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Agricultural irrigation equipment — Pressure losses in irrigation valves — Test method

Matériel agricole d'irrigation — Pertes de pression dans les vannes d'irrigation — Méthode d'essai

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 18, *Irrigation and drainage equipment and systems*.

This third edition cancels and replaces the second edition (ISO 9644:2008), which has been technically revised. The main changes compared to the previous edition are as follows:

— addition of Annexes A and B.

Agricultural irrigation equipment — Pressure losses in irrigation valves — Test method

1 Scope

This document applies to manually-activated valves only.

This document specifies a test method for determining the pressure loss in agricultural irrigation valves under steady-state conditions when water flows through them. The scope and accuracy of the valve performance specifications presented will assist agricultural irrigation system designers in comparing pressure losses through various types of valves.

The measurement of pressure losses provides a means for determining the relationship between pressure loss and flow rate through the valve.

This document also describes the method of reporting pertinent test data.

No attempt is made to define product use, design or applications.

The test method is suitable for valves with equal inlet and outlet nominal sizes.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
nominal size
DN
conventional numerical design used to indicate the size of an irrigation valve

3.2
volume flow rate
flow rate
q_V
volume of water flowing through the valve per unit time

3.3
pressure loss
Δp
difference in pressure due to water flow between two specified points in a system or in part of a system

3.4
piping pressure loss
Δp_p
pressure loss in the upstream and downstream portions of the test bench piping between the pressure taps, but excluding the pressure loss in the valve tested (see 5.4.4)

3.5
bench pressure loss
Δp_b
head loss between the pressure taps upstream and downstream from the measurement area without the device being tested

3.6
valve pressure loss
Δp_v
pressure loss in the valve tested

3.7
reference velocity
v_{ref}
velocity of flow through the valve calculated from the actual flow rate through the valve divided by the reference cross-sectional area of the valve

3.8
steady-state flow
state of flow where the flow rate through a cross-section does not vary with time

3.9
valve flow coefficient
K_v
number equal to the flow rate of water, in cubic metres per hour, that will flow through a fully open valve with a one bar pressure loss across the valve

3.10
flow resistance coefficient
ζ
coefficient used in non-dimensional presentation of valve loss

4 Test installation

4.1 Permissible deviation of measuring devices

The permissible deviation of the reading indicated on the measuring devices from the actual value shall be as follows:

flow rate:	±2 %
differential and actual pressure:	±2 %
temperature:	±1 °C

The measuring devices shall be calibrated according to the existing calibration rules in the country performing the test.

4.2 Test equipment

4.2.1 Piping

Upstream and downstream piping shall be the same diameter as that of the test valve connection. The lengths of the straight, uniform-bore pipe shall be as specified in Figure 1. The inside surface of the piping shall be free of flaking rust, mill scale and irregularities which might cause excessive turbulence.

In that part of the test apparatus shown within the frame, in Figure 1, the order of the fittings/devices shown in the key and the distances between them shall be adhered to, with the exception that the lengths indicated as 5*d* and 10*d* shall be understood to be the minimum allowable lengths.

4.2.2 Throttling valve

A downstream throttling valve shall be used to control the flow through the test specimen. There are no restrictions on the size or type of this valve. The throttling valve shall be located downstream of the downstream pressure tap (used for measuring bench pressure).

4.2.3 Flow measuring device

Locate the measuring device at the head of the system.

If an open measuring device (such as a calibrated volumetric tank) is used, it shall be located at the downstream end of the assembly, i.e. downstream of the downstream throttling valve.

The flow-measuring device shall be installed in accordance with the specific installation instructions and, where applicable, shall be installed with the required length of straight piping before and after the device.

The accuracy of the measuring device shall be ±2 %.

4.2.4 Pressure differential measuring device

Any device capable of measuring pressure differential with acceptable accuracy may be used.

4.2.5 Pressure taps

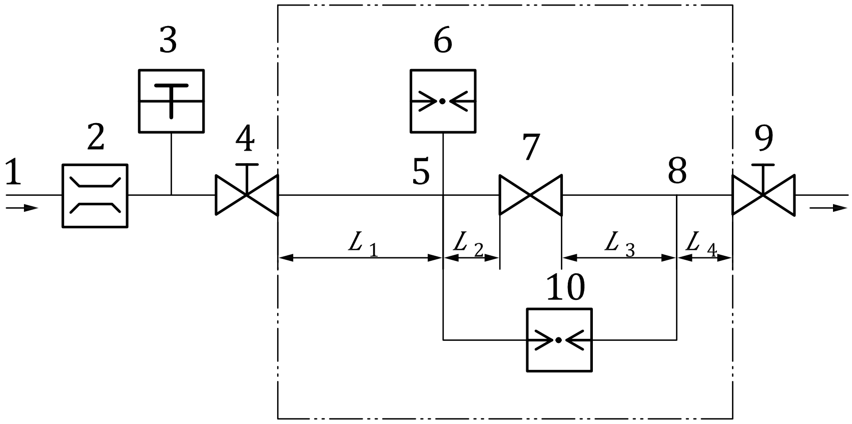
Pressure taps (see Figure 2) shall be provided on piping for measurement of static pressure, and spaced as shown in Figure 1. The drilling centreline of the taps shall intersect the centreline of the pipe perpendicularly, as shown in Figure 2. The diameter shall depend on the DN of the valve, see Table 1.

Table 1 — Pressure tap hole diameter

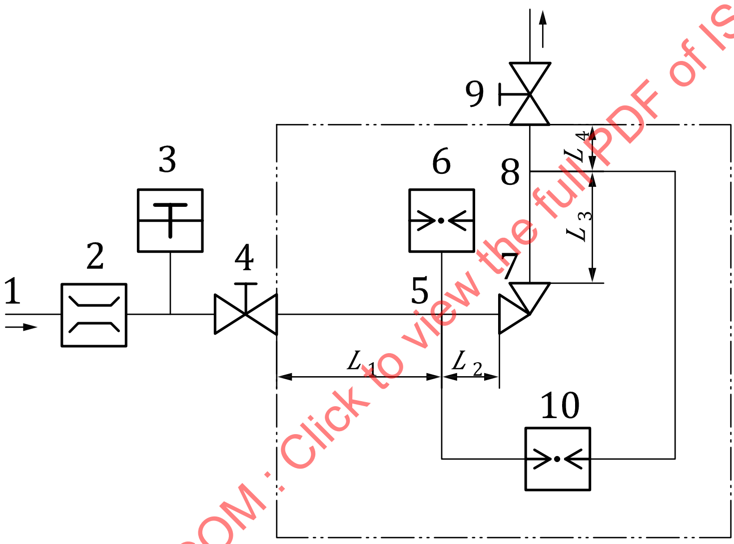
DN	Minimum hole diameter mm	Maximum hole diameter mm
<20	1,5	2
20 to 50	2	3
>50	3	5

The length, *l*, of the tap bore shall be not less than twice the diameter of the bore. For thin-walled pipes where the wall thickness is less than $2d_1$, a boss may be added to the pipe wall where the pressure taps are to be located (see Figure 2).

Pressure taps shall be free of burrs and other irregularities and the inside wall of the piping shall be machine-finished. For pipes of 50 mm diameter and larger, four taps shall be made, situated 90° ± 5° apart on the circumference so that no tap is located on the lowest point of the pipe circumference. For pipe diameters of less than 50 mm, two taps will suffice. All taps, whether two or four in number, shall be connected by a conduit whose bore shall not be less than two pressure-tap cross-sections. The pressure taps shall provide appropriate values of d_1 and l, and may be made as illustrated in Figure 2.



a) Straight valves



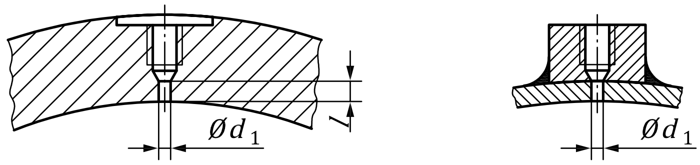
b) Angle or multiport valves

Key

1 water supply
2 flow meter
3 temperature measurement
4 regulating valve
5 upstream pressure tapping point
6 upstream pressure measuring point
7 valve under test
8 downstream pressure tapping point
9 regulating valve
10 differential pressure measuring device

NOTE In subfigures a) and b), L_1 and $L_3 \geq 10d$ and L_2 and $L_4 \geq 2d$.

Figure 1 — Test installation



a) Thick wall   b) Thin wall

Figure 2 — Static pressure taps in thick and thin-wall piping

4.2.6 Temperature sensors

Any temperature-sensing device that is capable of measuring water temperature with acceptable accuracy (see 4.1) shall be used. The device shall be located upstream of the throttling valve.

4.2.7 Filtration

If the valve manufacturer recommends the use of filtered water, a manufacturer-recommended filter shall be installed upstream of the test circuit.

5 Test procedure

5.1 Test installation

Install the test specimen on a suitable test bench for testing valves, as shown in Figure 1. Ensure that the water temperature during the test is between 5 °C and 50 °C.

5.2 Test conditions

5.2.1 Permissible fluctuations in measurements

For each quantity to be measured, the permissible fluctuation is given in Table 2 and Table 3.

If fluctuations of greater than the values in Table 2 and Table 3 are present, measurements may be carried out by providing a damping device. The installation of the damping device shall not affect the accuracy of the readings. Symmetrical and linear damping devices shall be used.

Table 2 — Differential pressure fluctuation

Flow resistance coefficient [a] ζ	Δp fluctuation %
$\zeta > 20$	±6
$4 < \zeta \leq 20$	±10
$1 < \zeta \leq 4$	±17
$0,1 \leq \zeta \leq 1$	±26

[a] See 6.2.2.

Table 3 — Flowrate and pressure fluctuations

Quantity	Fluctuation %
Flow rate, q_V	5
Upstream pressure, p_1	5

NOTE More information about accuracy is given in Annex B.

5.2.2 Steady conditions

Test conditions are steady if the variations of each quantity, observed at the test operating point for at least 10 s, do not exceed a value of 1,2 % (the difference between the largest and the smallest readings of the quantity related to the mean value).

If this condition is met and if the fluctuations are less than the permissible values given in 5.2.1, only one set of readings of individual quantities is to be recorded for the test point.

Record all readings only after steady flow conditions have been reached, and the flow is free from pulsations.

5.2.3 Unsteady conditions

Test conditions are unsteady when variations exceed the limits of 5.2.2. In unsteady conditions, the following procedure shall be followed.

At each test point, repeated readings of the measured quantities shall be made at random intervals of time, but not less than 10 s. A minimum of three sets of readings shall be taken at each test point, with more sets required as the fluctuation increases, as indicated in Table 4.

Table 4 — Minimum reading set requirements

Number of sets	Permissible difference between largest and smallest values of readings of each quantity, related to mean value %
3	1,8
5	3,5
7	4,5
9	5,8
13	5,9
>30	6,0

The arithmetic mean of all the readings for each quantity shall be taken as the actual value for the purposes of the test.

If the excessive variation cannot be eliminated, the limits of error shall be calculated by statistical analysis.

5.3 Test bench pressure loss

Measure the bench pressure loss, Δp_b, at the fully open position of the test specimen, unless specified otherwise in a specific standard, or as recommended by the manufacturer in the installation and operating instructions.

The bench pressure loss measured shall include the loss through the throttling valve (see 3.2.2), Δp_v, and the loss through the piping, Δp_p, of the test set-up:

$$\Delta p_b = \Delta p_v + \Delta p_p \quad (1)$$

5.4 Test of valve

5.4.1 The test specimen shall be installed, opened or operated as in normal agricultural irrigation practice. Valve to be tested at the full open position as defined by the manufacturer or inherent mechanical limitations.

5.4.2 The pressure loss curve shall be confirmed by testing at least five flow rates within the flow range declared by manufacturer. The test shall be conducted at an approximate pressure of at least 3 bar higher than the pressure loss declared at a pressure rate that is higher by at least 3 bar than the pressure loss declared by the manufacturer of the valve.

The manufacturer's published head loss should not vary by more than ±10 % from the test results.

5.4.3 Tests of pressure loss shall be conducted successively in progressive steps — first, with increasing flow rates, followed by decreasing flow rates.

5.4.4 Calculate the valve pressure loss, Δp_v, of the test specimen by subtracting the piping pressure loss, Δp_p, from the bench pressure loss, Δp_b, measured by the differential pressure measuring device:

$$\Delta p_v = \Delta p_b - \Delta p_p \quad (2)$$

The piping pressure loss, Δp_p, is determined by the following method.

— Remove the test specimen from the test bench.

— Connect pipe sections either directly or by means of a fitting that does not introduce significant pressure losses.

— Measure the piping pressure loss separately.

5.4.5 When the test specimen is supplied together with special fittings for connection to the water line, the connecting fittings are considered to be part of the valve.

6 Test results

6.1 Presentation of test results

The pressure loss of the valve, Δp_v, measured and calculated as described in Clause 4, shall be presented by one or both of the following:

a) by means of a table listing values of pressure loss and other coefficients at corresponding flow rates, q_V (see Table 5);

b) by means of a graph showing pressure loss, Δp_v, as a function of flow rate, q_V.

If only one of the above means is presented, b) is the one that is recommended.

If the results from the increasing and decreasing flow rate tests are substantially the same (within a tolerance range up to 5 % of the higher value), then only one column of pressure loss values shall be tabulated [a)], or only one curve shall be shown [b)].

6.2 Calculated valve coefficients

6.2.1 General

For valves with fixed internal geometry, i.e. valves whose internal cross-section remains unchanged by pressure or discharge variations, the following coefficients shall be calculated from the data given in the table or graph according to 6.1.

6.2.2 Flow resistance coefficient, ζ

The flow resistance coefficient, represented by the symbol zeta (ζ), is calculated using Formula (3):

$$\zeta = \frac{2\Delta p_\mathrm{v}}{\rho \cdot {v_\mathrm{ref}}^2} \tag{3}$$

where

Δp_v is the valve pressure loss;

ρ is the mass density, kg/m^3;

v_ref is the reference velocity calculated from Formula (4):

$$v_\mathrm{ref} = \frac{q_V}{A_\mathrm{ref}} \tag{4}$$

where

q_V is the volume flow rate, in cubic metres per hour (m^3/h);

A_ref is the reference cross-sectional area, in square metres, calculated from Formula (5):

$$A_\mathrm{ref} = \frac{\pi}{4}\left(\frac{\mathrm{DN}}{1\,000}\right)^2 \tag{5}$$

where DN is the nominal size of the valve, in millimetres.

This designation equals the nominal diameter or thread size of the pipe to which the valve is connected without intermediate fittings.

A single number designation is adequate if the inlet and outlet ports are the same size.

The value of ζ for the valve tested shall be the arithmetic mean of the three flow resistance coefficient values, ζ_1, ζ_2 and ζ_3, calculated using Formula (3), with the three valve pressure loss values, $\Delta p_\mathrm{v,min}$, $\Delta p_\mathrm{v,max}$ and $\Delta p_\mathrm{v,med}$, inserted respectively, and using the corresponding measured values of q_V to calculate v_ref for insertion in the formula. The three Δp_v values are obtained from the table or graph according to 6.1 a) or b).

The presentation of the valve pressure loss by means of the flow resistance coefficient, ζ, is valid only if the values of ζ_1, ζ_2 and ζ_3 do not vary by more than 2,5 % of the calculated average value of ζ.

6.2.3 Valve flow coefficient, K_v

It is customary to compare the performance of different valves on the basis of their flow capacity which can be defined by the valve flow coefficient, K_v, which indicates the flow rate required to create a one bar pressure loss across the valve.

For water flow, K_v is calculated from Formula (6):

$$K_v = q_V \sqrt{\frac{\rho}{\Delta p_v \cdot \rho_0}} \tag{6}$$

where

q_V is the volume flow rate, in cubic metres per hour (m^3/h);

ρ is the mass density of the water at the temperature used during the test;

ρ_0 is the mass density of the water at 15 °C;

Δp_v is the valve pressure loss, in bar.

The value of K_v for the valve tested shall be the arithmetic mean of the three values of K_v as obtained when inserting in Formula (6) the measured values of q_V and Δp_v ($\Delta p_{v,min}$, $\Delta p_{v,max}$ and $\Delta p_{v,med}$), obtained from the table or graph as specified in 6.1 a) or b).

The permissible difference between the maximum and the minimum value of the flow coefficient shall not exceed 4 % of the maximum.

6.3 Test report

The test report shall include

a) a description of the valve (manufacturer's name, type and model of valve, valve size, and special information and identification),

b) confirmation that the valve has been installed for the test in accordance with the direction of flow indicated on the valve body,

c) confirmation that the valve has been set to its normal fully open position,

d) confirmation that the valve test was conducted in accordance with this document,

e) temperature and pressure of the water used during the test,

f) presentation of test results in accordance with 6.1,

g) a statement to the effect that the test was performed with filtered water (if its use is recommended by the manufacturer),

h) a graph showing the pressure losses obtained in the test, as recommended in 6.1 b), and/or

i) a table showing the pressure losses obtained in the test, such as Table 4.

Table 5 — Example of tabular presentation of test results

Flow rate q_V m^3/s	**Pressure loss** Δp_v kPa	**Flow resistance coefficient** ζ	**Valve flow coefficient** K_v $m^3/h\sqrt{\frac{1}{bar}}$

Annex A
(informative)

Measurement uncertainty

A.1 Overview

Measurements are inevitably marred with uncertainty even though the measurement procedure and instrument, as well as the analysis methods, strictly meet the existing rules and, more specifically, the procedures in this document.

Measurement uncertainty partly depends on residual uncertainty in the instruments or the measurement method. Once all known errors are cancelled by calibration and when dimension measurements are strictly recorded and the facility suitably prepared, there remains an uncertainty which is never cancelled and cannot be reduced by measurement repetition, if the same instrument and the same measuring method are implemented. The evaluation of this uncertainty component based on the knowledge of the instrument used and the measurement methods is referred to as systematic uncertainty.

Another source of error due either to the measurement system properties or the measured quantity variations, or to both, directly appears in the form of measurement spread. The evaluation of this measurement uncertainty component is referred to as random uncertainty. Its evaluation requires the measurement and analysis (by statistic methods in cases) of the fluctuations and the stability of the measured physical quantities.

To reduce systematic uncertainty, the operators resort to more precise instruments or apply several measurement methods.

With the same instrument and measurement method, the uncertainty caused by random uncertainty can be reduced by increasing the number of measurements for the same physical quantity, in the same conditions.

When systematic and random uncertainties are determined, the total measurement uncertainty is calculated as the square root of the sum of the squares of the systematic and random uncertainty.

However, in this document, if the requirements pertaining to systematic uncertainty (in 4.1) and if all requirements imposed on the test procedure (as indicated in this document) are applied, it can be assumed that total uncertainty does not exceed the values stated in 5.2.1.

A.2 Permissible measurement fluctuations

A.2.1 General

The examples below are based on the assumption that the physical quantities to be measured are not damped before their acquisition by the measurement systems.

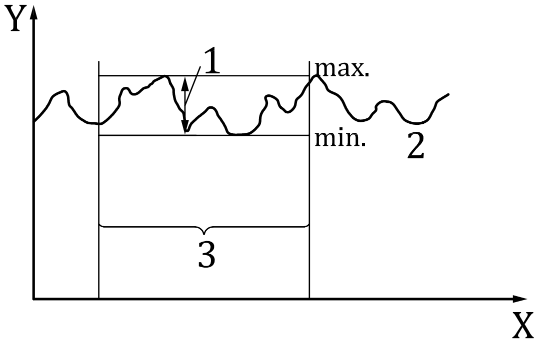
A.2.2 Direct visual observation of signals delivered by the systems

If the measurement device does not include an electronic damper system, the signal values from the measurement device are subject to fluctuations during the time required for acquisition.

The user tries to visualize the maximum and minimum values reached by the signal.

Generally, readings are considered as:

$$x_R = \frac{x_{max} + x_{min}}{2} \tag{A.1}$$



Key

X time

Y signal

1 amplitude of fluctuations

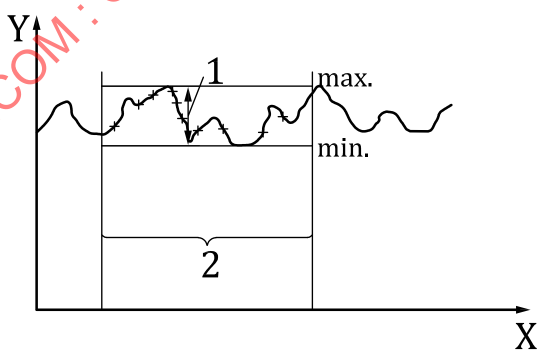
2 signal delivered by an instrument

3 time for one reading by visual observation

Figure A.1 — Fluctuation amplitude

A.2.3 Automatic recording of signals delivered by measurement systems

When an automatic acquisition system is used, a number *n* of measurements is taken in a given time period. The number of measurements, *n*, the time period and the time between two measurements depend on the acquisition system properties and configuration.



Key

X time

Y signal

1 amplitude of fluctuations

2 time for one set of measurements

+ values delivered by a data logging system

Figure A.2 — Fluctuation amplitude

In this case, the measurement is the arithmetic mean between n measurements:

$$\bar{x} = \frac{1}{n}\sum_{J=1}^{n} x_j \tag{A.2}$$

The maximum (x_{max}) and minimum (x_{min}) measurement values are taken from the n measurements:

$$x_{max} = \max\{x_1, x_2, ..., x_n\} \tag{A.3}$$

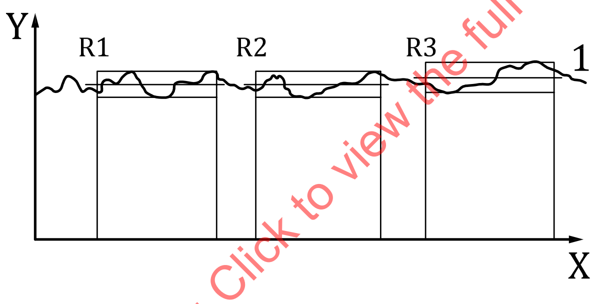
$$x_{min} = \min\{x_1, x_2, ..., x_n\} \tag{A.4}$$

The percentages, $(x_{max} - x_R)/x_R$ and $(x_R - x_{min})/x_R$, shall be compared with the values in Tables 1, 2 and 3.

A.2.4 Automatic integration of signals delivered by the measurement systems

If the measurement system used includes an integration module which automatically ensures, with the required accuracy, the integration required for mean value calculation over an integration period longer than the corresponding system response time, the fluctuations on read values are generally much lower than those stated in 5.2.2 and 5.2.3.

A.3 Measured value stability on physical quantities



Key

X time

Y signal

1 signal delivered by an instrument

Figure A.3 — Reading a signal delivered by an instrument

The above diagram shows three series of readings on a signal. Values x_{R1}, x_{R2}, x_{R3} are mean values determined as instructed in A.2.2 or A.2.3.

To verify whether the signal is stable, proceed as follows:

a) Calculate the average of three values:

$$x_{avg,1} = (x_{R1} + x_{R2} + x_{R3})/3 \tag{A.5}$$

b) Determine the maximum and minimum readings (in this example: $x_{max} = x_{R3}$ and $x_{min} = x_{R2}$).

- — If $(x_{R3} - x_{avg,1})/x_{avg,1}$ and $(x_{avg,1} - x_{R2})/x_{avg,1}$ are lower than 1,8 %, the signal is considered as stable with respect to this document.
- — If $(x_{R3} - x_{avg})/x_{avg}$ or $(x_{avg} - x_{R2})/x_{avg}$ is slightly higher than 1,8 %, carry out two additional acquisitions.

c) Calculate the average of five values:

$$x_{avg,2} = (x_{R1} + x_{R2} + x_{R3} + x_{R4} + x_{R5})/5 \quad (A.6)$$

d) Determine the maximum and minimum readings.

— If $(x_{max} - x_{avg,2})/x_{avg,2}$ and $(x_{avg,2} - x_{min})/x_{avg,2}$ are lower than 3,5 %, the signal is considered as stable with respect to this document.

— If $(x_{max} - x_{avg,2})/x_{avg,2}$ or $(x_{avg,2} - x_{min})/x_{avg,2}$ is slightly higher than 3,5 %; carry out two additional acquisitions.

e) Repeat this procedure until very close to values stated in 5.2.3 are reached. However, if you reach 20 measurement series and if the permissible deviation between the highest and the lowest values read, versus the mean value, is higher than six, the process shall be stopped: the signal is not permanent.

A.4 Determining flow rate and pressure loss coefficients in turbulent rating condition

For the test of a DN_{50} valve, Table A.1 shows the mean value of the obtained measured quantities for three different points.

Table A.1 — Mean value of the measured quantities

Measurement point	Flow rate m^3/h	Upstream pressure bar	Differential pressure on valve and tube bar	Tube differential pressure bar	Valve differential pressure bar	Rate m/s	*Re*	K_v	ζ
1	41,44	5,150	0,254	0,042	0,212	5,86	2,93E + 05	90,0	1,235
2	36,36	5,556	0,194	0,032	0,162	5,15	2,58E + 05	90,3	1,222
3	28,99	5,679	0,122	0,021	0,101	4,10	2,05E + 05	91,2	1,202

In this example, the minimum value of the Reynolds number is five times the authorized value (4E + 04) required by this document. This is justified by the fact that it is necessary to operate with a high enough differential pressure to obtain measurements with the required accuracy.

The arithmetic mean of K_v is:

$$(90{,}0 + 90{,}3 + 91{,}2)/3 = 90{,}5$$

The difference between the maximum and minimum values of K_v, divided by the arithmetic mean and expressed in %, is:

$$[(91{,}2 - 90{,}0) \times 100]/90{,}5 = 1{,}32\ \%$$

As the difference is lower than 4 %, the K_v factor of the valve in turbulent rating and without cavitation is considered as equal to 90,5.

Annex B
(informative)

Evaluation of uncertainty of flow rate coefficient, K_V, and pressure losses coefficient, ζ

B.1 Generality

ISO/IEC Guide 98-3 (known as the GUM) provides the international method to estimate the measurement uncertainty. There are different methods to estimate these measurement uncertainties, The strict mathematical way is described most extensively in the GUM, but the other methods which are in conformity with it can be used.

The GUM groups uncertainty components into type A and type B according to the way these data were obtained. Type A components are calculated by statistical means from repeated measurements, while type B components are taken from other sources, e.g. reference material, calibration certificates, accepted values of constants, resolution, instability, environmental conditions.

A combined approach is often the most suitable; this combined approach is applied very often, as it is impossible to estimate each uncertainty individually. Here, the type B is used with reference sensors and a quality control sensor to avoid some systematic measuring uncertainties.

Type A uncertainty is an estimation issued from the statistical analysis of experimental data. This type of uncertainty evaluation is preferably used when the value of a measurand is the average of several test results or is in relation with non-independent variables.

B.2 Evaluation of measurement uncertainty of the K_V (Cv)

B.2.1 Determination of flow rate coefficient

The flow rate characteristic parameter of a valve is the flow coefficient K_V. The formula, the quantity subject to measurement and input quantities are the following.

$$K_V = q_V \sqrt{\frac{\rho}{\rho_0 \Delta p}} \quad \text{(B.1)}$$

where

q_V is the volume flow rate, in cubic metres per hour (m^3/h);

ρ is the density of test fluid (water), in kilograms per cubic metres (kg/m^3);

ρ_0 is the density of test fluid (water) at 15 °C, in kilograms per cubic metre (kg/m^3);

Δp is the pressure loss in the valve, in bar.

B.2.2 Identification of uncertainty of input quantities

According to Formula (B.1), the input quantities subject to measurement are the following:

— q_V volume flow rate.

The maximum values of uncertainty, e_q, according to the accuracy of measuring instrument are given in Table 2.

For some technologies in flow rate measurement devices, additional uncertainties can appear; sometimes the value of flow measurement depends on upstream pressure. This kind of deviation shall be evaluated and added to the previous e_q. For this reason, the flow meter is preferably located before the upstream measuring tube, because this part is not subject to significant pressure variations.

— Δp upstream stagnation pressure.

The maximum values of uncertainty, $e_{\Delta p}$, according to the accuracy of measuring instrument are given in Table 1.

These input quantities are independent variables and the sensitivity can be calculated.

B.2.3 Sensitivity coefficient

Sensitivity coefficients are obtained from partial derivatives of Formula (B.1) with respect to the input parameters

$$\mathrm{d}K_\mathrm{v} = \frac{\delta K_\mathrm{v}}{\delta q_V}\mathrm{d}q_V + \frac{\delta K_\mathrm{v}}{\Delta p}\mathrm{d}\Delta p + \frac{\delta K_\mathrm{v}}{\delta \rho}\mathrm{d}\rho + \frac{\delta K_\mathrm{v}}{\delta \rho_0}\mathrm{d}\rho_0 \quad \text{(B.2)}$$

The sensitivity coefficient a_{qV} is given by:

$$a_{qV} = \frac{\delta K_\mathrm{v}}{\delta q_V}\left(\frac{q_V}{K_\mathrm{v}}\right) = 1 \quad \text{(B.3)}$$

The sensitivity coefficient $a_{\Delta p}$ is given by:

$$a_{\Delta p} = \frac{\delta K_\mathrm{v}}{\delta \Delta p}\left(\frac{\Delta p}{K_\mathrm{v}}\right) = -\frac{1}{2} \quad \text{(B.4)}$$

The sensitivity coefficient a_ρ is given by:

$$a_\rho = \frac{\delta K_\mathrm{v}}{\delta \rho}\left(\frac{\rho}{K_\mathrm{v}}\right) = \frac{1}{2} \quad \text{(B.5)}$$

The sensitivity coefficient $a_{\rho 0}$ is given by:

$$a_{\rho_0} = \frac{\delta K_\mathrm{v}}{\delta \rho_0}\left(\frac{\rho_0}{K_\mathrm{v}}\right) = -\frac{1}{2} \quad \text{(B.6)}$$

B.2.4 Type A evaluation uncertainty

An estimation of the mean value of the coefficient K_v is obtained by the average of several measurement points, such as:

$$\overline{K_\mathrm{v}} = \frac{1}{n}\sum_i K_{\mathrm{v}i} \quad \text{(B.7)}$$

where

n is the number of measurement points;

$K_{\mathrm{v}i}$ is the measurement result of data at i.