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SELECTION PROCEDURE OF HYDRAULIC VALVES FOR TRIBOLOGICAL RESEARCH

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Abstract: *A number of methods are available to test the wear resistance of different hydraulic components, along with the known hydraulic fluid. Some of the methods have become standardised, while others are dedicated and of an internal nature, linked to a single manufacturer, either components or fluid. However, none of the represented methods allows a comprehensive insight into developments in all components of the hydraulic system. Tests concerned with lubricating properties and the service-lives of hydraulic components, usually use techniques and procedures similar to those occurring during the actual component usages, and are based mainly on testing the pumps – s. c. tribological standardised pump tests methods based on precisely defined pump types.*

Tribological tests of hydraulic valves, especially continuously acting control valves, also highly-loaded components of a hydraulic system, are mentioned very rarely, or not at all. For valve testing purposes it is necessary first, to establish the appropriate testing methodology and the corresponding test rig, to determine the correlations between operating conditions as input variables and valve performance criteria as output variables during a preliminary test series.

In order to provide a comparison of tribological testing results, it is necessary to select valves with exactly the same characteristics for these tests. In this paper, the selection process of valves with the same characteristics is presented in more detail. Only in this way, will the results of a long-lasting tribological testing be comparable, and the conclusions credible.

Keywords: *tribological tests, hydraulic control valves, characteristics, selection procedure, measurement*

1. INTRODUCTION

One of the more important tasks to be performed by any hydraulic fluid is to prevent direct contact of two metal parts. Producers of hydraulic components take this task very seriously and, thus, they pay significant attention to it. Inadequate lubricant's properties affect largely the component degradation and the machine operation reliability. Therefore, a large number of standardised tests have been developed and used in order to establish the relation between the fluid condition and the lubricating properties, and its effect on the component wear.

The tests concerned with lubricating properties and the service-lives of hydraulic components usually use techniques and procedures similar to those occurring during the actual component usages. Testing is performed in approximately identical environmental conditions as during actual use:

The temperature conditions, presence of contamination, water, metals, alternating pressure … and the operating conditions, in most cases, are tightened up (higher lubricant temperature, higher circulation number …).

Hydraulic fluid specifications themselves are not enough to assure that the hydraulic fluid used at normal operating conditions will provide adequate protection over the desired timeframe. Specifications provide a basis for performance, but the reality in today's environment is that equipment demands have increased, which has, in turn, increased the need for the fluid to perform properly in much harsher conditions.

So how does the lubrication industry measure or evaluate a hydraulic fluid's ability to perform under harsher conditions if the specifications haven't changed? There are a number of industry tests to answer this question. [1] Some of them are standardised, while others are used for targeted testing (tailored testing) or are adapted. They can be divided into two main groups of tests. The first group represents s. c. thermal oxidation tests for testing the oxidation stabilities of fresh and used hydraulic fluids (mainly oils), and determining the degradation behaviour of liquid lubricants, e. g. mineral based hydraulic oil (TOST, RPVOT, PDSC, UDS … and other more complex oxidation tests). [2], [3]

The second group of testing methods represent mechanical tests of hydraulic fluids using laboratory testing devices, such as four-ball, pin-on V-block, Timken anti wear test, Brugger test, Reichert test, Falex test, FZG test ... All of these mentioned tests, either oxidation or mechanical, are more or less laboratory tests related to the fluid. For example, the impact of a lubricant on a real hydraulic component, can only be observed or predicted indirectly.

The often used mechanical tests for determining the impact of tested fluid on the real hydraulic component, based on the standardised test procedure along with specific pump type, are s. c. pump tests. The Vickers test falls in this group of tests, for example, with an exactly prescribed type of vane pump, the Denison test with a defined vane or piston pump, as the most widely used, or the first such tests. This group includes a number of other tests: The Sundstrand test, Komatsu 500 hour test, Bosch-Rexroth test, Lapotko test ... to name only the most well-known. [4] Almost all of these test are very time consuming (they can last several days, weeks or months), they consume a lot of energy, they need a large amount of fluid, require the use of specified real components. So, they are more appropriate for the tribological investigation of used hydraulic pumps together with the used lubricant, and do not give an accurate, comprehensive and detailed answer regarding other components of a hydraulic system, e.g. hydraulic control valves.

2. VALVE TESTING METHODS

For all the methods mentioned above, the conclusions were related only to the pump. Other, also highly loaded components of the hydraulic system, e.g. valves, were not even mentioned at all.

A test method suitable for hydraulic valves should allow testing under variable conditions ranging from real to extreme. Therefore, an appropriate test procedure and test rig should be used, to determine the correlations between operating conditions as input variables and valve performance criteria as output variables during a preliminary test series.

2.1 Wear types inside hydraulic valves

Tribological systems in general are subject to different types of wear. Three of these types of wear are dominant in hydraulic valves (see Figure 1): Erosion, three-body abrasion, and impact wear. The characteristics of these wear types and the factors governing wear behaviour are discussed as follows.

In spite of any filtering measures, fluid power circuits are invariably subject to contamination with solid particles. When passing component walls and edges with high velocity, suspended particles effect *erosive* *wear* on the component material by washing it off subtly. This type of wear affects both spool and poppet valves, particularly at small valve openings with narrow flow channels, and all kinds of valve components – spool, sleeve, housing, poppet, and seat –, when they are paired tribologically with solid contaminants. Depending on the valve type, erosive wear phenomena are perceptible in the rounding of metering geometry, such as spool edges, spool notches, and sleeve orifices, or sealing geometry, such as poppet or seat edges.

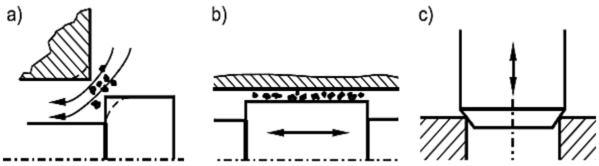

Figure 1. Valve wear mechanisms: a) Erosive wear, b) Abrasive wear, c) Impact wear)

When relative motion is imposed on the valve components in the presence of solid contaminants, *abrasive wear* occurs. This type of wear affects mainly spool valves during operation of the spool. The tribological pairing, in effect, consists of the spool, any solid particles, and the housing or sleeve. Component material is sheared off by the particles entering the valve gap when the components are moved. The results of three-body abrasion can be observed in gap widening and deformation of the housing.

In poppet valves, the poppet is frequently pressed into the seat with high velocity and energy when the valve is closed. Especially in pilot-operated valves, this implicates *wear due to the impact* of the components of the tribological pairing comprising poppet and valve seat. During continuous operation, material can be cracked out of the geometry under stress, resulting in fractures or pitting at the sealing edge or the seat. [5, 6, 7, 8, 9]

2.2 Wear tests of hydraulic valves

The tribological parameters governing the wear process inside hydraulic valves have been the subject of various investigations. Wear has been found to be aggravated mainly by the conditions (Table 1), of which only those marked in italics are examined at the wear test rig.

Compared to the tribological tests with pumps, there are very few tribological tests for valves, but they are not standardised. An example of the valve test is the so-called IFAS test.

Table 1. Wear influencing factors - IFAS test [8]

Category	Parameter
Fluid contaminants	*High particle concentration*
	Distribution of particle sizes around gap high
	Abrasive particle type (protrusive shape, high hardness)
Fluid conditions	*Low fluid viscosity/high temperatures*
	High flow velocities
	Large pressure drops
Duty cycle	*Large valve command amplitudes*
	Large valve command gradients/high spool velocities
	High impact energy when closing
Geometry	Small gap length/gap high ratio
	Small effective wear ratio
Material	Low component hardness

An IFAS test rig has been designed for examination of three-body abrasion, erosion, and impact wear in hydraulic directional spool and seat valves. Certain influence parameters from the fields of Fluid Contamination, Flow Conditions, and Duty Cycle, have been investigated experimentally. The focus is set on fluid contamination with ISO MTD (A3) test dust, as this is anticipated to accelerate the wear process significantly. More details about the IFAS test, the test rig, test procedure and conditions are available in the literature. [8]

The precondition for this test and all similar tests is the same: For comparison and conclusions, it is always necessary to use the same valves with identical baseline characteristics. These must be checked by standard measurement procedures.

3. VALVE CHARACTERISTICS` MEASUREMENT

If we want to compare the characteristics of the hydraulic equipment between different manufacturers, check the characteristics of the same valve types, of the same manufacturer, compare the characteristics and evaluate the variation of the characteristic over the useful life of the valve, or evaluate the wear impact ... the characteristics must be comparable. Comparability is achieved by standardised tests and a standardised presentation of results. For continuously acting hydraulic control valves the Standard ISO 10770 is valid.

3.1 ISO 10770-1 static tests

The ISO 10770-1 Standard, applies to electrically modulated hydraulic control valves and consists of three parts. The first part refers to the testing of 4-port directional valves, the second part relates to the testing of 3-port valves, and the third part to the pressure control valves. [10]

The Standard is divided into electrical tests, performance tests that are further divided into dynamic and static tests, and pressure impulse tests. For the preselection of control valves, the static performance tests of 4-port directional valves are relevant. With this Standard different static tests resp. characteristics are defined: Proof pressure tests, internal leakage test, output flow versus input signal test, flows across lands versus input signal, output flow versus load pressure difference, output flow versus valve pressure drop, limiting output flow versus valve pressure drop, output flow versus fluid temperature, pressure difference versus fluid temperature etc.

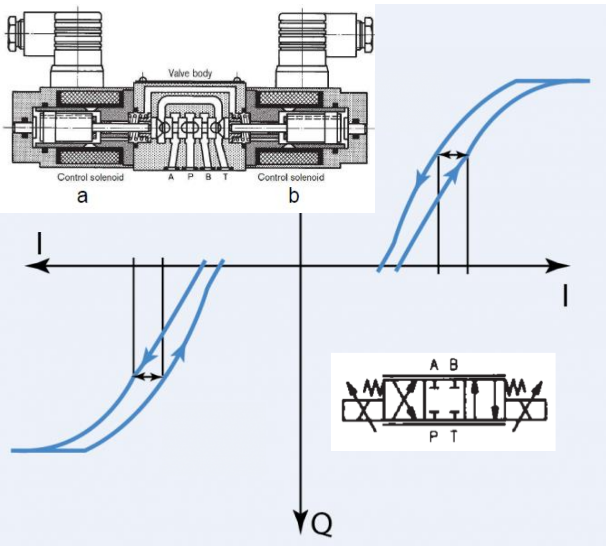

Figure 2. Typical flow-input signal characteristic of a 4-port directional proportional valve

Of the above tests, three are the most important for tribological research purposes: Output flow versus input signal at constant valve pressure drop, internal leakage versus input signal, and the metering test.

On the basis of these three tests, much information can be obtained about the valve properties linked to valve internal design and characteristic changes due to wear. Therefore, we can obtain information on, e.g., rated flow, flow gain, flow linearity, flow hysteresis, flow symmetry, flow polarity, spool lap condition, threshold etc. A typical characteristic flow vs. input signal for a directional proportional valve is shown in Figure 2.

3.2 Interpretation of valve flow characteristics

A much more detailed plan than given in the technical literature from valve manufacturers (=data sheet), if given, reveals several key valve operating characteristics, necessary to evaluate the valve condition of the valve. Characteristic detail is depicted in Fig. 3.

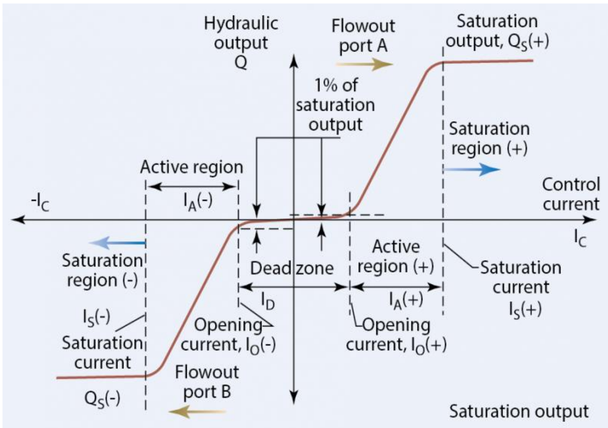

Figure 3. More detailed given valve flow characteristic [11]

A very important valve parameter is the *dead zone*. A valve with a substantial dead zone is rendered useless in applications that seek null as the ultimate operating conditions, such as in positioning systems and some pressure-control systems.

The valve *cracking point* is that instant where the valve just begins to open. That may seem a simple and clear statement, however, it is not. Because there is always leakage in spool valves, flow variations take place all through the overlap, or *dead zone* of the valve.

The next important parameter is the *valve linearity,* the degree to which the metering curve agrees with a best fit straight line.

For a proportional valve, *hysteresis* is the point of widest separation between the metering characteristic curve with increasing input relative to the characteristic with decreasing input, as measured along a horizontal line. This idea is presented in Figure 2 for a proportional valve with substantial overlap.

Threshold is an attempt to separate and measure the portion of valve hysteresis caused by friction from the portion caused by the magnetization properties of the torque motor's internal ferromagnetic parts. In that respect, the threshold represents the very minimum possible hysteresis when all the magnetic effects have been eliminated.

All very briefly mentioned parameters are important for the comparison of different valves, and for a later comparison of the condition of the degraded valve with its baseline condition.

4. RESULTS OF THE SELECTION PROCEDURE

Let's look at the importance of using a valve preselection procedure for further tribological research. For this research it is of extraordinary importance that we use valves with exactly the same respectively identical characteristics. The importance of the pre-selection process of valves is shown on an example of classical directional proportional valve type of usual market quality, without a control spool measuring system.

In the considered case, we used three identical valves of the same manufacturer, with the same label and code, and, thus, expected the same characteristics. The results of the preselection process are presented in the form of three different valve test-characteristics: A leakage test, metering test and output flow vs. input signal test. The results of the characteristics` measurements are shown in Figures 4, 5 and 6.

Based on a comparison of three different characteristics of the same type of valve, it is more than obvious that all valves are not identical, even though they are declared as the same type of valve.

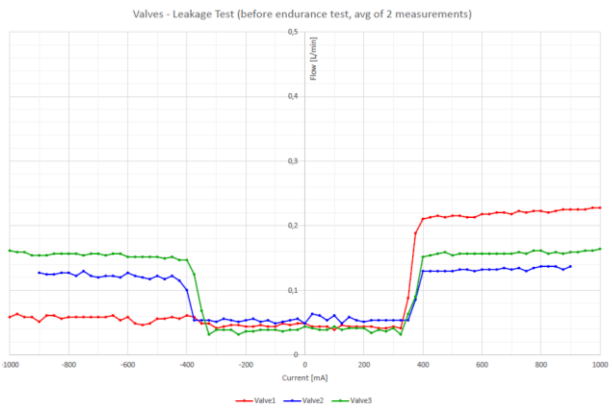

Figure 4. Comparison of an internal leakage test characteristic for three valves

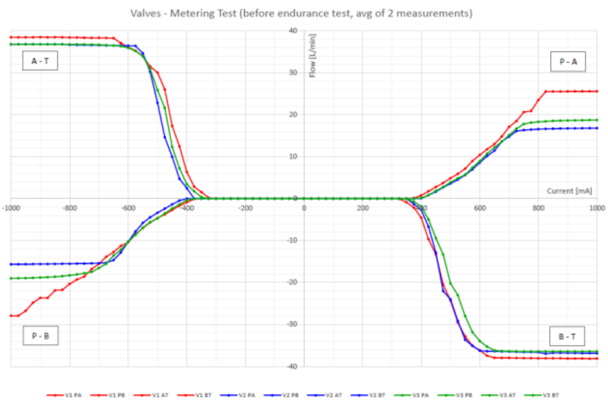

Figure 5. Comparison of a metering test characteristics for three valves

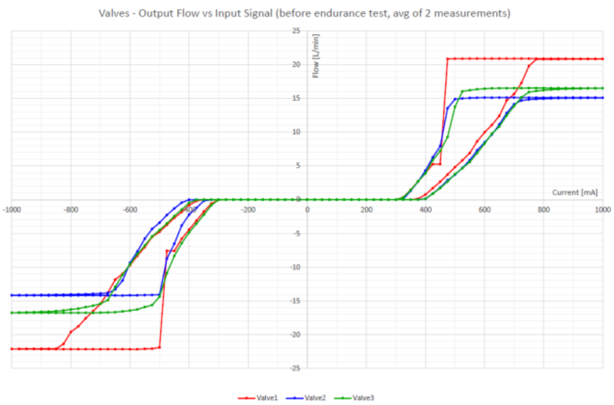

Figure 6. Comparison of output flow vs. input signal characteristics for three valves

The differences between the characteristics of valves occur due to a valve manufacturer's fault, whether an incorrect/different built-in valve spool, or the error is due to the incorrect code listed on the valve plate.

Whatever is the cause of the mistake in these differences, this is reflected consequently as different valves with different properties. When conducting the tribological research, in this case, false conclusions would arise. If we know exactly the baseline situation, we will be able to give an appropriate assessment of the condition of the valve leakage range, degree of wear, wear and change in the geometry of the control edges.

5. CONCLUSION

A number of methods are available to test the wear resistance of individual components, along with the known hydraulic fluid. Some have become standardised, others are dedicated and of an internal nature, linked to a single manufacturer, either components or fluids. However, none of the represented methods allows a comprehensive insight into developments in all components of the hydraulic system. This is especially true for hydraulic valves.

In the case of tribological tests with hydraulic pumps, the type of pump used is defined precisely. In the case of tribological tests with hydraulic valves, nothing is specified. In order to compare the behaviour of different lubricants with the same type of valve, it is necessary first of all to provide the same starting points. In this case, we can only rely on the valve characteristics, which are measured by standardised procedures.

Except for the use of identical valves in all subsequent tests, we have also come up with other important information, for example: To know the actual leakage rate of the new valve and the leakage rate of the already worn-out valve, to determine the actual valve characteristic compared to those available in data sheets, to know all the characteristics of the same valve according the Standard.

On the basis of later changes in the individual characteristics, we get the information about the impact of the lubricant on the individual valve component and, consequently, the impact of the valve on the hydraulic actuator behaviour and the entire controlled hydraulic system.

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