PRESSURE TRANSDUCERS WITH UNIFIED (4 - 20) mA OR (10 - 50) mA OUTPUT SIGNAL

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CONTENTS:

1. Scope

This recommendation applies to the pressure transducers with unified (4 - 20) mA or (10 - 50) mA output current signal which are used for measuring gauge pressure in the range from -100 kPa to 60 MPa, absolute pressure in the range from 0 to 60 MPa and differential pressure in the range from 0 to ±1 MPa by line pressures up to 20 MPa in liquids, vapours and gases. It lays down metrological and technical requirements related to their verification and type testing, i.e. the procedures required to guarantee a reliable operation of these measuring instruments.

A device under test (DUT) generally represents an integral functional unit composed of a pressure sensor and of a module that modifies and amplifies a signal received from the pressure sensor. This module comprises also means for zero and range adjustments. The sensor with the above mentioned module is built in a protective enclosure (case). There is (are) a pressure adapter(s) and an output connector or an output of the electrical connection on this enclosure. The output information delivered by the DUT is in the form of a current with value of (4 - 20) mA or (10 - 50) mA.

This recommendation does not cover the DUTs with output signal in the form of voltage or frequency, the complete DUTs with digital or analogue indication or the sole pressure sensors.

2. Terminology

The terminology of this recommendation complies with „International vocabulary of basic and general terms in metrology“ (edition 1993) and with „Vocabulary of legal metrology“ (edition 2000).

In order to eliminate any misinterpretation the terms given below have the following meanings (according to EN 472 - Pressure measuring instruments - and to EN 60 770):

- standard reference environment - is defined by temperature of 20 °C or 23 °C, relative humidity of 65% and atmospheric pressure of 101.325 kPa

- error of indication of a pressure measuring instrument - the indication of a DUT minus the correct value of the pressure to be measured

- intrinsic error of a pressure measuring instrument - the error measured at or corrected to the standard reference environment

- accuracy class - a family of DUTs, described by a class index which is equal to the absolute value of their maximum permissible basic error, complying with the metrological requirements aiming to maintain errors within specified limits

- limits of permissible errors - the limit values of permissible errors of DUT specified by the accuracy class or other similar technical requirements or regulations

- measuring range – the range of pressure to be measured with a pressure transducer

- hysteresis error - the maximum difference between the indications of the instrument when the same pressure is reached by decreasing and increasing the pressure

- repeatability - the ability of a DUT to give responses very close for repeated measurements of the same output signal under specified conditions

- non-linearity - specifies the degree of approximation of a curve to a straight line

- type A uncertainty - the uncertainty evaluated by the statistical analysis of series of observations

- type B uncertainty - the uncertainty evaluated by means other than the statistical analysis of series of observations

3. Units of measurement

The unit of measurement of pressure is the pascal, Pa or its multiples hPa, kPa, MPa, GPa, according to the rules of the International System of Units, SI. The unit bar and its submultiples, especially the mbar, may be used insofar as they are admitted by national regulations, and there is an international decision on their use.

4. Metrological requirements

4.1 General requirements

Construction of the transducer must enable to prevent the settings from a non-authorized change.

Most of the transducers can have many measuring spans and ranges. The verification or calibration is only for one span with fixed measuring limits.

The transducer should have a good adaptability for the supply voltage and its output must not be very sensitive to voltage changing.

4.2 Accuracy classes

Pressure transducers with unified output signal are classified into the following accuracy classes:

0.02; 0.05; 0.1; 0.2; 0.5; 1; 2.

The number designating the accuracy class is also the maximum permissible error as a percentage of the measuring span.

Pressure transducers with unified output signal of higher accuracy classes may be developed in the future.

5. Technical requirements

5.1 Environmental conditions

Pressure transducers are generally intended for use under the following environmental conditions:

- temperature within the range:
  - (20 ± 2) °C or (23 ± 2) °C (laboratory with air-condition),
  - 15 °C to 30 °C (laboratory with heating),
  - -10 °C to 40 °C (room without heating or cooling),
  - -40 °C to 60 °C (outside rooms),
- maximum relative humidity of the ambient air 80 %.

Detailed operating conditions (ambient air temperature, humidity and dust contents, vibration and shocks, physical and chemical properties of the measured medium, explosive environment, electromagnetic compatibility etc.) should be specified in Manufacturer's documentation.

5.2 Condition of the pressure transducer

A pressure transducer shall not display significant traces of corrosion or damage capable to influence its metrological characteristics.

5.3 Markings

On the case of a DUT the following information shall be indicated (e.g. on a nameplate):

- name or designation of the manufacturer,
- type or model,
- serial number,
- measuring range specified by the manufacturer,
- accuracy class specified by the manufacturer or by a pattern approval,
- output signal form,
- power supply specification,
- temperature range in that the instrument works without an additional error,
- if gauge pressure transducer does not have an opening to the atmospheric pressure, it must be marked on the instrument dial,
- type approval number, if required.

6. Metrological controls

6.1 Type approval

The requirements for a type approval of DUTs can be divided into following groups:
- metrological requirements,
- technical requirements,
- safety requirements.

These requirements are given in the international standards EN 60770-1 and EN 60770-2. The conditions and tests specified in this standard may not be sufficient for instruments designed for extreme applications. In particular, for type testing of DUTs intended for use in an explosive environment this conditions and tests shall be extended by other conditions and tests relating to this environment. On the contrary, only a limited number of tests can be sufficient for instruments intended for use in a special environment (e.g. in a laboratory). Therefore the specifications of the manufacturer shall be taken into account when deciding for the testing programme.

If the DUT has passed all the tests required for the type approval of the measuring instrument, the type approval certificate is issued containing, among others, the official type approval mark.

6.2 Verification

According to national regulations, initial and subsequent verifications should only be carried out in an authorized laboratory and on pressure transducers that have been manufactured according to an approved pattern.

The verification procedure is essentially equal to the testing procedure (see clause 7), the only difference being the evaluation and presentation of the results. In the verification procedure, the errors found out during the DUT testing are compared against the maximum permissible error. These values are given as follows:
- for new and repaired DUTs, 80 % of DUT accuracy class,
- for DUTs in service, the DUT accuracy class.

DUT that has passed the verification tests is marked by a verification mark. At the same time, a verification certificate containing the following information is issued:
- all the information prescribed for a testing certificate,
- a statement that the DUT has passed the tests specified by this recommendation,
- the validity period of the certificate.

If the DUT has failed the verification tests, the stamping is denied and the certificate of the failure of the verification can be issued.

7. Test method and model test report

7.1 Testing and reference conditions

7.1.1 Testing room

- The entire procedure must be carried out in an air-conditioned room with relative humidity between 40 % and 80 % and with temperature between 18 °C and 25 °C, while temperature variations during testing procedure may not exceed 2 °C and 1 °C per hour.
- To maintain a stable and draught-free atmosphere around DUTs it is necessary to eliminate any opening of doors and entering and exiting of persons.
- It is necessary to make sure that the vibrations caused by the environment do not lead to significant errors with respect to the uncertainty of measurement.
- It is necessary to ensure that no sources of electromagnetic radiation of intensity or frequency which could adversely affect measurements are in the vicinity of the devices. For instance, arc welding jigs, electromagnetic valves, electromagnetic relays, radio emitters and receivers, etc.
- It is necessary to check that the parameters of the mains supply comply with the corresponding standard.

The ambient air shall comply with any health and safety regulations at the workplace; in addition it shall not contain dust or impurities likely to corrode any part of the instrument with which it may come in contact.

7.1.2 Installation of equipment to be used for tests

- Any item of the equipment shall be placed in the room where the testing procedures will be carried out at least 6 hours before starting the operations in order to reach thermal equilibrium of the whole system.
- The equipment shall be placed so to avoid the measurements being disturbed by air currents.
- The reference and testing equipment shall be at the same height level and any difference in the levels shall be considered when calculating head corrections of the measured results and measurement uncertainties.
- The DUT shall be placed in its normal position of use according to the specifications of the manufacturer of this equipment.
- Pipes and / or tubes of the shortest length possible and with sufficient cross section shall be used for interconnections of the equipment used to transfer the working medium between the connected instruments. The connecting elements shall withstand the maximum applicable pressure without any substantial deformation.
- No filters, pressure relief valves and return valves shall be arranged between the DUT and the reference instrument.
- No leakage shall appear along the pipes and / or tubes.
- It is necessary to make sure that the DUT does not contain corrosive fluid or fluid which is not suitable for the system and for the reference instrument in particular.

7.1.3 Pressure generation

a) Pressure in gas medium

- Only clean and dry neutral gas whose temperature is approximately equal to the ambient temperature shall be used. In order to protect the equipment the pressure-reducing valves shall be adapted to the pressure range of the instruments to be used.
- Before and during the measurements any liquid shall be removed from the pipes and / or tubes.

b) Pressure in liquid medium

- Only the liquids recommended by the manufacturer of the installed instrument shall be used.
- Before and during the measurements any gas shall be removed from the pipes and / or tubes.

7.2 Methods to be applied

The only method to be applied is the direct comparison method which consists of comparing the responses of the DUT and of the reference instrument, both instruments being subjected to the same pressure and at the same environmental conditions.

The method of testing must also allow the evaluation of the hysteresis, the non-linearity and the repeatability of the DUT. The procedure differs in dependence on the accuracy class of the DUT.

7.2.1 Method A

It is recommended to use this method for DUTs of the accuracy classes 1 and 2. Testing is carried out in at least 6 points equally spaced apart including the lower and upper limit of the measurement range. These points are successively reached by increasing values (6 points) from the low range limit and after waiting for (approximately) 5 minutes at high pressure limit by decreasing values (5 points). Then after waiting for (approximately) 5 minutes one point (preferably in approximately 50 % of the full scale of the DUT) is reached by increasing pressure. The three values at this point will serve for estimation of repeatability of the DUT.

7.2.2 Method B

It is recommended to use this method for DUTs of the accuracy classes 0.2 and 0.5. Testing is carried out in at least 11 points equally spaced apart and covering the lower and the upper limit of the measurement range. These points are successively reached by increasing values (11 points), and after waiting for (approximately) 5 minutes by decreasing values (10 points). This series of operation is carried out at least twice. There shall be waiting for (approximately) 5 minutes between the series. Then the third series is performed in at least 3 points (preferably in approximately 1/3 and 2/3 of the full scale and in the full scale of the DUT) both by increasing and decreasing pressures to estimate repeatability of the DUT.

7.2.3 Method C

It is recommended to use this method for testing instruments whose accuracy classes are 0.02, 0.05 and 0.1. Testing is carried out in at least 11 points as for method B but in this case, the series of operations is carried out at least three times. The repeatability of the instrument is estimated point by point by three series of testings.

Note: It may be necessary to carry the testing in a greater number of measurement points.

7.3 Test equipment

7.3.1 Reference instrument

The reference instrument shall comply with the following conditions:

a) its expanded uncertainty (for $k = 2$) that includes also contributions due to a voltmeter and a standard resistor shall be lower than accuracy class of the instrument to be tested and generally in ratio higher or equal to 1 : 3. When accuracy class of the DUTs to be tested is 0.02, the ratio of accuracy class of the reference instrument to accuracy class of the instrument to be tested may be smaller, but must at least equal to 1 : 2.

b) it shall be traceable to national standards and have a valid calibration certificate.

7.3.2 Mechanical set-up

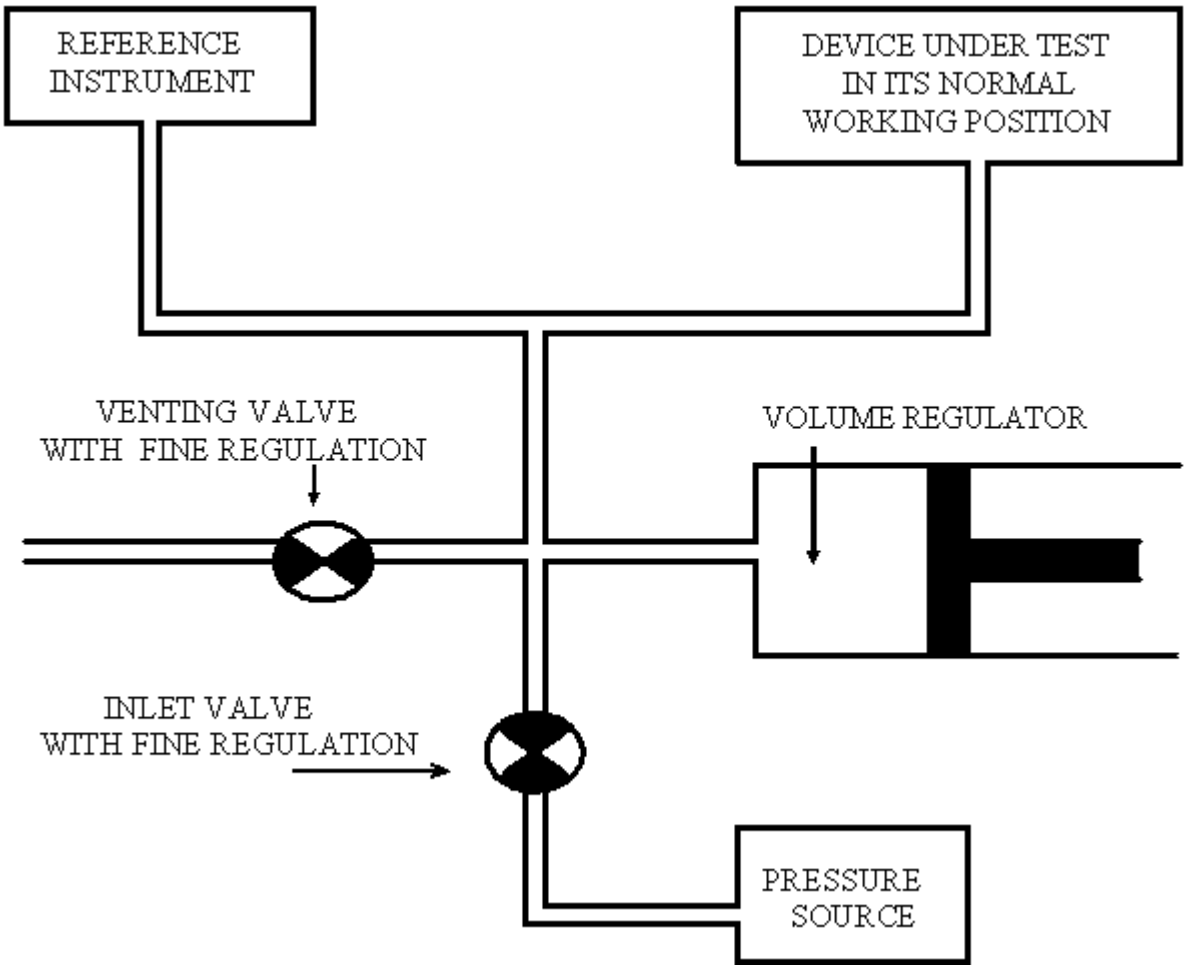

Figure 1: The recommended set-up for calibration of the gauge pressure transducers in gas medium.

a) The recommended set-up for **gauge pressures in gas medium** is presented in Figure 1. It is strongly recommended to use a bottle with dry and clean gas as the pressure source; it shall be equipped with a pressure-reducing valve or connected to a pressure control valve if required by the measurement range of the DUT. The pressure value required is controlled by the means of an inlet and a venting valve.

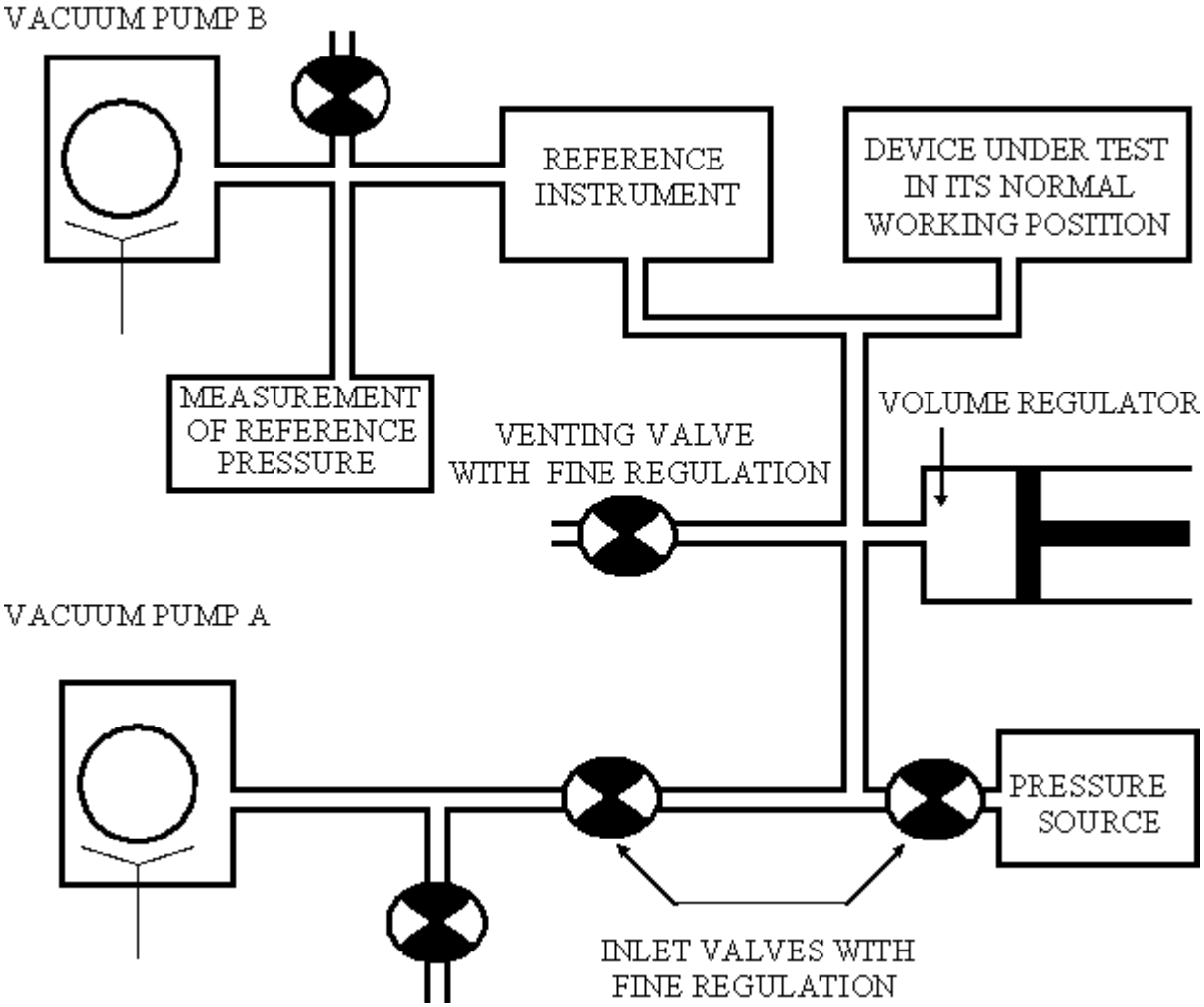

Figure 2: The recommended set-up for calibration of the absolute pressure transducers in gas medium.

b) The recommended set-up for **absolute gas pressures** is presented in Figure 2. The principle of pressure generation is the same as for the relative gas pressures, however, it is important to add a vacuum pump A upstream from the inlet valve, so that pressures below the atmospheric pressure can be generated, and a vacuum pump B (if necessary) for the reference pressure and an instrument to measure the reference pressure (if necessary). In order to ensure the cleanliness of the pipes, the vacuum pumps must be equipped with suitable accessories (such as traps and venting valves).

In the case of absolute pressures greater than atmospheric pressure, it is acceptable to use reference equipment for relative pressures and to measure the atmospheric pressure with the aid of a barometer. (In this case, the set-up according to Figure 1 is to be used.) The value of the absolute pressure is obtained by summation of the values of the pressures measured with the barometer and the gauge pressure manometer.

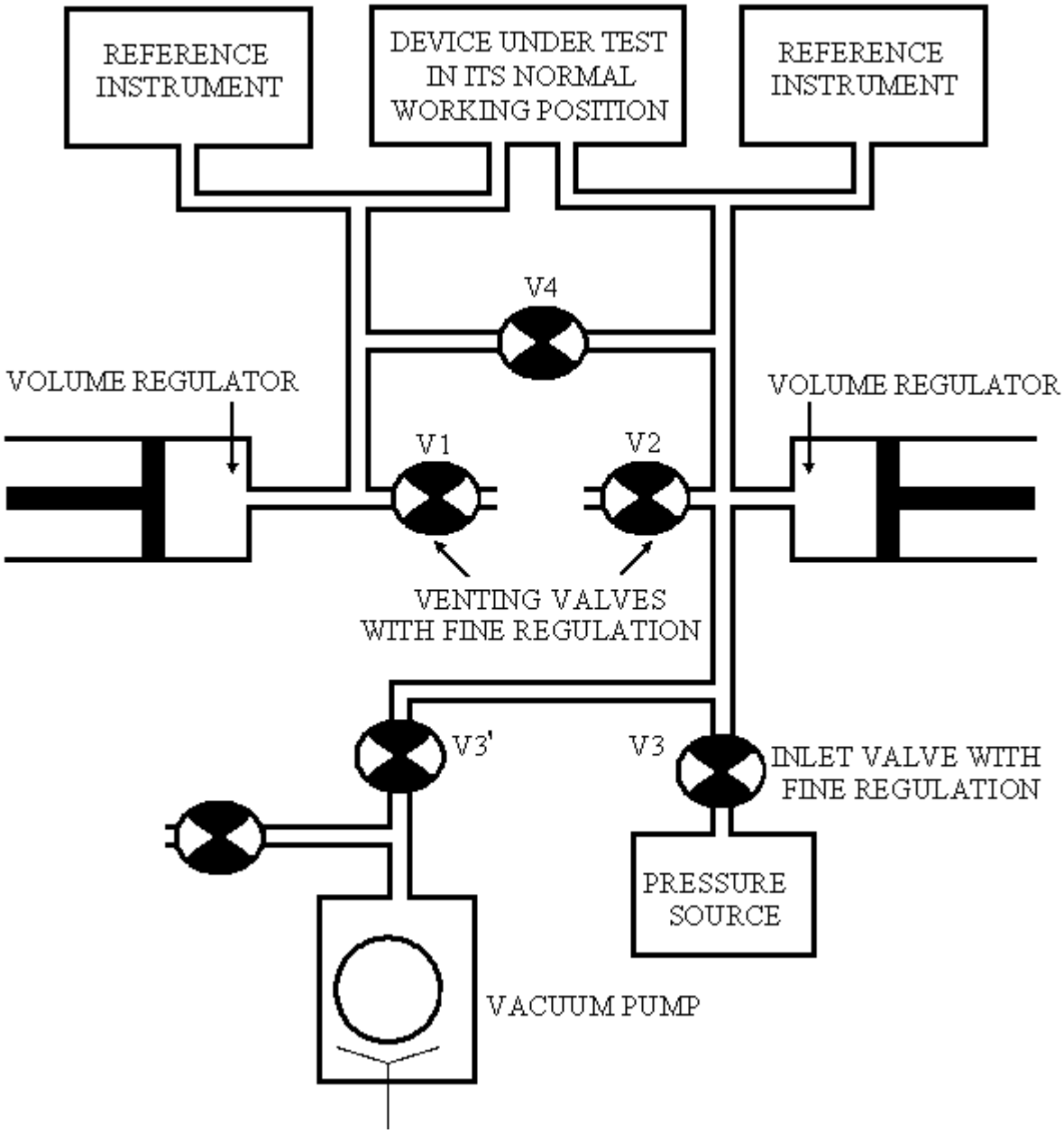

Figure 3: The recommended set-up for calibration of the differential pressure transducers in gas medium.

c) For **differential gas pressures** the recommended set-up is presented in Figure 3. The pressure source is the same as for the gauge gas pressures.

The required line pressure is set up opening valve V3 while V4 being open and performing the final pressure adjustment using the volume regulator. The required pressure difference Δp is then set up using the corresponding volume regulator after V4 being closed.

Reference instruments 1 and 2 can be replaced by a differential pressure standard. Some of these standards have built in pressure regulating devices (e.g. manometric balances). In this case, the pressure source may be directly connected to the inputs of the manometers under test.

The vacuum pump allows lowering the line pressures below the atmospheric pressure.

d) For **liquid pressure medium** the set-ups presented in Figures 1 and 3 shall be modified in the following way: the venting valves are replaced by discharge valves connected to the liquid reservoir of the pressure source and the pressure source is replaced by a hydraulic pump.

7.3.3 Electrical set-up

The DUTs with unified (4 - 20) mA or (10 - 50) mA output signal should be arranged according to the diagram in Figure 4. The current I is measured by means of the output voltage U at the terminals of a standard resistor R:

$$I = U/R.$$

For the supply voltage U_S and the load resistance values, manufacturer's recommendations shall be met.

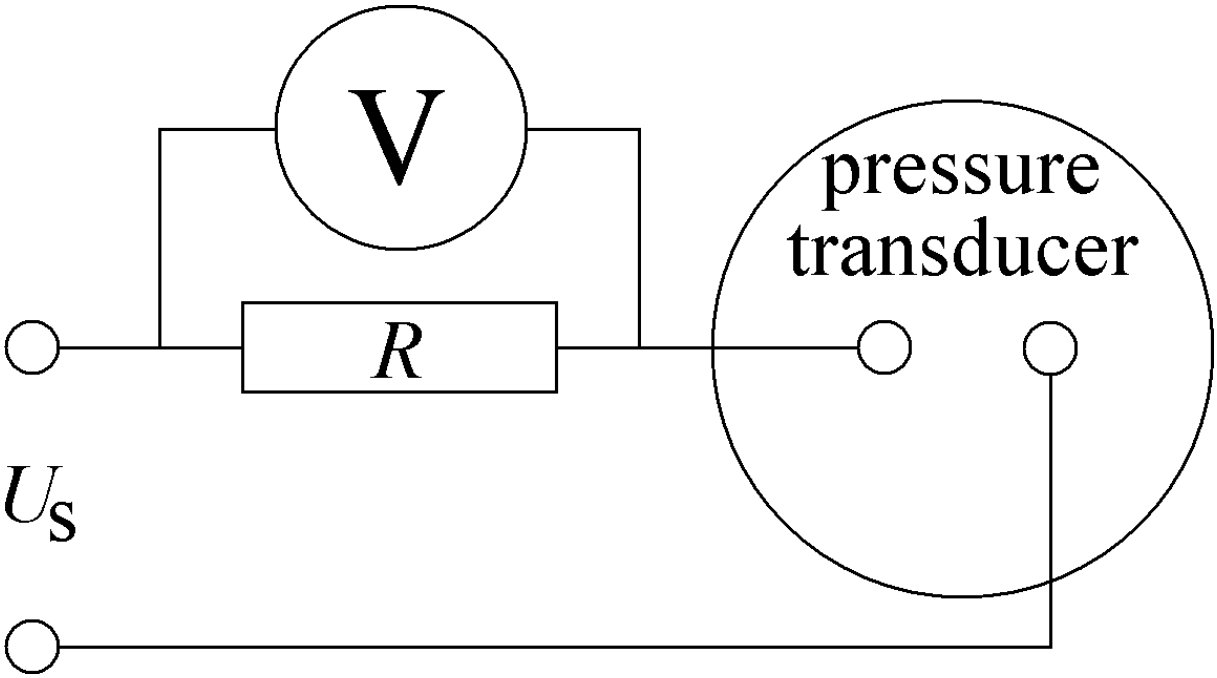

Figure 4: Electrical set-up. U_s – supply voltage, R – standard resistor, V – voltmeter.

7.3.4. Influence quantities

The influence quantities, especially temperature, atmospheric pressure, reference level differences, acceleration due to the gravity and the density of the pressure transmitting medium affect the measurement.

For influence quantities measurement the following instruments shall be used:

- a calibrated thermometer covering the range between 15 °C and 25 °C with the maximal permissible error of 0.1 °C,

- a calibrated barometer with the maximal permissible error lower then 1/5 of accuracy class of the DUT (0.05, 0.1, 0.2, 0.5, 1, 2) or a calibrated barometer with the maximal permissible error lower then 1/3 of accuracy class of the DUT (0.02),
- a calibrated hygrometer with the maximal permissible error of 5 % RH,
- an instrument allowing measurement of the reference height level with the accuracy not worse than 1 mm for liquid pressure medium for testing instruments of accuracy classes 0.02, 0.05, 0.1, 0.2, or 0.5 and not worse than 5 mm for liquid pressure medium for testing instruments of accuracy classes 1 or 2 and for gas pressure medium.

It is also recommended to determine the local value of the acceleration due to gravity (if necessary) and the density of the fluid used.

7.4 Test procedures

7.4.1 Visual inspection

Before the tests can start, it is necessary to check, whether the instrument to be tested is in good working order, i.e. inspecting of its cleanliness (visual check) and the state of the connectors.

7.4.2 Preparatory work

Then it is recommended to carry out of the following operations and checks:
- install the instrument to be tested according to the instructions given above and allow it warming up according to the manufacturer's specifications,
- the pressure circuit is considered leak proof, if the pressure drop at upper range limit (or the lower range limit in the case of negative gauge pressures) enumerated as percentage of the maximal pressure per one minute is less then the accuracy class of the DUT, but not higher than 0.2 % of the maximal pressure per one minute,
- evaluate the difference between the reference levels of the reference instrument and of the DUT,
- adjust the zero pressure corresponding output signal following manufacturer's instructions.

7.4.3 Test operations

The test operations are carried out in following three successive steps:
- initial check at limited number of pressure points of the measurement range to determine the current status of the DUT,
- adjustment of the instrument (this operation is to be carried out only if the first step does not yield satisfying results and if this operation is allowed),
- the complete test of the instrument over its whole measurement range.

a) Initial check

Load the instrument at least twice with nominal maximum pressure, keep the maximum pressure for at least 1 minute. Check and record the indications of the instrument at limited

number of pressure points of the measurement range to determine the current status of the DUT.

b) Adjustment
Adjust the instrument (if necessary) following manufacturer's instructions.

c) Test
The method shall be selected depending on the accuracy class of the instrument under the test according to 7.2. The pressure points must be generated within ±3 % of their nominal values. The following data shall be recorded at every pressure point in the test record file:

- the pressure indicated by the reference instrument or quantities corresponding to it,
- the output current of the DUT,
- the values of the influence quantities (e.g. temperature, atmospheric pressure).

7.5 Evaluation of the test

7.5.1 Calculation of mean values

Let us denote:

P_H high range limit pressure,
P_L low range limit pressure,
I_H current output corresponding to the high range limit pressure,
I_L current output corresponding to the low range limit pressure.

So the current output corresponding to the pressure P is:

$$I = I_L + \frac{I_H - I_L}{P_H - P_L}\left(P - P_L\right).$$

Similarly, the nominal current corresponding to the nominal value P_{nomj} of the pressure point of the order j equals:

$$I_{nomj} = I_L + \frac{I_H - I_L}{P_H - P_L}\left(P_{nomj} - P_L\right).$$

Let I_{mji} be the output of the DUT by applied standard pressure P_{stji} in the pressure point of the order j in the series of the order i. So the measured current corresponding to the nominal pressure point of the order j equals:

$$I'_{mji} = I_{mji} + \frac{I_H - I_L}{P_H - P_L}\left(P_{nomj} - P_{stji}\right).$$

And the mean value in the point of the order *j*:

$$I'_{\mathrm{m}j} = \frac{1}{N}\sum_{i=1}^{N} I'_{\mathrm{m}ji} ,$$

where *N* is the number of series.

7.5.2 Type A uncertainty evaluation

The type A uncertainty characterising the repeatability in the pressure point of the order *j* shall be evaluated according to the following formula:

$$u_{\mathrm{A}j} = \frac{t_{95.45}(\nu)}{2}\sqrt{\frac{\sum_{i=1}^{N}\left(I'_{\mathrm{m}ji} - I'_{\mathrm{m}j}\right)^2}{N(N-1)}} .$$

where $t_{95.45}$ is a value of *t*-factor of the *t*-distribution for 95.45 % and corresponding number of degrees of freedom ν. See Table 1 for some important *t*-factors.

For the method A, the repeatability is determined in one point and it is assumed that $u_{\mathrm{A}} = u_{\mathrm{A}j}$.

For the method B, the repeatability is determined in three points and it is assumed that $u_{\mathrm{A}} = \max\{u_{\mathrm{A}j}\}$.

For the method C, the repeatability $u_{\mathrm{A}j}$ is determined in each point.

ν	2	3	4	5	6	7	8	9	∞
$t_{95,45}(\nu)$	4,53	3,31	2,87	2,65	2,52	2,43	2,37	2,32	2,00

Table 1: Some *t*-factors for 95.45 %.

7.5.3 Type B uncertainty evaluation

In this subclause, all the uncertainties are considered being not expanded. Single constituents of the total uncertainty of the type B (u_{B}) are the following:

The uncertainty due to the standard (generating pressure with uncertainty $u(P_j)$) is:

$$u_{\mathrm{st}j} = \frac{I_{\mathrm{H}} - I_{\mathrm{L}}}{P_{\mathrm{H}} - P_{\mathrm{L}}} u(P_j) .$$

The uncertainty of the measured current is dependent on the voltmeter uncertainty $u(U_j)$ and uncertainty of the standard resistor $u(R)$:

$$u_{Ij} = \sqrt{\left(\frac{u(U_j)}{R}\right)^2 + \left(\frac{U_j u(R)}{R^2}\right)^2} .$$

The uncertainty due to the resolution equals:

$$u_{res} = \frac{r}{2\sqrt{3}},$$

where r is the resolution of the voltmeter.

The uncertainty due to the head correction is:

$$u_{hj} = \sqrt{(\rho_j g u(h))^2 + (h g u(\rho_j))^2 + (h \rho_j u(g))^2} ,$$

where the following notation has been introduced:
h head,
g local acceleration due to the gravity,
r_j density of the pressure medium in the point of the order j,
$u(x)$ uncertainty of the corresponding quantity.

The type B uncertainty for the point of the order j is then determined as:

$$u_{Bj} = \sqrt{u_{stj}^2 + u_{Ij}^2 + u_{res}^2 + u_{hj}^2} .$$

For the methods A and B, the type B uncertainty is determined in all the measured points and it is assumed that $u_B = \max\{u_{Bj}\}$.

For the method C, the type B uncertainty u_{Bj} is determined in each point.

7.5.4 Expanded uncertainty evaluation

For the methods A and B, the expanded uncertainty of the DUT indication with the expansion coefficient $k = 2$ is given by the following formula:

$$U_j = 2\sqrt{u_A^2 + u_B^2} .$$

For the method C, the expanded uncertainty of the DUT indication with the expansion coefficient $k = 2$ is given in each pressure point by the following formula:

$$U_j = 2\sqrt{u_{Aj}^2 + u_{Bj}^2} .$$

7.6 Presentation of results

Note: This subclause is informative with regard to implementation of this Recommendation in national regulations; however use of the test report format is mandatory for the application of the Recommendation within the OIML Certificate System.

A test report intended for use in the OIML Certificate System or for other purposes shall include the following information.

1. Name and address of the testing laboratory(ies)

2. Reference to this Recommendation (number and year of edition)

3. General information on the pressure transducer under test:
   - type of instrument,
   - manufacturer,
   - model,
   - serial number,
   - accuracy class,
   - pattern designation,
   - measuring range (with gauge, absolute or differential pressure specification),
   - form of the output signal.

4. Information on the test procedure:
   - date of measurement,
   - laboratory conditions,
   - used standards and their uncertainties,
   - used pressure medium,
   - used static pressure (in the case of differential pressure transducers).

5. The test results shall be presented in a form of a table containing the values of nominal pressures, corresponding nominal currents, corresponding mean output currents of DUT (both by increasing and decreasing pressures) and corresponding uncertainties of the outputs of DUT for each pressure point.

6. If there were performed any adjustments then they be listed together with the table of the results of the initial check.

7. Brief statement of the conclusions as to whether the DUT meets the requirements of this Recommendation for the specified accuracy class.

8. Signature of the responsible person(s), date of issue, and unique test report number.