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**Hydraulic fluid power — Measurement techniques —**

Part 1:  
**General measurement principles**

*Transmissions hydrauliques — Techniques de mesurage —  
Partie 1: Principes généraux de mesurage*

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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](http://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](http://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](http://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 9110-1:1990), which has been technically revised.

The main changes compared to the previous edition are:

- new normative and informative references have been added;
- new definitions have been added;
- classes of accuracy to measurement have been renamed;
- assessment of uncertainties has been revised and expanded and general measurement considerations and requirements have been renamed;
- guidance on gravity correction has been added;
- readability uncertainty evaluation has been added;
- determination of uncertainty limits and classification of uncertainties has been combined and uncertainty limit specifications have been renamed;
- frequency of calibration has been revised and assurance control techniques have been renamed;
- total measurement uncertainty clause has been added;
- original [Annex A](#) has been deleted;
- new [Annex A](#) - Measurement System Acceptance Designated Information Sheet, has been added;
- new [Annex B](#) - Uncertainty Propagation, has been added;

— new [Annex C](#) - Best Practices Tutorial, 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](http://www.iso.org/members.html).

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## Introduction

Universal measurement standards are required if meaningful comparisons are to be made and valid conclusions deduced. A fundamental aspect of fluid power technology is the need to quantify the performance characteristics of hydraulic components and systems to provide a basis for action or decision-making. The method of measurement used is capable of reliably determining such performance characteristics.

This document provides guidance for identifying uncertainty sources and magnitudes in the calibration of instruments and their use in measurement situations encountered in hydraulic fluid power testing. Methods are described for assessing the uncertainty in measurements and derived results.

It is widely recognized that no measurement, irrespective of the amount of care exercised, can ever be absolutely accurate and free of error. Different circumstances each have unique uncertainty requirements. The value of a measurement is dictated by the use that will be made of it, as well as the particular circumstance. Therefore, the maximum value of a reported measure can only be realized if it can be applied under many different circumstances, requiring that the uncertainty associated with a measure be assessed and reported.

This document is intended to be used in conjunction with others that address the measurement of specific physical parameters: flow, pressure, torque, speed and temperature.

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

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# Hydraulic fluid power — Measurement techniques —

## Part 1: General measurement principles

### 1 Scope

This document establishes general principles for the measurement of performance parameters under static or steady-state conditions.

This document provides guidance on the sources and magnitudes of uncertainty to be expected in the calibration of and measurements using hydraulic fluid power components. It describes practical requirements for assessing the capability of the measuring system, and hence the level of uncertainty of the measurement system, or for assisting in developing a system which will meet a prescribed level of uncertainty.

### 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 7870-1, *Control charts — Part 1: General guidelines*

ISO 7870-2, *Control charts — Part 2: Shewhart control charts*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

### 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

##### **data reduction errors**

errors that stem from any processing of test data to the final result, as from digital computer resolution, numerical rounding of results, and uncertainty in model curve fitting and interpolation

#### 3.2

##### **indicated value**

magnitude of the measure and the parameter subject to measurement

#### 3.3

##### **parallax**

phenomenon responsible for reading errors when the observer's eye is not perpendicular to the meter face, and is not directly in line with a pointer whose tip is not in the same plane as the instrument scale

### 3.4

#### **readability**

ability of a human observer to discern a numeric value to the quantity displayed on the readout device

### 3.5

#### **uncertainty model**

chart, graph or equation that relates the *indicated value* (3.2) to the value of the measure and the parameter being measured

## **4 Uncertainty of limit specifications**

### **4.1 General aspects**

**4.1.1** Each performance test standard that incorporates this document as a normative reference shall have its own uncertainty defined for each of the three classes of measurement accuracy described herein, and instrumentation selection criteria stated.

**4.1.2** The maximum uncertainty which may be allowed in a fluid power test measurement can only be established by considering the component or system under test, the expected use of the test results, and the economics of the test program.

**4.1.3** Each test procedure complying with this document shall include a table of permissible uncertainty that provides the limits for each of the three classes of measurement accuracy relevant to this test procedure: A, B, and C (see 4.2.1, 4.2.2, and 4.2.3). The limits should be based upon the maximum uncertainty allowable for each measurement.

### **4.2 Classes of measurement accuracy**

**4.2.1** Class A is the most restrictive and is intended for those measurement situations that are scientific in nature and directed at investigating phenomena. Equipment capabilities and technical expertise required to perform class A measurements would generally be used only in the most stringent applications.

**4.2.2** Class B is intended to encompass performance measurements required for selection and application of components and for quality audits. The requirements for class B measurements should be within the capabilities of most fluid power testing laboratories.

**4.2.3** Class C would apply to diagnostic situations where the objective is to determine if hardware is functioning properly or has failed, and to monitor the operational status of equipment. Users with limited expertise in fluid power measurements using standard commercial instrumentation would possess the required capabilities.

## **5 General measurement considerations and requirements**

### **5.1 Calibration**

The uncertainty inherent in a measurement system may be associated with individual elements of that system or the system as a whole. In general, calibrating and evaluating the uncertainty of the system as a whole results in smaller errors and reduced uncertainty.

All reference standards and measuring instruments shall be calibrated utilizing traceable standards of known uncertainty and environmental influences. The reference standard shall be traceable to a nationally or internationally certified calibration agency or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration technique. Reference

standards or physical constants are those recognized by the International Committee for Weights and Measure (CIPM), the International Bureau of Weights and Measures (BIPM), or the National Standard Institute of the respective country. The reference standard used for calibration shall be recorded.

It is recommended that measurement and calibration laboratories establish a measurement assurance program. Analyzing calibration data using control chart methods may be used to characterize the short- and long-term behaviour of instruments. This time dependent behaviour may be used to establish and validate calibration intervals.

The reference standard uncertainty included in the total measurement system uncertainty summation in [Clause 10](#) is obtained either from the manufacturer or certifying agency that provided certification traceable to the reference standards laboratory.

**5.1.1** The calibration interval of reference standards is determined by:

- a) consideration of usage and environmental factors;
- b) manufacturer's recommendations;
- c) governing contract, government regulation, or specific industry specifications/customer requirements;
- d) inherent stability of the standard.

**5.1.2** The complete calibration interval of measuring instruments shall be determined by using the results of intermediate calibrations as per [Clause 9](#). Calibration intervals may also be based on a time interval considering the following factors:

- equipment stability and drift using historical trend analysis or control charts;
- industry and government-related organizations' recommendations;
- quality standards, customer/contract requirements, and industry regulations;
- experience with instrument usage and frequency;
- environmental operating conditions in the application;
- criticality and complexity of the calibration process;
- risks associated with using un-calibrated instruments;
- risk for damage.

For Class A measurements, intermediate calibration should be conducted immediately prior to instrument use. If this is not practical in the test situation, e.g. calibration carried out by an external agency, an intermediate calibration at the end of testing is recommended.

For Class B and C measurements, intermediate calibrations are normally based on a time interval.

**NOTE** All test results acquired in the preceding calibration interval are suspect if at the next calibration the results fall outside the required allowable measurement uncertainty or control chart limits.

The risk of acquiring suspect data can be assessed considering the following factors:

- a) instrument manufacturer's recommendations and specifications;
- b) instrument past operating experience and calibration control chart history;
- c) calibration data history of similar existing instruments.

**5.1.3** New instruments and those without a prior calibration history shall be calibrated at no less than ten calibration points and five repeated trials at each point. Calibration can be conducted internally, or by the instrument manufacturer or an outside calibration agency.

See OIML D10, NCSL International RP-1, ANSI Z540.3, and ISO 10012.

**5.1.4** Calibration increments for instruments with linear characteristics shall be spaced in a linear manner. For non-linear instruments, such as turbine flow meters, logarithmically spaced increments are recommended to provide better definition in the non-linear range. The calibration increments selected shall include the end points encountered in the measurement situation.

For instruments with prior calibration history, an intermediate calibration performed at 25 %, 50 %, and 100 % of full scale with three repeated trials is sufficient.

**5.1.5** Eliminate systematic standard uncertainty observed during calibration by instrument adjustment or by correcting all data obtained. If systematic standard uncertainty correction is not implemented, include the maximum value of the systematic standard uncertainty in the computation of the total measurement system uncertainty in [Clause 10](#). For example, if the calibration of an instrument reveals a 3 % deviation at mid-range and 1 % at the end points, and the data obtained using the instrument is to be used without correction, the 3 % deviation shall be used in the uncertainty computation.

**5.1.6** Correct standard uncertainties which are the result of a physical relationship with another independent variable by using a known mathematical function. This class of uncertainties is normally due to environmental factors. If the standard uncertainty is neglected and no correction is made for its effect, the maximum value of the uncertainty shall be included in the computation of total measurement system uncertainty in [Clause 10](#). The effect of temperature on a transducer strain gage bridge is an example of such an effect.

Gravity varies depending upon the location on earth. Therefore, the need for gravity correction arises because gravity at the location of a reference standard or instrument varies from the internationally accepted standard value.

The value for local gravity may be calculated using [Formula \(1\)](#), the International Gravity Formula (IGF) and the current World Geodetic System model WGS84, which accounts for the rotation of the earth, height above sea level, and the spheroidal shape of the globe.

$$g_l = 9,7803267714 \left\{ \frac{1 + 0,0019385138639[\sin(\theta)]^2}{\sqrt{1 - 0,006694379990139[\sin(\theta)]^2}} \right\} \left( \frac{R}{R+e} \right)^2 \quad (1)$$

where

- $g_l$  local gravity value (m/s<sup>2</sup>);
- $\theta$  is the geographic latitude;
- $e$  is the elevation above sea level (m);
- $R$  is the nominal radius of the earth (6 378 137,0 m).

See References [\[6\]](#), [\[7\]](#), [\[8\]](#) and [\[10\]](#).

Gravity correction is accomplished using a ratiometric method in [Formulae \(2a\)](#) and [\(2b\)](#). For example, in torque or pressure measure calibration, which relies upon reference dead weight, the following relationship for correction applies:

$$m_c = \frac{m \cdot g_l}{g_s} \quad (2a)$$

$$p_C = \frac{p \cdot g_1}{g_s} \quad (2b)$$

where

- $m_C$  and  $p_C$  are the corrected values for mass and pressure;
- $m$  is the mass under standard conditions (kg);
- $p$  is the pressure (MPa);
- $g_1$  is the local gravity value (m/s<sup>2</sup>);
- $g_s$  is the international standard gravity value (9,808665 m/s<sup>2</sup>).

Gravity correction applies to fluid elevation head instruments such as manometers. Gravity correction is accomplished using the relationship in [Formula \(3\)](#):

$$h_{C,t} = \frac{h_t \cdot g_1}{g_s} \quad (3)$$

where

- $h_{C,t}$  is the corrected value for the height of the indicating fluid (cm, or m);
- $h_t$  is the height of the indicating fluid (cm, or m);
- $g_1$  is the local gravity value (m/s<sup>2</sup>);
- $g_s$  is the international default value for gravity (9,806 65 m/s<sup>2</sup>).

**5.1.7** If a testing agency is not equipped to perform either an intermediate or a complete calibration, the instrument manufacturer or other agency may be contracted to perform these services. The testing agency and its independent contractor are not exempted from any of the requirements set forth herein.

## 6 Complete calibration procedure

### 6.1 Selection of reference standard

Select a reference standard which:

- a) is free of physical damage, or the damage was previously noted in the calibration records and is not considered to affect its function;
- b) is certified and traceable as per the requirement of [5.1](#);
- c) has its total uncertainty evaluated and documented.

### 6.2 Procedure

**6.2.1** Mount the reference standard in an attitude indicated in its calibration record or as recommended by its manufacturer.

**6.2.2** Select the measuring instrument to be calibrated.

**6.2.3** Mount the measuring instrument in an attitude recommended by the manufacturer or in an attitude expected in the measurement situation.

**6.2.4** Make zero value checks with the measuring instrument physically uncoupled from any possible loading effects.

**6.2.5** Couple the measuring instrument to the reference standard and begin calibration data collection.

**6.2.6** For instruments which are subject to hysteresis effects (e.g. material characteristics or static friction), conduct the calibration for both increasing and decreasing reference values. Evaluate the results of the first calibration trial to assess hysteresis effects.

**6.2.7** Correct for systematic standard uncertainty. Take advantage of any correction charts or uncertainty models which resulted from calibration of the reference standard.

**6.2.8** Correct the reference values for any other systematic standard uncertainties when the relationships with other physical variables are known and the physical variables themselves are known (measured) at the time of instrument calibration.

In circumstances where reading correction is undesirable or the reference instrument is subject to uncontrolled variations, include the maximum expected value of the systematic standard uncertainty in computing the total measurement system uncertainty as per [Clause 10](#).

**6.2.9** Record the reference value, after correction as per [6.2.7](#) and [6.2.8](#), and the corresponding instrument indicated value for each calibration increment.

**6.2.10** Develop an uncertainty model in accordance with [Clause 7](#).

**6.2.11** Sign and date the calibration sheets. Record all pertinent information concerning the reference standard used for calibration, any physical damage observed to the instrument calibrated or unusual characteristics, environmental conditions, and mounting attitude of the reference standard and instrument. Place these records in a permanent file or in an instrument calibration database.

**6.2.12** A label affixed to the instrument is recommended. The information may also be entered in an instrument calibration database. Attach the label to the instrument's readout device in a manner which will discourage its inadvertent removal and not interfere with readability. The label should contain the following information:

- a) date of last complete calibration;
- b) instrument identification information;
- c) identification of the person or agency responsible for calibration of the instrument.

## 7 Instrument calibration uncertainty models

### 7.1 General

This clause sets forth the procedures for deriving uncertainty models of a measuring instrument and, when significant, for evaluating the effects of environmental factors. Based on the uncertainty model selected, the measuring instrument calibration uncertainty can be determined.

### 7.2 General procedure

**7.2.1** Select a suitable uncertainty model from either First order ([7.3](#)), Second order ([7.5](#)), or Third order ([7.7](#)).

NOTE The amount of calibration uncertainty in most instruments depends upon the model selected. Higher order models yield smaller uncertainties.

7.2.2 Enter the calibration uncertainty on the instrument's calibration record or database.

### 7.3 First order uncertainty model

A first order uncertainty model makes direct use of the indicated value of the instrument readout device without any corrections to the measured value. The model includes the measuring instrument, interconnect cabling and the readout device as a measuring system.

### 7.4 First order calibration uncertainty evaluation

7.4.1 Use the calibration data as recorded in [Clause 6](#).

7.4.2 Calculate the difference between the indicated value and the reference value of the five trials at each reference value using [Formula \(4\)](#):

$$\Delta x = (x_i - x_r) \quad (4)$$

where

$x_i$  is the indicated value;

$x_r$  is the reference value.

7.4.3 Calculate the standard deviation for each repeated trial in [6.2.9](#) for all trials over the total range of reference values, using [Formula \(5\)](#):

$$s_j = \sqrt{\frac{\sum_{i=1}^n (x_i - x_r)^2}{n-1}} \quad (5)$$

where

$s_j$  is the standard deviation at reference value  $j$ ;

$x_i$  is the indicated value at trial  $i$ ;

$x_r$  is the reference value;

$n$  is the number of values at each reference increment and repeated trial.

7.4.4 Implement the model by using the reading as indicated on the readout device.

7.4.5 The calibration uncertainty is 4 times the maximum standard deviation,  $s_j$  ( $s_1, s_2, \dots, s_j$ ), for a 95 % confidence level calculated in [\(7.4.3\)](#).

### 7.5 Second order uncertainty model

A second order uncertainty model makes use of a point-to-point correction of instrument reading in the measurement situation. The assumption is that corrections are linear when indicated values taken in the measurement situation lie between data points used during calibration. Linear interpolation between discrete reference increments is used for reading corrections.

## 7.6 Second order calibration uncertainty evaluation

7.6.1 Use the calibration data as recorded in [Clause 6](#).

7.6.2 For each reference value:

- a) calculate the average indicated value of all the trials at each reference value;
- b) calculate the difference between the indicated value and the average indicated value of all the trials by using [Formula \(6\)](#):

$$\Delta x = x_i - \bar{x}_i \quad (6)$$

where

- $x_i$  is the indicated value;
- $\bar{x}_i$  is the average indicated value.

7.6.3 Calculate the standard deviation of all values found in [Clause 6.2.9](#) over the total range of reference values using [Formula \(7\)](#):

$$s_k = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x}_i)^2}{n-1}} \quad (7)$$

where

- $s_k$  is the standard deviation of all trials at reference value k;
- $x_i$  is the indicated value;
- $\bar{x}_i$  is the average indicated value;
- $n$  is the number of trials of values at each reference increment and repeated trial.

7.6.4 Implement the model by constructing a chart of the average indicated values found in [7.6.2](#) (as averaged over all the trials for each referenced value) and the reference values.

In the measurement situation, convert indicated values into the best estimates of the actual values. Use linear interpolation between discrete data entries to arrive at the actual value.

7.6.5 The calibration uncertainty is four times the maximum standard deviation,  $s_k$  ( $s_1, s_2, \dots, s_k$ ), for a 95 % confidence level calculated in [7.6.3](#), for each of the reference values used in the calibration.

## 7.7 Third order uncertainty model

A third order uncertainty model allows incorporating relevant environmental factors assuming that a mathematical relationship exists between relevant environmental factors and the conventional true value of a physical variable. The corrected value is arrived at by correcting the indicated value in a manner similar to the second order model. The third order uncertainty model is, in effect, a second order model with additional correction for environmental factors.

A formula expressing the relationship between the variables shall be developed using linear regression analysis.

**7.7.1** Determine the relationship of environmental factors and indicated values with one or more of the following methods:

- a) use proven mathematical relationships based upon physical laws;
- b) use empirical data as measured during controlled experiments conducted in the measuring instrument calibration;
- c) use manufacturer's data (for example, zero shift due to temperature, or span shift due to viscosity etc.);
- d) ignore environmental factors when they are brought into agreement with measurements of values that existed during calibration, and any factors which are known to have an insignificant influence upon the indicated value.

## 7.8 Third order calibration uncertainty evaluation

**7.8.1** Calculate the difference between the indicated value and the value predicted by the derived mathematical formula of all trials at each reference value by using [Formula \(8\)](#):

$$\Delta x = x_i - \bar{x}_p \quad (8)$$

where

$x_i$  is the indicated value;

$\bar{x}_p$  is the predicted average indicated value.

**7.8.2** Calculate the standard deviation of all values found in [7.8.1](#) over the total range of reference values using [Formula \(9\)](#):

$$s_l = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x}_p)^2}{n-1}} \quad (9)$$

where

$s_l$  is the standard deviation of all predicted values at reference value  $l$ ;

$x_i$  is the indicated value;

$\bar{x}_p$  is the predicted average indicated value;

$n$  is the number of predicted values at each reference increment.

**7.8.3** Implement the uncertainty model by substituting the indicated values and values of the environmental factors into the mathematical formula. That result is the estimate of the actual value at measurement time. The calibration uncertainty is 4 times maximum standard deviation,  $s_l$  ( $s_1, s_2, \dots, s_l$ ) calculated in [7.8.2](#) for a 95 % confidence level for each of the reference values used in the calibration.

## 8 Readability uncertainty evaluation

### 8.1 General

Evaluate the readability uncertainty for the readout device using the following procedure. This error arises because of the inability to assign an unlimited number of digits to the indicated value of a measured quantity.

### 8.2 Analog readout devices

**8.2.1** The readability uncertainty ( $u_r$ ) for a readout device equipped with a pointer shall be calculated using [Formula \(10\)](#):

$$u_r = \frac{x_{ssd}}{[f_{r,d} \times f_{r,p} + 2, 0]} + f_{r,\theta} \quad (10)$$

where

- $f_{r,d}$  is the readability factor of the dial;
- $f_{r,p}$  is the readability factor of the pointer;
- $f_{r,\theta}$  is the angular or parallax readability factor;
- $x_{ssd}$  is the value of the smallest scale division.

The readability uncertainty can be estimated by using [Formula \(11\)](#).

$$u_r = \frac{x_{ssd}}{2} + f_{r,\theta} \quad (11)$$

where

- $f_{r,\theta}$  is the angular or parallax readability factor.
- $x_{ssd}$  is the value of the smallest scale division.

This formula yields the maximum readability uncertainty. Therefore, if an estimate is used for  $u_r$  in lieu of the exact value, the resulting uncertainty is always conservative.

The preceding factors are determined from properties of the readout device.

**8.2.1.1** If the readout device is equipped with a parallax error minimizing feature, determine within 10 % the width ( $w$ ) of the smallest scale division in mm.  $f_{r,d}$  is calculated by substituting the value for  $w$  in the appropriate [Formula \(12\)](#) or [\(13\)](#).

$$f_{r,d} = 3(1 - e^{0,5 - 1,1w}) \text{ when } w \geq 0,5 \text{ mm} \quad (12)$$

$$f_{r,d} = 0,0 \text{ when } w < 0,5 \text{ mm} \quad (13)$$

where

$$f_{r,\theta} = 0$$

Determine 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 by the pointer width to form the ratio,  $\alpha$ , using [Formula \(14\)](#):

$$\alpha = \frac{w_{\text{ssd}}}{w_{\text{p}}} \quad (14)$$

where

$w_{\text{ssd}}$  is the width of the smallest scale division;

$w_{\text{p}}$  is the pointer width.

Calculate  $f_{\text{r,p}}$  with the [Formula \(15\)](#) or [\(16\)](#): (Refer to [Figure 1](#).)

$$f_{\text{r,p}} = 1 - e^{0,6(1-\alpha)} \quad \alpha > 1,0: \quad (15)$$

$$f_{\text{r,p}} = 0 \quad \alpha \leq 1,0 \quad (16)$$

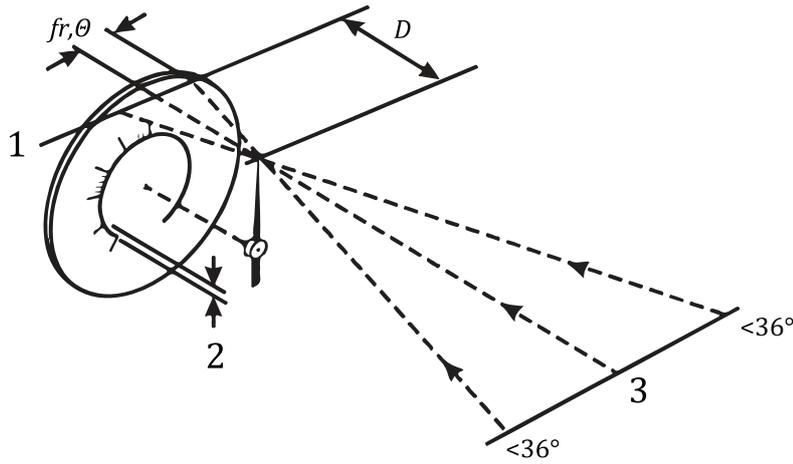
**8.2.1.2** For a readout device without a parallax minimizing feature, the observers viewing field shall be within the limits shown in [Figure 1](#).

Determine  $f_{\text{r,d}}$  and  $f_{\text{r,p}}$  as per [8.2.1.1](#).

Measure or estimate the distance,  $D$ , in mm between the pointer and scale face, and the angle,  $\theta$ , of the observer's line of sight as shown in [Figure 1](#). Calculate  $f_{\text{r,\theta}}$  in terms of the scale's units of measure using [Formula \(17\)](#):

$$f_{\text{r,\theta}} = D \tan \theta \times f_{\text{s}} \quad (17)$$

The scale factor,  $f_{\text{s}}$ , can be obtained by either reference to the instrument manufacturer's specification or by measurement. The scale factor is expressed in units of the measured quantity per unit length (mm), for example, 0,85 MPa per mm of the scale face.



**Key**

- 1 gage face
- 2 scale factor (MPa/mm)
- 3 normal line of sight
- D distance of pointer from scale face (mm)

**Figure 1 — Readout device parallax error**

**8.2.1.3** Calculate the readability uncertainty for the readout device with the formula given in clauses 8.2.1.1 and 8.2.1.2 using Formula (10).

**8.2.2** The overall readability factor for a readout device having a moving column, such as is the case with a liquid manometer, shall be calculated using Formula (18):

$$u_r = \frac{2 \times x_{ssd}}{(f_{r,d} + 2, 0)} \tag{18}$$

NOTE  $f_{r,d}$  is determined as in 8.2.1.1.

**8.3 Digital readout devices**

**8.3.1** The readability error shall be calculated using either Formula (19) or (20):

$$u_r = \frac{\Delta_{s,lsd}}{\sqrt{3}} \text{ if smallest reading is truncated} \tag{19}$$

$$u_r = \frac{\Delta_{s,lsd}}{\sqrt{12}} \text{ if smallest reading is rounded} \tag{20}$$

where

$\Delta_{s,lsd}$  is the smallest change in least significant digit.

**8.4 Readout device records**

Enter the overall readability uncertainty, as determined in (8.2) or (8.3), into the readout device's calibration record or database, and label if used.

## 9 Assurance control techniques

Evaluate intermediate calibration results from [Clause 6](#) with the use of statistical quality control charts to determine if a complete calibration is required. Validation that the measurement system is in a state of statistical control is thereby established. Drifts, trends, or movements indicating out of control situations shall be investigated and corrected. The methods presented herein are only valid for well-defined stable and repeatable measurement systems. Control chart limits may be compared to those based upon either the instrument manufacturer's specified uncertainty or the instrument's uncertainty as established by the user. ISO 7870-1 and ISO 7870-2 describe statistical quality control charts and shall be used.

## 10 Total measurement uncertainty

### 10.1 Determination of measurement system uncertainty

The measurement system uncertainty is determined by summation of the various standard uncertainty contributing terms as applicable. This summation is accomplished by applying the root sum of squares (RSS) methods presented in the ISO/IEC Guide 98-3. The method requires that each standard uncertainty contributor be characterized as either type A (those that are evaluated by statistical analysis of a series of observations) or type B uncertainties (those which shall be evaluated by other means).

See NIST Technical Note 1297, M3003 and [Annex C](#).

**10.1.1** Determine uncertainty contributing terms from the instrument's calibration records, this or other standards referencing this document, or from the instrument manufacturer. Determine the measurement system uncertainty by summing up all of the following standard uncertainty terms:

- a) reference standard uncertainty;
- b) instrument calibration uncertainty;
- c) readability uncertainty;
- d) thermal and environmental sensitivity effects;
- e) remaining uncertainty contributing terms as applicable, e.g. environmental factors (temperature), elevation errors (elevation head), pressure tap induced errors, data acquisition errors.

**10.1.2** Total measurement uncertainty shall encompass a summation of the following uncertainty contributing terms:

- a) propagated uncertainty for derived quantities which are not measured directly (see [Annex B](#));
- b) data reduction errors.

Record the total measurement uncertainty. An example is given in [Annex A](#).

If the actual measurement uncertainty is within the maximum allowed uncertainty for the measurement class selected, or the limits specified in the governing component or system document, then the measured parameters are qualified in that test situation.

When the uncertainty exceeds the maximum allowed uncertainty limits, the uncertainty shall be reduced by recalibrating the measurement system as a whole, selecting a higher order uncertainty model, changing the measurement system, or minimizing/reducing data reduction errors.

**Annex A**  
(informative)

**Measurement system acceptance designated information sheet**

Parameter	Measurement class (A, B, C)	Maximum allowed measurement uncertainty	Total measurement uncertainty
Input signal	-----	-----	-----
Flow	-----	-----	-----
Pressure	-----	-----	-----
Differential pressure	-----	-----	-----
Temperature	-----	-----	-----
Torque	-----	-----	-----
Speed	-----	-----	-----
Time	-----	-----	-----
Force	-----	-----	-----
Linear distance	-----	-----	-----

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## Annex B (informative)

### Uncertainty propagation

In certain measurement situations, some physical quantities cannot be measured directly but must be derived to arrive at the end result. For example, consider a leakage measurement in which a volume and time interval are recorded, and the end result calculated, i.e. mm<sup>3</sup>/min. In other cases, several measured parameters are needed to calculate a result, e.g. pump overall efficiency.

In these situations, the uncertainty evaluation of the final result should also be calculated. First, the total uncertainty in each primary measured quantity should be determined as in [Clause 10](#), then, the procedures contained in this section may be applied to determine how the primary uncertainty propagates through to the calculated end result. Uncertainty levels of calculated values should be reported in accordance with ISO/IEC Guide 98-3.

Table B.1 summarizes the general form of mathematical function (formula), which may have been used in calculating the end result, and the corresponding expression for determining the propagated uncertainty.

**Table B.1 — Mathematical function and uncertainty propagation**

Formula	Expression for uncertainty propagation
C = General arbitrary function of one variable	$u_C = u_x \frac{\delta C}{\delta x}$
C = General arbitrary function of several variables	$u_C = \left\{ \left( u_x \frac{\delta C}{\delta x} \right)^2 + \left( u_l \frac{\delta C}{\delta l} \right)^2 + \left( u_a \frac{\delta C}{\delta a} \right)^2 + \left( u_b \frac{\delta C}{\delta b} \right)^2 + \left( u_d \frac{\delta C}{\delta d} \right)^2 \right\}^{1/2}$
<p>NOTE If the derived result was calculated in terms of a formula given in the left column, the propagated uncertainty is calculated using the corresponding expression in the right column. Symbols are defined as follows:</p> <p>C is the independent calculated variable;</p> <p>x, l, a, b, d are the dependent variables representing primary measured quantities;</p> <p><math>u_x, u_l, u_a, u_b, u_d</math> are uncertainties to be propagated;</p> <p><math>u_C</math> is the sum of the individual uncertainties.</p>	

## Annex C (informative)

### Best practices tutorial

#### C.1 General

In the past, the emphasis has been on data generation and not evaluation. Current trends emphasize quality, and this will require greater attention to data evaluation. The basic motivation for examining measurement uncertainty is the realization that test data is no better than the measurement process involved in generating it. Improving product quality demands more reliable and accurate test data.

The purpose of testing and data collection is to provide a basis for action or decision-making. If an analysis of uncertainty is neglected, the utility of test results is compromised. Decisions cannot be made with any degree of confidence if the data uncertainty is not assessed. The aim of this annex is to provide relevant means to enable the user of test data to evaluate the total information content of that data.

NOTE This tutorial is informative and can assist in establishing a more complete understanding of best practices to support good measurement approaches in the test situation.

**C.1.1** Often, one of the biggest sources of uncertainty comes from the reference standard (or calibrator) that is used in calibrations. Select a suitable reference standard for each measurement. It is also important to remember that it is not enough to use the manufacturer's accuracy specification for the reference standard and to keep using that as the uncertainty of the reference standards for years. Instead, reference standards shall be calibrated regularly in a calibration laboratory that has sufficient capabilities (small uncertainties) to calibrate the standard and make it traceable. Pay attention to the total uncertainty of the calibration that the laboratory documented for the reference standard. Also, follow the stability of your reference standards between its regular calibrations using statistical quality control charts.

**C.1.2** Written work instructions detailing the procedures for calibrating instruments provide a reference that technicians can use and thereby ensure consistency in results. These instructions should include uncertainty limits along with a reaction plan when results are not within limits.

**C.1.3** Written work instructions detailing the procedures for making measurements provide a reference that technicians can use and thereby ensure consistency in results. Technician training and qualifications for using the measurement system should be assessed before data collection commences.

**C.1.4** The long-term aspect of uncertainty is control. The economics involved are sometimes difficult to justify. It is uneconomical to calibrate prior to every measurement, and it is equally uneconomical to make measurements without instrument calibration. The risks and costs associated with using improperly calibrated equipment needs to be assessed.

**C.1.5** Statistical quality control chart techniques have been proven as an economical means of control in mass production and are equally applicable in measurement practice. Control chart methodology is well researched and published extensively. Recording and analysing the resulting calibration data in control charts can be used to establish the short and long-term behaviour of measuring instruments.

**C.1.6** Calibration intervals of reference standards, and measuring instruments, can be established using a variety of approaches:

- a) Statistical Process control chart methodology.