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British Standard

Valves for hydraulic fluid power systems

Part 2. Methods for determining performance

Distributeurs pour transmissions hydrauliques

Partie 2. Méthodes de détermination des caractéristiques de fonctionnement

Ventile für fluidtechnische Systeme

Teil 2. Verfahren zur Bestimmung der Leistung

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BS 4062 : Part 2 : 1982

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Foreword

This revised British Standard, prepared under the direction of the Mechanical Engineering Standards Committee, deals with the testing of valves used in hydraulic fluid power systems. This Part of this standard, together with BS 4062 : Part 1, supersede BS 4062 : 1966, which is withdrawn.

This Part 2 of this standard describes methods for determining the performance of valves under steady state and dynamic conditions. It corresponds to the methods described in the latest proposals (ISO/DIS 6403*) under consideration by Technical Committee ISO/TC 131 of the International Organization for Standardization (ISO). For this reason, the standard is published in two Parts; Part 1 describes a method for determining the pressure differential/flow characteristics of valves under steady state conditions.

Three classes of accuracy, A, B and C, are associated with the tests and are related as detailed in appendix A. The class of accuracy should be agreed between manufacturer and user. It is expected that the methods of measurement used for testing the majority of valves will be those included in class C. The methods of measurement in class B may be employed where a higher degree of accuracy is required. Class A methods of measurement will necessitate laboratory conditions, and may be employed exceptionally on tests where the attainment of high accuracy is held to justify the greatly increased time and cost expended.

It is hoped that the standard will unify testing methods and enable the performance of different types of valve to be more readily compared.

*In course of preparation.

British Standard

Valves for hydraulic fluid power systems

Part 2. Methods for determining performance

1. Scope

This Part of this British Standard describes methods for determining the steady state and dynamic performance of hydraulic fluid power valves.

Requirements for test installations and presentation of results are given. This standard does not establish how closely production unit performance complies with specification requirements, nor specifies which performance characteristics should be checked during a production test. It does not establish limits of performance, since the suitability of the valve for its intended purpose should be agreed between the manufacturer and the user.

The types of device dealt with are:

- (a) directional control valves;
- (b) non-return (check) valves;
- (c) pressure control valves;
- (d) flow-regulating valves;
- (e) flow-dividing valves.

Accuracy of measurement is divided into three classes, A, B and C, which are explained in appendix A. Guidance in the use of practical units for the presentation of results is given in appendix B. Appendix C provides a pretest checklist of those items where agreement is necessary between the parties concerned.

Proportional control valves are not dealt with in this standard. Electrohydraulic servovalves are dealt with in BS 5995.

NOTE. The titles of the publications referred to in this standard are given on the inside back cover.

2. Definitions

For the purposes of this standard, the following definitions, together with those given in BS 5775 for quantities and units, and BS 4062 : Part 1, apply.

2.1 bleed-off. A circuit condition where there is control over the inlet flow to a component by diverting part of that flow to a reservoir or part of a circuit having lower pressure.

2.2 meter-in. A circuit condition where there is control over the inlet flow to a component.

2.3 meter-out. A circuit condition where there is control over the outlet flow from a component.

2.4 volumetric stiffness. The stiffness of a given portion of a hydraulic circuit determined by the value of the partial differential $\partial p / \partial v$ for the fluid contained in that part of the circuit.

3. Symbols and units

The units and symbols used in this standard are as given in table 1.

Table 1. Symbols and units

Quantity	Symbol	Dimension*	Unit†
control element angular displacement	β	dimensionless	rad
control element linear displacement	L	L	m
flow	$Q^\ddagger$	$L^3 T^{-1}$	m^3/s
force	F	MLT^{-2}	N
internal diameter of pipe	d	L	m
isentropic bulk modulus	K_s	$ML^{-1} T^{-2}$	Pa§
kinematic viscosity	ν	$L^2 T^{-1}$	m^2/s
loading valve coefficient	k	$M^{-1} L^4 T$	—
mass density	ρ	ML^{-3}	kg/m^3
nominal diameter of valve	D	L	m
pressure	p	$ML^{-1} T^{-2}$	Pa
pressure differential	Δp	$ML^{-1} T^{-2}$	Pa
temperature	θ	Θ	K or °C
time	t	T	s
volume	V	L^3	m^3

*M denotes mass, L denotes length, T denotes time, Θ denotes temperature.

†The practical units that may be used for the presentation of results are described in appendix B.

‡A less preferred symbol for flow is Q_v .

§1 Pa = 1 N/m².

4. Test installations

4.1 Test circuit

4.1.1 Use a test circuit similar to those shown in figures 1 and 5 to 13 appropriate to the type of valve under test in accordance with the following relevant clauses.

NOTE 1. Although figures 1 and 5 to 13 demonstrate basic circuits specific to one or more tests, and utilize the minimum number of components, it is acceptable to use an integrated test circuit that embraces two or more test conditions.

NOTE 2. The figures in this standard showing basic test circuits do not incorporate all the safety devices necessary to protect against damage in the event of any component failure. It is important that those responsible for conducting these tests give consideration to safeguarding personnel and equipment.

NOTE 3. The graphical symbols used in the figures depicting test circuits are in accordance with BS 2917.

4.1.2 Use a fluid supply with a controllable flow that has a higher maximum than the rated flow of the valve under test.

4.1.3 Install a pressure control valve in the supply line to protect the circuit from excessive pressure.

Install further control valves, as necessary, to regulate the flow or pressure in various parts of the circuit.

4.1.4 The inside diameters of pipes and fittings that interface with the test valve, including pressure-tapping points, shall be consistent with the diameters of the ports.

4.1.5 Connect drain ports to a reservoir.

4.2 Pressure- and temperature-sensing points

4.2.1 Location of pressure tapings

NOTE. In the case of class C accuracy of measurements (see appendix A), pressure readings taken for expediency at points other than those described in 4.2.1 will give sufficient accuracy providing that, where appropriate, correction is made for pipe losses.

4.2.1.1 Provide pressure tapings both upstream and downstream of the valve being tested, and if required, in other points.

4.2.1.2 Ensure that the inlet pressure-tapping point is:

- (a) not less than $10d$ downstream of any perturbation-producing element, such as a valve or a bend; and
- (b) not less than $5d$ upstream of the test valve.

4.2.1.3 Ensure that the outlet pressure-tapping point is not less than $10d$ downstream of the test valve.

4.2.1.4 Correct the measured data for pipe losses by the method given in appendix B of BS 4062 : Part 1 : 1982.

4.2.2. Pressure tapings. Ensure that:

- (a) the tapings have diameters equal to or less than $0.1d$ but not less than 1 mm diameter nor greater than 6 mm diameter;
- (b) the internal pipe surface at the tapping has been deburred without the removal of the sharp edge of the tapping hole;
- (c) the length of the tapping hole is not less than twice its diameter;
- (d) the bore of the pipe containing the tapping is clean and smooth;
- (e) the instrument connecting pipes are not less than 3 mm bore;
- (f) any entrained air between each tapping point and the measuring instrument is purged.

4.2.3 Location of temperature-sensing point. Measure the fluid temperature at the inlet to the test valve at a distance not greater than $15d$ upstream of the inlet pressure tapping.

4.3 Filtration and contamination level

4.3.1 Install filters that provide a standard of filtration at least equal to that recommended by the test valve manufacturer.

4.3.2 State in the test report the position and specific description of each filter used in the test circuit.

4.3.3 During tests conducted in accordance with 5.2 to 5.6, where inconsistencies may arise owing to silting, the standard of filtration shall be such that test measurements can be made within 60 s. State the actual interval in the test report.

4.3.4 Determine the actual contamination level of the test fluid from samples taken during the test. State in the report the test method used and the level found.

5. Test procedures

5.1 General

5.1.1. Test fluid

5.1.1.1 Declare the following in the test report:

- (a) description of test fluid;
- (b) kinematic viscosity ν and mass density ρ of the test fluid at the controlled temperature of the test.
- (c) isentropic bulk modulus K_s of the test fluid, if dynamic tests are performed.

5.1.1.2 When it is required to determine the effect of viscosity, perform the tests at agreed fixed temperature(s), using different fluids of the same fundamental type but with different viscosities. Give details in the test report.

5.1.2 Test temperatures

5.1.2.1 Carry out tests at agreed fluid inlet temperatures. Select the fluid inlet temperature(s) within the range recommended by the valve manufacturer. Give details in the test report.

When selecting temperatures give consideration to whether the valve to be tested is to be examined for temperature compensation.

5.1.2.2 If the selected test temperature is 25°C or above stabilize the equipment and the working fluid at that temperature prior to commencement of the test. Maintain the temperature throughout the test.

5.1.2.3 If the selected temperature is less than 25°C (considered a cold start condition) allow the temperature of the fluid to rise after the start of the test. Record the temperature, pressures and flows against time.

5.1.3 Steady-state conditions. Take each set of measurements when the values of controlled parameters are within the tolerances given in table 2. Select the number of readings taken and their disposition over the range to give a representative indication of the performance of the unit over the full range of the function being varied. To ensure repeatable results establish the mean values of the parameters being measured over an agreed interval of time.

Table 2. Limits of permissible variation of mean indicated values of controlled parameters

Class of measurement (see appendix A)	Flow	Pressures	Fluid temperature	Viscosity
	%	%	K	%
A	± 0.5	± 0.5	± 1.0	± 5
B	± 1.5	± 1.5	± 2.0	± 10
C	± 2.5	± 2.5	± 4.0	± 15

5.1.4 Proof pressure. Carry out the following proof pressure test to examine the integrity of the valve assembly under test before conducting any further tests.

(a) Apply to each port (other than drain ports) a proof pressure 1.5 times the maximum operating pressure for that port. Increase the pressure at a rate of approximately 2 % proof pressure per second and maintain the proof pressure for a period of 5 min. There shall be no external leakage throughout this period.

(b) Subject to any limitation on pressure in the outlet port imposed by the manufacturer, simultaneously subject the inlet and outlet ports to their respective proof pressure(s) for a period of 5 min. There shall be no external leakage throughout this period.

5.2 Directional control valves

5.2.1 Test circuit. Use a test circuit similar to that shown in figure 1.

5.2.2 Steady-state pressure differential/flow characteristics. At stated control element positions, determine the pressure differential/flow characteristics in accordance with BS 4062 : Part 1.

5.2.3 Internal leakage

5.2.3.1 Immediately before conducting this test, operate the valve over the full range of movement at least 10 times in close succession.

5.2.3.2 Carry out tests to determine the rate of leakage between the ports by applying agreed pressures at each port at which these tests are to be made.

5.2.4 Switching envelope.

5.2.4.1 General. Monitor the movement of the control element by displacement transducers. Use the test methods given in 5.2.4.2 to 5.2.4.5 for valves in which the control element is displaced by an electrical solenoid, pilot pressure or force, and with or without spring return

NOTE. The objective of these tests is to determine the operating threshold, i.e. the maximum pressure and associated maximum flow values at which the control element can be operated over the full range of its displacement in both directions of travel (see figure 2).

5.2.4.2 Direct operated solenoid valves. Carry out tests at the maximum stable temperature for the solenoid. Ensure that this temperature is within the limits given in BS 2757 for the class of insulation used for the coil winding.

Determine the temperature of the continuously energized winding at its nominal operating voltage under the condition of zero flow with the complete valve soaked in an ambient temperature equal to the temperature agreed for the test fluid by the following steps (a) to (d), where the mean winding temperature is calculated from the change in

resistance of the winding after various periods of energization.

(a) Measure the basic resistance after the de-energized valve has soaked for a period of not less than 4 h at the agreed ambient temperature.

(b) Energize the solenoid for 1 h. At the end of this period, measure the resistance 15 s after de-energization and at each 15 s interval thereafter for a period of 90 s.

(c) Repeat step (b) as often as is necessary until temperature stabilization is achieved.

(d) Determine the temperature at the instant of de-energization by regression analysis; this is the continuously energized winding temperature.

Conduct all subsequent tests after a period of energization sufficient to ensure that temperature stabilization has been achieved.

Determine the valve's operating thresholds at a voltage 10 % below the nominal rating, unless other values are agreed. Conduct the tests over agreed ranges of pressure and flow to determine the limiting conditions at which the control element just fails to complete its full displacement under the force produced by the solenoid and/or under the return force exerted by the spring or reverse direction solenoid.

From this data, over an agreed number of tests, which shall be not less than six total, determine the limiting values at which operation is consistently satisfactory.

To demonstrate that the voltage has been maintained at the intended value at all current levels, take time-based recordings of the current taken by the solenoid and the voltage at the terminals of the coil.

5.2.4.3 Solenoid controlled two-stage valves. Carry out tests to determine the pilot pressure at which the final control element just fails to complete its full displacement. Conduct the test over agreed ranges of pressure and flow. State the ranges used in the test report. Set the solenoid voltage at 10 % below the nominal rating, unless other values are agreed.

Determine the limiting values at which operation is consistently satisfactory from this data over an agreed number of tests, which shall be not less than six.

To demonstrate that the voltage has been maintained at the intended value at all current levels, produce time-based recordings of the current taken by the solenoid and the voltage at the terminals of the coil.

5.2.4.4 Pilot pressure operated valves. Carry out tests to determine the minimum pilot pressure at which the final control element just fails to complete its full displacement under the force exerted by the pilot and/or the return spring, or the reverse direction pilot piston. Conduct these tests over agreed ranges of pressure and flow. State the ranges used in the test report.

By agreement, carry out these tests, either:

(a) with a gradually increasing pilot pressure applied at a rate not exceeding 2 % of maximum rated pilot pressure per second; or

(b) dynamically with the pilot pressure applied at a rate of not less than 700 MPa/s; or

(c) both (a) and (b).

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Determine the limiting values at which operation is consistently satisfactory from this data over an agreed number of tests, which shall be not less than six total.

5.2.4.5 Mechanically operated valves. Conduct the tests over agreed ranges of pressure and flow. State the ranges used in the test report.

Determine the limiting values of control-operating effort at which operation is consistently satisfactory over an agreed number of tests, which shall be not less than six total.

5.2.5 Transient characteristics

5.2.5.1 Determine the transient characteristics of the valve at a flow equivalent to 80 % of the switching threshold at the maximum rated pressure, and where applicable, at the stated pilot pressure.

5.2.5.2 For the tests ensure that the capacitance of the circuits on the output side of the valve is limited to the volume enclosed by the valve including its associated manifolds. Also blank off the ports in a manner appropriate to the pressures to be applied, and prefill the volumes with the operating fluid.

5.2.5.3 In the case of solenoid operated valves conduct the test at the nominal rated voltage and at the temperature conditions of the solenoid used in 5.2.4.2, the switching being initiated at the moment of zero voltage in the case of a.c. operation.

5.2.5.4 For pilot pressure operated valves arrange the rate of change of pressure in the pilot circuit to achieve rapid operation of the control element, for example by operating the mechanism by means of a falling weight.

5.2.5.5 If practicable, obtain the delay times t_1 and t_2 and the response times t_3 and t_4 from recorded data, indicating the spool displacement in response to the command signal to the control element (see figure 3). When presenting this data also describe the technique used for measuring the displacement.

Alternatively, obtain the delay times t_5 and t_6 and the response times t_7 and t_8 from recorded data, indicating the rate of change of pressure in the outlet ports in response to the command signal to the control element (see figure 4).

5.3 Non-return (check) valves

5.3.1 Test circuits. Use test circuits similar to those shown in:

- (a) figures 5 and 6, for direct-acting non-return valves;
- (b) figure 7, for pilot pressure operated non-return valves. When the flow is from port A to port B conduct the tests with and without pressure applied to port X, and when the flow is reversed, i.e. from port B to port A, apply the pilot pressure to port X.

5.3.2 Pressure differential/flow characteristics. Determine the pressure differential/flow characteristics in accordance with BS 4062 : Part 1.

5.3.3 Pilot pressure

NOTE. The purpose of this test is to establish both:

- (a) the minimum pilot pressure $p_{X, \text{open}}$ necessary, both to open the valve, and to maintain it fully open;
- (b) the maximum pilot pressure $p_{X, \text{closed}}$ that will allow the valve to reseal, over an agreed range of pressures p_A and p_B and flow Q .

5.3.3.1 Establish p_A before the valve is opened.

5.3.3.2 With the system parameters p_A , p_B and Q present under steady-state conditions, raise the pilot pressure p_X from zero to a value at which the flow reaches Q .

Record pilot pressure p_X and flow Q on a suitable recording instrument and from the recording determine the minimum values of $p_{X, \text{open}}$ necessary to open the valve and to permit the selected flow conditions.

5.3.3.3 With the system parameters p_A present as low as possible and p_B and Q present under steady-state conditions, lower the pilot pressure p_X at least until the valve closes.

Record the pilot pressure p_X and flow Q on a suitable recording instrument and from the recording determine the maximum pilot pressure $p_{X, \text{closed}}$ to permit the valve to close.

5.3.4 Leakage. Conduct the following leakage tests for periods of 5 min and record the quantities measured.

(a) *Direct-acting valves.* Measure the leakage from port A with the agreed range of pressure applied to port B with port A at atmospheric pressure.

(b) *Pilot operated valves.* Measure the leakage from port A with the agreed range of pressure applied to port B with ports A and X at atmospheric pressure. Where applicable, also measure the leakage from drain port Y.

5.4 Pressure control valves

5.4.1 Test circuits. Use test circuits for pressure relief and pressure-reducing valves similar to those shown in figures 8 and 9 respectively.

Ensure that the amplitude of the pressure ripple measured in the supply circuit does not exceed ± 0.5 MPa. Ensure that the volumetric stiffness of the relevant parts of the test valve and circuit is such that the rate of change of pressure lies within the limits of one agreed range selected from the following:

- (a) 3000 MPa/s to 4000 MPa/s;
- (b) 600 MPa/s to 800 MPa/s;
- (c) 120 MPa/s to 160 MPa/s.

5.4.2 Control setting

5.4.2.1 Immediately before the measurements in 5.2.4.2 are taken, operate the valve over the full cycle of its range of adjustment at least 10 times in close succession. To avoid inconsistencies owing to silting, complete each set of measurements within 60 s of setting the control element position.

5.4.2.2 Measure and state in the test report, the torque, force, pressure or electrical input necessary to change the control setting position throughout the pressure range from minimum to maximum and back to minimum over the agreed range of flows through the valve.

5.4.3 Pressure-relief valves (see figure 8)

5.4.3.1 Steady-state pressure/flow characteristics.

Measure the inlet pressure for the range of flows from zero to the agreed maximum for both increasing flow and decreasing flow, at an agreed number of settings of the control element of the test valve, including the minimum and maximum adjustments provided on the valve. Adjust the pressure in the return line at the outlet of the valve to be constant at agreed level(s) by the operation of valve 8.

5.4.3.2 Transient characteristics. Measure the pressure transient with time for any given setting of the control valve at agreed values of flow, by using valve 3a (as shown in figure 8), which when in the unloaded condition reduces the pressure at the inlet valve to not more than 20 % of the required operating pressure of the test valve. By means of

operating valve 3a, produce a rate of pressure rise (chosen in 5.4.1) in the blanked-off circuit at the flow(s) selected for the test.

Determine the rate of change of pressure from the time taken for the pressure to rise from 10 % to 90 % of the difference between the initial and final steady state pressures.

Ensure that the operating time of valve 3a does not exceed 10 % of the measure response time with a maximum of 10 ms. The pressure gradient due to oil compressibility, as calculated from the expression $dp/dt = QK_s/V$ shall be at least 10 times the measured gradient, where V is the volume of fluid between test valve 6 and valves 3a and 3b.

NOTE 1. The response time and transient recovery time of the valve under test are as defined in figure 17.

NOTE 2. When a pressure control valve is being tested, the flow indicator 9 should show that there is no flow through the test circuit relief valve 2.

5.4.4 Pressure-reducing valves (see figure 9)

5.4.4.1 Steady-state pressure/flow characteristics.

Measure the steady-state output pressure for agreed increments of controlled flow set by valve 8 from zero to maximum and reducing to zero. Take these measurements over an agreed range of inlet pressures set by valve 2a and range of control element settings, including the maximum and minimum. Also take measurements of the leakage through flowmeter 7b. When applicable, repeat this procedure for reverse flow condition with port A at atmospheric pressure.

5.4.4.2 *Transient characteristics.* Carry out transient tests in which the outlet pressure is measured over an agreed range of pressure settings in accordance with the procedure for pressure-relief valves given in 5.4.3.2 for flows in the normal and, when agreed, reverse directions. Apply agreed step functions to the input pressure and to the output flow at each pressure setting. Apply the agreed changes in pressure over the agreed range of flows to the inlet, including an initial pressure of less than 50 % of the setting of the valve under test to ensure that the control element is fully open.

5.4.5 *Vented valves.* Where relief or reducing valves are pilot operated, they may be vented (i.e. reduced to the minimum controlled pressure) by bypassing the pilot stage by means of a venting valve 3b as shown in figures 8 and 9. Measure the resultant minimum operating pressures of the valve under test for an agreed range of flows in accordance with BS 4062 : Part 1.

Carry out transient tests in accordance with 5.4.3.2 or 5.4.4.2 to establish the times to achieve minimum pressure, and to re-establish maximum pressure, from the operation of the venting valve 3b.

Operate the venting valve 3b manually or hydraulically, or by a solenoid operated or electrohydraulic servo valve and ensure that it has an operating time not exceeding 10 % of the measured response time subject to a maximum of 10 ms.

5.5 Flow-regulating valves

5.5.1 *Test circuit.* Use test circuits similar to those shown in figures 10, 11 and 12.

Install in the supply circuit an accumulator of sufficient capacity to maintain the supply pressure within the limits given in table 2. Ensure that the amplitude of the pressure ripple measured in the supply circuit does not exceed ± 0.5 MPa.

5.5.2 Steady-state flow/pressure characteristics.

Measure the regulated flow and bypass flow, if applicable, over agreed ranges of control element settings and pressure differentials.

(a) *Valves with pressure compensation.* Carry out tests at agreed steps of inlet and outlet pressures from minimum to maximum specified pressures and flows.

(b) *Valves without pressure compensation.* Carry out tests in accordance with BS 4062 : Part 1.

5.5.3 Control setting

5.5.3.1 Immediately before the measurements in 5.5.3.2 are taken, operate the valve over the full cycle of its range of adjustment at least 10 times in close succession. To avoid inconsistencies owing to silting, complete each set of measurements within 60 s of setting the control element position.

5.5.3.2 Measure and state in the test report, the torque, force, pressure or electrical input necessary to change the control setting position over the flow range from minimum to maximum and back to minimum over the agreed range of pressures whilst the valve is operating.

5.5.4 Transient tests on pressure compensated valves.

Measure the regulated flow over agreed ranges of control element settings and pressure differentials when the inlet pressure is varied in the case of meter-out, bleed-off and 3-way bleed-off configurations and when the outlet pressure is varied in the case of a meter-in configuration.

Ensure that the operating time of valve 9 (see figures 10 to 12) does not exceed 10 % of the measured response time with a maximum of 10 ms. The pressure gradient due to fluid compressibility, as calculated from the expression $dp/dt = QK_s/V$ shall be at least 10 times the measured gradient, where V is the volume of fluid between test valve 5 and valves 8a and 8b. Adopt the following procedure:

(a) establish steady-state flow Q by setting valve 5 and pressure drop Δp_2 by setting valve 8a with valve 9 closed;

(b) establish pressure drop Δp_1 by setting valve 8b with valve 9 open;

(c) introduce a load step by either of the following methods:

(1) *preferred method 1 (using a high frequency response flow transducer):* by operating 2-way valve 9 and monitoring the transient flow Q_t ;

NOTE. A check on the adequacy of the response of the flow transducer can be obtained by simultaneously recording the transient pressure Δp and observing that the flow and pressure oscillations are in phase.

(2) *alternative method 2 (using a pressure transducer):* by operating 2-way valve 9, monitoring the pressure drop Δp and deriving the corresponding transient characteristics from the initial flow and transient flow, which are calculated from the following expressions:

$$\text{initial flow, } Q_1 = k\sqrt{\Delta p_1}$$

$$\text{transient flow, } Q = k\sqrt{\Delta p}$$

where

Δp is the pressure differential across the loading valves measured by the pressure indicators 4a and 4b (see figures 10 to 12).