INTERNATIONAL STANDARD

ISO 6358-1

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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)

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Foreword

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

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

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

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

ISO 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*

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}	$m^3/(s·Pa)$(ANR)
3.4.2	Sonic conductance	C	L^4TM^{-1}	$m^3/(s·Pa)$(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.

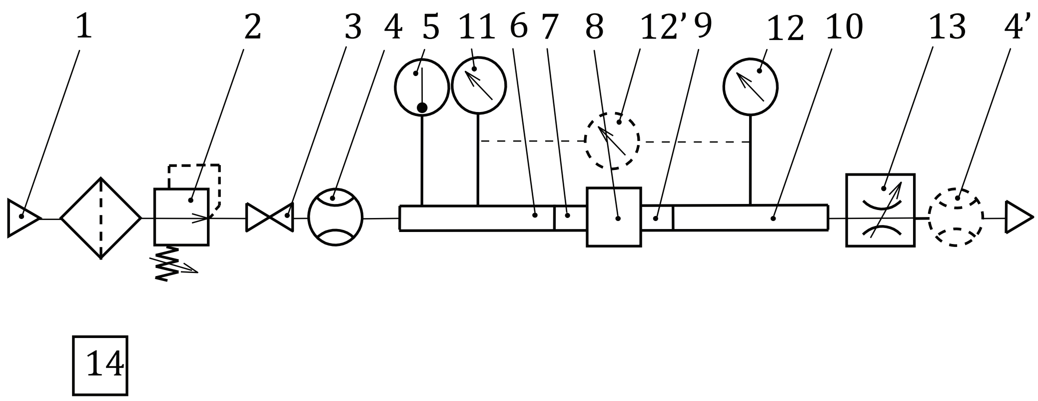
4.3 The graphic symbols used in Figures 1 and 2 are in accordance with ISO 1219-1.

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.



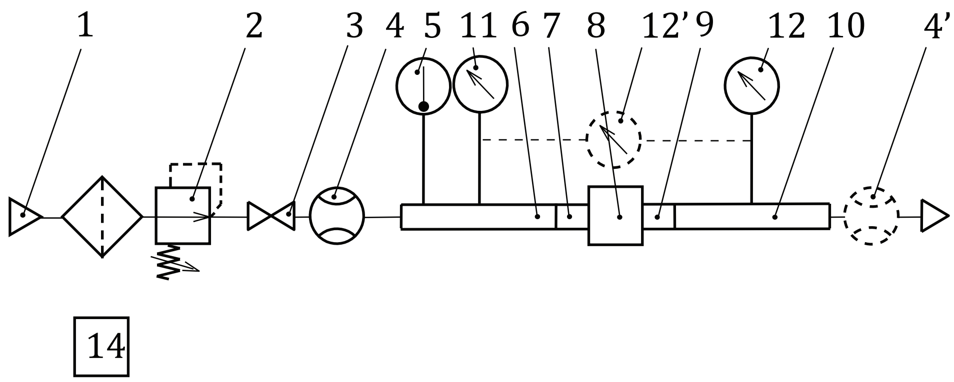
NOTE See Table 4 for the key to test circuit components.

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.

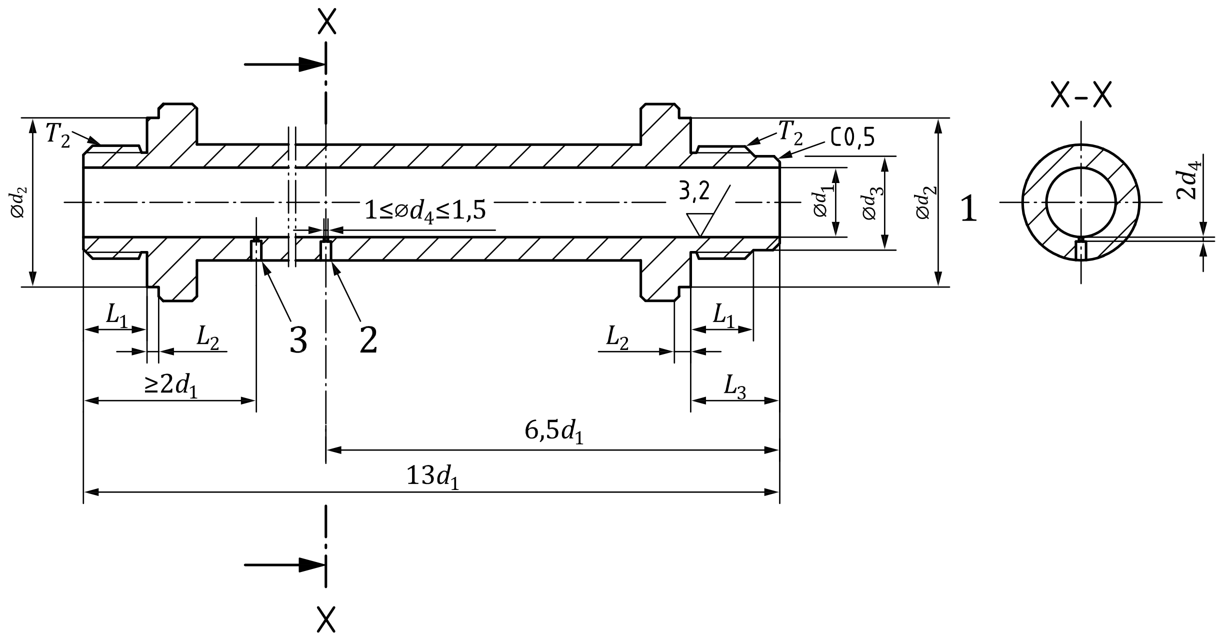
5.3.7 Calibrate the flowmeter (see Annex B for information) before conducting the test. For tests conducted to determine or verify catalogue data, the flowmeter shall have been calibrated in accordance with the best practices of the laboratory.

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.

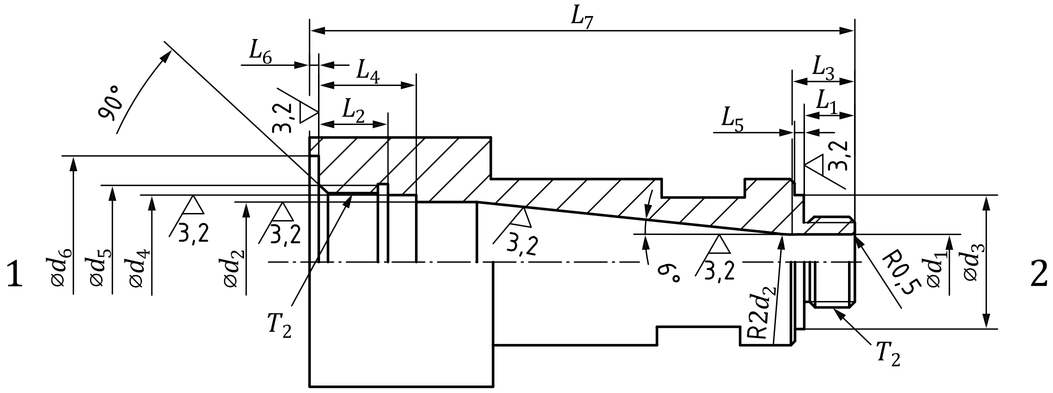
5.4.3 Because the location of the temperature sensor does not have a significant impact on the test results, the temperature sensor can be located in a convenient location upstream from the component under test. Alternate locations of the temperature sensor should be in a large-diameter section of the 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)

