ValveExpert 7.1

Check / Adjust / Repair
Servo- and Proportional Valves

Automatic Test Equipment

Contents

Introduction

ValveExpert 7.1 is an automatic test stand for checking, maintenance, and adjustment of servo- and proportional valves. This test equipment is developed in accordance to the standards established in SAE ARP 490 and ARP 4493.[1] Below are the main features.

- Wide range of servo- and proportional valves is supported. Testing flow is up to 100 L/min (25.5 Gal/min) and working pressure is up to 315 bar (4500 PSI).
- Compact high efficient and low noise 45.6kW hydraulic power station is already inside.[2]
- Temperature control system stabilizes the oil temperature in a specified range with tolerance ±2°C.[3]
- The integrated 3µ filtration system achieves a cleanliness level 5 of NAS1638 (level 14/11 of ISO4406) or better.
- An additional, the "last chance" 10µ filter protects the valve from contamination.
- Extremely robust construction of the stand. The most of hydraulic components are mounted on one steel manifold. The only top quality components are used.
- Multi-level alarm system protects the operator from risky conditions. This system informs the operator if service is required.
- Different hydraulic liquids can be used.[4]
- The computer subsystem is based on a high performance Intel processor and a DAQ system from National Instruments.
- The computer interface is intuitively clear and simple. Special education and knowledge are not required. Operator works with a powerful virtual hydraulic laboratory on a 19-inch touch-screen monitor.
- Internal user-defined database keeps all test parameters. This database contains also overlay polylines for automated pass/fail evaluation. The operator can use keyboard, touch screen monitor, trackball, or bar-code scanner for fast access to the database.
- The system supports manual and automatic modes.
- The measurement data includes the most of static and dynamical characteristics. Up to 20 different subtests can be done during one automatic test.
- Complete test process requires a soft time. Computer shows the results during the testing process.
- A powerful mathematical analysis of the results is already embedded into the system. The ValveExpert 7.1 program saves the data in a standard MS Excel format and Excel tools can be used for an additional analysis. The operator can use template files to prepare required printout forms.
- ValveExpert can work with any measurement units, i.e. the operator can decide which units he will use for pressure, flow, temperature and so on.
- High precision measurement tools are used. All instruments are individually calibrated and scaled. Nonlinear calibration allows compensate nonlinearity of transducers, and reach extremely high precision.
- Calibration process is very simple and can be made by the operator. The only standard measurement tools are required.

[1] The general ideas which are used in the stand can be found in http://arxiv.org/abs/math/0202070.
[2] This hydraulic station requires three-phase 380-500V, 120A electric power supply connection.
[3] Water connection for the cooling system is required.
[4] Aerospace hydraulic fluids like Skydrol®, Hyjet® or similar require modifications in the construction of the test stand.

Review of Specifications

Applications

Test stand ValveExpert 7.1 is developed for checking, maintenance and adjustment of two, three and four ways servo- and proportional valves.[5] Working pressure of the stand is up to 315 bar (4500 PSI). The maximal test flow is 100 L/min (25.5 Gal/min).

Control Signals

A servo- or proportional valve under testing can be controlled by voltage or current command signal. There are five standard ranges for control signal: ±10V, ±10mA, ±20mA, ± 50mA and ±100mA. Additional PWM amplifiers can generate current up to ±1000mA and up to 0…+3500mA for valves with differential coil configurations. The build in relays can change polarity of control signal and the coil configurations (for two coil electric servo- or proportional valves): Series, Parallel, Coil No.1 and Coil No.2.

Spool Position Signals (Feedback)

The most of modern servo- or proportional valves have a build in electronics. These valves are usually equipped by spool position transducers. ValveExpert 7.1 can check the signal from such a transducer. The standard signal ranges ±10V, ±10mA, ±20mA, 4–20mA are supported.

Electric Power Supply for Servovalve

Servovalves with build in electronics require external power supplies. In the most cases, it is ±15V or 24V. Such power suppliers are built in the test stand.[6]

Hydraulic Fluid

The test stand ValveExpert 7.1 was developed and tested for a mineral oil with viscosity about 30 cSt. We recommend you to use Mobil DTE24, Shell Tellus 29, MIL-H-5606, MIL-H-83282, MIL-H-87257 or oil with the similar parameters. Note that aerospace hydraulic fluids like Skydrol® or Hyjet® require modifications in the stand construction. The integrated filtration system achieves a cleanliness level 5 of NAS1638 (level 14/11 of ISO4406) or better. The capacity of the oil tank is about 200L (50Gal).

Hydraulic Power Supply

The test stand does not require an external hydraulic power supply. A modern high efficient and low noise 45.6kW hydraulic power station is already inside! Maximal flow of the power station is about 100 L/min (25.5 Gal/min) and working pressure is up to 315 bar (4500 PSI). The integrated hydraulic power pack requires three-phase 380-500V, 120A electric power supply connection and a water connection for cooling. Note, the temperature control system allows to stabilize the oil temperature in a specified range with tolerance ±2°C.

[5] Additional adaptor manifolds allow use this test equipment for different purposes.
[6] Maximal current is 2A for ±15V and 5A for the power supply 24V.

Hardware

Hydraulics

Hydraulic circuit of ValveExpert 7.1 is shown on the Figure 1. The most of hydraulic components are mounted on a steel manifold (see Figure 2, Figure 3).[7] The only top quality components are used. Directional valves are used to configure the hydraulic circuit for different tests. The main configurations are described in the section “Hydraulic Configurations”.

[7] These hydraulic components are shown in the blue area (see Figure 1).

Hydraulic circuit ValveExpert 7.1

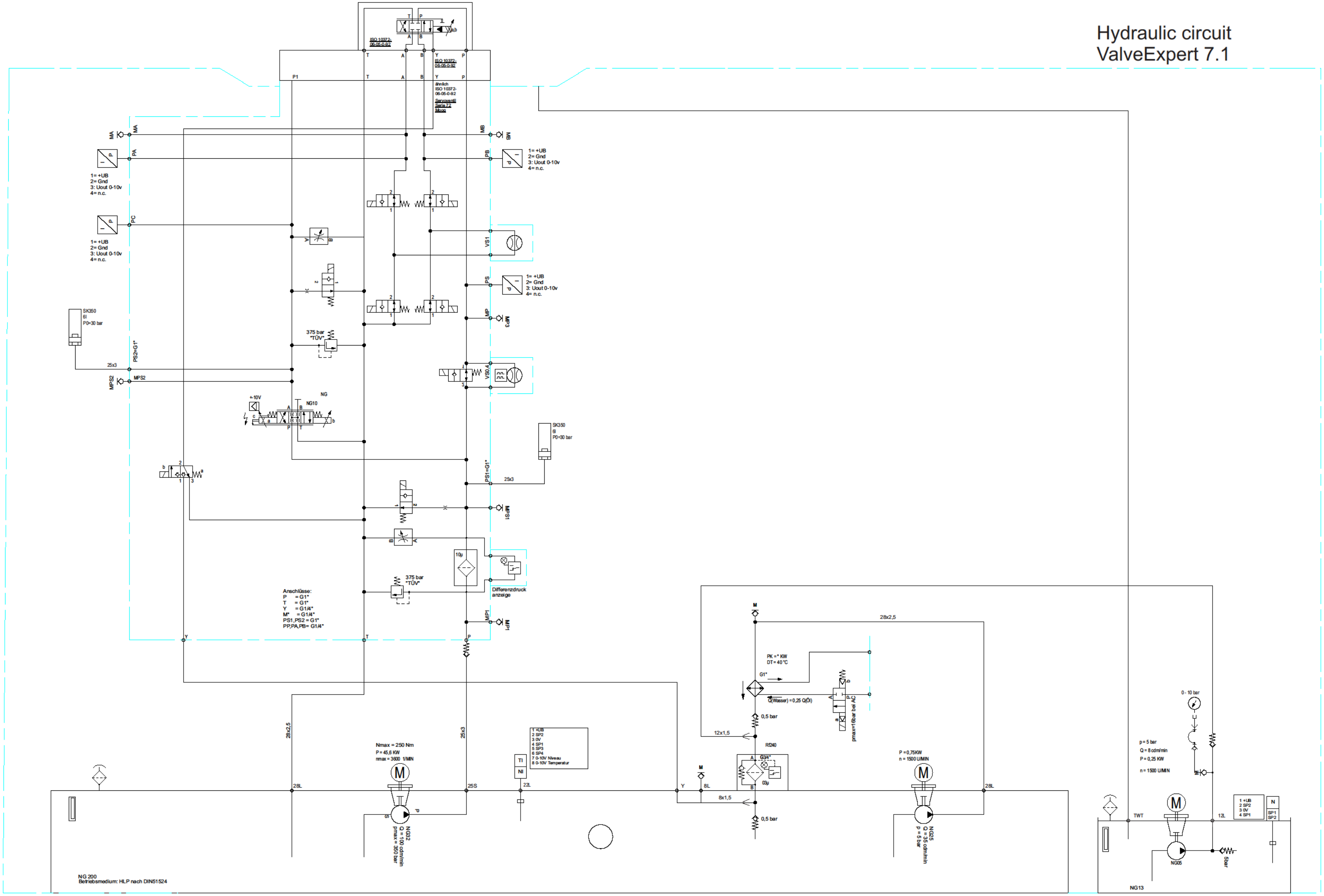

Figure 1. Hydraulic circuit of the test stand ValveExpert 7.1

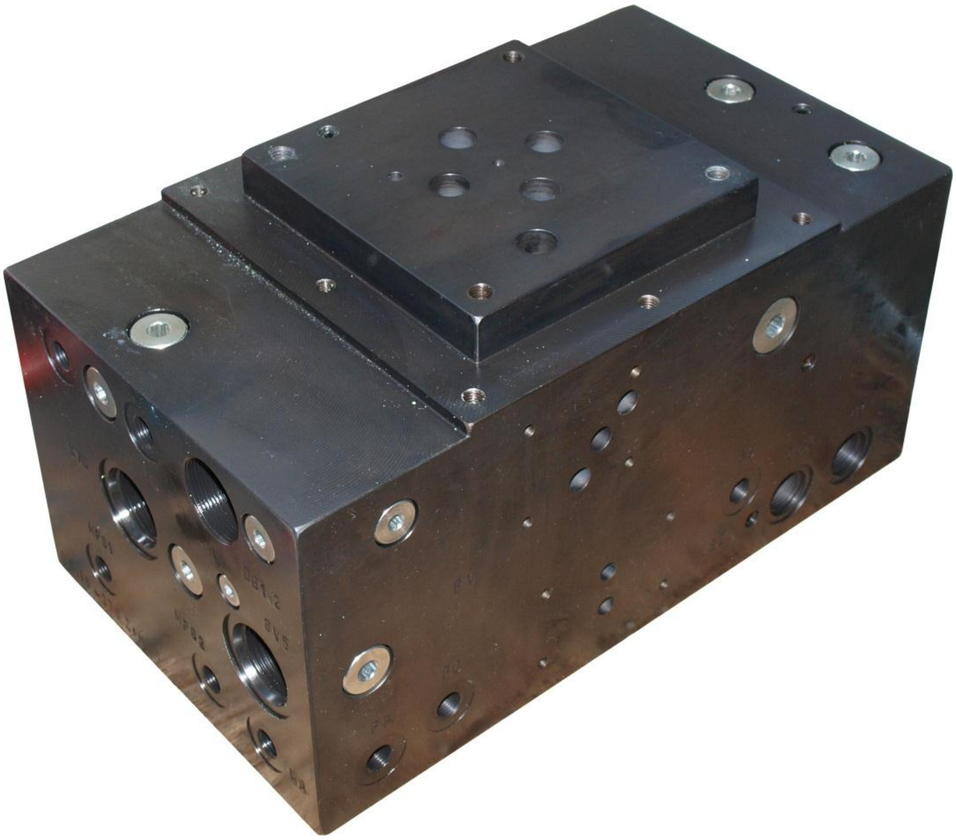

Figure 2. Hydraulic manifold of the stand

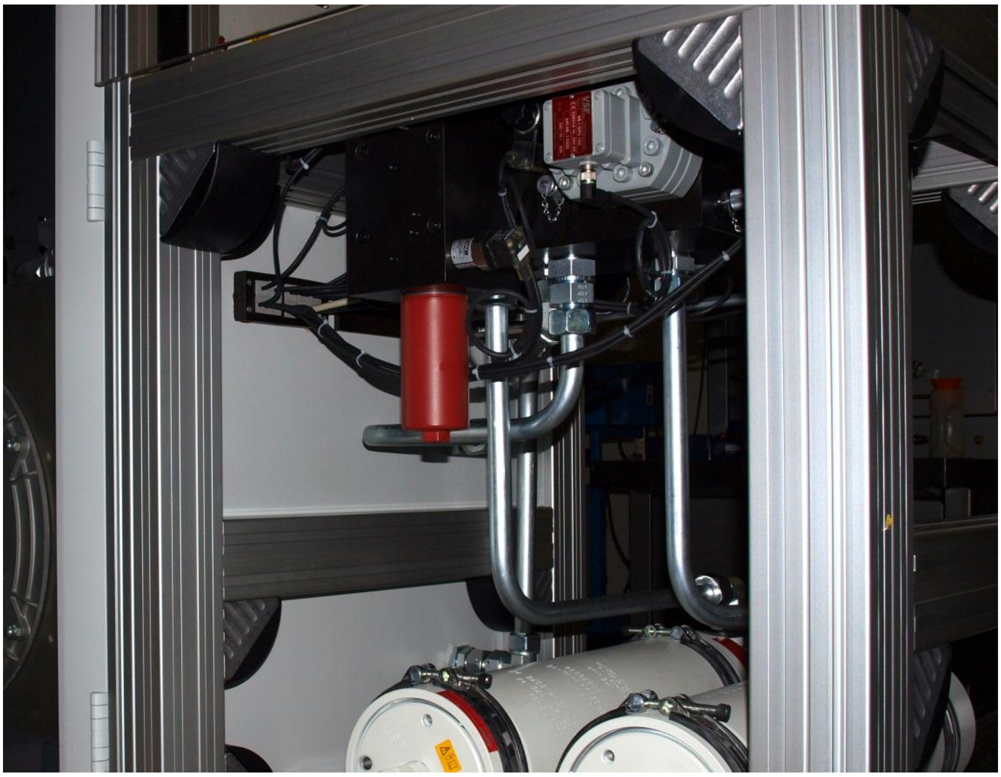

Figure 3. Most of hydraulic components are mounted on a manifold

Hydraulic power pack (see Figure 4) uses a low noise internal gear pump and a brushless motor with variable rotation frequency. Maximal power of the hydraulic system is 45.6kW. Maximal working pressure is 315bar (4500PSI). Maximal flow is 100L/min (25.5 Gal/min).

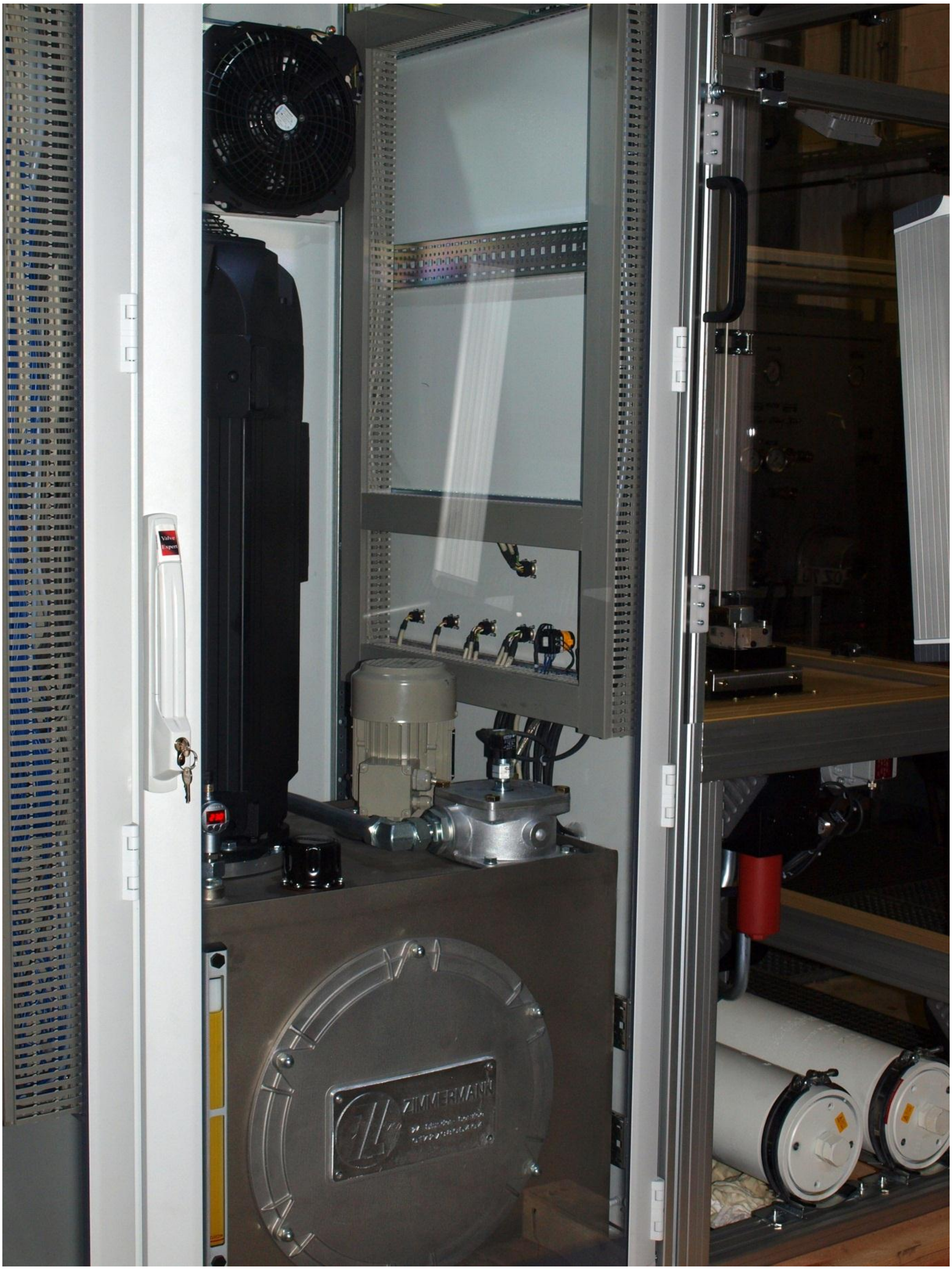

Figure 4. Hydraulic power pack

Figure 5. Drain oil and cooling subsystems

Electric Power Supply

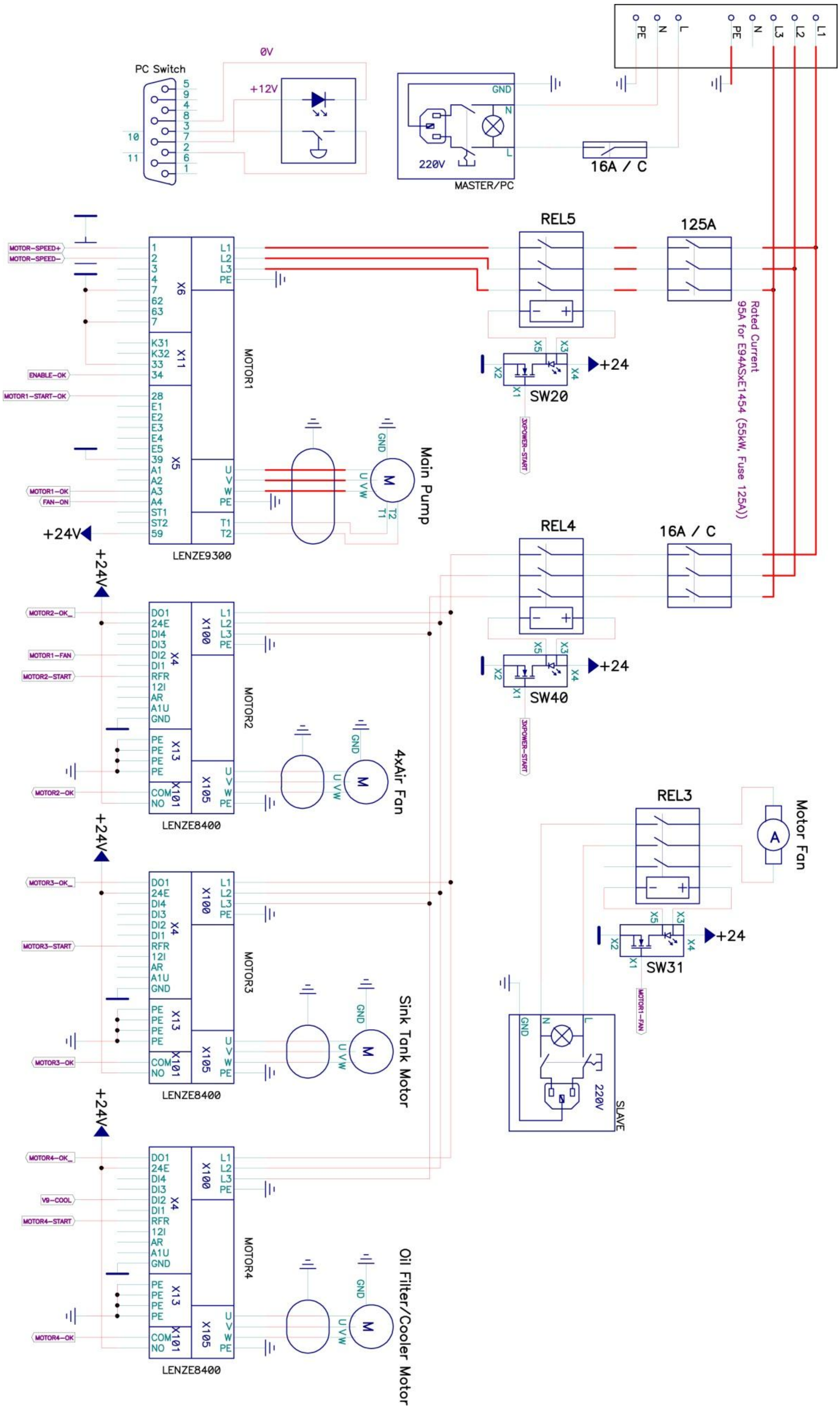

Figure 6. Electric power supply the stand

Figure 7. Module of the power electronics

Interface Electronics

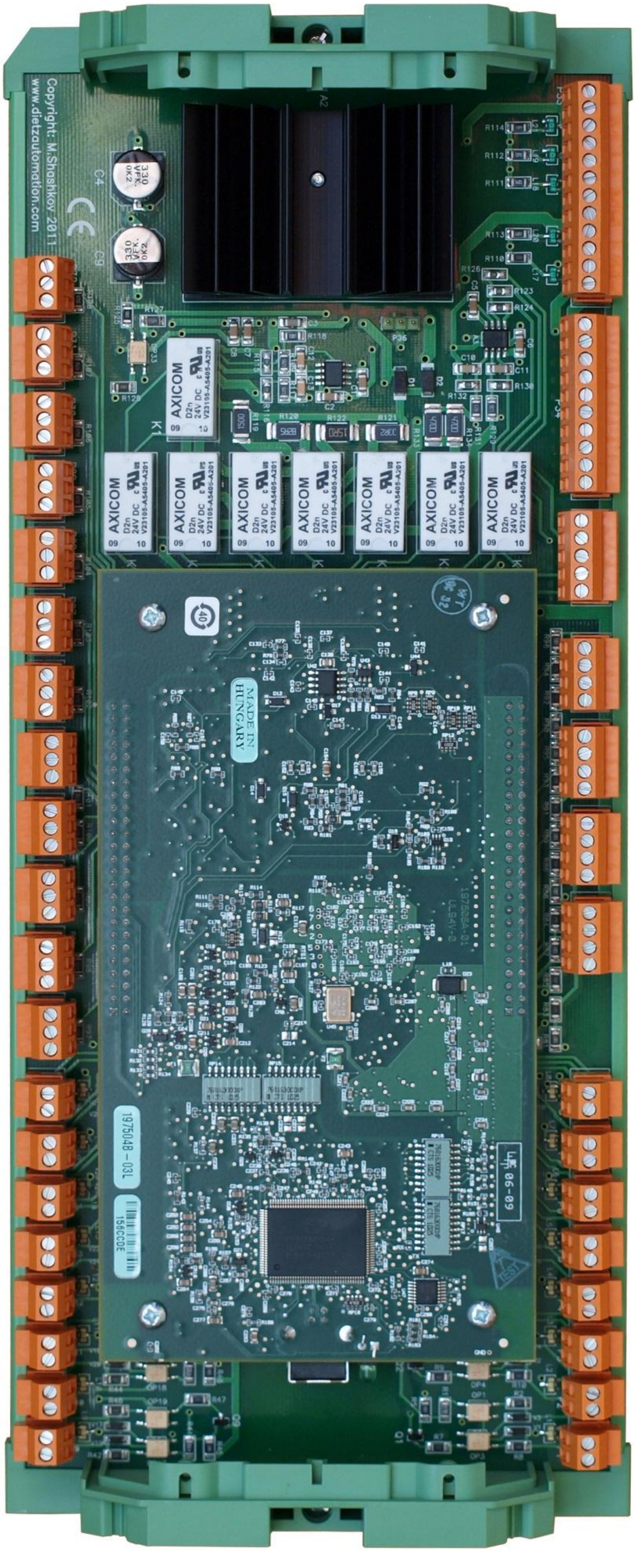

Figure 8. Interface electronics of the test stand ValveExpert 7.1

Alarm System

Multi-level alarm system protects an operator from risky conditions. This system also informs the operator if service is required. Two alarm levels are organized with a Windows base computer and with a Siemens microcontroller correspondently. An electromechanical safety relay stops power motor if at least one of emergency stop switches is activated. Program ValveExpert 7.1 informs the operator about all problems of the stand. This information will be shown as well by the microcontroller.

Figure 9. A safety relay and a microcontroller “Logo!” from Siemens are used for the alarm system

Computer Subsystem

The computer subsystem is based on Windows 7 computer with Intel processor. National Instruments DAQ card is used for input/output system. The system includes a 19” touch-screen monitor, a stainless steel keyboard with trackball, and a bar-code scanner for fast access to the database. See Figure 10 and Figure 27. Software includes Windows 7 operation system, drivers, Backup software, MS Office 2010 with Excel, and the program ValveExpert 7.1.

Figure 10. Virtual hydraulic laboratory of a touch screen monitor of ValveExpert 7.1

Figure 11. Windows base computer of the stand ValveExpert 7.1

Data Acquisition Electronics

The measurement subsystem of ValveExpert 7.1 is based on the National Instruments USB-6212 OEM card (see Figure 12). The detailed documentation of this card is available on web site http://www.ni.com/

Figure 12. National Instruments USB-6212 OEM DAQ card

Amplifier for Proportional Directional Control Valves

Test stand ValveExpert equipped by programmable PWM current amplifier which can drive most of two or one coils proportional directional control valves without position feedback and with maximal current up to 3.5A (see Figure 13, Figure 14). All parameters of the electronics can be adjusted via a serial connection (RS232 – null modem). The Parker software ProPxD can be used to adjust the device. Look the manual for more details.

Figure 13. Programmable PWM current amplifier

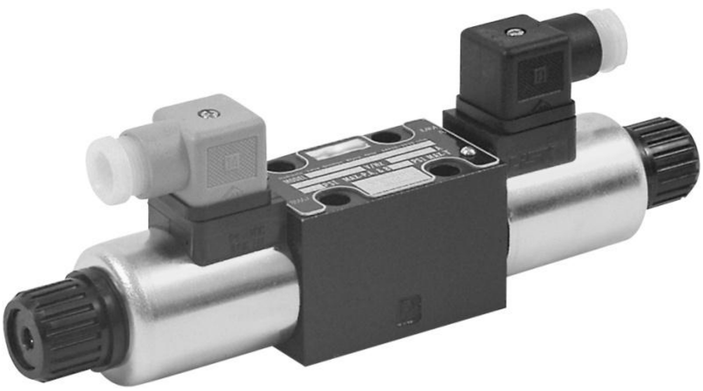

Figure 14. Two solenoids proportional valve

Connectors

In order to test a servo- or proportional valve operator has to use a proper adapter manifold for hydraulic power supply and a proper electric cable. One or two coils proportional valves without feedback electronics require connection to the PWM current amplifier. The mounting manifold must conform to ISO 10372-06-05-0-92. Connectors of the stand are shown on Figure 15. Pinout configurations of the test stand connectors are shown on Figure 16, Figure 18, and Figure 21. Please note that you will need a dynamic cylinder (see Figure 19) to measure frequency response data of your valve if it has not a spool position transducer. Such a frequency response cylinder is an optional equipment. Coil connectors (see Figure 21) are used to drive two or one coils proportional directional control valves without position feedback (see Figure 14).

Figure 15. Connectors of the stand

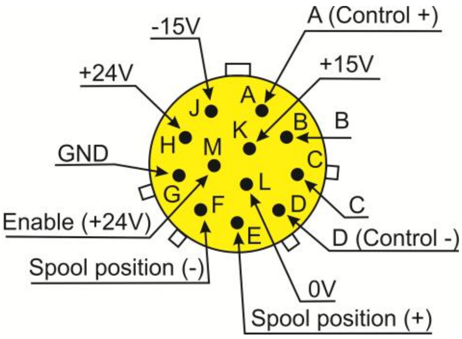

Figure 16. Pinouts of the main servovalve connector
(Ranges: ±10V, ±10mA, ±20mA, 4-20mA, ± 50mA and ±100mA)

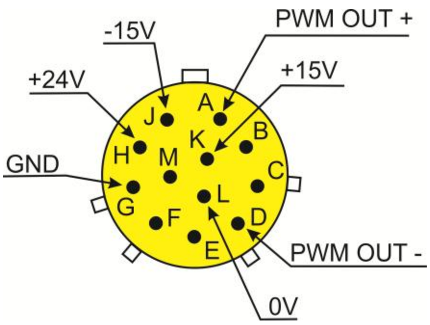

Figure 17. Pinouts of a 1A differential PWM amplifier connector.
The only inductive load can be used!

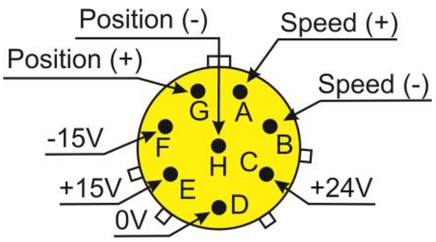

Figure 18. Pinouts of the connector for frequency response cylinder

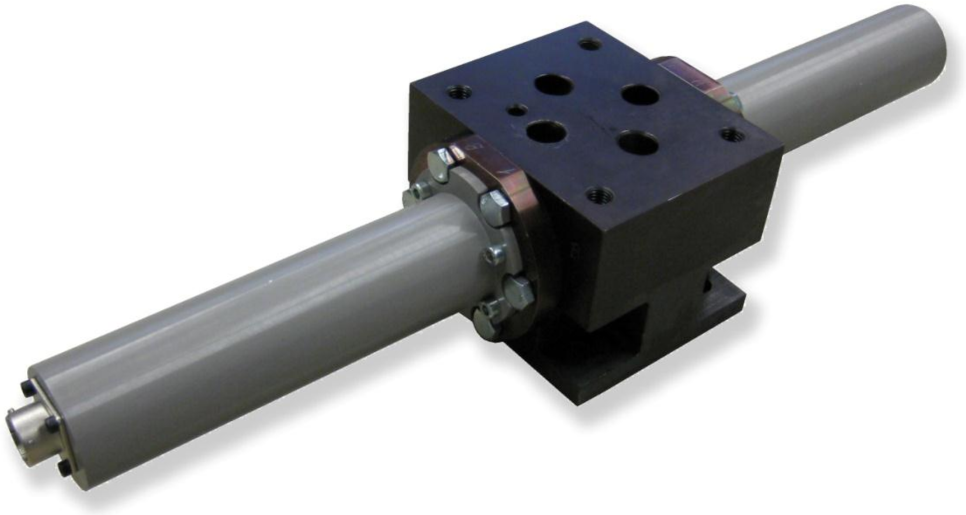

Figure 19. Frequency response cylinder (optional)

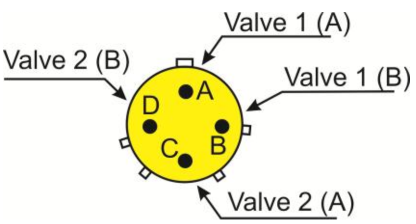

Figure 20. Pinouts of the connector to control 2 On/Off valves (DC 24V)

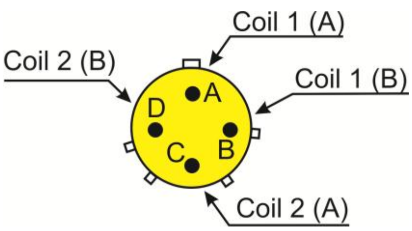

Figure 21. Pinouts of the PWM current amplifier connector for valves with differential coils
The only inductive load can be used!

Software

Virtual Laboratory ValveExpert 7.1

The test equipment ValveExpert 7.1 has got an intuitively clear software. Operator works with a powerful virtual hydraulic laboratory on a 19-inch touch-screen monitor. This laboratory has two modes of operation: “Manual” (see Figure 22) and “Automatic” (see Figure 42, Figure 43, Figure 44). Hydraulic circuit, shown on the monitor, corresponds to the real hydraulic configuration of the stand. Seven different hydraulic configurations (Figure 28 – Figure 34) are available. All measuring and control devices can be simply adjusted. These adjustments can be saved in a database which contains also all parameters for the automatic tests and some additional information. The main functions are duplicated by the functional keys (see Figure 23). Detailed description of the virtual hydraulic laboratory is done below.

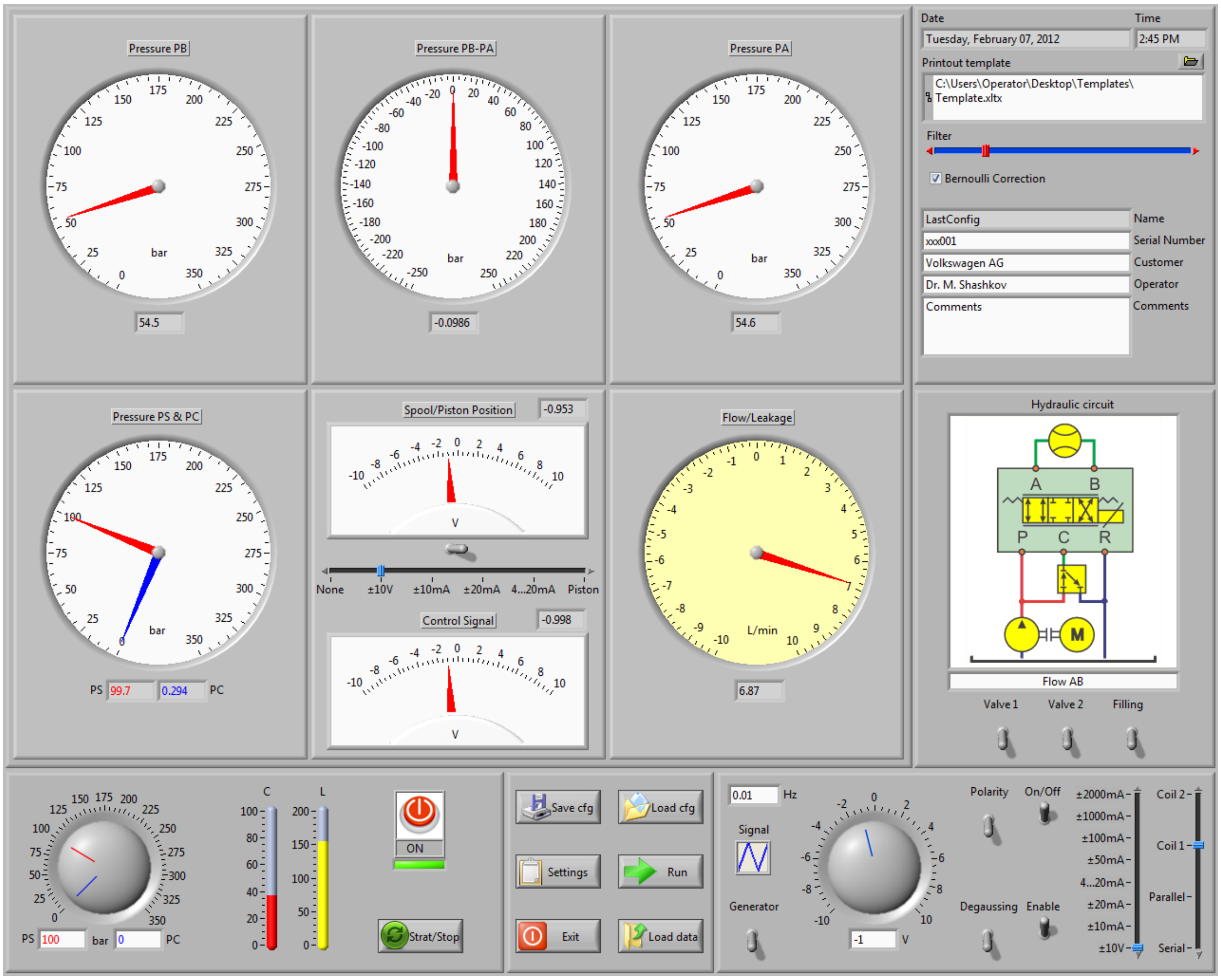

Figure 22. Virtual hydraulic laboratory. Manual test mode

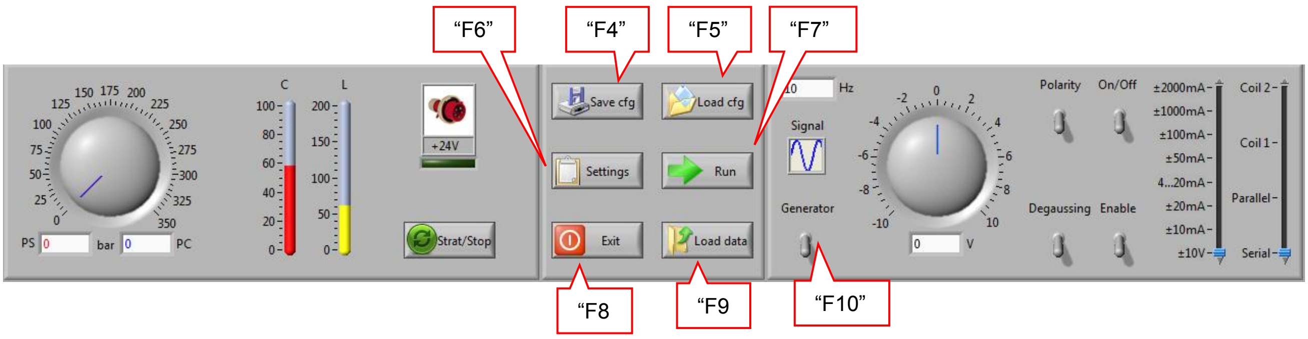

Figure 23. Functional keys

Hydraulic Power Supply

Controls and indicators of the hydraulic power pack are shown on Figure 24.

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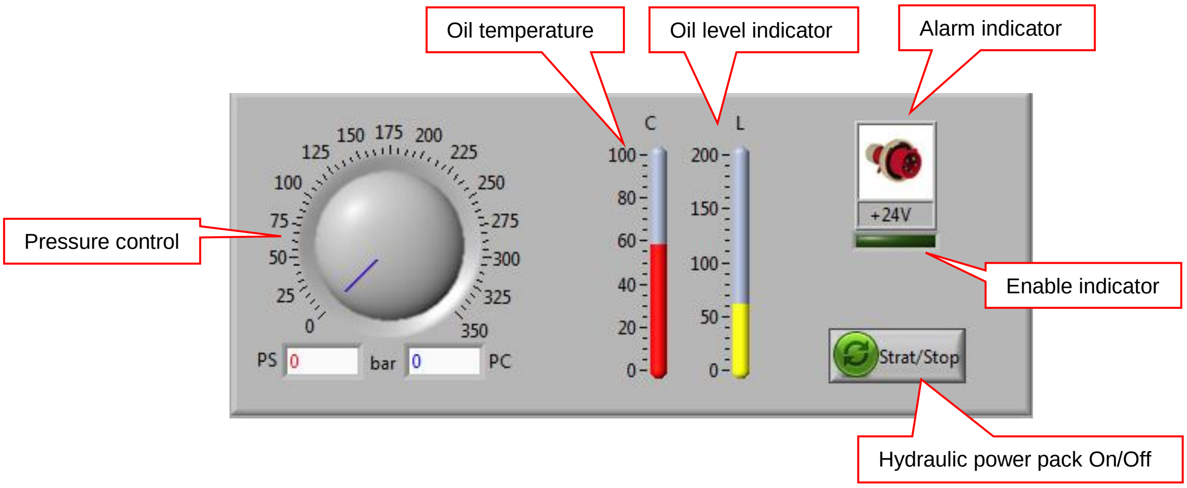


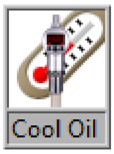
Figure 24. Controls of the hydraulic power station

Possible values of the alarm indicator are:

- 

System is ready to work
- 

Hydraulic power pack is switched ON
- 

Cooling of the main motor is switched ON
- 

Oil cooling system is switched ON
- 

Sink oil pump is started
- 

Problem with motor of the filtering system

- 

Problem with sing tank motor
- 

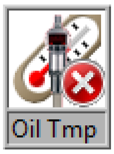
Problem with air cooling motors.
- 

Problem with the main power motor
- 

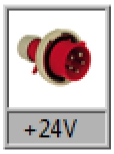
(Option) Window of the test area is open
- 

Emergency stop activated
- 

3μ filter is polluted
- 

10μ filter is polluted
- 

High temperature of oil
- 

Low oil level
- 

Problem with power supply +24V

Universal Amplifier

Controls of the universal amplifier are shown on Figure 25.

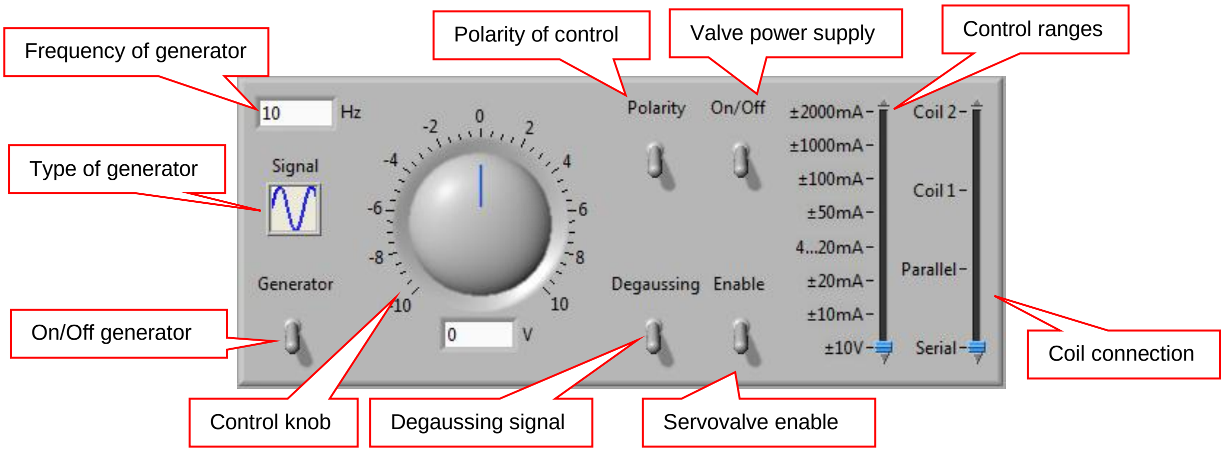


Figure 25. Controls of the universal amplifier

This amplifier has got 3 modes: manual control, generator and degaussing. In order to control valve manually operator can use the control knob. The generator mode is used for the automatic control. This mode supports the following standard signals: sawtooth , triangle , sinus  and square . Frequency of the generator belongs to the interval 0.001 – 1000 Hz. Degaussing signal allows to eliminate the initial magnetic field of the valve.

The Main Controls

The main control buttons are shown on Figure 26. They are used to load or save settings, start or stop automatic testing process, exit the program and so on. The operator can use the touch-screen monitor or touch pad on the keyboard to access the buttons. Moreover, functions of these buttons are duplicated by functional keys on the keyboard. Operator can use also a two dimensional bar-code scanner (see Figure 27) for fast access to the database when he loads or saves settings. In this case he will never make a mistake and load wrong settings!

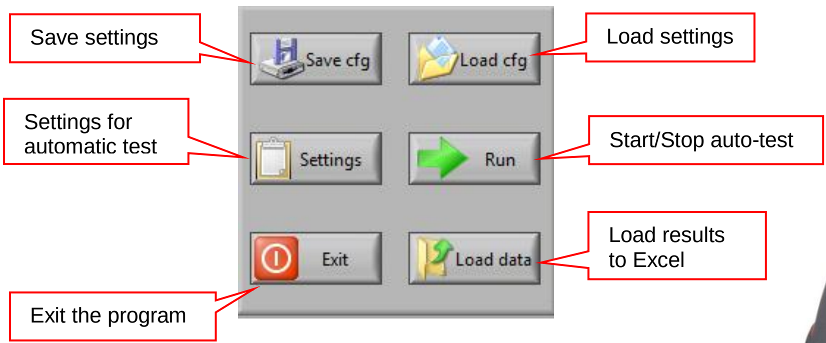


Figure 26. Main control buttons

Figure 27. Bar-code scanner

Hydraulic Configurations

Virtual hydraulic laboratory has got seven different hydraulic configurations. Figure 28 –Figure 34.

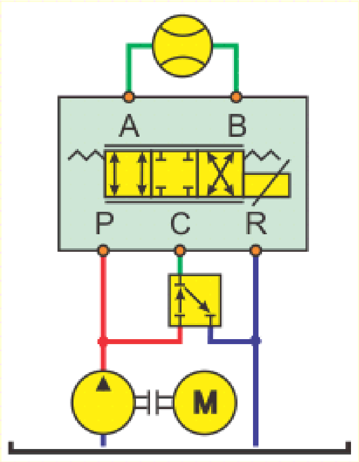


Figure 28. Flow AB test

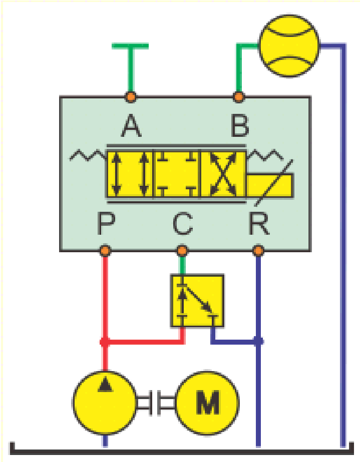


Figure 31. Flow B test

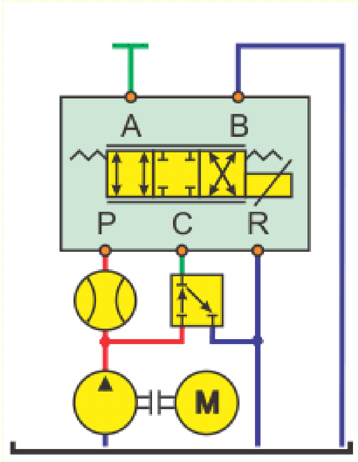


Figure 34. Flow B test near bias

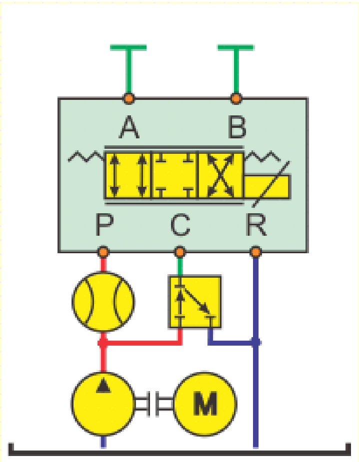


Figure 29. Leakage test

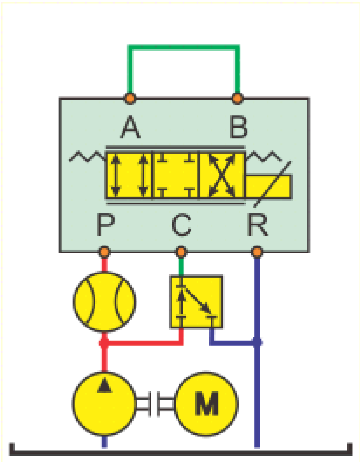


Figure 32. Flow AB test near bias in V-form

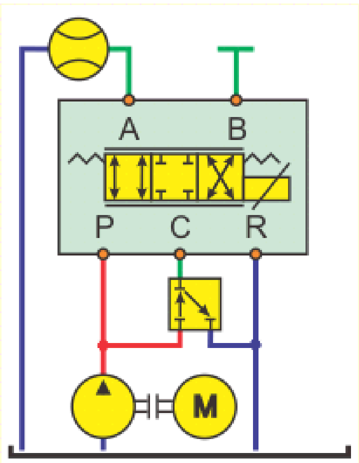


Figure 30. Flow A test

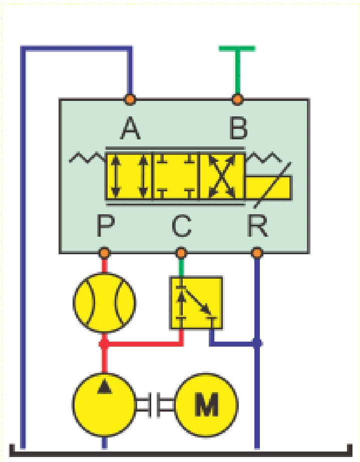


Figure 33. Flow A test near bias

Measurement Instruments

All measurement instruments (see Figure 35 – Figure 40) are software adjustable. Operator can calibrate the devices, change physical units and limits.

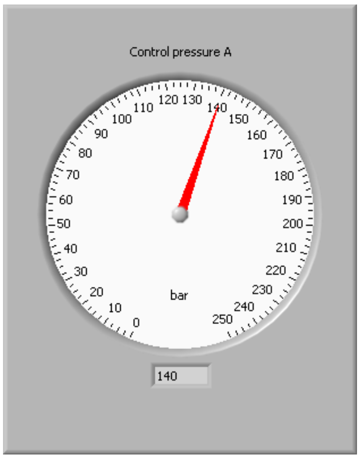


Figure 35. Pressure gauge of control port A

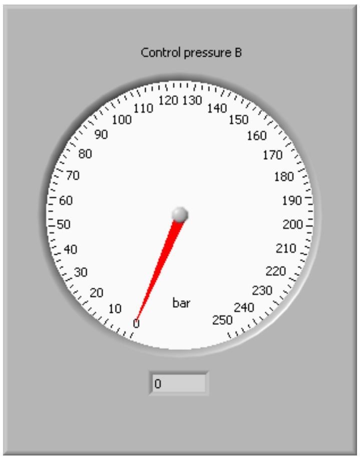


Figure 36. Gauge of control port B

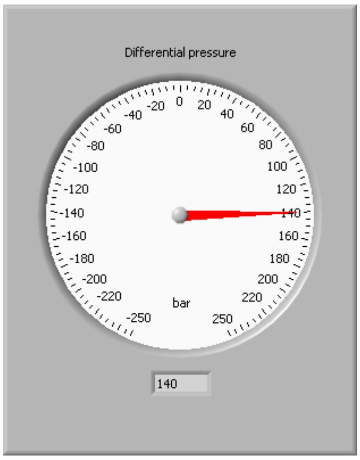


Figure 37. Gauge for differential pressure between control ports A and B

Figure 38. Supply and Control pressures gauge

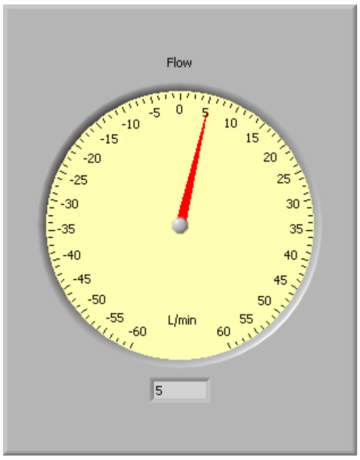


Figure 39. System flow-meter

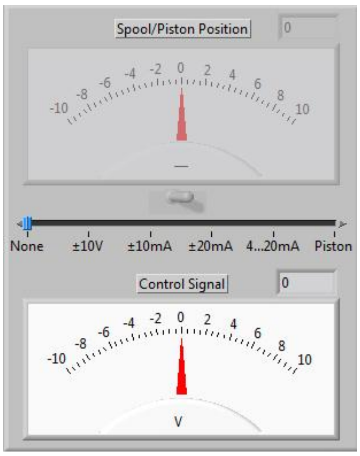


Figure 40. Multi-meters show the spool or piston position and the control signal

Settings for Automatic Tests

The button “Settings” allows set all the parameters for automatic tests (hydraulic configuration, type and configuration of control signal, supply pressure, and so on). Up to 20 subtests can be done during one test process. The picture below shows parameters for subtest with “0” index.

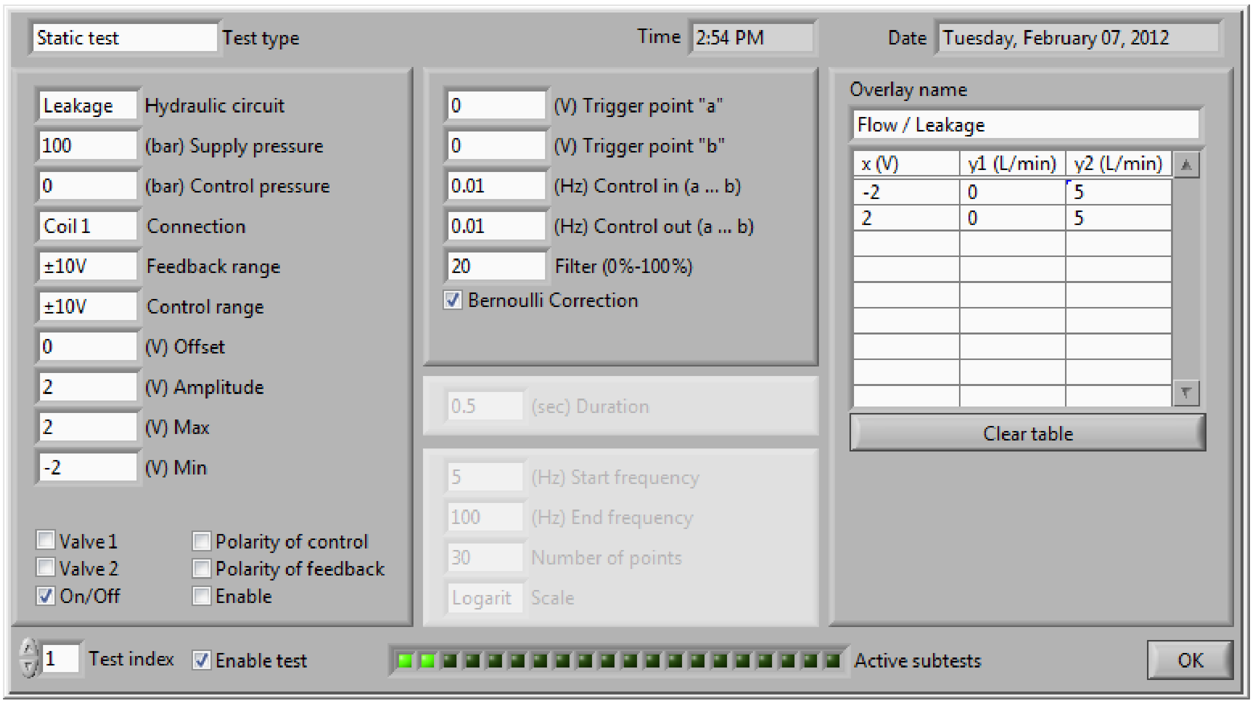


Figure 41. Settings for automatic mode

Automatic Test

In order to make an automatic test, the operator loads settings from the database and runs the test with “Start/Stop” button. In several minutes all test will be done and the operator will get results. During the test process the operator will see the data. It is possible to interrupt the test in any time. The measurement data includes the most of static and dynamical characteristics. The detailed mathematical analysis of the measured data will be done after the test (see section Mathematical Analysis).

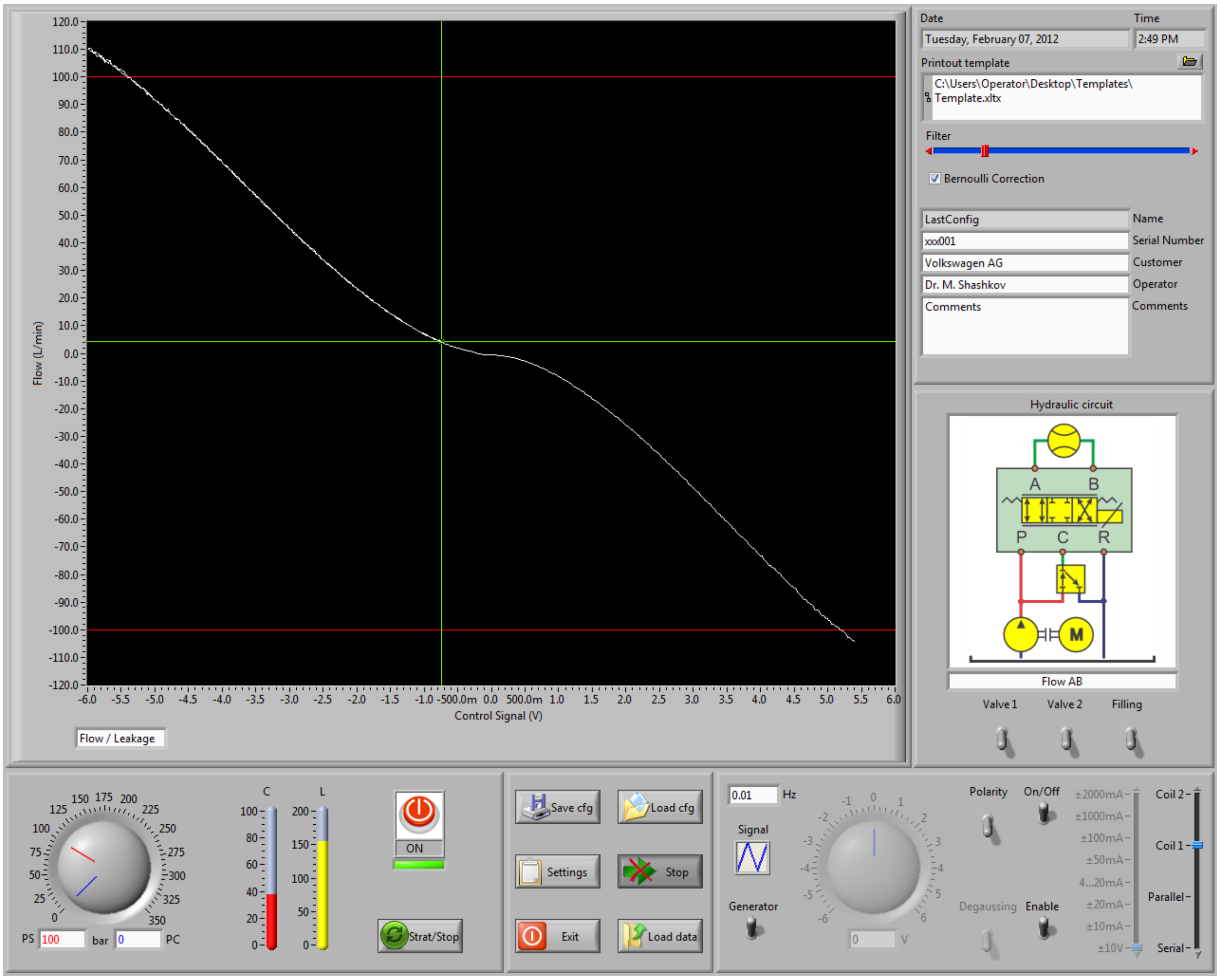


Figure 42. Virtual hydraulic laboratory. Flow test.

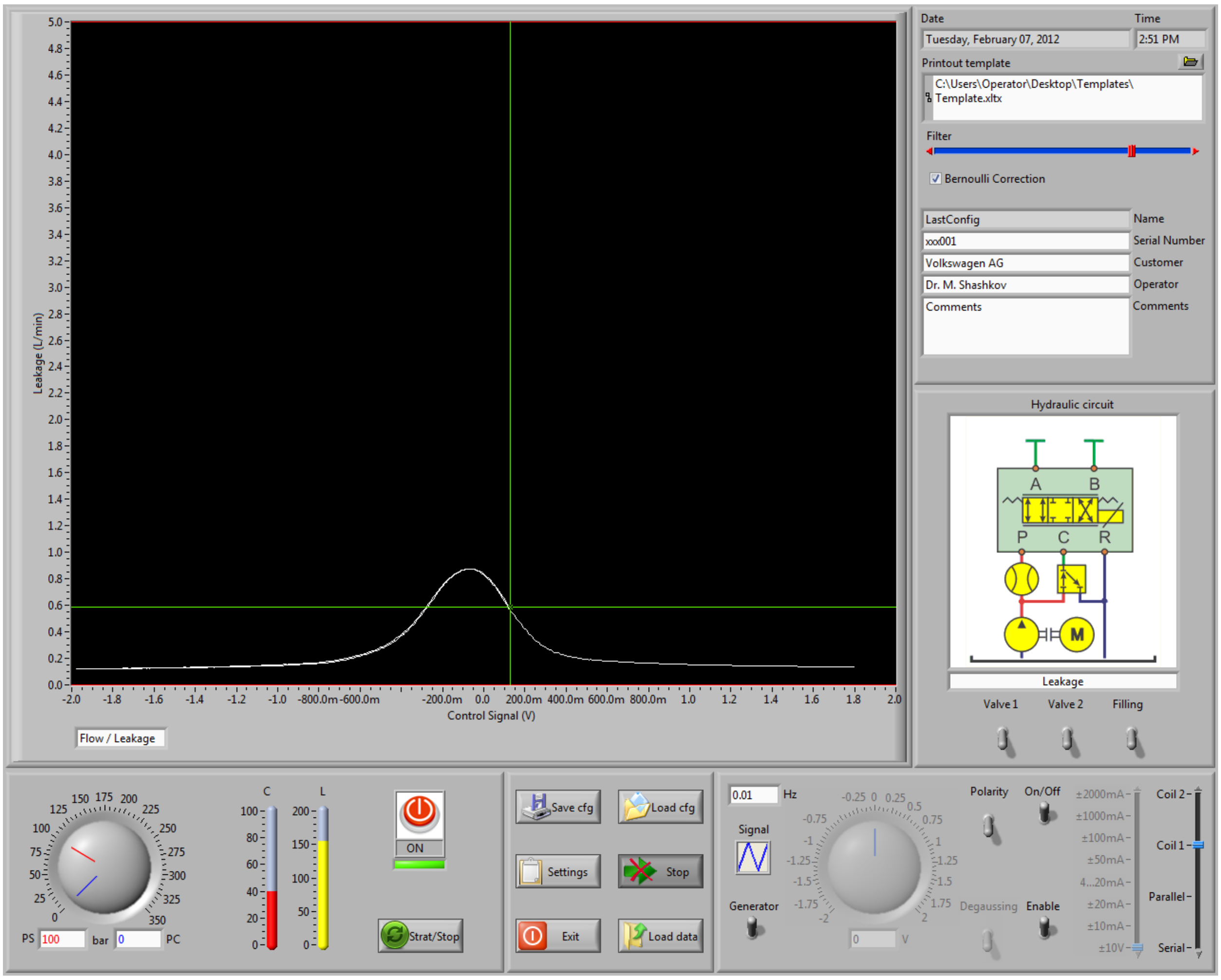


Figure 43. Virtual hydraulic laboratory. Leakage test.

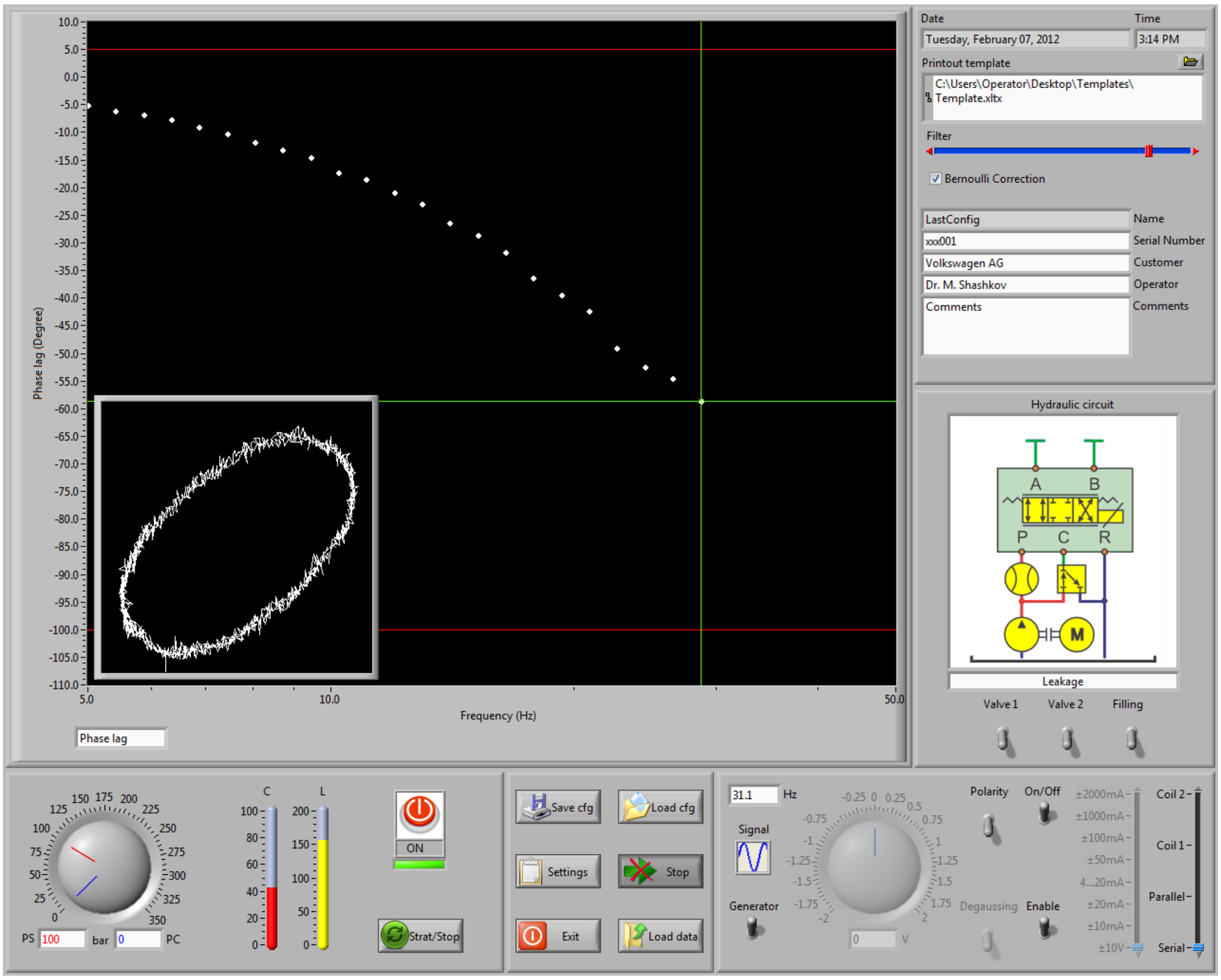


Figure 44. Virtual hydraulic laboratory. Dynamic test.

Printout of the Results

A powerful report generator is integrated into the system ValveExpert. This generator puts the measured data to a Microsoft Excel file. In order to prepare a view form of the printout the operator can use a template file. Such a template contains the only information the customer needs, i.e. text, data, formulas, pictures, conditional formatting, pass/fail evaluation and so on. The different configurations may have different templates files. In this case type of the report can depend of custom, type of valve under the test, and so on. Customers from different countries can have reports in different languages. The template files can have photos and other additional information. For more details please read MS Excel manual. Figure 45 – Figure 51 below show examples for the output forms.

DIFFERENTIAL PRESSURE TEST

GENERAL INFORMATION
Customer: Servocontrols India
Valve model: D633-356A
Serial nummer: D224
Date: Thursday, November 30, 2006
Time: 16:58

TEST CONDITIONS
Supply pressure: 140 bar
Control amplitude: 2.0 V
Offset: 0.0 V
Control connection: Single
Polarity of control: Positive

TEST RESULTS
Gain: 277 bar/V
Bias: 0.08 V
Hysteresis: 0.39 %

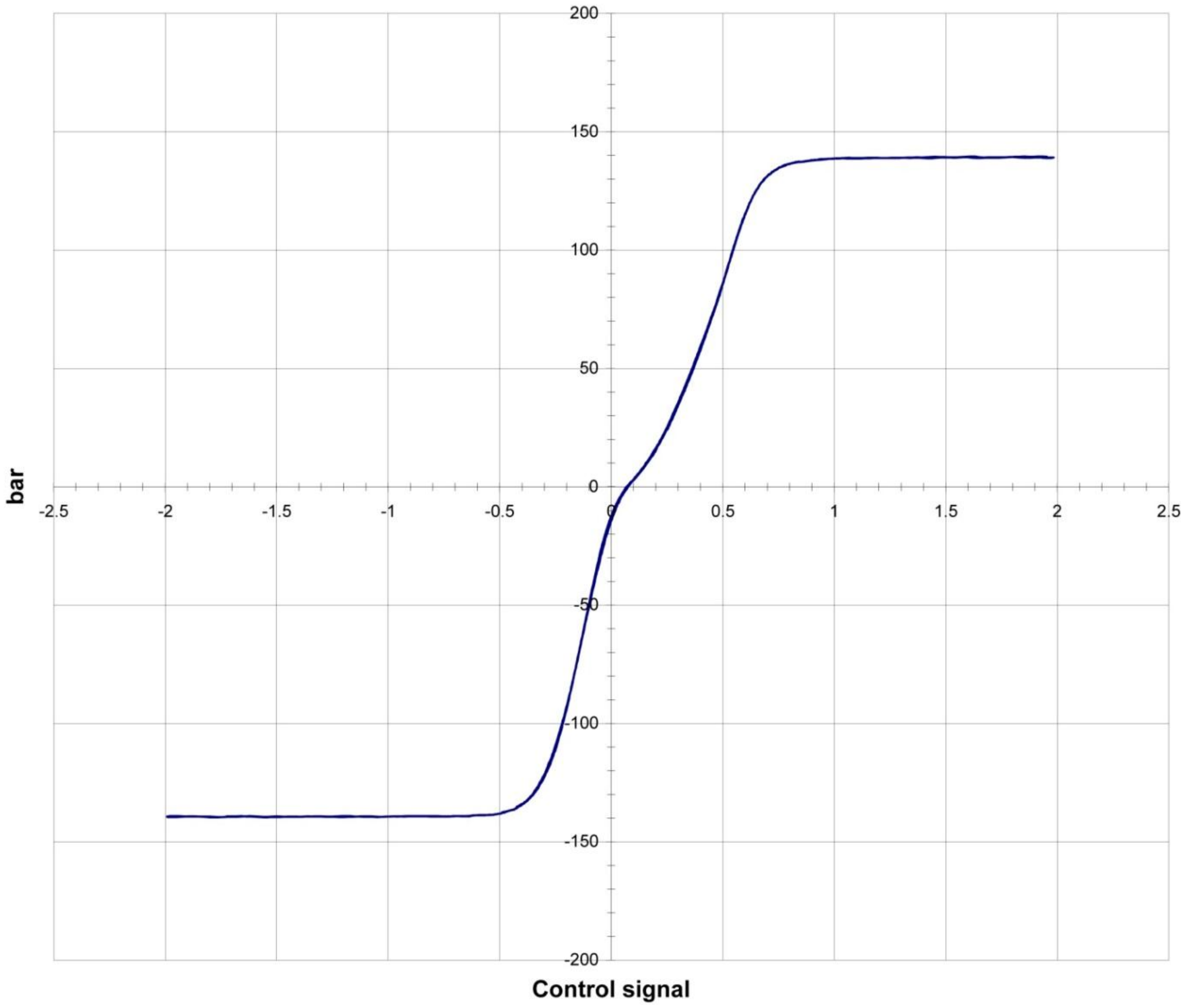


Figure 45. Differential pressure plot

LEAKAGE TEST

GENERAL INFORMATION
Customer: Servocontrols India
Valve model: D633-356A
Serial nummer: D224
Date: Thursday, November 30, 2006
Time: 16:58

TEST CONDITIONS
Supply pressure: 140 bar
Control amplitude: 2.0 V
Offset: 0.0 V
Control connection: Single
Polarity of control: Positive

TEST RESULTS
Maximal leakage: 1.84 L/min

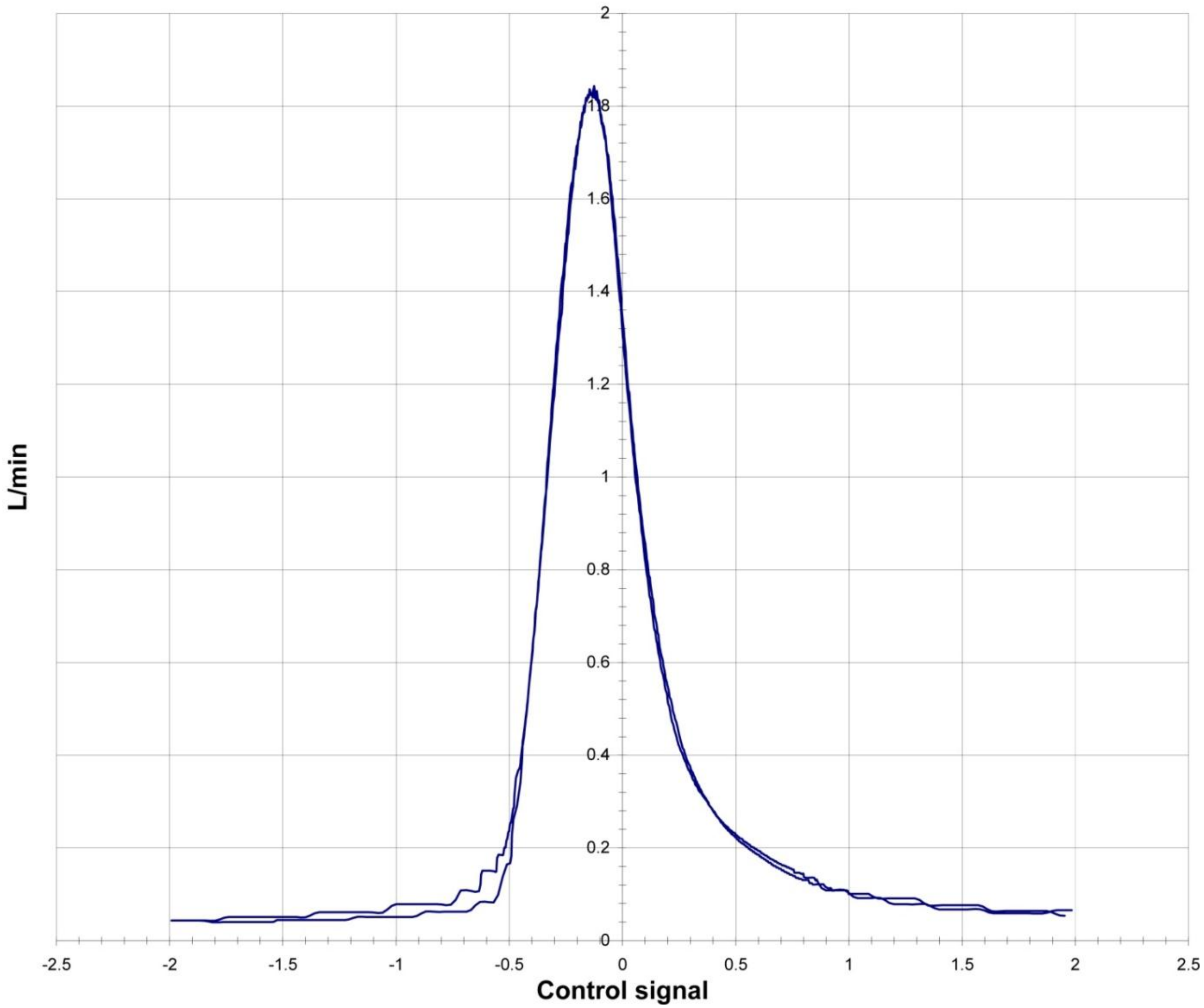


Figure 46. Leakage diagram

SPOOL POSITION TEST

GENERAL INFORMATION
Customer: Servocontrols India
Valve model: D633-356A
Serial nummer: D224
Date: Thursday, November 30, 2006
Time: 16:58

TEST CONDITIONS
Supply pressure: 140 bar
Control amplitude: 2.0 V
Offset: 0.0 V
Control connection: Single
Polarity of control: Positive
Spool signal: 4-20mA

TEST RESULTS
Gain: 0.79 mA/V
Shift: 11.81 mA
Hysteresis: 0.09 %

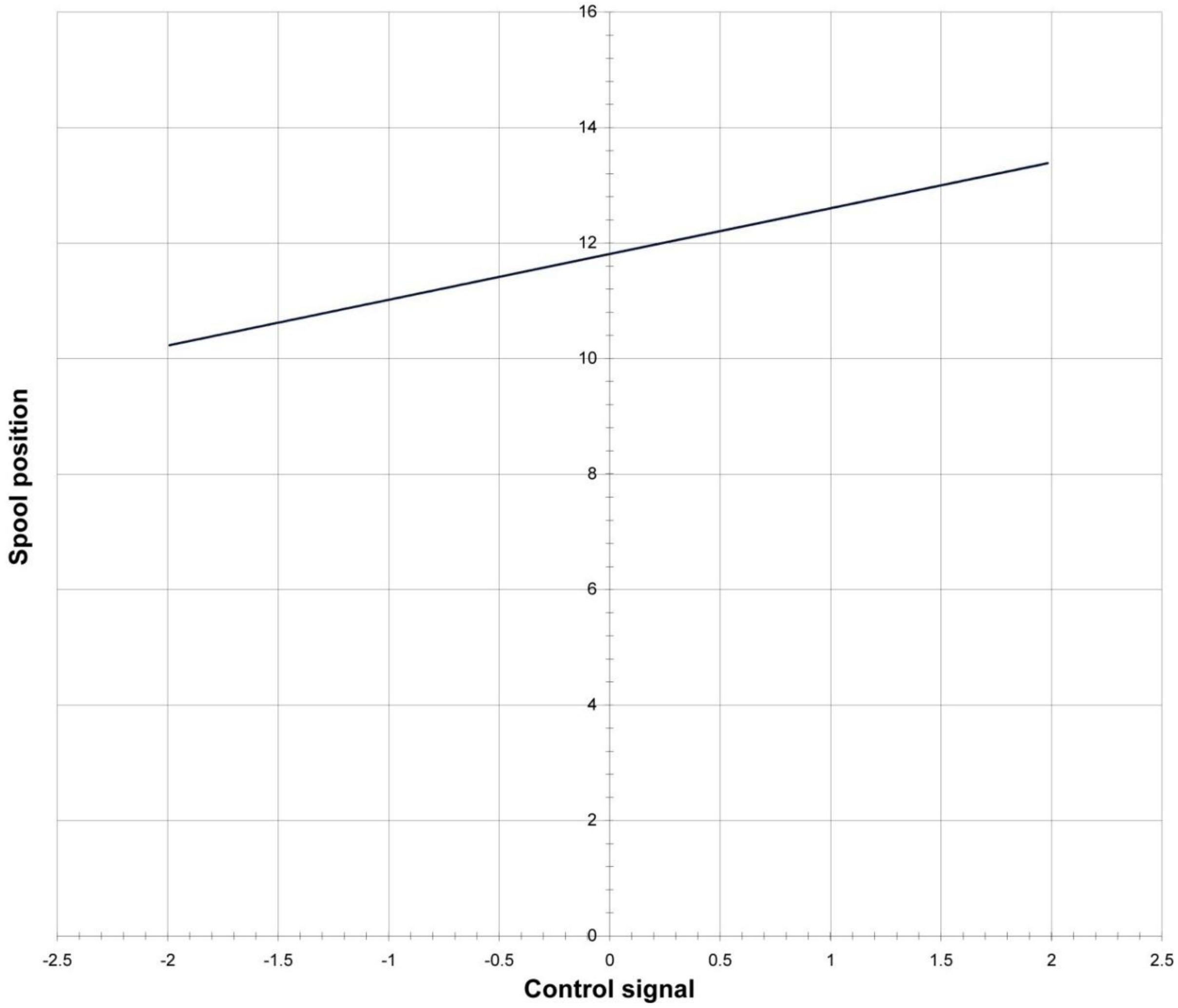


Figure 47. Plot of the spool position

FLOW TEST

GENERAL INFORMATION
Customer: Servocontrols India
Valve model: D633-356A
Serial nummer: D224
Date: Thursday, November 30, 2006
Time: 16:58

TEST CONDITIONS
Supply pressure: 70 bar
Control amplitude: 5.0 V
Offset: 0.0 V
Control connection: Single
Polarity of control: Positive

TEST RESULTS
Maximum: 11.6 L/min
Minimum: -13.2 L/min
Hysteresis: 0.77 %
Gain: 2.66 L/min/V
Bias: 0.37 V
Nonlinearity: 3.82 %
Nonsymmetry: 3.14 %

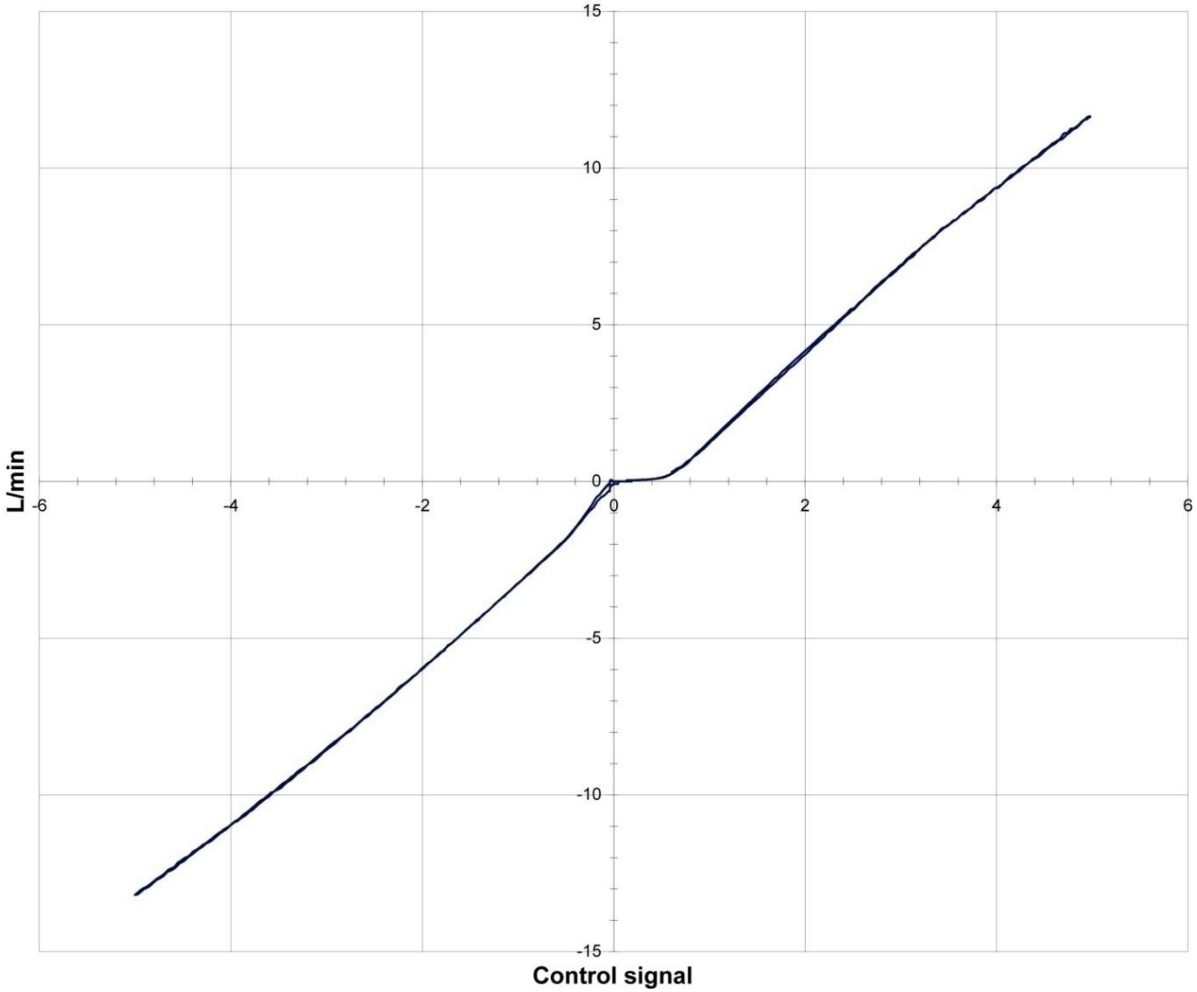


Figure 48. Flow diagram

GAIN-FREQUENCY RESPONCE

GENERAL INFORMATION
Customer: Servocontrols India
Valve model: D633-356A
Serial nummer: D224
Date: Thursday, November 30, 2006
Time: 16:58

TEST CONDITIONS
Supply pressure: 70 bar
Control amplitude: 4.0 V
Offset: 0.0 V
Control connection: Single
Polarity of control: Positive
Test signal: Spool position
Start frequency: 5 Hz
End frequency: 100 Hz
Number of points: 30
Scale: Logarithmic

TEST RESULTS
Natural frequency: 75.9 Hz
Natural amplitude: -7.1 dB
Maximal amplitude: 0.1 dB

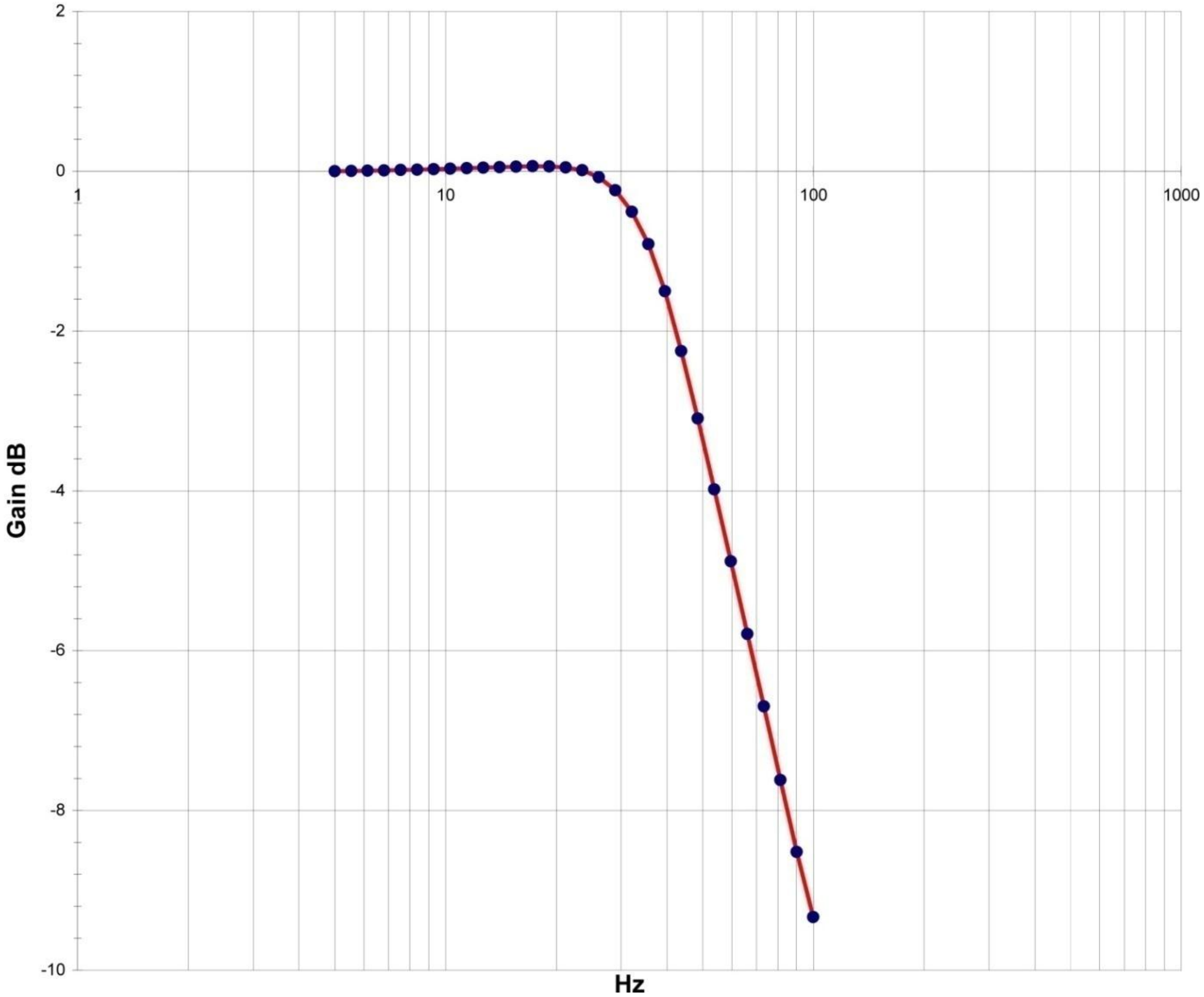


Figure 49. Plot of the Phase-Frequency Response

PHASE-FREQUENCY RESPONCE

GENERAL INFORMATION

Customer: Servocontrols India
Valve model: D633-356A
Serial nummer: D224
Date: Thursday, November 30, 2006
Time: 16:58

TEST CONDITIONS

Supply pressure: 70 bar
Control amplitude: 4.0 V
Offset: 0.0 V
Control connection: Single
Polarity of control: Positive
Test signal: Spool position
Start frequency: 5 Hz
End frequency: 100 Hz
Number of points: 30
Scale: Logarithmic

TEST RESULTS

Natural frequency: 75.9 Hz

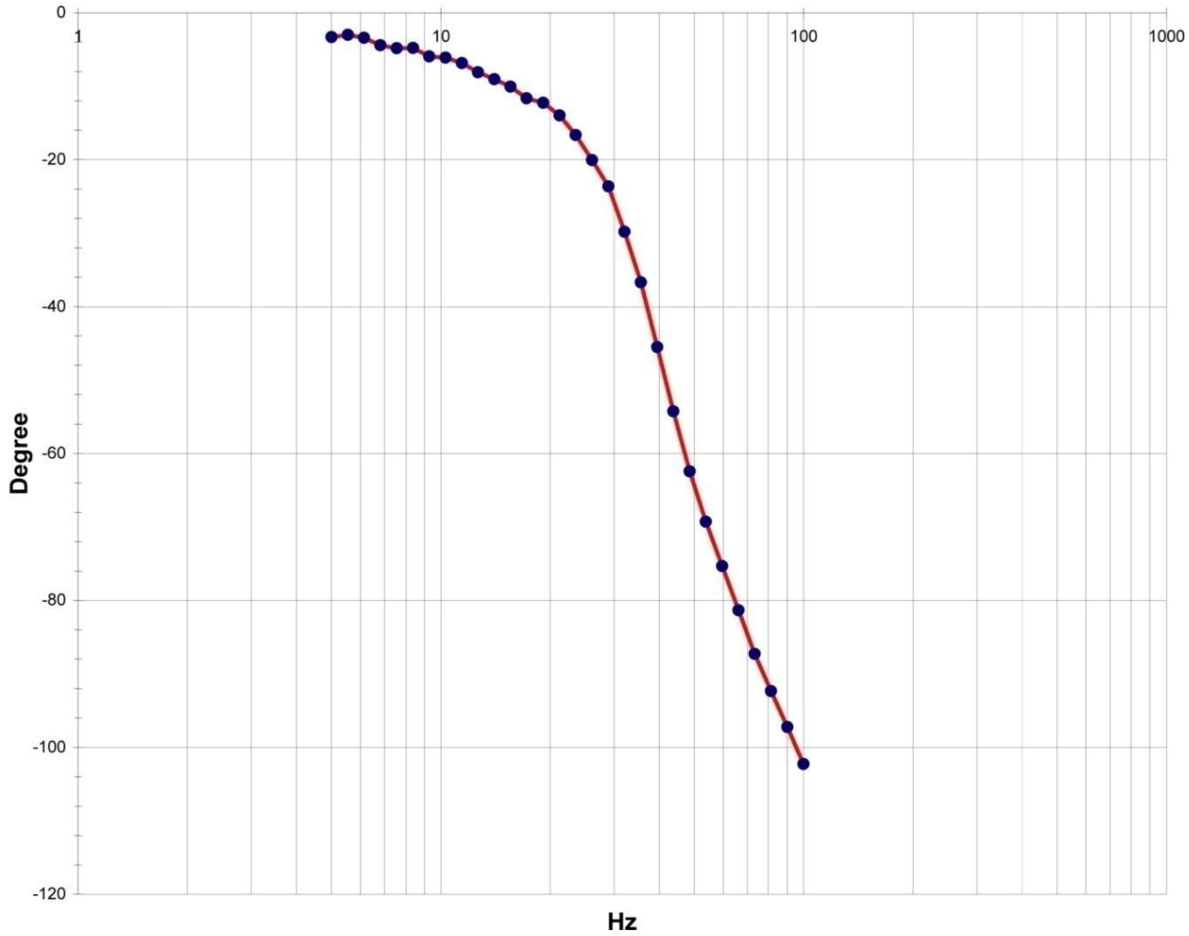


Figure 50. Plot of the Gain-Frequency Response

STEP RESPONCE

GENERAL INFORMATION
Customer: Servocontrols India
Valve model: D633-356A
Serial nummer: D224
Date: Thursday, November 30, 2006
Time: 16:58

TEST CONDITIONS
Supply pressure: 70 bar
Control amplitude: 4.0 V
Offset: 0.0 V
Control connection: Single
Spool signal: 4-20mA
Test duration: 40 msec

TEST RESULTS

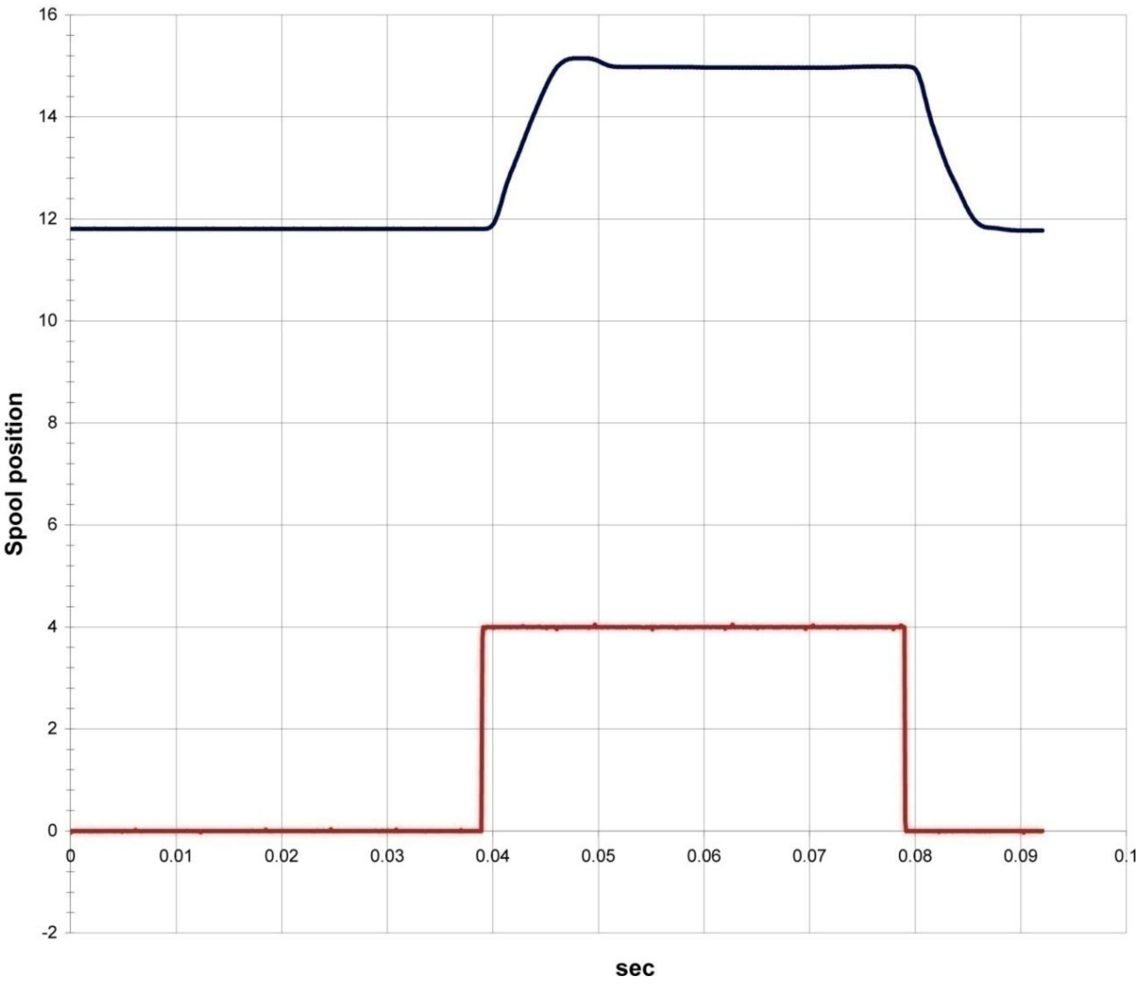
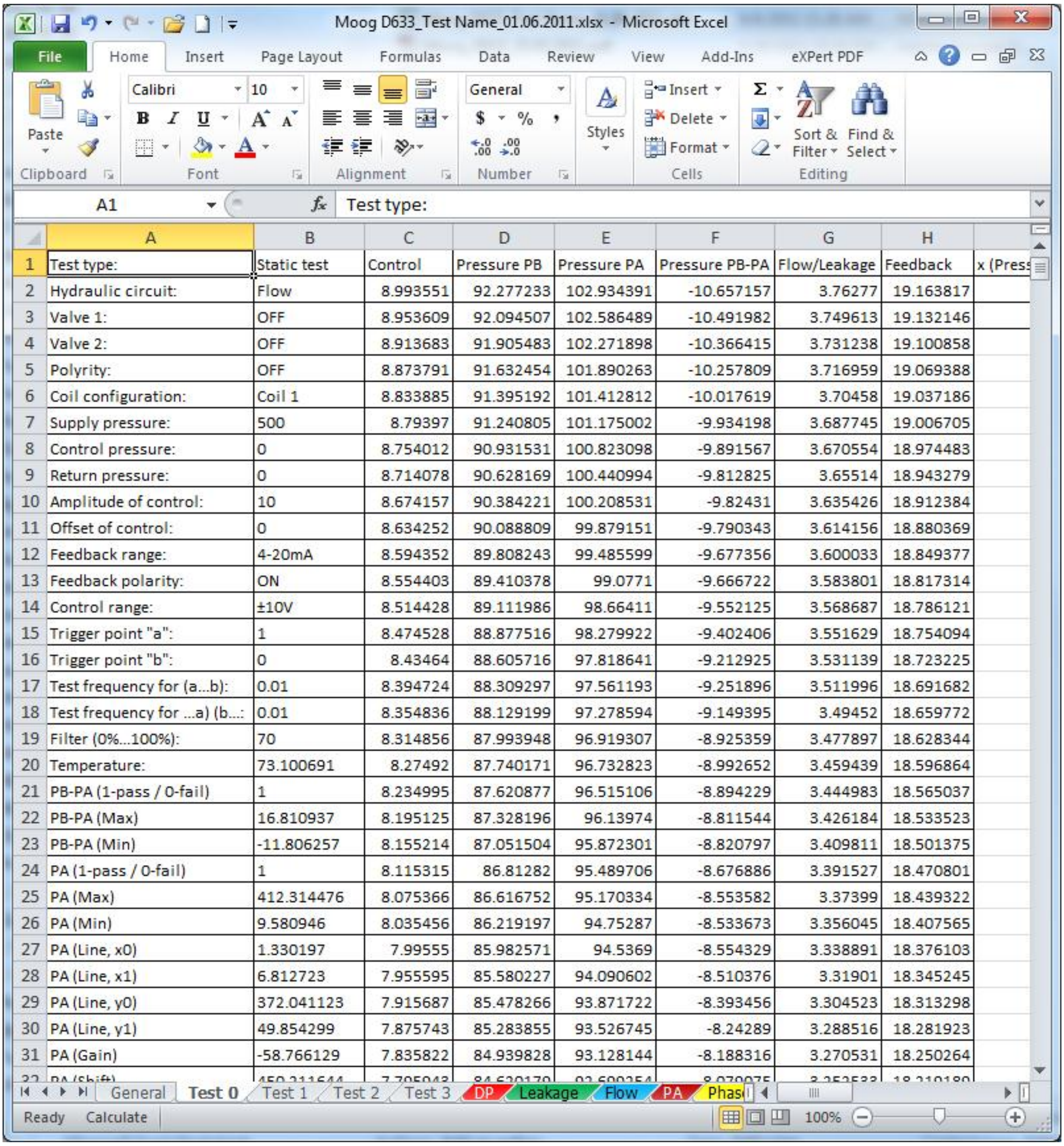


Figure 51. Plot of the Step Response

Structure of the Report File

As mentioned, the report generator puts data to a Microsoft Excel file which is based on a user defined template. Each subtest (with index from “0” to “19”) writes measured data and analysis to a separate Excel sheet “Test 0”, “Test 1”, …, “Test 19” correspondingly. General information about servovalve, customer, measurement units, date, name of operator, and so on will be written to the sheet General. All the data have got the corresponded descriptions. The analyzed values like “pressure gain”, “bias”, “overlap”, and so on are calculated in according to the approach described in the section Mathematical Analysis. The picture below shows data for a subtest with index “0”



	A	B	C	D	E	F	G	H
1	Test type:	Static test	Control	Pressure PB	Pressure PA	Pressure PB-PA	Flow/Leakage	Feedback
2	Hydraulic circuit:	Flow	8.993551	92.277233	102.934391	-10.657157	3.76277	19.163817
3	Valve 1:	OFF	8.953609	92.094507	102.586489	-10.491982	3.749613	19.132146
4	Valve 2:	OFF	8.913683	91.905483	102.271898	-10.366415	3.731238	19.100858
5	Polyrity:	OFF	8.873791	91.632454	101.890263	-10.257809	3.716959	19.069388
6	Coil configuration:	Coil 1	8.833885	91.395192	101.412812	-10.017619	3.70458	19.037186
7	Supply pressure:	500	8.79397	91.240805	101.175002	-9.934198	3.687745	19.006705
8	Control pressure:	0	8.754012	90.931531	100.823098	-9.891567	3.670554	18.974483
9	Return pressure:	0	8.714078	90.628169	100.440994	-9.812825	3.65514	18.943279
10	Amplitude of control:	10	8.674157	90.384221	100.208531	-9.82431	3.635426	18.912384
11	Offset of control:	0	8.634252	90.088809	99.879151	-9.790343	3.614156	18.880369
12	Feedback range:	4-20mA	8.594352	89.808243	99.485599	-9.677356	3.600033	18.849377
13	Feedback polarity:	ON	8.554403	89.410378	99.0771	-9.666722	3.583801	18.817314
14	Control range:	±10V	8.514428	89.111986	98.66411	-9.552125	3.568687	18.786121
15	Trigger point "a":	1	8.474528	88.877516	98.279922	-9.402406	3.551629	18.754094
16	Trigger point "b":	0	8.43464	88.605716	97.818641	-9.212925	3.531139	18.723225
17	Test frequency for (a...b):	0.01	8.394724	88.309297	97.561193	-9.251896	3.511996	18.691682
18	Test frequency for ...a) (b...:	0.01	8.354836	88.129199	97.278594	-9.149395	3.49452	18.659772
19	Filter (0%...100%):	70	8.314856	87.993948	96.919307	-8.925359	3.477897	18.628344
20	Temperature:	73.100691	8.27492	87.740171	96.732823	-8.992652	3.459439	18.596864
21	PB-PA (1-pass / 0-fail)	1	8.234995	87.620877	96.515106	-8.894229	3.444983	18.565037
22	PB-PA (Max)	16.810937	8.195125	87.328196	96.13974	-8.811544	3.426184	18.533523
23	PB-PA (Min)	-11.806257	8.155214	87.051504	95.872301	-8.820797	3.409811	18.501375
24	PA (1-pass / 0-fail)	1	8.115315	86.81282	95.489706	-8.676886	3.391527	18.470801
25	PA (Max)	412.314476	8.075366	86.616752	95.170334	-8.553582	3.37399	18.439322
26	PA (Min)	9.580946	8.035456	86.219197	94.75287	-8.533673	3.356045	18.407565
27	PA (Line, x0)	1.330197	7.99555	85.982571	94.5369	-8.554329	3.338891	18.376103
28	PA (Line, x1)	6.812723	7.955595	85.580227	94.090602	-8.510376	3.31901	18.345245
29	PA (Line, y0)	372.041123	7.915687	85.478266	93.871722	-8.393456	3.304523	18.313298
30	PA (Line, y1)	49.854299	7.875743	85.283855	93.526745	-8.24289	3.288516	18.281923
31	PA (Gain)	-58.766129	7.835822	84.939828	93.128144	-8.188316	3.270531	18.250264

Figure 52. Structure of the Excel report

Calibration process

Test system ValveExpert has robust and precision transducers which are factory precalibrated. Nevertheless, all transducers of the test stand can be simple recalibrated by an operator. In order to calibrate a transducer the operator has to use Measurement & Automation Explorer (MAX). This National Instruments software can use different formulas for calibration and operator can choose any physical units for pressure, flow, temperature and so on. In order to calibrate a transducer the operator has to correct the correspondent scale. For more details about the scales please read the MAX manual. Below are the scales of the system ValveExpert 7.1.

NI-DAQmx Scales

- Flow - scale for Coriolis type flow meter (option)
- Flow1 Hz – scale for "flow" gear-type flow meter
- Flow2 Hz – scale for "leakage" gear-type flow meter
- Level – scale for level transducer
- Pa – scale for pressure transducer installed in port A
- Pb – scale for pressure transducer installed in port B
- Pc – scale for pressure transducer installed in port C (option)
- Pc control – scale for control pressure in port C (option)
- Position – scale for position of the frequency response cylinder (option)
- Pr – scale for pressure transducer installed in port R (option)
- Pr control – scale for control pressure in port R (option)
- Ps – scale for pressure transducer installed in port P
- Ps control – scale for control pressure in port P
- Speed – scale for speed of the frequency response cylinder (option)
- Spool mA – scale for current mode of the spool position transducer
- Spool V– scale for voltage mode of the spool position transducer
- SV 10mA – scale for current sensor (10mA range)
- SV 10mA control – scale for current control (10mA range)
- SV 10V – scale for voltage sensor (10V range)
- SV 10V control – scale for voltage control (10V range)
- SV 20mA – scale for current sensor (20mA range)
- SV 20mA control – scale for current control (20mA range)
- SV 50mA – scale for current sensor (50mA range)
- SV 50mA control – scale for current control (50mA range)
- SV 100mA – scale for current sensor (100mA range)
- SV 100mA control – scale for current control (100mA range)
- SV 1000mA – scale for current sensor (1000mA range)
- SV 1000mA control – scale for current control (1000mA range)
- SV 2000mA – scale for current sensor (2000mA range)
- SV 2000mA control – scale for current control (2000mA range)
- T line – scale for temperature transducer installed in supply line (option)
- T tank – scale for temperature transducer installed in oil tank

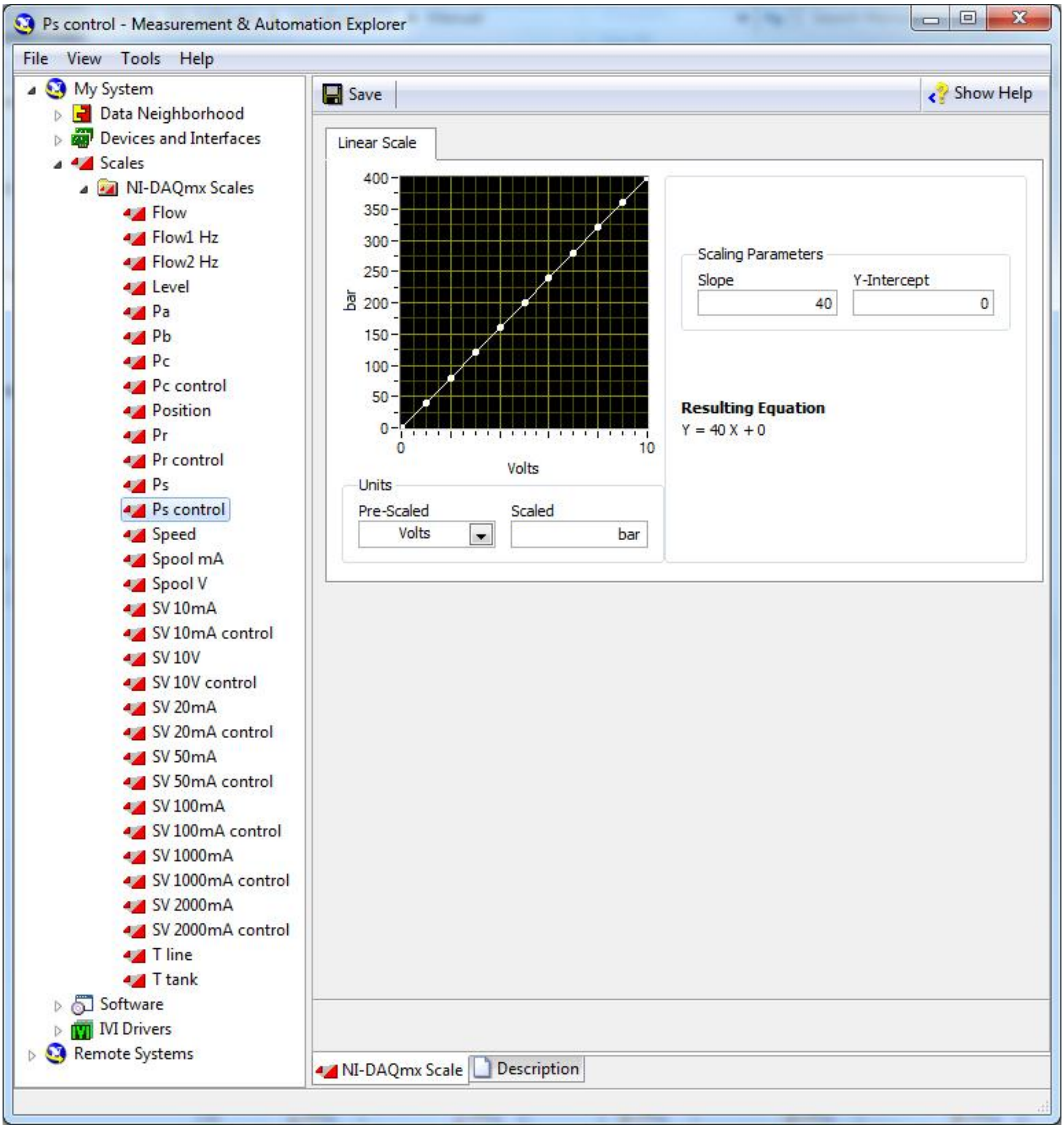


Figure 53. Measurement & Automation Explorer from National Instruments

Mathematical Analysis

Linear Analysis

In order to get the most of static parameters like “Hysteresis”, “Pressure Gain”, “Flow Gain”, “Bias”, “Non-Symmetry”, “Non-Linearity”, “Overlap” and so on, the test equipment ValveExpert makes the linear analysis. The algorithm of this analysis is illustrated on the Figure 54. In order to analyze this flow curve, the program eliminates data which belong to the “Null” and “Saturations” regions.[8] After that the rest data will be split onto four curves. The software finds the best linear approximation for each of these curves, i.e. “Line 1” – “Line 4”.[9] Maximal distance between lines “Line 1”, “Line 2” and lines “Line 3”, “Line 4” is the “Hysteresis”. Maximal deviation of the flow curves from “Line 1” – “Line 4” is the “Non-Linearity”. “Line 5” is the average of the “Line 1” and “Line 2”. “Line 6” is the average of the “Line 3” and “Line 4”. These two lines (“Line 5” and “Line 6”) are the linear approximations of the normalized flow curve for positive and negative control signals correspondently. The difference between slopes of these curves divided onto the maximal slope is the “Non-Symmetry”. Distance between intersection points of lines “Line 5” and “Line 6” with x-axis is the “Overlap”. “Line 7” is the average of “Line 5” and “Line 6”. This line is used to calculate “Flow Gain” and “Bias”.

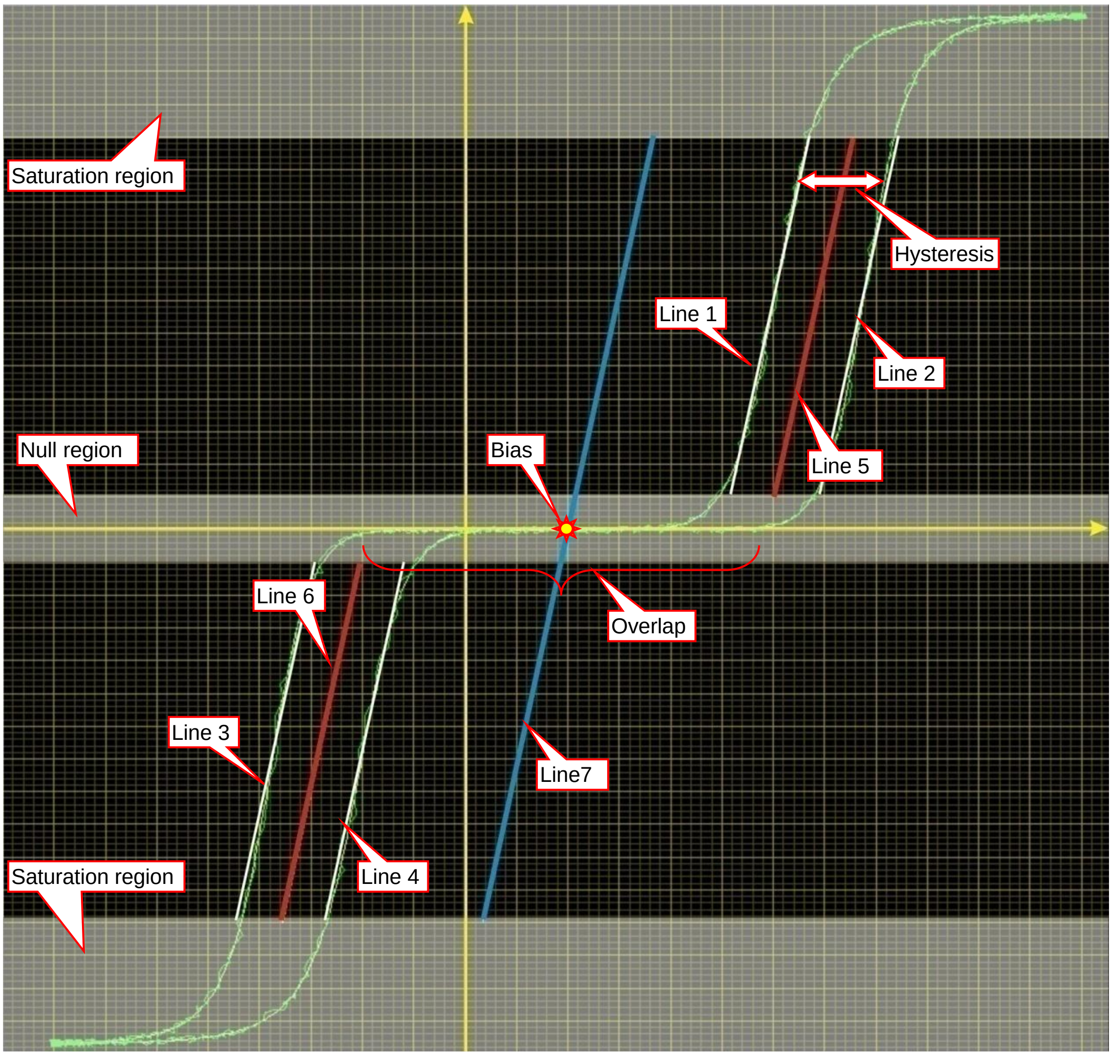


Figure 54. Illustration of the linear analysis

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[8] These regions are defined by operator.

[9] In order to get the best linear approximation the program uses the „Least Square Method“.

Frequency Response Analysis

One of the main dynamical characteristics of a servovalve is the "Frequency Response". This is the relationship between no-load control flow or spool position signal and harmonic (sinus-type) input signal. Frequency response expressed by the amplitude ratio and phase angle which are constructed for harmonic signals from a specific frequency range. Definition of the amplitude ratio and phase lag based on the Fourier method is given below. Let $x(t)$ be the control flow or spool position signal corresponding to input signal $u(t) = A\sin(\omega t)$. Here $\omega = 2\pi f$ – frequency of the test signal. After some transition time Δt the output signal $x(t)$ will be a periodic function with the same frequency ω. In this case $x(t)$ can be represented by the following Fourier series

$$x(t) = \sum_{k=0}^{\infty} R_k(\omega)\sin(k\omega t + \varphi_k(\omega)).$$

For any k, the amplitude $R_k(\omega)$ and initial phase $\varphi_k(\omega)$ expressed by the formulas

$$R_k(\omega) = |K_k(i\omega)|, \;\; \varphi_k(\omega) = \arg\left(K_k(i\omega)\right),$$

$$K_k(i\omega) = \frac{\omega}{2\pi} \int_{\Delta t}^{\Delta t + 2\pi/\omega} x(t) e^{-ik\omega t} dt.$$

The graph of the function $R_1(\omega)/R_1(0)$ represents the normalized amplitude ratio of the valve.[10] The graphical representation of the function $\varphi_1(\omega)$ is the phase lag. Examples of phase lag and amplitude ratio are shown below on Figure 55 and Figure 56. Note that valve frequency response may vary with the input amplitude, temperature, supply pressure, and other operating conditions. Note also, that for linear systems $K_1(i\omega) \equiv K(i\omega)$ and $K_k(i\omega) \equiv 0, \;\; k = 2, 3, \ldots, \infty$.

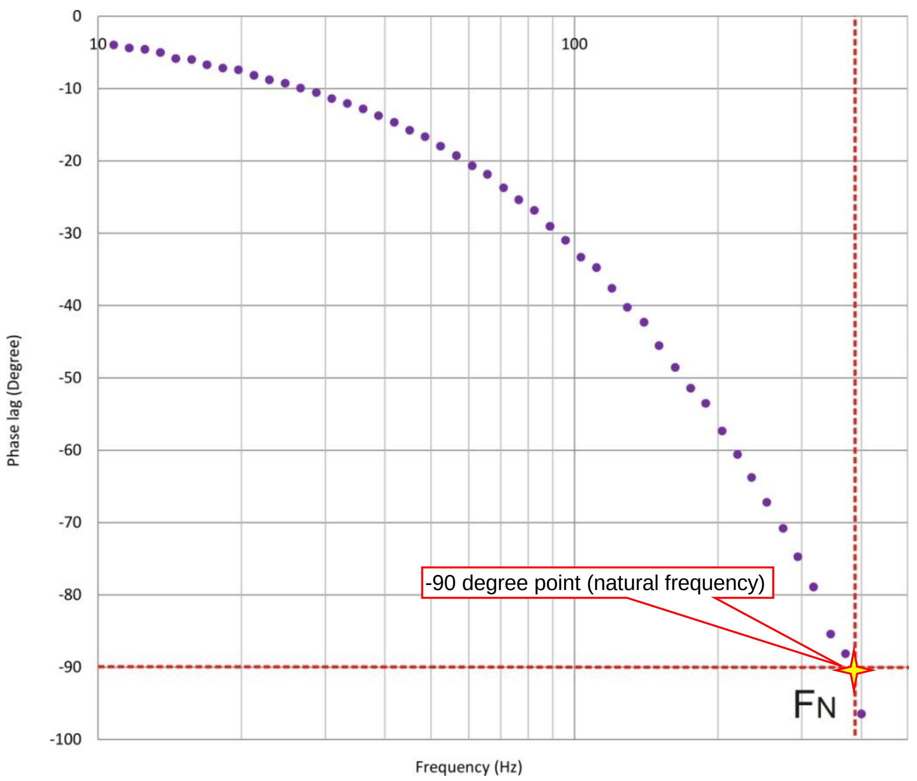

Figure 55. Phase-lag characteristics

[10] $R_1(0)$ is a formal notation for $R_1(\omega_0)$ where ω_0 is small enough. Usually ω_0 is 5-10Hz.

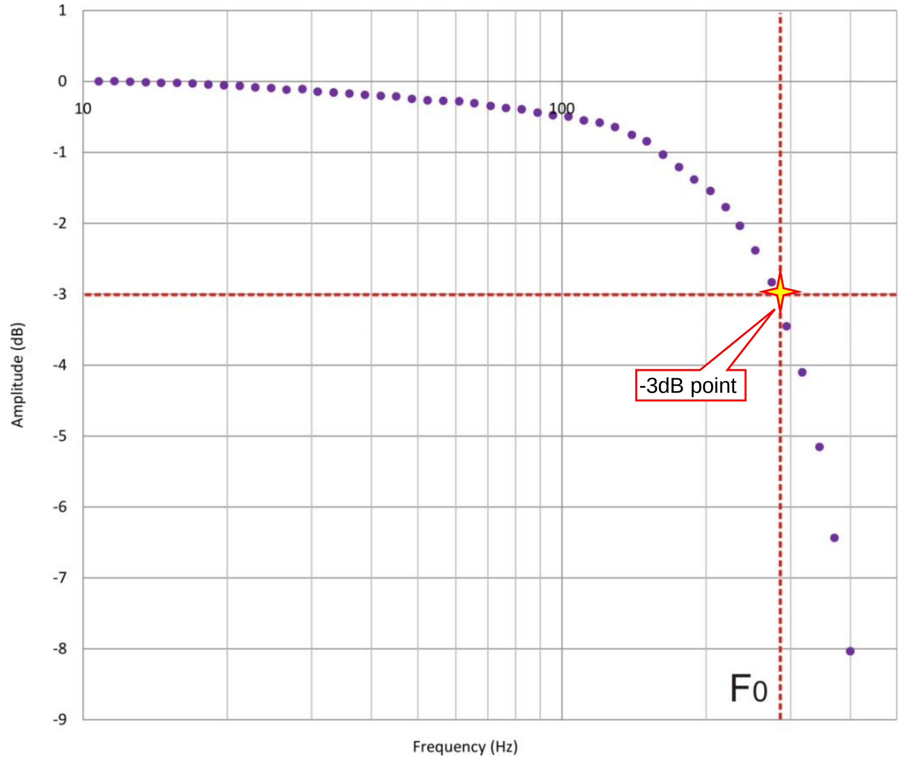

Figure 56. Amplitude ratio characteristics

Step Response Analysis

A very important dynamical characteristic of a servovalve is a response for a step-type control signal (see Figure 57). The main parameters of such a test are: "Rise Time" and "Overshoot". These parameters for positive and negative steps are demonstrated on Figure 57.

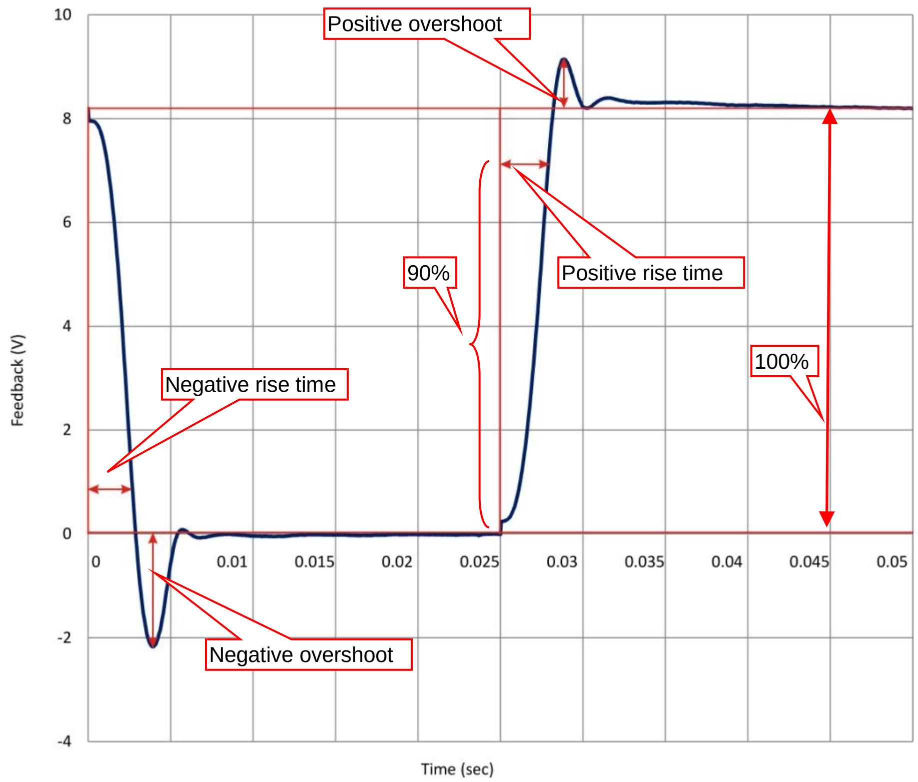

Figure 57. Step response

Excel Report File

General Information (Excel Sheet “General”)

The sheet “General” contains common information for all subtests (See below).

- Test stand name:
- Author:
- Date:
- Time:
- Test name:
- Serial number:
- Customer:
- Operator:
- Comments:
- Login name:
- Flow units:
- Pressure units:
- Temperature units:
- Control units:
- Feedback units:
- Time units:
- Frequency units:
- Amplitude ratio units:
- Phase lag units:

Measured data & analysis (Excel Sheets “Test 0”, …, “Test 19”)

Test conditions

- Test type:
- Hydraulic circuit:
- Valve 1:
- Valve 2:
- Polarity:
- Coil configuration:
- Supply pressure:
- Control pressure:
- Amplitude of control:
- Offset of control:
- Feedback range:
- Feedback polarity:
- Control range:
- Trigger point "a":
- Trigger point "b":
- Test frequency for (a...b):
- Test frequency for ...a) (b...:
- Filter (0%...100%):
- Temperature:

Analysis of the Differential Pressure Curve

- PB-PA (1-pass / 0-fail)
- PB-PA (Max)
- PB-PA (Min)
- PB-PA (Line 1, x0)
- PB-PA (Line 1, x1)
- PB-PA (Line 1, y0)
- PB-PA (Line 1, y1)
- PB-PA (Gain 1)
- PB-PA (Shift 1)
- PB-PA (Bias 1)
- PB-PA (Hysteresis 1)
- PB-PA (Nonlinearity 1)
- PB-PA (Line 2, x0)
- PB-PA (Line 2, x1)
- PB-PA (Line 2, y0)
- PB-PA (Line 2, y1)
- PB-PA (Gain 2)
- PB-PA (Shift 2)
- PB-PA (Bias 2)
- PB-PA (Hysteresis 2)
- PB-PA (Nonlinearity 2)
- PB-PA (Line, x0)
- PB-PA (Line, x1)
- PB-PA (Line, y0)
- PB-PA (Line, y1)
- PB-PA (Gain)
- PB-PA (Shift)
- PB-PA (Bias)
- PB-PA (Hysteresis)
- PB-PA (Nonlinearity)
- PB-PA (Overlap)
- PB-PA (Saturation %)
- PB-PA (Null %)

Analysis of the Pressure A Curve

- PA (1-pass / 0-fail)
- PA (Max)
- PA (Min)
- PA (Line, x0)
- PA (Line, x1)
- PA (Line, y0)
- PA (Line, y1)
- PA (Gain)
- PA (Shift)
- PA (Bias)
- PA (Hysteresis)
- PA (Nonlinearity)

- PA (Saturation %)

Analysis of the Pressure B Curve
- PB (1-pass / 0-fail)
- PB (Max)
- PB (Min)
- PB (Line, x0)
- PB (Line, x1)
- PB (Line, y0)
- PB (Line, y1)
- PB (Gain)
- PB (Shift)
- PB (Bias)
- PB (Hysteresis)
- PB (Nonlinearity)
- PB (Saturation %)

Analysis of the Spool position Curve
- Feedback (1-pass / 0-fail)
- Feedback (Max)
- Feedback (Min)
- Feedback (Line, x0)
- Feedback (Line, x1)
- Feedback (Line, y0)
- Feedback (Line, y1)
- Feedback (Gain)
- Feedback (Shift)
- Feedback (Bias)
- Feedback (Hysteresis)
- Feedback (Nonlinearity)
- Feedback (Saturation %)

Analysis of the Flow AB Curve
- Flow (1-pass / 0-fail)
- Flow (Max)
- Flow (Control at Max)
- Flow (Min)
- Flow (Control at Min)
- Flow (Line 1, x0)
- Flow (Line 1, x1)
- Flow (Line 1, y0)
- Flow (Line 1, y1)
- Flow (Gain 1)
- Flow (Shift 1)
- Flow (Bias 1)
- Flow (Hysteresis 1)
- Flow (Nonlinearity 1)
- Flow (Line 2, x0)

- Flow (Line 2, x1)
- Flow (Line 2, y0)
- Flow (Line 2, y1)
- Flow (Gain 2)
- Flow (Shift 2)
- Flow (Bias 2)
- Flow (Hysteresis 2)
- Flow (Nonlinearity 2)
- Flow (Line, x0)
- Flow (Line, x1)
- Flow (Line, y0)
- Flow (Line, y1)
- Flow (Gain)
- Flow (Shift)
- Flow (Bias)
- Flow (Hysteresis)
- Flow (Nonlinearity)
- Flow (Overlap)
- Flow (Saturation %)
- Flow (Null %)

Measured Data

- Control
- Pressure PB
- Pressure PA
- Pressure PB-PA
- Flow/Leakage
- Feedback

Differential Pressure Overlay

- x (Pressure PB-PA)
- y1 (Pressure PB-PA)
- y2 (Pressure PB-PA)

Pressure A Overlay

- x (Pressure PA)
- y1 (Pressure PA)
- y2 (Pressure PA)

Pressure B Overlay

- x (Pressure PB)
- y1 (Pressure PB)
- y2 (Pressure PB)

Leakage/Flow Overlay

- x (Leakage/Flow)
- y1 (Leakage/Flow)
- y2 (Leakage/Flow)

Feedback (Spool Position) Overlay

- x (Feedback)
- y1 (Feedback)
- y2 (Feedback)

SAE Recommended Terminology

The following definitions describe recommended terminology for Direct Drive Servovalves made by Society of Automotive Engineers (SAE) in ARP4493.

Servovalve, Direct Drive Flow-Control

An electrically commanded single stage flow control valve which produces continuously increasing flow in approximate proportion with the input voltage and drive current. The term "Direct Drive" implies that electrical energy is converted to metering spool motion by mechanical means.

Force Motor:
The electromechanical device which is used to directly drive the hydraulic flow control element.

Number of Coils:
The number of independent and isolated motor windings which may be used to drive the valve. The effect of all coils is nominally identical.

Output Stage:
The final stage of hydraulic distribution used in a DDV.

Port:
Fluid connection to the DDV, e.g., supply port, return port, control port.

Two-Way Valve:
An orifice flow-control component with a supply port and one control port arranged so that action is in one direction only, from supply port to control port.

Three-Way Valve:
A multiorifice flow-control component with a supply port, return port and one control port arranged so that valve action in one direction opens supply port to control port and reversed valve action opens the control port to return port.

Four-Way Valve:
A multiorifice flow-control component with a supply port, return port, and two control ports arranged so that valve action in one direction opens supply port to control port #1 and opens control port #2 to return port. Reversed valve action opens supply port to control port #2 and opens control port #1 to return port.

Simplex DDV:
A DDV which controls hydraulic flow from a single supply of fluid.

Tandem DDV:
A DDV which controls the flow of two independent hydraulic systems simultaneously.

Chip Shear Force:
The valve force available at the metering element to shear a lodged chip or foreign particle. This is typically defined at the maximum valve stroke, the closing direction, and includes forces produced by the motor and by mechanical springs but does not include flow forces.

Natural Frequency:
A frequency at which, in the absence of damping, a limited input tends to produce an unlimited output. It is a function of the valve mass elements and spring rates (which includes flow forces where applicable).

Open Loop DDV:
A DDV which has no electrical position feedback means for correcting error between the commanded position and the actual position. These devices usually feature centering or biasing springs on the hydraulic output stage, and/or force motor.

Electrical Feedback DDV:
A DDV which uses electrical position feedback and an electronic amplifier to minimize the error between the commanded position and the actual control element position.

Rip Stop Construction:
A mechanical means of construction which isolates a structural failure of one hydraulic system from propagating into another.

Position Feedback:
Electrical or mechanical means for closing a position loop within the DDV. Closed loop systems typically enjoy improved-performance characteristics and reduced sensitivity to construction variations at the cost of added complexity. Devices for electrical position feedback include LVDTs, RVDTs, radiomatic potentiometer, and Hall effect sensors. Mechanical feedback can be accomplished by the use of springs, linkages, or gears.

Electrical Characteristics

Input Current:
The DC or effective pulse modulated current supplied to the motor coils expressed in amperes per channel or amperes total.

Rated Current:
The input current of either polarity, supplied to the motor coils, which is required to produce rated no-load flow under specified conditions of fluid temperature, number of operating channels and differential pressure, expressed in amperes per coil or amperes total.

Maximum Current:
The maximum input current expressed in amperes per coil or amperes total that may be applied to the DDV motor coils as limited by the control amplifier.

Chip Shear Current:
The input current expressed as amperes per coil or amperes total required to produce the specified chip shear force at the valve metering element. Typically the chip shear current and the maximum current are the same.

Supply Voltage:
The maximum voltage which may be used in meeting the specified performance requirements.

Rated Voltage:

The input voltage of either polarity which is required to produce rated current. The parameter is specified at 68°F (20°C) and is expressed in volts DC unless otherwise noted.

Rated Power:
The electrical power, expressed in watts, required to produce rated current. The power is specified at 68°F (20°C) unless otherwise noted.

Chip Shear Power:
The electrical power required to produce chip shear force specified at 68°F (20°C) and expressed in watts unless otherwise noted.

Continuous Power:
The electrical power level which may be sustained for a specified period of time with the DDV at specified fluid and ambient temperatures, without exceeding material limitations that may damage the assembly or degrade performance beyond acceptable limits. Normally this is specified at the maximum current level.

Maximum Power:
The maximum power level which corresponds with the maximum current level for the specified conditions of fluid temperature and ambient temperature. Maximum power is expressed in watts.

Coil Resistance:
The DC resistance of each motor coil expressed in ohms and measure data nominal temperature of 68°F (20°C) unless otherwise noted.

Coil Inductance:
The coil self inductance as measured at the winding leads with the motor at null. The inductance is expressed in millihenries and measured at 1.0 kHz. Since a moving motor will generate a back-EMF that will effectively increase inductance, the user should specify whether a specified inductance assumes a locked motor or one that is free to rotate.

Transformer Coupling:
The mutual inductance between individual coils of the motor driven by separate control amplifier channels. The measurement may be expressed in V/V with the test coil left open circuit or in A/A with the test coil shorted, and in a specified frequency range.

Polarity:
The relationship between the direction of control flow and the direction of input current or voltage.

Dither:
A low amplitude, relatively high frequency (when compared to the DDV natural frequency) periodic electrical signal, sometimes superimposed on the DDV input to reduce threshold. Dither is expressed by the dither frequency (Hz) and the peak-to-peak dither current or voltage amplitude.

Static Performance Characteristics

Control Flow:

The flow through the valve control ports, expressed in l/min or gal/min. Control flow is referred to as loaded flow when there is load-pressure drop. Conventional fest equipment normally measures no-load flow.

Rated Flow:

The specified control flow corresponding to rated command at specified temperature and pressure conditions, and specified load pressure drop. Rated flow is normally specified as the no-load flow.

Flow Curve:

The graphical representation of control flow versus input current or command. This is usually a continuous plot of a complete full flow valve cycle. See Figure 58.

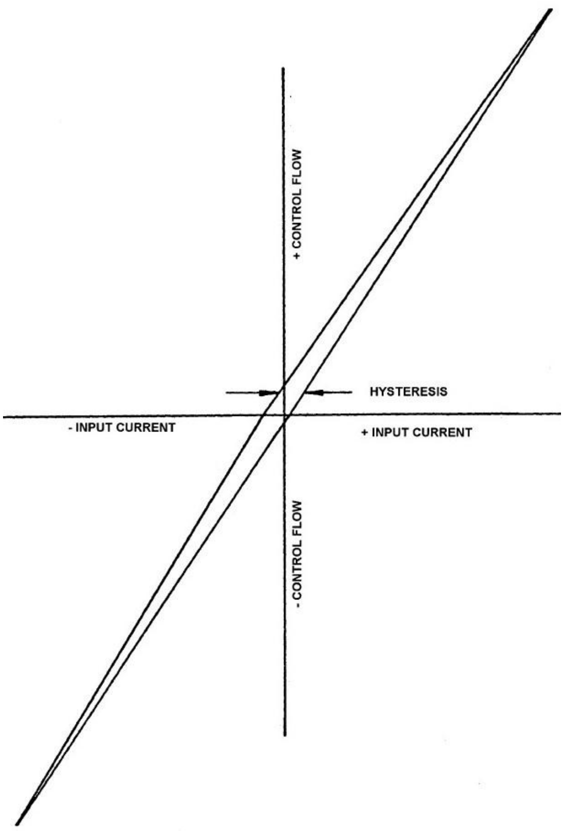

Figure 58

Normal Flow Curve:

The locus of the midpoints of the complete cycle flow curve, which is zero hysteresis flow curve. Usually valve hysteresis is sufficiently low, such that one side of the flow curve can be used for the normal flow curve. See Figure 59.

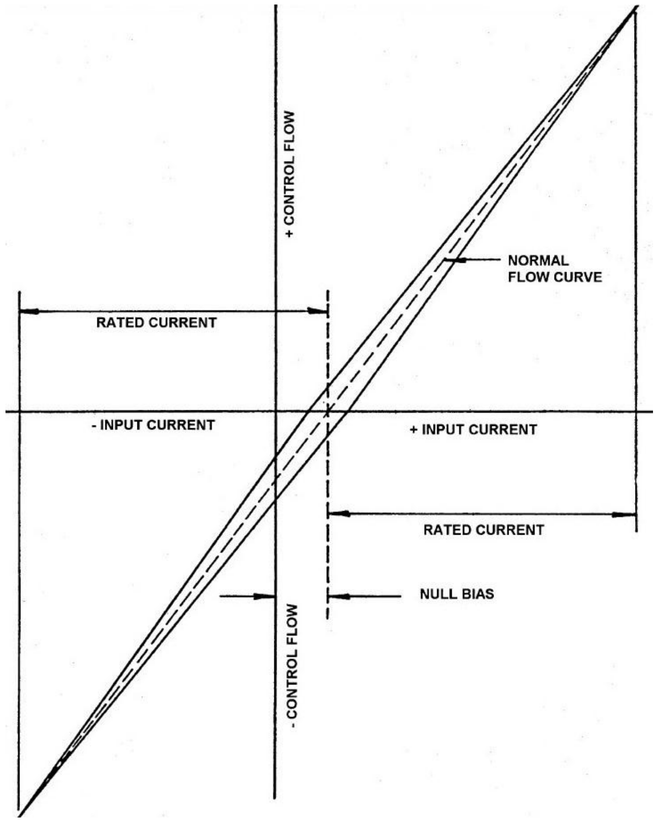

Figure 59

Flow Gain:

The slope of the control flow versus input command curve in any specific operating region, expressed in l/min/A, gal/min/V, etc. Three operating regions are usually significant with flow control servovalves: (1) the null region, (2) the region of normal flow control, and (3) the region where flow saturation effects may occur. Where this term is used without qualification, it is assumed to be defined by the region of normal flow gain. See Figure 60.

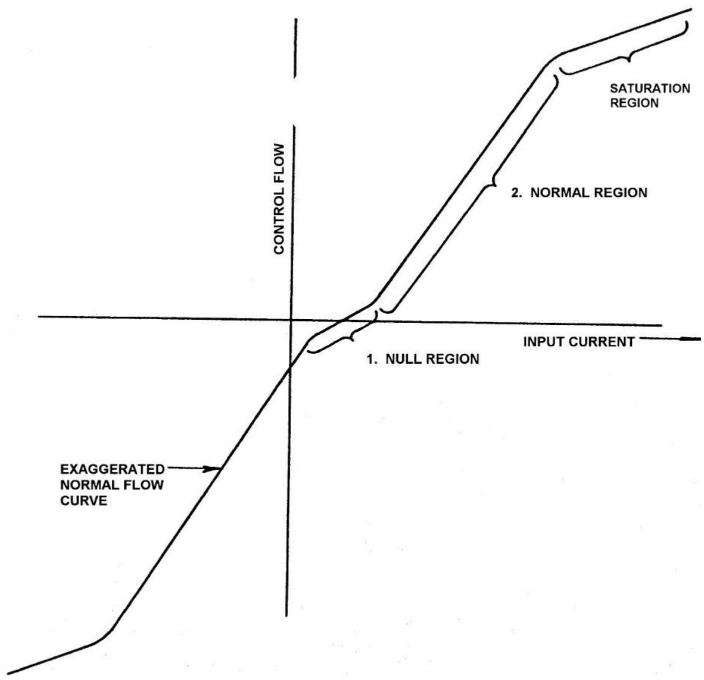

Figure 60

Normal Flow Gain:
The slope of a straight line drawn from the zero flow point of the normal flow curve, throughout the range of rated current of one polarity, and drawn to minimize deviations of the normal flow curve from the straight line. Flow gain may vary with the polarity of the input, with the magnitude of load differential pressure and with changes in operating conditions. See Figure 61.

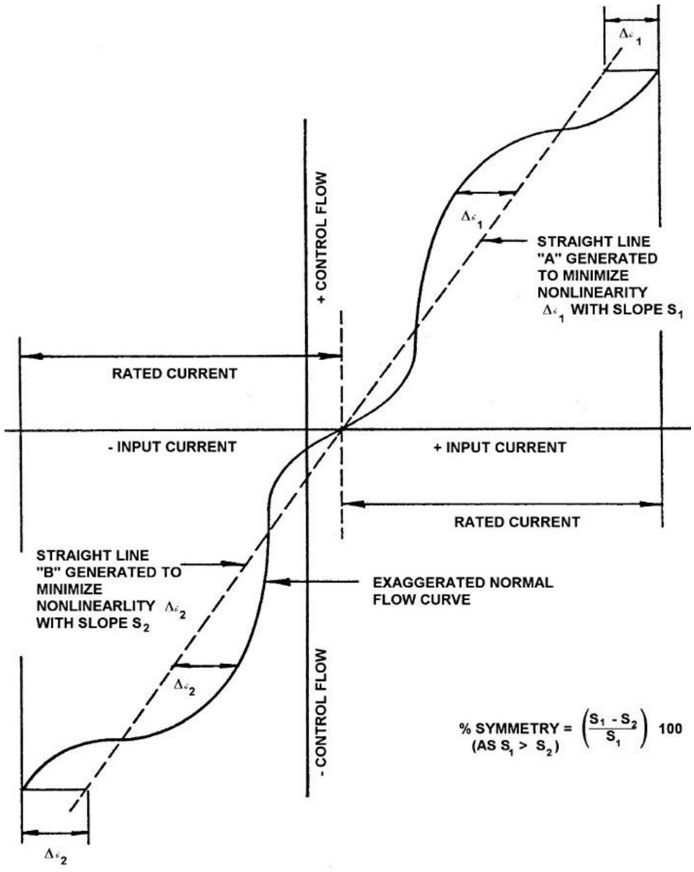

Figure 61

Rated Flow Gain:
The ratio of rated flow to rated current or command, expressed in l/min/A, gal/min/V, etc.

Flow Saturation Region:
The region where flow gain decreases with increasing command. See Figure 60.

Flow Limit:
The condition where in control flow no longer increases with increasing input current. Flow limitation may be deliberately introduced within the DDV.

Symmetry:
The degree of equality between the normal flow gain of each polarity, expressed as percent of the greater. See Figure 61.

Linearity:
The degree to which the normal flow curve conforms to the normal flow gain line with other operational variables held constant. Linearity is measured as the maximum deviation of the normal flow curve from the normal flow gain line, expressed as percent of rated command. See Figure 61.

Hysteresis:

The difference in the valve input command required to produce the same valve output during a Single cycle of valve stroke when cycled at a rate below that at which dynamic effects are important. Hysteresis is normally specified as the maximum difference occurring in the flow curve throughout plus or minus rated command, and is expressed as percent of rated command. See Figure 58.

Threshold:

The increment of input command required to produce a change in valve output, expressed as percent of rated command increment required to revert from a condition of increasing output to a condition of decreasing output, when valve command is changed at a rate below that at which dynamic effects are important.

Internal Leakage:

The total internal valve flow from pressure to return with zero control flow (usually measured with control ports blocked), expressed in l/min or gal/min. Leakage flow will vary with valve position, generally being a maximum at the valve null (null leakage).

Load Pressure Drop:

The differential pressure between the control ports, expressed in bar or psi. In conventional DDVs, load pressure drop may be expressed as an equation, where in it is equated to the supply pressure, less return pressure, and less the pressure drop across the active control orifices.
(P_s-P_r-P_0=P_L)

Valve Pressure Drop:

The sum of the differential pressures across the control orifices of the output stage, expressed in psi or bar. Valve-pressure drop will equal the supply pressure minus the return pressure minus the load pressure drop.

Pressure Gain:

The rate of change of load pressure drop with input command at zero control flow (control ports blocked), expressed in bar/amp, psi/volt, etc. Pressure gain is usually specified as average slope of the curve of load pressure drop versus command between ±40% of maximum load pressure drop. See Figure 62.

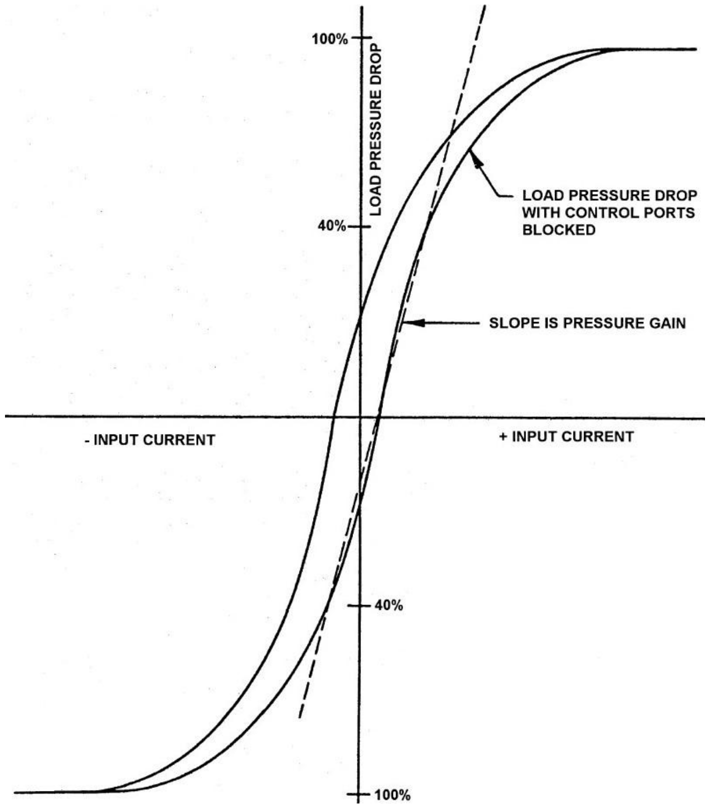

Figure 62

Null Region:
The region about null where in effects of lap (i.e., initial metering, geometry) in the output stage are dominant.

Element Null:
Each hydraulic channel has its own, individual, null. It is the valve position where, with a specified set of supply and return pressures, that hydraulic channel supplies zero control flow at zero load pressure drop.

Valve Hydraulic Null:
This is the valve position where, if each valve hydraulic channel were connected to its own equal area cylinder in a tandem actuator, with a specified set of supply and return pressures, the actuator would not move. Except for a simplex valve, this valve position will generally not coincide with the null positions of the individual elements.

Null Pressure:
The pressure existing at both control ports at null, expressed in psi or bar, and measured with control ports blocked.

Null Bias:
The input command required to bring the valve to null, excluding the effects of valve hysteresis, expressed as percent of rated current or voltage.

Null Shift:
A change in null bias, expressed in percent of rated command. For open-loop DDVs null shift may occur with changes in supply pressure, temperature, and other operating conditions. Null shift is predominately dependent on feedback transducer characteristics for closed-loop valves.

Lap:
In a spool valve, the relative axial position relationship between the fixed and movable flow-metering edges with the spool at null. For a DDV, lap is measured as the separation in the minimum flow region of the straight line extensions of nearly straight positions of the normal flow curve, drawn separately for each polarity, expressed as percent of rated command.

Zero Lap:
The lap condition where there is no separation of the straight line extensions of the normal flow curve. See Figure 63. Also known as critical lap.

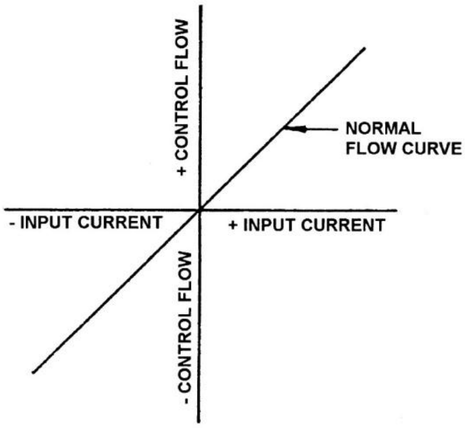

Figure 63

Overlap:
The lap condition which results in a decreased slope of the normal flow curve in the null region. See Figure 64.

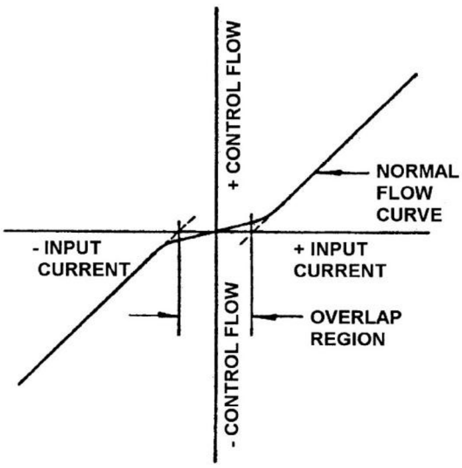

Figure 64

Underlap:
The lap condition which results in an increased slope of the normal flow curve in the null region. See Figure 65.

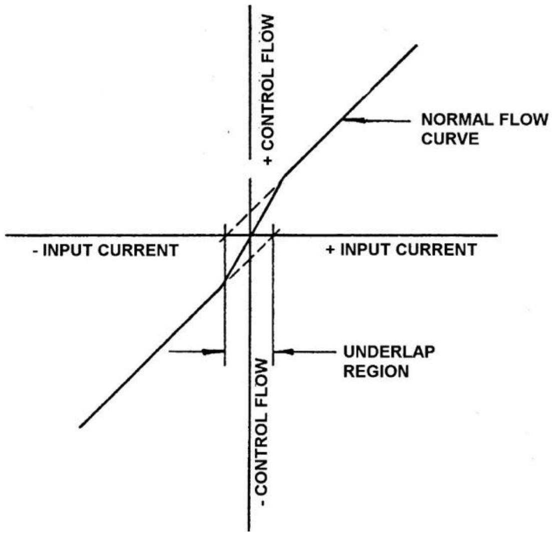

Figure 65

Intersystem Leakage:

Applies to tandem valves wherein fluid from one hydraulic system may be internally transferred to the other system. This is measured with one system at the specified operating pressures while the system under test is vented to atmosphere. The leakage is usually expressed in l/min or gal/min, and this measurement is normally made with the valve held at null.

Null Coincidence:

On valves which incorporate a means to measure output element position, the difference between the zero position of such a measurement and hydraulic null of the valve or each side of a tandem valve, expressed in displacement units.

Pressure Mismatch:

The differential pressure (in psi or bar) between the output pressures of the elements of a tandem valve when the valve assembly is at hydraulic null.

Flow Mismatch:

The difference in flow between any two valve elements, expressed as a percentage of the smaller flow, with the valve at a fixed position and with the same supply and return pressures applied to each system.

Position Measurement Error:

On valves which incorporate means to measure output element position, the difference between the measured position and the actual position expressed as a percentage of the rated stroke of the output element.

Dynamic Performance Characteristics

Frequency Response:

The complex ratio of flow-control flow to input command as the command is varied sinusoidally over a range of frequencies. Frequency response is normally measured with constant input-command amplitude and zero load pressure drop, expressed as amplitude ratio, and phase angle. Valve frequency response may vary with the input-command amplitude, temperature, and other operating conditions. DDVs may also measure frequency response by using output spool position if a transducer is employed.

Normalized Amplitude Ratio:
The ratio of the control-flow amplitude to the input-command amplitude at a particular frequency divided by the same ratio at the same input-command amplitude at a specified low frequency (usually 5 or 10 Hz). Amplitude ratio may be expressed in decibels.

Phase Lag:
The instantaneous time separation between the input command and the corresponding control-flow variation, measured at a specified frequency and expressed in degrees.

Rise Time:
The time required to achieve 90% of commanded spool position or flow following the initiation of a specified step command amplitude under no-load conditions.

Overshoot:
The valve is said to have overshoot when the valve control spool momentarily travels beyond the commanded steady State position following a step command. Overshoot is expressed as the percentage of over travel with respect to the commanded position and is measured with step input commands of specified amplitude.

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