
Hydraulic fluid power — Measurement techniques —

**Part 2:
Measurement of average steady-state
pressure in a closed conduit**

Transmissions hydrauliques — Techniques de mesure —

Partie 2: Mesurage de la pression moyenne dans un conduit fermé en régime permanent

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 8, *Product testing*.

This second edition cancels and replaces the first edition (ISO 9110-2:1990), which has been technically revised. The main changes compared to the previous edition are as follows:

- the list of normative references has been revised;
- additional terms and definitions have been added;
- the evaluation of the readability of measuring instruments has been deleted and moved to ISO 9110-1;
- the calibration of working instruments has been deleted and moved to ISO 9110-1;
- the selection and installation of test equipment has been revised and combined and test data acquisition has been renamed as measuring instrument selection;
- total measurement uncertainty has been added.

A list of all parts in the ISO 9110 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Universal and standardized techniques for the measurement of pressure are required for accurate and repeatable evaluation of fluid power systems. The purpose of this document is to present recommended practices for the measurement of average steady-state pressure in hydraulic fluid power systems. This document is intended for use in conjunction with ISO 9110-1.

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Hydraulic fluid power — Measurement techniques —

Part 2:

Measurement of average steady-state pressure in a closed conduit

1 Scope

This document establishes procedures for measuring the average steady-state pressure in a hydraulic fluid power conduit.

It is applicable to the measurement of average steady-state pressure in closed conduits with inside diameters greater than 3 mm, transmitting hydraulic fluid power with average fluid velocities less than 25 m/s and average steady-state static pressures less than 70 MPa.

It is not applicable to sensors which are flush mounted with, or an integral part of, the closed fluid conduit wall.

It provides the formulae for estimating the total uncertainty in a given pressure measurement.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 9110-1, *Hydraulic fluid power — Measurement techniques — Part 1: General measurement principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

tare pressure differential

pressure loss between the pressure tapping points as generated by the test circuit exclusive of the component under test

4 Measuring instrument selection

4.1 The following subclauses shall be evaluated in accordance with ISO 9110-1.

4.2 A complete calibration on measuring instruments which have not been previously calibrated shall be conducted. Gage or absolute pressure instruments are calibrated following established procedures using a traceable reference standard. The reference standard used shall be recorded.

Differential pressure instruments should be calibrated at the line pressures corresponding to their application by pressurizing both instrument ports simultaneously. If bidirectional pressures are to be measured, calibration should encompass both the positive and negative measurement quadrants of the instrument.

If this is not practical or the differential pressure instrument is subject to varying line pressures in the measurement situation, include the maximum expected value of the line pressure effect as a standard uncertainty contributing term in computing the total measurement uncertainty in [Clause 7](#).

Perform an intermediate instrument calibration as required by the measurement class specified.

4.3 Evaluate the readability uncertainty of the readout device to which the measuring instrument is connected or equipped.

4.4 Each measuring instrument shall be described by an uncertainty model, which is derived from the calibration results. Evaluate the calibration uncertainty.

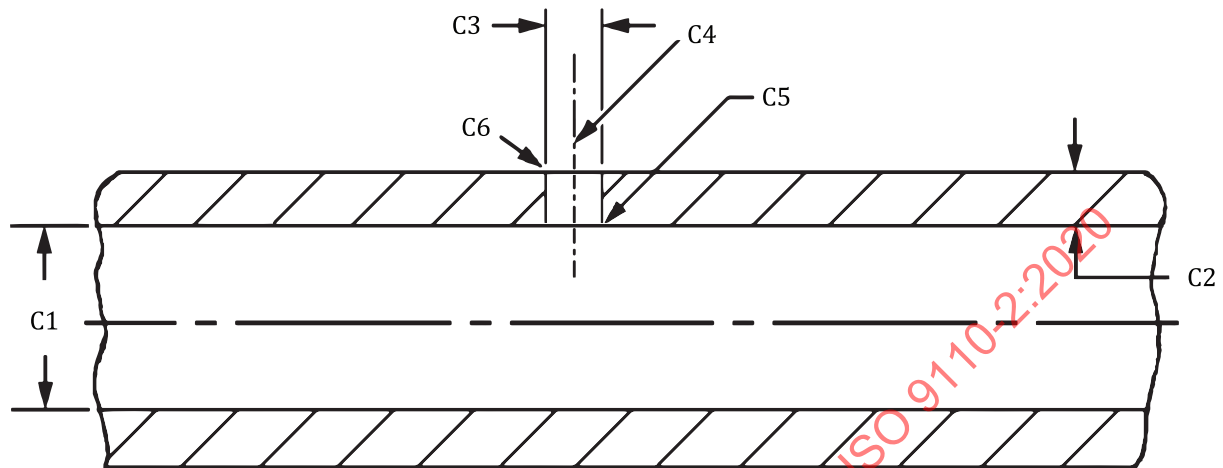
4.5 Each measuring instrument shall be supported by calibration records or calibration database and should have a calibration label attached. See ISO 9110-1:2020, 6.2.12.

4.6 Consider influencing environmental factors in order to minimize their standard uncertainty contribution. Environmental conditions usually limit the usefulness of instruments because they are not designed to operate under diverse operating conditions of temperature, vibration or supply voltage variations, for example. Consider environmental factors carefully since they often are the largest uncertainty contributors.

With knowledge of the instrument operating environment and the instrument manufacturer's specifications, environmental factors can be minimized or evaluated. Either correct for or include the uncertainty contribution of environmental factors in computing the total measurement uncertainty in [Clause 7](#).

5 Pressure taps

5.1 Select and install one of the following types of pressure taps. Types 1 and 2 are constructed in accordance with [Figure 1](#) and [Table 1](#). The Type 3 tap consists of a construction other than Type 1 or 2.



NOTE Drawing is not to scale.

Figure 1 — Pressure tap hole construction

Table 1 — Pressure tap hole construction

Characteristic	Description	Requirement
C1	Inside diameter	Application Specific
C2	Fluid conductor wall thickness	Application Specific
C3	Tap hole diameter	$C2 / C3 \geq 1,5$
C4	Tap hole centre line	Centre line of tap hole diameter (C4) shall meet conductor centre line and be normal to it.
C5	Corner radius	Corner radius $R_{\max} = 1/8 (C3)$.
C6	Corner break	Break sharp edge

More than one pressure tap hole is permitted, but only one may be used in the measurement situation (not a piezometer ring). The tap hole should not be situated on the lowest point of the fluid conductor when fluid contamination effects are significant. The fabrication technique used for connecting the fitting to the fluid conductor is optional provided the geometric requirements of [Figure 1](#) are adhered to.

- Type 1 – This tap is constructed by drilling a hole into a straight piece of the fluid conductor and shall be free of all visible burrs.
- Type 2 – It is constructed in the same manner as Type 1, but either has visible burrs or the interior edge of hole C3 cannot be verified as being free of all visible burrs.
- Type 3 – It is a tap consisting of a construction other than that described in a) and b). For example, a tap which consists of a commercial type straight fitting, tee, or cross, often used in applications utilizing hose or steel tube conduits to implement a tap, would be classified as Type 3.

5.2 Evaluate the uncertainty associated with the type of pressure tap selected for each tap used in the test circuit.

For each pressure tap, determine the maximum fluid velocity expected at any time in the fluid conductor by using [Formula \(1\)](#):

$$v_t = 0,667 \frac{q}{\pi d^2} \quad (1)$$

where

- v_t is fluid velocity (m/s);
- q is the maximum expected flow past the tap (l/min);
- d is the inside diameter of the fluid conductor (cm);
- π is a constant (3,141 592 653 6).

Calculate the velocity induced pressure uncertainty, u_p , using the applicable [Formula \(2\)](#), [\(3\)](#), or [\(4\)](#), corresponding to the type of pressure tap selected for use.

For a Type 1 pressure tap:

$$u_p = 0,000\ 025\ v_t^2\ g_t \quad (2)$$

where

- u_p is the velocity induced pressure uncertainty constant (MPa/(m/s)²);
- v_t is fluid velocity (m/s);
- g_t is fluid specific gravity.

For a Type 2 pressure tap:

$$u_p = 0,000\ 144\ v_t^2\ g_t \quad (3)$$

where

- u_p is the velocity induced pressure uncertainty constant (MPa/(m/s)²);
- v_t is fluid velocity (m/s);
- g_t is fluid specific gravity.

For a Type 3 pressure tap:

$$u_p = 0,000\ 407\ v_t^2\ g_t \quad (4)$$

where

u_p is the velocity induced pressure uncertainty constant (MPa/(m/s)²);

v_t is fluid velocity (m/s);

g_t is fluid specific gravity.

5.3 Locate each pressure tap a minimum of 10 times the inside diameter of the fluid conductor (10d) downstream from a flow disturbance and (5d) upstream or in conformance with the governing component or system standard. Use fluid conductors, which have straight and uniform bores.

If a bidirectional flow is expected in the conductor, then locate the pressure tap at (10d) both up and downstream from a flow disturbance.

5.4 For differential pressure measurements, obtain the pressure loss (tare) between the pressure taps as generated by the test circuit exclusive of the component under test.

Tare pressure differential is determined by using one of the following methods under the same test conditions and for each flow increment evaluated in the prior measurement situation. The method described in 5.5 is recommended and most commonly used.

Correct all data by subtracting the tare value from the corresponding measured differential pressure.

5.5 Tests are repeated with the component under test removed from the circuit. The connecting lines entering the component are close coupled.

5.6 The tare pressure differential may be calculated using [Formula \(5\)](#) with consistent units:

$$p = K f_{d,f} \rho \frac{l v_t^2}{2d} \quad (5)$$

where

$f_{d,f}$ is the dimensionless friction factor, which may be determined by calculation using:

$f_{d,f} = 64/Re$ Poiseuille equation for laminar flow,

$f_{d,f} = 0,316/Re^{0,25}$ Blasius equation for turbulent flow,

Re is the Reynolds number.

l is the conductor length (m);

d is the inside diameter of the fluid conductor (m);

v_t is fluid velocity (m/s);

ρ is fluid mass density (kg/m³);

p is the tare pressure (MPa);

K is a constant: 10^{-6} for p (MPa).

5.7 $f_{d,f}$ may be determined experimentally by substituting a straight suitable length of identical line between the two pressure tapping points. The length of line is such as to provide a measurable pressure drop. Test results obtained are substituted in [Formula \(6\)](#):

$$f_{d,f} = \frac{2d\Delta p}{K\rho l v_t^2} \quad (6)$$

where

$f_{d,f}$ is the dimensionless friction factor;

d is the inside diameter of the fluid conductor (m);

Δp is the measurable pressure drop between two pressure tapping points;

K is a constant: 10^{-4} for p (MPa);

ρ is fluid mass density (kg/m^3);

l is the conductor length (m);

v_t is fluid velocity (m/s);

5.8 Correct each pressure reading for fluid head effects due to a fluid elevation difference between the measuring instrument and the pressure tap using [Formula \(7\)](#):

$$\gamma_{ht} = \rho g h_t \times 10^{-6} \quad (7)$$

where

γ_{ht} is the fluid head effect (MPa);

g is gravity value. Values for either g_l or g_s can be used (see ISO 9110-1);

g_l is the local gravity value. See ISO 9110-1 for additional guidance on determining local gravity;

g_s is the international standard gravity value, $9,806\,65\text{ m/s}^2$;

ρ is the fluid mass density (kg/m^3);

h_t is the head of fluid (m).

If the fluid elevation varied during the measurement situation, or if correcting each reading is undesirable, include the maximum expected value of γ_{ht} as a standard uncertainty contributing term in computing the total measurement uncertainty in [Clause 7](#).

6 General procedure

6.1 Mount the measuring instrument in an orientation which agrees with that used during its calibration. Vibration sensitive instruments shall be mounted in a manner that minimizes mechanical vibrations.

6.2 Install pressure tap(s) in accordance with [Clause 5](#).

6.3 Bleed the air from the measuring instrument and interconnecting line either by loosening the fitting closest to the measuring instrument, or, if the measuring instrument is equipped with a bleed

capability, bleed the instrument and line at that point. If practicable, bleed air from the highest point in the system.

WARNING — Care shall be exercised when bleeding lines under pressure.

6.4 Measuring instruments, which exhibit thermal sensitivity, should be installed in such a manner that there is no significant temperature effect upon the measurement. If the ambient temperature of the measuring instrument in the measurement situation conforms to the temperature at which the measuring instrument was calibrated to within 5 °C, thermal effects may be ignored.

If this is not practical, correct each pressure reading for the effect due to temperature. In circumstances where reading correction is undesirable or the instrument is subjected to uncontrolled thermal transients, include the maximum expected value of the thermal effect on the pressure measurement as a standard uncertainty contributing term in computing the total measurement uncertainty in [Clause 7](#).

Methods used to eliminate or minimize thermal sensitivity effects include:

- a) Calibrate the measuring instrument at the operating temperature encountered in the measurement situation.
- b) Use a sufficient interconnecting line length between tap and measuring instrument to provide thermal isolation from elevated fluid temperatures.
- c) For strain gage type pressure transducers, reset the zero and span output using the shunt resistor method at the operating temperature encountered in the measurement situation. Connect the shunt resistor at the transducer, or in situations where this is impractical, a six-wire transducer cable connection should be used.

WARNING — Zero pressure shall be applied to the transducer when resetting its null output.

This method shall be validated by transducer calibration at both standard ambient temperature and at the operating temperature of interest. The method is only applicable to transducers with a four-arm bridge and integral temperature compensation.

6.5 If a device is used for pulsation damping, it shall be demonstrated by the user that no inaccuracies are introduced. Pulsation damping may be accomplished either mechanically or electrically, depending on the measurement system employed.

6.6 A sintered or sharp edge orifice is recommended as a pulsation damper. However, capillary tubes or accumulators may also be used. The preferred position of the pulsation damper is as close to the pressure tap as is practical to take advantage of the line and measuring instrument hydraulic capacitance to facilitate damping of pulsations. Interconnecting line length may be increased for this purpose.

6.7 If an adjustable pulsation damper is used, make adjustment while the test system is in operation. Close down the pulsation damper until all discernible reading fluctuation stops, then slowly open the pulsation damper until the reading again just begins to fluctuate, but not to the extent that the fluctuation is excessive. Record the reading under this condition.

WARNING — Some pulsation dampers are known to cause measurement errors due to resistance asymmetry. If the pulsation damper is located at the gage, this effect is more pronounced.

6.8 Pressure measurement errors can be caused by standing wave gain in the interconnecting lines between the pressure tap and pulsation damper (if installed) or between pulsation source and the reflecting load. Locate the pressure tap at a node if possible. Evidence of this is usually exhibited by a sinusoidal oscillation. Under these circumstances, the lengths of interconnecting lines and tap locations

should not be odd integer multiples of one quarter wavelength of the fundamental pressure pulsation frequency.

The wavelength can be determined in fluids using [Formula \(8\)](#):

$$\lambda = \frac{C}{f_{fp}} \quad (8)$$

where

λ is the wavelength (m);

f_{fp} is the fundamental pumping frequency (Hz);

C is the speed at which a pressure wave travels in a fluid (m/s).

C is defined by [Formula \(9\)](#):

$$C = \sqrt{\frac{B_e}{\rho}} \quad (9)$$

where

B_e is the effective bulk modulus of the fluid (N/m²);

ρ is the fluid mass density (kg/m³).

The effective bulk modulus of a fluid can be substantially affected by even small amounts of entrained air and/or mechanical system compliance, e.g. hoses or tubing. For example, 1 % entrained air by volume in the fluid reduces the effective bulk modulus to approximately 5 % of the modulus of the fluid without any entrained air. In critical applications, it is difficult to determine the effective bulk modulus of a fluid other than by direct measurement. Also, an analysis of mechanical system compliance should be conducted. However, in many cases, the modulus of the transmission line can usually be ignored for steel tubing and piping but shall be considered for flexible hoses. The effective bulk modulus of hose and fluid is in the (200×10^6) to (400×10^6) N/m² range.

6.9 Electronic filtering techniques for smoothing or averaging an electrical transducer's signal, caused by pressure pulsations, may be used in lieu of mechanical damping. Select filter networks whose output produce an average steady-state pressure reading for the pulsation frequency range encountered in the measurement situation.

Commercially available electronic signal conditioning/processing instrumentation may not produce an output signal proportional to the average pressure. Passive and active type analogue filters, and digital filtering techniques may introduce data acquisition errors.

Electronic measuring instrumentation shall be evaluated for frequency dependent error contribution by comparison to a non-frequency dependent reference. Uncertainty evaluation shall be approached dynamically, encompassing the frequency range of the pressure pulsations. Include the maximum expected value of the signal conditioning frequency effect, if significant, as a standard uncertainty contributing term in computing the total measurement uncertainty in [Clause 7](#).

6.10 If quick disconnects are used in the measuring instrument interconnecting line, it shall be demonstrated by the user that no inaccuracies are introduced.

WARNING — Some quick disconnects are known to exhibit similar measurement errors as those caused by pulsation dampers.