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ISO 10094-2

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Pneumatic fluid power — Electro-pneumatic pressure control valves —

Part 2:
Test methods to determine main characteristics to include in the supplier's literature

Transmissions pneumatiques — Appareils électropneumatiques de distribution à commande continue de pression —

Partie 2: Méthodes d'essai pour déterminer les principales caractéristiques à inclure dans la documentation des fournisseurs

Reference number
ISO 10094-2:2010(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 10094-2 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 5, *Control products and components*.

ISO 10094 consists of the following parts, under the general title *Pneumatic fluid power — Electro-pneumatic pressure control valves*:

- *Part 1: Main characteristics to include in the supplier's literature*
- *Part 2: Test methods to determine main characteristics to include in the supplier's literature*

Introduction

In pneumatic fluid power systems, power is transmitted and controlled through a gas under pressure within a circuit.

When pressure tracking or pressure regulation is required, electro-pneumatic continuous pressure control valves can be used to track a variable set point with low tracking error or to maintain the pressure of the gas at an approximately constant level.

These control valves continuously modulate the pneumatic power of a system in response to a continuous electrical input signal and link the electrical input value to a proportional pressure value.

It is therefore necessary to know some performance characteristics of these electro-pneumatic continuous pressure control valves in order to determine their suitability.

INTERNATIONAL STANDARD **ISO 10094-2:2010(E)**

Pneumatic fluid power — Electro-pneumatic pressure control valves —

Part 2:
Test methods to determine main characteristics to include in the supplier's literature

1 Scope

This part of ISO 10094 specifies the test procedures and a method of presenting the results concerning the parameters which define the main characteristics to be included in the supplier's literature of the electro-pneumatic continuous pressure control valves, conforming to ISO 10094-1.

The purpose of this part of ISO 10094 is

- to facilitate the comparison by standardizing the test methods and the presentation of the test results, and
- to assist in the proper application of these components in compressed air systems.

The specified tests are intended to allow comparison between the different types of continuous pressure control valves; these are not production tests to be carried out on each manufactured product.

NOTE 1 The tests related to non-electrically modulated pneumatic continuous pressure control valves are specified in ISO 6953-2.

NOTE 2 The tests related to electro-pneumatic continuous flow control valves are specified in ISO 10041-2.

NOTE 3 The tests described in this part of ISO 10094 are realised on components with an exhaust port vented to the atmosphere.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 6358-1[1], *Pneumatic fluid power — Determination of flow-rate characteristics of components — Part 1: General rules and test methods for steady-state flow*

ISO 6953-1, *Pneumatic fluid power — Compressed air pressure regulators and filter-regulators — Part 1: Main characteristics to be included in literature from suppliers and product-marking requirements*

ISO 10094-1:2010, *Pneumatic fluid power — Electro-pneumatic pressure control valves — Part 1: Main characteristics to include in the supplier's literature*

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[1] To be published.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598, ISO 6953-1 and ISO 10094-1 apply.

4 Symbols and units

For the purposes of this document, the symbols and units listed in Table 1 apply.

Table 1 — Symbols and units

Description	Symbol	SI unit
Maximum sonic conductance at the inlet	$C_{\text{f,max}}$	$m^3/(s \cdot Pa)$ (ANR)[b]
Sonic conductance at the exhaust	C_{r}	$m^3/(s \cdot Pa)$ (ANR)[b]
Atmospheric pressure	p_{atm}	Pa
Reference pressure[b]	p_0	Pa
Total relative pressure at the inlet port[a]	p_1	Pa
Total relative pressure at the outlet port[a]	p_2	Pa
Total relative pressure at the exhaust port[a]	p_3	Pa
Pressure difference	Δp	Pa
Hysteresis	H	%
Maximal difference of hysteresis	$\Delta p_{\text{2,h,max}}$	Pa
Linearity	L	%
Maximal difference of the linearity	$\Delta p_{\text{2,l,max}}$	Pa
Volume flow rate at standard reference atmosphere	q_V	m^3/s (ANR)[b]
Maximum volume flow rate at the inlet	$q_{V,\text{f,max}}$	m^3/s (ANR)[b]
Volume flow rate at the outlet	$q_{V,\text{r}}$	m^3/s (ANR)[b]
Repeatability	r	—
Reference temperature	T_0	K
Temperature at the inlet port[a]	T_1	K
Temperature at the outlet port[a]	T_2	K
Electrical control signal for which the regulated pressure increases again	w_{start}	V, mA or numerical signal
Electrical control signal for which the regulated pressure no longer evolves	w_{stop}	V, mA or numerical signal
Resolution	S	%

[a] In accordance with ISO 11727.

[b] The reference atmosphere is defined in ISO 8778, i.e.: T_0 = 293,15 K, p_0 = 100 kPa (1 bar) and a relative humidity of 65 %.

5 Test conditions

5.1 Gas supply

Unless otherwise specified, testing shall be conducted with compressed air. If another gas is used, it shall be noted in the test report.

5.2 Temperature

The ambient, fluid and the component-under-test temperatures shall be maintained at 23 °C ± 10 °C during all the tests.

5.3 Pressures

5.3.1 General

The specified pressures shall be maintained within ±2 %.

5.3.2 Inlet pressure

The inlet pressure used for testing shall be the lower of the following pressures:

- the maximum regulated pressure, $p_{2,\text{max}}$, plus 200 kPa (2 bar); and
- the specified maximum inlet pressure, $p_{1,\text{max}}$.

5.3.3 Test pressures

The preferential test pressures are chosen as approximately equal to 20 %, 40 %, 60 %, 80 % and 100 % of the maximum of the setting pressure scale.

5.3.4 Checking

It shall be periodically verified that no pressure bleed of measuring instruments is obstructed by solid or liquid particles.

5.4 Electrical supply

The tests shall be carried out under electrical nominal conditions.

6 Test procedures

6.1 Test conditions

The component under test shall be used according to the manufacturer's application instructions.

6.2 Inlet pressure

During every measurement concerning the static or dynamic tests described in Clauses 7 to 11, the inlet pressure, p_1, shall be maintained constant.

In the case of the dynamic tests as described in Clause 11, a tank buffer shall be used in order to reduce the inlet pressure, p_1, fluctuations, as indicated in Figures 9 and 10.

6.3 Static tests

During every measurement series concerning static tests described in Clauses 7, 8, 9 and 10, as soon as the steady conditions are reached, every series of results obtained with related specified test conditions shall be recorded. When these measurements are performed step by step, slowly modify the conditions to prevent instability.

NOTE 1 Figures 1, 6, 8, 9 and 10 represent typical circuits that do not show the electrical supply circuit necessary to operate electrically modulated pneumatic valves and that do not contain all the necessary safety devices for protection against hazards that may be caused by the failure of a component or piping. It is important that those responsible for conducting the tests take into account the necessity to protect personnel and property.

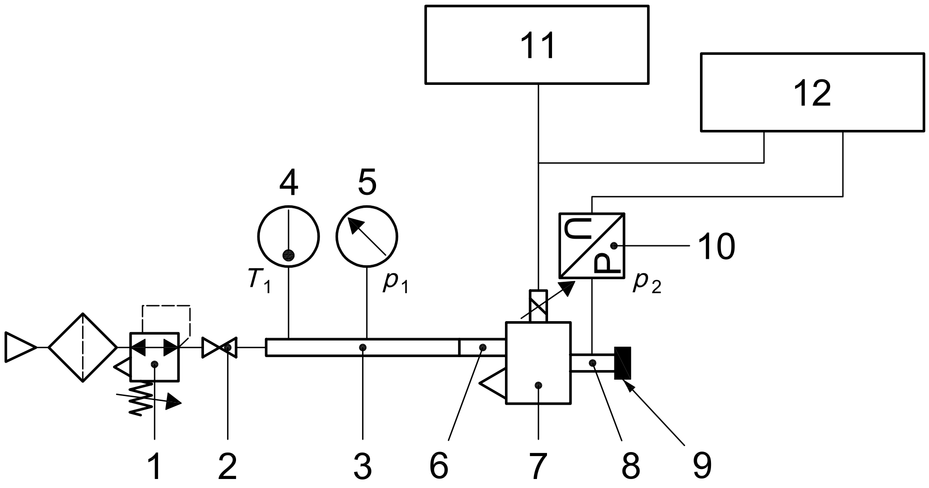
NOTE 2 The graphic symbols used in Figures 1, 6, 8, 9 and 10 are in accordance with ISO 1219-1.

7 Control signal/pressure static-characteristics test at null forward or relief flow rate

7.1 Test installation

7.1.1 Test circuit

Figure 1 represents a typical test circuit for the control signal/pressure characterization at null forward or relief flow rate. For all tests described in 7.2, apply the inlet pressure chosen according to 5.3.2.



Key

1	supply pressure regulator	7	component under test
2	shut-off valve	8	connector with pressure-measuring tap
3	pressure-measuring tube	9	plug
4	inlet temperature T_1 measuring-element	10	regulated pressure p_2 gauge or transducer
5	inlet pressure p_1 gauge or transducer	11	signal generator
6	upstream transition connector	12	X-Y recorder

Figure 1 — Typical test circuit for control signal/pressure characterization

7.1.2 Pressure measurement

The inlet pressure sensor is installed on a pressure-measuring tube in accordance with ISO 6358-1. The regulated pressure sensor is an external measurement sensor, even if the component under test has an internal pressure sensor. The connector 8 which measures the regulated pressure in Figure 1, is plugged to guarantee a null operating flow rate. The length (volume) of this connector shall be as short (small) as possible.

7.2 Test procedures

7.2.1 Control signal/pressure static characteristics test

Using a signal generator to create a triangular signal to explore the control signal full-scale (0 % to 100 %), record the electrical control signal, w, in the X-axis and the regulated pressure, p_2, in the Y-axis of a recorder so as to obtain a hysteresis curve.

The triangular electrical control signal shall evolve with a sufficiently low ramp speed so as to avoid dynamic effects and influence the regulated pressure measurements: 0,5 % of full scale per second is the recommended ramp speed.

7.2.2 Minimum regulated pressure test

Leave the component under test pressurized with the minimum control signal (0 %) at rest for at least 5 min.

From the minimal electrical control signal (0 %), measure the regulated pressure, p_2 for the following control signal values which allow to point out what is happening around this minimal signal:

- 0 %, 0,5 %, 1 % of the control signal full-scale;
- then every 1 % up to 5 % of the control signal full-scale.

Every measurement is made after a rest time of 10 s at each stage. The measurements shall always be made by increasing the control signal.

7.2.3 Resolution test

7.2.3.1 From the minimal electrical control signal (0 %), gradually modify the electrical control signal value by increasing values only, until reaching the value corresponding to 15 % of the regulated pressure full-scale.

7.2.3.2 Note this electrical control signal value w_{stop} and record the pressure evolution as a function of the electrical signal.

7.2.3.3 Maintain this state more than 10 s and gradually re-increase the input signal. Then note the electrical control signal, w_{start}, for which the regulated pressure, p_2, starts re-increasing.

7.2.3.4 Repeat the operations described in 7.2.3.2 and 7.2.3.3 for the electrical control signal values corresponding to 50 % and 85 % of the regulated pressure full-scale. Gradually modify the control signal, by increasing values only, until reaching these values.

7.2.4 Repeatability test

Using a signal generator to create a square signal between 0 % and 50 % of the electrical control signal full-scale, record the regulated pressure, p_2, as a function of time for at least 20 periods.

The frequency of the electrical control signal shall be sufficiently low so as to have a good stabilization of the regulated pressure at 0 % and 50 % of the electrical control signal full-scale.

At each period indicated by the index $j = 1, \dots , 20$, when the regulated pressure is stabilized for 50 % of the electrical control signal full-scale, note the corresponding regulated pressure, $p_{2\,j}$.

7.3 Calculation of characteristics

7.3.1 Characteristic curve

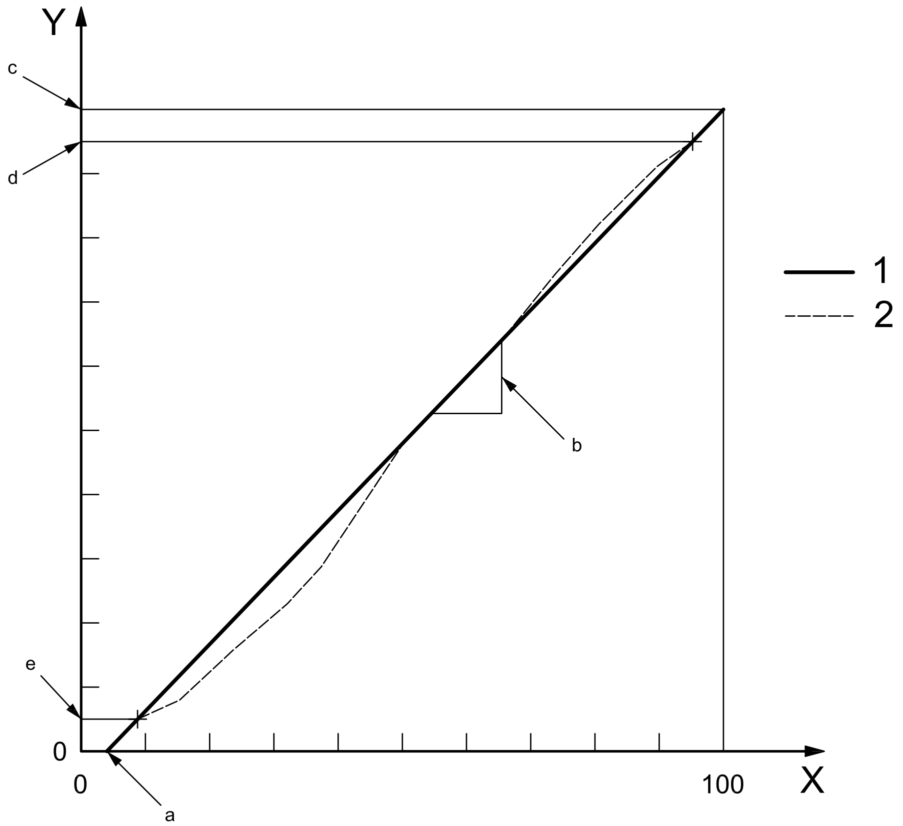
For each value of the control signal, calculate the mean value of the two corresponding pressures measured according to the procedure described in 7.2.1, respectively with an increasing and a decreasing control signal.

Plot the mean pressure curve as a function of the control signal as represented in Figure 2.

The characteristic line is the straight line passing by the mean regulated pressure values of 5 % and 95 % of the regulated pressure full-scale according to Figure 2.

The offset of the straight line shall be determined by the intersection of the straight line with the abscissa axis (regulated pressure, p_2, equal to 0 kPa) as shown in Figure 5.

The slope and the offset of the straight line shall be indicated on the graph, as represented in Figure 2.



Key

X electrical control signal, %

Y regulated pressure p_2, in kPa

1 characteristic line

2 mean pressure curve

[a] Offset.

[b] Slope.

[c] $p_{2,\text{ max.}}$

[d] 95 % of $p_{2,\text{ max.}}$

[e] 5 % of $p_{2,\text{ max.}}$

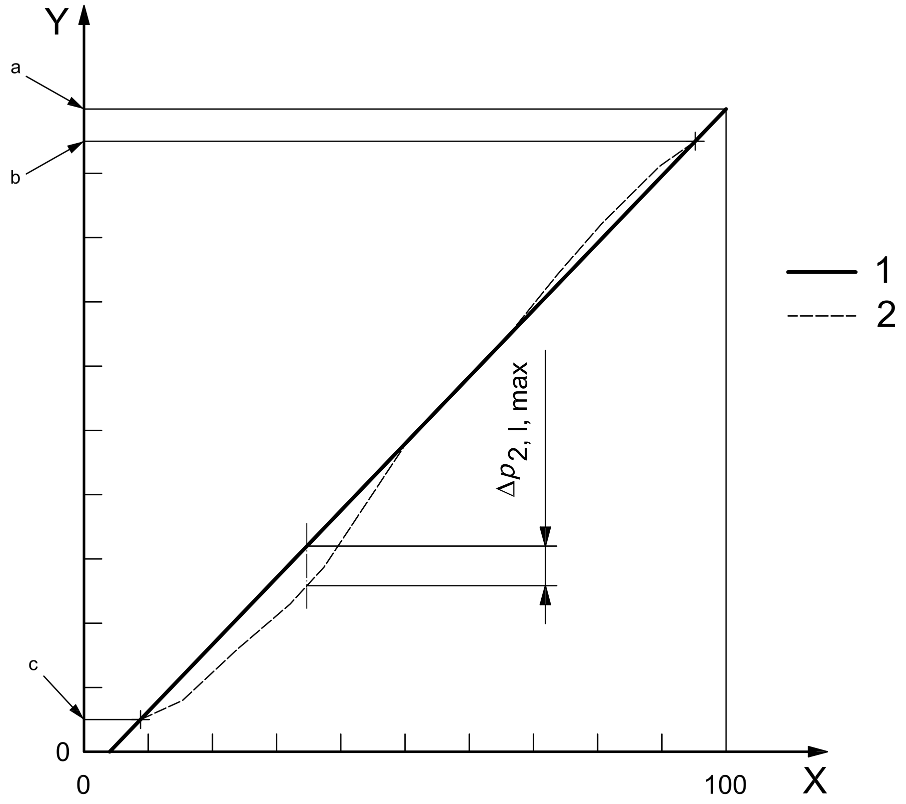
Figure 2 — Determination of the characteristic curve

7.3.2 Linearity

For each control signal value corresponding to regulated pressure value between 5 % and 95 % of the regulated pressure full-scale, calculate, in absolute value, the difference between the mean regulated pressure value calculated in 7.3.1 and the corresponding value on the characteristic straight line plotted in 7.3.1.

Determine the maximal difference, $\Delta p_{2,\mathrm{l,max}}$, according to Figure 3, and calculate the linearity value, Δp_{l}, expressed as a percentage of the regulated pressure full-scale using Equation (1):

$$\Delta p_{\mathrm{l}} = \frac{\left| \Delta p_{2,\mathrm{l,max}} \right|}{p_{2,\mathrm{max}}} \times 100 \tag{1}$$



Key

X electrical control signal, %

Y regulated pressure p_2, in kPa

1 characteristic line

2 mean pressure curve

[a] $p_{2,\ \mathrm{max.}}$

[b] 95 % of $p_{2,\ \mathrm{max.}}$

[c] 5 % of $p_{2,\ \mathrm{max.}}$

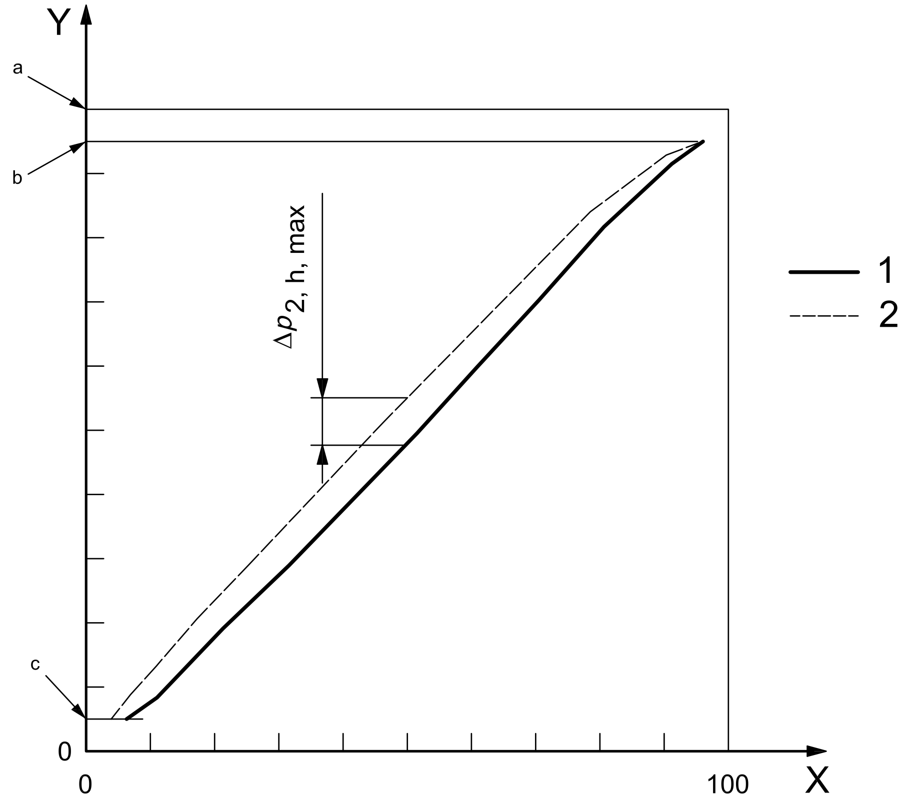
Figure 3 — Representation of the maximal scattering of linearity

7.3.3 Control signal/pressure hysteresis

For each control signal value corresponding to regulated pressure value between 5 % and 95 % of the regulated pressure full-scale, calculate in absolute value, the difference between the regulated pressure values p_2 measured respectively with an increasing and a decreasing control signal. These values are obtained according to the procedure described in 7.2.1.

Determine the maximal difference, $\Delta p_{2,\mathrm{h,max}}$, according to Figure 4. Calculate the hysteresis characteristic value, Δp_{h}, evaluating this difference in percentage of the regulated pressure full-scale according to equation:

$$\Delta p_{\mathrm{h}} = \frac{\left| \Delta p_{2,\mathrm{h,max}} \right|}{p_{2,\mathrm{max}}} \times 100 \qquad (2)$$



Key

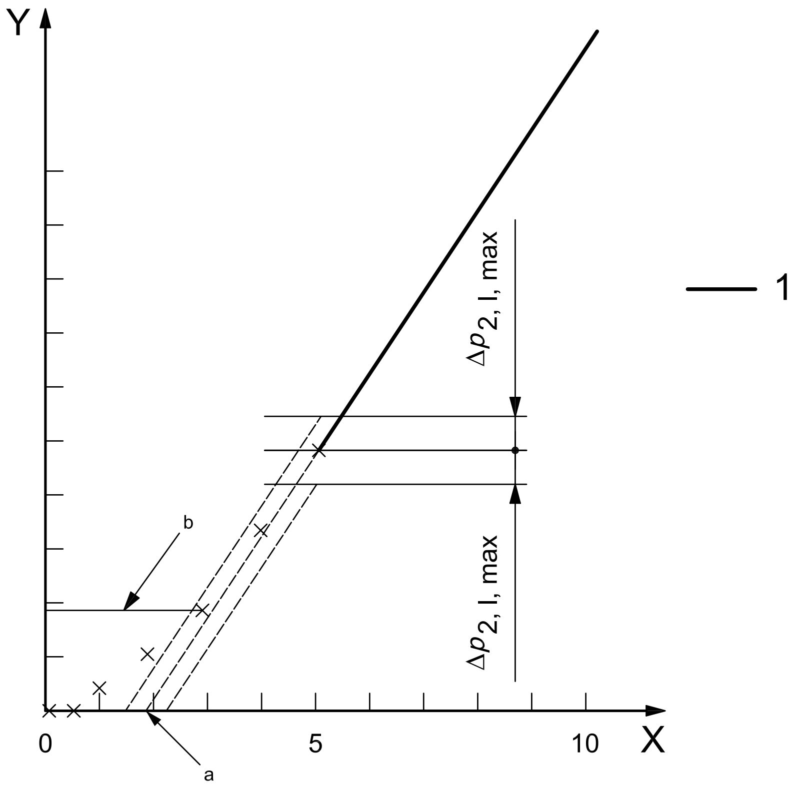
X	electrical control signal, %	1	characteristic line measured with increasing signal	a	$p_{2,\,\max}$.
Y	regulated pressure p_2, in kPa	2	characteristic line measured with decreasing signal	b	95 % of $p_{2,\,\max}$.
				c	5 % of $p_{2,\,\max}$.

Figure 4 — Representation of the maximal scattering of hysteresis difference

7.3.4 Minimum regulated pressure

With the data measured according to the procedure described in 7.2.2, determine the pressure at the first point which is within the allowable limits of linearity of the control signal/pressure characteristic curve, as shown in Figure 5.

This regulated pressure value, expressed as a percentage of the regulated pressure full-scale, corresponds to the minimum regulated pressure value.



Key

X	electrical control signal, %
Y	regulated pressure p_2, in kPa
1	characteristic line

[a] Offset.

[b] Minimum regulated pressure.

Figure 5 — Graphic determination of the minimum regulated pressure value and of the offset

7.3.5 Resolution

7.3.5.1 For each of the three tests done according to 7.2.3, for electrical control signal values corresponding to 15 %, 50 % and 85 % of the regulated pressure full-scale, calculate the corresponding resolution, expressed as a percentage of the control signal full-scale, using Equation (3):

$$S = \frac{w_{\mathrm{start}} - w_{\mathrm{stop}}}{w_{\mathrm{max}} - w_{\mathrm{min}}} \times 100 \qquad (3)$$

7.3.5.2 Calculate the resolution by taking the maximal value of the three values obtained in 7.3.5.1.

7.3.6 Repeatability

Using the stabilized regulated pressures values, $P_{2,\mathrm{j}}$, obtained according to the procedure described in 7.2.4, calculate the repeatability value, r, expressed as a percentage of the regulated pressure full-scale, using Equation (4):

$$r = \frac{p_{2,j,\mathrm{max}} - p_{2,j,\mathrm{min}}}{p_{2,\mathrm{max}}} \times 100 \qquad (4)$$

8 Flow/pressure static characteristics test

8.1 Test circuit for flow rate measurement

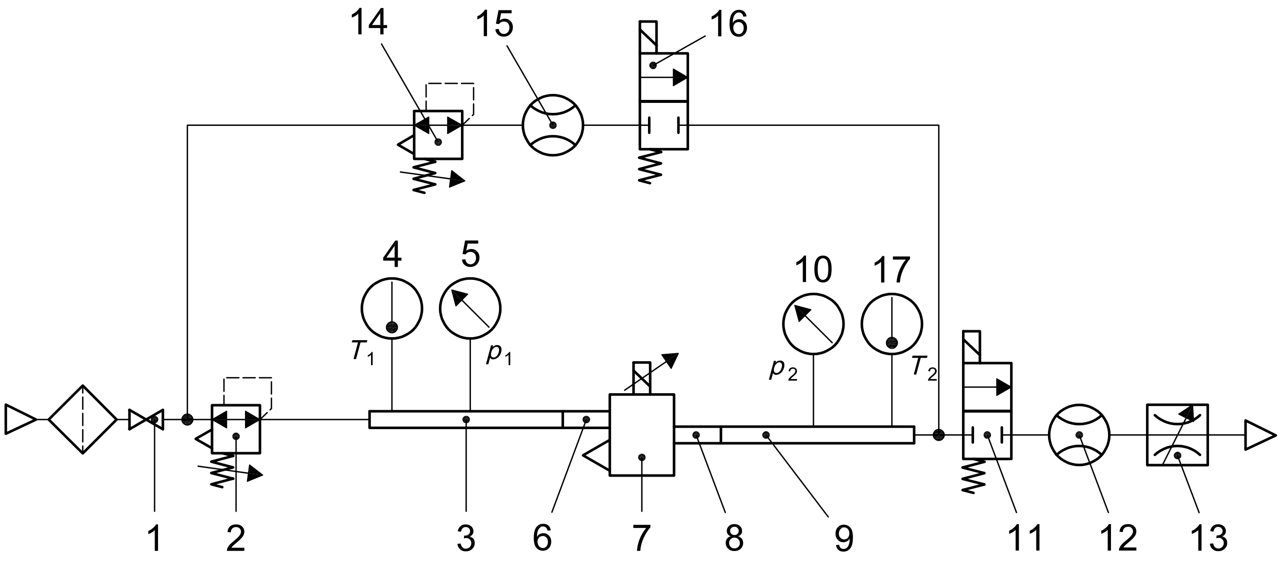
A suitable test circuit, as shown in Figure 6, shall be used for measuring forward or relief flow rates. This test circuit combines

a) the in-line test circuit, as described in ISO 6358-1 for characterizing, in steady state conditions, the components with upstream and downstream pressure-measuring connectors (used for forward flow rate measurements), and

b) the exhaust-to-atmosphere test circuit, as described in ISO 6358-1 for characterizing, in steady state conditions, the components exhausting directly to atmosphere (used for relief flow rate measurements).

This test circuit shall be used for

- the flow-pressure static characteristics measurements, and
- the pressure regulation characteristics measurements.



Key

1	inlet shut-off valve
2	inlet pressure regulator
3, 9	pressure-measuring tubes
4	inlet temperature, T_1, measuring-element
5	inlet pressure, p_1, gauge or transducer
6, 8	transition connectors
7	component under test
10	regulated pressure, p_2, gauge or transducer
11, 16	solenoid valves
12	forward flow meter
13	flow control valve (for forward flow rates)
14	pressure regulator (for relief flow rates)
15	relief flow meter
17	temperature, T_2, measuring-element (for relief flow rates)

NOTE If the component under test already operates with an external sensor, place it at the same place as the regulated pressure sensor.

Figure 6 — Test circuit for flow rate/pressure characterization and pressure regulation

8.2 General requirements

8.2.1 The component under test shall be located in the test circuit so as to connect its inlet port to the upstream transition connector and pressure-measuring tube, and its exhaust port to the atmosphere. Its outlet port is connected to a transition connector and a pressure-measuring tube enabling to measure the regulated pressure, p_2.

8.2.2 Pressure-measuring tubes and transition connectors shall be in accordance with ISO 6358-1.

8.2.3 Components 1 to 6 in Figure 6 correspond to the upstream part of the test circuit used for forward flow rates measurements. These components shall be also used for relief flow rate measurements as the inlet port of the component under test shall be connected to the supply circuit, following the normal use of the component.

8.2.4 Components 8 to 13 in Figure 6 correspond to the downstream part of the test circuit used for forward flow rates measurements.

8.2.5 The sonic conductances of the pressure regulator and of the solenoid valve 11 should be at least twice the forward sonic conductance of the component under test.

8.2.6 Components 8, 9, 10, 14, 15, 16 et 17 in Figure 6 correspond to the upstream part of the test circuit used for relief flow rate measurements.

8.2.7 The sonic conductances of the pressure regulator and of the solenoid valve 16 should be at least twice the relief sonic conductance of the component under test.

8.2.8 The flow-meters shall always be located at the outlet port in order to measure the actual forward or relief flow rate.

8.3 Test procedures

8.3.1 Initial test procedure

8.3.1.1 Install the electro-pneumatic continuous pressure control valve according to Figure 6, without flow, with shut-off valve, solenoid valves and flow control valve closed.

8.3.1.2 Open shut-off valve 1 and set the pressure regulator 2 to apply the inlet pressure, p_1, chosen according to 5.3.1.

8.3.1.3 From the minimal electrical control signal (0 %), gradually modify the control signal by increasing values only, until reaching the regulated pressure value, p_2, corresponding to 20 % of the regulated pressure full-scale.

8.3.1.4 Follow successively the procedure described in 8.3.2 for forward flow rates and then the procedure described in 8.3.3 for relief flow rates.

8.3.2 Forward flow rate/pressure characteristics test

8.3.2.1 Open the solenoid valve. By using the flow rate control valve, let the air pass through the component under test.

8.3.2.2 When the flow is steady, measure the forward flow rate using the flow meter 12, the corresponding regulated pressure, p_2, using the pressure transducer, and the inlet temperature, T_1.

8.3.2.3 Continue the measurements by gradually modifying the flow value, by increasing values only until reaching the maximal flow rate in the test circuit. Measure the additional data for a decreasing forward flow rate until zero. During the variations of the forward flow (increasing and decreasing), keep the inlet pressure, p_1, constant.

8.3.3 Relief flow rate/pressure characteristics test

8.3.3.1 Set the pressure regulator 14 at the same pressure value as the regulated pressure value of the component under test obtained without flow at the end of the procedure described in 8.3.2.3. Close the solenoid valve 11 and open the solenoid valve 16 to apply this pressure on the outlet side of the component under test.

8.3.3.2 Increase the regulated pressure using the pressure regulator 14. When the flow is steady, measure the relief flow using the flow meter, the corresponding regulated pressure, p_2, using the pressure transducer and the temperature, T_2, since the air passes through the exhaust port of the component under test.

8.3.3.3 Continue the measurements by gradually increasing the flow rate by increasing the pressure using the pressure regulator until the pressure reaches a level of the maximum regulated pressure plus 200 kPa (2 bar). Measure the additional data for decreasing pressure until the flow rate reaches zero. During the variations of the relief flow (increasing and decreasing), keep the inlet pressure, p_1, constant. Close the solenoid valve 16.

8.3.4 Procedure for other control signal values

Repeat the above procedures described in 8.3.1.4 for control signal values corresponding to about 40 %, 60 %, 80 % and 100 % of the regulated pressure full-scale. Without flow, gradually modify the control signal, by increasing values only, until reaching these values.

8.4 Calculation of characteristics

8.4.1 Characteristic curves

8.4.1.1 For the regulated pressure equal to 20 % of the regulated pressure full-scale, for each forward flow rate value, calculate the mean value of the two corresponding regulated pressures, p_2, measured according to the procedure described in 8.3.2, respectively with increasing and decreasing forward flow rates.

Plot in a graph the mean regulated pressure values, function of the forward flow rate, as represented in the first quadrant of Figure 7.

8.4.1.2 For the electrical control signal equal to 20 % of the control signal full-scale, for each relief flow rate value, calculate the mean value of the two corresponding regulated pressures, p_2, measured according to the procedure described in 8.3.3, respectively with increasing and decreasing relief flow rates.

Plot in a graph the mean regulated pressure values, a function of the relief flow rate as represented in the second quadrant of Figure 7.

8.4.1.3 Repeat the procedure of calculation and layout for the four other regulated pressure values: 40 %, 60 %, 80 % and 100 % of the full scale.

8.4.2 Flow rate/pressure hysteresis

For each forward flow rate or relief flow rate value, calculate the difference between the regulated pressure values measured, respectively with increasing and decreasing flow rates. These values are measured according to the procedures described in 8.3.2 and 8.3.3.

Determine the maximal difference, $\Delta p_{2,\mathrm{h,max}}$, and, using Equation (2), calculate the hysteresis characteristic value, expressed as a percentage of the regulated pressure full-scale.

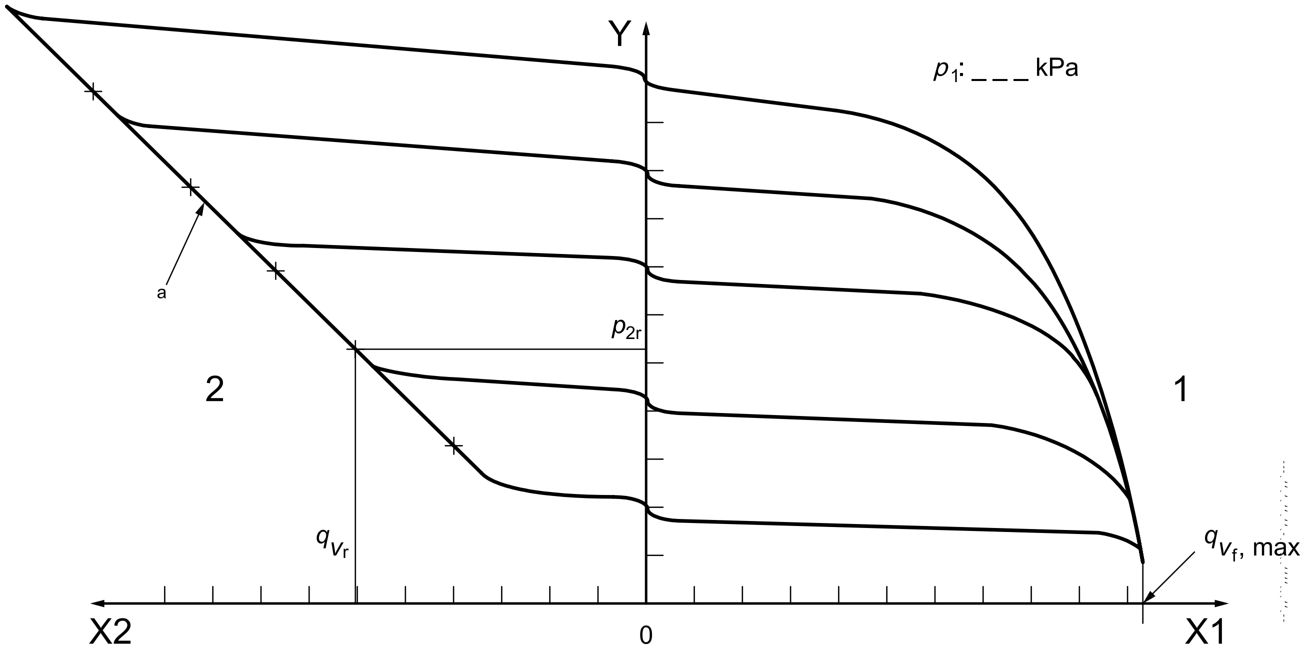
8.4.3 Maximum forward sonic conductance

8.4.3.1 Graphically determine the maximum forward flow rate, $q_{V,\text{f,max}}$, as the intersection of an extension line of forward flow rate-pressure characteristic curves obtained in 8.4.1.1 with the abscissa axis (regulated pressure is null in relative value), according to Figure 7.

8.4.3.2 Calculate the value of the maximal forward volumic sonic conductance, $C_\text{f,max}$, by dividing this flow rate value by the inlet pressure in accordance with ISO 6358-1, using Equation (5):

$$C_\text{f,max} = \frac{q_{V,\text{f,max}}}{p_1 + p_\text{atm}} \sqrt{\frac{T_1}{T_0}} \tag{5}$$

NOTE The square root is necessary to take into account the test upstream temperature T_1 deviation from the reference temperature, T_0, in accordance with ISO 8778.



Key

X1	forward flow rate, in dm^3/s (ANR)	1	1st quadrant
X2	relief flow rate, in dm^3/s (ANR)	2	2nd quadrant
Y	regulated pressure, p_2, in kPa	p_1	inlet pressure, in kPa
		a	Asymptote.

Figure 7 — Graphic determination of the necessary values for calculation of the sonic conductances

8.4.4 Maximum relief sonic conductance

8.4.4.1 Choose graphically 5 points all over the asymptote of the relief flow rate/pressure curves obtained in 8.4.1.2 according to Figure 7. Each one of them is defined by a relief flow rate value, $q_{V,\text{r}}$, and a regulated pressure value, $p_{2\text{r}}$.

8.4.4.2 For each one of these points, calculate the corresponding volumic sonic conductance value, C_r, by dividing the flow rate value by the regulated pressure in accordance with ISO 6358-1 (upstream pressure in this case), using Equation (6):

$$C_\mathrm{r} = \frac{q_{V,\mathrm{r}}}{p_2 + p_\mathrm{atm}} \sqrt{\frac{T_2}{T_0}} \tag{6}$$

NOTE The squared root is necessary to take into account the test upstream temperature, T_2, deviation from the reference temperature, T_0, in accordance with ISO 8778.

8.4.4.3 Calculate the maximal relief sonic conductance by determining the average value of these five values.

9 Pressure regulation characteristics test

9.1 Test circuit

The same test circuit as shown in Figure 6 shall be used for the pressure regulation test. Only the part of the circuit for measuring forward flow rate shall be used.

The general requirements 8.2.1 to 8.2.5 and 8.2.8 concerning the measurement of forward flow rates shall be respected.

9.2 Test procedure

9.2.1 Install the electro-pneumatic continuous pressure control valve according to Figure 6, without flow, with shut-off valve, solenoid valves, and flow control valve closed.

9.2.2 Open shut-off valve 1 and set the pressure regulator 2 to apply an inlet pressure, p_1, such as it will be very much higher than the setting range of the component under test and shall be reasonably tested, without exceeding the inlet capacity of the component under test.

9.2.3 From the minimal electrical control signal (0 %) gradually modify the control signal by increasing values only, until reaching the value corresponding to 20 % of the regulated pressure full-scale.

9.2.4 Open the solenoid valve 11. By using the flow rate control valve, set the forward flow rate to 10 % of the maximal flow rate, $q_{V,\mathrm{f,max}}$, determined in 8.4.3.1. Set the inlet pressure, p_1, once again to reach the initial value determined in 9.2.2.

9.2.5 Reduce the inlet pressure, p_1, and measure the corresponding regulated pressure, p_2, using the pressure transducer 10 while maintaining the flow rate constant, up to the lowest inlet pressure allowing the chosen flow rate to be maintained.

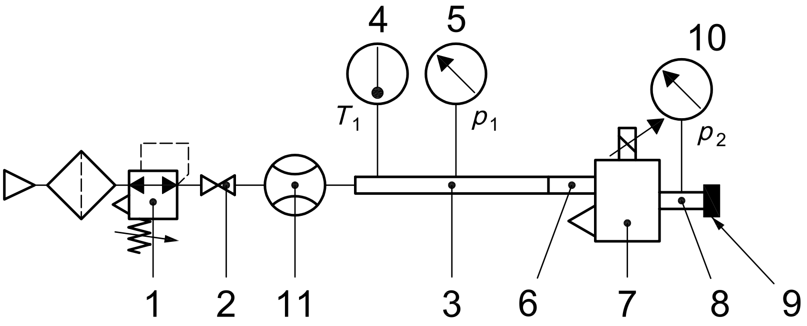
9.2.6 Repeat the procedures 9.2.1 to 9.2.5 for control signal values corresponding to about 40 %, 60 %, 80 % and 100 % of the regulated pressure full-scale. Without flow, increase gradually the control signal until reaching these values.

10 Leakage at null forward flow rate or relief flow rate characteristic test

10.1 Test circuit

Figure 8 represents a typical test circuit for characterizing the leakage at null forward flow rate or relief flow rate. This figure uses the upstream part of the test circuit for the in-line test, as described in ISO 6358-1, for characterizing in steady state conditions the components with upstream and downstream pressure-measuring tubes, adding the following indications:

- the connector at the outlet port is plugged to guarantee a null forward flow rate or relief flow rate; the length (volume) of this connector with the pressure-measuring tap shall be as short (small) as possible;
- the flow meter is placed upstream on the supply line.



Key

1	supply pressure regulator
2	shut-off valve
3	pressure-measuring tube
4	inlet temperature, T_1, measuring-element
5	inlet pressure, p_1, gauge or transducer
6	upstream transition connector
7	component under test
8	connector with pressure-measuring tap
9	plug
10	regulated pressure, p_2, gauge or transducer
11	leakage flow meter

Figure 8 — Typical test circuit for leakage characterization

10.2 Test procedure

Apply the inlet pressure, p_1, chosen according to 5.3.1.

From the minimum to the maximum of the electrical control signal, measure the leakage flow. Make additional measurements when the leakage variations are important.

The measurement shall always be made by increasing the control signal until its maximum value, then decreasing its value to obtain a hysteresis curve.

10.3 Calculation of characteristic

For each value of the control signal, calculate the mean value of the two corresponding leakage flow rates according to the procedure described in 10.2, respectively with an increasing and a decreasing control signal.

Determine the inlet leakage flow rate maximum value.

11 Dynamic characteristics

11.1 Step responses

11.1.1 Test installations

11.1.1.1 Figures 9 and 10 represent typical test circuits for the dynamic characterization of electro-pneumatic continuous pressure control valve respectively with a tank and with no tank.

11.1.1.2 The port of every test tank at which the component under test is connected shall have a diameter at least equal to the one of the outlet port of the component under test.

11.1.1.3 Maintain as short as possible the length of the piping between the outlet port of the component under test and the tank.

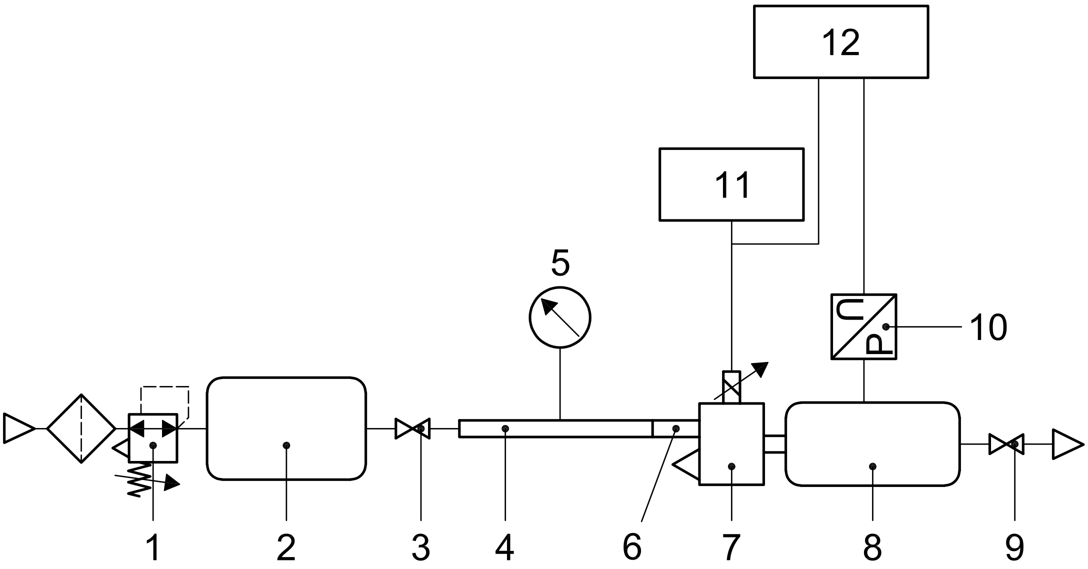
11.1.1.4 The buffer tank 2 used to limit inlet pressure fluctuations shall be as close as possible to the inlet port of the component under test.

11.1.1.5 The pressure sensor 10 is an external sensor installed on one of the ports of the test tank situated perpendicularly to the inlet port of the tank as shown in Figure 9.

When there is no tank, as shown in Figure 10, the external pressure sensor is mounted on a plugged connector with a pressure-measuring tap. The length (volume) of this connector shall be as short (small) as possible.

NOTE If the component under test already operates with an external sensor, place it at the same place as the measurement sensor.

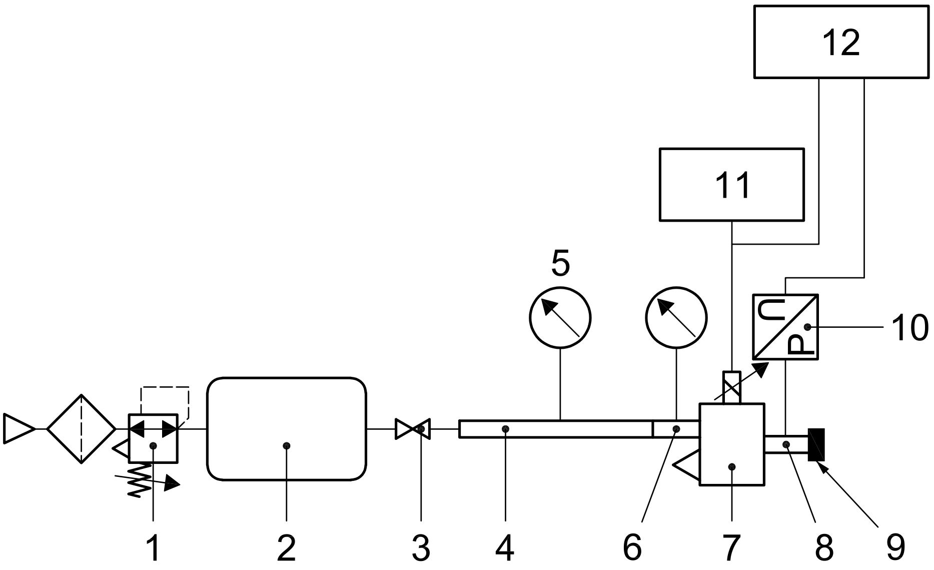
11.1.1.6 Use an oscilloscope or other appropriate electronic equipment in order to record the time dependent electrical control and pressure signals.



Key

1	supply pressure regulator
2	buffer tank
3, 9	shut-off valves
4	pressure-measuring tube
5	inlet pressure, p_1, gauge or transducer
6	upstream transition connector
7	component under test
8	test tank
10	pressure gauge or transducer
11	signal generator
12	recorder

Figure 9 — Test circuit for dynamic characterization with a tank



Key

1	supply pressure regulator
2	buffer tank
3	shut-off valve
4	pressure-measuring tube
5	inlet pressure, p_1, gauge or transducer
6	upstream transition connector
7	component under test
8	connector with pressure-measuring tap
9	plug
10	pressure gauge or transducer
11	signal generator
12	recorder

Figure 10 — Test circuit for dynamic characterization with no tank

11.1.2 Test procedures

11.1.2.1 According to the port size of the pressure control valve under test, choose a tank whose volume corresponds to one of those in Table 2.

11.1.2.2 Install the electro-pneumatic continuous pressure control valve according to Figure 9, without flow. Apply the inlet pressure, p_1, chosen according to 5.3.1.

11.1.2.3 From the minimal electrical control signal (0 %) generate a control signal step with amplitude of 100 % of its full scale. Simultaneously record the evolution of the control signal and the evolution of the measured pressure at tank level throughout the tank charge until the pressure becomes steady in the tank.

11.1.2.4 From the maximal electrical control signal (100 %) generate a control signal step up to 0 % of its full scale. Simultaneously record the evolution of the control signal and the evolution of the measured pressure at tank level throughout the tank discharge until the pressure becomes steady in the tank.

11.1.2.5 Repeat test procedures 11.1.2.3 and 11.1.2.4 for the following control signal steps:

- 25 % to 75 %;
- 45 % to 55 %.

11.1.2.6 Repeat test procedures 11.1.2.2 to 11.1.2.5 for the two other test tank volume values of Table 2.

11.1.2.7 With no tank, install the electro-pneumatic continuous pressure control valve according to Figure 10, without flow. Apply the inlet pressure, p_1, chosen according to 5.3.1. Repeat test procedures 11.1.2.3 to 11.1.2.5.

Table 2 — Volume values of the test tanks depending on the control valve port size

Port size	Test tank Volume dm^3			
G1/8	0	0,02	0,1	0,5
G1/4 G3/8	0	0,1	0,5	2
G1/2 G3/4	0	0,5	2	10
⩾ G1	0	2	10	20

11.1.3 Calculation of characteristics

11.1.3.1 Charge characteristic curves

For each of the three control steps, with the same time scale for the three volume values and for no tank, plot in the same graph the time responses of the pressure evolution in the tank during the charge of the four volumes, as shown in ISO 10094-1:2010, Figure 5.

Use, as a reference for the time scale, the time of the initiation of the control signal steps.

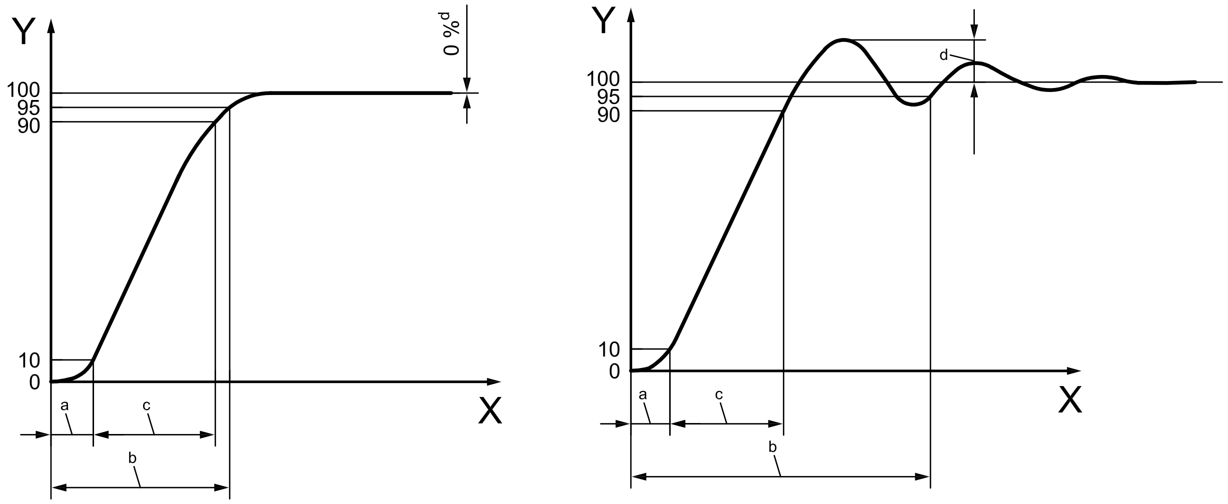
11.1.3.2 Discharge characteristic curves

For each of the three control steps, with the same time scale for the three volume values and for no tank, plot in the same graph the time responses of the pressure evolution in the tank during the discharge of the four volumes as shown in ISO 10094-1:2010, Figure 6.

Use, as a reference for the time scale, the time of the initiation of the control signal steps.

11.1.3.3 Charge characteristics

From the charge characteristics curves obtained in 11.1.3.1, determine for each control step and for each of the four volumes, the shifting time, the response time, the settling time and the overshoot, as defined in Figure 11 for two cases of pressure response.



a) **Pressure response without oscillations** b) **Pressure response with oscillations**

Key

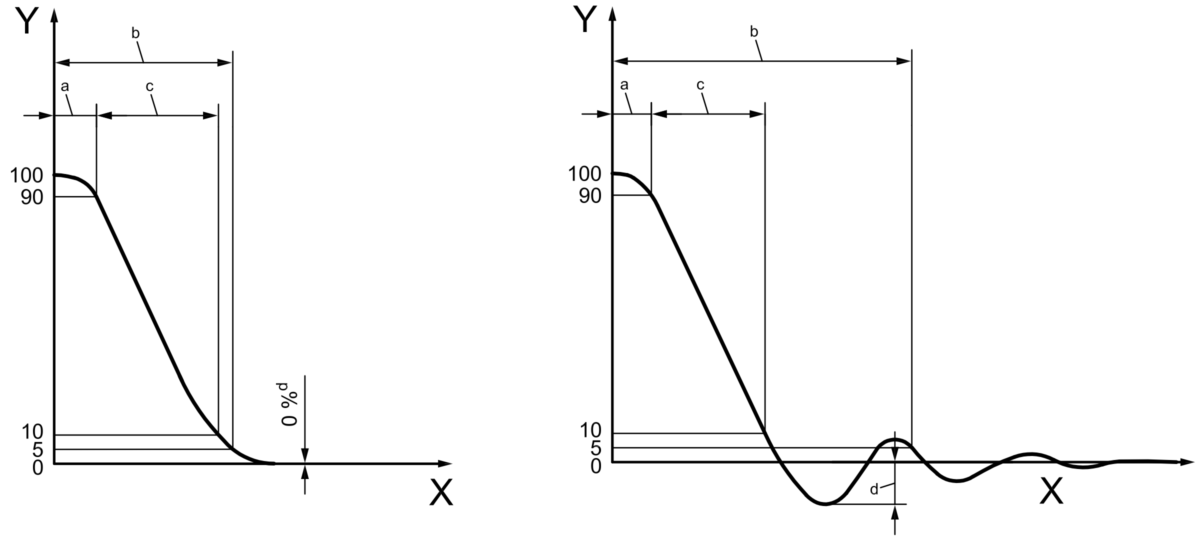
X	time, in s	a	Shifting time.
Y	tank pressure, %	b	Response time.
		c	Settling time.
		d	Overshoot, %.

Figure 11 — Determination of charge characteristics from pressure response

Report these values corresponding to charge tests as shown in ISO 10094-1:2010, Table 2.

11.1.3.4 Discharge characteristics

From the discharge characteristics curves obtained in 11.1.3.2, determine for each control step and for each of the four volumes, the shifting time, the response time, the settling time and the undershoot for intermediary steps as defined in Figure 12 for two cases of pressure response.



a Pressure response without oscillations

b Pressure response with oscillations

Key

X time, in s

Y tank pressure, %

[a] Shifting time.

[b] Settling time.

[c] Response time.

[d] Undershoot.

Figure 12 — Determination of discharge characteristics

Report these values corresponding to discharge tests as shown in ISO 10094-1:2010, Table 2.

11.2 Frequency responses

11.2.1 Test installation

The test circuits for frequency characterization are the same as for step responses. They are shown in Figures 9 and 10, respectively with a tank and with no tank. They are built according to the recommendations of 11.1.1.

The test tank volumes are chosen from Table 2.

11.2.2 Test procedure

11.2.2.1 According to the port size of the pressure control valve under test, choose a tank whose volume corresponds to one of those of Table 2.

11.2.2.2 Install the electro-pneumatic continuous pressure control valve according to Figure 9, without flow. Apply the inlet pressure, p_1, chosen according to 5.3.1.

11.2.2.3 Generate a sinusoidal control signal around 50 % of the maximum regulated pressure with an amplitude of 10 % of its full scale (thus varying from 45 % to 55 %), with a low frequency of 0,1 Hz. Simultaneously record the evolution of the control signal and the evolution of the measured pressure at tank level. If necessary, adjust the value of the control signal central value in order to obtain pressure oscillations between two constant values. If 0,1 Hz is too high, the initial value of frequency may be reduced to a lower value.

11.2.2.4 Determine the amplitude characteristic in decibels and the phase lag characteristic in degrees of the pressure signal at tank level compared to the setpoint signal given by the control signal. Annex A illustrates way to read these data and describes the calculation method because response curves can sometimes be to fairly non-linear.

11.2.2.5 Progressively increase the frequency of the control signal, while maintaining its amplitude constant.

11.2.2.6 For each frequency, record the amplitude characteristic of the tank pressure and its phase lag versus the control signal. Record especially for the frequencies corresponding respectively to

- an attenuation of 3 dB (amplitude ratio equal to 0,7), and
- a phase lag of 90°.

11.2.2.7 Repeat test procedures 11.2.2.5 and 11.2.2.6 for about 15 different frequencies until an attenuation of 15 dB is reached (amplitude ratio equal to 0,18).

11.2.2.8 Repeat procedures 12.2.2.4 to 11.2.2.7 for sinusoidal control signals around 50 % of the maximum regulated pressure with amplitudes of 50 % (25 % to 75 %) and 90 % (5 % to 95 %) from a low frequency of 0,1 Hz. If necessary adjust the value of the control signal central value in order to obtain pressure oscillations between two constant values.

11.2.2.9 Repeat procedures 11.2.2.2 to 11.2.2.8 for the two other test tank volume values of Table 2.

11.2.2.10 With no tank, install the electro-pneumatic continuous pressure control valve according to Figure 10, without flow. Apply the inlet pressure, p_1, chosen according to 5.3.1. Repeat test procedures 11.2.2.3 to 11.2.2.8.

11.2.3 Frequency response characteristic curves

11.2.3.1 For each volume and each control signal amplitude, draw a Bode diagram based on the results (amplitude characteristic in decibels and the phase lag characteristic in degrees) obtained according to the procedure described in 11.2.2. The amplitude characteristic and the phase lag values are plotted in a graph, function of the frequency based on a logarithmic scale as shown in ISO 10094-1:2010, Figure 7.

11.2.3.2 For a given volume, report these curves for different amplitudes in the same graph, as shown in ISO 10094-1:2010, Figure 7.

11.2.3.3 Build as many graphs as volume values.

11.2.4 Characteristic frequencies

For each volume and each control signal amplitude, report the frequency values, determined on the characteristic curves obtained in 11.2.3 corresponding respectively to an attenuation of 3 dB and a 90° phase lag, as shown in ISO 10094-1:2010, Table 3.

12 Presentation of test results

12.1 General

Data from which the performances of the electro-pneumatic continuous pressure control valve can be compared shall be presented as follows.

12.2 Control signal/pressure static characteristics

The static control-pressure characteristics, determined according to 7.3, shall be presented as follows:

- a data graph in accordance with ISO 10094-1:2010, Figure 1;
- the value of the linearity obtained according to Equation (1);
- the hysteresis value obtained according to Equation (2);
- the minimum regulated pressure value obtained according to 7.3.4;
- the resolution value obtained according to 7.3.5;
- the repeatability value obtained according to Equation (4).

12.3 Flow rate/pressure characteristics

The static flow rate/pressure characteristics, determined according to 8.3, shall be presented as follows:

- a data graph in accordance with ISO 10094-1:2010, Figure 3;
- the hysteresis value obtained according to 8.4.2;
- the value of the maximum forward sonic conductance according to Equation (5);
- the value of the maximum relief sonic conductance according to 8.4.4.

12.4 Pressure regulation characteristics

The static pressure regulation characteristics, determined according to 9, shall be presented as follows:

- a data graph in accordance with ISO 10094-1:2010, Figure 4.

12.5 Leakage characteristic

The static characteristic of the leakage at null forward flow rate or relief flow rate, determined according to Clause 10, shall be presented as follows:

- the maximal value of the leakage, according to 10.3.

12.6 Dynamic characteristics

The dynamic characteristics, determined according to Clause 11, shall be presented as follows:

- a graph of time dependent curves of the evolution of the pressure in the volume during the charge of the tanks, in accordance with ISO 10094-1:2010, Figure 5;
- a graph of time dependent curves of the evolution of the pressure in the volume during the discharge of the tanks, in accordance with ISO 10094-1:2010, Figure 6;
- a table of charge and discharge characteristic values, in accordance with ISO 10094-1:2010, Table 2;
- a graph of frequency responses curves in accordance with ISO 10094-1:2010, Figure 7;
- a table indicating the characteristic frequencies for different amplitudes in accordance with ISO 10094-1:2010, Table 3.

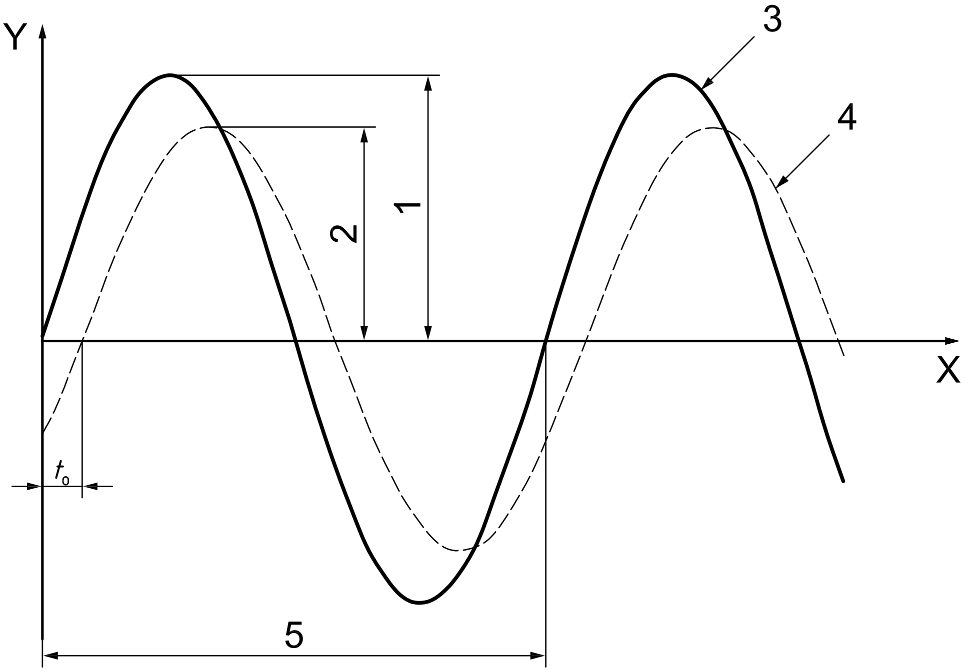
Annex A
(informative)

Calculation procedures of gain and phase lag

A.1 Ideal case

A.1.1 General

Consider that the valve is controlled with a sinusoidal control signal that corresponds to a sinusoidal pressure setpoint signal, p_s. Then the output pressure (tank pressure p_t) is also changed by means of a harmonic function that demonstrates the same frequency as setpoint signal, but has a different amplitude and phase position. Figure A.1 shows the time evolutions of both signals for a given frequency, in the ideal case where the behaviour of the valve is linear.



Key

X time, in s

Y tank pressure/setpoint, Pa

1 setpoint amplitude, A_S

2 tank pressure amplitude A_{pt}

3 setpoint signal, p_s

4 tank pressure, p_t

5 setpoint period, T_s

Figure A.1 — Tank pressure and setpoint signal evolutions versus time for a given frequency $f_s = \dfrac{1}{T_s}$

The frequency response is composed of the amplitude characteristic and the phase characteristic relative to setpoint frequency, f_s.

A.1.2 Amplitude characteristic, A_{dB}

The amplitude characteristic, A_{dB}, is the result of the ratio of tank-pressure amplitude, $A_{p\mathrm{t}}$, to setpoint amplitude, A_{s}, and is specified in decibels according to Equation (A.1):

$$A_{\mathrm{dB}} = 20\log_{10}\left(\frac{A_{p\mathrm{t}}}{A_{\mathrm{s}}}\right) \tag{A.1}$$

A.1.3 Phase characteristic, φ

The phase characteristic, φ, is determined from the time offset, $t\varphi$, between the setpoint signal, p_{s}, and the output pressure signal, p_{t}, and is determined as shown in Figure A.1 at zero crossing. The phase characteristic is a negative quantity because the output pressure signal lags behind the setpoint signal, and is specified in degrees by Equation (A.2).

$$\varphi = -360 t_{\varphi} f_{\mathrm{s}} \tag{A.2}$$

with frequency f_{s} expressed by by Equation (A.3) from the setpoint signal period:

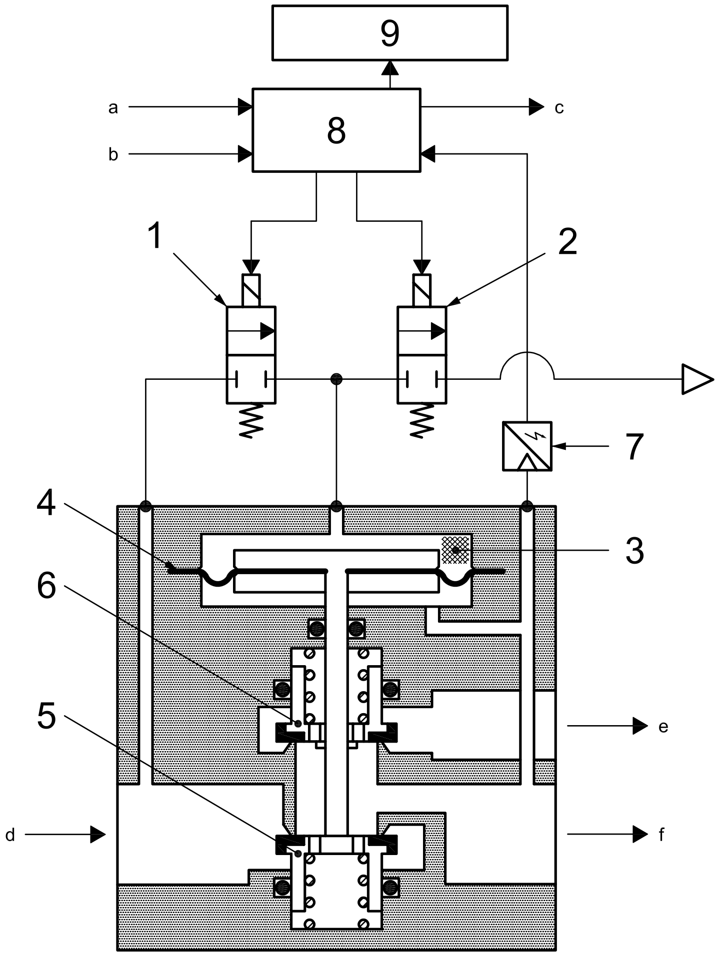
$$f_{\mathrm{s}} = \frac{1}{T_{\mathrm{s}}} \tag{A.3}$$

A.2 Real cases

In reality, the output pressure signal is often not a real sinusoid as in Figure A.1: the generated pressures are distorted due to the nonlinear behaviour of valve and compressed air as in Figures A.3 and A.4.

For the pressure valve of Figure A.2, Figures A.3 and A.4 show the setpoint (target value) and tank pressure (generated value) time evolutions for two different conditions, f_{s} = 0,1 Hz and f_{s} = 2 Hz, respectively.

The setpoint signals are sinusoidal wave signals; however, the tank pressure signals are distorted due to non linearities. Figures A.3 and A.4 show graphically how to determine, in these cases the amplitudes, A_{s} and A, and the time offset, $t\varphi$, to calculate respectively the gain and phase characteristics, A_{dB} and φ.



Key

1	air-supply solenoid valve	a	Power supply.
2	exhaust solenoid valve	b	Input signal.
3	pilot chamber	c	Output signal.
4	diaphragm	d	Supply.
5	supply valve	e	Exhaust.
6	exhaust valve	f	Output.
7	pressure sensor		
8	control circuit		
9	pressure display		

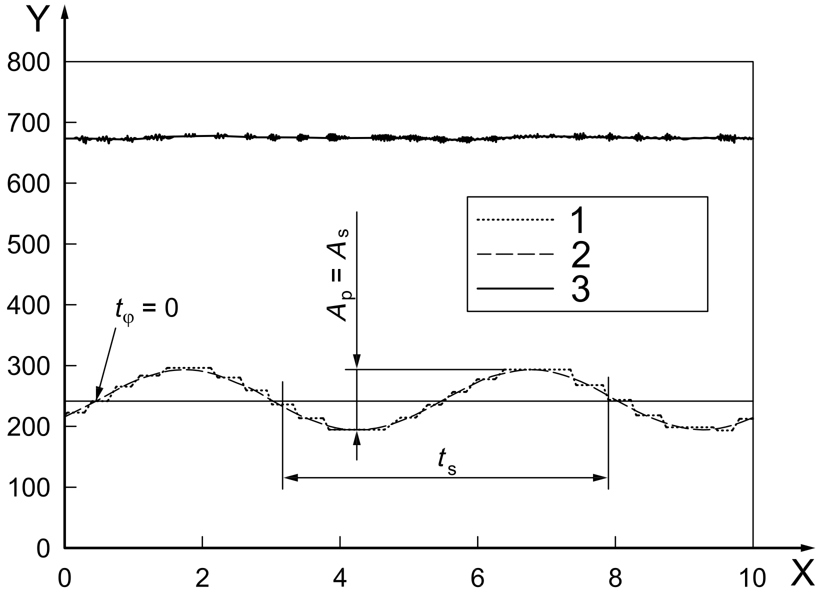
NOTE Maximum supply pressure: 1 MPa

Input: (0 to 5) V

Port: Rc 1/4

Output/Set pressure: (0,05 to 0,9) MPa.

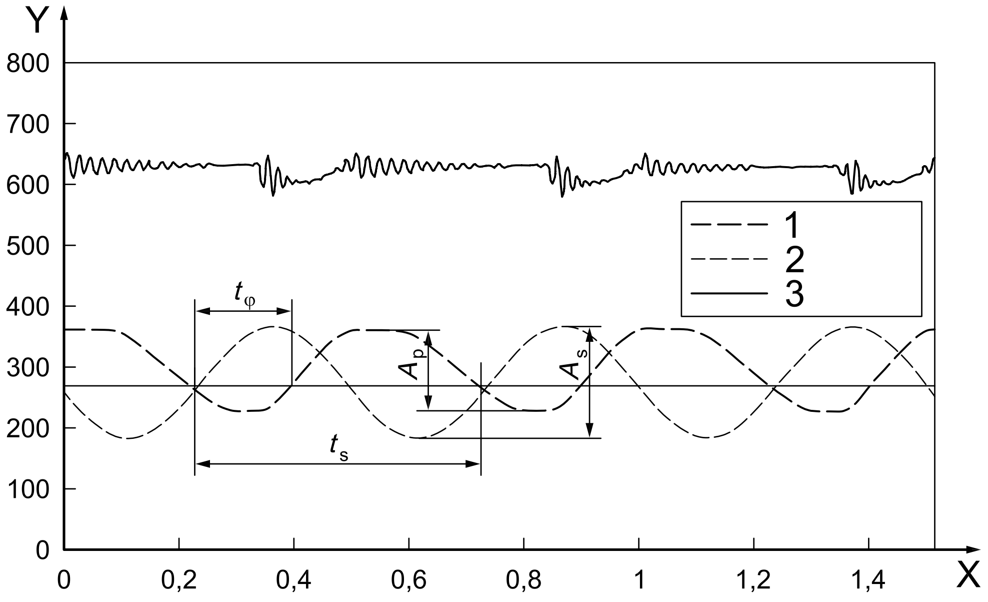
Figure A.2 — Valve under test



Key

X	time, in s	1	pressure value
Y	pressure, in kPa	2	setpoint value
		3	supply pressure

Figure A.3 — Gain and phase determination for f_s = 0,1 Hz



Key

X	time, in s	1	pressure value
Y	pressure, in kPa	2	setpoint value
		3	supply pressure

Figure A.4 — Gain and phase determination for f_s = 2 Hz

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