BS ISO 6358-1:2013

BSI Standards Publication

Pneumatic fluid power — Determination of flow-rate characteristics of components using compressible fluids

Part 1: General rules and test methods for steady-state flow

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National foreword

This British Standard is the UK implementation of ISO 6358-1:2013. Together with BS ISO 6358-2:2013 and BS ISO 6358-3, it supersedes BS 7294:1990 (dual numbered as ISO 6358:1989) which will be withdrawn on publication of Part 3.

The UK participation in its preparation was entrusted to Technical Committee MCE/18, Fluid power systems and components.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Pneumatic fluid power — Determination of flow-rate characteristics of components using compressible fluids —

Part 1: General rules and test methods for steady-state flow

Transmissions pneumatiques — Détermination des caractéristiques de débit des composants traversés par un fluide compressible —

Partie 1: Règles générales et méthodes d'essai en régime stationnaire

Reference number
ISO 6358-1:2013(E)

Foreword

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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 6358-1 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 5, *Control products and components*.

This first edition of ISO 6358-1, together with ISO 6358-2 and ISO 6358-3, cancels and replaces ISO 6358:1989, which has been technically revised. However, ISO 6358-2 and ISO 6358-3 are new standards whose scopes were not included in ISO 6358:1989.

ISO 6358 consists of the following parts, under the general title *Pneumatic fluid power — Determination of flow-rate characteristics of components using compressible fluid*:

Part 1: General rules and test methods for steady-state flow

Part 2: Alternative test methods

The following parts are under preparation:

— *Part 3: Method for calculating steady-state flow-rate characteristics of assemblies*

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Introduction

In pneumatic fluid power systems, power is transmitted and controlled through a gas under pressure within a circuit. Components that make up such a circuit are inherently resistive to the flow of the gas and it is necessary, therefore, to define and determine the flow-rate characteristics that describe their performance.

ISO 6358:1989 was developed to determine the flow-rate characteristics of pneumatic valves, based upon a model of converging nozzles. The method included two characteristic parameters: sonic conductance, C, and critical pressure ratio, b, used in a proposed mathematical approximation of the flow behaviour. The result described flow performance of a pneumatic valve from choked flow to subsonic flow, based on static pressure. This new edition uses stagnation pressure instead, to take into account the influence of flow velocity on the measurement of pressures.

Experience has demonstrated that many pneumatic valves have converging-diverging characteristics that do not fit the ISO 6358:1989 model very well. Furthermore, new developments have allowed the application of this method to additional components beyond pneumatic valves. However, this now requires the use of four parameters (C, b, m, and Δp_c) to define the flow performance in both the choked and subsonic flow regions.

This part of ISO 6358 describes a set of four flow-rate characteristic parameters determined from test results. These parameters are described as follows and are listed in decreasing order of priority:

> The sonic conductance, C, corresponding to the maximum flow rate (choked) is the most important parameter. This parameter is defined by the upstream stagnation conditions.
>
> The critical back-pressure ratio, b, representing the boundary between choked and subsonic flow is second in importance. Its definition differs here from the one in ISO 6358:1989 because it corresponds to the ratio of downstream to upstream stagnation pressures.
>
> The subsonic index, m, is used if necessary to represent more accurately the subsonic flow behaviour. For components with a fixed flow path, m is distributed around 0,5. In these cases, only the first two characteristic parameters C and b are necessary. For many other components, m varies widely. In these cases, it is necessary to determine C, b, and m.
>
> The parameter Δp_c is the cracking pressure. This parameter is used only for pneumatic components that open with increasing upstream pressure, such as non-return (check) valves or one-way flow control valves.

Several changes to the test equipment were made to overcome apparent violations of the theory of compressible fluid flow. This includes expanded inlet pressure-measuring tubes to satisfy the assumptions of negligible inlet velocity to the item under test and to allow the inlet stagnation pressure to be measured directly. Expanded outlet tubes allow the direct measurement of downstream stagnation pressure to better accommodate the different component models. The difference between stagnation pressure at upstream and downstream of component means a loss of pressure energy.

For testing a component with a large nominal bore, to shorten testing time or to reduce energy consumption, it is desirable to apply the methods specified in ISO 6358-2, which covers a discharge test and a charge test as alternative test methods.

ISO 6358-3 can be used to calculate without measurements an estimate of the overall flow-rate characteristics of an assembly of components and piping, using the characteristics of each component and piping determined in accordance with this part of ISO 6358 or ISO 6358-2.

It should be noted that performance characteristics measured in accordance with this edition of ISO 6358 differ from those measured in accordance with ISO 6358:1989.

Pneumatic fluid power — Determination of flow-rate characteristics of components using compressible fluids —

Part 1:
General rules and test methods for steady-state flow

1 Scope

This part of ISO 6358 specifies a steady-state method for testing pneumatic fluid power components that use compressible fluids, i.e. gases, and that have internal flow paths that can be either fixed or variable in size, to determine their flow-rate characteristics. However, this part of ISO 6358 does not apply to components whose flow coefficient is unstable during use, i.e. components that exhibit remarkable hysteretic behaviour (because they can contain flexible parts that deform under the flow) or that have an internal feedback phenomenon (such as regulators). In addition, it does not apply to components that exchange energy with the fluid during flow-rate measurement, e.g. cylinders, accumulators, etc.

Table 1 provides a summary of which parts of ISO 6358 can be applied to various components.

Table 1 — Application of ISO 6358 test methods to components

Components		Constant upstream pressure test		Variable upstream pressure test	
		ISO 6358-1 **constant upstream pressure test**	ISO 6358-2 **charge test**	ISO 6358-1 **variable upstream pressure test**	ISO 6358-2 **discharge test**
Group 1	Directional control valves	yes	yes	yes	yes
	Flow control valves	yes	yes	yes	yes
	Connectors	yes	yes	yes	yes
	Valve manifolds	yes	yes	yes	yes
	Group of components	yes	yes	yes	yes
Group 2	Filters and lubricators	yes	no	no	no
	Non-return (check) valves	yes	no	no	no
	Tubes and hoses	yes	no	no	no
Group 3	Silencers and exhaust oil mist separators	no	no	yes	yes
	Blow nozzles	no	no	yes	yes
	Quick-exhaust valves	no	no	yes	yes
	Cylinder end heads	no	no	yes	yes

This part of ISO 6358 specifies requirements for the test installation, the test procedure, and the presentation of results for the steady-state method.

This part of ISO 6358 includes several test procedures, including the one described in Annex A, which is from ISO 6358:1989. Flowmeter calibration is described in Annex B. Evaluation of measurement uncertainties is described in Annex C. Observations of the error in the test results are described in Annex D. Equations and graphical representations of flow-rate characteristics are given in Annex E. Guidance on the use of practical units for the presentation of results is given in Annex F. Test results using commercially available pneumatic components are given in Annex G. Guidance on calculating the flow-rate characteristics is given in Annex H.

2 Normative references

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

ISO 228-1, *Pipe threads where pressure-tight joints are not made on the threads — Part 1: Dimensions, tolerances and designation*

ISO 1219-1, *Fluid power systems and components — Graphical symbols and circuit diagrams — Part 1: Graphical symbols for conventional use and data-processing applications*

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

ISO 8778, *Pneumatic fluid power — Standard reference atmosphere*

ISO 14743:2004, *Pneumatic fluid power — Push-in connectors for thermoplastic tubes*

ISO 16030, *Pneumatic fluid power — Connections — Ports and stud ends*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following apply. The terms and definitions given in 3.1 through 3.3 are those for which it seems useful to emphasize the meaning. The terms and definitions in 3.4 and 3.5 are given for the purposes of this part of ISO 6358.

3.1 Terms and definitions related to pressures

3.1.1
static pressure
pressure measured perpendicularly to the flow direction without influence of disturbances

Note 1 to entry: Static pressure can be measured by connecting a pressure-measuring device to a pressure-tapping mounting in a wall.

3.1.2
stagnation pressure
pressure that would exist in a flowing gas stream if the stream were brought to rest by an isentropic process

Note 1 to entry: In this part of ISO 6358, the static pressure measured in the pressure-measuring tubes is effectively the stagnation pressure within 6 %.

3.2 Terms and definitions related to temperature

3.2.1
static temperature
temperature that would be measured by a device that moves with the flowing gas at its velocity

3.2.2
stagnation temperature
temperature that would exist in a flowing gas stream if the stream were brought to rest by an isentropic process

Note 1 to entry: In this part of ISO 6358, the temperature measured in the pressure-measuring tubes with either an immersed temperature probe or a probe in the side wall of the tube is effectively the stagnation temperature within 1 %.

3.3 Terms and definitions related to flow

3.3.1
choked flow
flow whose velocity is equal to the local speed of sound in at least one section of the component, which means that the Mach number equals 1

Note 1 to entry: In this condition, the mass flow rate of the gas is proportional to the upstream pressure, p_1, and independent of the downstream pressure, p_2.

3.3.2
subsonic flow
flow whose velocity is lower than the local speed of sound, that is, whose Mach number is below 1, in every section of the component

Note 1 to entry: In this condition, the mass flow rate of the gas is dependent on the upstream and downstream pressures.

3.4 Terms and definitions related to flow-rate characteristics

3.4.1
conductance, C_e
measure of the ability of a pneumatic component or piping to conduct gas flow

Note 1 to entry: The conductance of a pneumatic component can be determined from the amount of flow at conditions of standard reference atmosphere, from the stagnation pressure and stagnation temperature ratio generating the flow, as described by the formula:

$$C_{\mathrm{e}} = \frac{q_{\mathrm{v}}}{p_1}\sqrt{\frac{T_1}{T_0}} = \frac{q_{\mathrm{m}}}{\rho_0 p_1}\sqrt{\frac{T_1}{T_0}}$$

3.4.2
sonic conductance, C
conductance in the choked flow region

3.4.3
conductance ratio
ratio of the conductance to the sonic conductance

Note 1 to entry: The conductance ratio, C_{e}/C, is less than or equal to 1.

3.4.4
critical back-pressure ratio, b
ratio of the downstream stagnation pressure to the upstream stagnation pressure when the mass flow rate of the gas through the component or piping just reaches the choked flow region of the flow-rate or conductance curve

3.4.5
subsonic index, m
exponential index for expressing the characteristic function of the mass flow rate in the subsonic flow region of the flow-rate or conductance curve

3.4.6
cracking pressure, Δp_{c}
differential pressure between upstream and downstream pressures required for the mass flow rate to be greater than the lowest practical ratio of $q_{\mathrm{m}}/q_{\mathrm{m}}^*$

3.4.7
pressure dependence coefficient, K_p
ratio by which sonic conductance is affected by upstream pressure

Note 1 to entry: See Formula (3).

3.5 Miscellaneous terms and definitions

3.5.1
pressure-measuring tube
tube with a defined inside diameter and with pressure-tapping holes for measuring the pressure perpendicular to the direction of flow

3.5.2
transition connector
connector with tapered passage for connecting the ports of the component under test to a pressure-measuring tube

3.5.3
variable internal flow path
flow path whose size depends on the pressure difference between the component's inlet port and outlet port (e.g. that caused by a spring-loaded poppet seal)

4 Symbols and units

4.1 The symbols and units used throughout this part of ISO 6358 shall be in accordance with Table 2.

Table 2 — Symbols and units

Reference	Description	Symbol	Dimension[a]	SI unit[b]
3.4.3	Critical back-pressure ratio	b	pure number	–
3.4.2	Conductance	C_e	L^4TM^{-1}	$m^3/(s \cdot Pa)$(ANR)
3.4.2	Sonic conductance	C	L^4TM^{-1}	$m^3/(s \cdot Pa)$(ANR)
3.4.4	Subsonic index	m	pure number	–
-	Absolute stagnation pressure	p	$ML^{-1}T^{-2}$	Pa[c]
-	Mass flow rate	q_m	MT^{-1}	kg/s
-	Volume flow rate at standard reference atmosphere	q_V	L^3T^{-1}	m^3/s(ANR)
-	Gas constant (for a perfect gas)	R	$L^2T^{-2}\Theta^{-1}$	J/(kg·K)
-	Absolute stagnation temperature	T	Θ	K
3.4.5	Cracking pressure	Δp_c	$ML^{-1}T^{-2}$	Pa [c]
3.4.7	Pressure dependence coefficient	K_p	$M^{-1}LT^2$	Pa^{-1}
-	Mass density	ρ	ML^{-3}	kg/m^3

a M = mass; L = length; T = time; Θ = temperature.

b The use of practical units for the presentation of results is described in Annex F.

c 1 Pa = 1 N/m^2.

4.2 The numerals used as subscripts and the asterisk (*) used as a superscript to the symbols listed in Table 2 shall be used as specified in Table 3.

Table 3 — Subscripts and superscripts

Superscript	Subscript	Meaning
	0	Conditions of standard reference atmosphere defined in ISO 8778, i.e.: T_0 = 293,15 K p_0 = 100 kPa (1 bar[a]) ρ_0 = 1,185 kg/m^3 65 % relative humidity
	1	Upstream conditions
	2	Downstream conditions
*		Conditions during choked flow tests

[a] 1 bar = 100 kPa = 0,1 MPa; 1 Pa = 1 N/m^2.

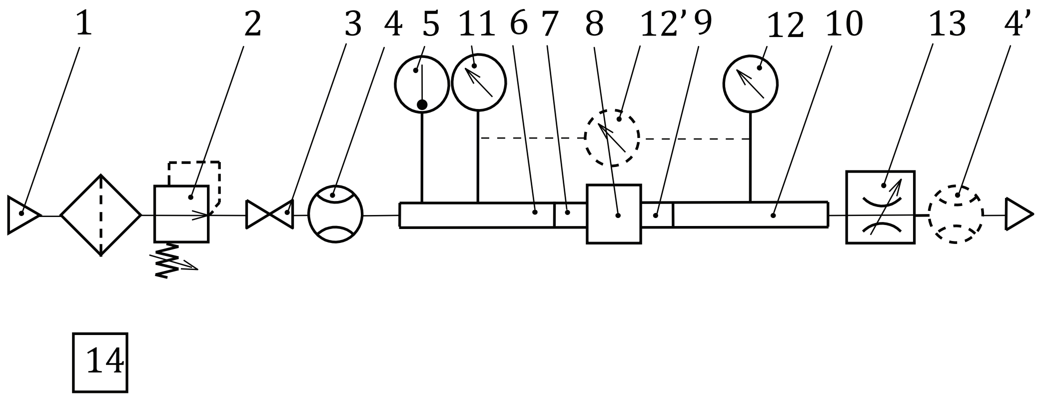
4.3 The graphic symbols used in Figures 1 and 2 are in accordance with ISO 1219-1.

5 Test installation

CAUTION — Figures 1 and 2 illustrate basic circuits that 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 carrying out the test give due consideration to safeguarding both personnel and equipment.

5.1 Test circuit for constant upstream pressure test

5.1.1 If pressure-measuring tubes can be connected on the upstream and downstream sides of the component under test, a suitable test circuit as shown in Figure 1 shall be used.



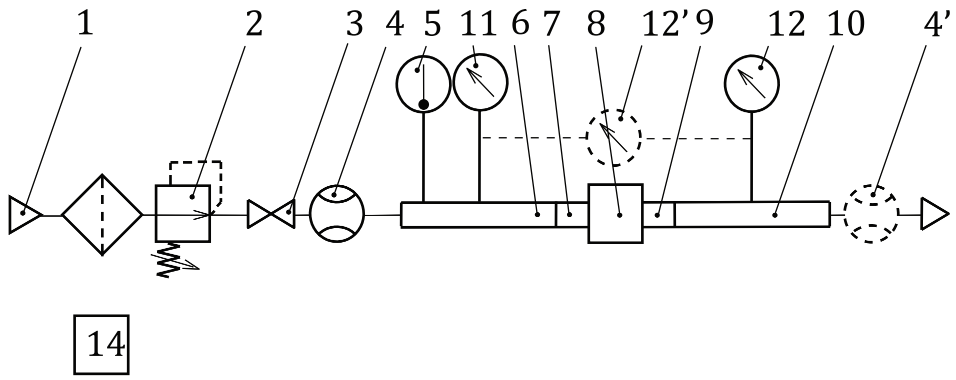
NOTE See Table 4 for the key to test circuit components.

Figure 1 — Test circuit for constant upstream pressure test

5.1.2 An alternative to this test circuit is shown in Figure A.1.

5.2 Test circuit for variable upstream pressure test

If the component under test has a connecting port on its downstream side, a suitable test circuit as shown in Figure 2 shall be used. If the component does not have a connecting port on its downstream side (such as a silencer), see 5.3.4 for more information.



NOTE See Table 4 for the key to test circuit components.

Figure 2 — Test circuit for variable upstream pressure test

Table 4 — Key to test circuit components shown in Figures 1 and 2

Key item number	Relevant subclause or paragraph	Description	Additional recommendations and requirements
1	5.3.2	Compressed gas source and filter	
2	-	Adjustable pressure regulator	
3	-	Shut-off valve	Preferably with a straight flow path
4	-	Flow-rate measuring device	May also be placed in position 4’ [i.e. downstream of the downstream pressure-measuring tube (item 10)]
5	-	Temperature-measuring instrument	Sensor located on axis of the upstream pressure-measuring tube (item 6). See 5.4.2 and 5.4.3.
6	5.4	Upstream pressure-measuring tube	
7	5.5	Upstream transition connector	Attached to the pressure-measuring tube and component under test
8	-	Component under test	
9	5.5	Downstream transition connector	Attached to the pressure-measuring tube and component under test
10	5.4	Downstream pressure-measuring tube	
11	-	Upstream pressure gauge or transducer	
12	-	Downstream pressure gauge or transducer	A differential pressure gauge or transducer, 12’, may be used as an alternative.
[a] As an option, a set of push-in connectors may also be used.			

Table 4 *(continued)*

Key item number	Relevant subclause or paragraph	Description	Additional recommendations and requirements
13	-	Flow control valve	The sonic conductance of this flow control valve shall be about four times larger than that of the component under test.
14	-	Barometer	
15	5.6.3	Nipple[a]	Not shown in Figures 1 and 2; see Figure 7.
16	5.6.3	Close nipple[a]	Not shown in Figures 1 and 2; see Figure 7.

[a] As an option, a set of push-in connectors may also be used.

5.3 General requirements

5.3.1 The component under test shall be installed and operated in the test circuit in accordance with the manufacturer's operating instructions.

5.3.2 A filter shall be installed which provides a standard of filtration specified by the manufacturer of the component under test.

5.3.3 A test setup shall be constructed from the items listed in Table 4, except that item 13 is not required for the variable upstream pressure test.

5.3.4 Items 9, 10, and 12 are not required for the variable upstream pressure test when the component under test does not have a downstream port.

5.3.5 All connections for pressure measurement shall be arranged so that entrained liquid cannot be trapped or retained; a drain may be provided at any locations where liquid collects.

5.3.6 The inlet connector of the upstream pressure-measuring tube shall have a gradual profile to avoid disturbance of the flow.

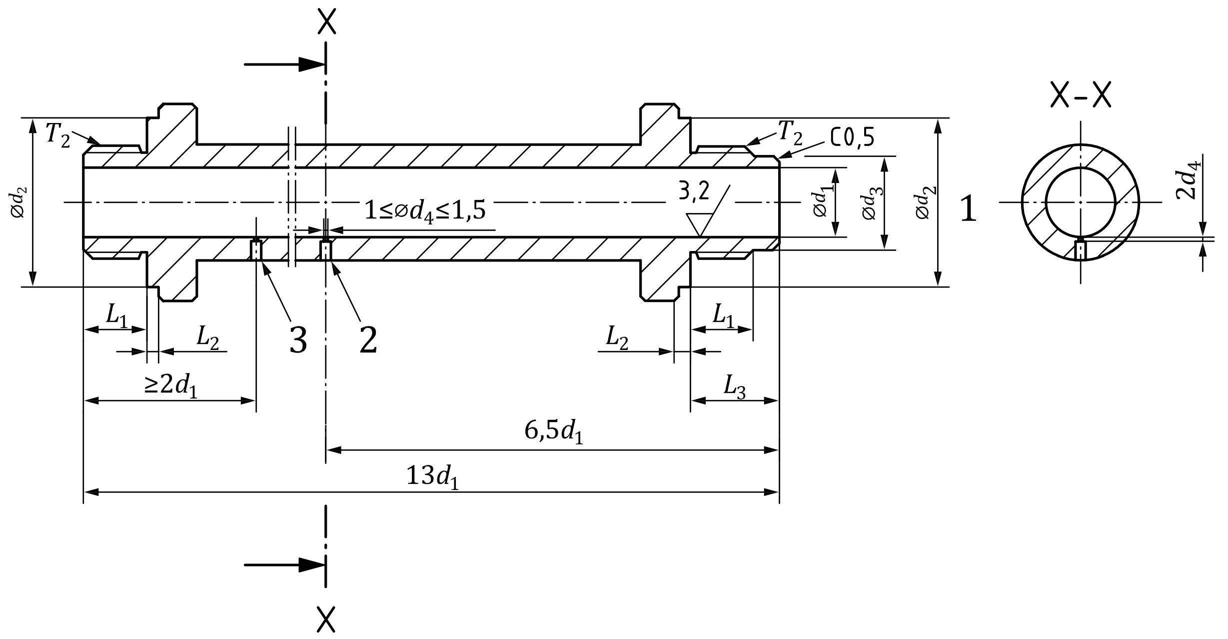
5.3.7 Calibrate the flowmeter (see Annex B for information) before conducting the test. For tests conducted to determine or verify catalogue data, the flowmeter shall have been calibrated in accordance with the best practices of the laboratory.

5.3.8 Perform a dead weight test of the pressure measuring instrumentation at least annually.

5.3.9 Instrumentation in a circuit should not be located where vibration can affect its accuracy.

5.4 Pressure-measuring tubes (items 6 and 10)

5.4.1 Pressure-measuring tubes that conform to Figure 3 shall be used. Typical dimensions of the pressure-measuring tubes are also specified in Table 5. The tube shall be straight, with a smooth, circular internal surface, and a constant diameter throughout its length. The longitudinal centreline of the tube shall intersect with the centreline of the holes, and the centreline of the holes shall be normal to the longitudinal centreline. The junction of the hole with the internal surface of the tube shall have a sharp edge and be free from burrs. There shall be no obstruction or branch connection other than those specified.



Key

1 end that connects to transition connector

2 pressure-tapping hole

3 optional temperature-tapping hole (may be deleted for the downstream pressure-measuring tube, or if a different upstream location is used)

Figure 3 — Pressure-measuring tube

Table 5 — Typical dimensions of pressure-measuring tubes

Dimensions in millimetres

T_2[a]	d_1	d_2[b]	d_3[c]		L_1[b]		L_2[b]	L_3	
	min.		nom.	tol.	nom.	tol.		nom.	tol.
G 1/8	6	14,5	8	−0,040 −0,076	5,5	0 −0,2	1	7,5	0 −0,4
G 1/4	9	18,5	11	−0,050 −0,093	6,5	0 −0,4	1,5	9,5	0 −0,4
G 3/8	12,5	22,5	14,5	−0,050 −0,093	7,5	0 −0,4	1,5	10,5	0 −0,4
G 1/2	16	26,5	18	−0,050 −0,093	9	0 −0,4	1,5	12	0 −0,4
G 3/4	22	32,5	24	−0,065 −0,117	10,5	0 −0,4	1,5	13,5	0 −0,4
G 1	28	39	30	−0,065 −0,117	11,5	0 −0,4	1,5	14,5	0 −0,4
G 1 1/4	36	49	38	−0,080 −0,142	16,5	0 −0,4	2,5	21,5	0 −0,4
G 1 1/2	42	55	44,5	−0,080 −0,142	17,5	0 −0,4	2,5	22,5	0 −0,4

[a] G threads in accordance with ISO 228-1.

[b] G thread length L_1 and dimensions d_2 and L_2 in accordance with ISO 16030.

[c] Limit deviations of tolerance class d_9 in accordance with ISO 286-2.

Table 5 *(continued)*

T_2[a]	d_1	d_2[b]	d_3[c]		L_1[b]		L_2[b]	L_3	
	min.		nom.	tol.	nom.	tol.		nom.	tol.
G 2	53	68	56	−0,100 −0,174	19,5	0 −0,4	2,5	24,5	0 −0,4
G 2 1/2	68	80	72	−0,100 −0,174	23	0 −0,4	3	29	0 −0,4
G 3	81	91	84,5	−0,120 −0,207	25,5	0 −0,4	3	31.5	0 −0,6

[a] G threads in accordance with ISO 228-1.

[b] G thread length L_1 and dimensions d_2 and L_2 in accordance with ISO 16030.

[c] Limit deviations of tolerance class d_9 in accordance with ISO 286-2.

5.4.2 One temperature-tapping hole may be provided on the upstream pressure-measuring tube, in accordance with Figure 3, for a temperature-measuring sensor that does not protrude into the flow stream.

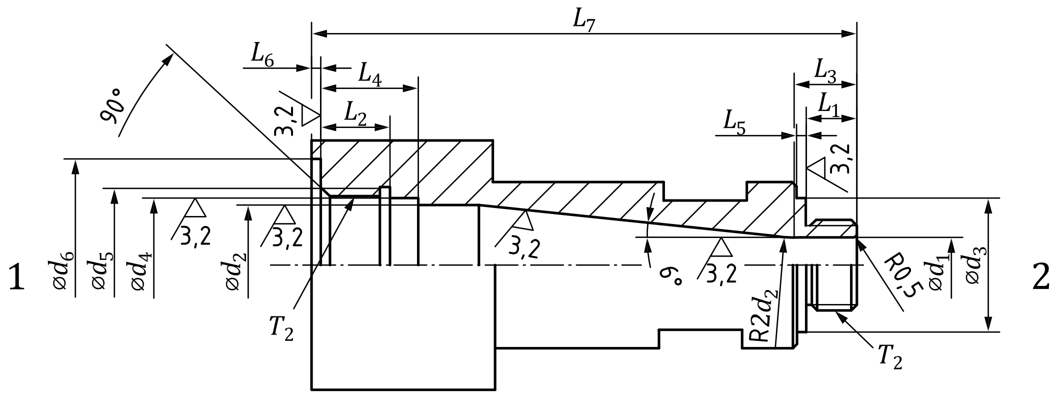
5.4.3 Because the location of the temperature sensor does not have a significant impact on the test results, the temperature sensor can be located in a convenient location upstream from the component under test. Alternate locations of the temperature sensor should be in a large-diameter section of the supply system piping, away from any areas of sudden expansion.

5.4.4 When connecting pressure-measuring instruments, the dead volume shall be limited as much as possible to avoid long response time.

5.5 Transition connectors (items 7 and 9)

5.5.1 Transition connectors should be made of stainless steel or carbon steel for machine structural use. Maximum torque values should be twice the torque value given in ISO 16030 (i.e. maximum torque values for M3, M5, and M7 size connectors should be, respectively, 0,6 N·m, 1,6 N·m, and 4 N·m.)

5.5.2 Components under test that have female ports shall be connected to a type 1 transition connector, as shown in Figure 4. Typical dimensions of type 1 transition connectors are given in Table 6.



Key

1 end that connects to the pressure-measuring tube

2 end that connects to the component under test

Figure 4 — Type 1 transition connector (threaded connection)

Table 6 — Typical dimensions of type 1 transition connectors

Dimensions in millimetres

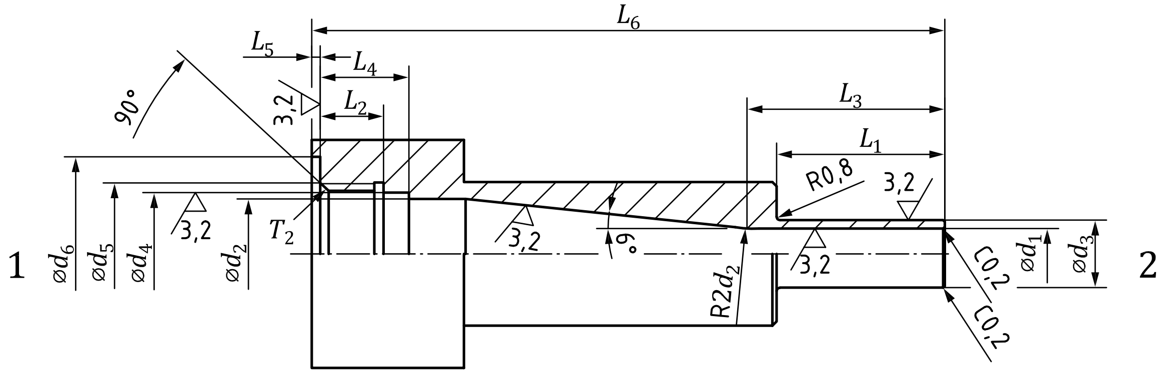
Size	L_1[a]	L_2		L_3	L_4		L_5[a]	L_6[a]	L_7	d_1		d_2	d_3[a]	d_4[c]		d_5	d_6[a]	T_1[b]	T_2[b]
		nom.	tol.		nom.	tol.				nom.	tol.	min.		nom.	tol.				
M3 × 1/8	3	5,5	+0,2 0	5	7,5	+0,4 0	1	0,5	39	1,5	+0,1 0	6	6,5	8	+0,058 0	9,9	15	M3	G 1/8
M5 × 1/8	4	5,5	+0,2 0	6	7,5	+0,4 0	1	0,5	39	2,7	+0,1 0	6	8,5	8	+0,058 0	9,9	15	M5	G 1/8
M7 × 1/4	5,5	6,5	+0,4 0	7,5	9,5	+0,4 0	1	1	48	4	+0,1 0	9	11,5	11	+0,070 0	13,4	19	M7	G 1/4
1/8 × 3/8	5,5	7,5	+0,4 0	7,5	10,5	+0,4 0	1	1	59	6	+0,2 0	12,5	14,5	14,5	+0,070 0	16,9	23	G 1/8	G 3/8
1/4 × 1/2	6,5	9	+0,4 0	9,5	12	+0,4 0	1,5	1	63	9	+0,2 0	16	18,5	18	+0,070 0	21,2	27	G 1/4	G 1/2
3/8 × 3/4	7,5	10,5	+0,4 0	10,5	13,5	+0,4 0	1,5	1	75	13	+0,2 0	22	22,5	24	+0,084 0	26,6	33	G 3/8	G 3/4
1/2 × 1	9	11,5	+0,4 0	12	14,5	+0,4 0	1,5	1	92	16	+0,2 0	28	26,5	30	+0,084 0	33,7	40	G 1/2	G 1
3/4 × 1 1/4	10,5	16,5	+0,4 0	13,5	21.5	+0,4 0	1,5	2	112	22	+0,2 0	36	32,5	38	+0,100 0	43,2	50	G 3/4	G 1 1/4
1 × 1 1/2	11,5	17,5	+0,4 0	15	22.5	+0,4 0	1,5	2	120	28	+0,2 0	42	39	44,5	+0,100 0	49,7	56	G 1	G 1 1/2
1 1/4 × 2	16,5	19,5	+0,4 0	21	24,5	+0,4 0	2,5	2	138	36	+0,3 0	53	49	56	+0,120 0	62,7	69	G 1 1/4	G 2
1 1/2 × 2 1/2	17,5	23	+0,4 0	22	29	+0,4 0	2,5	2,5	185	43	+0,3 0	68	55	72	+0,120 0	79,4	81	G 1 1/2	G 2 1/2
2 × 3	19,5	25,5	+0,4 0	24	31,5	+0,6 0	2,5	2,5	204	53	+0,3 0	81	68	84,5	+0,140 0	92,1	92	G 2	G 3

a Thread length L_1 and dimensions L_5, L_6, d_3, and d_6 are in accordance with ISO 16030.

b M threads are in accordance with ISO 261; G threads are in accordance with ISO 228-1.

c Limit deviations of tolerance class H10 in accordance with ISO 286-2.

5.5.3 Components under test that have ports for push-in connections shall be connected to a type 2 transition connector as shown in Figure 5. Typical dimensions of type 2 transition connectors are given in Table 7.



Key

1 end that connects to the pressure-measuring tube

2 end that connects to the component under test

Figure 5 — Type 2 transition connector (push-in connection)

Table 7 — Typical dimensions of type 2 transition connectors

Dimensions in millimetres

Size	L_1[a]	L_2		L_3	L_4		L_5[b]	L_6	d_1	d_2	d_3[d]		d_4[f]		d_5	d_6[b]	T_2[e]
		nom.	tol.		nom.	tol.				min.	nom.	tol.	nom.	tol.			
3 × 1/8	16	5,5	+0,2 0	18	7,5	+0,4 0	0,5	51	c	6	3	±0,08	8	+0,058 0	9,9	15	G 1/8
4 × 1/8	18	5,5	+0,2 0	20	7,5	+0,4 0	0,5	50		6	4	±0,08	8	+0,058 0	9,9	15	G 1/8
6 × 1/4	19	6,5	+0,4 0	22	9,5	+0,4 0	1	63		9	6	±0,08	11	+0,070 0	13,4	19	G 1/4
8 × 3/8	20	7,5	+0,4 0	23.5	10,5	+0,4 0	1	75		12,5	8	±0,08	14,5	+0,070 0	16,9	23	G 3/8
10 × 1/2	24	9	+0,4 0	27,5	12	+0,4 0	1	88		16	10	±0,08	18	+0,070 0	21,2	27	G 1/2
12 × 3/4	25	10,5	+0,4 0	28,5	13,5	+0,4 0	1	112		22	12	±0,1	24	+0,084 0	26,6	33	G 3/4

[a] Dimension L_1 is in accordance with ISO 14743.

[b] Dimensions L_5 and d_6 are in accordance with ISO 16030.

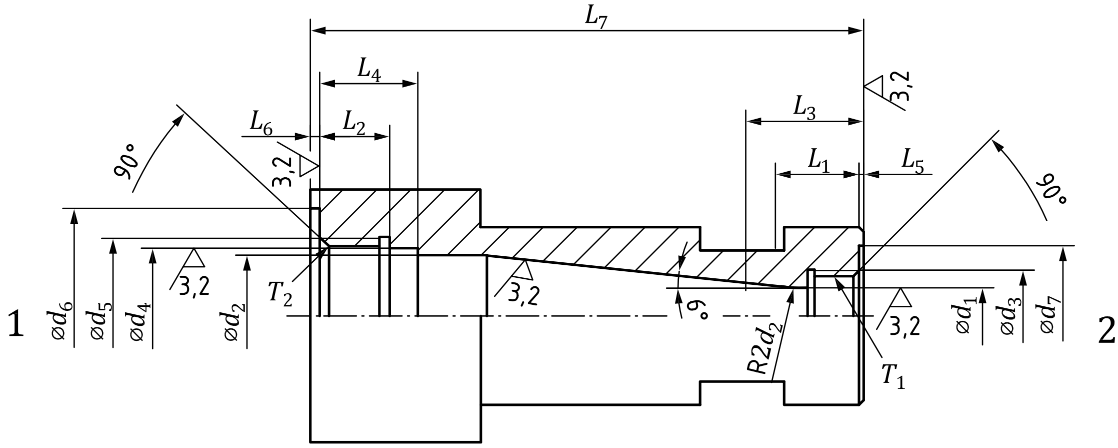
[c] Dimension d_1 shall be equal to the inside diameter of the connecting tube.

[d] Dimension d_3 is in accordance with Annex A of ISO 14743:2004.

[e] G threads are in accordance with ISO 228-1.

[f] Limit deviations of tolerance class H10 in accordance with ISO 286-2.

5.5.4 Components under test that have male ports shall be connected to a type 3 transition connector as shown in Figure 6. Typical dimensions of type 3 transition connectors are given in Table 8.



Key

1 end that connects to the pressure-measuring tube

2 end that connects to the component under test

Figure 6 — Type 3 transition connector

Table 8 — Typical dimensions of type 3 transition connectors

Dimensions in millimetres

Size	L_1	L_2		L_3	L_4		L_5[a]	L_6[a]	L_7	d_1		d_2	d_3	d_4[c]		d_5	d_6[a]	d_7[a]	T_1[b]	T_2[b]
		nom.	tol.		nom.	tol.				nom.	tol.	min.		nom.	tol.					
M3 ×1/8	3	5,5	+0,2 0	5	7,5	+0,4 0	0,5	0,5	39	1,5	+0,1 0	6	3	8	+0,058 0	9,9	15	7	M3	G 1/8
M5 × 1/8	4	5,5	+0,2 0	6	7,5	+0,4 0	0,5	0,5	39	2.7	+0,1 0	6	5	8	+0,058 0	9,9	15	9	M5	G 1/8
M7 × 1/4	5,5	6,5	+0,4 0	7,5	9,5	+0,4 0	0,5	1	48	4	+0,1 0	9	7	11	+0,070 0	13,4	19	12	M7	G 1/4
1/8 × 3/8	5,5	7,5	+0,4 0	7,5	10,5	+0,4 0	0,5	1	59	6	+0,2 0	12,5	9,9	14,5	+0,070 0	16,9	23	15	G 1/8	G 3/8
1/4 × 1/2	6,5	9	+0,4 0	9,5	12	+0,4 0	1	1	63	9	+0,2 0	16	13,4	18	+0,070 0	21,2	27	19	G 1/4	G 1/2
3/8 × 3/4	7,5	10,5	+0,4 0	10,5	13,5	+0,4 0	1	1	75	13	+0,2 0	22	16,9	24	+0,084 0	26,6	33	23	G 3/8	G 3/4
1/2 × 1	9	11,5	+0,4 0	12	14,5	+0,4 0	1	1	92	16	+0,2 0	28	21,2	30	+0,084 0	33,7	40	27	G 1/2	G 1
3/4 × 1 1/4	10,5	16,5	+0,4 0	13,5	21,5	+0,4 0	1	2	112	22	+0,2 0	36	26,6	38	+0,100 0	43,2	50	33	G 3/4	G 1 1/4
1 × 1 1/2	11,5	17,5	+0,4 0	15	22,5	+0,4 0	1	2	120	28	+0,2 0	42	33,7	44,5	+0,100 0	49,7	56	40	G 1	G 1 1/2
1 1/4 × 2	16,5	19,5	+0,4 0	21	24,5	+0,4 0	2	2	138	36	+0,3 0	53	43,2	56	+0,120 0	62,7	69	50	G 1 1/4	G 2
1 1/2 × 2 1/2	17,5	23	+0,4 0	22	29	+0,4 0	2	2,5	185	43	+0,3 0	68	49,7	72	+0,120 0	79,4	81	56	G 1 1/2	G 2 1/2
2 × 3	19,5	25,5	+0,4 0	24	31,5	+0,6 0	2	2,5	204	53	+0,3 0	81	62,7	84,5	+0,140 0	92,1	92	69	G 2	G 3

[a] Dimensions L_5, L_6, d_6, and d_7 are in accordance with ISO 16030.

[b] M threads are in accordance with ISO 261; G threads are in accordance with ISO 228-1.

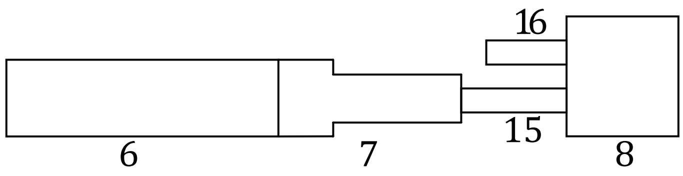
[c] Limit deviations of tolerance class H10 in accordance with ISO 286-2.

5.6 Special requirements

5.6.1 When the inlet and outlet ports of the component under test are different in structure or size from those described above, or are different from each other, pressure-measuring tubes and transition connectors that are suited to the relevant ports shall be used, but they shall conform in principle to the dimensions shown in 5.5.

5.6.2 Pressure-measuring tubes and transition connectors may be joined or welded together by means other than shown if all internal dimensions in the flow path are maintained and the pilot fit is used between them.

5.6.3 When a transition connector interferes with the body of the component under test, or an adjacent connector, the variable upstream pressure test shall be performed. In this case, a transition connector (item 7) shall be used with a nipple (item 15) or short tube connected to the upstream port. A close nipple (item 16) shall also be installed to the downstream port, as shown in Figure 7. The inside diameter of the nipple and close nipple (items 15 and 16) should be equal to the inside diameter, d_1, of the transition connector.



NOTE See Table 4 for the key to identify circuit components.

Figure 7 — Test arrangement for component with ports that are close to each other

5.6.4 All special requirements shall be recorded in the test report.

6 Test procedures

6.1 Test conditions

6.1.1 Test fluid

6.1.1.1 Air should be used as the test fluid. If a different fluid is used, it shall be stated in the test report.

6.1.1.2 The gas shall be filtered and conditioned to comply with the recommendations of the manufacturer of the component under test.

6.1.2 Checks

Periodically check that the pressure-tapping holes are not blocked by liquids or solid particles.

6.1.3 Test measurements

6.1.3.1 Each set of test readings shall be recorded after steady-state conditions have been reached. The variations of pressures, temperature, and flow rate indications shall not exceed the limits given in the column "Allowed test conditions variation" in Table 9.

6.1.3.2 Pressure, temperature, and flow rate shall be measured within the measurement accuracy specified in Table 9.

Table 9 — Measurement accuracy and allowed test condition variation of parameters

Parameter	Measurement accuracy	Allowed test condition variation
Temperature	±1 K	±2 K
Pressure	±0,5 %	±1 %
Flow rate	±2 %	±4 %
NOTE See ISO/IEC Guide 98-3:2008 and the Guide to the expression of uncertainty in measurement (GUM:2008 from ISO/IEC/BIPM).		

6.1.3.3 Flow conditions in each flow path shall be maintained constant within the component while taking measurements to ensure there is no inadvertent movement of component parts.

6.2 Measuring procedures

6.2.1 Requirements for testing to publish catalogue ratings

If data are to be used for publishing ratings in a catalogue, a sample consisting of a minimum of five test units selected from a random production lot shall be tested in accordance with the following procedures.

6.2.2 Selection of measuring procedure

Either the procedure described in 6.2.3 or the procedure described in 6.2.4 shall be selected in accordance with the scope of this part of ISO 6358. If the alternative test circuit in A.2 is used, only the procedure described in 6.2.3 shall be selected, with the pressures adjusted as described in A.3 and A.4.

NOTE If the variable upstream pressure test is used, it is not possible to determine the cracking pressure, Δp_c.

6.2.3 Measuring procedures for discharge test (See Figure 1)

6.2.3.1 Maintain a constant upstream pressure, p_1, of not less than 500 kPa (5 bar) and preferably higher. Adjust the pressure regulator (item 2) as required to maintain p_1 at a constant value throughout the test for each measured point. Measure the atmospheric pressure using the barometer (item 14).

6.2.3.2 Decrease the downstream pressure, p_2, to its smallest possible value by opening the flow control valve (item 13) to its maximum flow rate. In these conditions, most components are choked. Measure upstream temperature, T_1*, upstream pressure, p_1*, choked mass flow rate, q_m*, and downstream pressure, p_2*.

6.2.3.3 Partly close the flow control valve (item 13) step by step to obtain two more data points in the choked flow region. Record the same additional data as in 6.2.3.2. Allow sufficient time between settings for the system to stabilize because the data cannot be recorded when the flow rate varies continually.

6.2.3.4 Continue closing the flow control valve (item 13) step by step to obtain at least five approximately equally spaced data points in the subsonic flow region. For each point, measure and record the upstream temperature, T_1, upstream pressure, p_1, mass flow rate, q_{m}, and downstream pressure, p_2. This is a decreasing flow rate test.

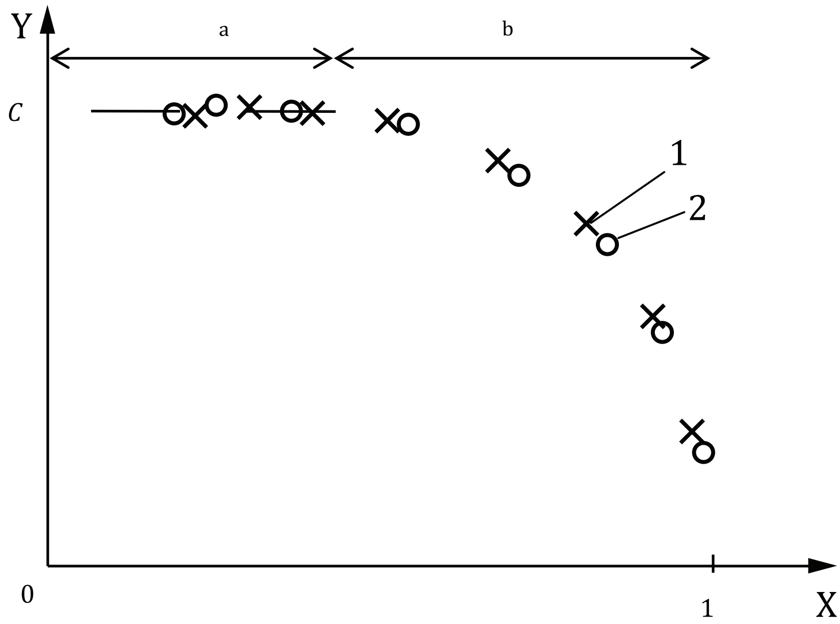
6.2.3.5 If it can be assumed that the component has a cracking pressure, the following additional measurement shall be performed to obtain the cracking pressure. Continue to close the flow control valve (item 13) to reduce the mass flow rate, q_{m}, to the lowest ratio of $q_{\mathrm{m}}/q_{\mathrm{m}}$* that is practically obtainable, and measure the mass flow rate, q_{m}, upstream temperature, T_1, upstream pressure, p_1, and cracking pressure, Δp_{c}.

6.2.3.6 To check whether the conductance curve of the component under test has dispersion or hysteresis, partly open the flow control valve (item 13) step by step to measure five points spread out over the subsonic flow region of pressure ratio p_2/p_1 and three points spread out over the choked flow region. This is an increasing flow rate test.

For each point in the subsonic flow region, measure and record the upstream temperature, T_1, upstream pressure, p_1, mass flow rate, q_m, and downstream pressure, p_2.

For each point in the choked flow region, measure and record the upstream temperature, T_1*, upstream pressure, p_1*, choked mass flow rate, q_m*, and downstream pressure, p_2*.

6.2.3.7 Using the data from above, make a plot as shown in Figure 8. Calculate the back-pressure ratio for each data point as the ratio of the downstream to upstream measured pressure. Using the formula in 3.4.1, plot the corresponding conductance, C_{e}, for each back-pressure ratio.



Key

X back-pressure ratio, p_2/p_1

Y conductance, C_e

a choked flow region

b subsonic flow region

1 increasing mass flow rate

2 decreasing mass flow rate

Figure 8 — Plot of conductance, C_e, versus back-pressure ratio

6.2.3.8 If the difference between the conductance values of the increasing and decreasing flow rates is greater than 5 % of C_e for the decreasing flow rate at the boundary of the choked flow region, then either the hysteresis curves or no information shall be reported.

6.2.3.9 This allows a first trial of the flow rate curve and an observation of the transition area between choked and subsonic flow. If the choked flow region illustrated in Figure 8 does not appear, repeat the procedure using a higher value for the upstream pressure, p_1.

6.2.4 Measuring procedures for charge test (See Figure 2)

6.2.4.1 Set the upstream pressure, p_1, to approximately 500 kPa (5 bar) to ensure that the flow in the component under test is choked. Measure the downstream pressure, p_2. If the downstream transition connector cannot connect to the component under test, measure the atmospheric pressure as p_2.

6.2.4.2 Measure the choked mass flow rate, q_m*, upstream temperature, T_1*, upstream pressure, p_1*, and downstream pressure, p_2*.

6.2.4.3 Adjust the pressure regulator (item 2) to reduce step by step the upstream pressure, p_1, to obtain two more data points in the choked flow region. Record the same additional data, as in 6.2.4.2.

Allow sufficient time between settings for the system to stabilize because the data cannot be recorded when the flow rate varies continually.

6.2.4.4 Continue adjusting the pressure regulator (item 2) step by step to obtain at least five approximately equally spaced data points in the subsonic flow region. For each data point, measure and record the upstream temperature, T_1, upstream pressure, p_1, mass flow rate, q_m, and downstream pressure, p_2. This is a decreasing flow rate test.

6.2.4.5 To check whether the conductance curve of the component under test has dispersion or hysteresis, adjust the pressure regulator (item 2) to increase step by step the upstream pressure, p_1, to measure five points spread out over the subsonic flow region of back-pressure ratio p_2/p_1 and three points spread out over the choked flow region. This is an increasing flow rate test.

For each point in the subsonic flow region, measure and record the upstream temperature, T_1, upstream pressure, p_1, mass flow rate, q_m, and downstream pressure, p_2.

For each point in the choked flow region, measure and record the upstream temperature, T_1*, upstream pressure, p_1*, choked mass flow rate, q_m*, and downstream pressure, p_2*.

6.2.4.6 If the difference between conductance values of the increasing and decreasing flow rates is greater than 5 % of C_e for the decreasing flow rate at the boundary of the choked flow region, then either the hysteresis curves or no information shall be reported.

6.2.4.7 Using the data from above, make a plot as shown in Figure 8. Calculate the back-pressure ratio for each data point as the ratio of the downstream to upstream measured pressure. Using the formula in 3.4.1, plot the corresponding conductance, C_e, for each back-pressure ratio.

6.2.4.8 If the C_e vary significantly in the choked flow region, the component could be considered to exhibit pressure dependence. In this case, first repeat the procedure in 6.2.4.1 through 6.2.4.5 at the upper limit of the pressure range of the component, then determine the K_p and C in accordance with 6.3.3.

6.3 Calculation of characteristics

6.3.1 Sonic conductance, *C*

6.3.1.1 Calculate the value of the sonic conductance, C, using Formula (1). Values of C_i shall be calculated using data from a component whose back-pressure ratio is in the choked flow region shown in Figure 8:

$$C = \frac{1}{n}\sum_{i=1}^{i=n} C_i \quad \text{where} \quad C_i = \frac{q_{mi}^*}{\rho_0 p_{1i}^*}\sqrt{\frac{T_{1i}^*}{T_0}} \qquad (1)$$

and i is each data point from 1 to n in the choked flow region.

6.3.1.2 When the increasing and decreasing flow test are performed, C is determined by the mean value of each respective test. If the difference exceeds 5 %, report the values from both the increasing and decreasing flow tests.

6.3.1.3 If the component exhibits pressure dependence, use 6.3.3 to determine the coefficient K_p.

6.3.2 Critical back-pressure ratio, *b*, and subsonic index, *m*

6.3.2.1 Using data from decreasing flow rate in the subsonic flow region

Calculate the critical back-pressure ratio, b, and subsonic index, m, using Formula (2) by the least-square method using all sets of back-pressure ratios and conductance ratios (Ce/C) in the subsonic flow region, as well as the cracking pressure, Δpc, determined in 6.2.3.5. Characteristics *b* and *m* shall be calculated with Δpc = 0 in Formula (2) for the variable upstream pressure test. See Annex H for the calculation.

$$\frac{C_e}{C} = \left\{ 1 - \left(\frac{\frac{p_2}{p_1} - b}{1 - \frac{\Delta p_c}{p_1} - b} \right)^2 \right\}^m \qquad (2)$$

6.3.2.2 Using data from the increasing and decreasing flow tests

When the increasing and decreasing flow tests are performed, *b*, *m*, and Δp_c are determined by the mean value of the increasing and decreasing flow tests. If the two values of *b* or the two values of *m* differ by 0,1 or more, or the two values of Δp_c differ by 50 kPa (0,5 bar) or more, the characteristics of both increasing and decreasing flow tests, respectively, should be reported, or the characteristics curve should be reported instead of the numerical values.

6.3.2.3 Value of *m*

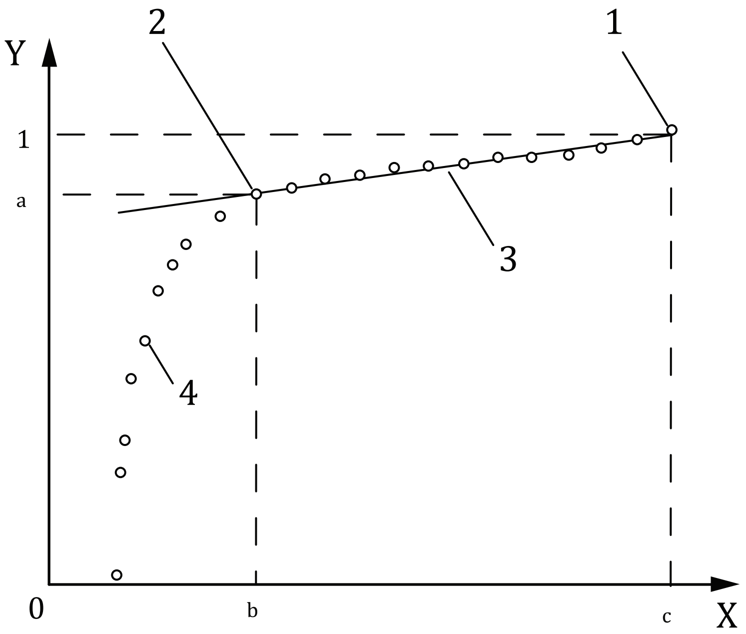
If the value of the subsonic index, *m,* calculated in 6.3.2.1 is between 0,48 and 0,52, its value may be corrected to 0,5 to reduce the number of characteristic parameters. In this case, recalculate the corresponding critical back-pressure ratio, *b*, in accordance with 6.3.2.1, with *m* = 0,5.

6.3.3 Pressure dependence coefficient, K_p

Taking C_{max} as the value of conductance for the maximum upstream pressure, plot the pressure dependence as shown in Figure 9 using the test result stated in 6.2.4.8, then find the correlative line in the range of the conductance ratio close to 1. The plot on this line can be considered to define the choked flow region. The slope of this line is the value of the pressure dependence coefficient, K_p. When selecting a conductance ratio and upstream pressure at two positions on this line, K_p can be calculated by using Formula (3).

$$K_p = \frac{1 - \frac{C_{low}}{C_{max}}}{p_{1max} - p_{1low}} \qquad (3)$$

where p_{1low} is the lower upstream pressure of the linear dependence.



Key

X upstream pressure, p_1

Y conductance ratio, C_e/C_{max}

1 first data point, taken at maximum upstream pressure

2 second point on the line

3 correlative line

4 test results

a conductance ratio, C_{low}/C_{max}

b upstream pressure, p_{1low}

c upstream pressure, p_{1max}

Figure 9 — Plot of conductance ratio versus upstream pressure

7 Presentation of test results

7.1 All measurements, including the inside diameter of the pressure-measuring tube, and the results of calculations shall be tabulated by the testing laboratory.

7.2 If data are to be used for publishing ratings in a catalogue, the average of results from the test units for each characteristic listed in 7.3 shall be reported.

7.3 The following performance characteristics related to flow-rate capacity, which are calculated in accordance with 6.3, shall be stated:

a) sonic conductance, *C* [see item e) below],

b) critical back-pressure ratio, *b*,

c) subsonic index, *m,* and

d) cracking pressure, Δp_c, if its value is not zero,

e) if necessary, pressure dependence coefficient, K_p, and upstream pressure, p_{1max}, at the sonic conductance, C_{max}, and sonic conductance, C_{max}, at the upstream pressure value, p_{1max}.

From these characteristics, the performance of the component can be predicted using Formulae (E.1) and (E.2) of Annex E and compared.

7.4 The record of the calibration of measuring devices shall be available.

8 Identification statement (reference to this part of ISO 6358)

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

"Flow-rate characteristics of pneumatic components determined in accordance with ISO 6358-1, *Pneumatic fluid power — Determination of flow-rate characteristics of components — Part 1: General rules and test methods for steady-state flow.*"

Annex A
(normative)

Alternative test procedure

A.1 General

This alternative test procedure

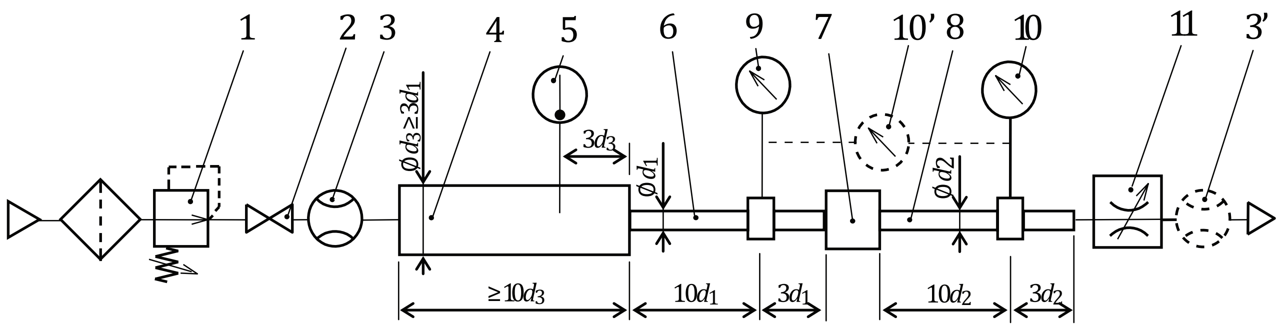
applies only to the constant upstream pressure test and components that reach choked flow,

does not apply to the variable upstream pressure test or components that do not reach choked flow, and

allows the use of the pressure-measuring tubes specified in ISO 6358:1989; however, the new test circuits and components defined in Clause 5 should be used in the future.

A.2 Test circuit for alternative test procedure

A.2.1 The test circuit for this alternative test procedure is shown in Figure A.1. This test circuit differs from the test circuit in Figure 1 in that it does not use transition connectors.



NOTE See Table A.1 for the key of the test circuit components.

Figure A.1 — Alternative test circuit

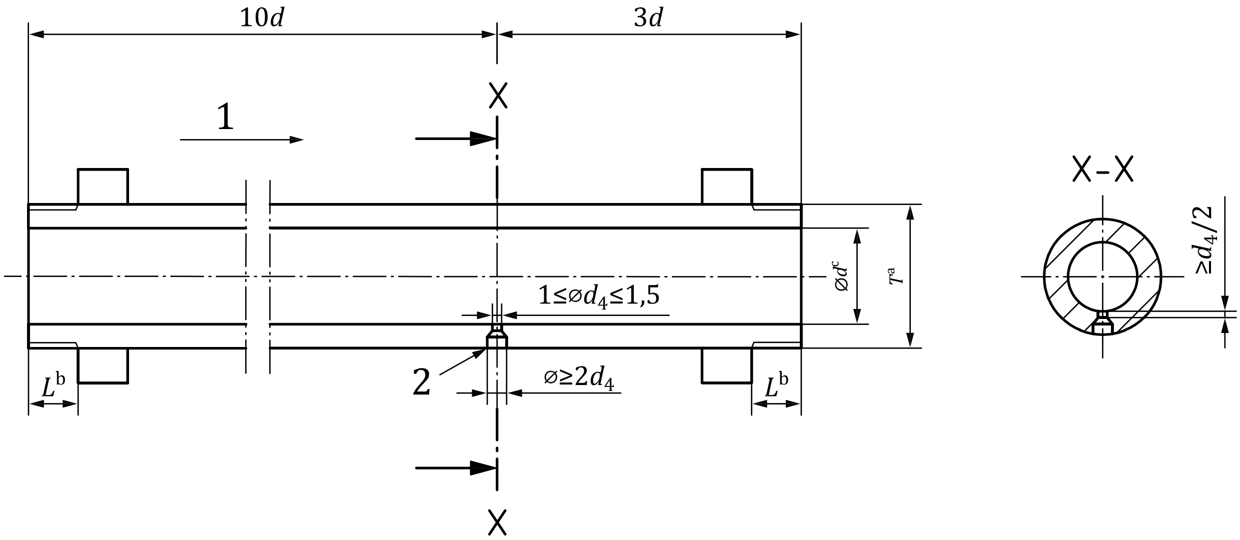
Table A.1 — Key to test circuit components

Key number	Relevant subclause	Description	Comments
1	-	Adjustable pressure regulator	
2	-	Shut-off valve	Preferably with straight flow path
3, 3'	-	Flowmeter	May also be placed in position 3'
4	-	Temperature-measuring tube	See Figure A.1 for dimensions.
5	-	Temperature-measuring instrument	
6	5.4	Upstream pressure-measuring tube	
7	-	Component under test	

Table A.1 *(continued)*

Key number	Relevant subclause	Description	Comments
8	5.4	Downstream pressure-measuring tube	
9	-	Upstream pressure gauge or transducer	
10	-	Downstream pressure gauge or transducer	A differential pressure gauge or transducer 10' may be used as an alternative.
11	-	Flow control valve	With a flow-rate capacity greater than the component under test

A.2.2 The pressure-measuring tube shown in Figure A.2 is the one specified in ISO 6358:1989, but the pressure-measuring tube defined in 5.4 can also be used in the alternative test circuit.



Key

1 flow direction

2 pressure tapping(s)

a Thread to suit component under test.

b Thread length to suit component under test.

c Actual inside diameter of tube.

Figure A.2 — Pressure-measuring tube

A.3 Measuring procedure for alternative test procedure

Follow the constant upstream pressure test procedure specified in 6.2.3. However, using the test circuit in accordance with A.2 measures static pressure, p_s, instead of stagnation pressure, p_t. Therefore, it is necessary to calculate stagnation pressure, p_t, from the measured static pressure, p_s, using Formula (A.1). For each measurement, adjust the value of p_1 to keep constant the upstream stagnation pressure, p_{t1}.

In order for the data to be considered valid, it is necessary that back-pressure ratios in the choked flow region are less than the value of b calculated from the data. If this is not achieved, repeat the test at higher inlet pressures.

A.4 Calculation of stagnation pressure

Calculate stagnation pressure, p_{tx}, from the measured static pressure, p_{sx}, using Formula (A.1):

$$p_{tx} = p_{sx}\left\{\frac{1}{2}+\sqrt{\frac{\gamma-1}{2\gamma}RT_t\left(\frac{q_m}{p_{sx}A_x}\right)^2+\frac{1}{4}}\right\}^{\frac{\gamma}{\gamma-1}} \quad \text{(A.1)}$$

where

A is the cross-sectional area of the inside diameter of the pressure-measuring tube in mm^2,

R is the individual gas constant [at air = 287 J/(kg·K)],

T_t is the measured air temperature in the temperature-measuring tube in K,

γ i is the ratio of specific heat capacities (for air = 1,4), and

subscript x indicates the location of pressure measurement, i.e. upstream or downstream.

Annex B
(informative)

Flowmeter calibration

B.1 General

The flowmeter is a delicate measuring instrument and shall be checked frequently. A flowmeter may have two levels of calibration:

a) A primary calibration, performed in accordance with legal metrology rules, resulting in a calibration curve associated with a measurement uncertainty. From this, a calibration table or a set of functions is used for corrections to the flowmeter readings when used in a laboratory.

b) A secondary calibration checking performed by comparison to a primary device, which permits verifying that precision and bias continue to be under adequate control. These verifications can be made frequently and quickly and can use reference devices such as fixed orifice or, preferably, Venturi nozzles.

B.2 Reference devices

Critical flow Venturi nozzles (CFVN) are widely used as flowmeters, check standards, and transfer standards. The popularity of these devices is a result of their excellent long-term reproducibility, simple geometric design, straightforward application, and well-understood physics.

The flowmeter calibration check in this annex compares the flowmeter readings to those of the reference Venturi nozzles.

ISO 9300 specifies the geometry and method of use (installation in a system and operating conditions) of CFVN used to determine the mass flow rate of a gas flowing through a system.

B.3 Flowmeter calibration checking procedure

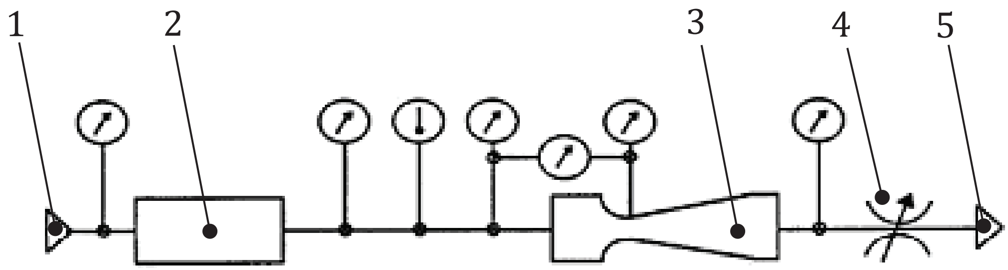
B.3.1 A typical setup for a calibration is shown in Figure B.1, but other arrangements are possible.

B.3.2 Record the barometric pressure.

B.3.3 As flow passes through the system, record the pressures and temperatures.

B.3.4 Compare the flowmeter readings to those of the reference device.

B.3.5 Prepare correction factors to apply to the flowmeter readings for use during testing.



Key

1 air supply

2 flowmeter being calibrated

3 reference Venturi nozzle

4 flow control valve

5 exhaust to atmosphere

Figure B.1 — Circuit for flowmeter calibration

B.4 Application to test data

Apply the correction factors to the flow measurements made during a test run, and use the corrected results as the final data.

Annex C
(informative)

Evaluation of measurement uncertainty

C.1 General

The ISO guide on uncertainty in measurement (GUM:2000) provides the current international consensus method for estimating measurement uncertainty. There are different possibilities to estimate measurement uncertainty; the strict mathematical way is described most extensively in the GUM, but the other pragmatic methods that are in conformity with GUM can be used. The most important rule is: effort and expenditure for determination of uncertainties should be clearly guided by the principle "fit for purpose", that is, it should be good enough to meet the requirements of the user of the measurement data, but it should not be overdone in light of the application. This annex uses this principle.

GUM groups uncertainty components into type A and type B according to the way data were obtained. Type A components are calculated by statistical means from repeated measurements, while type B components are taken from other sources, e.g. reference material, calibration certificates, accepted values of constants, resolution, instability, environmental conditions.

In practice, however, a combined approach is the most suitable. This combined approach will apply very often, as it is impossible to estimate each uncertainty individually. In this case, type B will be used with reference materials and quality control materials to avoid some systematic measuring error. The single uncertainties are combined applying the law of propagation of uncertainty. The type A uncertainty estimate is an estimate derived from the statistical analysis of experimental data. This type of uncertainty evaluation is preferred when the value of a measurand will be the average of several test results or is in relation with non-independent variables.

C.2 Evaluation of measurement uncertainty of the sonic conductance, *C*, using type B

C.2.1 Measurand sonic conductance, *C*

According to this part of ISO 6358, the most important flow-rate characteristic parameter of a pneumatic component is the sonic conductance, C. The equation relating measurand C, i.e. the quantity subject to measurement, and input quantities is:

$$C = \frac{q_{\mathrm{m}}^{*}}{\rho_0 p_1^{*}} \sqrt{\frac{T_1^{*}}{T_0}} \quad C = f\left(q_m^{*}, p_1^{*}, T_1^{*}\right) \tag{C.1}$$

C.2.2 Identification of uncertainty of input quantities

According to Formula (C.1), the input quantities subject to measurement are:

a) q_{m}^{*} – mass flow rate in the choked flow region

Uncertainty follows the accuracy of measuring instrument: $\frac{\Delta q_{\mathrm{m}}^{*}}{q_{\mathrm{m}}^{*}} \le 2\%$

All measurement instability is included in the previous limits of uncertainty. If it is not, the reality in this range of instability must be added at the previous $\Delta q_{\mathrm{m}}^{*}$.

For some kind of flowmeters, additional uncertainty can appear, in particular the value of flow measurement depends on pressure in the conduit. This kind of deviation shall be evaluated and added at the previous Δq_m*. It is preferable to locate the flowmeter upstream, before the upstream pressure measuring tube, because this part is not subject to significant pressure variations.

b) p_1* – upstream stagnation pressure

Uncertainty follows the accuracy of measuring instrument: $\frac{\Delta p_1^*}{p_1^*} \le 0{,}5\%$

Method of measurement of stagnation pressure (wall tapping): $\frac{\Delta p_1}{p_1} = +0{,}75\%$

All measurement instability is included in the previous limits of uncertainty. If it is not, the reality in this range of instability must be added at the previous Δp_1.

c) T_1* – upstream stagnation temperature

Uncertainty follows the accuracy of measuring instrument: $\Delta T_1 \le 1\mathrm{K}$

It shall be noted here that all measurement instabilities are included in the previous limits of uncertainty. If it is not, the reality in this range of instability needs to be added at the previous ΔT_1*.

These input quantities are independent variables and the sensitivity can be calculated.

C.2.3 Sensitivity coefficient

Sensitivity coefficients are obtained from partial derivatives of the model function, *f*, with respect to the input quantities. For the sonic conductance:

$$\frac{\partial f}{\partial q_m^*} = \frac{1}{\rho_0 p_1^*}\sqrt{\frac{T_1^*}{T_0}} = \frac{C}{q_m^*} \text{ for the input } q_m^* \tag{C.2}$$

$$\frac{\partial f}{\partial p_1^*} = \frac{-q_m^*}{\rho_0 p_1^{*2}}\sqrt{\frac{T_1^*}{T_0}} = \frac{-C}{p_1^*} \text{ for the input } p_1^* \tag{C.3}$$

$$\frac{\partial f}{\partial T_1^*} = \frac{1}{2}\frac{q_m^*}{\rho_0 p_1^*\sqrt{T_0 T_1^*}} = \frac{1}{2}\frac{C}{T_1^*} \text{ for input } T_1^* \tag{C.4}$$

C.2.4 Expression of absolute standard uncertainty

The absolute standard uncertainty for the measured sonic conductance is given by:

$$\Delta C = \left|\Delta q_m \frac{\partial f}{\partial q_m}\right| + \left|\left(\Delta p_1 + \Delta_s p_1\right)\frac{\partial f}{\partial q_m}\right| + \left|\Delta T_1 \frac{\partial f}{\partial T_1}\right| \tag{C.5}$$

If the relative or percentage standard uncertainty is desired, it is given by:

$$\Delta C_r\% = 100\frac{\Delta C}{C} \tag{C.6}$$

with $\frac{\Delta C}{C} = \left|\frac{\Delta q_m^*}{q_m^*}\right| + \left|\frac{\Delta p_1^*}{p_1^*}\right| + \left|\frac{\Delta p_1}{p_1}\right| + 0{,}5\left|\frac{\Delta T_1^*}{T_1^*}\right|$

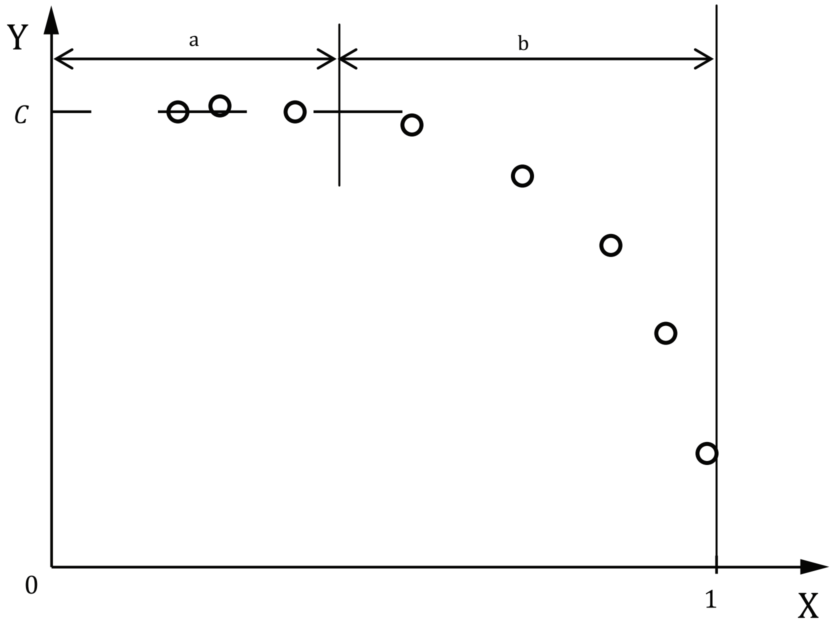
in accordance with Formulae (C.2) to (C.5) and C.2.2.

C.3 Evaluation of measurement uncertainty of the sonic conductance, *C*, using type A

C.3.1 Measurand sonic conductance, *C*

According to this part of ISO 6358, the most important flow-rate characteristic parameter of a pneumatic component is the sonic conductance, *C*. See Formula (C.1).

The conductance, C_e, values can be plotted over the back-pressure ratio, p_2/p_1; see Figure C.1. This curve is independent of the temperature or upstream pressure variations (in the case of variable upstream pressure test) and shows clearly the variation in flow-rate characteristics.



Key

X back-pressure ratio, p_2/p_1

Y conductance, C_e

a choked flow region

b subsonic flow region

○ measurement

Figure C.1 — Graphical representation of conductance, C_e, versus back-pressure ratio

C.3.2 Expression of standard uncertainty

If measurement points in the choked flow region are considered, an estimate of the measurand is obtained that is the average of several measurement points, as follows:

$$C = \frac{1}{n}\sum_{i=1}^{i=n} C_i \quad \text{(C.7)}$$

where

n is the number of measurement points in the choked flow region,

C_i is the measurement result of data at *i*.

The experimental standard deviation, s_c, characterizes the variability of observed values, C_i, in the choked flow region (up to the experimental critical point), as follows:

$$s_c = \sqrt{\frac{\sum_{i=1}^{i=n}(C_i - C)^2}{n-1}} \; (n > 1) \quad \text{(C.8)}$$

This experimental standard deviation of the sonic conductance measurement can be taken as an estimate of uncertainty (type A).

C.4 Evaluation of measurement uncertainty of the critical back-pressure ratio, *b*, and subsonic index, *m*, using type B

C.4.1 Measurands

According to this part of ISO 6358, the second most important flow-rate characteristic parameter of a pneumatic component is the critical back-pressure ratio, *b*. The subsonic index, *m*, is eventually used to represent the subsonic flow behaviour. The equation relating measurands *b* and *m*, i.e. the quantity subject to measurement, and input quantities is:

$$\frac{C_e}{C} = \left\{1 - \left(\frac{\frac{p_2}{p_1} - b}{1 - b}\right)^2\right\}^m \quad \text{(C.9)}$$

This equation is solved by the non linear-least square (NLLSQ) method with the variables as follows:

$$y_i = \frac{C_e}{C} \quad \text{(C.10)}$$

$$x_i = \frac{p_{2,i}}{p_{1,i}} \tag{C.11}$$

The difference between an observed value and the value given by the model is:

$$\delta_i = y_i - \left\{ 1 - \left(\frac{x_i - b}{1 - b} \right)^2 \right\}^m \tag{C.12}$$

The sum of squared difference is the least values (see Annex H). The NLLSQ are conceptually inadequate to generate a statistical estimator of uncertainty. A pragmatic way to estimate the variability of b and m can be to use the NLLSQ with the minimum and maximum values of C found in C.3.2.

C.4.2 Identification and expression of uncertainty

As mentioned in C.4.1, the functional relationship between the measurands b and m and the influence quantities is an arduous task. In this paragraph, two calculations focus on the upper and lower limits of these characteristics. The uncertainty of these flow-rate characteristics is defined here as limits associated with the NLLSQ calculation results from the maximum and minimum sonic conductance determined in the choked flow region. In these conditions:

$$\{C - s_\mathrm{c}\} \rightarrow NLLSQ \rightarrow [b,m]_{C\,\mathrm{min}} \tag{C.13}$$

$$\{C + s_\mathrm{c}\} \rightarrow NLLSQ \rightarrow [b,m]_{C\,\mathrm{max}} \tag{C.14}$$

From these calculation results, the maximum absolute differences between these limits and the best values attributable to these measurands are the two values: $|\Delta b|_\mathrm{max}$ and $|\Delta m|_\mathrm{max}$. These values are now considered as the uncertainty of the result of a measurement, which is expressed as:

$$b \pm |\Delta b|_\mathrm{max} \text{ for the critical back-pressure ratio} \tag{C.15}$$

$$m \pm |\Delta m|_\mathrm{max} \text{ for the subsonic index} \tag{C.16}$$

C.5 Repeatability and reproducibility

A simple method for basing uncertainty estimates on repeatability and reproducibility can be made by statistical means from repeated measurements. This method has a great advantage in that most testing laboratories are already acquainted with repeatability and reproducibility experiments, but this method assumes that all significant systematic effects have been identified and either eliminated or compensated for by the application of suitable corrections.

For complete details, see ISO 5725 (in particular ISO 5725-2) and ISO 21748.

The results of the test may be presented in either tabular or graphical form using the practical units given in Table F.1.

Annex D
(informative)

Observations on error in test results

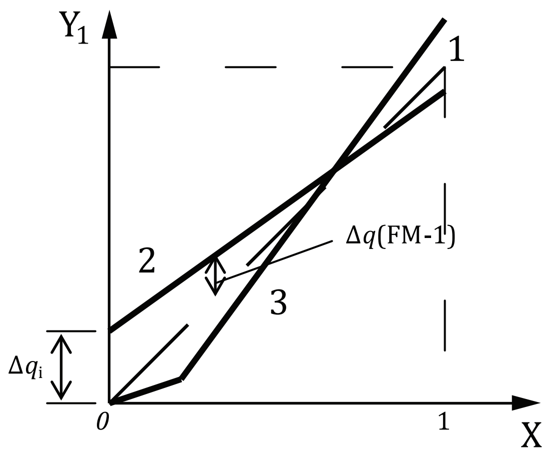
D.1 Error related to flow-rate measurement

Flowmeters available in the market are calibrated to a reference standard, such as a critical flow Venturi nozzle specified by ISO 9300 to measure air flow rate indirectly, and always have an inherent error as shown in Figure D.1. Normally, the error is expressed as a maximum error by a percentage of the full scale, but it should be possible to quantify the error Δq (FM-x) of the flowmeter by using Formula (D.1). The second term in Formula (D.1) shows the slope (K_{fm}) shown in Figure D.1, which appears to depend on the pressure in the measurement of a component.

$$\Delta q(\text{FM-x})\% = \Delta q_i + K_{\text{fm}}\, p_1\% \qquad \text{(D.1)}$$

where x in the expression FM-x designates the specific flowmeter.

The Δq_i in Figure D.1 shows a random scatter (depending on the flowmeter type) and becomes much larger than the value of the second term. It is well known that the reliability of a flowmeter for air is lower than the one for liquids, and the characteristics of the flowmeter used at each test laboratory are difficult to obtain. For this reason, the results of the constant upstream pressure test and variable upstream pressure test conducted in accordance with ISO 6358-1 are largely scattered.



Key

X true value of Δq

Y measured value of Δq

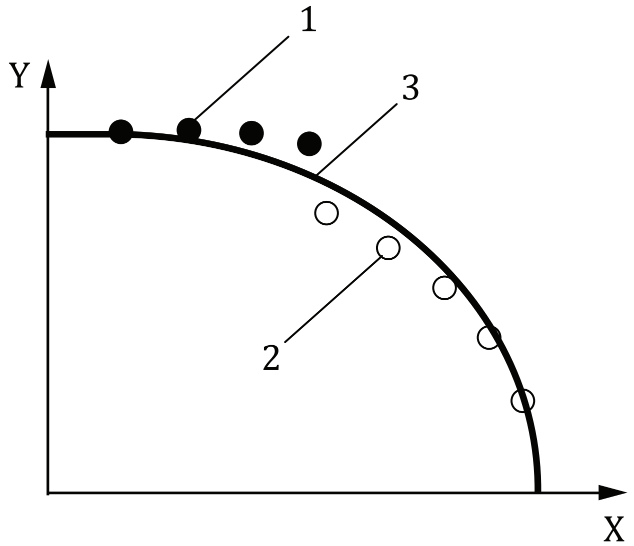
1 ideal

2 flowmeter 1

3 flowmeter 2

Figure D.1 — Characteristic of flowmeter

Care should be taken if several flowmeters are used to measure different ranges of the flow rate during a test. For example, as shown in Figure D.2, if C is calculated based on the values measured in the choked flow region using the flowmeter 1 (FM-1) and b and m are calculated based on the values measured in the subsonic flow region using the flowmeter 2 (FM-2), the calculated value of b can be smaller or larger due to the instrumental errors of the two flowmeters. Careful attention should be paid especially in the variable upstream pressure test, which has a broader flow-rate measurement range.



Key

X back-pressure ratio

Y flow rate

1 flowmeter 1

2 flowmeter 2

3 calculated characteristics

Figure D.2 — Measurement using multiple flowmeters

D.2 Error related to temperature

D.2.1 Stagnation temperature

The measured upstream temperature, T_1, can be converted to the stagnation conditions, T_{STG}, using Formula (D.2). The error created here is related to the Mach number, Ma, of flow in the area of the temperature measuring instrument and is estimated by Formula (D.3). The slope, K_{temp}, is determined in a way similar to that shown in Figure D.1. The error of using T_1 instead of T_{STG} is 1,25 % if the Mach number of the flow does not exceed 0,25 in the temperature measuring area. In Formula (D.2), γ is the ratio of specific heat at constant pressure to the specific heat at constant volume.

$$\frac{T_{STG}}{T_1} = 1 + \frac{1}{2}(\gamma - 1)Ma^2 \quad \text{(D.2)}$$

$$\Delta T_1(\text{STG})\% = K_{temp} p_1 \,\% < 1{,}25\% \quad \text{(D.3)}$$

D.2.2 Temperature measurement

The error caused by the characteristics or mounting method of a temperature-measuring instrument should be recognized as a random error at each test laboratory.

D.3 Error related to pressure

D.3.1 Stagnation pressure

In the round robin testing conducted to support the development of this part of ISO 6358 (see Annex G), upstream pressure, p_1, was measured in a pressure-measuring tube with an inside diameter two sizes larger than the port size of the component. The fluid velocity was low, but not zero, and so the measured static pressure was slightly smaller than the actual stagnation pressure, p_{STG}. According to ISO 9300, the stagnation conditions are converted by Formula (D.4).

When pressure-measuring tubes in accordance with 5.4 are used, the error in using p_1 is 1 % or less in almost all cases. This means that the calculated sonic conductance, C, is about 1 % greater than the result based on the actual stagnation pressure. The error created here is related to the Mach number, Ma, of flow in the area of the pressure-measuring instrument and is estimated by Formula (D.5). The slope, K_{press}, is determined in a way similar to that shown in Figure D.1.

$$\frac{p_{STG}}{p_1} = \left\{1 + \frac{1}{2}(\gamma - 1) Ma^2\right\}^{\frac{\gamma}{\gamma - 1}} \quad \text{(D.4)}$$

$$\Delta p_1 (STG)\% = K_{press} p_1 \% < 1\% \quad \text{(D.5)}$$

D.3.2 Pressure measurement

The error caused by the characteristics or mounting method of pressure gauges should be recognized as the random error at each test laboratory.

D.3.3 Pressure dependence coefficient

As described above, many factors depend on the upstream pressure. Furthermore, there are various types of flow behaviour in pneumatic components, so the flow-rate characteristics are influenced by upstream pressure. This pressure dependence appears in the sonic conductance but rarely appears in the critical back-pressure ratio, b, and subsonic index, m.

Therefore, a combination of these factors can be seen in the test results for the sonic conductance, as expressed in Formula (D.6).

$$\Delta C\% = K_{\mathrm{p}} p_1 \ \% \tag{D.6}$$

Figure D.3 shows examples of the test results. Error of C is calculated using Formula (D.7):

$$\text{Error of } C = \frac{(C - C_{\mathrm{mean}})}{C_{\mathrm{mean}}} \times 100\% \tag{D.7}$$

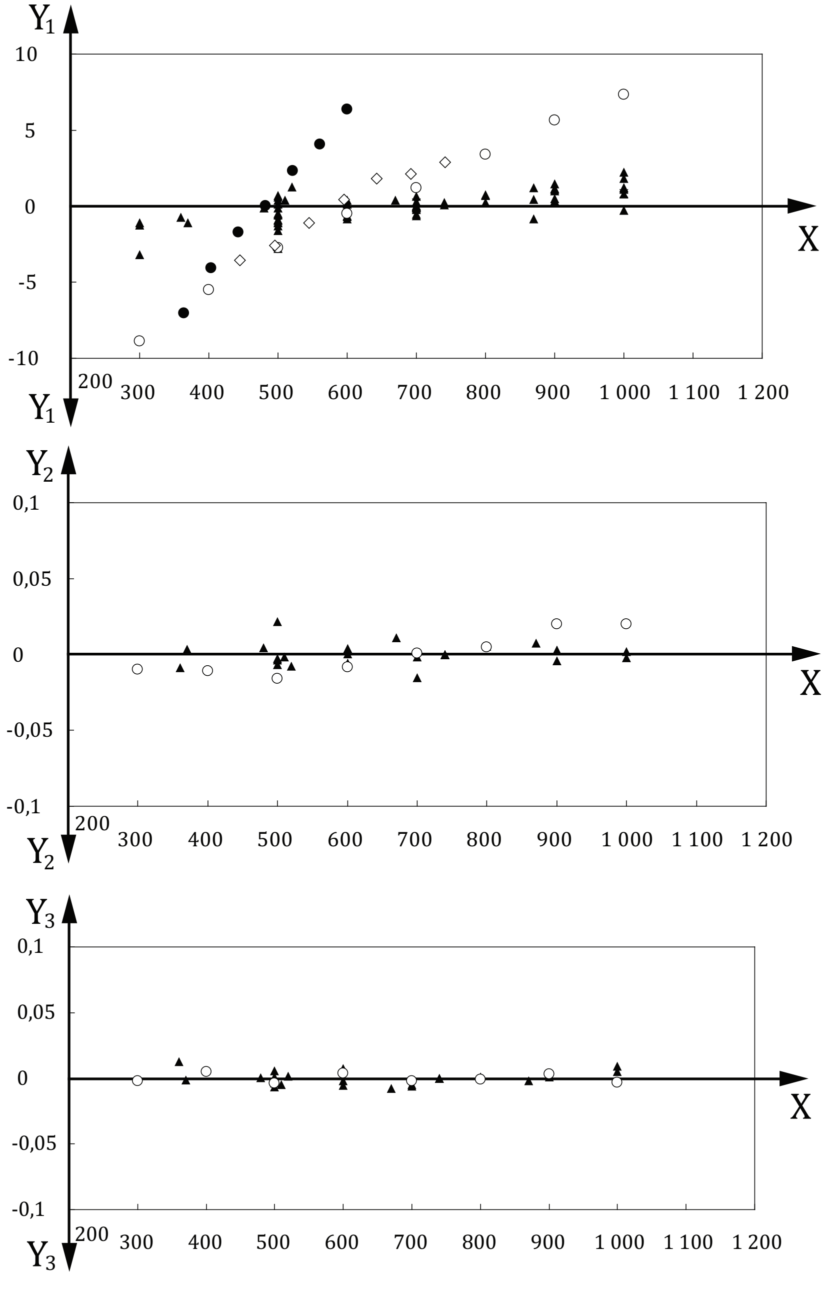
Error of b is calculated using Formula (D.8):

$$\text{Error of } b = b - b_{\mathrm{mean}} \tag{D.8}$$

Error of m is calculated using Formula (D.9):

$$\text{Error of } m = m - m_{\mathrm{mean}} \tag{D.9}$$

The K_{p} of spool type directional control valves with G1/8 to G1/2 size is approximately 0,5 %/kPa (bar). The K_{p} of components whose flow behaviour is close to that of a nozzle does not exceed, for the most part, 1 %/kPa (bar). The K_{p} of silencers with flow passing through porous material made from resin, and tubes with flow that experiences friction loss, is approximately 2 %/kPa (bar). Also, K_{p} of one-way flow control valves in free flow with a fully closed metering valve and lip type non-return valve mounted is approximately 5 %/kPa (bar).


Y1
10
5
0
-5
-10
200
300
400
500
600
700
800
900
1 000
1 100
1 200
X
Y1
Y2
0,1
0,05
0
-0,05
-0,1
200
300
400
500
600
700
800
900
1 000
1 100
1 200
X
Y2
Y3
0,1
0,05
0
-0,05
-0,1
200
300
400
500
600
700
800
900
1 000
1 100
1 200
X
Y3

Key

X upstream pressure, p_1 (kPa)

Y_1 error of C (%)

Y_2 error of b

Y_3 error of m

▲ directional control valve (JP, FR, US)

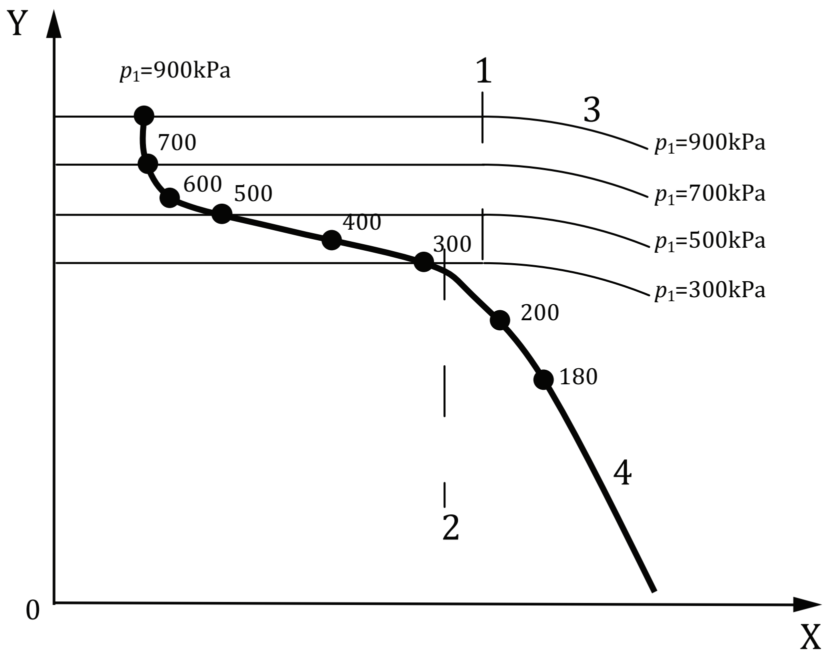
○ tube

◇ silencer

● flow control valve

Figure D.3 — Error due to upstream pressure

For the variable upstream pressure test, C also varies slightly in the choked flow region due to the dependence on pressure as shown previously in Figure D.3. In addition, it shall be recognized that each data point obtained from that test is on a separate flow curve, as shown in a detailed way in Figure D.4, because the inlet pressure is different for each data point. Here again, some human error can be generated in taking these different measurements.



Key

X back-pressure ratio, p_2/p_1

Y conductance, C_e

1 b from constant upstream pressure test

2 b from variable upstream pressure test

3 constant upstream pressure test

4 variable upstream pressure test

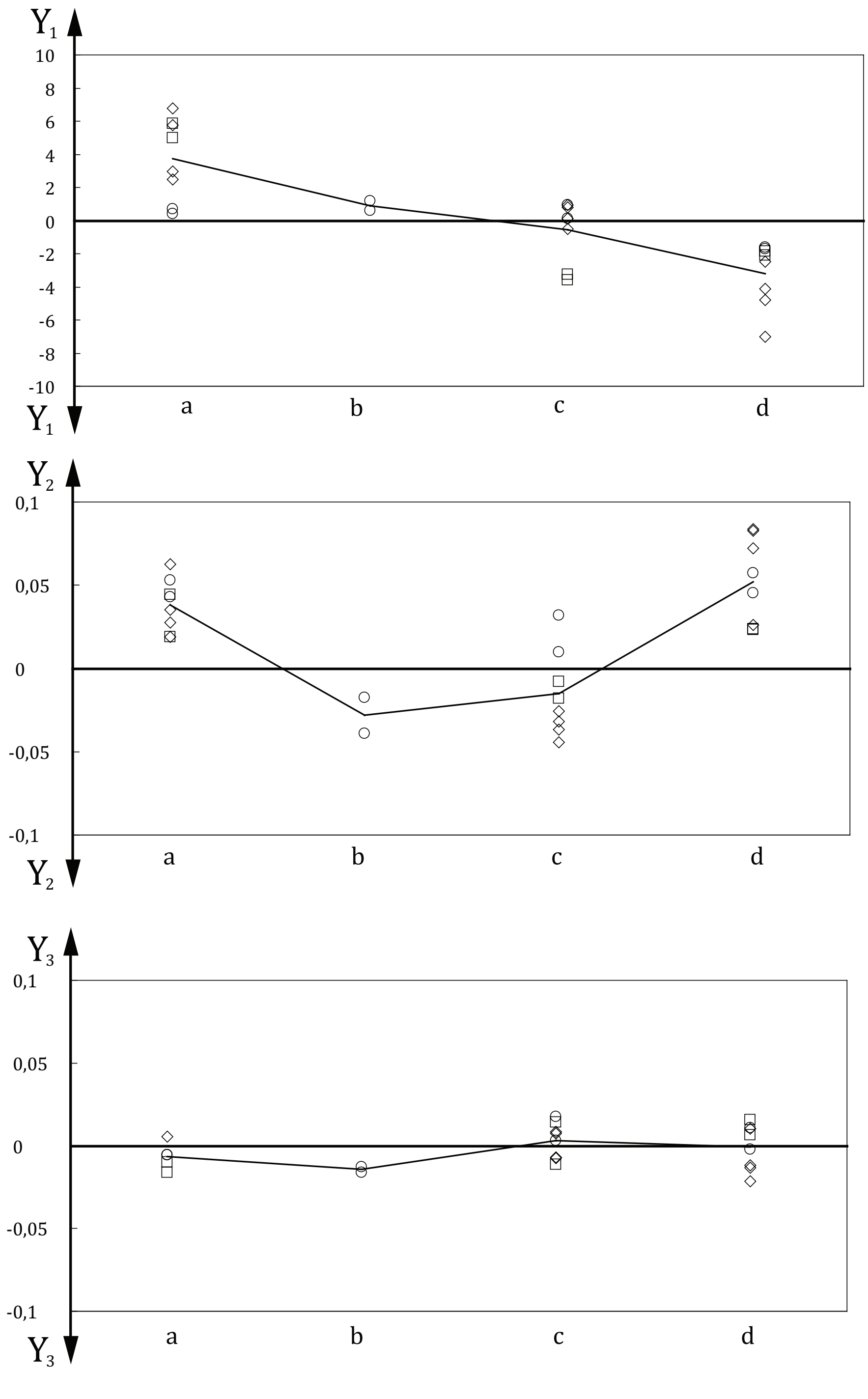
Figure D.4 — Choked flow region of the variable upstream pressure test

D.4 Total amount of error

The error distribution of the results of the round robin test on solenoid valves is shown in Figure D.5. Also, the error distribution of each laboratory is shown in Figure D.6. The error of the sonic conductance, *C*, from constant upstream pressure test is the largest, and that of the charge test (see ISO 6358-2) is the smallest.

The reason why the error of *C* from the discharge test (see ISO 6358-2) is smaller than that of the constant upstream pressure test and variable upstream pressure test can be attributed to the dependence on pressure and temperature. The reason why the error of *C* from the charge test is the smallest would be attributed to the dependence on pressure under the condition where the upstream pressure is the atmospheric pressure.

The difference between the largest error of *b* obtained by the charge test as well as the constant upstream pressure test and the smallest error of *b* obtained by the variable upstream pressure test is about 0,08. The difference between the largest error of *m* and smallest error of *m* is 0,02.

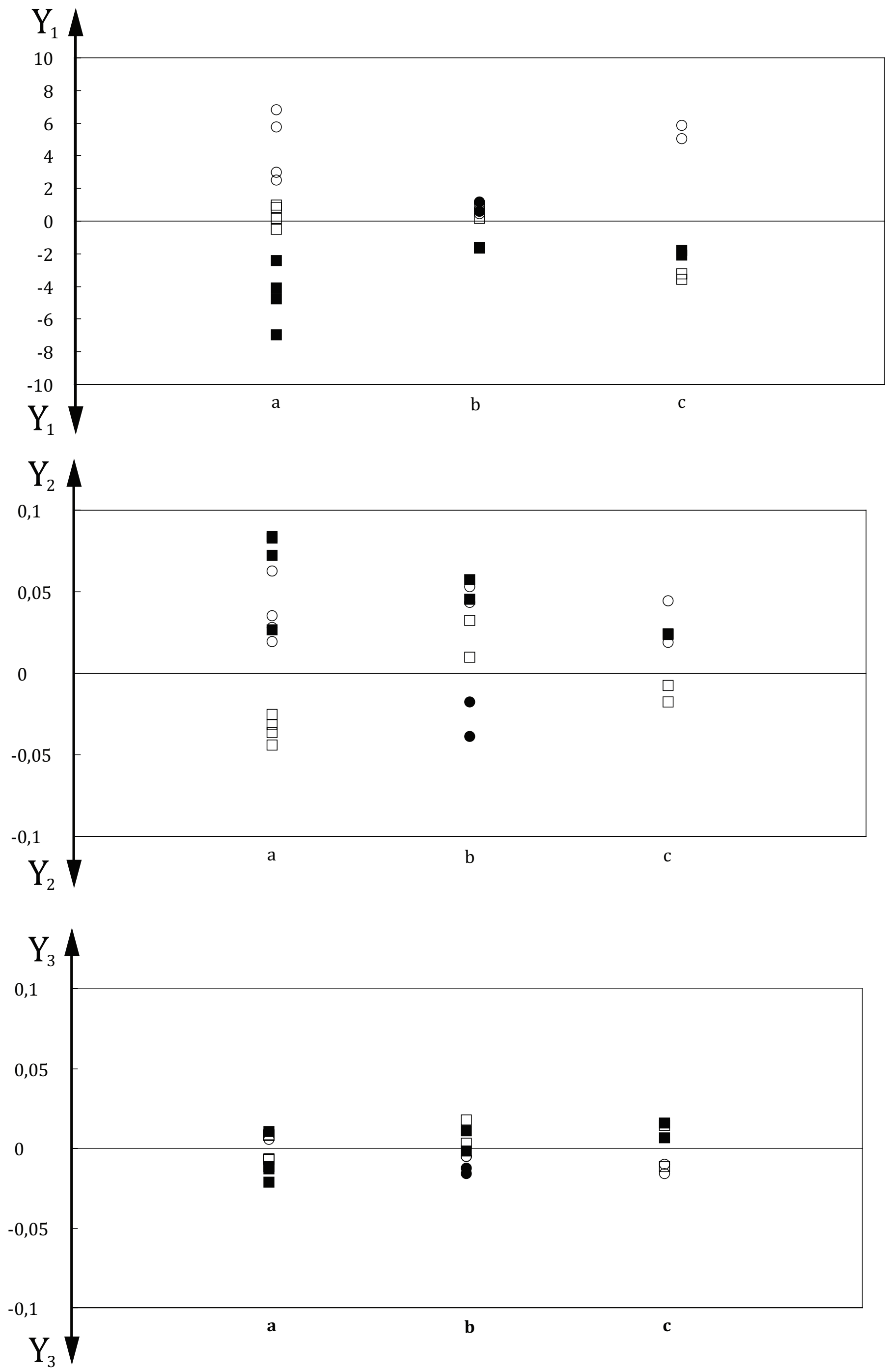

Y1
10
8
6
4
2
0
-2
-4
-6
-8
-10
a
b
c
d
Y1
Y2
0,1
0,05
0
-0,05
-0,1
a
b
c
d
Y2
Y3
0,1
0,05
0
-0,05
-0,1
a
b
c
d
Y3

Key

Y_1 error of C (%)
Y_2 error of b
Y_3 error of m
a constant upstream pressure test
b variable upstream pressure test
c discharge test
d charge test

◇ laboratory a
○ laboratory b
□ laboratory c
— mean

Figure D.5 — Error distributions for each test method


Y1
10
8
6
4
2
0
-2
-4
-6
-8
-10
Y1
a
b
c
Y2
0,1
0,05
0
-0,05
-0,1
Y2
a
b
c
Y3
0,1
0,05
0
-0,05
-0,1
Y3
a
b
c

Key

Y_1 error of C (%)
Y_2 error of b
Y_3 error of m
a laboratory a
b laboratory b
c laboratory c

○ constant upstream pressure test
● variable upstream pressure test
□ discharge test
■ charge test

Figure D.6 — Error distributions for each laboratory

Annex E
(informative)

Equations and graphical representations of flow-rate characteristics

E.1 General

This annex describes the application of the technology developed in this part of ISO 6358.

E.2 Equations

E.2.1 Flow-rate characteristics of a pneumatic component can be approximated by Formulae (E.1) to (E.3). These equations show an irrecoverable pressure energy loss caused by the turbulent flow through a component. They use four characteristic parameters C, b, m, and Δp_c.

— For choked flow, i.e. when $p_2/p_1 \le b$,

$$q_m^* = C p_1^* \rho_0 \sqrt{\frac{T_0}{T_1^*}} \qquad \text{(E.1)}$$

For subsonic flow, i.e. when $b < p_2 / p_1 \le -\frac{\Delta p_c}{p_1}$,

$$q_m = C p_1 \rho_0 \sqrt{\frac{T_0}{T_1}} \left\{ 1 - \left(\frac{\frac{p_2}{p_1} - b}{1 - \frac{\Delta p_c}{p_1} - b} \right)^2 \right\}^m \qquad \text{(E.2)}$$

For the case when: $1 - \frac{\Delta p_c}{p_1} < p_2 / p_1 \le 1$, then, $q_m = 0$

(E.3)

E.2.2 As an option, the pressure dependency of sonic conductance expressed by upstream pressure can be approximated by using Formula (E.4):

$$\frac{C}{C_{max}} = 1 - K_p \left(p_{1max} - p_1 \right) \qquad \text{(E.4)}$$

where C_{max} is the sonic conductance for the maximum upstream pressure, p_{1max}.

E.3 Priority order of the characteristic parameters in practical use

E.3.1 Sonic conductance, *C*

The use of sonic conductance, *C,* is the first priority. If the maximum flow rate of a component needs to be identified, only *C* may be used.

E.3.2 Sonic conductance, *C*, and critical back-pressure ratio, *b*

The use of sonic conductance, *C*, with critical back-pressure ratio, *b*, is the second priority. As shown in Figure G.3, some components (such as solenoid valves and blow nozzles) have a subsonic index, *m*, close to 0,5, and cracking pressure $\Delta p_c = 0$. In these cases, only *C* and *b* may be applied. Formula (E.2) is expressed as follows:

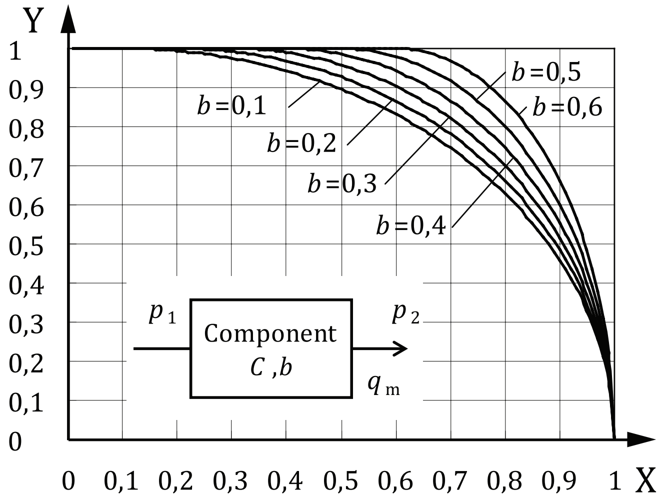
$$q_m = C p_1 \rho_0 \sqrt{\frac{T_0}{T_1}} \sqrt{1 - \left(\frac{\frac{p_2}{p_1} - b}{1 - b} \right)^2} \qquad \text{(E.5)}$$

In the case where *m* is actually different than 0,5, an error in the value of *b* occurs if *m* is still assumed to be 0,5, as shown in Figure G.5. For example, when a component whose *m* = 0,55, *b* is smaller by approximately 0,05 to 0,1 (if *m* is assumed to be 0,5). Therefore, the ability of the component is underestimated.

Using the conductance ratio defined in Formula (2) in 6.3.2.1, and assuming $\Delta p_c = 0$ and *m* = 0,5,

$$C_e = \frac{q_m}{\rho_0 p_1} \sqrt{\frac{T_1}{T_0}} \qquad \text{(E.6)}$$

The influence of parameter *b* is demonstrated in Figure E.1.



Key

X back-pressure ratio, p_2/p_1

Y conductance ratio, C_e/C

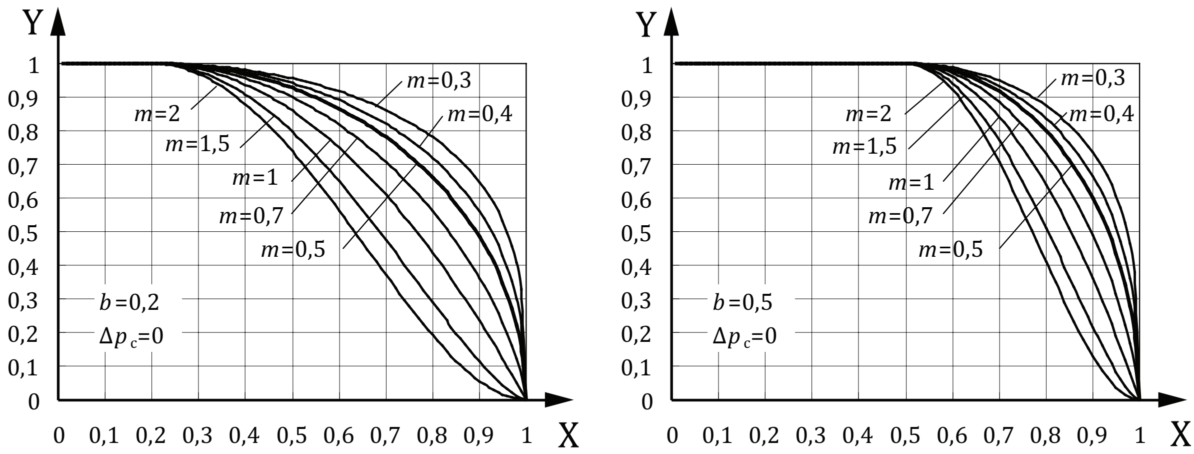
Figure E.1 — Typical graphical representation of conductance ratio versus back-pressure ratio for *m* = 0,5 and $\Delta p_c = 0$

E.3.3 Sonic conductance, *C*, critical back-pressure ratio, *b*, and subsonic index, *m*

The use of sonic conductance, *C*, with critical back-pressure ratio, *b*, and subsonic index, *m*, is the third priority. These parameters are applied to a component whose cracking pressure, Δp_c, can be considered as 0. In this case, Formula (E.2) becomes Formula (E.7) and is expressed as follows:

$$q_m = Cp_1\rho_0\sqrt{\frac{T_0}{T_1}}\left\{1-\left(\frac{\frac{p_2}{p_1}-b}{1-b}\right)^2\right\}^m \quad \text{(E.7)}$$

Figure E.2 shows the influence of the subsonic index *m* on the form of the subsonic flow region of the conductance curve when the sonic conductance is the same, Δp_c is 0, for two different values of the back-pressure ratio *b*. In this graph, when *m* is 0,5, an ellipse can approximate the curve, and when *m* is 1,0, it is approximated by a parabola.



Key

X back-pressure ratio, p_2/p_1

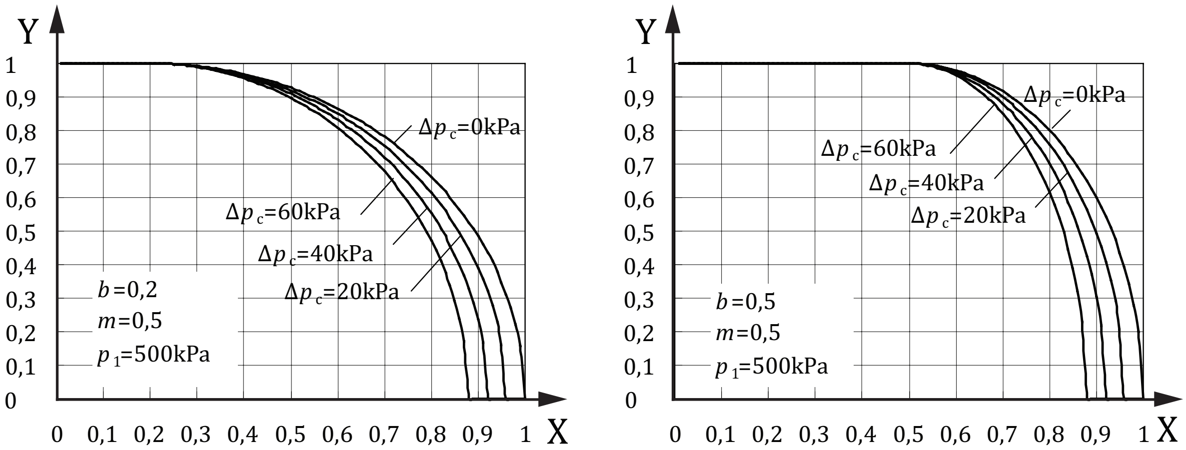
Y conductance ratio, C_e/C

Figure E.2 — Typical graphical representation of conductance ratio versus back-pressure ratio for a given value of *b* and Δp_c = 0 showing the influence of subsonic index, *m*

E.3.4 Sonic conductance, *C*, critical back-pressure ratio, *b*, subsonic index, *m*, and cracking pressure, Δp_c

The use of *C*, *b*, *m*, and Δp_c is the fourth priority. When a component has cracking pressure characteristics, as shown in Figure E.4, the flow-rate characteristics can be properly approximated using Formulae (E.1) to (E.3).

When flow starts and stops passing through some components, such as a non-return (check) valve, cracking pressure becomes zero or more. In order to present flow-rate characteristics when cracking occurs, cracking pressure, Δp_c, is used as shown in Figure E.3 for fixed values of *b* and *m* to demonstrate its influence on the conductance curve for the same sonic conductance.



Key

X back-pressure ratio, p_2/p_1

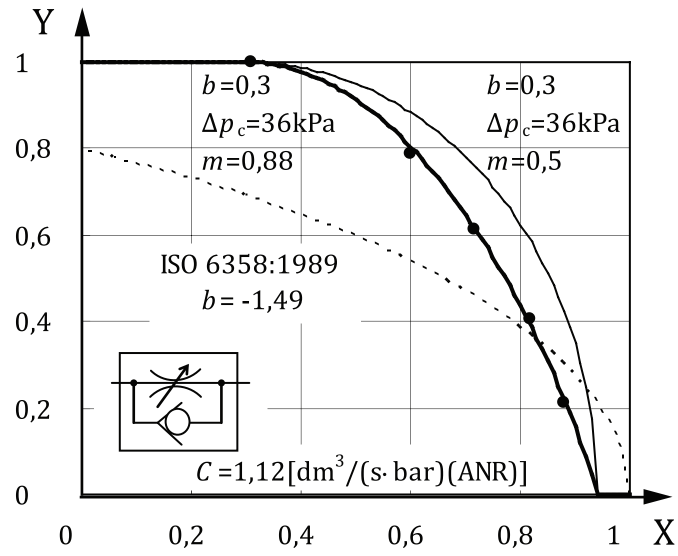
Y conductance ratio, C_e/C

Figure E.3 — Typical graphical representation of conductance ratio versus back-pressure ratio with variable Δp_c for given values of *b*, *m*, and p_1

E.4 Flow-rate characteristics in subsonic flow

An example of a one-way flow control valve in free flow (with the metering valve fully closed) is given in Figure E.4. Plotted points are the measured results when upstream pressure, p_1, is 600 kPa, which is obtained in accordance with Clause 6 of ISO 6358:1989. When calculating the characteristics using the measured results in accordance with the characteristic calculation procedure in 6.3 of ISO 6358:1989, a sonic conductance, *C*, of 1,12 dm^3/(s.bar)(ANR) (see Annex F for practical units) and a critical back-pressure ratio, *b*, of −1,5 are obtained. Substituting these values for *C* and *b* into the basic theoretical equations described in Annex C of ISO 6358:1989, a characteristic curve plotted as a broken line is obtained and appears to drastically deviate from the measured results.

Using this part of ISO 6358, derived Δp_c = 36kPa, *m* = 0,88, and *b* = 0,30 are obtained, assuming that the data would have come from the pressure-measuring tubes and transition connectors in accordance with this part of ISO 6358. From these values, the curve is plotted in Figure E.4 as a bold solid line. If the value of *m* = 0,5 is used (the value called for in ISO 6358:1989), the light solid line results. It is obvious that the characteristics in subsonic flow do not fit the elliptical curve.



Key

X back-pressure ratio, p_2/p_1

Y conductance ratio, C_e/C

Figure E.4 — Data example of a one-way flow control valve

Annex F
(informative)

Use of practical units

The results of the test may be presented in either tabular or graphical form using the practical units given in Table F.1.

Table F.1 — Practical units

Quantity	Symbol	Practical unit
Critical back-pressure ratio	b	–
Sonic conductance	C	$dm^3/(s·kPa)$(ANR) or $dm^3/(s·bar)$ (ANR)[a]
Subsonic index	m	–
Pressure dependence coefficient	K_p	%/bar
Absolute stagnation pressure	p	MPa, kPa or bar
Mass flow rate	q_m	g/s or kg/s
Volume flow rate at standard reference atmosphere	q_V	dm^3/s (ANR) or dm^3/min (ANR)
Gas constant	R	J/(kg·K)
Absolute temperature	T	K
Cracking pressure	Δp_c	MPa, kPa or bar
Mass density	ρ	g/dm^3

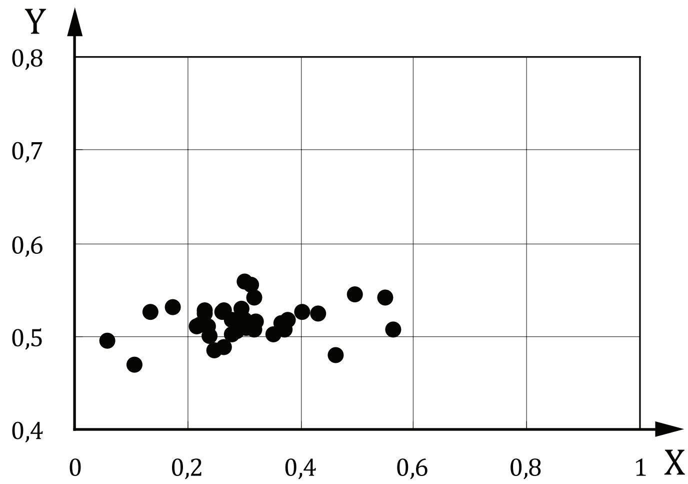
[a] 1 bar = 100 kPa = 0.1 MPa = 10^5 Pa = 10^5 N/m^2

Annex G
(informative)

Results of testing performed on commercially available pneumatic components

G.1 Example of test result

Examples of tests done on various types of components made by multiple manufacturers are given below. Figure G.1 shows results of tests performed on two-port, three-port, and five-port solenoid valves in terms of subsonic index, *m,* and critical back-pressure ratio, *b*. Critical back-pressure ratio, *b,* is widely distributed; its average is 0,31, and its standard deviation is 0,110. Subsonic index, *m,* is narrowly distributed; its average is 0,52, and its standard deviation is 0,034. Figure G.2 shows results of tests performed on a silencer in a correlation of *m* and *b.* The average of critical back-pressure ratio, *b,* is 0,22 while the standard deviation is 0,147. Subsonic index, *m,* is widely distributed; its average is 0,78, and its standard deviation is 0,306. Table G.1 shows a test result of a cracking pressure of a one-way flow control valve in free flow with the metering valve fully closed. The total average Δp_c is 22 kPa.

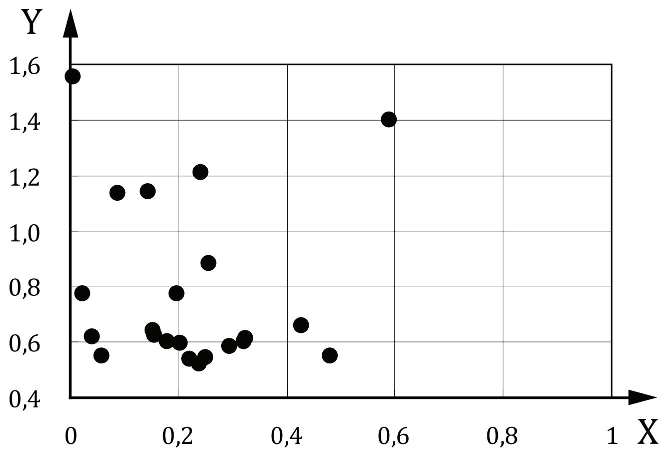


Key

X critical back-pressure ratio, *b*

Y subsonic index, *m*

Figure G.1 — Subsonic index, *m*, and critical back-pressure ratio, *b*, of a solenoid valve



Key

X critical back-pressure ratio, *b*

Y subsonic index, *m*

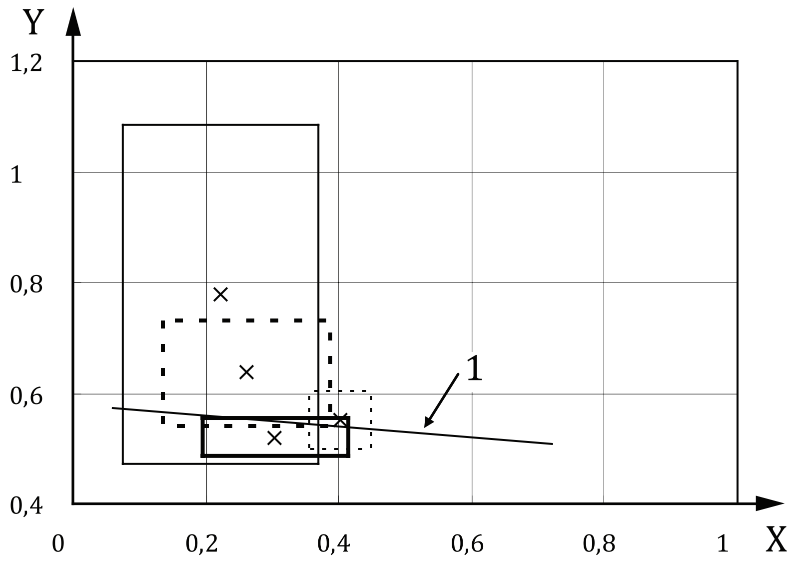
Figure G.2 — Subsonic index, *m*, and critical back-pressure ratio, *b*, of a silencer

Table G.1 — Cracking pressure, Δp_c, of a one-way flow control valve in free flow (with the metering valve fully closed)

Type of check valve	Average	Standard deviation
Poppet and spring	17 kPa	15 kPa
Lip packing	26 kPa	9 kPa
Total	22 kPa	13 kPa
NOTE Upstream pressure p_1 = 600 kPa.		

G.2 Distribution of flow characteristics for various types of component

More than 200 tests were performed on five types of components made by seven manufacturers. The data are summarized in Figure G.3. Plotted points specify the averages of the components. Areas enclosed with lines indicate ranges of standard deviations. For the solenoid valve and blow nozzle, the data form a curve close to an elliptical curve whose *m* is 0,5. For the silencer and one-way flow control valve (in free flow with the metering valve fully closed), the data largely deviate from the elliptical curve and are also widely distributed. For the resin tube, as its length becomes longer, *b* decreases and *m* increases from 0,5 to 0,6.



Key

X critical back-pressure ratio, *b*

Y subsonic index, *m*

1 resin tube

——— solenoid valve

- - - - - blow nozzle

——— silencer

— — — one-way flow control valve (free flow)

Figure G.3 — Distribution of flow-rate characteristics of various types of pneumatic components

Figure G.4 shows the ranges of components to which ISO 6358:1989 and this part of ISO 6358 apply. ISO 6358:1989 covered the centre circle (m = 0,5 and Δp_c = 0). ISO 6358-1 covers various kinds of components and systems, for example, silencers, non-return (check) valves, resin tubes, combined components such as valve manifolds and cylinder end heads, and combined systems.

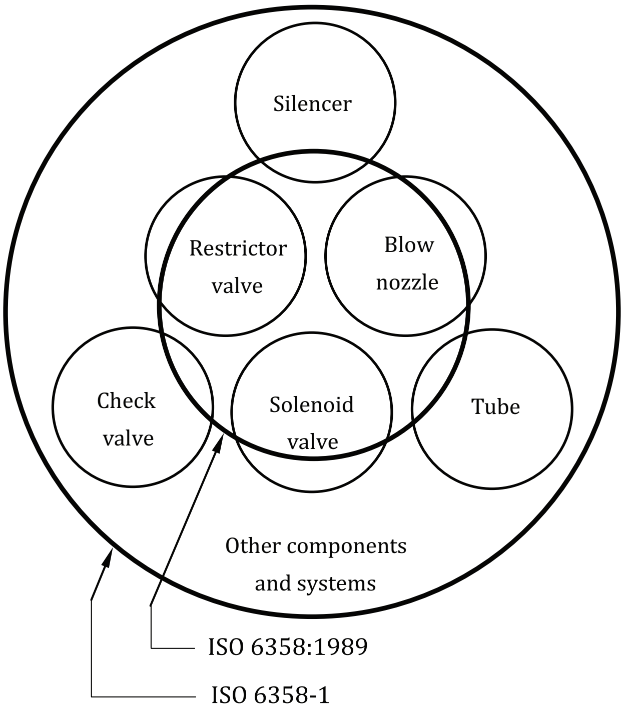
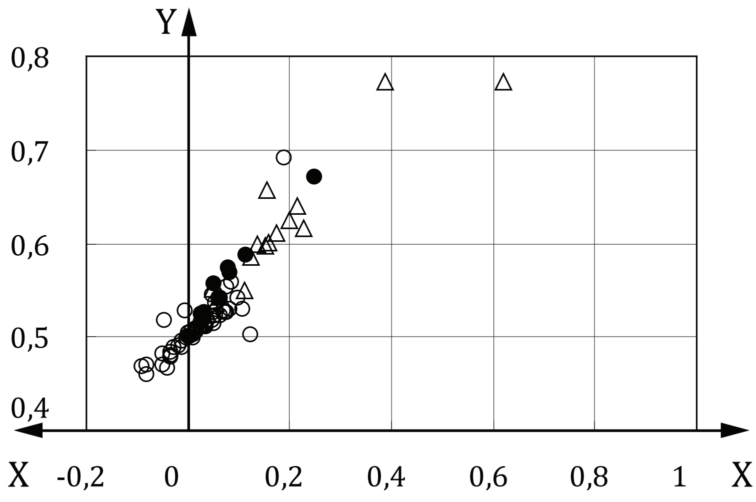


Figure G.4 — Applicability of ISO 6358:1989 and ISO 6358-1

G.3 Correlation with calculated values of *b*

Consider a component whose critical pressure ratio, b_e, is determined in accordance with ISO 6358:1989, where the value of $m = 0,5$. If the value of m with critical back-pressure ratio, b, for the component is actually greater than 0,5, (as determined in accordance with this part of ISO 6358) the critical pressure ratio, b_e, becomes much smaller than b. Figure G.5 shows the subsonic index, m, plotted against the difference $(b - b_e)$. For example, when $m = 0,6$, the calculated value of b is approximately 0,2 greater than b_e. The calculation result with b and m becomes significantly better to agree with the test measurement result.



Key

X b-b_e

Y subsonic index, m

○ solenoid valve

● blow nozzle

○ silencer

Figure G.5 — Correlation of *m* and differences between *b* and b_e

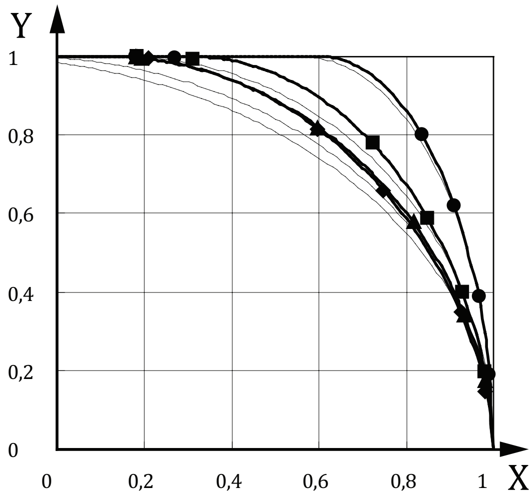
G.4 Test results on pneumatic tube

Tests were performed on a total of 12 flexible tubes with different combinations of outside and inside diameters of 4 mm/2,5 mm, 6 mm/4 mm, and 8 mm/6,5 mm, and lengths of 0,1 m, 1 m, 10 m, and 20 m. All of the tubes are made from polyurethane. For the pressure-measuring tube, size G 1/4 is selected. Upstream pressure is set to 500 kPa.

The flow-rate characteristics for each inside diameter are shown in Figures G.6 to G.8. It appears that flow-rate characteristics curve assumed m = 0,5 does not represent the flow-rate characteristics exactly. Sonic conductance, C, critical back-pressure ratio, b, and subsonic index, m, are obtained using this part of ISO 6358.

From the test results, the relationship between C and L/d is shown in Figure G.9. The relationship between b and C/d^2 is shown in Figure G.10. The relationship between m and b is shown in Figure G.11.

The approximate Equations (G.1) to (G.3) are obtained from Figures G.9 to G.11, where C is the sonic conductance in $dm^3/(s·bar)$(ANR), b is critical back-pressure ratio, m is subsonic index, d is the inside diameter of tube in millimetres, and L is length of tube in metres.



Key

X back-pressure ratio, *p2*/*p1*

Y conductance ratio, *Ce*/*C*

● 0.1 m

■ 1 m

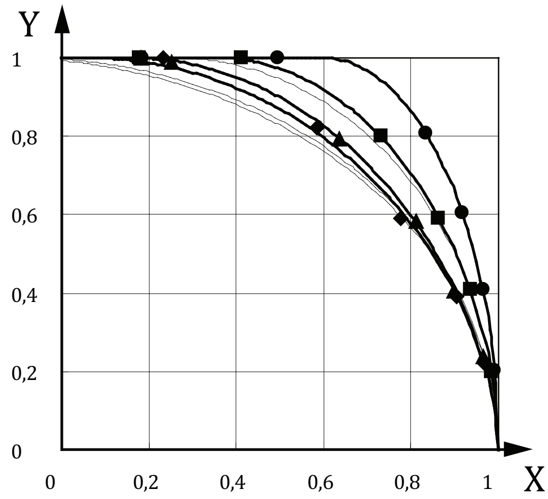
▲ 10 m

◆ 20 m

——— (thin line) ISO 6358:1989

——— (thick line) ISO 6358-1

Figure G.6 — Flow-rate characteristics of pneumatic tube (inside diameter 2,5 mm)



Key

X back-pressure ratio, p_2/p_1

Y conductance ratio, C_e/C

● 0.1 m

■ 1 m

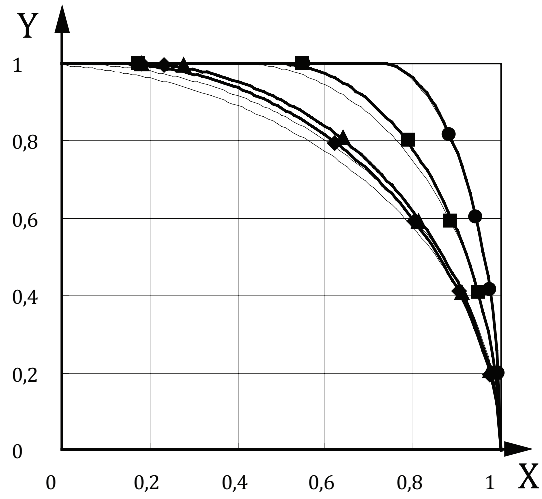
▲ 10 m

◆ 20 m

——— (thin line) ISO 6358:1989

——— (thick line) ISO 6358-1

Figure G.7 — Flow-rate characteristics of pneumatic tube (inside diameter 4 mm)



Key

X back-pressure ratio, p_2/p_1

Y conductance ratio, C_e/C

● 0.1 m

■ 1 m

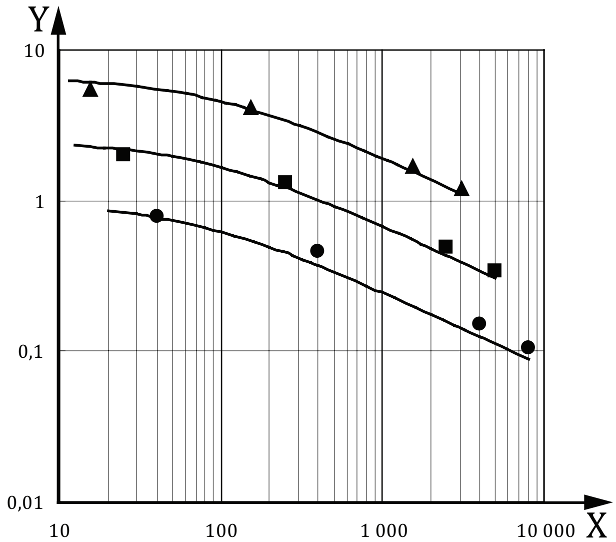
▲ 10 m

◆ 20 m

──── (thin line) ISO 6358:1989

──── (thick line) ISO 6358-1

Figure G.8 — Flow-rate characteristics of pneumatic tube (inside diameter 6,5 mm)



Key

X L/d

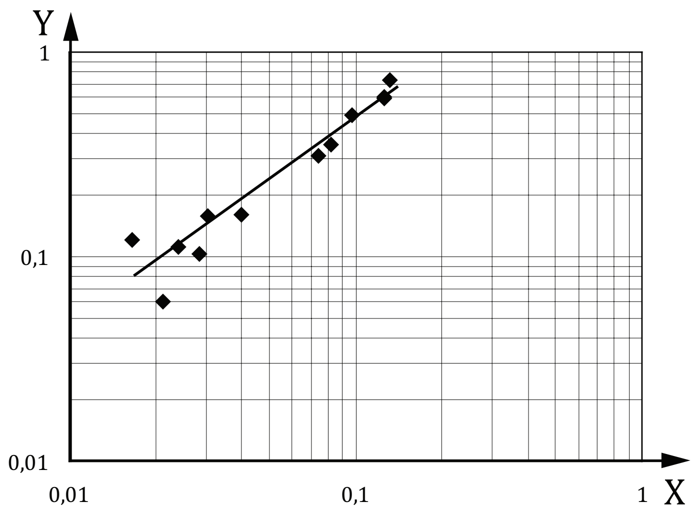
Y sonic conductance, C [dm^3/(s·bar)(ANR)]

▲ 8 mm/6,5 mm

■ 6 mm/4 mm

● 4 mm/2,5 mm

Figure G.9 — Relationship between *C* and *L*/*d*

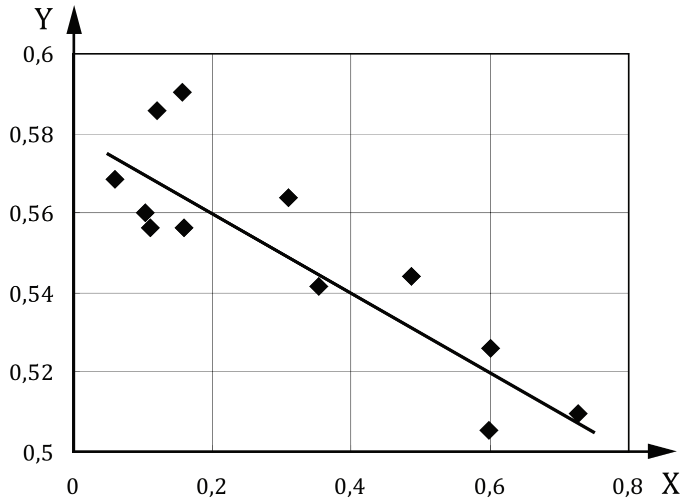


Key

X C/d^2

Y critical back-pressure ratio, b

Figure G.10 — Relationship between *b* and C/d^2



Key

X critical back-pressure ratio, *b*

Y subsonic index, *m*

Figure G.11 — Relationship between *m* and *b*

$$C = \frac{\pi}{20} d^2 \frac{1}{\sqrt{\frac{20L}{d^{1,31}} + 1}} \quad \text{(G.1)}$$

$$b = 4,8 \frac{C}{d^2} \quad \text{(G.2)}$$

$$m = -0,1b + 0,58 \quad \text{(G.3)}$$

Annex H
(informative)

Procedures for calculating critical back-pressure ratio, *b*, and subsonic index, *m*, by the least-square method using the Solver function in Microsoft Excel

H.1 Using data from decreasing flow tests

Critical back-pressure ratio, *b*, and subsonic index, *m*, are calculated by the least-square method using Equation (H.1), back-pressure ratio, $x_i = p_2/p_1$, conductance ratio, $y_i = C_e/C$, and cracking pressure ratio, $a = 1 - \Delta p_c/p_1$. *b* and *m* are calculated with $a = 1$ in Equation (H.1) for the variable upstream pressure test. Five points are measured in the range of subsonic flow, as shown in Table H.1.

Table H.1 — Pressure and conductance ratios

Measured value	
p_2/p_1	C_e/C
x_1	y_1
x_2	y_2
x_3	y_3
x_4	y_4
x_5	y_5

$$\frac{C_e}{C} = \left\{1 - \left(\frac{x_i - b}{a - b}\right)^2\right\}^m \quad \text{(H.1)}$$

Determine *b* and *m* so that the total sum, *E* [see Equation (H.3)], becomes the least of the squared difference, δ_i [see Equation (H.2)] between conductance ratio, C_e/C, or $\left[1 - \left\{(x_i - b)/(a - b)\right\}^2\right]^m$, calculated by substituting the measured back-pressure ratio, x_i, in Equation (H.1), and flow-rate ratio, y_i, obtained by measurement. An example calculation is shown in H.3.

$$\delta_i = y_i - \left\{1 - \left(\frac{x_i - b}{a - b}\right)^2\right\}^m \quad \text{(H.2)}$$

$$E = \sum_{i=1}^{N} \delta_i^2$$

$$= \left[y_1 - \left\{1 - \left(\frac{x_1 - b}{a - b}\right)^2\right\}^m\right]^2 + \left[y_2 - \left\{1 - \left(\frac{x_2 - b}{a - b}\right)^2\right\}^m\right]^2 + \left[y_3 - \left\{1 - \left(\frac{x_3 - b}{a - b}\right)^2\right\}^m\right]^2 + \cdots + \left[y_N - \left\{1 - \left(\frac{x_N - b}{a - b}\right)^2\right\}^m\right]^2$$

(H.3)

H.2 Calculating parameters using data from both increasing and decreasing flow rates as defined in 6.3.1.2 and 6.3.2.1

Prepare a data calculation table similar to the example given in Table H.2; additional columns for pressures and other data are helpful.

Table H.2 — Arbitrary example data from testing conducted at increasing and decreasing flow rates

Condition	No.	Flow rate	Ratio p_2/p_1	C_e	C_e/C	b	m	δ	δ^2	$\sum\delta^2$
Increasing flow rate	1	0	0,99	•	0,01	0,400	0,500	•	•	~ 0
	2	1	0,90	•	0,24			•	•	
	3	2	0,75	•	0,57			•	•	
	4	3	0,60	•	0.74			•	•	
	5	4	0,45	•	0,82			•	•	
	6	5	0,35	•	0,92			•	•	
	7	6	0,25	•	0,98				0	
	8	7	**0,20**	•	1,00				0	
Choked flow region	9	7	**0,15**	•	1,00				0	
	10	7	**0,12**	•	0,99				0	
	11	7	**0,15**	•	1,01				0	
Decreasing flow rate	12	7	**0,20**	•	0,99				0	
	13	6	0,25	•	0,97				0	
	14	5	0,35	•	0,91			•	•	
	15	4	0,45	•	0,78			•	•	
	16	3	0,60	•	0,59			•	•	
	17	2	0,75	•	0,43			•	•	
	18	1	0,90	•	0,19			•	•	
	19	0	0,99	•	0,03			•	•	

In Table H.2, data are entered for flow rate and back-pressure ratio in the order shown — increasing and decreasing flow rates, plus the choked flow region in the middle. Values for C_e are determined for each entry using the formula in 3.4.1. The value of C is determined from Formula (1), using only data that are well within the choked flow region, shown by the cells with text in boldface. The conductance ratio is then determined by dividing the calculated values in the C_e column by the calculated value of C. The values in the choked flow region are close to 1,00.

Trial values of b and m are entered in row 1 only, and these are used to calculate the δ and δ^2 values [in accordance with Equations (H.2) and (H.3)] for all of the rows, except those shown blank. Those are not included in the calculation because they are not in the subsonic flow region. The final column is the sum of the squares of the previous column, and the value is only shown in row 1. It may be a large number before the final calculation.

The procedure described in H.3 is used to determine final values of b and m for combined data of increasing and decreasing flow rates. This is repeated with the data separated into increasing and decreasing flow rates to make the comparison to determine if a hysteresis difference exists, as described in 6.3.1.2 and 6.3.2.2.

H.3 Using the Solver function built in Microsoft Excel

H.3.1 Function

Solver is a function available in the software program Microsoft Excel. Using assumed initial values for the variables to be calculated, the Solver function varies these initial values in the base equation to give a best fit to the data entered for the base equation.

H.3.2 Calculation of critical back-pressure ratio, *b*, and subsonic index, *m*

H.3.2.1 Enter the measured value of a in cell A4 (see Figure H.1). Enter the values of back-pressure ratio, p_2/p_1, and conductance ratio, C_e/C. In the target cell H4, an equation expressing the total sum of a squared difference between the measured conductance ratio and the theoretical conductance ratio is entered; these ratios are used to obtain b and m. The values of b (in cell B4) and m (in cell C4) are considered solved when the value derived from this equation becomes the minimum. A value of 0,5 is entered both for b in cell B4 and for m in cell C4 as initial values.

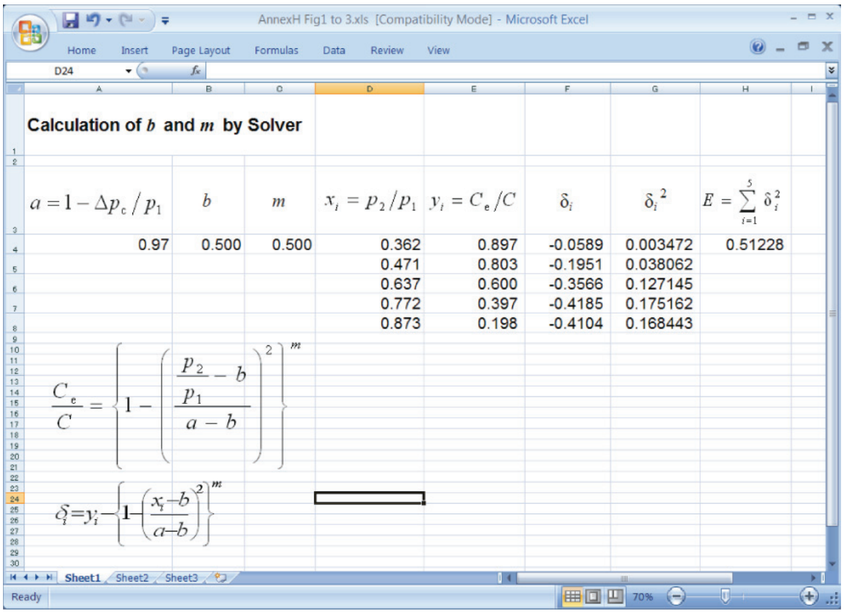


Figure H.1 — Input of data

H.3.2.2 Start Solver (see Figure H.2) as follows:

a) Go to tool (T) and select Solver (V). If the “Tool (T)” menu does not contain the “Solver” command, consult Excel’s “Help (H)” to install the Solver to Excel; then

b) Specify the target cell (H4), the target value (minimum value), and the cells for variables (B4) on the “Solver: Parameter Setting” screen and click “Solve (S).”

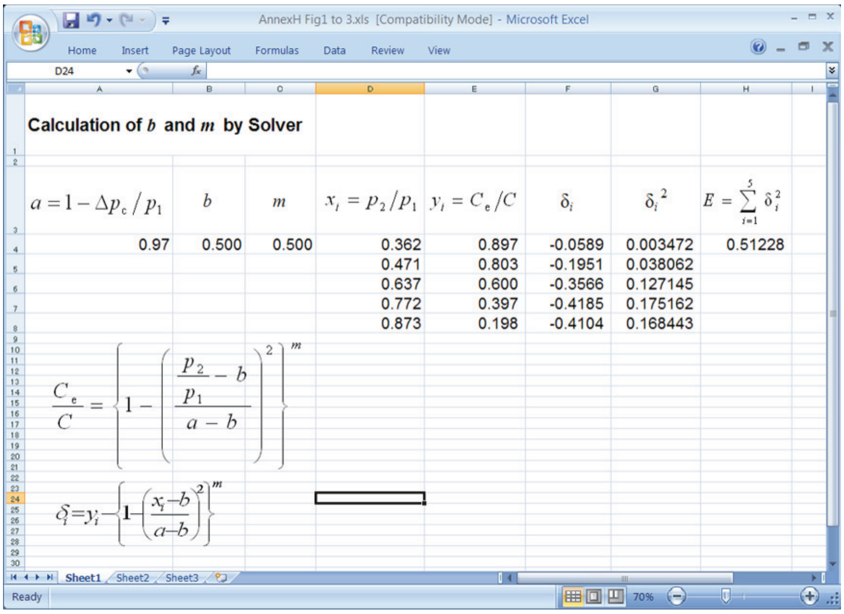


Figure H.2 — Start of Solver

H.3.2.3 The values in cells B4 and C4 are varied (see Figure H.3). Then, the value of b and m are obtained.

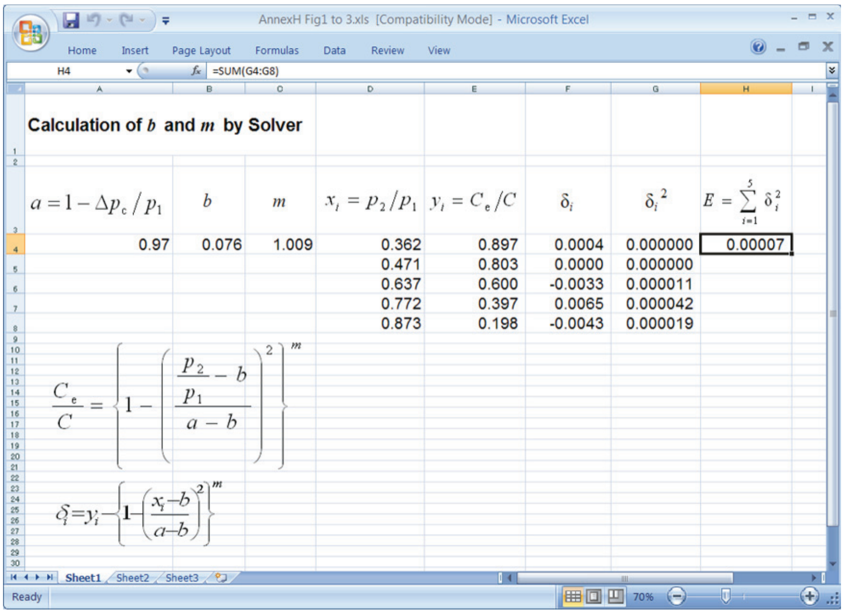


Figure H.3 — Calculation of *b* and *m*

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[2] ISO 6358-2, *Pneumatic fluid power — Determination of flow-rate characteristics of components using compressible fluids — Part 2: Alternative test methods*

[3] ISO 6358-3, *Pneumatic fluid power — Determination of flow-rate characteristics of components using compressible fluids — Part 3: Method for calculating steady-state flow-rate characteristics of assemblies*

[4] ISO 9300, *Measurement of gas flow by means of critical flow Venturi nozzles*

[5] ISO 21748, *Guidance for the use of repeatability, reproducibility and trueness estimates in measurement uncertainty estimation*

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