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Title: Pressure transmitters with elastic sensing elements

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Contents

PART 1
TERMINOLOGY

The terminology used in this Recommendation generally follows the “International Vocabulary of Basic and General Terms in Metrology” (VIM-2007 edition) and the “Vocabulary of Legal Metrology” (VML-2000 edition). In addition, for the purposes of this Recommendation the following terminology applies.

Absolute pressure
Absolute pressure p_{abs} is the pressure compared to the zero pressure in a molecular-free volume

Gauge pressure
The pressure greater or less than ambient pressure, the latter being considered as the datum point.

Differential pressure
Difference between two pressures p_1 and $p_{2,}$ when it is itself a measurand: $\Delta p = p_1 - p_2$ pressure difference or also differential pressure $p_{1,2}$

The unified output signal
The electric output signal that is the result of the electric signal conversion coming from primary pressure transmitter into direct current standard signal of current: (0 - 5), (0 - 20), (4 - 20) mA; of voltage: (0 - 1), (0 - 5) V and others, if they are allowed by National Regulations.

The digital parameter of output signal
The transmitter signal, proportional to input pressure enounced in different digital protocols (for example, HART, BRAIN, Profibus, etc).

Single-ranged transmitter
The transmitter which output signal is proportional to only single value of measured pressure.

Re-adjustable transmitter
The transmitter, which could be tuned on every input value inside the range.

The pattern approval
Testing program needed for the determination of the conformity of a transmitter to the requirements of this Recommendation and Manufacturer's Technical Documents; the same transmitter pattern means that the transmitters are of the same design, operation, principle and they are manufactured according to the identical Technical Documentation.

Verification
The procedure (other than type approval) which includes the examination and marking and/or issuing of a verification certificate, that ascertains and confirms that the measuring instrument complies with the statutory requirements
The aim of verification is determination is determination of intrinsic deviation.

Calibration
Operation, that, under specified conditions, in a first step establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step uses this information to establish a relation for obtaining a measurement result from an indication.
Usually, the aim of calibration is uncertainty determination, but intrinsic deviation may be determined too.

Normal conditions
Usage conditions of measurement device, prescribed for undergoing tests or for providing veracity of intercomparison of measured data.

Metrological parameters

1. The nominal transfer function
Calculated dependence:
$I_{out} = F_1(P_{in})$,
$U_{out} = F_2(P_{in})$,
$Q_{out} = F_3(P_{in})$
Where: I_{out} - output current (mA),
U_{out} - output voltage (V),
Q_{out} - digital output signal,
$F_1(P_{in})$ - current nominal transfer function,
$F_2(P_{in})$ - voltage nominal transfer function,
$F_3(P_{in})$ - digital output signal nominal transfer function,
P_{in}* - input value (for example, pressure) at transmitter input

2. The actual transfer function (calibration diagram)
Experimentally determined actual dependence of output signal of a particular transmitter at the input value (pressure as a rule).
Actual transfer function is presented in tabulated from or in the from of calibration diagram.

3. The intrinsic deviation
The transmitter deviation in normal conditions. Furthermore the following types of deviation are distinguished:

3.1. The absolute deviation – Δ
The largest difference between values of actual transfer function and values of nominal transfer function of the transmitter for the same measured value, expressed in measured value units.

* Here P_{in} means the influence of input value at transmitter input (for example, of measured differential pressure), or input parameter of transmitter measuring channel (for example, working pressure), or electric signal, that simulates output signal of ambient temperature sensor.

3.2. The fiducial deviation – γ
The largest difference between values of actual transfer function and corresponding values of nominal transfer function of the transmitter, expressed in percentage of output signal range.

3.3. The relative deviation - δ
The largest difference between values of actual transfer function and corresponding values of nominal transfer function of a transmitter, expressed in percentage of reading value.

3.4. The combined deviation
The combined deviation of a transmitter is a combination of 2 or 3 of mentioned above types of determination. Sometimes the constituents of deviation are added to them. For example value of definition in the form of digits of the last position (when output signal is digital).

3.5. Maximum permissible error (MPE)
Extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system.

3.6. Maximum permissible deviation (MPD)
The maximum deviation received experimentally.

4. Constituents of measurement deviation and uncertainty

4.1. The variation of output signal (hysteresis)
The largest difference between values* of transmitter output signal at the variation of input influence P_{in} from smaller values to larger values and from larger to smaller ones at the same value of input influence.
The variation is expressed in percentage of output signal range.
The variation includes an uncertainty or determination conditioned by hysteresis and dead band of the transmitter.
The variation is not determined in the first and in the last points of actual transfer function.

4.2. The terminal based non-linearity of actual transfer function.
The largest deviation between the average values of actual transfer function and the values of calculated straight line coincided with actual transfer function in the first and the last points, at the same input pressure, expressed in percentage of output signal range variation (V or mA).
Non-linearity of output signal is **systematic** constituent of deviation of transmitter. In this recommendation it is considered to be numerically equal to systematic constituent.

4.3. The repeatability of output signal.
The repeatability is determined as dispersion of output signal expressed in percentage of variation of output signal range, at multiple transmitter checkings carried out in turn at the same output pressure and the same loading direction.
The dispersion can be determined either in the form of maximal range of linear deviations or in the form of RMS range of output signal deviation when verifications of transmitter are frequentative and ensuing directly one by one.
Sometimes the repeatability is called as short-term stability characteristics.

* At multiple measurings the term "value" means the average value of actual transfer function at a given input pressure.

4.4. Sensitivity of transmitter
Quotient of the change in an **indication** of a **measuring system** and the corresponding change in a **value** of a **quantity** being measured

5. Measurement uncertainty
Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used, including measurement uncertainty of instrument (transmitter), uncertainty of measuring method and some other uncertainties. In this recommendation only instrumental uncertainty is considered.

5.1. Instrumental measurement uncertainty
Component of **measurement uncertainty** arising from a **measuring instrument** or **measuring system** in use.

1. SCOPE

1.1. This Recommendation determines basic technical and metrological requirements for static pressure measurement transmitters with linear output signal (transmitters in the text), as well as the transmitter pattern evaluation requirements, initial and subsequent verifications, calibration and the OIML certification.

2. THE DESCRIPTION OF THE TRANSMITTER

2.1. The Recommendation is applicable to the following types of the instruments:
a) transmitters for gauge and absolute pressure* as well as differential pressure transmitter of liquid or gas with unified analog electrical output signals:
0 - 5, 0 - 20, 4 - 20, (mA);
0 - 1, 0 - 5, 0 - 10, 1 - 5, 1 - 10 (V).
The usage of other electrical output signals according to National Regulations is also allowed. The transmitters should be additionally equipped with indicating, digital or other measurement devices either indicators of pressure to be measured including noncontact, for example “Bluetooth”, “IR” or “Wi-Fi”.

b) transmitters equipped with a microprocessor carrying out so called "smart" functions with output coded signals (HART, BRAIN or other protocols), transformed into digital information of indication devices on transmitter body, on computer display, or on manual control board display. The transmitters may have analog output signal as well.

In addition to the main pressure measurement channel, the transmitters may be supplied with one or several accessory measurement channels, namely:
- Static (working), line pressure measurement channel for differential pressure transmitters.
- Channels of process ambience or ambience air temperature measurements (sometimes without primary transducer).

* The measurement chamber of an absolute pressure transmitter should be vacuumized

- Measurement channels for flow, liquid level and other values functionally connected with pressure in the form of computing device which main calculating parameter is pressure (or differential pressure), defined by primary channel of pressure measurement.

The channels of transmitters having primary transducers of other measurement quantities (for example, temperature), as well as the channels of electrical measuring and testing signals should be tested, calibrated and verified according to corresponding OIML International Recommendations, or with National regulations for this type of measurements.

It is allowed to carry out testing, calibration and verification of measurement channels of flow, level or density separately: with pressure channels and with a calculating device.

This Recommendation is applied to static pressure transmitters with a nominal linear increasing or decreasing transfer function.

3. THE UNITS OF PRESSURE MEASUREMENT

3.1. The pressure measurement unit is the pascal, Pa, which is equal to newton per square meter (N/m^2).

3.2. The transmitter should be graduated in Pa or its multiples: kPa, MPa and hPa, according to the Rules of the International System of Units (SI).

The bar and its submultiples, especially the mbar, as well as other units (for example mm Hg), may be used insofar as they are admitted by National Regulations and until there is an international decision on their use.

4. TECHNICAL REQUIREMENTS

4.1. The basic parameters.

4.1.1. The transmitters may be manufactured as a unified design, or in separate units.

4.1.2. The transmitters can be single-ranged or re-adjustable depending on the possibility of adjustment.

4.1.3. The nominal supply voltage value should be chosen from the following series:
6 12 15 24 27 36 42 48 60 110 220 and 230 V of direct or alternating current.

It is permitted to show a range of supply voltage values, for example, (12 - 42) V.

4.1.4. The requirements for power supply voltage are set in technical documents for particular types of transmitters.

4.1.5. The basic parameters of output signal of the transmitter should be chosen from the following series:
(0 - 5), (0 - 20), (4 - 20), (10 - 50) mA;
(0 - 1), (0 - 5), (0 - 10), (1 - 5), (1 - 10) V.

4.1.6. The transmitter should be capable of indicating measured values either directly or remotely. Indications may be analogue or digital.
The transmitters should be supplied with needle, digital or other measuring devices or indicators of measured values, which may have different metrological characteristics; digital measurement information may be taken from the transmitter body, from computer display, or control board display; the digital measuring device may be supplied with a fixed, as well as with "floating" comma.

4.1.7. The transmitter may be supplied with a microprocessor carrying out "smart" functions:
- remote control: measurement range re-adjustment, information readout, etc;
- self-diagnostics;
- output signal compensation in practical operation, as well as other functions.

4.1.8. The transfer function of a transmitter may be linearly increased or decreased.

4.1.9 The transmitters may be supplied with one or several measurement channels, measuring not only pressure.

4.1.10. The requirements towards mass and dimensions of transmitters are determined in Technical Documents for transmitters of particular types.

4.1.11. Keys and inscriptions:
The body of the transmitter should be supplied with the following inscriptions, if body dimensions allow it:
- the Manufacturer's trademark or name,
- the name and/or type of a transmitter,
- the serial number and the year of Manufacture,
- the measurement limits (including measurement units and measured pressure type),
- the main accuracy parameters.
- the output signal range,
- the power supply data,
- any other symbols and inscriptions connected with the use of the transmitter.

4.2. Metrological requirements

Depending on constructional features of the transmitter or on the customer’s requests the Manufacturer may establish (standardize) accuracy indices in various combinations considered in this chapter. Furthermore the reference to this publication and to the chapter, in which particular index and method of its determination are described, is necessary.

As accuracy figures the following parameters may be used:

4.2.1. The maximum permissible deviation.

4.2.1.1. The maximum permissible fiducial deviation of the transmitter, expressed in the percentage of output signal span should be chosen from the following series:
±0.02 ±0.04 ±0.05 ±0.06 ±0.1 ±0.15 ±0.2 ±0.25 ±0.4 ±0.5 ±0.6 ±1.0 ±1.5.
It is allowed to use others deviation values, for instance, ±0,075 or ±0,08, if they are not contradictory to National Regulations.
It is permitted to normalize absolute or relative deviations, their combination, and its constituents, for example:

- nonlinearity (systematic deviation),
- hysteresis
- repeatability
- reproducibility

It's permitted to normalize the measurement uncertainty and its constituents only in normal conditions and in units similar to deviation.

4.2.1.2. It is permitted to set different deviation values for analog, digital, needle or other measurement devices of transmitters.

4.2.1.3. It is permitted to set the maximum permissible deviations for re-adjustable transmitters different, depending on the span, as mathematical function.

4.2.1.4. The separate setting of zero drift and maximum deviation of other points of transmitter's actual transfer function is allowed.

4.2.1.5. The output signal variation, including the dead band should not exceed the 50% of the maximum permissible deviation.

4.2.1.6. It is allowed to normalize the uncertainty of the transmitter, if it is necessary. Furthermore its constituents should be chosen and grouped, as it is shown in the Annex C.

4.2.1.7. During the calculation of instrumental measurement uncertainty of the transmitter with microprocessor, compensating non-linearity (systematic constituent of uncertainty) the fulfillment of following condition should be checked:

$U\,exp \leq 0.33\,|MPE|$

Where:
U exp – expanded uncertainty of the transmitter
MPE – the limit of the permitted intrinsic deviation.

4.2.2. Influence factors

4.2.2.1. The influence of environmental factors towards the actual transfer function may be established as analytic transfer function for each influencing factor. The influence may be established separately for zero point and for other points of the actual transfer function. In the case, the transfer function is not known (or too complicated), it is permitted to normalize additional deviation towards given influencing factor. For example, the additional deviation may be expressed in the form of the part of the range, or of the whole range of transfer function.

4.2.2.2. Permitted limits of additional deviations or measurement uncertainty or permitted variations of output signal, caused by the influence:

- supply voltage,
- load resistance,
- ambient air and/or measured medium temperature,
- ambient relative humidity,
- mounting position change,
- shock and vibration parameters,
- overload,
- static (working) pressure for differential transmitters,

- external magnetic and electromagnetic fields,
- atmospheric (barometric) pressure for transmitters of absolute pressure,
- re-adjustment,
- transport influence

should be set in Technical Documents in accordance with future working conditions for particular transmitters.

It is permitted to test transmitters for the influence of other factors according to IEC Publication 60770, SAMA standard or other documents, according to National prescriptions.

It is permitted to set the limits of additional deviation analytically (in formulas, graphs or tables) as well as (approximately) in absolute values, or in the percentage of output signal range, corresponding to influencing factor variation range or to its part.

4.2.2.3. The determination of additional deviation (or output signal variation) with each of influencing factors should be carried out in the absence of other factors' influence.

Present at special equipment it is permitted to carry on additional testing with simultaneous influence of two and more factors according to specially developed methods, if it is not contradictory to National Regulations.

4.2.2.4. At the determination of operating factors' influence, the maximum variation of output signal, related to output signal range (additional deviation), should not exceed permissible values, specified in Technical (and advertising) Documents of the Manufacturer as well as in National Regulations.

4.2.2.5. It's permitted to normalize general measurement uncertainty of the transmitter in working conditions:

$Y_s = Y_{nc} + Y_{wc}$, where:

Y_s – general deviation in working conditions.
Y_{nc} – deviation in normal conditions
Y_{wc}- deviation in working conditions

$$Y_{wc} = K_p \cdot \sqrt{\gamma_t^2 + \gamma_u^2 + \gamma_r^2 + \gamma_d^2 + \gamma_n^2 + \gamma_x^2}$$, where

γ_t – change of output signal of the transmitter due to the change of ambient air temperature.
γ_u – change of output signal of the transmitter due to the voltage change.
γ_r – change of output signal of the transmitter due to readjustment.
γ_d – change of output signal of the transmitter due to static pressure change.
γ_n – change of output signal of the transmitter due to vibration.
γ_x – change of output signal of the transmitter due to other influences (for example position change influence or other)
K_p – coverage factor depended on reliability requirements.

5. SAFETY REQUIREMENTS

5.1. The safety of testing, calibration and verification of transmitters is provided with the following:

- the strength and tightness of measurement chambers,
- the dielectric strength and resistance of insulation;
- the use of standards and auxiliary equipment according to their safety instructions.

5.1.1. The transmitter design should be strong and hermetically sealed at pressure not less than 125 % of upper measurement limit. The exposure time – 60 minutes.
For transmitters with upper measurement limit from 100 MPa up to 250 MPa test pressure of 115 % of upper measurement limit is permitted, for transmitters with upper measurement limit more than 250 MPa permissible test pressure should be 110 % of upper measurement limit.
Transmitters for absolute pressure with upper measurement limit not exceeding 0.1 MPa should be strong and hermetically sealed at atmospheric pressure.
Transmitters for differential pressure should withstand 15 minutes 125 % of upper nominal pressure difference to plus chamber and alternate (one minute to plus and minus chambers) – 100 % working pressure.
The requirements for metrological characteristics of transmitters after overload are established by the Manufacturer in Technical Documents for particular types of transmitters.

5.1.2. Insulation dielectric strength measurements
Insulation dielectric strength measurements are checked according to IEC Publication 61010-1-90 or National Regulations concerning electrical safety.

5.2. The transmitters may be used in explosion hazardous conditions. In this case they should be supplied with a corresponding Certificate or the other document according to National Regulations on explosion proof technique.

6. METROLOGICAL CONTROLS

6.1. Types of metrological controls

This type of controls should include all or several of the following types according to the National Regulations of a given country:

- the pattern evaluation and approval,
- the calibration,
- the verification.

6.2. The pattern evaluation and approval

6.2.1. Any new or modified design of transmitters intended for use as a metrological control object, should be first evaluated as a pattern with corresponding metrological service.
The pattern approval is carried on according to the Manufacturer's application, or another private or a juridical person (with a written agreement of a Manufacturer’s presence).

6.2.2. The pattern approval testing is carried out for the determination of the transmitter's conformity with the requirements of this Recommendation and includes the following operations:

- studying of Manufacturer's Technical Documents, design, operation principle, operating conditions of transmitters,
- testing program development for pattern evaluation and approval,
- selection of particular transmitters for testing,
- visual inspection and preparation for work of chosen transmitters,
- evaluation of technical (including metrological) characteristics of transmitters in reference conditions and determination of intrinsic deviation,
- successive evaluation of technical (including metrological) characteristics of transmitters under the influence of every influencing factor and determination of additional deviation,
- registration of test results and issue of pattern approval Certificate.

PART2

7. TEST PROCEDURES

7.1. The quantity of tested samples is determined depending on design features and selected so as to present as completely as possible all modifications, measurement limits, types of measured pressures and output signals; in any case the number of tested samples should not be less than three*; for metrological testing designs with minimal measurement limits are preferable.

7.2. The transmitters should not have defects preventing the procedure of testing.

7.3. Before starting tests the transmitters should be connected to the test stand, to check strength and tightness of pneumatic or hydraulic networks, strength and tightness of transmitters themselves, to expose transmitters in ambient conditions for not less than 2 hours (at switched on power supply for not less than 15 minutes as well), then to expose them with three loading cycles, until otherwise mentioned in Manufacturer's Technical Documents.

The transmitter should be connected to the circuit specified in Manufacturer's Technical Documents, intended for transmitters and standards.

7.4. The transmitters should be adjusted the same way that the values of zero and other actual transfer function points (at least the values corresponding to the lower and upper measurement limits), for all measurement devices of the transmitters should be at a maximum close to the corresponding transfer function values (to the calculated values).

7.5. For transmitters with analog output signals the maximum load resistance of direct current and minimum load resistance of output signal of direct voltage should be set until otherwise mentioned in Manufacturer's Technical Documents.

7.6. Power supply voltage of a tested transmitter should be chosen arbitrarily within the range mentioned by the Manufacturer (preferably the middle of the range).
During tests the supply voltage of the transmitter should not be changed for more than 1 %.

7.7. The transmitters having analog, digital and/or other output devices are adjusted and checked separately with every output device used.

7.8. The sequence of tests is determined before testing depending on the number of selected samples and the efficiency of testing equipment; recommended test sequence is given in Annex A.
If the influence of ambient factors are not within the frame of operating conditions such as, overload, transmitters are so far tested at the end of the test procedure.
All the software used in the course of testing for pattern approval, calibration or verification should be agreed with the metrological service carrying out testing, calibration or verification.

7.9. Reference test conditions
7.9.1. Pattern approval testing, calibration and verification should be carried out in the following reference conditions:

* Each transmitter may not be tested with a complete Annex A program.

- the instruments should be installed in normal working position (in the course of particular testing the position of a transmitter should not be changed),
- pressure variation should be slow and smooth,
- the temperature of the tested instruments and ambient air should be:

20 °C ± 1 °C - for transmitters with maximum permissible intrinsic deviation: ±0,02; ±0,04; ±0,05; ±0,06 %,

20 °C ± 2 °C - for transmitters with maximum permissible intrinsic deviation: ±0,1; ±0,15 (±0,16); ±0,2; ±0,25 %; ±0,4; ±0,5; ±0,6; ±1,0; ±1,5; ±1,6 %,

- ambient relative humidity should not exceed 75 % (preferably 65 % ± 5 %),
- atmospheric pressure from 86 kPa to 106 kPa (preferably 101.3 kPa),
- vibration, shaking and other influence factors should be eliminated, except those the elimination of which is not possible (for instance, gravity).
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7.9.2. The accuracy parameters of all standard instruments should be as small, as it possible (preferably not higher than 25% of limit of permissible intrinsic deviation of a tested transmitter)

7.9.3. The measurement range of standard instruments should not be less than to the measuring range of tested instruments.

7.10. Determination of metrological characteristics.

The metrological characteristics of transmitters are checked for conformity with 4.2 of this Recommendation.

For this the actual transfer function of the selected transmitters is experimentally determined or the curve of their deviation of nominal transfer function is plotted.

7.10.1. The points along those actual transfer function is plotted, should be more or less uniformly distributed along measurement span; the number of points at the determination of intrinsic deviation, hysteresis and constituents of deviation should not be less than 5 for transmitters with the deviation bigger than 0,1 % and not less than 9 for transmitters with the deviation less than 0,1 %, including zero and maximum points.

The input pressure is sequentially increases and then decreases step by step from lower to upper range and backward. The amplitudes of steps are set with the help of the standard. Furthermore the proper values of output current, voltage and/or values from showing devices are registered. The transmitter is exposed in each point as long as it is necessary for transmitter and standard stabilization.

The transmitter should be exposed in the point, which corresponds to the upper measurement limit as long as it is needed in Manufacturer's opinion for completing the transfer processes. The indicated value of the transmitter is determined in every point and registered in the table. Then this data will be used for plotting the deviation curve and calculation the accuracy characteristics of the transmitter. All necessary formulas are presented in the Annex C.

7.10.2. The plots of the actual transfer function and/or deviation curve are plotted separately for each of output measurement devices, for not less than in three (preferably in five and more) transmitter testing series (for transmitter verification and at the determination of additional deviation only one cycle is carried on).

7.10.3. The transmitter is considered as having passed the test successfully in the determination of the basic and fiducial accuracy parameters, if the experimentally determined values of these accuracy parameters do not exceed the values specified in the Technical Documents of the Manufacturer.

7.10.4. The determination of operating condition influence

a. The check of the supply voltage variation influence

1) The check of the steady-state supply voltage variation influence.

The check of the smooth supply voltage variation influence is carried out at three output signal values: from 20 % to 30 %, from 50 % to 60 %, from 80 % to 90 % of output signal span. After the determination of output signal at the average (nominal) supply voltage, its settled value should be checked in the extreme lower (upper) points of the supply voltage range.

The transmitter is considered as having passed the test successfully, if after the tests with supply voltage variation its characteristics do not exceed maximum permissible accuracy parameters, specified in the Technical (and advertising) Documents of the Manufacturer.

2) The check of the supply voltage frequency variation influence.

The check of the supply voltage frequency variation influence is carried out with three output signal values in the intervals from 20 % to 30 %, from 50 % to 60 %, from 80 % to 90 % of output signal range. Setting one of the output signal value with the power supply frequency 50 (60) Hz, its value is determined at frequency equal to 49 and 51 (59 and 61) Hz.

The transmitter is considered as having passed the test, if the additional accuracy parameters (or the output signal variation) do not exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

3) The check of the transient supply voltage variation influence.

The check of the intermittent supply voltage variation influence is carried out at any output signal value in the interval from 10 % to 90 % of output signal range. Setting one of the output signal values at the extreme minimum supply voltage the check is carried out according to 7.10.1, then the supply voltage of the transmitter is intermittently changed up to nominal, then the value and duration of the output signal ejection are measured with an oscilloscope and again the check is carried out according to 7.10.1. The same measurements are carried out with the intermittent supply voltage change from extreme maximum to nominal.

The transmitter is considered as having passed the test successfully, if after the tests its characteristics do not exceed maximum permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

4) The check of the reverse supply voltage protection.

For transmitters incorporating protection against power supply reversal, the maximum allowed reverse power supply voltage should be applied.

5) The check of the output signal circuit break and the short circuit influence.

The check of the output signal circuit break and the short circuit influence is carried out as follows: the output signal circuit break or the short circuit is made for the period, determined in the Technical Documents for the transmitters of particular types.

The break or the short circuit is eliminated and the check is carried out according to 7.10.1.

The transmitter is considered as having passed the test successfully, if at three span points: 0, 50% and 100 % the accuracy parameters don’t exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

6) The check of the load resistance influence.
The check of the load resistance variation influence of transmitters with current output signals is carried out according to 7.10.1 (with one series) of this Recommendation with three load resistance values: from 20 % to 30 %, from 50 % to 60 %, from 90 % to 100 % of its upper span limit.
The transmitter is considered as having passed the test successfully, if during the tests its characteristics don't exceed maximum permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

7) The check of the external magnetic field influence.
The check of the external magnetic field influence is carried out as follows. The transmitter is placed into the center of the coil that creates a uniform magnetic field, the intensity of which is specified in Technical Documents for transmitters of particular types (400 A/m, 50 Hz or 80 A/m of constant magnetic field).
The control instruments should be placed at a distance of 3 m, not less from the installation.
The wires connecting the tested transmitter with standard instruments should be twisted and placed into a grounded screen.
The check is carried out with three output signal values: from 20% to30 %, from 50% to 60%, from 80 % to 90 % of output signal range. The output signal with no magnetic field is measured, then, changing the phase and direction of magnetic field, the output signal is measured at the most unfavorable position that produces the largest output signal variation.
The transmitter is considered as having passed the test successfully, if during the tests its characteristics does not exceed maximum permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

8) The check of the radio interference level, created by the transmitter and the check of the electromagnetic compatibility of transmitters with other devices.
The check of the radio interference level, created by the transmitter and the check of the electromagnetic compatibility of transmitters with other devices should be carried out according to National Regulations.

b. The check of the ambient air temperature variation and/or measured temperature of the ambient medium influence
The check of the measured air temperature variation influence is carried out successively for increased and decreased temperatures as follows.

The transmitter is placed into a heat (cold) chamber, and then it is switched on and checked according to 7.10.1 of this Recommendation (within reference conditions with two series, one after another).
The chamber temperature is increased (decreased) to extreme value, specified in the Technical Documents and after the exposure at this temperature for not less than 2 hours the transmitter is again checked two times according to 7.10.1, successively one after another.
The permissible temperature limits are in the chamber is ± 2 °C.
The chamber temperature is increased (decreased) to a normal temperature and after the exposure at this temperature for not less than 2 hours the transmitter is again checked two times, successively one after another.
The permissible temperature difference among these three checkings is ± 2°C.
During the whole period of testing, the transmitter should be switched on and with a connected load.
All the checking operations should be carried out with no transmitter readjustment.

The output signal correction is permitted only before the first check.
The additional accuracy parameters (or output signal variation) are determined as the difference between maximum deviation values (or output signal values) obtained at two measurements with the extreme temperature and four measurements at temperature in normal conditions.
The transmitter is considered as having passed the test successfully, if during and after the tests its characteristics do not exceed maximum permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.
In well-founded cases (for example, after the analysis of preliminary test results) it is permitted to use more intermediate points of temperature range used.
The test for the influence of measured medium temperature is carried out in the same way. During this test only that part of the tested transmitter is placed into a chamber, with which the measured medium is in contact (if the transmitter design permits).
It is permitted to carry out the check of the temperature measured medium influence (with Manufacturer's agreement) by heating (or cooling) the transmitter to some value of measured medium permitted temperature.
The experimental or theoretical data concerning tested transmitter's body temperature variation under the influence of measured medium temperature can also be taken into consideration.

c. Ambient relative humidity effects
To determine the resistance of the tested transmitter toward the influence of the increased humidity, the transmitter is placed into a heat and moisture chamber and is carried out checking once according to 7.10.1 in normal conditions.
Then it is exposed in switched on position during 48 hours with increased temperature and relative humidity, the values of the latters are established in the Technical Documents for transmitters of particular types, depending on their working characteristics.
The chamber conditions are established as follows. First, the temperature is increased up to the required value, the transmitter is exposed during 2 hours, then the relative humidity is increased and these conditions are maintained during 2 days.
After the exposure of the transmitter in increased humidity conditions, its characteristics are checked once again according to 7.10.1.
The normal conditions are established in the chamber and the transmitter is exposed there during the period specified in the Technical Documents for transmitters of particular types.
The transmitter is considered as having passed the test successfully, if there is no corrosion on its external and internal parts, scalings and deterioration of coatings, breaking efficiency and deteriorating appearance and the accuracy parameters don’t exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.
The output signal correction is permitted only before the first check.

d. The check of the mounting position change influence
The check of the working position change influence is carried out at the declination from the working position, specified by the Manufacturer.
The test is carried out with one measurement series at the declines of the transmitter to the left, right, forward and backward according to 7.10.1.
The transmitter is considered as having passed the test successfully, if the additional accuracy parameters (or the output signal variation) as compared to the normal position don’t exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

e. The check of the vibration influence

The following tests are carried out at the check of the vibration load influence:

- vibration endurance test,
- resonance frequency detection test,
- vibration robustness test.

These test methods are established according to the National Regulations or to 6.2.14 of IEC Publication 60770 depending on working characteristics for transmitters of particular types.

f. Overload influence

The overload test is carried out according to 6.1.1 of this Recommendation.

g. The check of the static pressure effects

The check of the working pressure variation influence is carried out for differential pressure transmitters. The check is separately carried out for zero point and for other points of actual transfer function.

1) The check of the working pressure variation influence for zero span point of minimum measurements range

The initial output signal value (other than zero) is set at the zero of the differential pressure with the zero corrector or in a different way.

By means of smooth working pressure increase simultaneously in both chambers from zero up to permissible extreme value and then decrease it down to zero, the variation of output signal zero value is determined.

The transmitter is considered as having passed the test successfully, if the additional deviation (or the output signal variation) does not exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

2) The check of the working pressure variation influence to other points (for the inclination angle) of actual transfer function.

The check is carried out with special standards, the metrological characteristics of those do not practically depend on static pressure, and the sensitivity of these standards does not exceed 20 % of the tested transmitter intrinsic deviation.

For this, in the three points of static pressure variation span: 10 %, 50 % and 100 % the actual transfer function of the differential pressure transmitter should be plotted according to 7.10.1 and the additional accuracy parameters (or the output signal variation) should be determined.

The transmitter is considered as having passed the test successfully, if the additional accuracy parameters (or the output signal variation) does not exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

If the Technical Documents do not specify the limits for general additional accuracy parameters of the static pressure influence, the output signal variation for zero and other points of actual transfer function should be put together.

h. The check of the atmospheric pressure variation influence to absolute pressure transmitters

The check of the atmospheric pressure variation influence to the output signal of absolute pressure transmitters is carried out in the barometric chamber with one fixed value of measured pressure and with pressure of ambient air in the pressure chamber equal to atmospheric. Changing chamber pressure for ±10 kPa the output signal variation is determined.

The transmitter is considered as having passed the test successfully, if its characteristics don’t exceed maximum permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

i. The check of the ripple content of electrical output of the transmitter with current output signal

The check of the ripple content of electrical output of the transmitter with current output signal is carried out with an oscilloscope by the transmitter voltage alternating component at the upper and lower ends of the span and with maximum load resistance 250 Ω and 1000 Ω for transmitter with upper values of output signal 20 mA and 5 mA.

The transmitter is considered as having passed the test successfully, if the ripple content of electrical output of the transmitter does not exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer, but it should not exceed 0.5 of the maximum permissible deviation.

j. The check of the transmitter adjustment possibility for shifting span

The check of the transmitter adjustment possibility for shifting span is carried out with any transmitter which is first adjusted for minimum, average then for maximum measurement limit for the given model.

The check is carried out according to 7.10.1

The transmitter is considered as having passed the test successfully, if the additional accuracy parameters (or the output signal variation) don't exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

k. The check of the transmitters for transport conditions influence

1) The check of transport shake influence

The check is carried out in conditions, specified in Technical Documents for particular types of transmitters.

The check of transport shake influence is carried out as follows.

The packed transmitters according to the requirements of the Technical Documents are mounted on a test rig platform without additional outside amortization devices in a position shown on the packing mark.

The test is carried out at the transport shaking test rack or blow test rack with an acceleration of 30 m/s^2 and frequency of 10 to 120 shocks per minute, for 2 hours.

The transmitter is considered as having passed the test successfully, if after transport shaking its appearance is not deteriorated, and the accuracy parameters don't exceed values, specified in the Technical (and advertising) Documents of the Manufacturer.

2) The check of the increased (decreased) temperature influence that corresponds to transport conditions.

The check of the increased (decreased) temperature influence that corresponds to transport conditions is carried out as follows.

The packed transmitters according to the requirements of the Technical Documents are placed into a heat chamber (cold chamber) where the temperature increases (decreases) up to + 50 °C (down to – 50 °C or – 60 °C). In well-founded cases it is permitted to test transmitters at temperature – 70 °C.

The permitted temperature limits are is ± 3 °C. The exposure time in the chamber at the given temperature should not be less than 6 hours.

The transmitters are subjected to natural cooling (heating) down to normal temperature, exposed for the time, specified in Technical Documents for transmitters of particular types, after that the transmitters are unpacked, visually inspected and the accuracy parameters are determined.

The transmitter is considered as having passed the test successfully, if after the influence of the increased (decreased) temperature its appearance is not deteriorated, and the accuracy parameters don't exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

3) The check of the increased relative humidity influence corresponding to transport conditions.

The check of the increased humidity influence to the packed transmitters according to the requirements of the Technical Documents is carried out as follows.

The transmitters are placed into a heat and humidity chamber and relative humidity increases up to 90 % at 35 °C.

The permitted humidity limits are ± 5 %.

The exposure time in the chamber should not be less than 6 hours.

The transmitters are subjected to natural cooling down to temperature and relative humidity that corresponds to normal conditions and expose them in these conditions during the period of time, specified in the Technical Documents for transmitters of particular types, after this, the transmitters are unpacked, visually inspected and the accuracy parameters are determined.

The transmitter is considered as having passed the test successfully, if after the influence of the increased relative humidity its appearance is not deteriorated, and the accuracy parameters don't exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.

It is permitted to test transmitters for transport condition influence without packing.

If transport conditions are not beyond the scope of specified working conditions, it is allowed not to carry out these tests.

7.10.5. The determination of start-up drift

The start-up drift is determined as follows.

The transmitters are exposed in the ambient conditions during 24 hours, then the input signal value equal to 10 % is fed and the intrinsic deviation is determined according to 7.10.1 in 5 minutes, then in 1 hour and in 4 hours after switching on the transmitter.

After this, the transmitter is switched off and exposed for 24 hours in ambient conditions. Then, the test is repeated at input signal value equal to 90 %.

The maximum deviation from actual transfer function in percentage of output signal range determines a start-up drift.

7.10.6. The determination of long-term drift

The long-term drift is determined during 30 days with a stationary input signal that corresponds to 90 % of span.

The values of input and output signals are registered every day, the stability is determined, calculating the correction of it for any small deviation of input signal.

All the influenced factors except the time should remain within the limits of permissible values during the test.

Before testing and after 30 days it is necessary to register the values of the lower and the upper end of span.

7.10.7. Accelerated operational life tests

The transmitters should withstand accelerated reliability testing in working conditions: the influence of 20 000 pressure change cycles from (20-30) % to (70-80) % of span (the frequency ≤ 2 min^{-1}).

The transmitter is considered as having passed the test successfully, if after the test and correction of "zero" value of output signal the accuracy parameters don't exceed permissible values, specified in the Technical (and advertising) Documents of the Manufacturer.
It is permitted to correct "zero" output signal value, if it is specified in the instruction manual.

7.10.8. The determination of the power consumption

The power, consumed by the transmitter is determined by an ammeter and voltmeter connected to power supply circuit.

7.10.9. The check of the dynamic characteristics

The dynamic characteristics of the transmitter, determined by the output signal settling time and maximum variation of output signal or other characteristics, are defined with experimentally obtained transfer characteristics in the course of intermittent disturbance influence towards transmitter input, rising at the reset or dialing of the measured value (or its imitation) towards zero indication in accordance with the Technical Documents of the Manufacturer.

7.10.10. Test report

7.10.10.1 If the test results are satisfactory and the transmitter samples meet specified requirements, the metrological authorities, according to National Regulations:
1) define procedures for the initial and subsequent verifications of transmitters of tested pattern;
2) decide upon a maximum time interval between verifications. To take decision, it is also necessary to consider such factors as transmitter's purpose, stability, specified in the Manufacturer's Documents, the expected frequency of use, the conditions under which the instrument is housed and the frequency of transportations;
3) issue a pattern approval certificate containing the following information:

- the name of the testing authority,
- the Manufacturer's trademark or name,
- the pattern designation number, the name or the code of the approved pattern,
- the deviation,
- a brief description of the instrument and its function,
- the serial number of the transmitter,
- the pressure range of the examination,
- the temperature range of the examination,
- the traceability of the standards used in the evaluation,
- any special limitations on the use of the transmitter,
- the procedures for verification,
- the maximum time interval between verifications.

4) If in the course of one of the tests the accuracy parameters of the transmitter exceed permissible values, the additional testing is carried out twice towards a conflicted point.
5) In the case of at least one negative result, two more transmitters are checked towards this parameter. These results are considered completely final.

7.10.10.2. The test results for pattern approval of the transmitter type should have the form, specified in Annex A.

8. THE CALIBRATION

8.1. The calibration should be performed by the metrological service of the corporate or national metrological service accredited in accordance with the established procedure according to National Regulations about calibration and Guide 17095.

8.2. The general requirements related to the transmitter calibration are corresponded to 8.3 – 8.7.
The range of calibrated readjusted transmitters is determined by the Customer. In the case of no order, the transmitters may be calibrated for any measuring range within the maximum measurements range.
The range for which the transmitter has been calibrated should be pointed out either in Calibration Certificate or in technical specification of the Manufacturer.

8.3. The conditions for carrying out calibration should correspond to 7.9.1 of this Recommendation.

8.4. Calibration carrying out
8.4.1. The calibration is carried out by the direct comparison method - the comparison of characteristics of the calibrated instrument and the standard one, with the same pressure values and in the same ambient conditions not less than five testing cycles.

8.4.2. According to calibration results, the evaluation of transmitter accuracy parameters is carried.
It is permitted to use a different calibration procedure, depending on the accuracy class of the calibrated transmitter.

8.4.3. It is permitted to carry out calibration at Customer's request in conditions that are close to real (at the increased static pressure, at the increased (decreased) ambient temperature, etc). In this case a corresponding note in the calibration protocol should be made.

8.4.4. According to calibration results a calibration certificate and the protocol of calibration are issued.

8.5. The connection diagram is presented in Annex B.

9. THE VERIFICATION

9.1. A transmitter shall be verified initially and subsequently by the metrological service in accordance with National Regulations and according to confirmed in the prescribed manner procedure.

9.2. If a transmitter is overhauled it shall be verified before further use.

9.3. Verification operations
Verification includes the following operations:
- a visual inspection (in accordance with 7.2.),
- a preliminary check (in accordance with 7.3 – 7.8),
- the determination of metrological characteristics (in accordance with 9.6.1).

9.4. Means of verification

Means of verification are taken according to National Regulations, taking into account 7.9.3.

9.5. Conditions of verification
Conditions of verification should correspond to 7.9.1 – 7.9.2.

9.6. Verification carrying out
9.6.1. The transmitters presented for periodic verification shall bear the mark of the previous verification or be accompanied by the previous verification Certificate. The range of possible adjustment and/or measurement range should be pointed out by the Customer. In case of absence of directions it is permitted to establish measurements range or maximum measurements range, designated on transmitter body. During the process of verification only one load cycle is carried out. The verification is carried out in two stages. It's assumed not to carry the second cycle, if during the first one the accuracy parameters don't get into the toleration. If the transmitter doesn't get into the toleration during the first cycle, it should be corrected. In the case, when after the correction the transmitter befits, it is considered to be fit for use. If not – the notification about unsuitability is checked out.
The time interval between verifications is determined in accordance with National Regulations, based on the test results of compliance with the approved pattern as well as the rate of operating conditions of transmitters.

9.7. The official registration of verification results
9.7.1. The transmitters, corresponding to the requirements of this Recommendation are considered to be fit for use.

9.7.2. The transmitters fit for use are marked with a verification mark and/or with a verification Certificate.

9.7.3. The verification Certificate for the transmitter shall, according to National Regulations, include the following:
1) the name of the metrological service authority that performed the verification,
2) the name of the owner of the transmitter,
3) the Manufacturer's trademark or name,
4) the designation, number or code of the approved pattern with which it conforms,
5) the number, date and origin of the pattern approval certificate,
6) the accuracy parameters,
7) the brief description of the transmitter and its purpose,
8) the serial number of the transmitter,
9) the manufacture year,
10) the traceability of the standards used in the verification,
11) any special limitations on the use of the transmitter,
12) the date of expiry of the verification Certificate,
13) the procedures for verification,
14) the maximum time interval between verifications.

9.8. The connection diagram is presented in Annex B.

PART 3

10. TEST REPORT FORMAT

10.1. The tests of instruments in conformity to the requirements of this Recommendation include operations, specified in Annex A.
10.2. Besides, the transmitters are checked in conformity to the Technical Documents and the check of the operation documents.
Considering operation documents one can pay attention to the information completeness, as well as to the information of the procedures and means for verification. The capabilities for metrological assurance are evaluated.
10.3. Test report
10.3.1. The test report should be written according to the form, given in Annex A and should include the protocol of testing, given in Annex A. The testing protocol for every type should be compiled separately.
10.3.2. It is recommended to compile the test report and the conclusion as separate documents.
10.3.3. The OIML Certificate should be compiled according to the form, specified in the Document "OIML Certificate System for measuring instruments". Issue 1991.01.01.

11. CONCLUSION

In the Annex C the example of calculating of intrinsic deviation (table B.3, fig. 1) and instrumental measurement uncertainty (table B.4; table B.5, fig 2) are presented. For descriptive reasons and succession we used the experimental data from IEC Publication 60770.
The instrumental measurement uncertainty is calculated in two methods.
In the first method the average (systematic) deviation is not included to the content of expanded uncertainty, but comes to account when the maximum deviation (so called “error span”) is calculated.
In the second method the average (systematic) deviation is included to the content of expanded uncertainty.

12. BIBLIOGRAPHY

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10. IEC 61298-2: 1995-07, Process measurement and control devices – General methods and procedures for evaluating performance – Part 2: Tests under reference conditions.
11. IEC 61298-3:1998-02, Process measurement and control devices – General methods and procedures for evaluating performance – Part 3: Tests for the effects of influence quantities.

ANNEX A

TEST REPORT FORMAT

TEST REPORT N_____

Testing of _____Type _____
measuring instrument

Name and address of the Manufacturer

_____

_____

Name and address of the applicant (if other than the Manufacturer)

_____

_____

№ of instruments_____ Measuring range _____

Accuracy class _____

Date(s) of testing _____

Place of testing _____

Standard measuring instruments and equipment used for testing: _____

_____

Conclusion concerning compliance of the tested instruments to all requirements:

_____

Signature of the person issuing the certificate _____

Date of issue _____

Examination Report

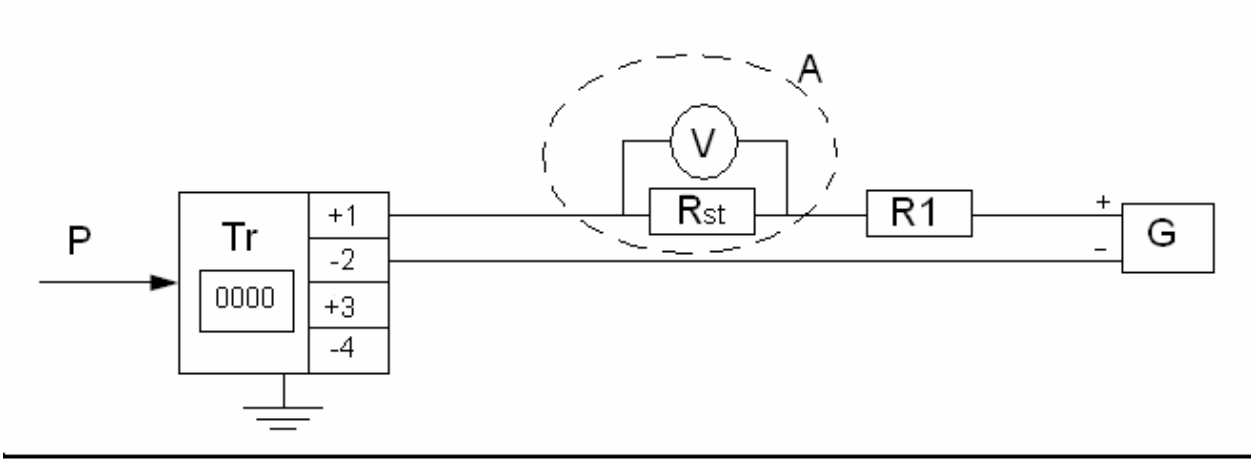
№№	Test description	Reference to R and requirement	Reference to R (test method)	Test results Conventional symbols of instruments Manufacturer's number Measurement limits	Conformity to requirements of R
1.	Safety requirements				
	a) overload effects	5.1.1	7.10.4 f. 5.1.1		
	b) insulation dielectric strength measurements	5.1.2			
	c) insulation resistance	5.1.2			
2.	Determination of metrological characteristics	4.2.1	7.10		
3.	Determination of operating condition influence	4.2.2	7.10.4		
a)	check of supply voltage variation influence		7.10.4.a.1		
	1) steady-state supply voltage		7.10.4.a.1)		
	2) supply voltage frequency		7.10.4.a.2)		
	3) transient supply voltage		7.10.4.a.3)		
	4) reverse supply voltage protection		7.10.4.a.4)		
	5) output signal circuit break and short circuit		7.10.4.a.5)		

№№	Test description	Reference to R and requirement	Reference To R (test method)	Test results Conventional symbols of instruments Manufacturer's number Measurement limits	Conformity to requirements of R
	6) load resistance		7.10.4.a.6)		
	7) external magnetic field		7.10.4.a.7)		
	8) radio interference level, created by the transmitter and electromagnetic compatibility of transmitters		7.10.4.a.8)		
b)	ambient air temperature and (or) measured medium temperature		7.10.4.b		
c)	ambient relative humidity		7.10.4.c		
d)	mounting position		7.10.4.d		
e)	vibration		7.10.4.e		
f)	overload		7.10.4.f		
g)	static pressure		7.10.4.g		
h)	atmospheric pressure (for absolute pressure transmitters)		7.10.4.h		
i)	ripple content of electrical output		7.10.4.i		
j)	transmitter adjustment possibility for shifting span		7.10.4.j		
k)	transportation		7.10.4.k		
	1) transport shake		7.10.4.k.1)		
	2) increased (decreased) temperature		7.10.4.k.2)		

№№	Test description	Reference to R and requirement	Reference to R (test method)	Test results Conventional symbols of instruments Manufacturer's number Measurement limits	Conformity to requirements of R
	3) increased relative humidity		7.10.4.k.3)		
4.	Determination of start-up drift		7.10.5		
5.	Determination of long-term drift		7.10.6		
6.	Accelerated operational life		7.10.7		
7.	Determination of power consumption		7.10.8		
8.	Check of dynamic characteristics		7.10.9		

ANNEX B

The connection diagram



P– input pressure
Tr– the transmitter
V – the voltmeter
R_{st} – the standard resistor
R1 – load resistance
A – the device for output current measuring
G – the generator

ANNEX C

DETERMINATION OF ACCURACY PARAMETERS
Determination of intrinsic deviation and its constituents

1. The measurement range is divided into ***m*** intervals.

2. The calculated input values X_{pi} are determined according to the formula.

$$X_i = X_0 + \frac{i}{m}(X_m - X_0) \tag{1.1}$$

Where $i = 0,1...m$;

X_0, X_m - lower and upper measurement limits of input value ***X***.

The values X_{pi} are inserted into table B.1.

3. The computed output signal Y_{pi} values are determined from the formula:

$$Y_{pi} = Y_0 + \frac{i}{m}(Y_m - Y_0) \tag{1.2}$$

where Y_0, Y_m - output signal computed value ***Y***, that corresponds to the lower X_0 and upper X_m limits of input value measurement ***X***.

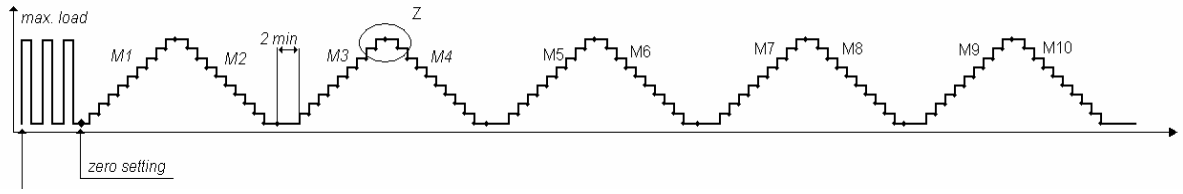
The values Y_{pi} are inserted into table B.1.

4. For every input value X_i the output signal values are measured in every of ***j*** checking cycles loading (testing) of output signal value:

– $Y_{ij}\uparrow$ – with input value variation from X_0 up to X_m (direct course);

– $Y_{ij}\downarrow$ – with input value variation from X_m up to X_0 (retrace).

The values $Y_{ij}\uparrow$ and $Y_{ij}\downarrow$ are inserted to the table B1.



5. For every input value X_i in every of ***j*** checking cycles the deviations of $\Delta_{ij}\uparrow$ (at the direct course) and $\Delta_{ij}\downarrow$ (at the retrace) of output signal measured values Y_{ij} from calculated values Y_{ci} of that signal (below – deviations $\Delta_{ij}\uparrow$ and $\Delta_{ij}\downarrow$) are determined from the formulas

$$\Delta_{ij}\uparrow = Y_{ij}\uparrow - Y_{pi} \tag{1.3}$$

$$\Delta_{ij}\downarrow = Y_{ij}\downarrow - Y_{pi} \tag{1.4}$$

The values $\Delta_{ij}\uparrow$ and $\Delta_{ij}\downarrow$ are inserted into table B.2

6. .For every input value X_i the maximum deviation Δ_{mi} of output signals Y_{ij} from values Y_{ci} of this signal is calculated from formula:

$$\Delta_{mi} = (Y_{ij} - Y_{pi})\max \tag{1.5}$$

The values Δ_{mi} are inserted into table B.3.

7. For every input value X_i the average deviation values $\Delta_{av\,i}\uparrow$ and $\Delta_{av\,i}\downarrow$ of measured output signal values Y_{ij} from calculated values Y_{ci} of this signal at the variation of input value from X_0 up to X_m (at the direct course) and from X_m up to X_0 (at the retrace) are calculated from the formulas:

$$\Delta_{avi}\uparrow = \frac{1}{j}\sum_{1}^{j}\Delta_{ij}\uparrow \tag{1.6}$$

$$\Delta_{avj}\downarrow = \frac{1}{j}\sum_{1}^{j}\Delta_{ij}\downarrow \tag{1.7}$$

The values $\Delta_{avi}\uparrow$ and $\Delta_{avi}\downarrow$ are inserted into table B.3

8. For every input value X_i repeatability $\Delta_{ri}\uparrow$ and $\Delta_{ri}\downarrow$ of the output signal Y_{ij} at the variation of input value from X_0 up to X_m and from X_m up to X_0 is calculated from the formulas:

$$\Delta_{ri}\uparrow = \sqrt{\frac{1}{j-1}\left(\sum\Delta_{ij}^2\uparrow - j\Delta_{avi}^2\uparrow\right)} \tag{1.8}$$

$$\Delta_{ri}\downarrow = \sqrt{\frac{1}{j-1}\left(\sum\Delta_{ij}^2\downarrow - j\Delta_{avi}^2\downarrow\right)} \tag{1.9}$$

The values $\Delta_{ni}\uparrow$ and $\Delta_{ni}\downarrow$ are inserted into table B.3.

9. For every input value X_{pi} the average deviation Δ_{avi} of output signal Y_i from computed value of that signal Y_{ci} is calculated from the formula:

$$\Delta_{avi} = \frac{1}{2}\left(\Delta_{avi}\uparrow + \Delta_{avi}\downarrow\right) \tag{1.10}$$

The values Δ_{avi} are inserted into table B.3.

10. The average hysteresis value (variations) Δ_{hi} for every input value X_i of output signal Y_i is determined according to the formula

$$\Delta_{hi} = \left|\Delta_{avi}\uparrow - \Delta_{avi}\downarrow\right| \tag{1.11}$$

The values Δ_{hi} are inserted into table B.3.

11. For every input signal value X_i the repeatability Δ_{ri} of output signal Y_i (below – repeatability Δ_{ri}) is calculated from the formula:

$$\Delta_{ri} = \sqrt{\left(\Delta_{ri}^2\uparrow + \Delta_{ri}^2\downarrow\right)/2} \tag{1.12}$$

The values Δ_{ri} are inserted into table B.3.

12. The constituents of fiducial deviation – γ_m, γ_{av}, γ_h, and γ_r are determined in percentage from the formula (1.13):

$$\gamma_z = \Delta_z\frac{100}{Y_m - Y_0} \tag{1.13}$$

Where z – appropriate indexes.

Y_0 and Y_m – calculated value of output signal according to p. 3.

13 The total (resulting) fiducial deviation value γ_Σ in percentage is determined from the formula (1.14):

$$\gamma_{\Sigma} = |\gamma_{av}| + \frac{1}{2}\gamma_h + \frac{1}{4}\gamma_r \quad (1.14)$$

The value γ_{Σ} is inserted into table B.3

Determination of uncertainty and its constituents.

1. The measurement range is divided into ***m*** intervals.

2. The calculated input values X_{ci} are determined according to the formula.

$$X_i = X_0 + \frac{i}{m}(X_m - X_0) \tag{2.1}$$

Where $i = 0,1...m$;

X_0, X_m - lower and upper measurement limits of input value ***X***.

The values X_{pi} are inserted into table B.1.

3. The computed output signal Y_{ci} values are determined from the formula:

$$Y_{ci} = Y_0 + \frac{i}{m}(Y_m - Y_0) \tag{2.2}$$

where Y_0, Y_m - output signal computed value ***Y***, that corresponds to the lower X_0 and upper X_m limits of input value measurement ***X***.

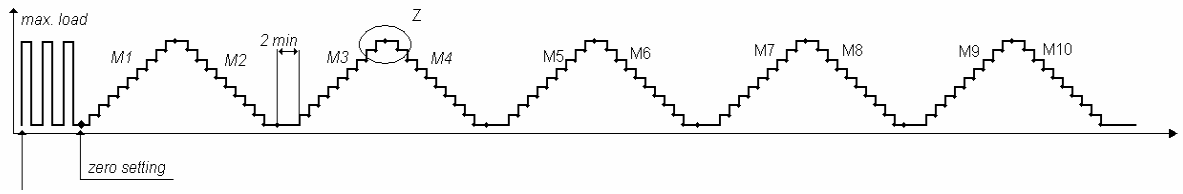
The values Y_{ci} are inserted into table B.1.

4. For every input value X_i the output signal values are measured in every of ***j*** checking cycles loading (testing) of output signal value:

– $Y_{ij}\uparrow$ – with input value variation from X_0 up to X_m (direct course);

– $Y_{ij}\downarrow$ – with input value variation from X_m up to X_0 (retrace).

The values $Y_{ij}\uparrow$ and $Y_{ij}\downarrow$ are inserted to the table B1.



5. For every input value X_i in every of ***j*** checking cycles the deviations of $\Delta_{ij}\uparrow$ (at the direct course) and $\Delta_{ij}\downarrow$ (at the retrace) of output signal measured values Y_{ij} from calculated values Y_{ci} of that signal (below – deviations $\Delta_{ij}\uparrow$ и $\Delta_{ij}\downarrow$) are determined from the formulas

$$\Delta_{ij}\uparrow = Y_{ij}\uparrow - Y_{pi} \tag{2.3}$$

$$\Delta_{ij}\downarrow = Y_{ij}\downarrow - Y_{pi} \tag{2.4}$$

The values $\Delta_{ij}\uparrow$ and $\Delta_{ij}\downarrow$ are inserted into table B.2

6. .For every input value X_i the maximum deviation Δ_{mi} of output signals Y_{ij} from values Y_{ci} of this signal is calculated from formula:

$$\Delta_{mi} = (Y_{ij} - Y_{pi})\max \tag{2.5}$$

The values Δ_{mi} are inserted into table B.4 (B.5).

7. For every input value X_i the average deviation values $\Delta_{av\,i}\uparrow$ and $\Delta_{av\,i}\downarrow$ of measured output signal values Y_{ij} from calculated values Y_{ci} of this signal at the variation of input value

from $\boldsymbol{X_0}$ up to $\boldsymbol{X_m}$ (at the direct course) and from $\boldsymbol{X_m}$ up to $\boldsymbol{X_0}$ (at the retrace) are calculated from the formulas:

$$\Delta_{avi} \uparrow = \frac{1}{j}\sum_{1}^{j} \Delta_{ij} \uparrow \tag{2.6}$$

$$\Delta_{avj} \downarrow = \frac{1}{j}\sum_{1}^{j} \Delta_{ij} \downarrow \tag{2.7}$$

The values $\Delta_{avi} \uparrow$ and $\Delta_{avi} \downarrow$ are inserted into table B.4 (B.5).

8. For every input value $\boldsymbol{X_i}$ repeatability $\boldsymbol{\Delta_{ri}}\uparrow$ and $\boldsymbol{\Delta_{ri}}\downarrow$ of the output signal $\boldsymbol{Y_{ij}}$ at the variation of input value from $\boldsymbol{X_0}$ up to $\boldsymbol{X_m}$ and from $\boldsymbol{X_m}$ up to $\boldsymbol{X_0}$ is calculated from the formulas:

$$\Delta_{ri} \uparrow = \sqrt{\frac{1}{j-1}(\sum \Delta_{ij}^2 \uparrow - j\Delta_{avi}^2 \uparrow)} \tag{2.8}$$

$$\Delta_{ri} \downarrow = \sqrt{\frac{1}{j-1}(\sum \Delta_{ij}^2 \downarrow - j\Delta_{avi}^2 \downarrow)} \tag{2.9}$$

The values $\Delta_{ni} \uparrow$ and $\Delta_{ni} \downarrow$ are inserted into table B.4 (B.5).

9. For every input value $\boldsymbol{X_{pi}}$ the average deviation $\boldsymbol{\Delta_{avi}}$ of output signal $\boldsymbol{Y_i}$ from computed value of that signal $\boldsymbol{Y_{ci}}$ is calculated from the formula:

$$\Delta_{avi} = \frac{1}{2}(\Delta_{avi} \uparrow + \Delta_{avi} \downarrow) \tag{2.10}$$

The values Δ_{ci} are inserted into table B.4 (B.5).

10. The average hysteresis value (variations) $\boldsymbol{\Delta_{hi}}$ for every input value $\boldsymbol{X_i}$ of output signal $\boldsymbol{Y_i}$ is determined according to the formula

$$\Delta_{hi} = \left|\Delta_{avi} \uparrow - \Delta_{avi} \downarrow\right| \tag{2.11}$$

The values Δ_{hi} are inserted into table B.4 (B.5)

11. For every input signal value $\boldsymbol{X_i}$ the repeatability $\boldsymbol{\Delta_{ri}}$ of output signal $\boldsymbol{Y_i}$ (below – repeatability $\boldsymbol{\Delta_{ri}}$) is calculated from the formula:

$$\Delta_{ri} = \sqrt{(\Delta_{ri}^2 \uparrow + \Delta_{ri}^2 \downarrow)/2} \tag{2.12}$$

The values Δ_{ri} are inserted into table B.4 (B.5)

There are two methods of metrological characteristics normalization where the uncertainty is used.

In the first method (it is abided by authors of EA 10/17 “Guidelines on the Calibration of Electromechanical Manometers” and DKD-R 6-1 “Calibration of Pressure Gauges”) the average (systematic) deviation is not included to the content of expanded uncertainty, but comes to account when the maximum deviation (so called “error span”) is calculated.

In the second method the average (systematic) deviation is included to the content of expanded uncertainty. (This variant is assumed by authors of VIM 2007 (p. 2.27 (3.9) measurement uncertainty).

We offer you to examine these methods.

12. For every received value of Δ_{zi} (where *z* is one of following indexes: *h, r*) the uncertainty is calculated according the formula: $u_{zi} = \frac{\Delta_{zi}}{2\sqrt{3}}$ (2.15) The values u_x are inserted into table B.5	12. For every received value of Δ_{zi} (where *z* is one of following indexes: *av, h, r*) the uncertainty is calculated according the formula: $u_{zi} = \frac{\Delta_{zi}}{2\sqrt{3}}$ (2.15) The values u_x are inserted into table B.4
13. For every input value X_i the expanded uncertainty is calculated according the formula: $U_{\exp i} = 2\sqrt{\sum (u_{xi})^2}$ (2.16) The values U_{expi} are inserted into table B.4.	13. For every input value X_i the expanded uncertainty is calculated according the formula: $U_{\exp i} = 2\sqrt{\sum (u_{xi})^2}$ (2.16) The values U_{expi} are inserted into table B.5.
14. For every input value X_i the Maximum Deviation (error span) is calculated according the formula: $MD_i = U_{\exp i} + \Delta_{avi}$ (2.17) The values MD_i are inserted into table B.4.	14. For every input value X_i the fiducial uncertainty is calculated according the formula: $U_{fidi} = \frac{U_{\exp i}}{Y_{pm}} \cdot 100\%$ (2.17) The values U_{reli} are inserted into table B.5.
15. For every input value X_i the fiducial Maximum Deviation (error span) is calculated according the formula: $MD_{fidi} = \frac{MD_i}{Y_{pm}} \cdot 100\%$ (2.18) The values MD_{fidi} are inserted into table B.4.	

Table B.1

X, %	Y, mV	Output signal value Y, mV									
		Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
		$Y_{i1}\uparrow$	$Y_{i1}\downarrow$	$Y_{i2}\uparrow$	$Y_{i2}\downarrow$	$Y_{i3}\uparrow$	$Y_{i3}\downarrow$	$Y_{i4}\uparrow$	$Y_{i4}\downarrow$	$Y_{i5}\uparrow$	$Y_{i5}\downarrow$
0	0	-0,04	-0,04	-0,05	-0,05	-0,06	-0,06	-0,05	-0,05	-0,05	-0,05
10	100	100,06	100,14	100,04	100,15	100,05	100,16	100,05	100,15	100,04	100,15
20	200	200,13	200,23	200,08	200,26	200,09	200,26	200,10	200,25	200,11	200,24
30	300	300,11	300,24	300,09	300,25	300,10	300,26	300,10	300,25	300,11	300,25
40	400	399,96	400,13	399,93	400,15	399,96	400,17	399,95	400,15	399,96	400,15
50	500	499,82	499,98	499,84	500,01	499,87	500,01	499,84	500,00	499,85	500,01
60	600	599,73	599,88	599,75	599,90	599,77	599,92	599,75	599,90	599,76	599,91
70	700	699,68	699,83	699,70	699,84	699,72	699,88	699,70	699,85	699,71	699,88
80	800	799,73	799,83	799,74	799,85	799,78	799,87	799,75	799,85	799,75	799,86
90	900	899,84	899,94	899,85	899,95	899,86	899,96	899,85	899,95	899,86	899,96
100	1000	1000,09	1000,09	1000,11	1000,11	1000,10	1000,10	1000,10	1000,10	1000,11	1000,11

Table B.2

	Deviations, mV									
	Cycle 1		**Cycle 2**		**Cycle 3**		**Cycle 4**		**Cycle 5**	
X,%	$\Delta_{i1}\uparrow$	$\Delta_{i1}\downarrow$	$\Delta_{i2}\uparrow$	$\Delta_{i2}\downarrow$	$\Delta_{i3}\uparrow$	$\Delta_{i3}\downarrow$	$\Delta_{i4}\uparrow$	$\Delta_{i4}\downarrow$	$\Delta_{i5}\uparrow$	$\Delta_{i5}\downarrow$
0	- 0,04	- 0,04	- 0,05	- 0,05	- 0,06	- 0,06	- 0,05	- 0,05	-0,05	-0,05
10	0,06	0,14	0,04	0,15	0,05	0,16	0,05	0,15	0,04	0,15
20	0,13	0,23	0,08	0,26	0,09	0,26	0,10	0,25	0,11	0,24
30	0,11	0,24	0,09	0,25	0,10	0,26	0,10	0,25	0,11	0,25
40	- 0,04	0,13	- 0,07	0,15	- 0,04	0,17	- 0,05	0,15	-0,04	0,15
50	- 0,18	- 0,02	- 0,16	0,01	- 0,13	0,01	- 0,16	0	-0,15	0,01
60	- 0,27	- 0,12	- 0,25	- 0,10	- 0,23	- 0,08	- 0,25	- 0,10	-0,24	-0,09
70	- 0,32	- 0,17	- 0,30	- 0,16	- 0,28	- 0,12	- 0,30	- 0,15	-0,29	-0,12
80	- 0,27	- 0,17	- 0,26	- 0,15	- 0,22	- 0,13	- 0,25	- 0,15	-0,25	-0,14
90	- 0,16	- 0,06	- 0,15	- 0,05	- 0,14	- 0,04	- 0,15	- 0,05	-0,14	-0,04
100	0,09	0,09	0,11	0,11	0,10	0,10	0,10	0,10	0,11	0,11

Table B.3

X_p,%	Constituents of intrinsic deviation, mV								Fiducial constituents of intrinsic error, %
	Δ_m	$\Delta_{av}\uparrow$	$\Delta_{av}\downarrow$	$\Delta_r\uparrow$	$\Delta_r\downarrow$	Δ_{av}	Δ_h	Δ_r	γ_Σ *
0	-0,06	-0,05	-0,05	0,0071	0,0071	-0,05	0	0,0071	0,005177
10	0,16	0,048	0,15	0,0084	0,0071	0,099	0,102	0,0077	0,015194
20	0,26	0,102	0,248	0,0192	0,0130	0,175	0,146	0,0164	0,025211
30	0,26	0,102	0,25	0,0084	0,0071	0,176	0,148	0,0077	0,025194
40	0,17	-0,048	0,15	0,0130	0,0141	0,051	0,198	0,0136	0,01534
50	-0,18	-0,156	0,002	0,0182	0,0130	-0,077	0,158	0,0158	0,015995
60	-0,27	-0,248	-0,098	0,0148	0,0148	-0,173	0,15	0,0148	0,025171
70	-0,32	-0,298	-0,144	0,0148	0,0230	-0,221	0,154	0,0194	0,030284
80	-0,27	-0,25	-0,148	0,0187	0,0148	-0,199	0,102	0,0169	0,025422
90	-0,16	-0,148	-0,048	0,0084	0,0084	-0,098	0,1	0,0084	0,015009
100	0,11	0,102	0,102	0,0084	0,0084	0,102	0	0,0084	0,010409

* discounting the deviation of standard device.

Table B4

		The constituents of uncertainty, mV													
Y	**X,%**	**Δ_m**	**Δav↑**	**Δav↓**	**Δr↑**	**Δr↓**	**Δav**	**Δh**	**Δr**	**Uh**	**Ur**	**Ust***	**Uexp, mV**	**MD, mV**	**MDfid,%**
0	0	-0,06	-0,05	-0,05	0,0071	0,0071	-0,05	0	0,0071	0	0,0020	0,0288	0,05788	0,107879	0,01079
100	10	0,16	0,048	0,15	0,0084	0,0071	0,099	0,102	0,0077	0,0294	0,0022	0,0288	0,08259	0,181591	0,01816
200	20	0,26	0,102	0,248	0,0192	0,0130	0,175	0,146	0,0164	0,0421	0,0047	0,0288	0,10261	0,277609	0,02776
300	30	0,26	0,102	0,25	0,0084	0,0071	0,176	0,148	0,0077	0,0427	0,0022	0,0288	0,10322	0,279221	0,02792
400	40	0,17	-0,048	0,15	0,0130	0,0141	0,051	0,198	0,0136	0,0572	0,0039	0,0288	0,12831	0,179308	0,01793
500	50	-0,18	-0,156	0,002	0,0182	0,0130	-0,077	0,158	0,0158	0,0456	0,0046	0,0288	0,10834	0,185342	0,01853
600	60	-0,27	-0,248	-0,098	0,0148	0,0148	-0,173	0,15	0,0148	0,0433	0,0043	0,0288	0,10444	0,277435	0,02774
700	70	-0,32	-0,298	-0,144	0,0148	0,0230	-0,221	0,154	0,0194	0,0445	0,0056	0,0288	0,10660	0,327601	0,03276
800	80	-0,27	-0,25	-0,148	0,0187	0,0148	-0,199	0,102	0,0169	0,0294	0,0049	0,0288	0,08304	0,282044	0,02820
900	90	-0,16	-0,148	-0,048	0,0084	0,0084	-0,098	0,1	0,0084	0,0289	0,0024	0,0288	0,08179	0,179792	0,01798
1000	100	0,11	0,102	0,102	0,0084	0,0084	0,102	0	0,0084	0	0,0024	0,0288	0,05794	0,159937	0,01599

*the 0,1 mV value of the expanded uncertainty is corresponding to fiducial deviation ±0,01 %

Table B5.

		The constituents of uncertainty, mV													
Y	**X,%**	**Δ_m**	**Δav↑**	**Δav↓**	**Δr↑**	**Δr↓**	**Δav**	**Δh**	**Δr**	**Uav**	**Uh**	**Ur**	**Ust***	**Uexp, mV**	**Ufid,%**
0	0	-0,06	-0,05	-0,05	0,0071	0,0071	-0,05	0	0,0071	-0,0144	0	0,0020	0,0288	0,0647	0,0065
100	10	0,16	0,048	0,15	0,0084	0,0071	0,099	0,102	0,0077	0,0286	0,0294	0,0022	0,0288	0,1004	0,0100
200	20	0,26	0,102	0,248	0,0192	0,0130	0,175	0,146	0,0164	0,0505	0,0421	0,0047	0,0288	0,1440	0,0144
300	30	0,26	0,102	0,25	0,0084	0,0071	0,176	0,148	0,0077	0,0508	0,0427	0,0022	0,0288	0,1448	0,0145
400	40	0,17	-0,048	0,15	0,0130	0,0141	0,051	0,198	0,0136	0,0147	0,0572	0,0039	0,0288	0,1316	0,0132
500	50	-0,18	-0,156	0,002	0,0182	0,0130	-0,077	0,158	0,0158	-0,0222	0,0456	0,0046	0,0288	0,1171	0,0117
600	60	-0,27	-0,248	-0,098	0,0148	0,0148	-0,173	0,15	0,0148	-0,0499	0,0433	0,0043	0,0288	0,1445	0,0145
700	70	-0,32	-0,298	-0,144	0,0148	0,0230	-0,221	0,154	0,0194	-0,0638	0,0445	0,0056	0,0288	0,1663	0,0166
800	80	-0,27	-0,25	-0,148	0,0187	0,0148	-0,199	0,102	0,0169	-0,0574	0,0294	0,0049	0,0288	0,1418	0,0142
900	90	-0,16	-0,148	-0,048	0,0084	0,0084	-0,098	0,1	0,0084	-0,0283	0,0289	0,0024	0,0288	0,0995	0,0099
1000	100	0,11	0,102	0,102	0,0084	0,0084	0,102	0	0,0084	0,0294	0	0,0024	0,0288	0,0826	0,0083

* the 0,1 mV value of the expanded uncertainty is corresponding to fiducial deviation ±0,01 %

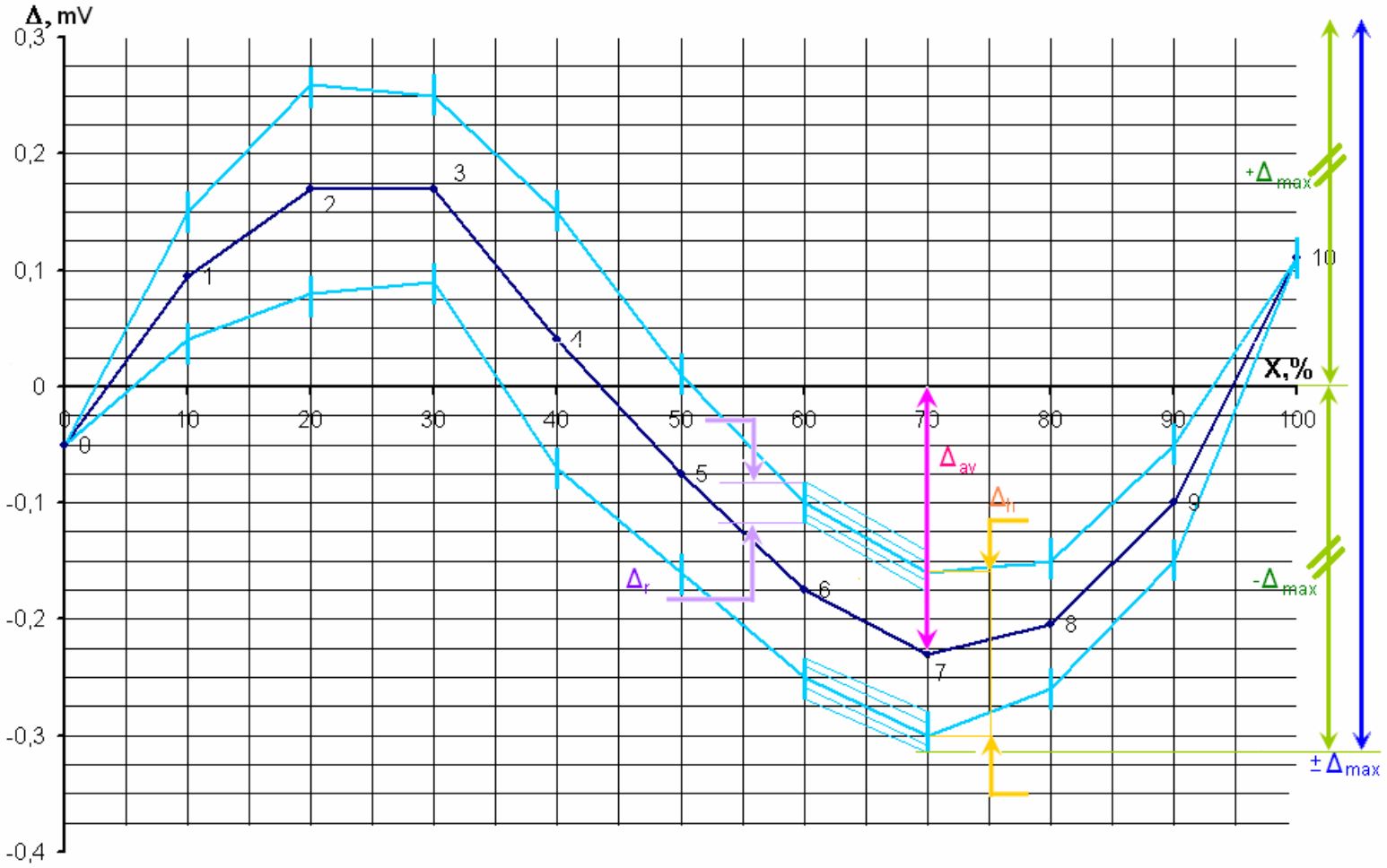


Fig. B.1

Constituents of intrinsic deviation.

Δ_{av} - average deviation

Δ_h - hysteresis

Δ_r - repeatability

The correlation between Maximum Permissible Error and Δ_{max} should be determined in accordance with National Regulations.

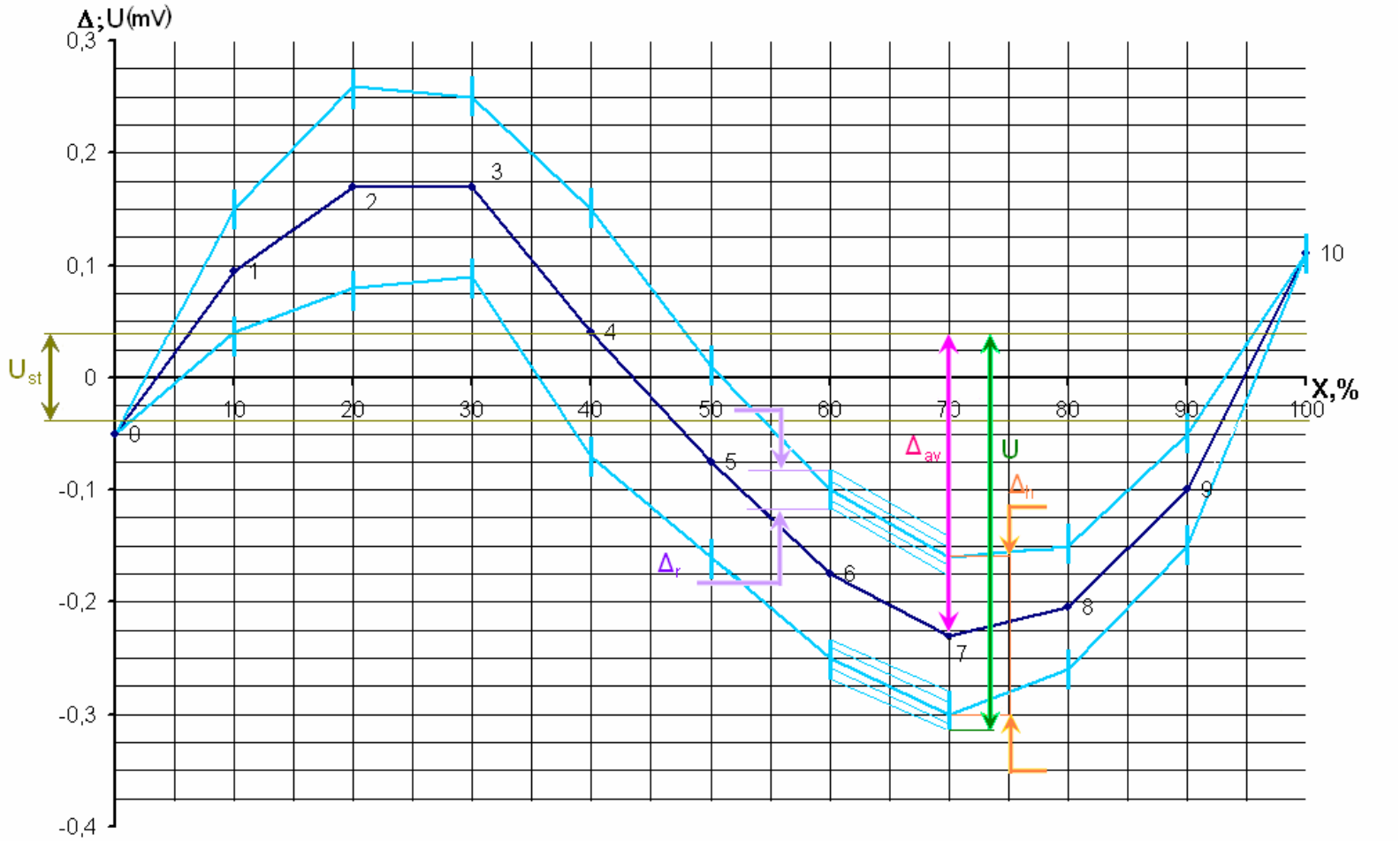


Fig. B.2.

Constituents of uncertainty.

Δ_{av} - average deviation

Δ_h - hysteresis

Δ_r - repeatability

U_{st} - Uncertainty of standards

$U = U_{exp} + |\Delta_{av}|$