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भाग 1 साधारण मापन सिद्धांत

(पहला पुनरीक्षण)

Hydraulic Fluid Power — Measurement Techniques

Part 1 General Measurement Principles

(Second Revision)

ICS 23.100.01

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NATIONAL FOREWORD

This Indian Standard (Part 1) (First Revision) which is identical to ISO 9110-1 : 2020 'Hydraulic fluid power — Measurement techniques — Part 1: General measurement principles' issued by the International Organization for Standardization was adopted by the Bureau of Indian Standards on the recommendation of the Fluid Power System Sectional Committee and approval of the Production and General Engineering Division Council.

This standard was first published in 2002. The first revision of this standard has been undertaken to align it with the latest version of ISO 9110-1.

The major changes in this revision are as follows:

a) New normative and informative references have been added;
b) New definitions have been added;
c) Classes of accuracy to measurement have been renamed;
d) Assessment of uncertainties has been revised and expanded and general measurement considerations and requirements have been renamed;
e) Guidance on gravity correction has been added;
f) Clause on 'Readability uncertainty evaluation' has been added;
g) Determination of uncertainty limits and classification of uncertainties has been combined and uncertainty limit specifications have been renamed;
h) Frequency of calibration has been revised and assurance control techniques have been renamed;
j) Clause on 'Total measurement uncertainty' has been added;
k) Original Annex A has been deleted;
m) New Annex A on 'Measurement system acceptance designated information sheet', has been added;
n) New Annex B on 'Uncertainty propagation', has been added; and
p) New Annex C on 'Best practices tutorial', has been added.

This standard is published in two parts. Other part in this series is:

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

The text of ISO standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to the following International Standard for which Indian Standard also exists. The corresponding Indian Standard which is to be substituted in its place is listed below along with its degree of equivalence for the editions indicated:

(*Continued on third cover*)

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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.

Indian Standard

HYDRAULIC FLUID POWER — MEASUREMENT TECHNIQUES

PART 1 GENEARL 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.

$$g_l = 9{,}7803267714 \left\{ \frac{1 + 0{,}0019385138639[\sin(\theta)]^2}{\sqrt{1 - 0{,}00669437999 0139[\sin(\theta)]^2}} \right\} \left(\frac{R}{R+e} \right)^2 \quad (1)$$

where

g_l local gravity value (m/s^2);

θ 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:

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

$$p_C = \frac{p \cdot g_l}{g_s} \qquad (2b)$$

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_I is the local gravity value (m/s²);

g_s is the international standard gravity value (9,808665 m/s²).

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

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

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_l is the local gravity value (m/s²);

g_s is the international default value for gravity (9,806 65 m/s²).

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):

$$\Delta x = (x_i - x_\mathrm{r}) \tag{4}$$

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):

$$s_j = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_\mathrm{r})^2}{n-1}} \tag{5}$$

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 ($s_{1,}$ $s_{2\ldots}s_j$), 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):

$$\Delta x = x_i - \overline{x_i} \tag{6}$$

where

x_i is the indicated value;

$\overline{x_i}$ 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):

$$s_\mathrm{k} = \sqrt{\frac{\sum_{i=1}^{n} \left(x_i - \overline{x_i}\right)^2}{n-1}} \tag{7}$$

where

s_k is the standard deviation of all trials at reference value k;

x_i is the indicated value;

$\overline{x_i}$ 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 ($s_{1,}$ $s_{2,...}$ 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):

$$\Delta x = x_i - \overline{x}_{\mathrm{p}} \tag{8}$$

where

x_i is the indicated value;

$\overline{x}_{\mathrm{p}}$ 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):

$$s_l = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x}_{\mathrm{p}})^2}{n-1}} \tag{9}$$

where

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

x_i is the indicated value;

$\overline{x}_{\mathrm{p}}$ is the predicted average indicated value;

n is the number of predicated 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 ($s_{1,}$ $s_{2\ldots}s_l$) 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, α, using Formula (14):

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

where

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

w_p is the pointer width.

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

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

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

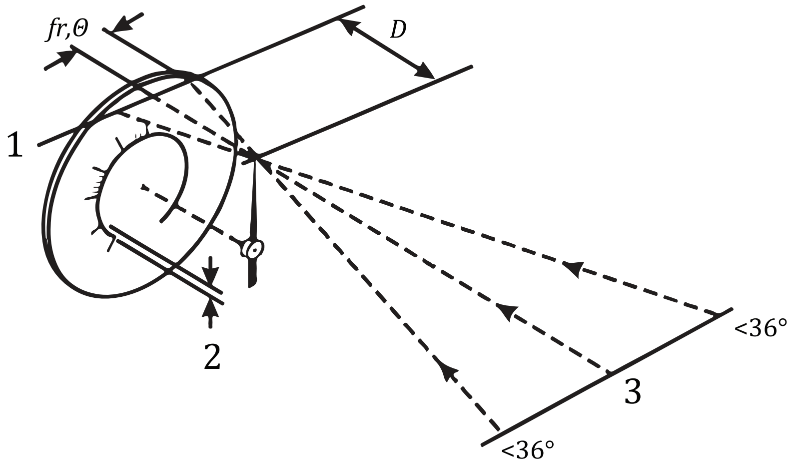
8.2.1.2 For a readout device without a parallax minimizing feature, the observers viewing field shall be within the limits shown in Figure 1.

Determine $f_{r,d}$ and $f_{r,p}$ as per 8.2.1.1.

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

$$f_{r,\Theta} = D \tan \Theta \times f_s \quad (17)$$

The scale factor, f_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):

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

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):

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

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

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	___________	___________	___________

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^3/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	$u_C = \left\{ \left(u_x \frac{\delta C}{\delta x} \right)^2 + \left(u_l \frac{\delta C}{\delta l} \right)^2 + \left(u_a \frac{\delta C}{\delta a} \right)^2 + \left(u_b \frac{\delta C}{\delta b} \right)^2 + \left(u_d \frac{\delta C}{\delta d} \right)^2 \right\}^{1/2}$
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: C is the independent calculated variable; x, l, a, b, d are the dependent variables representing primary measured quantities; u_x, u_l, u_a, u_b, u_d are uncertainties to be propagated; u_C is the sum of the individual uncertainties.	

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.

C.1.12 Figure C.1 depicts a variety of sources of standard uncertainties. It serves as a guide to identify uncertainties to be possibly included in the total uncertainty summation.

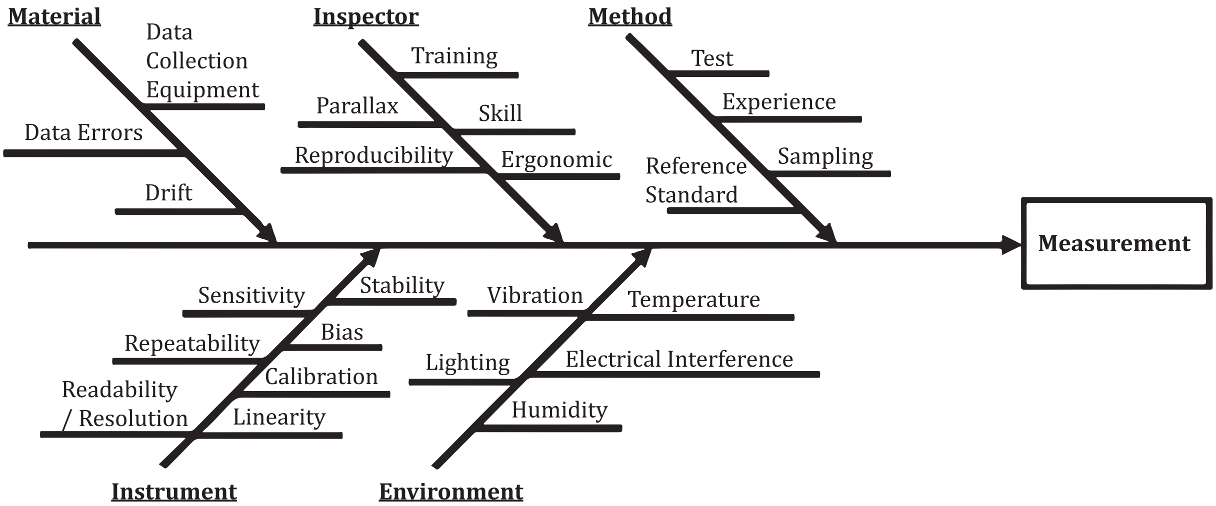


Figure C.1 — Measurement Uncertainty Contributors

C.1.13 A good approach to calculating the total measurement uncertainty is to use a method known as the uncertainty budget. An uncertainty budget is an itemized table of standard uncertainties that contribute to the total uncertainty in measurement results. It shows important information that identifies, quantifies, and characterizes each independent contributor. It may also be used to improve the quality of the measurement process. The objective of an uncertainty budget is to efficiently calculate measurement uncertainty using a structured approach. The benefit is that it provides a formal analysis process. An example from NIST is shown in Figure C.2, NIST Measurement Uncertainty Budget (*https://www.nist.gov › uncertaintybudgettabletemplate16jan2013xlsx*).

Measurement Result Units:					**Measurement Range and Parameter:**						
		Instructions: Fill in both "components" and "est unc in meas units" AND					*select "prob distribution" for complete calculations.*				
Uncertainty Component Description	**Symbol**	**Estimated Uncertainty**	**Units**	***d.f.***	**Estimated Unc in Measurement Units ()**	**Type (A, B)**	**Probability Distribution**	**Divisor**	**Std Unc ()**	**Relative Contribution (%)**	**Explanation/Source/Notes**
Instructions: Finish selections or assess resulting values.									***Instructions: Complete data entry.***		
Min Degrees of Freedom	v			*Entries incomplete.*							
Effective Degrees of Freedom	v_{eff}			*TBD*							
Combined Uncertainty, u_c									0	***Instructions: Assess data entry and values before reporting rounded result.***	
Coverage factor, k, *uses effective degrees of freedom*									TBD		
Expanded Uncertainty, U									TBD		
Expanded Uncertainty, U, Rounded to 2 Significant Digits									TBD	*No units selected.*	

Figure C.2 — NIST Measurement Uncertainty Budget

C.1.14 Classification of standard uncertainties as either A or B (see Clause 10.1.1) is sometimes difficult to determine. The following list of standard uncertainties may assist in that process.

Table C.1 — Standard uncertainty classification

Characteristic	Standard uncertainty classification
Bias	Type A
Drift	Type A
Hysteresis	Type B
Load	Type B
Nonlinearity	Type B
Readability	Type B
Reference standard	Type B
Reference standard stability	Type B
Repeatability	Type A
Reproducibility	Type A
Resolution	Type B
Sensitivity	Type B
Stability	Type A
Temperature effects	Type B
Zero offset	Type B

b) Using reliability analysis Weibull methods.

c) Periodic time intervals.

d) Based on frequency or elapsed time of use.

e) Instrument manufacturer's performance specifications and user experience.

f) Specific recalibration intervals depend on a number of factors including:

— requirements set by customers, contract, or regulation;

— inherent stability of the specific instrument or device;

— environmental factors that may affect the stability;

— instrument storage and use.

C.1.7 Use of an artefact substituting as a reference standard can be very effective in validating a measurement system over time. The artefact can be an actual test unit that is only used for that purpose. When results are tracked using control chart methods, or any statistical methods for comparison of data, any problems developing with the measurement system can be identified before conducting an extensive test and collecting data. The artefact needs to be calibrated periodically.

C.1.8 Efforts to establish that the measurement system is stable, repeatable, and under statistical control using statistical process control methods are a necessary prerequisite to data collection. This effort shall be conducted over time and is not a single event.

C.1.9 Observe any differences between environmental conditions in the calibration and the measurement situations and conduct an assessment of how these differences influence the integrity of data collected.

C.1.10 While some test standards have chosen to address the subject of uncertainty in terms of strictly the systematic error of the measuring instrument, this standard practice does not. In the test situation, systematic errors, random errors, calibration errors, environmental factors (in many cases the largest and often overlooked), all contribute to uncertainty in the test data. In the post-test situation, propagated uncertainty and data reduction errors enter in. By neglecting one or more of these, measurement uncertainty is ignored. Uncertainty in the final result is the prime concern, which necessitates that all possible sources of uncertainty be examined and quantified.

C.1.11 A practical means for selecting instruments used in a particular measurement situation is provided in Annex A. In most cases, all but the measurement system uncertainty is fixed, and this uncertainty is primarily a function of the instrument selected. The maximum allowable uncertainty corresponding to the specified measurement class is compared to the total measurement uncertainty. The measurement system is accepted if its total uncertainty is equal to or less than the maximum allowed uncertainty.

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(*Continued from second cover*)

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 5598 Fluid power systems and components — Vocabulary (*second revision*)	IS 10416 : 2019/ISO 5598 : 2008 Fluid Power systems and components — Vocabulary (*second revision*)	Identical
ISO 7870-1 Control charts — Part 1: General guidelines	IS 397 (Part 0) : 2021 Methods for statistical quality control during production : Part 0 Guidelines for selection of control charts (*second revision*)	Not Equivalent

The Committee has reviewed the provisions of the following International Standards referred in this adopted standard and has decided that they are acceptable for use in conjunction with this standard:

International Standard	*Title*
ISO 7870-2	Control charts — Part 2: Shewhart control charts
ISO/IEC Guide 98-3 : 2008	Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Amendments Issued Since Publication

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