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Hydraulic fluid power — Measurement techniques —

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

Transmissions hydrauliques — Techniques de mesurage —
Partie 2: Mesurage de la pression moyenne dans un conduit fermé en régime permanent

Reference number
ISO 9110-2:1990(E)

Foreword

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

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

International Standard ISO 9110-2 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*.

ISO 9110 consists of the following parts, under the general title *Hydraulic fluid power — Measurement techniques*:

- *Part 1: General measurement principles*
- *Part 2: Measurement of average steady-state pressure in a closed conduit*

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Introduction

ISO 9110-1 relates to general principles for the measurement of static or steady-state conditions. This part (ISO 9110-2) deals with the measurement of average steady-state pressure in a closed conduit and should be read in conjunction with ISO 9110-1.

Further parts will be published as technology develops.

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Hydraulic fluid power — Measurement techniques —

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

1 Scope

This part of ISO 9110 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 (700 bar).

It is not applicable to sensors which are flush mounted with, or are 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 reference

The following standard contains provisions which, through reference in this text, constitute provisions of this part of ISO 9110. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this part of ISO 9110 are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 9110-1:1990, *Hydraulic fluid power — Measurement techniques — Part 1: General measurement principles.*

3 Definitions

For the purposes of this part of ISO 9110, the definitions given in ISO 9110-1 and the following definitions apply.

3.1 half-range uncertainty: Half of the numerical value of an uncertainty. For example when a random uncertainty is $\pm R$, the half-range uncertainty is R.

3.2 pulsation damper: A device using a fixed or variable restrictor, inserted in the pipeline to a pressure-measuring instrument, to prevent damage to the instrument mechanism caused by fluctuations of fluid pressure.

3.3 total uncertainty: The range within which 95 % of the measurement values will be when a large number of measurements are taken of the same value under effectively identical conditions.

3.4 working instrument: A measuring instrument which has been calibrated against a reference standard.

4 Evaluation of the readability uncertainty of measuring instruments

4.1 General

This clause describes the procedures for determining the uncertainty attributable to the inability of the observer to determine exactly the indicated value of a measured quantity.

4.2 Analog measuring instruments — Evaluation of the readability uncertainty factor, RE

4.2.1 Calculate the readability uncertainty factor (RE) for a measuring instrument equipped with a pointer and a parallax error minimization feature from the following formula:

$$\mathrm{RE} = \frac{\text{Value of the smallest scale division}}{\mathrm{RF}_1 \times \mathrm{RF}_2 + 2}$$

where RF_1 and RF_2 are determined from the properties of the read-out device, in accordance with 4.2.1.1 and 4.2.1.2.

4.2.1.1 Determine, to within 10 %, the centre-to-centre separation, w, in millimetres, of the smallest scale division and calculate RF_1 from the following formulae:

$$\mathrm{RF}_1 = 3\left(1 - \varepsilon^{0,5 - 1,1w}\right) \text{ when } w \geqslant 0,5 \text{ mm}$$

$$\mathrm{RF}_1 = 0, \text{ when} w < \ 0,5 \text{ mm}$$

where ε is the repeatability uncertainty determined in accordance with ISO 9110-1:1990, 4.5.

4.2.1.2 Estimate the width of the pointer to the nearest 0,25 mm in the region on the pointer where the reading is interpreted. Divide the width of the smallest scale division, w (see 4.2.1.1), by the pointer width to form a ratio, α. Then calculate RF_2 from the formulae:

$$\mathrm{RF}_2 = 1 - \varepsilon^{0,6(1 - \alpha)}, \text{ when } \alpha \geqslant 1$$

$$\mathrm{RF}_2 = 0, \text{ when } \alpha \ < 1$$

4.3 Digital measuring instruments — Evaluation of the readability uncertainty factor, RE

Calculate the readability uncertainty factor using the following formula:

RE = smallest change in the least significant digit

It should be noted that the least significant digit in some digital read-outs does not have 10 discrete integer levels. In this case, use the value of the smallest integer change possible for the particular read-out.

5 Calibration of working instruments

5.1 Working instruments shall be calibrated in accordance with the instructions given in 5.2 to 5.11.

5.2 Select a reference standard certified to have been traceably calibrated within the interval specified in 5.3 of ISO 9110-1:1990 and which is free of physical damage, except as noted on its certificate.

5.3 Mount the reference standard in an attitude indicated on its certificate, or in that attitude recommended by its manufacturer.

5.4 Mount the working instrument in an attitude recommended by the manufacturer or in an attitude expected during measurement.

5.5 Make zero-value checks with the working instrument physically uncoupled from any possible loading effects.

5.6 Couple the working instrument to the reference standard.

5.7 Record the reference value and the indicated value from the working instrument for at least five trials and use at least 20 equally spaced calibration points over the range of interest for each trial, for full calibration. Use the same set of reference values during each trial.

Partial calibration is permitted; the number of calibration points is dictated by the application and circumstances, using as far as possible reference values which are the same as those used in earlier full calibrations.

If the working instrument is subject to hysteresis effects, carry out the calibration for both increasing and decreasing reference values.

5.8 Use any correction charts or mathematical models resulting from calibration of the reference standard and which help reduce the uncertainty contribution of the reference standard.

5.9 Make corrections to the references values for any other systematic errors, for example temperature effects when the relationships with other physical variables are known and the physical variables themselves are known (or measured) at the time of calibrating the working instrument.

5.10 Note anything unusual about the physical appearance of the instrument.

5.11 Sign and date the calibration data sheets and place them in a safe, permanent file. This record is the working instrument's certificate.

6 Determination of calibration uncertainty

6.1 General

This clause describes the procedures for deriving mathematical models of a working instrument and evaluating the effects of environmental factors on calibration and measurement uncertainty.

6.2 Calibration uncertainty

Adopt a suitable mathematical model from one of the three types described in 6.3. The expected calibration uncertainty in most instruments will depend upon the model selected. More complex models will yield smaller uncertainties.

6.3 Mathematical models

6.3.1 Model 1

Mathematical model 1 uses the indicated value of a read-out device without any corrections. The maximum deviation of the indicated value from the reference value is used as the calibration uncertainty. Enter this calibration uncertainty on the instrument's label or record.

6.3.2 Model 2

6.3.2.1 Mathematical model 2 assumes that the indicated value, p_i, is related to the actual value, p_a, of a physical variable and any influencing environmental factors through a formula of the form

$$p_\mathrm{a} = b_0 + p_\mathrm{i}^k \sum_{k=1}^{m} b_i k + \sum_{i=1}^{n} a_i f(E_i)$$

where

E_i is one of n influencing environmental factors;

$f(E_i)$ is the functional manner in which E_i affects the measurement of the actual value;

a_i is the linear gain coefficient which describes the degree of effect;

b_0, b_i and k are to be stated.

6.3.2.2 Determine $f(E_i)$ using any combination of the following methods:

a) Use accepted theories to develop the functions which describe the environmental effect and determine the coefficient using linear regression with empirical data as measured in controlled experiments during the calibration of the working instrument.

b) Use manufacturer's data, for example zero shift due to temperature or non-linearity due to construction factors.

NOTE 1 Environmental factors may be ignored if the conditions during measurement are brought into sufficient agreement with the values that existed during calibration.

6.3.2.3 Scan all data and find the maximum absolute value of the deviation between the indicated value and the value predicted by the derived mathematical model for each of the reference values as used in the calibration of the working instrument (see clause 5). Enter this maximum deviation as the calibration uncertainty on the instrument's label or record.

6.3.2.4 Use the mathematical model by substituting the indicated values and values of the environmental factors measured during measurement into the formula. The result is an estimate of the actual value at the time of measurement.

6.3.3 Model 3

6.3.3.1 Mathematical model 3 uses a point-to-point correction under the assumption that corrections are linear when indicated values taken during measurement lie between data points used during calibration.

6.3.3.2 Evaluate the calibration uncertainty.

6.3.3.3 For each reference value, p_r, used during calibration, and for each of the five trials, calculate the error as $p_\mathrm{r} - p_\mathrm{i}$.

6.3.3.4 For each reference value, calculate the average over the five trials of the difference found in 6.3.3.3.

6.3.3.5 Calculate the difference between each of the five errors calculated in 6.3.3.3 and the mean as determined in 6.3.3.4 for each reference value.

6.3.3.6 Take the maximum value from 6.3.3.5 and record this as the calibration uncertainty.

6.3.3.7 Use the mathematical model by constructing, from the five trials for each reference value, a graph of the averages determined in 6.3.3.4 *versus* the average indicated value.

6.3.3.8 Use the graph (6.3.3.7) to correct the indicated value obtained during the measurement in order to obtain the best estimate of the actual value.

Assume linear interpolation between discrete data entries.

6.3.3.9 Take environmental factors into account by

a) using an alternative mathematical model which includes their effects;

b) using instruments which are not significantly influenced by environmental factors;

c) checking that environmental factors during measurement are in significant agreement with their values during calibration.

6.4 Instrument record or label

6.4.1 Prepare a label or other record for the working instrument which will carry the following information:

a) the date of calibration;

b) identification of the reference standard used for calibrating the working instrument;

c) calibration uncertainty of the working instrument as determined after development of a mathematical model in accordance with 6.3.1, 6.3.2 or 6.3.3;

d) readability uncertainty as determined in accordance with clause 4, if applicable;

e) identification of the person responsible for the calibration of the working instrument.

6.4.2 When a label is used, ensure that the readout device is attached to the working instrument in a manner which will discourage its inadvertent separation and yet will not obstruct the reading.

7 Selection and installation of equipment

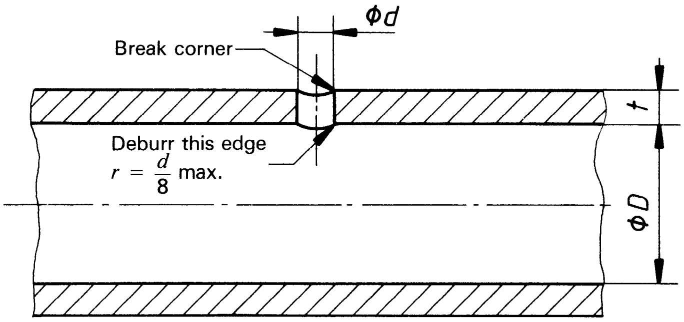
7.1 Selection

7.1.1 Choose a working instrument which has been calibrated in accordance with clause 5 and is connected to or equipped with a read-out device which has been evaluated in accordance with clause 4 and carries a label or other records which have been completed in accordance with 6.4.2.

7.1.2 The instrument should be described by a mathematical model evaluated in accordance with clause 6.

7.2 Pressure tapping

7.2.1 Choose and install a pressure tapping constructed in accordance with figure 1 and which has been freed of all visible burrs on the inside diameter of the pipe wall. If it is not possible to verify the construction details of the pressure tap, the uncertainty is increased. (See 8.3 for evaluating the pressure tap uncertainty.)



NOTE — Only one hole is permitted. Drill the hole normal to the centreline of the conduit.

$$\frac{1}{d} \geqslant 1,5$$

Figure 1 — Detail of pressure tapping

7.2.2 The specific location of the pressure tap relative to up- and downstream flow disturbances shall be a minimum of $5D$ upstream and a minimum of $10D$ downstream or in accordance with the applicable component or system standard.

7.3 Test set-up

7.3.1 Take the necessary precautions to protect personnel and equipment during both set-up and testing.

7.3.2 Mount the working instrument in an attitude which agrees with that used during its calibration.

7.3.3 Bleed the air from the working instrument and interconnecting line at a point as close as possible to the working instrument.

7.3.4 Working instruments which exhibit thermal sensitivity should be installed in such a manner that there is no significant temperature effect upon the measurement. When other means are not available, an interconnecting line of length 250 mm between the tap and the working instrument may provide sufficient thermal isolation.

7.3.5 The ambient temperature of the working instrument should be maintained within ± 10 °C of the temperature at which the working instrument was calibrated.

7.3.6 It is recommended that the lengths of pressure instrumentation lines should not be odd integer multiples of the one-quarter wavelength of the fundamental pumping frequency. The wavelength, λ, in metres, in hydraulic oils should be estimated from the following formula:

$$\lambda = \frac{c}{f}$$

where

c is approximately 1 100 m/s in rigid conduits and approximately 600 m/s in flexible conduits;

f is the fundamental pumping frequency, in hertz.

7.4 Pulsation dampers

7.4.1 If a pulsation damper is used, the preferred position of the damper is as close to the pressure tap as is practical in order to take advantage of the damping provided by the line and working instrument hydraulic capacitance.

NOTE 2 Some dampers are known to cause measurement errors due to resistance asymmetry.

7.4.2 Adjust the damper while the test system is in operation. Close down the damper until all discernible pointer fluctuation stops, then slowly open the damper until the gauge again just becomes live, but not so much that the pointer fluctuation becomes excessive.

8 Test data acquisition and calculation of tap uncertainty contributions

8.1 Test readings

Take test readings only after the measurement system and the test system reach steady-state conditions.

8.2 Pressure head corrections

8.2.1 Correct each pressure reading for pressure head effects due to a fluid elevation difference between the working instrument and the pressure tap using the pressure correction, δp_1, in bars, determined from the following formula:

$$\delta p_1 = g \rho h \times 10^{-5}$$

where

g is the acceleration due to gravity ($= 9{,}81$ m/s^2);

ρ is the fluid mass density, in kilograms per cubic metre;

h is the head of fluid, in metres.

8.2.2 If the fluid elevation varies during the test, the uncertainty contribution calculations of 8.2.1 must use the maximum expected elevation difference.

8.3 Pressure tap induced uncertainty

Evaluate the uncertainty caused by imperfections in a pressure tap using the pressure correction, δp_2, in bars, determined from the following equation:

$$\delta p_2 = K V_e^2 d^2$$

where

K is an empirically derived constant taking, for example, the following values:

$K = 0{,}25 \times 10^{-3}$, for a tap which complies with 7.2,

$K = 1{,}44 \times 10^{-3}$, for a tap in which the inside radius of the tapping hole cannot be verified but otherwise complies with 7.2,

$K = 4{,}07 \times 10^{-3}$, for a tap which deviates from 7.2 in any way;

V_e is the maximum fluid velocity expected at any time during the test, in metres per second;

d is the specific gravity of the fluid.