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DEVELOPMENT OF FULLY AUTOMATED TEST BED FOR MEASURING STATIC CHARACTERISTICS OF DIRECTIONAL HYDRAULIC VALVES

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Abstract: *Directional hydraulic valves are one of the basic and very important components of a hydraulic system as they control the direction and quantity of the flow of hydraulic fluid. In order to compare the performance of valves from different manufacturers, or in order to evaluate performance of the valve during its lifetime, a special test bed should be developed.*

The paper presents the development of fully automated test bed for measuring static characteristics of directional hydraulic vales according to ISO 10770-1. The test bed consists of hydraulic system equipped with modern sensors and is controlled by a soft PLC. The test procedure is fully automatic and the test results are displayed real-time.

Keywords: *hydraulic valves, directional valves, flow characteristics, pressure drop, test bed.*

1. INTRODUCTION

Directional hydraulic control valves are hydraulic components for regulating the flow direction of the fluid and the flow velocity in the hydraulic system. Their use in the hydraulic system allows the actuator to move (cylinder, hydraulic motor ...). The most common design of directional valves uses control spool that moves from the starting position (usually the middle) to the left or right operating position, depending on the desired direction of movement of the actuator. The movement of the spool is controlled by either lever, coil, hydraulic force or a spring. [1]

The properties and characteristics of directional hydraulic control valves have a strong influence on the behaviour of the entire hydraulic system. The performance of the valve is most influenced by its construction, but the characteristics also depend on the hydraulic fluid used, which changes the characteristics of the valve with different viscosity, compressibility and density.

With developed test bed for measuring static characteristics of directional hydraulic valves it is possible to obtain information on the properties of a particular valve of a particular manufacturer in combination with a particular hydraulic fluid based on standardized procedures. At a later repetition measurement of the same valve, we can conclude on its wear and degradation of the characteristics.

If we want to compare the characteristics of the hydraulic equipment between different manufacturers and evaluate the variation of the characteristic over the useful life of the valve, the characteristics must be comparable. Comparability is achieved by standardized tests and a standardized presentation of results.

2. ISO 10770 STATIC TESTS

ISO 10770 standard applies to electrically modulated hydraulic control valves and consists of three parts. The first part refers to the testing of four-port directional valves, the second part relates to the testing of three-port valves, and the third part to the pressure regulating valves [2].

The standard is divided into electrical tests, performance tests that are further divided into dynamic and static tests, and pressure impulse test. This paper focuses on the static performance tests of four-port directional valves. According to the standard these static tests exclude any dynamic effects. The standard also specifies the test conditions that are presented in Table 1.

Table 1. Required test conditions [2]

Ambient temperature	20 ±5 °C
Filtration	According to ISO 4406
Hydraulic fluid	Mineral hdraulic oil (ISO 6743-4) or other hydraulic fluids according to the valve
Hydraulic fluid temperature	40 ±6 °C at valve inlet
Fluid viscosity grade	VG 32 (ISO 3448)
Pressure	±2,5 % according to specific test
Pressure on the return line	According to manufacturer's recommendations

Further on, the paper will present development of fully automated test bed for measuring static characteristics of directional hydraulic valves and results of three most important and common test for four-port directional valves.

2.1 Internal leakage versus input signal

The internal leakage test measures the internal leakage flow between the individual valve ports. During the test both control ports are closed and the tank port is opened. The pressure port is loaded with 100 bar or with valve's maximum pressure allowed.

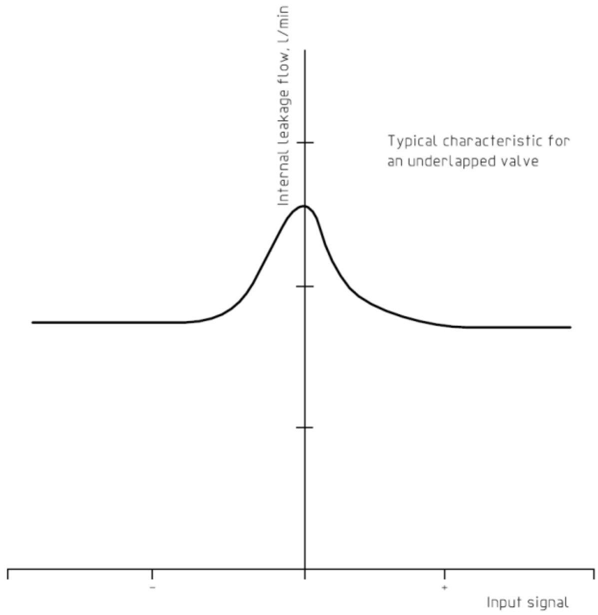

Figure 1. Internal leakage versus input signal [2]

Before performing the measurement, it is necessary to drive the valve several times over its entire control area. The flow of leakage on the tank port is then measured throughout the control area. The result is a graph of the leakage flow depending on the control signal as shown in Fig. 1 [2].

2.2 Output flow versus input signal at constant valve pressure drop

Figure 2 shows the static flow characteristics of the hydraulic fluid as a function of the control signal. This characteristic is defined at a constant pressure drop on the valve. Work ports are connected together via the flowmeter. The test is carried out at a pressure drop of 10 bar, of 70 bar or of one third of the maximum working pressure.

Before performing the measurement, it is necessary to drive the valve several times over its entire control area. During the test, the input control signal is adjusted from one limit (i.e. negative) to another limit (i.e. positive), while the flow value is recorded. The speed of the signal change must be slow enough so that the dynamic effects are not affected by the results. Between the test the pressure drop on the valve should be as constant as possible and should not deviate by more than 5 %.

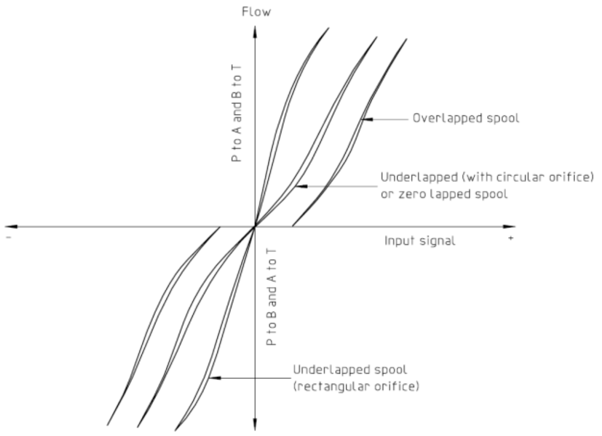

Figure 2. Output flow versus input signal at constant valve pressure drop [2]

In the obtained results, the following characteristics of the valve can be identified: output flow at rated signal, flow gain, linearity, hysteresis, null zone characteristics (i.e. spool lap condition, symmetry, polarity and limiting power [2].

2.3 Metering test

The purpose of this test is to determine the characteristics of each land of the main spool as shown in Fig. 3.

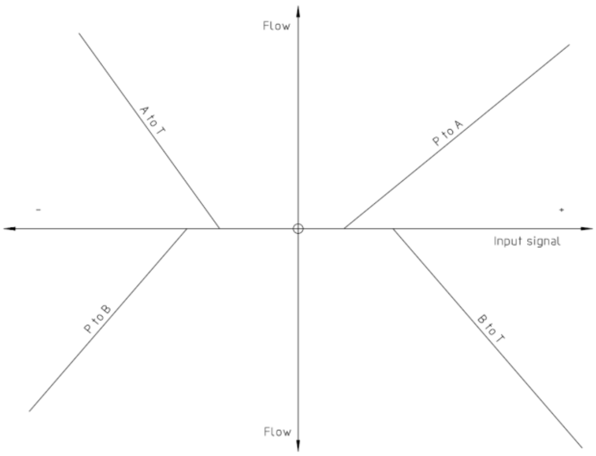

Figure 3. Metering test [2]

The test is made of four different measurements of the flow between two control ports at constant pressure drop: the flow from port P to A, P to B, A to T and flow from port B to T. [2]

3. DEVELOPMENT OF TEST BED

Based on the ISO 10770-1 test procedures (some described above) a test bed was designed and built (Fig. 4).

Figure 4. Test bed

The hydraulic system (Fig. 5) is mounted on the frame made of aluminum profiles. It consists of pipes, shut-off valves and several sensors for pressure, flow and temperature. Hydraulic power is provided by a hydraulic power unit with variable axial piston pump powered by a three-phase asynchronous motor, controlled via frequency converter.

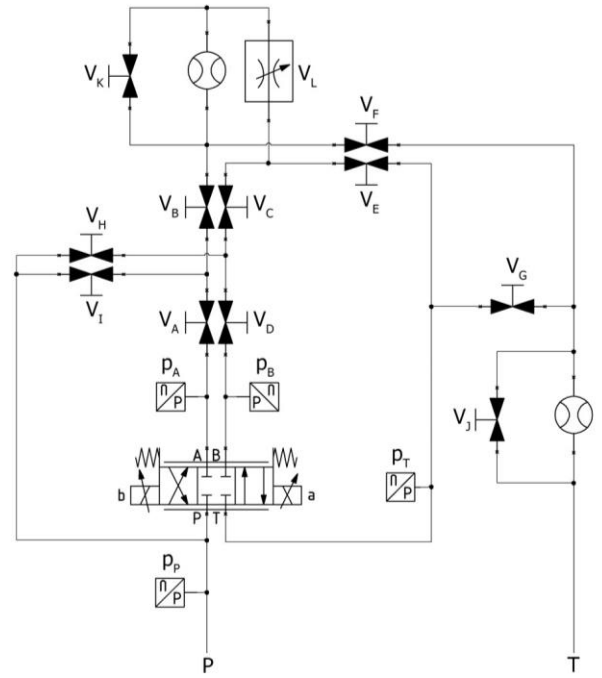

Figure 5. Hydraulic scheme of test bed

The use of variable axial piston pump powered by a three-phase asynchronous motor, controlled via frequency converter allows us to perform closed loop control (PID) of pump flow from 0 to 80 L/min to achieve desired constant pressure drop on the valve.

3.1 PLC control system

The PLC system is based on Beckhoff soft PLC with selected digital and analog input/output modules to control the system. Besides digital and analog modules, the system also incorporates counter modules to measure the flow by two gear type flow meters and a PWM current output module to control the coils of proportional directional valve. Using this special module (EL2535) allows us to have full control over pulse width modulation of closed loop current control together with PID parameters of PWM modulation and dither signal to the valve.

3.2 HMI and visualization

The user interface (shown in Figure 6) is made in C# Windows Forms where it is possible to include libraries for the graphical display of signals directly from the PLK.

The HMI graphical interface serves to select the test we want to perform, set the appropriate parameters, capture data and monitor the measurement. The results are displayed in the form of a graph and a table, and can be exported to Microsoft Excel XLS file.

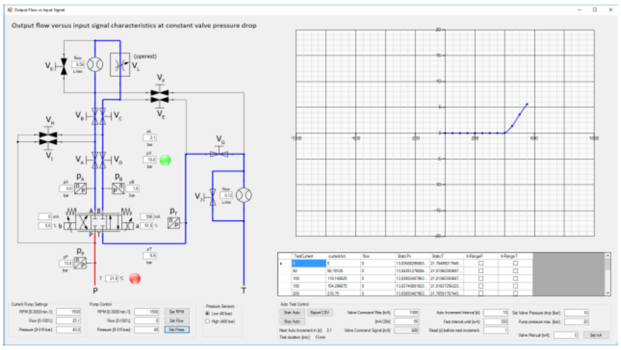

Figure 6. Windows application for HMI

HMI application window contains a hydraulic diagram that is equipped with digital displays of pressure and temperature values and a marked pathway of the current pipeline, thus making it easier to visualize the path of the hydraulic fluid. Under the hydraulic diagram we have indicators of current pump parameters: the rotational speed can be set from 0 to 3000 rpm, the flow can be set from 0 to 100 %, and the pressure can be set from 0 to 315 bar. The user can also define the desired pressure drop on the valve and time/step interval of performing individual measurements. On the right side of the window the results of the test are displayed in real time in in the form of a graph and a table.

4. RESULTS

Figure 7 shows the results of the internal leakage test.

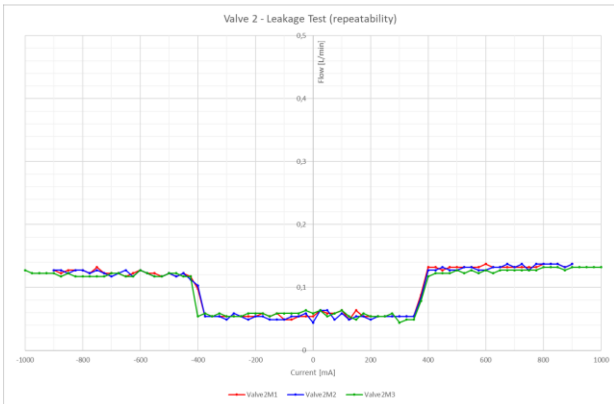

Figure 7. Results – Internal leakage test

During the test both control ports are closed (A and B) and the tank port (T) is opened. The pressure port was loaded with 300 bar and valve's internal leakage was recorded. The measurement was started with maximum negative signal and increased to maximum positive signal with 25 mA steps. To evaluate the accuracy and repeatability of the test bed, we have made three reiterations of each test (the results of each are shown as red, blue and green line).

The static flow characteristics of the hydraulic fluid as a function of the control signal is defined at a constant pressure difference on the valve. Since we were measuring a proportional directional control valve it was important to ensure a constant pressure drop of 10 bar. During the measurement, the signal changes from 0 to positive limit, then back to negative limit and back to 0. In this way also the hysteresis of the valve is recorded.

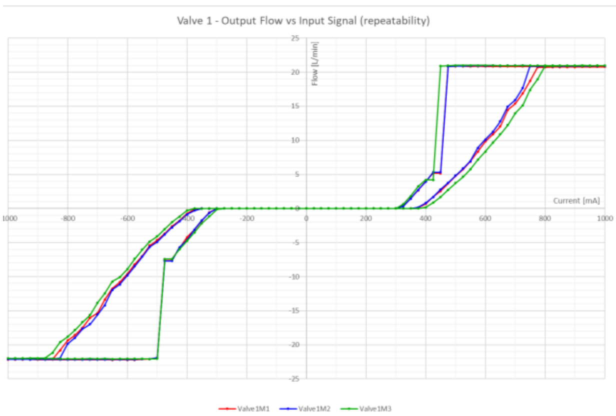

Figure 8. Results – Output flow vs Input signal

The obtained results can be seen in Figure 8 and show three reiterations of the test. A large hysteresis on the valve and poor linearity when decreasing control signal in both directions can be noticed.

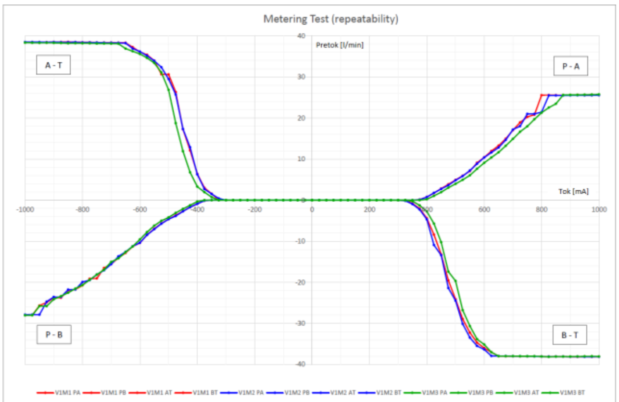

Figure 9. Results – Metering test

Additionally, the metering test is used to determine the flow characteristics of four individual connections: P-A, P-B, A-T and B-T. The measurement was also done with 25 mA step increase of current signal. The results of (three reiterations) of the test are presented in Figure 9. Better flow conditions can be recognized in A-T and B-T flow connections compared to P-A and P-B flow connections which have more flow restriction.

5. CONCLUSION

A fully automated test bed for measuring static characteristics of directional hydraulic valves was successfully developed and built. It allows us to perform all types of tests specified in ISO 10770-1 and determine the static characteristics of four-port directional hydraulic valves with desired accuracy and repeatability.

The test bed allows us to compare properties and characteristics of different new valves or to evaluate the performance of a single valve before and after being exposed to long-term endurance test, evaluating its performance after the endurance test.

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