaks which create hot spots at valves or cylinders, plugged coolers or kinked or damaged hoses, relief valve pressure settings too high, or oil of too high viscosity. In all cases, the use of predictive maintenance tools such as infrared thermography or an infrared thermometer using laser beams to instantly locate hot spots will locate the high temperature areas.

6. **The internal leakage test;** When a hot spot is located, such as at a cylinder barrel or servo valve, the use of a hand held ultrasonic tester will locate the leak. (During a leak, a liquid moves away from high pressure. As it passes through the leak site, a turbulent flow is generated that has strong ultrasonic sound waves that can be monitored.
   The intensity of the ultrasound will be loudest at the actual leak site). These ultrasonic sounds cannot be heard by the human ear. Very often, external leaks will cause hot spots that will burn the hand of a troubleshooter, so care must be taken when attempting to locate high temperature problems.

7. **The excessive noise test;** An ultrasonic tester can also be used to monitor conditions such as **cavitation** or **aeration** at hydraulic pump inlets or other components, as well as locating **electrostatic discharge noise at filters or reservoirs.** (Electrostatic charges may be generated in hydraulic fluids by turbulence, high fluid velocities, internal fluid friction, fluids flowing in ungrounded piping or when fluid discharges on to any free surface of the reservoir, particularly if there is free air present in the fluid).
   Electrostatic discharge most often manifests itself as a clicking sound as the charge repeatedly builds and then discharges to a surface of lower voltage through sparking. The increased use of synthetic fluids and mineral base oils with non-metallic anti-wear additives have resulted in fluids with low conductivity, increasing the potential for accumulated static charge levels.
   In severe cases, electrostatic discharge can result in etching, pitting or carbon deposits at the surfaces of the area where the discharge occurred and may leave burn marks or other damage on the filter element media.

8. **The foam and air entrainment inspection;** As noted earlier, a darkening color of hydraulic fluid suggests that oxidation is occurring. Oxidation rates are related directly to high temperatures and excessive air entrainment combined with high pressure. At atmospheric pressure and corresponding temperature, oils contain about 10% by volume of dissolved air. At 200 psi (1400 kPa), oils can absorb about 140% by volume.

The dissolved air provides the oxygen that is necessary to promote oxidation and oxidation rates rapidly increase as temperatures rise above 140ºF (60ºC) and hydraulic pressures increase to their normal operating ranges.

Dissolved air in oil under pressure will tend to produce foam as pressure is released and the air comes out of solution. This free air is now trapped inside operating cylinders and other components, which will cause erratic and spongy operation and increased temperatures.

If hydraulic systems begin to display erratic, spongy operational behavior or cylinder extension and retraction speeds are slower than normal or erratic in nature, there is a good possibility that there is excessive air entrainment in the hydraulic system. The presence of entrained air is readily apparent by the bubbly, opaque appearance of the fluid in the reservoir.

On systems using gas or air operated accumulators, a sudden foaming of oil in the reservoir and/or an accompanying lack of accumulator operation are indications of a faulty diaphragm or bladder in the accumulator.

When excessive levels of entrained air are suspected, inspect all system connections where air may be drawn into the system. Examples are; loose pump inlet connections, the fluid return line is broken or no longer below the oil level in the reservoir, the pump shaft seal has failed, inadequate or broken reservoir baffle plates, suction side of circuits are leaking or have loose connections.

Suction leaks (where air is being drawn into a component or circuit) can easily be located by applying hydraulic oil to the connection. If the oil disappears, the troubleshooter has located the air leak!

9. **Concluding recommendations;** Many books have been written about hydraulic system design, maintenance and troubleshooting. As systems improve and operating pressures increase, much more attention to predictive maintenance and reliability will be required. Two areas of concern will be a requirement for improved filter design, selection and installation and hydraulic system flushing techniques after a component failure has occurred.

   In the first instance, more consideration will be required for improved filter installation where increased vibration and/or higher pressure pulsation will require mitigation.

   In the second instance, mobile filtration systems and portable hydraulic fluid purifiers will become mandatory, if hydraulic system reliability is to be improved and maintained. **(SEE FIGURE 13.)**

FIGURE 13.

Finally, one of the very best hydraulic system troubleshooting reference books ever published is available from the Texaco Company, one of the Chevron family of lubricant producers. The book is called, ***Operation and Care of Hydraulic Machinery*** and it was printed in March 1996. It contains 32 pages of hydraulic system problems, their causes and solutions. It is a superb troubleshooting reference.

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