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Qualification of Hydraulic Fluid through Pump Testing

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Abstract

The life and reliability of the hydraulic system components are dependent upon the characteristics of the fluid circulating in the system. There is no doubt that the hydraulic component which suffers the most when wrong fluid is used in the system is the pump. There are three different types of hydraulic pumps widely used today—vane, gear, and piston pumps. The vane pump was the first to gain popularity. Then the gear pump and finally, today, the variable volume piston pump is rapidly gaining favor. Each of these pumps has its own needs and requirements relative to the hydraulic fluid used in the system. In addition, the pump of a particular manufacturer may possess different requirement than the same type of pump from other manufacturers. Therefore, each pump manufacturer must diligently conduct tests to insure that the fluid which are recommended will, indeed, adequately protect his pump. On the other hand, the fluid manufacturers are hard pressed to conduct several different pump tests on every developmental stage of the fluids research program within his company. Pump tests are time consuming and require expensive equipment to conduct a rigorous test.

This paper presents a brief overview of some of the various pump tests which are used today. In addition, the testing dilemma which confronts both the pump manufacturers and the fluid suppliers as more and different fluid are developed will be discussed.

Introduction

Hydraulic system are used throughout the industrial world primarily because of the flexibility which can be attained using such components. The fact that the pump can be mounted on the prime mover such as the engine while the control elements and the terminal elements can be located some distances away from the pump is a distinct advantage in many machines. The various components in a hydraulic system are connected to form an integral system by the use of hoses and conduits. The power is transformed by the pump from that provided by the engine or motor to hydraulic power by the pump. Fundamentally, a hydraulic pump is a flow generator while power is a function of both pressure and flow. The pressure at the pump outlet is a function of the load placed upon the system output. Therefore, the input parameters to the pump is usually torque and speed while the output parameters are flow and pressure. The power from the pump is controlled by the valving of the hydraulic system and is transformed to the parameters needed by the terminal elements such as rotary motors or linear cylinders.

The system component which is seldom discussed in the same terms as pumps and valves is the hydraulic fluid. With the components separated physically and connected by

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hoses, it is necessary to provide a reason medium to transfer the signals and power parameters from one component to the other. This medium is the hydraulic fluid. In the past the hydraulic fluid was used primarily as a transfer medium to carry the energy and control the various components. However, as enhanced performance was demanded of the hydraulic system, the pressure increased and the fluid temperature rose. In this new environment, the hydraulic fluid assumed a new role and one which is not as easily understood and predicted as the transfer of energy or the control function. The role of lubrication was added to the traditional role played by hydraulic fluid in the operation of the system. One of the primary reasons that the lubrication qualities needed in a hydraulic fluid are not well defined nor understood lies in the fact that there are very few(if any) rigorous research studies which have published reports dealing with the fundamental concepts and equations of tribology as applied to hydraulic components. In addition, there are few standard test methods which have shown to be of value in assessing the ability of a hydraulic fluid to lubricate the critical surfaces in the components of a hydraulic system.

In order to effectively develop new and better hydraulic components including fluids, it is important that the interaction between the hydraulic fluid and the hydraulic components be evaluated in some reasonable manner. Of course, the best situation would be to have a precise analytical model of this interaction which has been verified by thorough research. Such a model could be used to develop and design hydraulic components and systems as well as select the proper fluid for any system in any given situation. In addition, a complete tribological model would make life and reliability calculations very straightforward. Unfortunately, to this author's knowledge such a model does not exist at this time. Therefore, the most astute engineering decision is to perform tests to attain the information needed to evaluate the fluid/component interaction. This leads directly to the heart on the current problem. There is little doubt that the hydraulic pump is the component which suffers the most from the use of an incorrect fluid and gains the most from the selection of the best fluid. There are three types of pumps and a number of variations of each type which are widely used in hydraulic systems today. Each and every designer and manufacturer of hydraulic pumps firmly believes that his pump design has unique requirements in the lubrication area which can only be fulfilled by the circulating fluid. This leads to an extremely difficult situation from a fluid qualification standpoint and has led to the creation of a number of pump test and several bench test procedures.

At this point in time the type of test which is the most desirable depends upon the end use of the data. The component manufacturer and the hydraulic system user feel the need to run the particular pump of concern in the candidate fluid to be assured that this fluid will adequately protect the system. The component designer, however, needs much more information in order to improve the component design and could probably be satisfied with a bench test at least until the design has been completed. At that point the designer would probably want a full blown pump test to attain the confidence needed to proceed with production. The fluid supplier has a much more unique and difficult position than the component manufacturers or the users. He must make sure that his formulation performs adequately with every hydraulic pump. The fluid manufacturer many times uses a bench test during the development of the various formulations and then verifies the product by using pump testing. However, in all cases the fluid supplier must conduct a large number of pump tests to thoroughly qualify his fluid product.

The pump tests which have enjoyed the most wide spread use require fairly complex and expensive test equipment as compared to bench testing. The pump manufacturer normally already has such a facility while the fluid manufacturer must either hire the testing done or they must procure the necessary facilities. In any case, there is a substantial cost in the repair and maintenance of pump testing equipment and it requires a considerable amount of time to actually run each test. This leads to the conclusion that the use of pump tests to evaluate the performance of hydraulic fluid is a costly proposition at best. In addition, the repeatability and reproducibility of the various pump testing procedures has been questioned.

This paper discusses the wear surfaces which are found in the commonly used types of hydraulic pumps. This information provides a background for the evaluation of the some of the pump tests currently in use or proposed. The difference between some of the tests will be presented and discussed. The major problems encountered the use of the test or the data obtained from the test will be presented and potential solutions to some of the problems will be offered.

Wear In Hydraulic Pumps

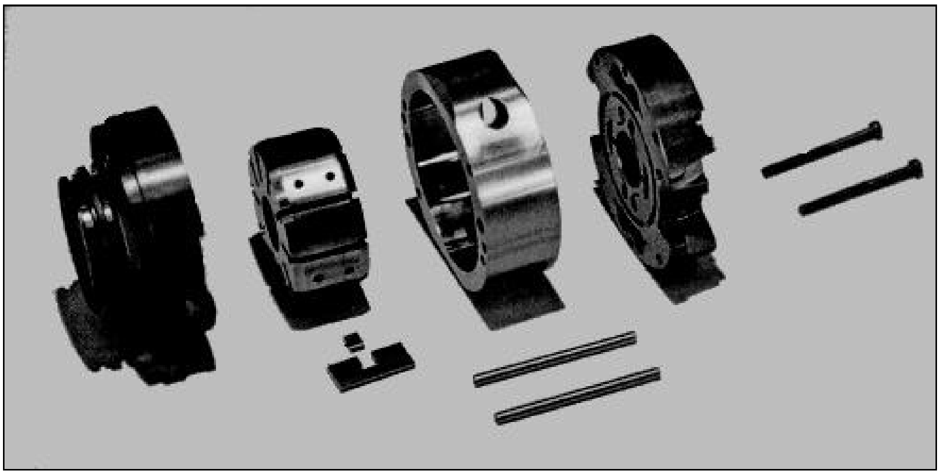
The three types of pumps commonly found in hydraulic systems are the vane pump, the gear pump, and the piston pump. From a design standpoint, each of these pumps offer a unique challenge in the improvement of life and reliability through the use of the hydraulic fluid. There is a wide spread belief that the lubrication role played by the fluid in the performance characteristics is vastly different from one pump design to the other even within the same pump type. To gain an appreciation for the underlying reasons behind these beliefs and establish a background from which the area of fluid qualification through the use of pump testing can be evaluated, the critical wear interfaces will be discussed for each type of pump. As mentioned previously there are fluid concerns in some pump designs which are not critical in other designs even within a pump type. For instance, the materials used in one design may require different fluid consideration than the materials used in another design. While these aspects are certainly important, they are considered beyond the scope of this paper.

The Vane Pump

A typical design for the vane pump is shown in Fig. 1. The vane pump uses sliding vanes riding on a cam ring to increase and decrease the volume of the pumping chambers within the pump. The sides of the vanes and rotor are sealed by side bushings. As can be seen from this figure the interfaces produced by two surfaces in relative motion are prime candidates for critical wear areas. This type of interfaces in the vane pump are as follows:

- The contact between the vane tips and the cam ring.
- The contact between the vanes and the rotor.
- The contact between the vanes, rotor, and side bushings.
- The contact between the pump shaft and the bearings.

Figure 1.
Typical Configuration
for a Vane Pump



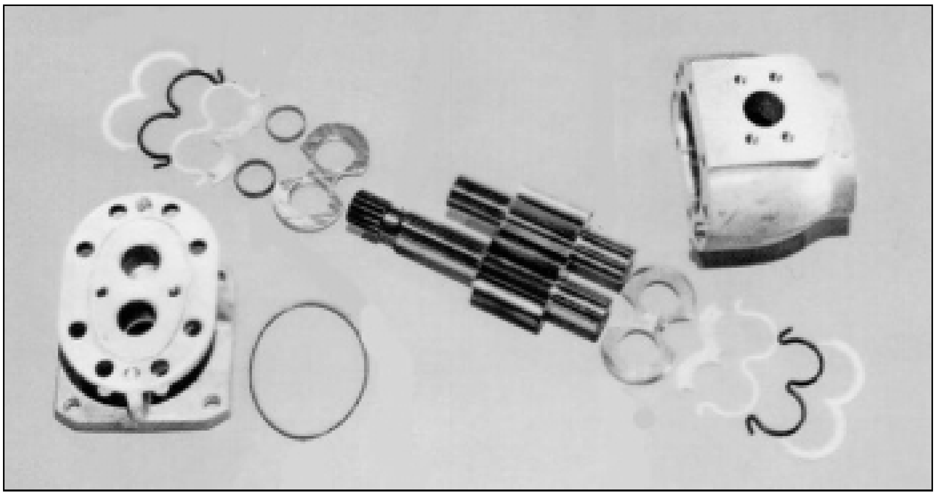
Of these interfaces the first three are probably encountered more often than the bearing wear situation. A deterioration in any of the wear areas will cause a degradation in the performance of the pump. This degradation results most often in a reduction of the volumetric efficiency of the pump but can produce a decrease in the mechanical efficiency as well. It should be pointed out that when the pump is operated at a constant speed, temperature, and output pressure, a loss in volumetric efficiency will result in a decrease in the flow generated by the pump. In addition, under these conditions, a reduction in mechanical efficiency produces an accompanying increase in the input torque to the pump. Therefore, if a pump test is conducted at constant speed, pressure, and temperature, measurement of the output flow and input torque will reveal any change in the performance of the pump.

The Gear Pump

A typical configuration for the gear pump is shown in Fig. 2. The wear areas common to the gear type of hydraulic pump are listed below:

- The tips of the gear teeth and the pump body.
- The sides of the gears and the compensating or wear plates.
- The interface between the bearings and the pump shaft.

Figure 2.
Typical Configuration of the Gear Pump



In a gear pump like a vane pump the bearings are seldom a major problem from a fluid qualification standpoint. In addition, unlike the vane pump, the gear pump can not be balanced for the forces created by the pressure. Therefore, the force vector created by the pressure acting upon the profile of the gear teeth will tend to dislocate the gears toward the suction port. That is, the pump is usually designed such that the gears are installed concentric with the shaft and the shaft is concentric with the bearings. The clearance between the outside diameter of the shaft and the inside diameter of the bearing necessary for proper fluid flow will be equal all around the clearance area until the pump is pressurized by a load. The interface between the gears and the shaft is extremely solid. Therefore, the unbalanced load produced by the pressure on the gears move the gear/shaft element and force the shaft to run concentric in the bearing. This motion will many times cause the gear teeth to encounter the inside of the pump housing and produce wear marks but not usually pump failure. While wear in any of the critical areas of the gear pump can result eventually in failure, the experience of this author suggests that the interface between the side plates and the sides of the gears is by far the most prone to wear. In addition, wear in this area will result in a reduction in volumetric efficiency. As was the case with the vane pump, when the gear pump is operated at constant speed, temperature, and pressure, and change in the performance of the pump can be readily measured by the output flow and the input torque.

The Piston Pump

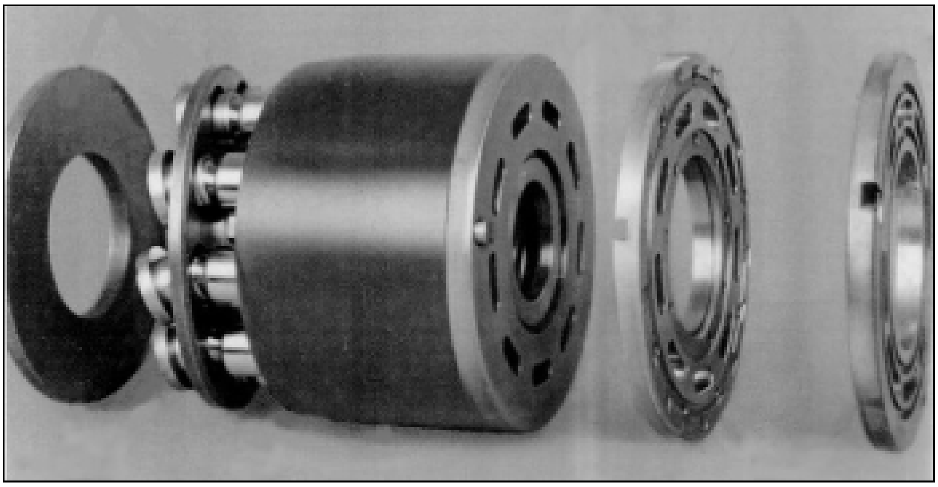
The piston pump offers a different set of problems when attempting to picture a typical configuration. That is, many times what is referred to as a piston pump is actually a pumping system. For example, the piston pump can be constructed such that the displacement of the pump can be changed from some maximum to zero while the pump is in operation. This feature is utilized in the pressure compensated piston pump among other pumping system configurations. In these pump systems the design of the actual pumping mechanism does not change.

However, valves and cylinders are added to control the displacement of the pump according to some built-in algorithm. The axial configured piston pump is the most common encountered in industry. The displacement of the axial piston pump is normally accomplished by rotating the swash plate so that the stroke of the pistons within the pump is changed. Discussions of piston pumps with all of the configuration variations that are available are beyond the scope of this paper. This does not imply that the valving and cylinders which are used to control the displacement of piston pumps is not important. However, at this time only the actual pumping mechanism will be considered.

A typical arrangement of the pumping mechanism for a piston pump is shown in Fig. 3. The critical wear surfaces of this type of pump are listed below:

- The interface between the piston shoes and the swash plate surface.
- The outside diameter of the piston and the inside diameter of the cylinder block bore.
- The valving surface of the cylinder block and the valve plate.
- The trunnion bearing and swash plate pintle
- The outside diameter of the pump shaft and the inside diameter of the pump bearing.

Figure 3.
Critical Wear Interfaces in a Piston Pump



In the pumping mechanism of the piston pump there are two areas which tend to be involved in the wear process more than the others. One of these interfaces is the piston shoe/swash plate while the other is the cylinder block/valve plate or back plate if a valve plate is not used in the design. It is obvious that wear of either of these critical interfaces will result in the loss of efficiency and therefore can be measured by the appropriate performance parameters.

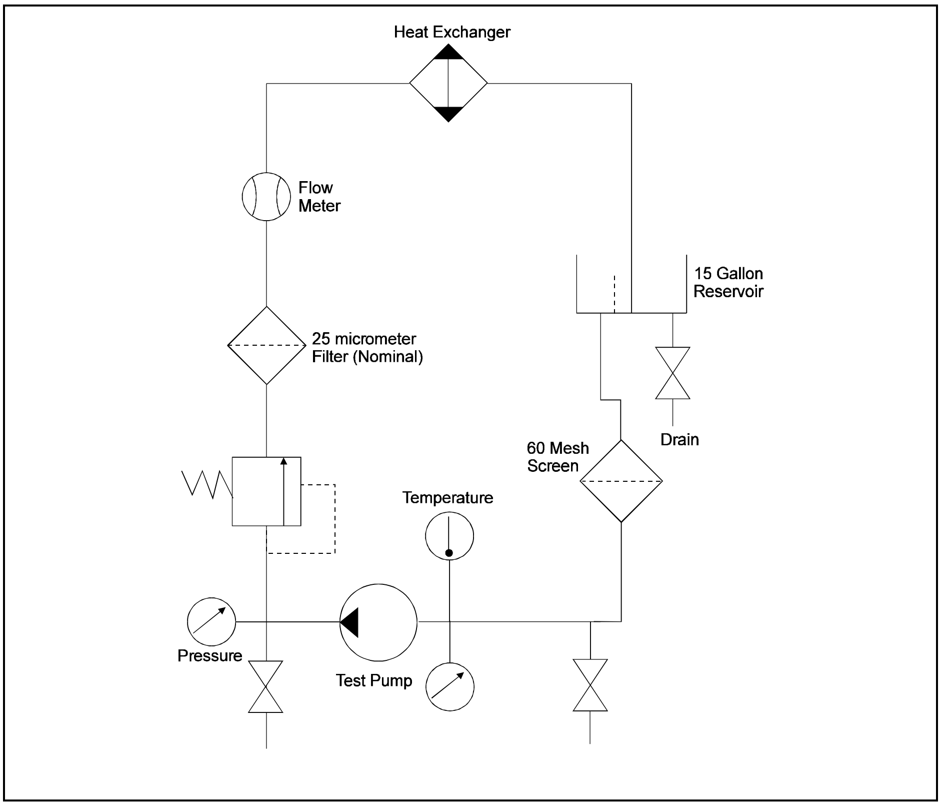
Qualification Of Hydraulic Through Pump Tests

Even a very cursory examination of the preceding discussions concerning the wear areas of the three most popular type of hydraulic pumps will reveal that the wear interfaces of the various designs are very different. Whether or not these differences produce a large problem for the fluid formulator is basically a major consideration in developing a single pump test for hydraulic fluid evaluation and qualification. That is, the gear pump manufacturer clearly believes that his pump offers a significantly different wear situation than any of the other pumps, while the vane pump manufacturer believes the same of their pump and the piston pump people follow suit. In fact, many of these pump manufacturer will not approve a fluid directly until it has been tested in the field. Until adequate research has been accomplished, reported, successfully defended, it is not likely that a single pump test will be universally accepted for the qualification of hydraulic fluid. Today, based upon the experience of this author, most pump manufacturers will not approve a hydraulic fluid until they have successfully accomplished both laboratory and field evaluation with their pumps operating in the candidate fluid. This leaves the fluid supplier in somewhat of a quandary since in order to sell their fluid they must have pump manufacturer approval. In order to receive pump manufacturer approval they must first conduct a wide variety of pump tests and then get the pump manufacturer to try the fluid themselves. Is it any wonder that hydraulic fluids are expensive.

There has been several different pump tests used to produce wear data which could be used to qualify various fluids (1). Some of these tests incorporated a vane pump while others utilized gear pumps and still others used piston pumps. To this author’s knowledge there has been no document published which compares the results of one particular fluid tested under very carefully controlled operating parameters using various pump types. In order words, a study is needed in which vane, gear, and piston pumps are all tested using the same fluid and the same test parameters. Then this data should be defended to pump manufacturers, fluid suppliers, and hydraulic system users.

A typical schematic for a fluid qualification pump test using a Vickers V-104 vane pump is shown in Fig. 4. This circuit approximates the system normally recommended in ASTM D-2882. As can be seen from this figure, the test is conducted at constant pressure generated by passing the output flow of the pump over a relief valve or using some other type of pressure control valve. The temperature of the fluid is held constant and the pump speed is constant. The contamination level of the candidate fluid is controlled by a very coarse filter and one which is inadequately specified. The Vickers V-104 vane pump is a very old design and attempts have been made to change the pump specification and the operating conditions to those more representative of the current situation. However, developing a standard test which receives wide spread acceptance is a very long and costly project. Gear pumps have been run using a schematic very closely approximating that shown in Fig. 4. The typical schematic for using a piston pump test to qualify a hydraulic fluid is somewhat different than that of the vane or gear pump. In the case of a piston pump test the case drain and the more sensitive inlet conditions must be accommodated. A typical schematic for using a fixed displacement piston pump in a fluid qualification test is shown in Fig. 5.

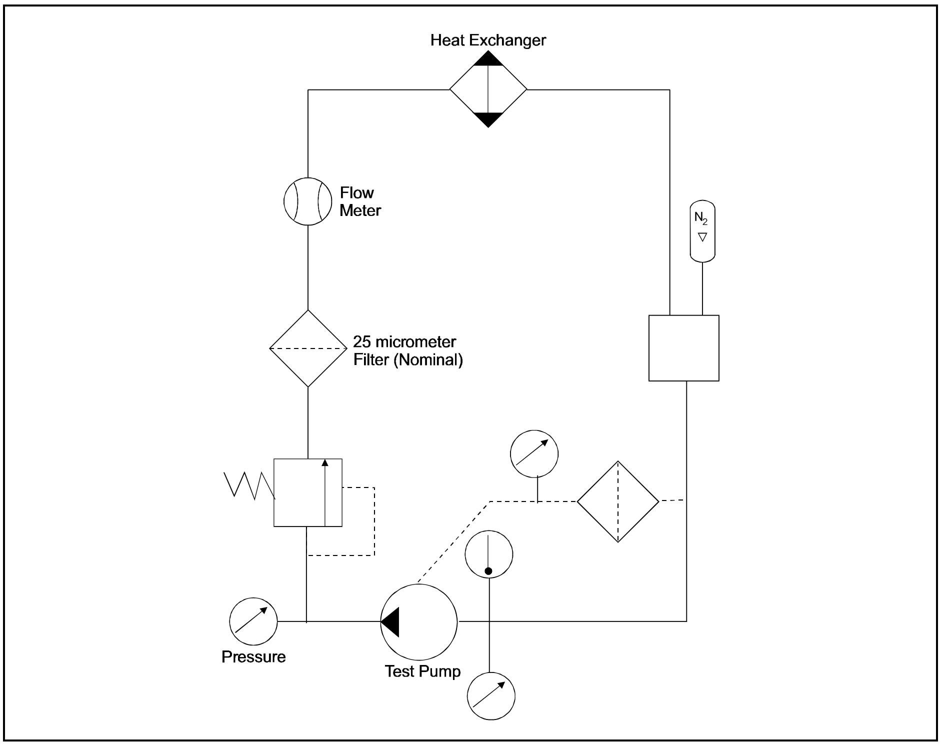
Figure 4.
Typical Schematic for a Vickers V-104 Vane Pump Fluid Qualification Tests



The various pump tests which have been reported in the literature evaluated hydraulic fluids over a broad range of operating conditions. For example, Perez nad Brenner (2) ran different vane pumps at different pressures and temperatures while Racine Fluid Power (3) used a cyclic pressure on vane pumps. Toogood (4) conducted tests using gear pumps with both constant and cyclic loading conditions. A great many pumps of all three types were tested at the Fluid Power Research Center of Oklahoma State University under controlled contaminant environment (5,6,7,&8). A very large portion of the work reported to date has utilized the change in dimensions of various parts to measure the amount of wear which occurred during the test. When the literature is fully explored, one will find that there are a large number of tests reported where one on more of the three types of pumps have been used to evaluate the performance of hydraulic fluids. Besides the type of pump, the operating pressure must be considered along with the manner in which the pressure is applied(steady or cyclic). The operating temperature is another parameter of great importance in the qualification of hydraulic fluids as well as the speed of the pump. There seems to be little among the experts that if the fluid will protect the pump adequately, it will indeed protect the other components in the system. The disagreement is concerned with what type of pump which should be used and what operating conditions are applied during the test. In addition, the repeatability and reproducibility of the tests which are conducted seems to be a point of contention.

Most of the pump tests used in the evaluation of the anti-wear properties of a hydraulic fluid are of the pass/fail variety. That is, when the test is over the parts are inspected for dimensional changes to determine whether or not the amount of dimensional change is acceptable. If there is too much change the fluid is said to fail the test. Most of these tests do not employ continuous monitoring of any kind. Of course, the change in the dimensions of internal pump parts can not be measured continuously. If fact, such measurement can not be made while the pump is operating. Therefore, in order to continuously monitor the wear of a pump while it is being tested the performance must be evaluated. If the pump is operated at constant pressure, speed, and temperature, then the output flow rate and the input torque provide a clear picture of what is happening to the pump. In addition, the use of performance information to monitor pump degradation does not require the disassembly of the pump either before the test to obtain the initial dimension of critical parts nor after the test to obtain dimensional information which can be used in comparison with the initial dimensions to determine the changes. Since the degradation in performance is the only gauge used by the user to determine the status of his pump, it seems more than reasonable to use performance measurement to qualify a hydraulic fluid. Therefore, it should be obvious that a need exists to update the fluid qualification pump tests to incorporate continuous performance measurements which would much more useful in the modeling of the wear phenomena that occurs in hydraulic pumps. The disassembly of the pump before or after the test has been completed can still be done but it is not recommended that the pump be disassemble at some intermediate point and then re-assemble for additional testing.

Figure 5.
Typical Schematic for a Fixed Displacement Piston Pump Fluid Qualification Tests



The duration of the pump test should be of utmost concern to anyone who is attempting to develop a widely accepted pump test for hydraulic fluid qualification. Tests currently being used for this purpose are run from 50 hours to 1000 hours. This is a major drawback because such lengthy tests are very expensive. Therefore, it is necessary to use some parameter or operating condition to accelerate the test to reduce the overall test time. Pressure has been used in the past for this purpose. In some case pump speed can be used. In addition, the contamination level of the fluid can be an accelerator. However, no matter how the test is accelerated care must be taken to insure that the acceleration does not render the test unreasonable. That is, pump outlet pressure can certainly be increased to reduce the test time. In fact, the test could be over in a matter of minutes if the pressure is high enough. However, a large over pressurization is considered unreasonable and would probably produce useless data.

Recommendations for Improving Fluid Qualification Pump Tests

The use of weight loss and/or dimensional changes to characterize pump wear does not lend itself readily to the modeling of the wear process. In fact, the use of these parameters insures that the pump would be disassembled both before and after the test. Any damage occurring during disassembly and re-assembly will negatively effect the test information. In addition, the thing which is of the most importance in the operation of a hydraulic pump is the performance. In the case of the fixed displacement pump the most important performance parameter is efficiency. Most of the work reported which employed performance degradation as a measurement of wear used the flow change at a fixed pressure. Since the pump is primarily a flow generator, this was logical. However, if the input speed and torque were measured along with the output flow and pressure the overall efficiency could be used as a criterion of pump wear. Secondly, in order to have any chance of accurate measurement when evaluating weight loss, the pump must be disassembled, the critical parts must be thoroughly cleaned and the initial weight must the measured. Then after the test is run, the same procedure must be followed to obtain the final dimensions or weight. The fact that the pump must be disassembled means that measuring intermediate wear point is not very desireable because the disassembling and re-assembling of the pump will cause the position of the various part to change and therefore potentially alter the wear situation. Therefore, it is very important that pump tests which are used to measure the performance characteristics of a hydraulic fluid employ continuous performance monitoring. This does not mean that dimensional changes or weight loss can not be used in addition to performance parameter, however, attempts to measure weight loss or dimensional changes at intermediate points during the test should be discouraged.

A second consideration concerns the contamination level of the fluid being tested. There has been reliable estimates made such suggest that about 70 % of the field failures of hydraulic systems can be traced to the presence of contamination. However, the pump tests used to establish the performance of the hydraulic fluid at this time do not measure or report contamination level of the fluid nor is there any qualification of the system to be sure that some selected contamination level is maintained. This observation leads to two possible considerations. One school of thought suggests that the fluid should be clean enough that particulate contamination will not influence the test results. This author quickly points out that particulate contamination in hydraulic system is a more of a fact than many would like to believe. If, however, the conclusion is that the particulate contamination should not be a part of the fluid qualification pump tests, then the contamination level of the circulating fluid must be measured to verify that the contamination present during the test will not influence the test results. A second approach is to conduct the test with a known contamination level. This is very close to the contaminant sensitivity test developed at the Fluid Power Research Center. In addition to accounting for the contamination, the contaminant sensitivity test accelerates the wear process such that useful results can be obtained in a much shorter period of time than in most of the tests currently being used for fluid qualification.

The question of using a constant or a cyclic pressure is worth consideration. However, not very much data is available with which to base a recommendation. In the field, the pump is subjected to a cyclic pressure load. That can not be denied. The larger question involves how high should the peak pressures be and what cycle rate should be used. Pump endurance test normally involve cyclic pressure, however, there is little agreement concerning the shape and frequency of the pressure curve. In addition, the level of pressure can be used as a means to accelerate the test. Great care should be exercised when using a pressure higher than that recommended by the pump manufacturer. The same thing applied to temperature and rotational speed or any combination of these three parameters.

Conclusions

Based upon all of information at hand, it is very doubtful that one pump test can be developed for the qualification of hydraulic fluid. Each pump manufacturer will maintain that the particular pump that he makes must be tested in the candidate fluid before he will qualify it. The best that can be hoped for is that the pump test can be made more useful in the modeling of the wear phenomena by using performance parameters for continuously monitoring test situation. Then the data can be presented in terms of a degradation curve instead of a pass/fail call. The use of cyclic pressure introduces a whole new situation. The equipment necessary to conduct cyclic pressure tests is much more complex and will require more expertise and maintenance than constant pressure tests. In addition, there is little evidence that cyclic pressure will provide more definitive results. The time required to conduct one of the tests currently being utilized is large. This can be greatly reduced by introducing a known and controlled contamination level. However, even if the advances shown by the contaminant sensitivity research is not employed the presence of contamination should be controlled to the extent that it is measured and reported as part of the test parameters.

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