INTERNATIONAL STANDARD

ISO 6403

First edition 1988-11-01

Corrected and reprinted 1989-05-01

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
ORGANISATION INTERNATIONALE DE NORMALISATION
МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ

Hydraulic fluid power — Valves controlling flow and pressure — Test methods

Transmissions hydrauliques — Régulateurs de débit et de pression — Méthodes d'essai

Reference number
ISO 6403 : 1988 (E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 6403 was prepared by Technical Committee ISO/TC 131, *Fluid power systems.*

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Printed in Switzerland

Contents

Annexes

Hydraulic fluid power — Valves controlling flow and pressure — Test methods

0 Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit. Hydraulic valves may be used to control the direction, pressure or flow rate of the working fluid by adjusting or controlling their resistance to flow.

ISO 4411, in which methods for determining the steady-state differential pressure/flow characteristics of hydraulic valves are specified, forms part of the same series of International Standards.

The test requirements for production purposes may differ from those specified in this International Standard.

1 Scope and field of application

This International Standard specifies methods for testing hydraulic valves which are used for the control of flow or pressure in a circuit in order to determine their steady-state and dynamic performance.

Requirements for test installations and procedures, measurements and presentation of results are specified. This International Standard 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.

Accuracy of measurement is divided into three classes (A, B and C) which are explained in annex A. Guidance as to the use of practical units for the presentation of results is given in annex B.

Proportional control valves are not dealt with in this International Standard. Electrohydraulic servovalves are dealt with in ISO 6404.

2 References

ISO 1219, *Fluid power systems and components — Graphic symbols.*

ISO 4411, *Hydraulic fluid power — Valves — Determination of pressure differential/flow characteristics.*

ISO 5598, *Fluid power systems and components — Vocabulary.*

IEC Publication 85, *Thermal evaluation and classification of electrical insulation.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 5598, together with the following, apply.

3.1 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.

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

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

3.4 volumetric stiffness: The stiffness of a given portion of a hydraulic circuit, which is determined by the value of the partial differential $\frac{\partial p}{\partial V}$ for the fluid contained in that part of the circuit.

4 Symbols and units

4.1 The units and symbols used throughout this International Standard are as shown in table 1.

Table 1 — Symbols and units

Quantity	Symbol	Dimension 1)	SI unit 2)
Nominal diameter of valve	D	L	m
Force	F	MLT^{-2}	N
Control element — linear displacement	L	L	m
Control element — angular displacement	β	—	rad
Volume flow rate	q_V	L^3T^{-1}	m^3/s
Internal diameter of pipe	d	L	m
Pressure, differential pressure	$p, \Delta p$	$ML^{-1}T^{-2}$	Pa
Time	t	T	s
Mass density of fluid	ϱ	ML^{-3}	kg/m^3
Kinematic viscosity	ν	L^2T^{-1}	m^2/s
Temperature (customary)	θ	Θ	°C
Isentropic bulk modulus	K_s	$ML^{-1}T^{-2}$	Pa
Volume	V	L^3	m^3

1) M = mass; L = length; T = time; Θ = temperature

2) The practical units which may be used for the presentation of results are tabulated in annex B.

4.2 The graphical symbols used in the figures depicting test circuits are in accordance with ISO 1219.

5 Test installation — General requirements

5.1 Test circuit

5.1.1 A test circuit similar to those shown in figure 1 and figures 5 to 13 and suitable for the type of valve being tested in accordance with the relevant clauses in this International Standard shall be used.

NOTES

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

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

5.1.2 A fluid supply with a controllable flow which has a higher maximum than the rated flow of the valve being tested shall be used.

5.1.3 A pressure control valve in the supply line shall be installed to protect the circuit from excess pressure.

Further control valves, as necessary, shall be installed to regulate the flow or pressure, as required, in various parts of the circuit.

5.1.4 The inside diameters of pipes and fittings that interface with the test valve, and which include pressure tapping points, shall be consistent with the diameters of the ports.

5.1.5 Drain ports shall be connected to a reservoir.

5.2 Pressure- and temperature-sensing points

5.2.1 Location of pressure tappings

NOTE — In the case of measurements to class C standard of accuracy (see annex A), pressure readings taken for expediency at other points other than those described in this sub-sub-clause will give sufficient accuracy providing that, where appropriate, correction is made for pipe losses.

Pressure tappings shall be provided both upstream and downstream of the valve being tested and, if required, at other points.

5.2.1.1 The inlet pressure tapping point shall be

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.

5.2.1.2 The outlet pressure tapping point shall be not less than $10d$ downstream of the test valve.

5.2.1.3 The measured data for pipe losses shall be corrected using the method described in ISO 4411.

5.2.2 Pressure tappings

5.2.2.1 The tappings shall have diameters equal to or less than $0{,}1d$ but not less than 1 mm nor greater than 6 mm.

5.2.2.2 The internal pipe surface at the tapping shall be deburred without the sharp edge of the tapping hole being removed.

5.2.2.3 The length of the tapping hole shall be not less than twice the diameter.

5.2.2.4 The bore of the pipe containing the tapping shall be clean and smooth.

5.2.2.5 The instrument-connecting pipes shall have bores not less than 3 mm.

5.2.2.6 Any entrained air between each tapping point and the measuring instrument shall be purged.

5.2.3 Location of temperature-sensing point

The fluid temperature at the inlet to the test valve shall be measured at a distance not greater than 15d upstream of the inlet pressure tapping.

5.3 Filtration and contamination level

5.3.1 Filters shall be installed which provide a standard of filtration which is at least equal to that recommended by the test valve manufacturer.

5.3.2 The position and specific description of each filter used in the test circuit shall be stated in the test report.

5.3.3 During tests conducted in accordance with clauses 7 to 11, where inconsistencies may arise due to silting, the standard of filtration shall be such that test measurements can be made within 60 s; the actual interval in the test report shall be stated in the test report.

5.3.4 The actual contamination level of the test fluid from samples taken during the test shall be determined; the test method used shall be stated in the test report.

6 General test conditions

6.1 Test fluid

6.1.1 The following information relating to the test fluid shall be included in the test report:

a) a description of test fluid;

b) the kinematic viscosity, ν, and density, ϱ, of the test fluid at the controlled temperature of the test;

c) the isentropic bulk modulus, K_s, of the test fluid (if dynamic tests are performed).

6.1.2 If it is necessary to determine the effect of viscosity, the tests shall be carried out at agreed fixed temperature(s), using fluids of different viscosity of the same fundamental type; details shall be included in the test report.

6.2 Test temperatures

6.2.1 Tests shall be carried out at agreed fluid inlet temperatures. The fluid inlet temperature(s) shall be selected within the range recommended by the valve manufacturer; details shall be included in the test report.

6.2.2 When selecting temperatures, due consideration shall be given to whether the valve to be tested is to be examined for temperature compensation.

6.2.3 If the selected test temperature is 25 °C or higher, the equipment and the working fluid shall be stabilized at that temperature prior to commencement of the test. The temperature shall be maintained throughout the test.

6.2.4 If the selected test temperature is less than 25 °C (considered as a cold-start condition), the temperature of the fluid shall be allowed to rise after the start of the test. Temperature, pressure and flows against time shall be recorded.

6.3 Steady-state conditions

6.3.1 Each set of measurements shall be taken when the values of controlled parameters are within the tolerances given in table 2.

6.3.2 The number of readings taken and their disposition over the range shall be selected so as to give a representative indication of the performance of the unit over the full range of the function being varied.

6.3.3 In order to ensure repeatable results, the mean values of the parameters being measured shall be established over an agreed interval of time.

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

Controlled parameter	Limits of permissible variation of mean indicated values of controlled parameters for class of measurement accuracy[1]		
	A	B	C
Flow rate, %	± 0,5	± 1,5	± 2,5
Pressures, %	± 0,5	± 1,5	± 2,5
Fluid temperature, K	± 1	± 2	± 4
Viscosity, %	± 5	± 10	± 15

1) See annex A.

6.4 Proof pressure

6.4.1 A proof pressure test in accordance with 6.4.1.1 to 6.4.1.5 shall be carried out to examine the integrity of the valve assembly being tested before any further tests are carried out.

6.4.1.1 Apply to each port (other than drain ports) a proof pressure 1,5 times the maximum operating pressure for that port.

6.4.1.2 Increase the pressure at a rate of approximately 2 % of proof pressure per second and maintain the proof pressure for 5 min.

6.4.1.3 There shall be no external leakage throughout this period.

6.4.1.4 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 5 min.

6.4.1.5 There shall be no external leakage throughout this period.

7 Test procedure for directional control valves

7.1 Test circuit

A test circuit similar to that shown in figure 1 shall be used.

7.2 Steady-state pressure differential/flow characteristics

At stated control element positions, determine the pressure differential/flow characteristics in accordance with the relevant clauses in ISO 4411.

7.3 Internal leakage

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

7.3.2 In order to determine the rate of leakage between the ports, apply agreed pressures to each port at which these tests are to be made.

7.4 Switching envelope

7.4.1 General

The purpose 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).

The movement of the control element shall be monitored by displacement transducers.

The test methods specified in 7.4.2 to 7.4.5 for valves in which the control element is displaced by an electrical solenoid, pilot pressure or force, and with or without spring return, respectively, shall be complied with.

In order to avoid inconsistencies due to silting, complete each set of measurements within 60 s of setting the control element position.

7.4.2 Direct-operated solenoid valves

7.4.2.1 Tests shall be carried out at the maximum stable temperature for the solenoid; this temperature shall be within the limits recommended in IEC Publication 85 for the class of insulation used for the coil winding.

7.4.2.2 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 following the procedure outlined in 7.4.2.2.1 to 7.4.2.2.4. The mean winding temperature is calculated from the change in resistance of the winding after various periods of energization.

7.4.2.2.1 Measure the basic resistance after the de-energized valve has soaked for not less than 4 h at the agreed ambient temperature.

7.4.2.2.2 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 over 90 s.

7.4.2.2.3 Repeat the step outlined in 7.4.2.2.2 as often as is necessary until the temperature has stabilized.

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

7.4.2.3 All subsequent tests shall be carried out after a period of energization which is sufficient to ensure that the temperature has stabilized.

7.4.2.4 The operating thresholds of the valve shall be determined at a voltage 10 % below the nominal rating, unless other values are agreed.

7.4.2.5 The tests shall be carried out over the 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.

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

7.4.2.7 In order to demonstrate that the voltage has been maintained at the intended value at all current levels, record time-based readings of the current taken by the solenoid and the voltage at the terminals of the coil.

7.4.3 Solenoid-controlled two-stage valves

7.4.3.1 Tests shall be carried out to determine the pilot pressure at which the final control element just fails to complete its full displacement.

7.4.3.2 The test shall be carried out over the agreed ranges of pressure and flow and the ranges used shall be stated in the test report.

7.4.3.3 The solenoid voltage shall be set at 10 % below the nominal rating, unless other values are agreed.

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

7.4.3.5 In order to demonstrate that the voltage has been maintained at the intended value at all current levels, record time-based readings of the current taken by the solenoid and the voltage at the terminals of the coil.

7.4.4 Pilot-pressure-operated valves

7.4.4.1 Tests shall be carried out 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.

7.4.4.2 These tests shall be carried out over the agreed ranges of pressure and flow and the ranges used shall be stated in the test report.

7.4.4.3 By agreement, these tests shall be carried out as follows:

a) either apply a gradually increasing pilot pressure at a rate not exceeding 2 % of the maximum rated pilot pressure per second, or

b) dynamically apply the pilot pressure at a rate of not less than 700 MPa/s (7 000 bar/s), or

c) follow both procedures outlined in a) and b).

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

7.4.5 Mechanically operated valves

7.4.5.1 The tests shall be carried out over the agreed ranges of pressure and flow and the ranges used shall be stated in the test report.

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

7.5 Transient characteristics

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

7.5.2 For these tests, the capacitance of the circuits on the output side of the valve shall be limited to the volume enclosed by the valve, including its associated manifolds.

7.5.3 The ports shall be blocked off in a manner appropriate to the pressures to be applied and the volumes shall be prefilled with the operating fluid.

7.5.4 In the case of solenoid controlled valves, the test shall be carried out at the nominal rated voltage and at the temperature conditions of the solenoid, as specified in 6.2, the switching being initiated at the moment of zero voltage in the case of a.c. operation.

7.5.5 In the case of pilot-pressure-operated valves, the rate of change of pressure in the pilot circuit shall be arranged so as to achieve rapid operation of the control element, for example by operating the mechanism by means of a falling weight.

7.5.6 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).

7.5.7 When presenting this data, the technique used for measuring the displacement shall also be described.

7.5.8 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).

8 Test procedure for non-return (check) valves

8.1 Test circuits

8.1.1 Test circuits similar to those shown in figures 5 and 6, for direct-acting non-return valves, and in figure 7, for pilot-pressure-operated non-return valves, shall be used.

8.1.2 When testing pilot-pressure-operated non-return valves for which the flow is from port A to port B, the tests shall be carried out with and without pressure applied to port X. When the flow is reversed, i.e. from port B to port A, the pilot pressure shall be applied to port X.

8.2 Pressure differential/flow characteristics

Determine the pressure differential/flow characteristics in accordance with the relevant clauses in ISO 4411.

8.3 Pilot pressure

8.3.1 The purpose of this test is to establish

a) the minimum pilot pressure, $p_{X,\,open}$, necessary both to open the valve and to maintain it fully open;

b) the maximum pilot pressure, $p_{X,\,closed}$, which will allow the valve to reseat, over an agreed range of pressures p_A and p_B, and flow q_V.

NOTE — Establish p_A before the valve is opened.

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

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

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

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

8.4 Leakage

The leakage tests outlined in 8.4.1 and 8.4.2 shall be carried out for periods of 5 min and the quantities measured shall be recorded.

8.4.1 Direct acting valves

Measure the leakage from port A with the agreed range of pressure applied to port B and with port A at atmospheric pressure.

8.4.2 Pilot-pressure-operated valves

Measure the leakage from port A with the agreed range of pressure applied to port B and with ports A and X at atmospheric pressure; in addition, where applicable, measure the leakage from drain port Y.

9 Test procedure for valves controlling pressure

9.1 Test circuits

9.1.1 Test circuits for pressure-relief and pressure-reducing valves similar to those shown in figures 8 and 9 respectively shall be used.

9.1.2 The amplitude of the pressure ripple measured in the supply circuit shall not exceed ± 0,5 MPa (5 bar).

9.1.3 The volumetric stiffness of the relevant parts of the test valve and circuit shall be such that the rate of change of pressure, with the maximum agreed input flow, lies within the limits of one agreed range selected from the following:

- 3 000 to 4 000 MPa/s (30 000 to 40 000 bar/s)
- 600 to 800 MPa/s (6 000 to 8 000 bar/s)
- 120 to 160 MPa/s (1 200 to 1 400 bar/s)

9.2 Control setting

9.2.1 Immediately before the measurements specified in 9.2.2 are taken, operate the valve over the full cycle of its range of adjustment at least 10 times in quick succession.

9.2.2 Measure 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. Record these values in the test report.

9.2.3 In order to avoid inconsistencies due to silting, complete each set of measurements within 60 s of setting the control element position.

9.3 Pressure-relief valves

9.3.1 Steady-state pressure/flow characteristics

9.3.1.1 Measure the inlet pressure p_a, as recorded by instrument **5a** of figure 8, 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.

9.3.1.2 The pressure p_b in the return line, as recorded by instrument **5b**, at the outlet of the test valve in figure 8 shall be adjusted, by operating valve **8** so that it remains constant at agreed level(s).

9.3.2 Transient characteristics

9.3.2.1 Measure the transient pressure p_a 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, shall reduce the pressure at the inlet of the test valve to not more than 20 % of the required operating pressure. The pressure p_a is indicated by instrument **5a** of figure 8.

9.3.2.2 During pressure transient characteristic tests, the restrictor **8** in figure 8 shall be fully open.

9.3.2.3 Record the pressure/time curve and deduce or record the rate of change of pressure. Record the mean linear rise value, in megapascals per second (MPa/s) [bars per second (bar/s)], over the portion from the operation of valve **3a** to the point of discontinuity, i.e. the point at which the valve starts to lift, as indicated in figure 17. Verify that, at the maximum agreed flow, this linearized rate falls within the selected range specified in 9.1.3.

9.3.2.4 The operating time of valve **3a** in figure 8 shall not exceed 10 % of the linearized portion of the pressure/time curve as described in 9.3.2.3.

9.3.2.5 The instrument used to measure the pressure gradient due to oil compressibility, as calculated from the expression $\frac{dp}{dt} = \frac{q_V \cdot K_s}{V}$, where V is the volume of fluid between test valve **6** and valves **3a** and **3b**, shall have a response capability at least 10 times the measured gradient.

NOTE — The response time and transient recovery time of the valve being tested are defined in figure 17.

9.3.2.6 When a valve controlling pressure is being tested, the flow indicator **9** shall show that there is no flow through the test circuit relief valve **2**.

9.4 Pressure-reducing valves

9.4.1 Steady-state pressure-flow characteristics

9.4.1.1 Measure the steady-state output pressure for agreed increments of controlled flow set by valve **8** from zero to maximum and reducing to zero.

9.4.1.2 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.

9.4.1.3 In addition, take measurements of the leakage through flowmeter **7b**.

9.4.1.4 When applicable, repeat this procedure for reverse flow condition, with port A at atmospheric pressure.

9.4.2 Transient characteristics

9.4.2.1 Transient tests shall be carried out in which the outlet pressure is measured over an agreed range of pressure settings in accordance with the procedure for relief valves given in 9.3.2 for flows in the normal and, when agreed, reverse directions.

9.4.2.2 Apply agreed step functions to the input pressure and to the output flow at each pressure setting.

9.4.2.3 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 being tested to ensure that the control element is fully open.

9.5 Unloading valves

9.5.1 Where pressure-relief or -reducing valves are pilot operated, they may be vented (i.e. reduced to the minimum controlled pressure) by by-passing the pilot stage by means of a venting valve **3b** (as shown in figures 8 and 9).

9.5.2 Measure the resultant minimum operating pressures of the valve being tested for an agreed range of flows in accordance with the relevant clauses of ISO 4411.

9.5.3 Transient tests in accordance with 9.3.2 or 9.4.2 shall be carried out to establish the times necessary to achieve minimum pressure and to re-establish maximum pressure, from the moment the venting valve **3b** is operated.

9.5.4 The venting valve **3b** may be operated manually or hydraulically, or by a solenoid operated or electrohydraulic servo-valve providing that it has an operating time not exceeding 10 % of the measured response time subject to a maximum of 10 ms.

10 Test procedure for flow control valves

10.1 Test circuits

10.1.1 Test circuits similar to those shown in figures 10, 11 and 12 shall be used.

10.1.2 An accumulator of sufficient capacity to maintain the supply pressure within the limits given in table 2 shall be installed in the supply circuit.

10.1.3 The amplitude of the pressure ripple, measured in the supply circuit, shall not exceed ± 0,5 MPa (5 bar).

10.2 Steady-state flow/pressure characteristics

The regulated flow and bypass flow, if applicable, shall be measured over agreed ranges of control element settings and pressure differentials.

10.2.1 Valves with pressure compensation

Tests shall be carried out at agreed steps of inlet and outlet pressures from minimum to maximum specified pressures and flows.

10.2.2 Valves without pressure compensation

Tests shall be carried out in accordance with the relevant clauses of ISO 4411.

10.3 Control setting

10.3.1 Immediately before the measurements specified in 10.3.2 are taken, operate the valve over the full cycle of its range of adjustment at least 10 times in quick succession.

10.3.2 Measure 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 while the valve is operating. Record these values in the test report.

10.3.3 In order to avoid inconsistencies due to silting, complete each set of measurements within 60 s of setting the control element position.

10.4 Transient tests on pressure-compensated valves

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

10.4.2 The operating time of valve **9** (see figures 10 to 12) shall not exceed 10 % of the measured response time with a maximum of 10 ms.

10.4.3 The pressure gradient due to fluid compressibility, as calculated from the expression $\frac{dp}{dt} = \frac{q_V \cdot K_s}{V}$, where V is the volume of fluid between test valve **5** and valves **8a** and **8b**, shall be at least 10 times the measured gradient.

10.4.4 The procedure outlined in 10.4.4.1 to 10.4.4.2 shall be followed.

10.4.4.1 Establish steady-state flow q_V, by setting valve **5**, and pressure drop Δp_2, by setting valve **8a** with valve **9** closed.

10.4.4.2 Establish pressure drop Δp_1, by setting valve **8b** with valve **9** open.

10.4.4.3 Introduce a load step by either of the following methods:

a) **Preferred method 1** (using a high frequency response flow transducer)

Operate two-way valve **9** and monitor the transient flow q_{V_t}.

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

b) **Alternative method 2** (using a pressure transducer)

Operate two-way valve **9**, monitor the pressure drop Δp and derive the corresponding transient characteristics from the initial flow and transient flow which are calculated from the following expressions:

— Initial flow, $q_{V_1} = k\sqrt{\Delta p_1}$

— Transient flow, $q_{V_t} = k\sqrt{\Delta p}$

where

k is the loading valve coefficient determined from the expression

$$k = \frac{q_V}{\sqrt{\Delta p_2}}$$

where Δp_2 is the pressure drop at the end of the test;

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

Δp_1 is the pressure drop at the beginning of the test.

NOTE — The response time and the transient recovery time of the valve are as defined in figure 19.

11 Test procedure for flow-dividing valves

11.1 Test circuit

11.1.1 A test circuit similar to that shown in figure 13 shall be used.

11.1.2 The amplitude of the pressure ripple, measured in the supply circuit, shall not exceed ± 0,5 MPa (5 bar).

11.2 Steady-state flow/pressure characteristics

11.2.1 Measure the input pressure and each output flow over an agreed range of input flows for an agreed range of output pressures selected from the conditions specified in table 3 for each agreed setting of the ratio control element, if such a setting is provided.

Table 3 — Output pressure conditions

Sequence	Output pressure conditions at port B1	Output pressure conditions at port B2
1	p_{min}	$p_{min} \rightarrow p_{max} \rightarrow p_{min}$
2	$p_{min} \rightarrow p_{max} \rightarrow p_{min}$	p_{min}
3	p_{max}	$p_{min} \rightarrow p_{max} \rightarrow p_{min}$
4	$p_{min} \rightarrow p_{max} \rightarrow p_{min}$	p_{max}
5	$p_{min} \rightarrow p_{max} \rightarrow p_{min}$	$p_{min} \rightarrow p_{max} \rightarrow p_{min}$

11.2.2 In sequence 5, the pressure at ports B1 and B2 shall be equal.

11.3 Transient tests

11.3.1 Measure the flows from each output port over an agreed range of input flows for an agreed range output pressure selected from the conditions specified in table 3 for each agreed setting of the ratio control element, if such a setting is provided.

11.3.2 Measure the steady-state flows $q_{V_{B1}}$ and $q_{V_{B2}}$, with valve **7a** set at the highest value of the pressure loading p_1 and with valve **6a** closed.

11.3.3 Record the pressure p_2 indicated by **4d**.

11.3.4 Establish the lower pressure loading p_3 by setting valve **7b** with valve **6a** open and record the pressure p_4 indicated by **4d**.

11.3.5 Repeat this procedure for the loading system for port B2 to determine pressures p_5, p_6, p_7 and p_8, respectively.

11.3.6 Calculate the pressure drops across loading valves **6a** and **6b** using the following expressions:

$$\Delta p_{2,B1} = p_1 - p_2$$

$$\Delta p_{1,B1} = p_3 - p_4$$

and

$$\Delta p_{2,B2} = p_5 - p_6$$

$$\Delta p_{1,B2} = p_7 - p_8$$

11.3.7 Introduce a load step by either of the following methods:

a) **Preferred method 1** (using a high frequency response flows transducer)

Operate two-way valves **6a** and/or **6b** and monitor the transient flows $q_{V_{t,A}}$ and $q_{V_{t,B}}$.

NOTES

1 A check on the adequacy of the response of the flow transducers can be obtained by simultaneously recording the translient pressures $p_{t,B1}$ and $p_{t,B2}$ and observing that the flow and pressure oscillations are in phase.

2 The response time of the valve is as defined in figure 19.

b) **Alternative method 2** (using pressure transducers)

Determine the loading valve coefficients k_A, k_B, k_C and k_D from the expressions

$$k_A = \frac{q_{V_A}}{\sqrt{\Delta p_{2,B1}}}$$

$$k_B = \frac{q_{V_B}}{\sqrt{\Delta p_{1,B1}}}$$

and similarly

$$k_C = \frac{q_{V_C}}{\sqrt{\Delta p_{2,B2}}}$$

$$k_D = \frac{q_{V_D}}{\sqrt{\Delta p_{1,B2}}}$$

Operate two-way valve(s) **6a** and/or **6b** and monitor the transient pressure drops $\Delta p_{t,A}$ and $\Delta p_{t,B}$.

To derive the corresponding flow transient characteristics, calculate the initial flow at port A, $q_{V_{1,A}}$, from the expression

$$q_{V_{1,A}} = k_A \sqrt{\Delta p_{1,B2}}, \text{ etc.}$$

and the transient flow, $q_{V_{t,A}}$, from the expression

$$q_{V_{t,A}} = k_A \sqrt{\Delta p_{B2}}, \text{ etc.}$$

Similarly calculate the initial flow, $q_{V_{1,B}}$, and the transient flow, $q_{V_{t,B}}$, at port B from the expressions

$$q_{V_{1,B}} = k_B \sqrt{\Delta p_{1,B2}}, \text{ etc.}$$

and

$$q_{V_{t,B}} = k_B \sqrt{\Delta p_{B2}}, \text{ etc.}$$

In the equations above

Δp_{B1} is the pressure drop across the loading valves **7a** and **7b** as measured by pressure indicators **4b** and **4d**.

Δp_{B2} is the pressure drop across the loading valves **7c** and **7d** as measured by pressure indicators **4c** and **4e**.

12 Test report

12.1 General

A test report which records the relevant data specified in 12.2 (as appropriate), test results and the class of measurement used shall be drawn up.

12.2 Test data

The minimum data, as specified in this sub-clause, referring to the valve being tested and to the test conditions shall be agreed and stated before the tests are carried out.

12.2.1 Data common to all valves

The following minimum data shall be included in the test report:

a) the class of measurement accuracy (see annex A);

b) the manufacturer's name;

c) the manufacturer's identification (type number, serial number, etc.);

d) the manufacturer's description of valve;

e) details of pipes, pressure tapping points and fittings which interface with the test valve (see 5.1.4 and 5.2.1);

f) the manufacturer's filtration requirements (see 5.3.1);

g) the standard of filtration installed in test circuit (see 5.3.2 and 5.3.3);

h) the actual contamination level of the test fluid (see 5.3.4);

i) the test fluid (by name and description) (see 6.1);

j) the test fluid kinematic viscosity or viscosities (see 6.1);

k) the test fluid density (see 6.1);

l) the test fluid isentropic bulk modulus (see 6.1);

m) the test fluid temperature(s) (see 6.2);

n) the ambient temperature;

o) the maximum operating pressure;

p) the pressure rating for each port;

q) the maximum flow rating agreed for the test, $q_{V_{max}}$.

12.2.2 Additional data for directional control valves

The following additional data pertinent to directional control valves shall be included in the test report:

a) the number of switching envelope tests (see 7.4.2.6);

b) electrical data for solenoid-operated valves (see 7.4.2);

c) minimum and maximum operating pressures for pilot-pressure-operated valves, if appropriate (see 7.4.3);

d) forces for mechanically operated valves (see 7.4.4);

e) any special features, e.g. constraints on mounting attitude.

12.2.3 Additional data for non-return (check) valves

The following additional data pertinent to non-return (check) valves shall be included in the test report:

a) minimum and maximum operating pressures for pilot-pressure-operated valves, if appropriate (see 8.3);

b) any special features, e.g. constraints on mounting attitudes.

12.2.4 Additional data for valves controlling pressure

The following additional data pertinent to valves controlling pressure shall be included in the test report:

a) the pressure range (see 9.1.3);

b) the minimum pressure setting (see 9.2);

c) the method used for control setting (see 9.2);

d) any special features, e.g. venting (see 9.5);

e) the selected range of rate of change of pressure (see 9.1 and 9.3.2).

12.2.5 Additional data for flow control valves

The following additional data pertinent to flow control valves shall be included in the test report:

a) the minimum flow (see 10.2, 10.3 and 10.4);

b) the method used for control setting (see 10.3).

12.2.6 Additional data for flow-dividing valves

The following additional data pertinent to flow-dividing valves shall be included in the test report:

a) the minimum flow (see 11.2);

b) the range of ratio adjustment, if appropriate (see 11.2).

12.3 Test results

All test measurements, including these outlined in 12.3.1 to 12.3.6, shall be tabulated and presented graphically, if appropriate, in the test report.

12.3.1 For all valves, as regards the proof pressure test, details of the test conditions at point of failure, if appropriate (see 6.4), shall be included.

12.3.2 For directional control valves, the following details shall be included:

a) the pressure/flow characteristics (see figure 3 in ISO 4411) (see also 7.2);

b) internal leakage, i.e. between specified ports at the agreed differential pressures (see 7.3);

c) the switching envelope, i.e. the working range (see figure 2 and 7.4);

d) the operating effort, i.e. torque, force, pressure or electrical input, as appropriate (see 7.4);

e) the response time, obtained from either

1) displacement/time relationships (see figure 3) (the method used to measure the displacement shall be stated), or

2) pressure/time relationships (see figure 4).

12.3.3 For non-return (check) valves, the following details shall be included:

a) the pressure/flow characteristics for direct acting valves, see figure 4 in ISO 4411 and for pilot-pressure-operated valves, see figure 14 in this International Standard and figure 4 in ISO 4411;

b) the pilot pressure, p_X (see figure 15 and 8.3.4);

c) the leakage characteristics (see 8.4.).

12.3.4 For valves controlling pressure, the following details shall be included:

a) the control setting effort over operating range (see 9.2);

b) the steady-state pressure/flow characteristics, including pilot flow, where appropriate (see figure 16 and 9.3.1);

c) the dynamic characteristics for each flow and pressure setting (see figure 17 and 9.3.2), i.e.

1) the rate of change of pressure in the blocked-off circuit,

2) the pressure/time recording,

3) the response time,

4) the ratio of maximum pressure overshoot to final steady-state pressure.

12.3.5 For flow control valves, the following details shall be included:

a) the steady-state flow/pressure characteristics over the agreed range of settings (see figure 18 and 10.2);

b) the control setting effort, i.e. torque, force, pressure or lectrical input, as appropriate (see 10.3);

c) the dynamic characteristics for each flow and pressure setting (see figure 9 and 10.4), i.e.

1) either flow/time recordings of transient tests showing superimposed pressure/time verification or pressure/time recordings of results showing the coordinates at which the flows are calculated, and a graphical representation of derived flow/time characteristics,

2) the response and transient recovery times,

3) the ratio of the flow overshoot to the final steady-state load step.

12.3.6 For flow-dividing valves, the following details shall be included:

a) the steady-state flow/pressure characteristics (see 11.2);

b) the dynamic characteristics for each flow and pressure rate for each port (in a manner similar to figure 19), i.e.

1) either flow/time recordings of transient tests showing superimposed pressure/time verification or pressure/time recordings of results showing the co-ordinates at which the flows are calculated, and a graphical representation of derived flow/time characteristics,

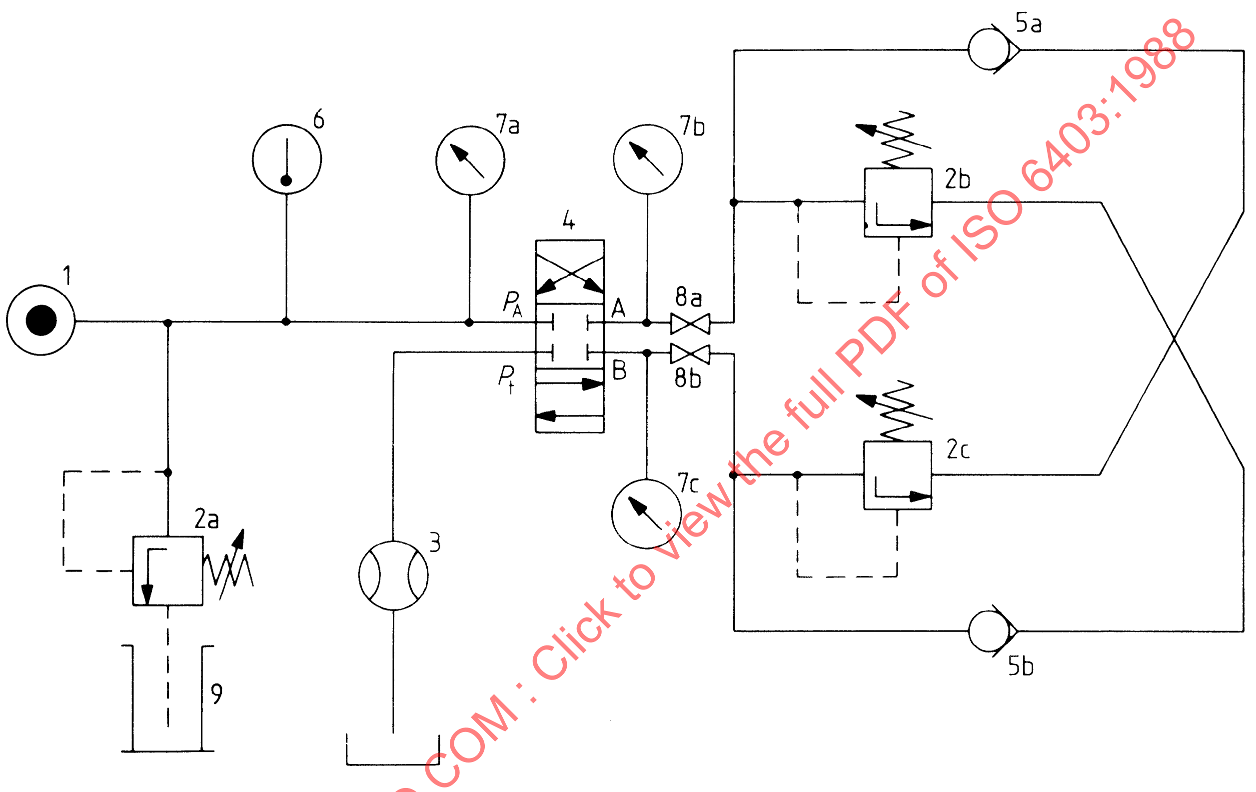
2) the response and transient recovery times,

3) ratio of the overshoot/undershoot to the final steady-state flow.

13 Identification statement (Reference to this International Standard)

Use the following statement in test reports, catalogues and sales literature when electing to comply with this International Standard:

"Tests for determining steady-state and dynamic performance conform with the appropriate methods described in ISO 6403, *Hydraulic fluid power — Valves controlling flow and pressure — Test methods.*"



Key

1	Flow source
2a, 2b, 2c	Pressure-relief valves
3	Flowmeter
4	Valve being tested
5a, 5b	Non-return valves
6	Temperature indicator
7a, 7b, 7c	Pressure indicators
8	Shut-off valve
9	Zero flow indicator

Figure 1 — Test circuit for directional control valves

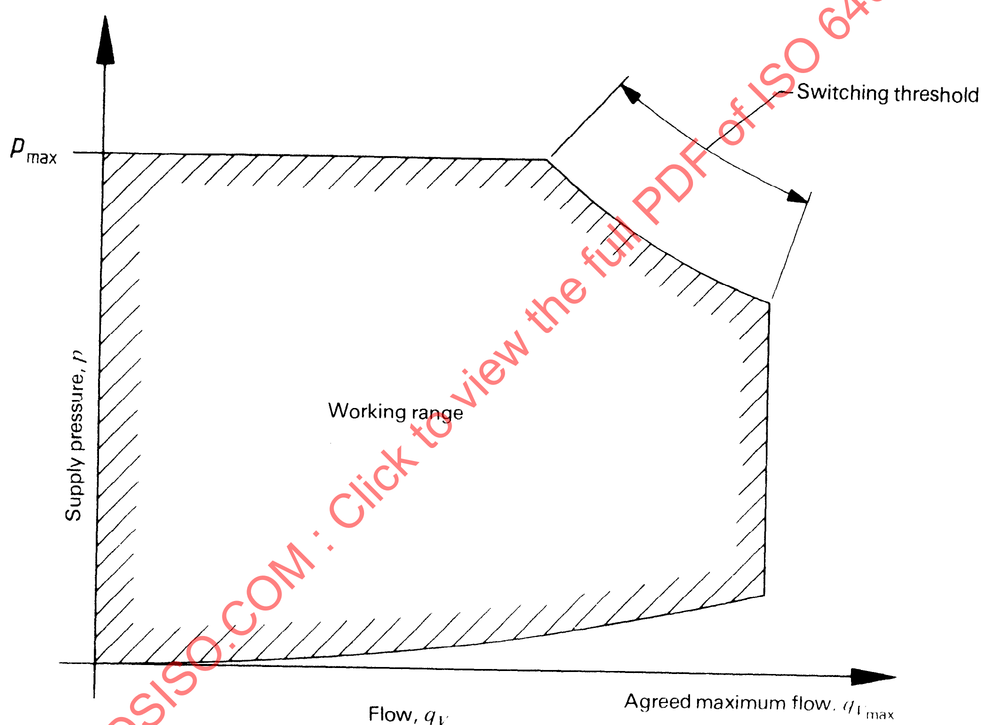


Figure 2 — Switching envelope for directional control valves

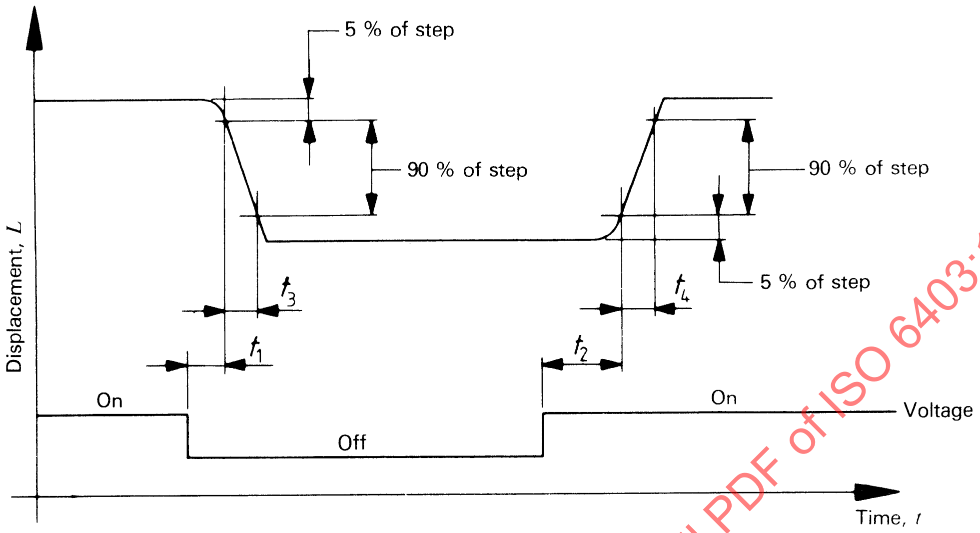


Figure 3 — Transient characteristics for operation of directional control valves — Relationship between displacement and time

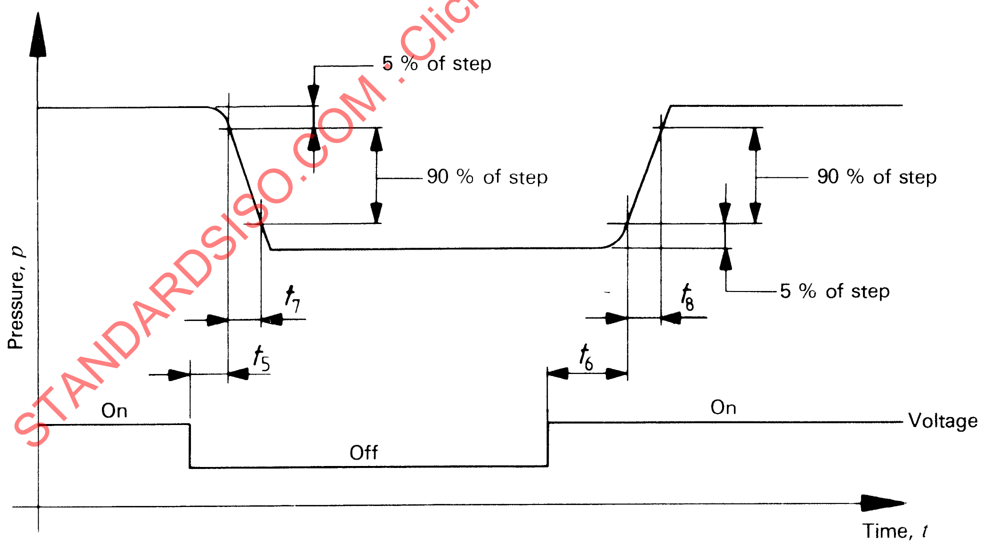
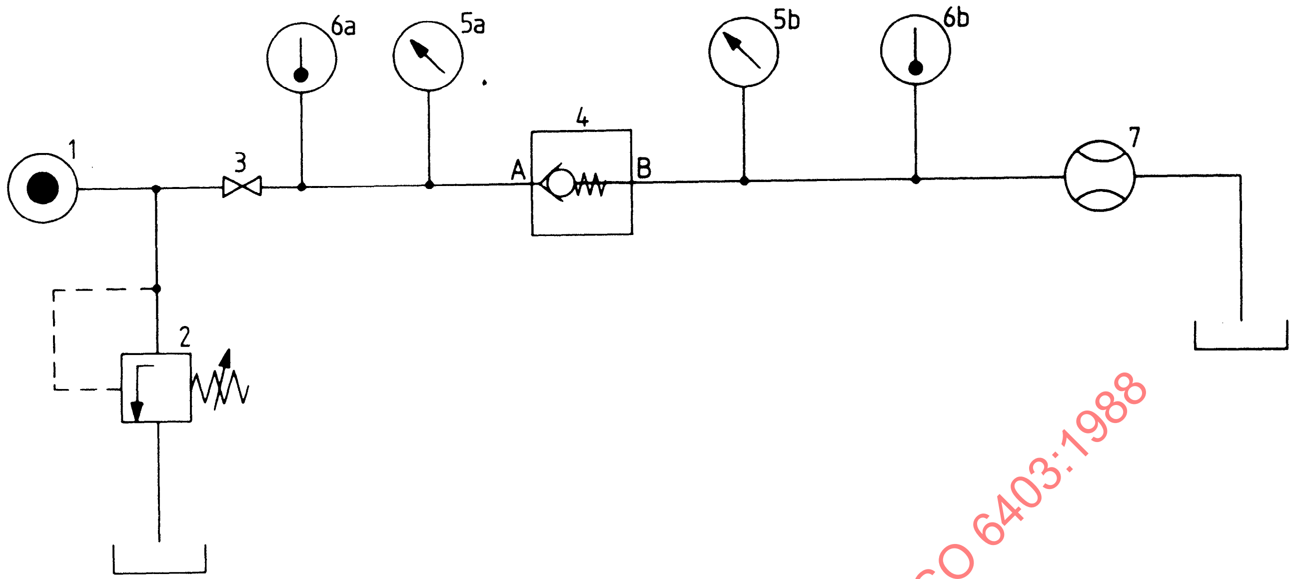


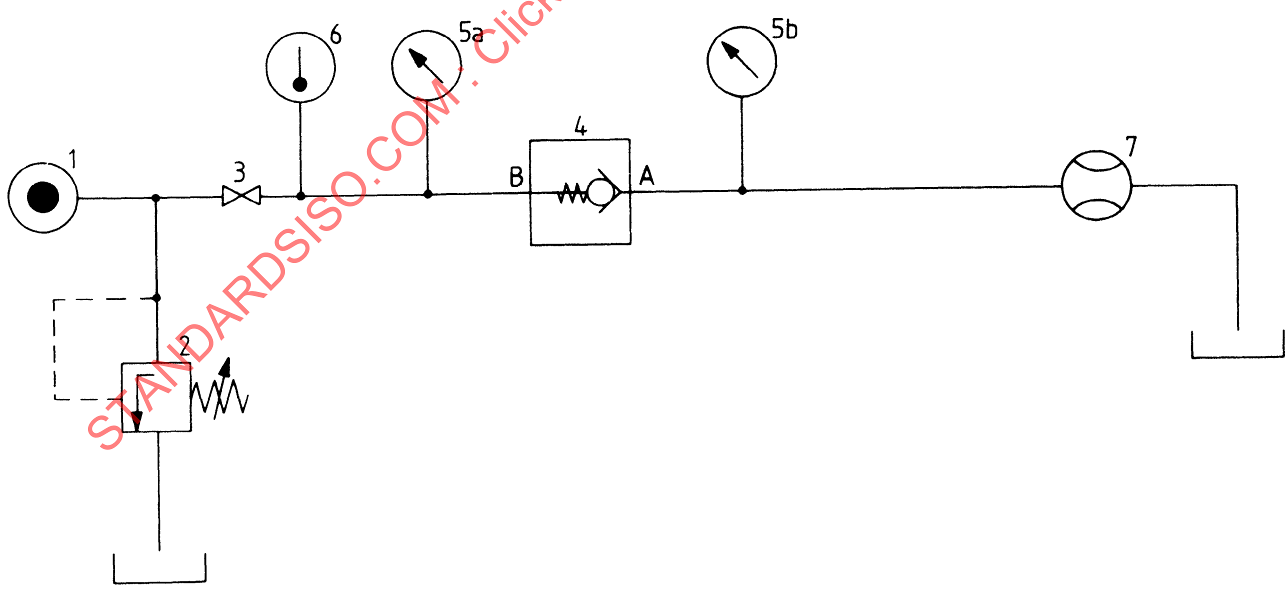
Figure 4 — Transient characteristics for operation of directional control valves — Relationship between pressure and time



Key

- **1** Flow source
- **2** Pressure-relief valve
- **3** Shut-off valve
- **4** Valve being tested
- **5a, 5b** Pressure indicators
- **6a, 6b** Temperature indicators
- **7** Flowmeter

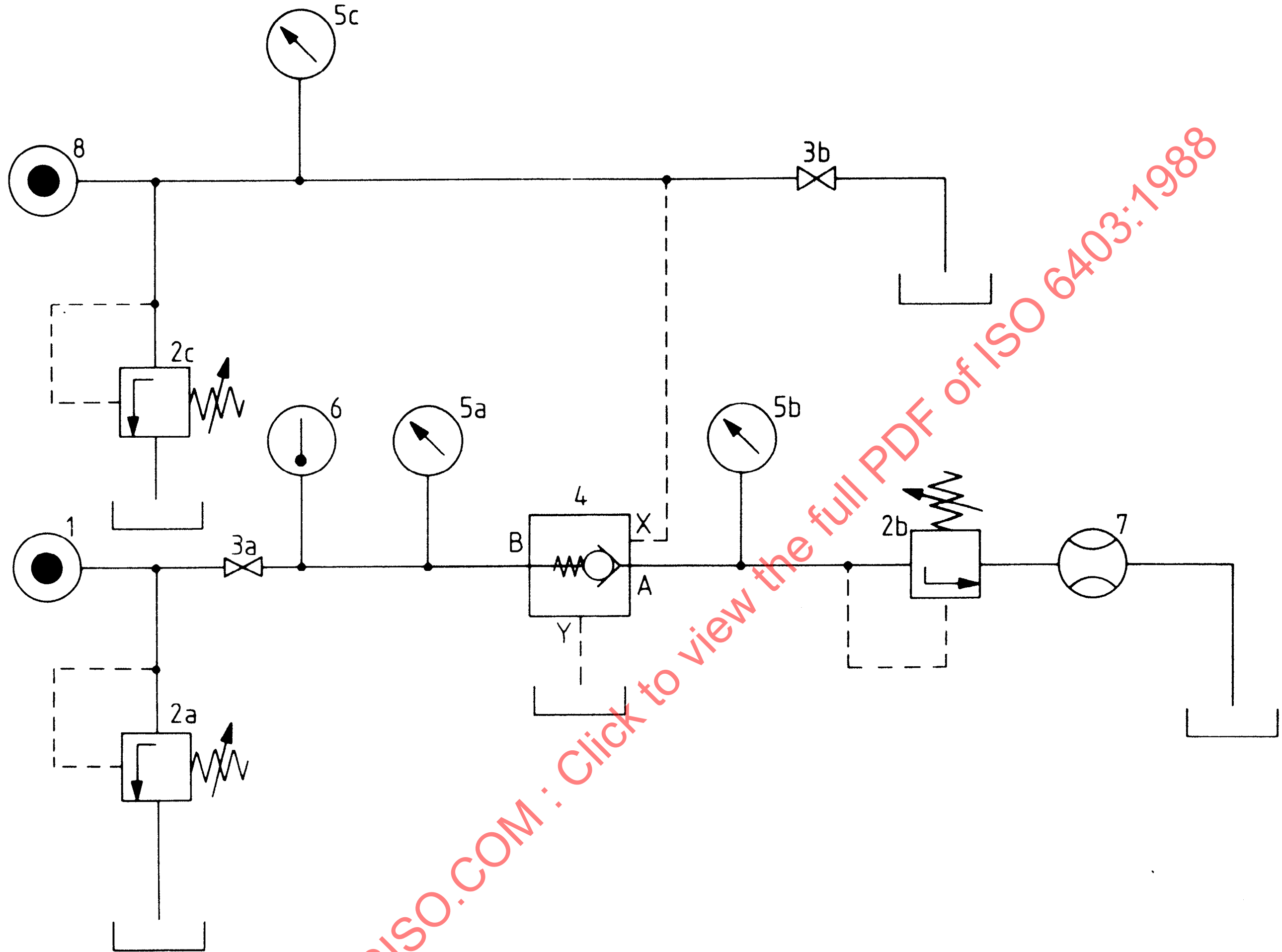
Figure 5 — Test circuit for direct-acting non-return valves



Key

- **1** Flow source
- **2** Pressure-relief valve
- **3** Shut-off valve
- **4** Valve being tested
- **5a, 5b** Pressure indicators
- **6** Temperature indicator
- **7** Flowmeter

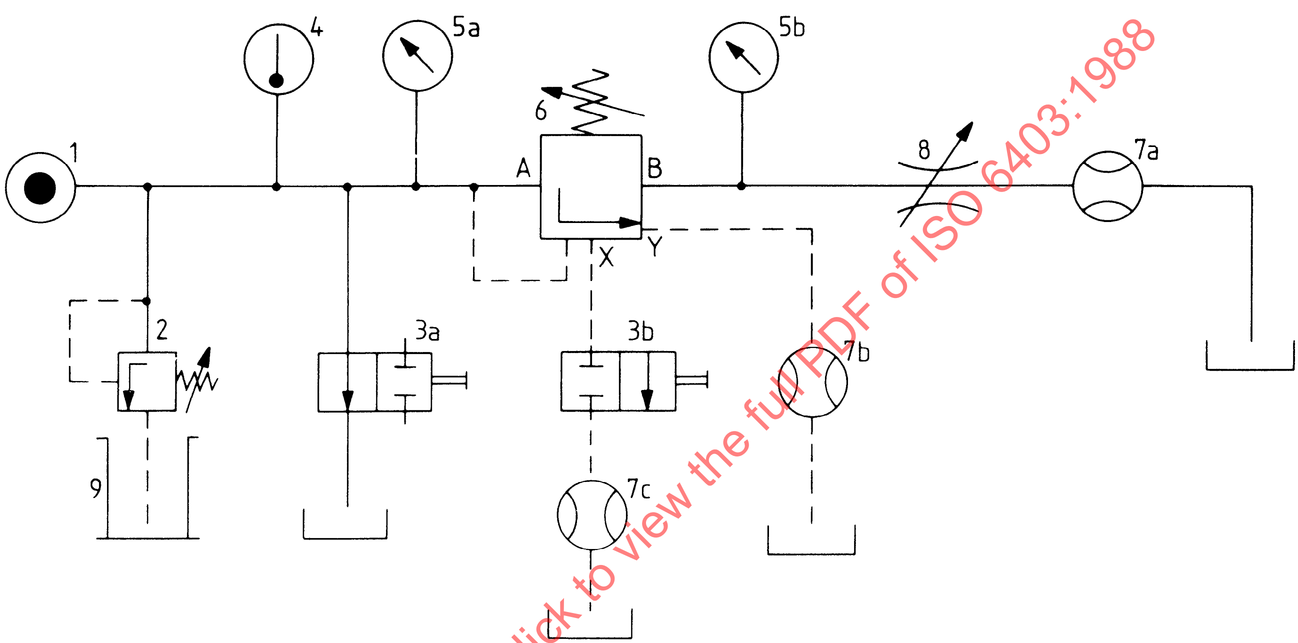
Figure 6 — Test circuit for leakage flow of direct-acting non-return valves



Key

1	Flow source
2a, 2b, 2c	Pressure-relief valves
3a, 3b	Shut-off valves
4	Valve being tested
5a, 5b, 5c	Pressure indicators
6	Temperature indicator
7	Flowmeter
8	Pilot flow source

Figure 7 — Test circuit for pilot-pressure-operated non-return valves

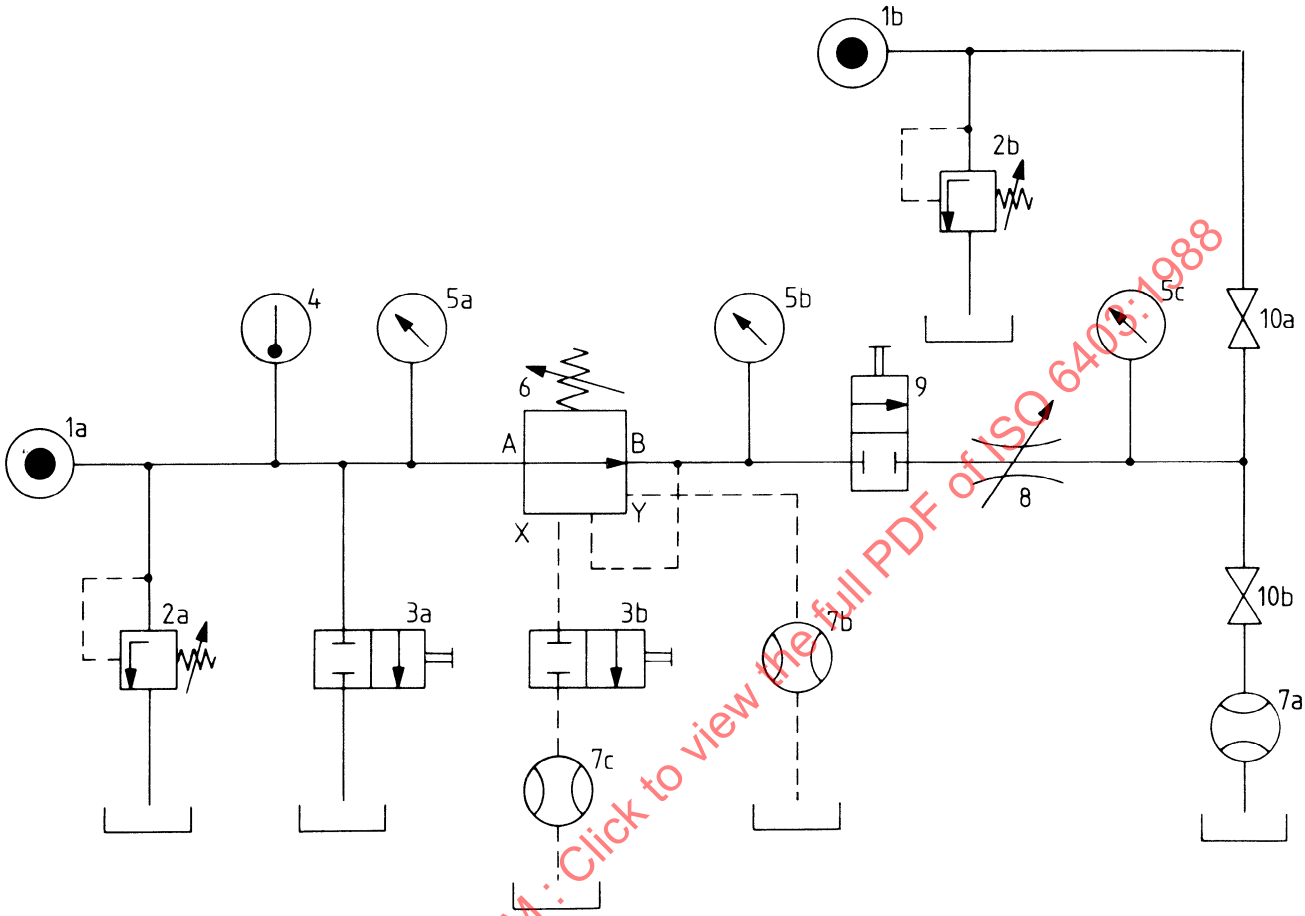


Key

1	Flow source
2	Pressure-relief valve
3a, 3b	By-pass valves
4	Temperature indicator
5a, 5b	Pressure indicators
6	Valve being tested
7a, 7b, 7c	Flowmeters
8	Variable orifice
9	Zero flow indicator

NOTE — The requirements for tapping point positions are given in 5.2.

Figure 8 — Test circuit for pressure-relief valves



Key

1a, 1b	Flow sources
2a, 2b	Pressure-relief valves
3a, 3b	By-pass valves
4	Temperature indicator
5a, 5b, 5c	Pressure indicators
6	Valve being tested
7a, 7b, 7c	Flowmeters
8	Variable orifice
9	Two-way valve
10a, 10b	Shut-off valves

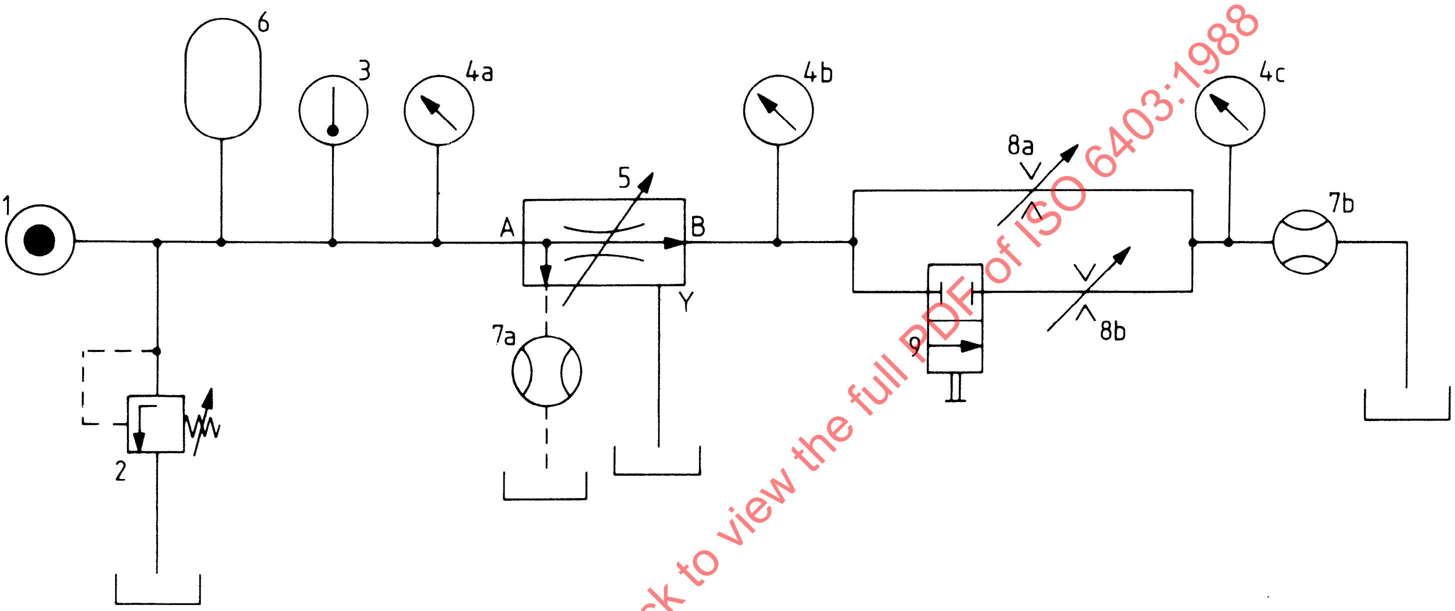
NOTES

1 Items **1b** and **2b** are not required for two-port reducing valves.

2 The circuit between test valve **6** and loading valve **8** should be assembled from rigid piping and the oil volume should be kept as small as possible.

3 The requirements for tapping point positions are given in clause 5.2.

Figure 9 — Test circuit for pressure-reducing valves



Key

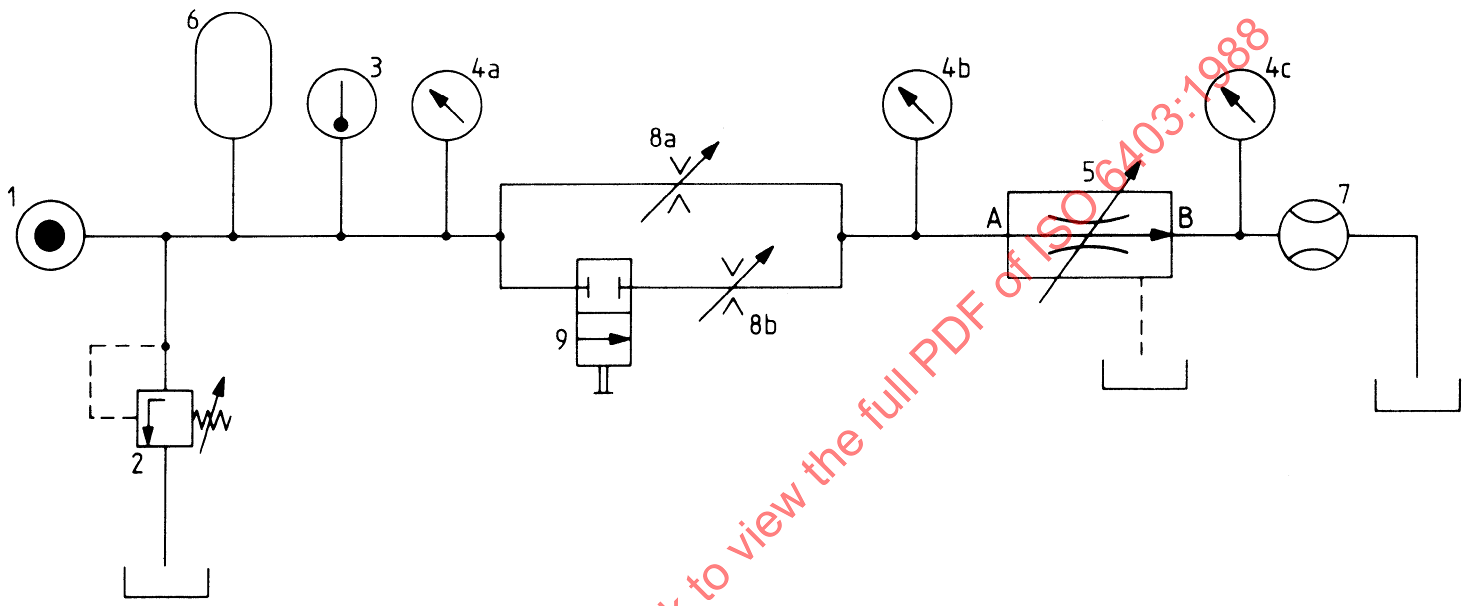
1	Flow source
2	Pressure-relief valve
3	Temperature indicator
4a, 4b, 4c	Pressure indicators
5	Valve being tested
6	Accumulator
7a, 7b	Flowmeters
8a, 8b	Variable sharp-edge orifices
9	Two-way valve

NOTES

1 The circuit between test valve **5** and loading valve **8a** and **8b** should be assembled from rigid piping and the fluid volume should be kept as small as possible.

2 The requirements for tapping point positions are given in clause 5.2.

Figure 10 — Test circuit for flow control valves (meter-in and three-way bleed-off)



Key

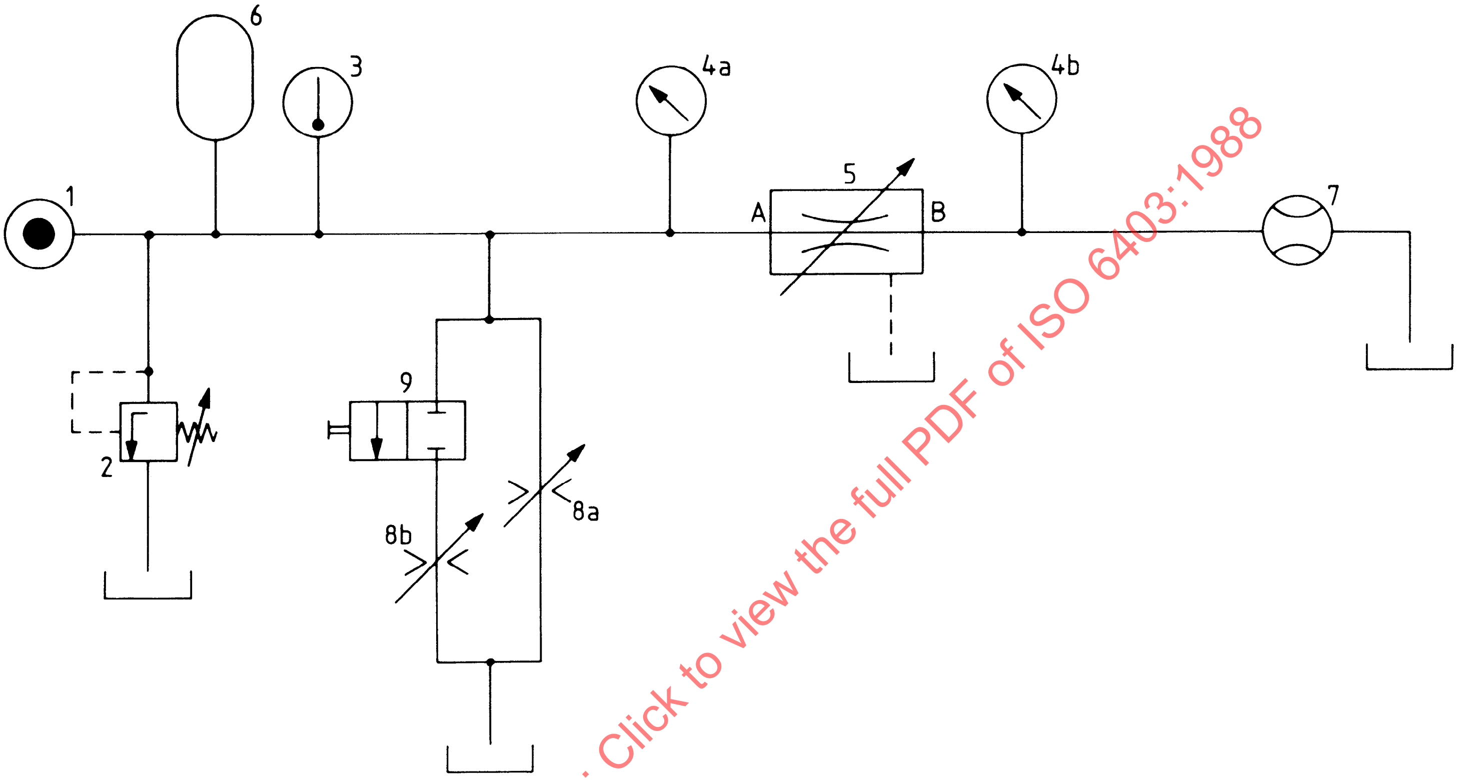
1	Flow source
2	Pressure-relief valve
3	Temperature indicator
4a, 4b, 4c	Pressure indicators
5	Valve being tested
6	Accumulator
7	Flowmeter
8a, 8b	Variable sharp-edge orifices
9	Two-way valves

NOTES

1 The circuit between test valve **5** and loading valves **8a** and **8b** should be assembled from rigid piping and the fluid volume should be kept as small as possible.

2 The requirements for tapping point positions are given in clause 5.2.

Figure 11 — Test circuit for flow control valves (meter-out)



Key

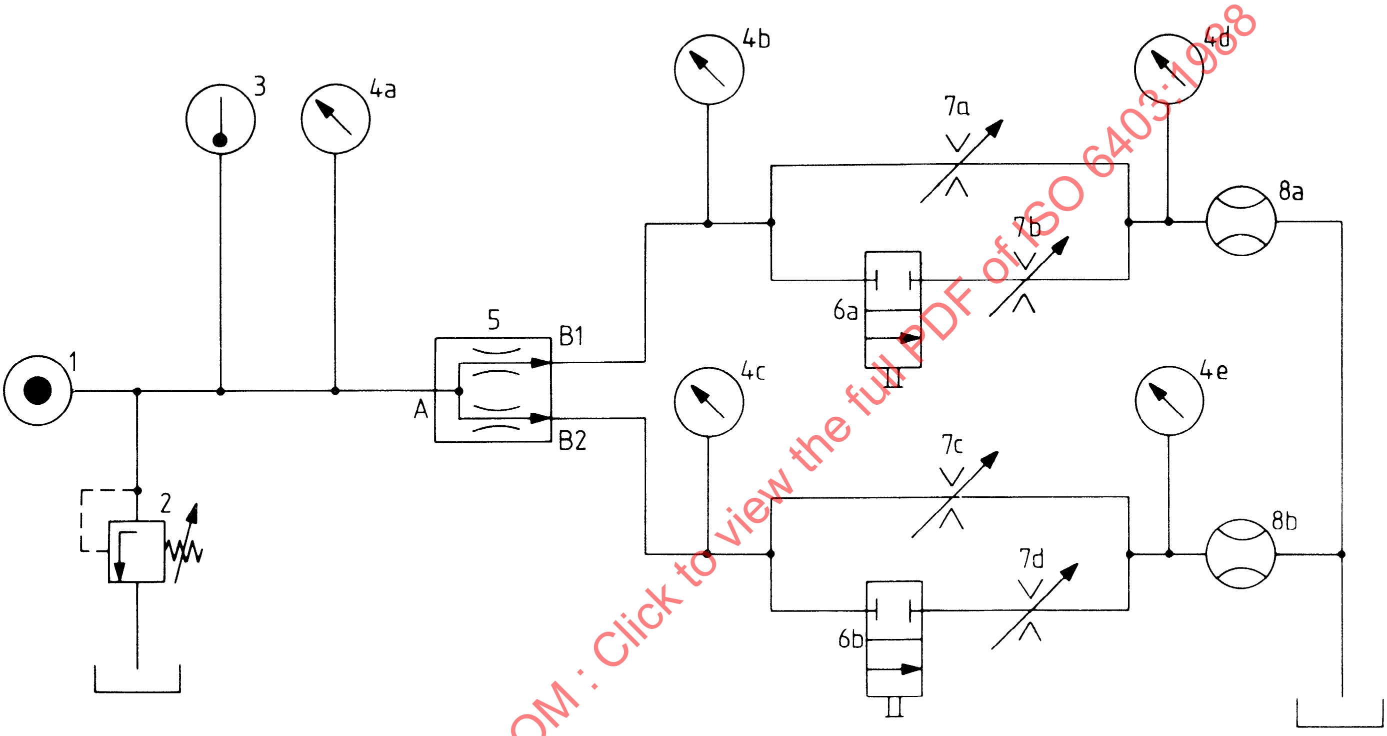
1	Flow source
2	Pressure-relief valve
3	Temperature indicator
4a, 4b	Pressure indicators
5	Valve being tested
6	Accumulator
7	Flowmeter
8a, 8b	Variable sharp-edge orifices
9	Two-way valve

NOTES

1 The circuit between test valve **5** and loading valves **8a** and **8b** should be assembled from rigid piping and the fluid volume should be kept as small as possible.

2 The requirements for tapping point positions are given in clause 5.2.

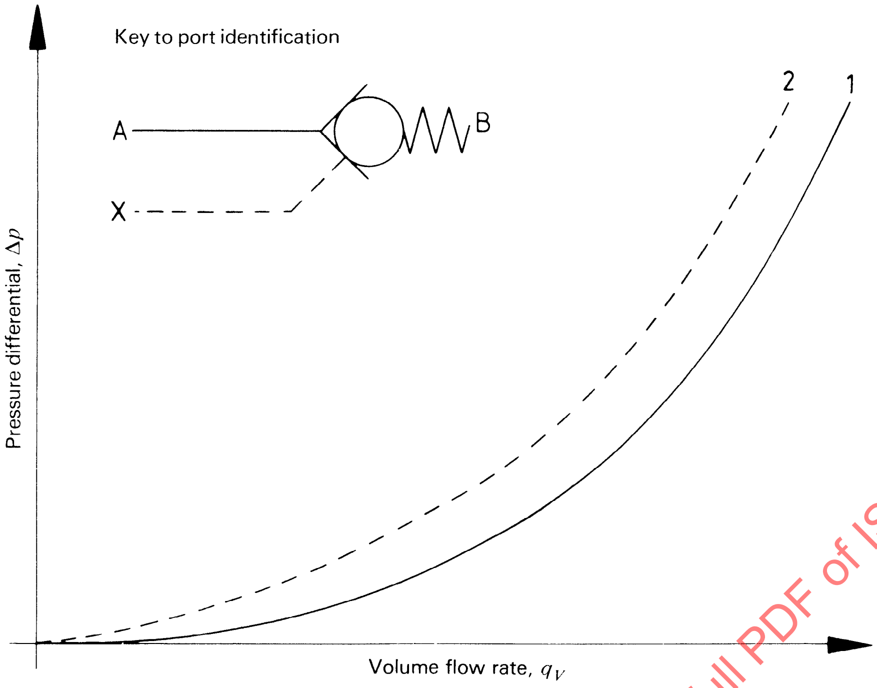
Figure 12 — Test circuit for flow control valves (bleed-off)



Key

1	Flow source
2	Pressure-relief valve
3	Temperature indicator
4a to **4e**	Pressure indicators
5	Valve being tested
6a, 6b	Two-way valves
7a to **7b**	Variable sharp-edge orifices
8a, 8b	Flowmeter

Figure 13 — Test circuit for flow-dividing valves



Curves

1 Port A to port B

2 Port B to port A

Both curves are drawn with valve fully open, i.e. when $p_{X,max}$ value is as shown in the graph in figure 15.

Figure 14 — Graphical representation of pressure/flow characteristics of pilot-pressure-operated non-return valves

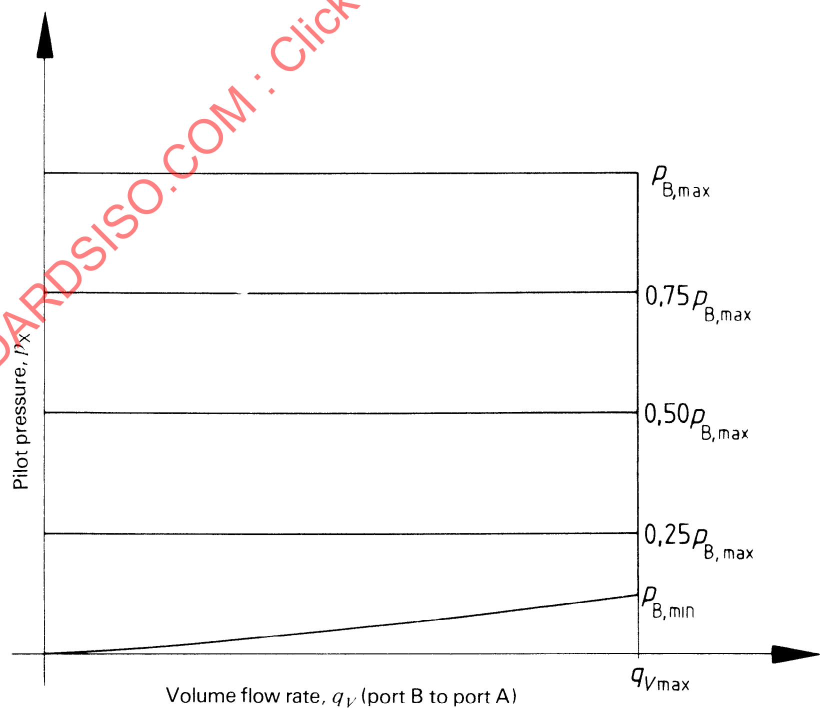


Figure 15 — Graphical representation of pilot pressure p_X permitting flow from port B to port A

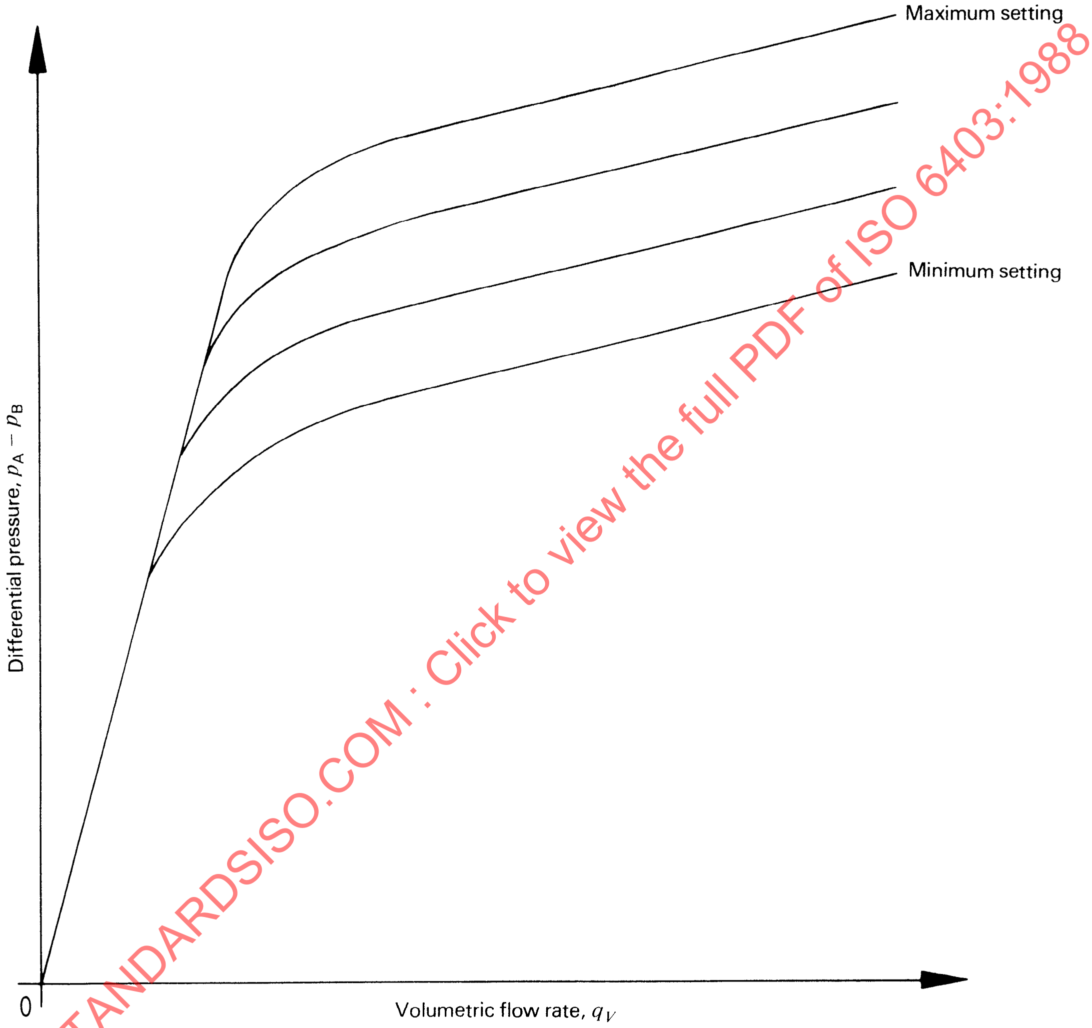


Figure 16 — Graphical representation of steady-state pressure/flow characteristics for pressure-relief valves