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The evaluation of flow standards and facilities used for testing water meters

Evaluation des étalons de débimètre et des dispositifs utilisés pour l'essai des compteurs d'eau

OIML D 7 Edition 1984 (E)

ORGANISATION INTERNATIONALE DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION OF LEGAL METROLOGY

Foreword

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The two main categories of OIML publications are:

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OIML Draft Recommendations and Documents are developed by technical committees or subcommittees which are formed by the Member States. Certain international and regional institutions also participate on a consultation basis.

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International Recommendations and International Documents are published in French (F) and English (E) and are subject to periodic revision.

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TERMINOLOGY

Calibration (*)

The set of operations which establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measurand.

Notes
1. The result of a calibration permits the estimation of errors of indication of the measuring instrument, measuring system or material measure, or the assignment of values to marks on arbitrary scales.
2. A calibration may also determine other metrological properties.
3. The result of a calibration may be recorded in a document, sometimes called a calibration certificate or a calibration report.
4. The result of a calibration is sometimes expressed as a calibration factor, or as a series of calibration factors in the form of a calibration curve.

Calibration is thus a comparison between a source of known accuracy called a measurement standard and the measuring instrument whose accuracy is not known, but to be found.

Calibration of a water meter involves the use of a flow standard to determine the error curve over the flowrate range Q_{min} to Q_{max}.

The uncertainty with which the error of the water meter can be determined at any flowrate depends on the repeatability of the water meter itself, and the random and systematic uncertainties of the flow standard used.

Calibration station (**)

An installation for the calibration or verification of a measuring instrument under conditions which are defined according to the conditions of use anticipated for the measuring instrument.

Primary standard (*)

A standard which has the highest metrological qualities in a specified field.

Note: The concept of primary standard is equally valid for base units and for derived units.

Comparison standard (**)

A standard designed for the comparison among themselves of standards of the same order of accuracy.

Flow standard

A standard used for the calibration of flowmeters, i.e. that portion of the flow-meter test facility used for determining the flowrate and volume flow.

A flow standard does not include the means used for providing the flow.

Reference standard (*)

A standard, generally of the highest metrological quality available at a given location, from which measurements made at that location are derived.

(*) Term defined in the « International vocabulary of basic and general terms in metrology », 1984
(**) Term defined in the OIML « Vocabulary of legal metrology », 1978.

Volume flow (see International Recommendation No. 49)

Volume of water passing through the water meter, disregarding the time taken.

Repeatability of measurements [*]

The closeness of the agreement between the results of successive measurements of the same measurand carried out subject to all of the following conditions:

— the same method of measurement,
— the same observer,
— the same measuring instrument,
— the same location,
— the same conditions of use,
— repetition over a short period of time.

Note: Repeatability may be expressed quantitatively in terms of the dispersion of the results.

Reproducibility of measurements [*]

The closeness of the agreement between the results of measurements of the same measurand, where the individual measurements are carried out changing conditions such as:

— method of measurement,
— observer,
— measuring instrument,
— location,
— conditions of use,
— time.

Notes 1. A valid statement of reproducibility requires specification of the conditions changed.
2. Reproducibility may be expressed quantitatively in terms of the dispersion of the results.

Intercomparison test

Tests in which two or more co-operating laboratories calibrate comparison standard meters to compare the overall calibration accuracy levels of each laboratory's calibration station.

Flow straightener [***]

General term used to describe various devices which have the following functions:

swirl remover: device inserted in a conduit to eliminate or reduce circumferential velocity components which produce swirl.

profile regulator: device inserted in a conduit to reduce the straight length requiered to achieve a regular velocity distribution.

Note: The difference between these two functions is not always clearly made in respect of particular flow straighteners, and indeed some devices may perform both functions to a greater or lesser extent.

[***] Term defined in ISO 4006-1977 « Measurement of fluid flow in closed conduits - vocabulary and symbols ». « Flow conditioner » is frequently used as a synonym of « Flow straightener ».

The EVALUATION of FLOW STANDARDS
and FACILITIES
USED for TESTING WATER METERS

1. Scope

This International Document is concerned with the methods by which the flow standards used in a calibration station for water meters shall be related to a country's national primary standards of mass, length, time, temperature and other relevant basic parameters.

This International Document sets out the procedures for tests on the flow standards and the test facilities used in a water meter calibration station to establish and hence improve the overall accuracy levels of the station. Such tests may involve intercomparisons with other collaborating laboratories and the use of comparison standard water meters. The Document stipulates the methods for presenting the results and the estimated accuracy of the tests.

ISO/DIS 4064 « Measuremnts of water flow in closed conduits - meters for cold potable water - Part III: Specification for test methods and equipment », is concerned with detailed aspects of the calibration and testing of water meters and the means used to do so. Reference should be made to this standard for practical and procedural details when testing water meters.

2. Water meter calibration methods and the flow standards employed

2.1. Calibration methods

The methods used to calibrate a water meter should be such that they will meet the required accuracy level (see International Recommendation No 49, point 13.1).

Some common methods used to calibrate water meters are given here as a guide to acceptable methods.

2.1.1. Collection method

The quantity of water passed through the water meter undergoing calibration is collected in one or more collecting vessels and the quantity determined volume-trically or by weighing.

2.1.2. Flowrate, time method

The quantity of water passed through the water meter undergoing calibration is determined from the results of the measurement of flowrate and time. This may be achieved by one or more repeated measurements of flowrate over a timed period, but avoiding flowrate measurements during the non-constant flowrate zone at the beginning or end of the test.

2.1.3. Reference meter method

The indications of the water meter being calibrated are compared with those of a reference meter of higher quality, previously calibrated at a smaller uncertainty level.

2.1.4. Displacement meter prover method

The indications of the water meter being calibrated are compared with the fixed volumes swept by a displacement meter prover.

2.2. Flow standards

All methods used to calibrate a water meter involve directly or indirectly the measurement of the quantity of water that has passed through the water meter and the determination of the mass or volume of this water in some way. Thus the flow standard being used, though ultimately only a standard of volume, may itself, for the purpose of comparing the volumetric indication of the water meter with the standard, be calibrated against standards of length, mass and time, with compensations for temperature, viscosity and buoyancy, and corrections for drainage time, water quality and flowrate changes.

For the water meter flow standard itself to be shown to have acceptable accuracy, it is necessary that it itself has been proved against other standards of higher accuracy.

A necessary first step in the establishment of accuracy level for a water meter test laboratory is to establish a « traceability chain » or « calibration hierarchy » of the reference standards used.

2.3. The hierarchy and traceability of standards used for water meter testing

All measurements in a water meter test laboratory having a bearing on the accuracy levels of calibration and used in the certification of water meters are to be made by standard devices having appropriate accuracy which can be related, through a calibration chain, to national primary standards (see International Document No 5 « Principles for the establishment of hierarchy schemes for measuring instruments »).

Traceability to national standards means:

a) that each standard used for calibration purposes has itself been calibrated against a standard of higher accuracy (referred to standard conditions) up to the level at which the higher quality instrument is the accepted national standard ; this is usually a unique item held in a national standards laboratory, but could in some cases be a local standard of equivalent quality built and operated to a national specification and confirmed as operating to that specification,

b) that the frequency of such calibration, which is dependent on the type, quality, stability, use and environment of the lower quality standard, is such as to establish reasonable confidence that between successive calibrations it will not move outside the limits of its specification,

c) that the calibration of any instrument against a standard is valid in exact terms only at the time of calibration and its performance thereafter must be inferred from a knowledge of the factors mentioned in (b) above.

2.4. Approved procedures for inter-laboratory comparison of standards used for water meter testing

The errors inherent in water meter calibration are only partially quantified by the use of traceable standards.

There remains a range of systematic and random errors attributable to reading errors, switching errors, level detection errors and time-dependent errors etc, which the use of traceable standards will not affect. These errors can be considered and their magnitude estimated by making a list of possible sources of uncertainty and ascribing a value to them. Since these errors contribute to the total uncertainty of a water meter calibration and the magnitude of their effect is not predictable, intercomparisons of one or a series of comparison standard water meters of a suitable design (see Appendix I) by collaborating metrological laboratories are recommended to assess the overall calibration accuracy levels of the participating laboratories.

Two types of intercomparison test are recognised:

a) intercomparison tests designed to establish the overall accuracy level of the flow standards used, in particular the sum of the systematic errors, the repeatability of measurement and the reproducibility of measurement,
b) intercomparison tests designed to establish the effect of the test facility on the errors of the water meter on test and, in particular, any effects of the flow conditions in the test section.

The laboratory or organisation providing the majority of the equipment for the intercomparison tests is called the «originating laboratory », the other laboratories taking part in these intercomparison tests are called « participating laboratories ».

The following recommendations apply to the two types of intercomparison test listed above:

— when metrological laboratories operating at approximately similar levels of accuracy or levels of traceability are being compared, at least three laboratories must take part in the intercomparison tests,
— when intercomparison tests between laboratories at different levels of accuracy or traceability are to be made, it may be sufficient that two laboratories only should take part. The laboratory having the higher level of accuracy or traceability should have been a participant in a « three or more » intercomparison test as described above,
— the comparison standard water meters used for the intercomparison tests form part of a special test section of pipework, all provided and transported in accordance with the specification given in Appendix I,
— the metrological laboratory originating the comparison should calibrate the comparison standard water meter(s) twice; initially at the commencement of the intercomparison tests and finally after the last test in order to determine if changes have occurred in the comparison standard during the duration of the intercomparison tests. If a large number of laboratories participate in the inter-laboratory comparison then the originating laboratory should recalibrate the comparison standard water meter(s) at regular intervals during the series of tests, so that the stability of the comparison standard is assured. The frequency of these recalibrations should be determined at the start of the tests so that any changes or damage to the comparison standard meter(s) during the series of tests may be quickly detected,
— the design of the tests and the analysis and presentation of results obtained in the laboratory intercomparisons should be accomplished in accordance with the provisions established in Appendix II,
— the data obtained by each laboratory during the intercomparison tests should be as specified in Appendix II and the data should be presented in accordance with the provisions in point II.2 of that Appendix,
— it may be agreed, before the intercomparison tests are conducted, that the test results from each laboratory should remain known only to that laboratory, and by agreement, with the originating laboratory, until all the tests have been concluded. Each laboratory's results may then be disclosed, but only to the laboratories taking part in the intercomparison tests. The results of the intercomparison tests should remain confidential to the participants unless all agree to publish the results as a combined report in an agreed manner (see Appendix II, point II.3),
— the intercomparison tests once commenced should be conducted as expeditiously as possible to minimise any change with time of the comparison standard meters used. Before intercomparison tests commence the participants should agree to a timetable for the tests.

APPENDIX I

THE CHOICE AND TRANSPORT OF COMPARISON STANDARD WATER METERS

I.1 The choice of comparison standard meters

A water meter to be used as a comparison standard may be a specially selected commercial water meter or a device especially designed and constructed for the work.

The repeatability and reproducibility of a water meter are important factors in determining its suitability for use as a comparison standard meter. The repeatability of a comparison standard meter is a measure of its variability when repeat measurements are made at quite short intervals of time keeping the different factors constant, for example, one or same operators, the same calibration facilities. The reproducibility of a comparison standard meter is a measure of its variability when repeat measurements are made in different laboratories, i.e. when different operators and calibration facilities are used.

The sensitivity of the comparison standard meter to upstream installation conditions determines its applicability to the two main types of intercomparison test:

a) for intercomparison t^sts on the flow standard, a comparison standard meter insensitive to installation conditions upstream of the meter is required,
b) for tests designed to investigate the performance of the water meter test facility and in particular to check the flow conditions in the meter test section, at least two flowmeters of a similar type to those to be calibrated subsequently in the test facility are required so that sensitivity to the upstream installation conditions in the facility can be checked.

The type of test dictates the choice of meter. A preferred design of test which gives details of upstream pipework for a two-meter transfer standard test is described in point II.4.1. of Appendix II.

Ideally, the error curve of the meter should be linear and horizontal, within its flowrate range. In practice, the use of those parts of the meter flowrange where a marked change in the error curve is exhibited should be avoided, particularly (as is common), at or near the minimum flowrate.

A meter chosen as a comparison standard meter should be of robust construction, and its accuracy level should be resistant to the effects of transport.

The chosen meter size must suit the flowrate range of the tests and more than one size of meter may be needed.

The number of meters that may be used at any flowrate is limited by the characteristics of the laboratory facilities of the participants; but in order to minimise random errors the use of several meters in series in intercomparison tests is recommended.

A filter when installed must be fixed and not able to rotate. The cleaning of the filter must be effected by a back flow through the meter at a flowrate that cannot damage the meter.

I.2 Design of special test section for comparison standard meters

The special test section (*) to be circulated between laboratories participating in the intercomparison tests should consist of the comparison standard water meter or meters, and the associated pipework and fittings necessary to allow the test section to be fitted into the test facilities of the participating laboratories.

(*) Hereinafter called « test section ».

A preferred design of the test section is shown in Figure 1, where A and B are similar meters and xD and yD are the lengths (in terms of number of diameter D) of straight pipe upstream of the meter at least as long as those recommended by the manufacturer. aD and bD are the lengths of pipework downstream recommended by the manufacturer. Meter A is thus installed in its own sub-test section having xD of straight pipe upstream and aD dowstream of it. Similarly, meter B is contained in a sub-test section having yD of straight pipe upstream and bD downstream.

Each sub-test section should be constructed as a readily demountable unit to facilitate interchange of the sub-test sections within the test section.

Separating the two sub-test sections is a flow straightener designed to ensure that the inlet conditions for the downstream meter (meter B in Figure 1) are suitable. The flow straightener is usually needed to eliminate swirl but where flow conditions downstream of the upstream meter (meter A in Figure 1) are known to cause an asymmetric velocity profile, the flow straightener shall contain additionally a profiling element. Suitable designs of flow straightener are given in Appendix III.

Immediately upstream of the upstream sub-test section is situated a traverse section at least 2D in length. The traverse section is fitted with the necessary means to enable the velocity profile of the flow to be measured in at least two planes at right angles and the swirl element of the flow to be determined.

Each participating laboratory should provide the necessary make-up pieces and adaptors to fit the complete test section (of length L in Figure 1), which is circulated between participating laboratories, into their own test facilities.

The internal surfaces of the pipework comprising the test section should be treated to prevent corrosion during transport, use or storage.

I.3 Assembly, packing and transport

I.3.1. Assembly Design

The test section should be so designed that it can be easily and precisely assembled in the different laboratories where it is to be used. Thus mismatch of the pipe bores of successive lengths of test pipe should be avoided by the use of flange spigots, dowels or the careful provision of flanges of similar outside diameter machined concentric with the pipe bore. Protrusion of insertion jointing into the pipe bore between pipeline components should be prevented. This may be best achieved by attention to detail at the design stage, for example the use of 0-ring seals, use of a location means for the insertion jointing, etc.

Identification

Pipes and pipeline components should be serially numbered or lettered in the direction of flow to ensure reproducibility of assembly in the different laboratories. The possibility of angular mismatch between successive pipes or pipeline components should be avoided by the clear marking of the upper surface of the pipe or flange, or by marking corresponding bolt holes in the matching flanges. The direction of flow should be clearly marked on each item.

Assembly drawings

An adequate assembly drawing of the test section should accompany it.

Small components

All the necessary bolts, nuts, washers, joints and gaskets or 0-rings to enable the parts of the test section to be assembled should be provided, and sufficient additional parts should be included to act as spares.

Special tools

If, during the intercomparison tests, it may be necessary to disassemble for cleaning or inspection any part of the comparison standard meters and test section, and special tools are necessary to accomplish this, then these special tools should accompany the test section.

Pressure tappings

The provision of small bore piping, manometers etc, to connect to pressure tappings on the test section or traverse section is the responsibility of each participating laboratory. Pressure tappings on the test section should end at a male stud coupling or a tapped hole having a screw thread in accordance with ISO 7/1 - 1978, preferably size R1/4, and are provided as part of the test section.

Electrical connections and equipment

If comparison standard meters employing electrical or electronic means are chosen, cabling between meter primary and secondary, and between secondary and counter (if the counter is provided) should be included. Power cables to the meter primary are normally the responsibility of the participating laboratories although power cables for secondary and counter being of low power consumption usually travel with them and are provided with the test section by the originating laboratory.

Normally, the electronic counter used in the intercomparison tests, being a standard item common to most laboratories, would not be supplied by the originating laboratory.

Electrical drawings, wiring information and electrical data should accompany the comparison standard meter(s).

Drainage and drying

Pipeline components, in particular the comparison standard flowmeters, should be provided with adequate drainage means where it would be otherwise possible for water used during the tests to remain trapped within the component after the tests.

Instructions for drying of components or alternatively, for keeping them in a humid environment, should be given by the originating laboratory.

I.3.2. Packing

The suitably disassembled sections of the test section should be adequately packed having regard for the type of transport envisaged. For example, it is permissible to employ lighter or less packing where the components are being transported by air freight.

Packing material and crates should be reusable bearing in mind the need to open and close crates frequently during the course of a series of tests.

Flange blanking covers should be used if pipes are not crated. Similarly, the ingress of loose packing material into the comparison standard meters should be prevented by blanking covers fitted to the meter flanges.

Screwed connections should be protected from damage and blanked by suitable protective plugs.

A list of items and a contents list of each crate should be prepared by the originating laboratory and sent separately to each participating laboratory.

The items comprising the test section should be addressed to nominated persons responsible for the tests in each participating laboratory and identified by an agreed reference number or letter group.

I.3.3. Transport

The cost should be borne and arrangements made for the onward despatch of the test section by each laboratory in turn, starting with the originating laboratory unless other arrangements are agreed.

To avoid lengthy delays and entry port storage costs, the necessary customs clearance forms, where applicable, should be circulated as necessary before the test section leaves the laboratory on the next stage of its journey.

APPENDIX II

DESIGN OF TEST, ANALYSIS OF RESULTS AND PRESENTATION OF THE RESULTS OF LABORATORY INTERCOMPARISON

II.1 Design of test

A preferred design of test is given in point II.4 of this Appendix, together with a method of interpreting the results obtained from this design of test.

II.1.1. Test programme

A detailed test programme should be agreed before commencing the intercomparisons and after establishing the following basic requirements for the tests :

a) the flowrate range to be covered by the intercomparison tests in each laboratory,

b) the accuracy levels claimed by each laboratory in the determination of volume of liquid and in the determination of flowrate,

c) the estimated component systematic errors in the determination of volume and flowrate for each laboratory,

d) the estimated overall random errors in the determination of volume and flowrate for each laboratory, based on the past experience of calibration tests performed on highest quality meters.

The foregoing information is necessary for the design of the test. A simple design may stipulate the use of a single comparison standard meter which is to be calibrated at two or three flowrates, three or more repeat points being taken at each flowrate. This procedure would then be repeated in each of the participating laboratories. More complicated test designs may include two or more comparison standard meters in order to determine the systematic errors due to flow conditions in each laboratory and perhaps other aspects. The design of test should include information about the test section and indicate whether for instance flow straighteners, traverse section or other features should be incorporated.

Using the information obtained from points a) to d) above, a test programme should be established which should stipulate as a minimum:

— the type and number of comparison standard meters to be used,
— the number and precise value of flowrates over the agreed flowrate range,
— the number of repeat points to be made at each flowrate,
— the data to be obtained at each flowrate, and
— the order, random or otherwise, in which the test points should be made and, if necessary, the pauses in the test programme.

II.1.2. Test data

It is not only necessary to agree on the form of the test programme, it is essential that the data to be collected for each test point at each laboratory should be sufficient and of the requisite level of precision to enable the required accuracy levels to be obtained.

Additionally, an agreed and common basis for specifying the test conditions and correcting the data to compensate for such factors as temperature, buoyancy effect, gravitational effects, etc. should be laid down, in order that the results obtained in the different laboratories are truly comparable.

The tests should be carried out carefully by competent operators using the normal procedures and techniques employed from day-to-day in the particular laboratory.

The originating laboratory, taking into consideration the experience gained during the initial tests on the test section, should produce either a list or a blank form of the data to be obtained during subsequent tests by the participating laboratory, and circulate it to them.

The data once obtained, should be tabulated and standard calculations performed in an agreed manner.

II.1.3. Analytical methods and calculations

The methods given are in accordance with ISO 5168 - 1978 «Measurement of fluid flow - estimation of uncertainty of a flowrate measurement ».

a) Overall uncertainty

A statement of the estimated accuracy should accompany every measurement result. The accuracy estimate is made up of two parts, the random and systematic components. Thus following the statement of the mean corrected value of the measurement « y », the accuracy should be stated as in the following example:

« y » ± 0.24 per cent (8 random 95 ± 0.16 per cent).

This is to be interpreted that the random component of the estimate has a Student's t value of 8 degrees of freedom at a level of 95 per cent confidence limits. In this example, this amounts to ± 0.16 per cent. (The standard error of the mean (random) was ± 0.069 per cent, Student's t for 8 degrees of freedom 95 per cent is 2.31)

The systematic uncertainty component of the estimate is obtained by subtracting the random variance from the overall variance, that is $(0.24^2 — 0.16^2)^{1/2} = 0.18$. Thus the systematic uncertainty component in this case is ± 0.18 per cent.

The mean corrected value of the measurement « y », should be expressed to no more than the overall accuracy estimate.

b) Calculations relating to the mean

The symbol Σ, represents the summation of n terms of the expression immediately following the symbol. The i suffix takes all values from 1 to n.

For example :

$$\Sigma\, y_i = y_1 + y_2 + \ldots + y_n$$

$$\bar{y} = \frac{\Sigma y_i}{n}$$

where $\bar{y}$ is the mean value of y.

The standard deviation s, is given by:

$$s^2 = \frac{\Sigma\left(y_i - \bar{y}\right)^2}{n-1}$$

The random component of the uncertainty of the mean (95 per cent confidence level) U_r, is given by:

$$U_r = st / \sqrt{n}$$

where t is the Student's t statistic for a significance level of 0.05 and n — 1 degrees of freedom.

These calculations are in accordance with ISO 2854 - 1976 « Statistical interpretation of data. Technique of estimation and tests relating to means and variances ».

Note: In sections a and b, use of the Student's t statistic is made. If sets of n observations are independently drawn from a normally distributed universe, the Student's statistic

$$t = \sqrt{n}(\bar{y} - \mu) / s$$

where $\bar{y}$ and s are the mean and standard deviation already defined and μ is the mean of the infinite population.

In this case the t values will be distributed symmetrically about zero in a form dependent only upon the number of degrees of freedom involved. This distribution can be determined mathematically and provides the data for the published Student's t tables.

Using the tabulated Student's t values then the 100 (1 — α) per cent confidence level for μ is:

$$\bar{y} - U_r \leq \mu \leq \bar{y} + U_r$$

where the probability α is 0.05 in this document, thus the range ($\pm st / \sqrt{n}$) gives a 95 per cent confidence level for μ, assuming that the expected value of y is μ,. In this document the 95 per cent confidence level for the mean is called the random component of the uncertainty of the mean.

The participants in an intercomparison may also agree upon a higher level of confidence (for example 99 per cent), particularly in the case of laboratories with a high level of accuracy.

c) Calculations

A group of test points giving the meter factor or error of the comparison standard flowmeter(s) at the same nominal flowrate or Reynolds number should be processed and the results of the calculations tabulated under the following headings: test point numbers; run, batch or group number; mean; number of test points; standard deviation; Student's t statistic; and random component of uncertainty of the mean.

It should be clear from the tabulations in what order the data was obtained.

A log of the tests should be produced and should include details of all happenings occurring during the tests. Details of a water quality and density analysis should be included.

The results of the intercomparison tests should be presented in a form common to all the laboratories, and previously agreed by them. The agreed method can be in tabular or graphical form or in any suitable combination.

At the conclusion of the intercomparison tests when all calculations and necessary retests have been completed, the results from each of the laboratories should be, by agreement, either circulated to all the laboratories or sent to one nominated laboratory for analysis.

II.2 Analysis of results

In any experiment, there are unavoidable random errors which give a variability to the test results. The object of analysing the results is to decide whether a difference observed between the results of two laboratories is significant.

Thus an analysis should produce statistics which are measures of the variability of the comparison standards and the test facility being evaluated. One statistic should be a measure of the repeatability, that is a measure of the variability of results obtained from the one laboratory and by one or the same operators using the same equipment. Another statistic could be termed reproducibility and is a measure of the variability of results obtained from all the participating laboratories. This recommendation allows a great variety of design models. It is recommended that assistance is obtained from a competent statistician in designing a test to ensure that the design model is efficient in obtaining the maximum amount of information required from the minimum amount of test work necessary. This statistician should carry out the analysis of the test results and assist in their interpretation.

At the conclusion of the analysis, some questions which should be asked are:

a) are the test methods capable of yielding acceptable agreement among results from different laboratories ?
b) if the results are not acceptable, what is wrong with the test method ?
c) which laboratories are outliers and why ?

Although details of the analysis of the results are not given, instructions are given for the analysis of results obtained using the preferred design of test (see point 11.4 of this Appendix).

Preferably, a meeting should be called to study the combined results as prepared by the nominated laboratory, but if this is not possible the study should be arranged by correspondence.

The intercomparison of results may be performed in any agreed manner.

II.3 Presentation of results

Since the object of any intercomparison test is to establish confidence in the ability of a laboratory to perform water meter calibrations at stipulated accuracy levels, there are likely to be considerable pressures both metrological and commercial, involved in the presentation of the results of such a test series.

Publication in the literature or at conference may be agreed as being the preferred means of presentation and publication, but the final draft of any such report should be agreed in writing by all laboratories before submission for publication.

In the event of disagreement, one or more laboratories may agree to delete all reference to themselves from the report in order that the results of the intercomparisons of the other laboratories may be published.

II.4 An example of an interlaboratory design of test and analysis

II.4.1. Preferred design of test

A preferred test programme (using the test section shown in Figure 1) is given by way of example.

In this test section a flow straightener is installed between the two comparison standard meters. With this arrangement the downstream meter is presented theoretically with « ideal » flow conditions, that is stable, swirl free and with a symetrical velocity profile, while the upstream meter experiences the laboratory's normal flow conditions. In this design, the systematic errors due to adverse flow conditions may be estimated, by comparing the performance of the upstream with the downstream meter.

In each of the laboratories in turn, the meters are installed in their sub-test sections, initially in the order shown in Figure 1, that is meter A upstream, meter B downstream.

Five repeat test points are made to determine the meter error or calibration factor at each of a minimum of three agreed flowrates in turn (total to be a minimum of 15 test points).

The test rig is completely closed down and then the whole sequence is repeated (15 test points).

The sub-test sections containing the meters are changed about so that meter B is now upstream and meter A is downstream.

The whole of the initial sequence of tests is now repeated identically as follows: five repeat test points are made again at each of the three agreed flowrates in turn (15 test points).

The test rig is completely closed down, and then a further 15 test points, as described above, are taken.

This completes the programme of tests. The sequence is shown in tabular form below, for the minimum of 15 test points, distributed in the preferred manner.

Run number	Test point numbers	Flowrate	Meter position in direction of flow
1	1-5	a	A → B
2	6-10	b	A → B
3	11-15	c	A → B
	close down rig		
4	16-20	a	A → B
5	21-25	b	A → B
6	26-30	c	A → B
	change meter positions		
7	31-35	a	B → A
8	36-40	b	B → A
9	41-45	c	B → A
	close down rig		
10	46-50	a	B → A
11	51-55	b	B → A
12	56-60	c	B → A

II.4.2. Graphical presentation of results

A graphical presentation may be made in a number of ways. Within one laboratory results of meter A may be plotted against results of meter B, for each flowrate and repeat points, when the meters are in the upstream position. These results should be statistically independent of each other since they were recorded at different times. As such, the results may be subjected to analysis of variance techniques as described below. Another combination is the result of meter A in the upstream position and the result of meter A in the downstream position. This latter combination may be useful in evaluating the effectiveness of the flow straightener.

When graphically presenting results from all the laboratories, the same combinations may be used but it may be necessary to plot graphs for one flowrate only to clearly exhibit the differences between laboratories. A similar graph should be plotted for each flowrate. This restriction is necessary if there are differences in the results obtained at different flowrates.

The chosen pairs of results are used to prepare a graph in the following way. The graph is prepared by drawing the customary x-axis at the bottom of the paper and laying off on this axis a scale that covers the range of results for the x points. At the left, the y-axis is provided with a scale in the same units that includes the range of results reported for the y points. The chosen pairs of results are then used to plot the points.

A horizontal median line is drawn parallel to the x-axis so that there are as many points above the line as below it. A second median line is drawn parallel to the y-axis so that there are as many points to the left as to the right of this line. Any points obviously separated from all the others should not be used in determining the median lines and could be omitted from the graph so that better scales might be used (see Figure 2). Different symbols should be used for the unique identification of the results.

The intersection median lines divide the graphs into quadrants. Ideally, when only random errors are present, the points will be equally numerous in all quadrants (see Figure 2). This follows because plus and minus errors should be equally likely. The degree to which the data lie in a circular pattern about the origin or are distributed elliptically with the major axis at a slope of ± 1 quantifies the nature of the variation in the test rig and the comparison standard meters. Using Cartesian notation, the data lying in the first quadrant is systematically « high » relative to the best available estimate of the true values for each comparison standard meter error or factor, namely the coordinates of the median intersection. Similarly, points lying in the third quadrant are systematically « low ». In the second and fourth quadrants the points are inconsistent or are random since the points in those areas are « low-high » or « high-low » relative to the intersection of the medians. Figure 3 illustrates a plot showing systematic bias of the participating laboratories.

II.4.3. Analysis of results

The nominated laboratory should take all the data obtained during the inter-comparison tests including that of the originating laboratory's retest at the conclusion of the testing sequence. It should carry out an analysis which should then be circulated to all participants for discussion.

The first question to answer from any analysis of results from this particular design of test is whether flow conditions are improved significantly by use of the flow straightener. The question has to be answered for each laboratory. For a graphical presentation, results of meter A in the upstream position are plotted against results of meter A in the downstream position. This procedure is repeated for meter B. The medians are plotted in the usual way. It then has to be decided if one particular position of meter gives a lower median value than the other for both meters. Any difference must be tested for significance.

The results obtained for the meters installed in series may be analysed to determine the extent to which the variance observed in each meter is attributable to the meters or to the test facility. This is achieved by calculating the correlation coefficient for the repeated meter results determined for a single flowrate.

The variance in the results for each meter may then be separated into :

a) that which correlates with the variance observed in the results of the other meter. This could be assumed to be due to some factor common to both of the meters in series, i.e. the flow through them produced by the test facility,

b) that which does not correlate with the variance observed in the other meter. This would then be attributed to the meters themselves as they perform in a particular laboratory. It could be expected that, given satisfactory meter performance, this uncorrelated portion of the total observed variation should be approximately a constant from test-to-test in each laboratory.

A comparison is then made of the results from all the laboratories. For one flowrate only, the results for meter A upstream and meter B upstream are plotted. This gives two points for each laboratory on each graph. This procedure is repeated for each flowrate giving three graphs. Three more graphs are produced for results from meter A downstream and meter B downstream. On these graphs, the medians are plotted as already described.

Each graph should be examined to decide whether repeat points for each laboratory are consistent. If, for instance, the repeat points for one particular laboratory are not within the estimated uncertainty for the laboratory, asked for in point II.1.1. of this Appendix, for a large percentage of the graphs, then it may be concluded that the particular laboratory's methods are inadequate or carelessly used. One or two inconsistencies may indicate mistakes (for example in reading of instruments or computation of results). Each graph should be examined with reference to the points made in point II.4.2. above.

An estimate of the standard deviation of the intercomparison test is made in the following Way. This estimate is made for each of the graphs plotted.

The difference together with sign is computed for the pairs of results used to plot the points giving Z_1, Z_2, Z_3 ... Z_n. The mean of these differences is then calculated and denoted by $\overline{Z}$. The standard deviation, S, of these data is then computed in the usual way.

$$S = \left\{ \frac{\sum_{i=1}^{n} \left(Z_i - \overline{Z}\right)^2}{n-1} \right\}^{1/2}$$

A circle of radius 2S centred about the median intersection should contain 95 per cent of the laboratories. Laboratories outside this circle should re-examine their test methods.

This computation is not exact but is provided for quick and easy use. More information may be obtained by a full statistical analysis of the results. However, the above analysis by the graphical approach should give sufficient information to draw conclusions.

Note: If only a few laboratories participate in this programme, then results for the different flowrates may be plotted on one graph provided the differences between the results obtained at different flowrates are not significant. If the results are different, the separate plots are superimposed matching the medians and all points are then transferred to the one graph. This procedure does not affect the computations for estimating the standard deviation.

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APPENDIX III
SUGGESTED DESIGNS FOR FLOW STRAIGHTENER

III.1 Purpose

As stated in Appendix I, point 1.2, the purpose of the flow straightener installed between the meters in series is to ensure that the downstream meter is unaffected by flow profile anomalies which may be present in the flow facility. It is expected that such anomalies in the flow profile may be due to any one (or to any combination) of several causes. By anomalies is meant any deviation from the proper flow profile, which is the one that can be theoretically expected to exist in the pipe given :

a) the pipe wall roughness,

b) the inertial and viscous phenomena,

c) the pertinent fluid properties, and

d) the position in the pipeline.

Examples would include:

— a skewed linear velocity profile (as might result from an upstream elbow or partially opened valve), and

— any distribution of swirl across the flow section (as might result from an upstream pair of elbows arranged « out of plane » or an upstream turbine meter).

A variety of flow straighteners have been designed to remove one (or both) of such anomalies. These devices invariably cause a decrease in the pressure as the fluid passes through the device thereby using pump energy thus affecting the pipeline efficiency. The various designs have shown a wide range of efficiencies in achieving their intended objectives.

Invariably, each type of flow straightener should be installed so that a straight length of constant diameter pipe separates the flow straightener and the meter downstream of it. In this length it is intended that the fluid flow attain a stable, symetrical and swirl free velocity profile before entering the meter. If this flow profile is not attained downstream of the flow straightener, then it is preferred that the flow enter the meter with a profile that is very repeatable considering the range of profiles that might enter the flow straightener. In this mode of operation, one would calibrate as much piping normally installed upstream of the flow straightener as was feasible, the flow straightener, the intervening straight length of pipe, the meter, and any pertintend downstream meter tube. This should provide an enhanced level of assurance that the meter performance is not radically perturbed by flow profile anomalies.

The pressure loss characteristics of any type of flow straightener can be related to the characteristic flow velocity through the device. To reduce this pressure loss, it may be feasible to perform the flow correction in an enlarged pipe section. In this way the characteristic velocity and hence the pressure loss can be reduced.

III.2 Types of flow straightener

Examples of flow straightener designed to rearrange anomalous linear velocity profiles are typified by such arrangements as:

Tube bundles

These consist of various configurations of a number (between 3 and 30) of smaller, thin-walled tubes whose length is between 1/2 and 3 diameters of the pipe in which the bundle is installed. Typical configurations are shown in Figure 4. These tube bundles have been found to reduce swirl in the flow due to the effect of the small tubes blocking azimuthal or swirl components of fluid velocity. The effectiveness of tube bundles (and their pressure loss) increases as the diameter to length ratio of the small tubes approaches zero. As the fluid passes out of and from between the small tubes, mixing of these individual flows occurs with the result that fluid kinetic energy can be distributed across the flow cross-sectional area, thereby possibly removing anomalies such as skewed linear velocity profiles that may have entered the bundle. As the flow passes downstream toward the meter, fluid viscosity and any prevailing turbulence are the only remaining factors which can further remove any anomalies left in the flow before it reaches the meter.

Perforated plates

These consist of one or more (generally 3 or less) plates in which numerous small holes have been drilled in a variety of patterns. Typical configurations are shown in Figure 5. These plates are placed across the internal pipe area and successive plates are spaced streamwise by a length equal to the diameter of the pipe in which they are installed. These plates condition the increasing flow through the mixing action produced in the wake of each plate. To obtain sufficient structural rigidity in these plates, the porosity of the perforated plate is generally lower than that of the tube bundle. This generally causes a larger pressure loss in the fluid passing through the plate. Because the holes in the perforated plate generally have a diameter to length ratio approximating unity, the « tubular action » of blocking swirl velocity components is not a prominent feature of this type of flow straightener. Thus the perforated plate type of straightener has, in the past, been used to remove anomalies such as skewed linear velocity profiles in pipe flows. This removal, initiated by the mixing produced by the plates can be completed through the factors of fluid viscosity and any prevailing turbulence in the flow toward the downstream meter.

Zanker type

These consist of a combination of the perforated plate and the tube bundle type flow straightener. The Zanker type flow straightener is shown in Figure 6. In this arrangement the fluid passes through one of the holes in a perforated plate and then into a small tubular conduit aligned with the hole, in which tubular action phenomena can, depending upon the tubular dimensions, reduce the swirl components of the inlet velocity profile. By appropriately sizing the holes in the perforated plate, it is feasible to arrange a radial distribution of linear velocity in the outlet flow that approximates the proper one as described above. In this manner, the need for further correction of the outlet profile by the effects of fluid viscosity and any prevailing turbulence is reduced. It should be noted that the Zanker type flow straightener being a combination of the two previously described types is more complicated and expensive to construct.

Etoile (star) type

This type of flow straightener consists of a number (3-8) of radial vanes separated by equal angles, which extend from the pipe centre line to the pipe wall. These vanes vary in length from one-half to several diameters; a typical etoile type flow straightener is shown in Figure 7. The way in which this type of device corrects the flow is probably quite similar to that of the tube bundle. The vanes reduce the swirl components of fluid velocity depending upon the angular separation and streamwise length of the vanes. Downstream of the device the prevailing mixing of the flows out of the triangular conduits would tend to distribute fluid kinetic-energy across the flow section. In addition, the blockage to the fluid flow produced by the intersection of the vanes at the pipe centre line would further tend to radially distribute fluid kinetic energy so that the flow dowstream of the device attained a «flattened» profile. Depending upon the number, thickness, and streamwise length of vanes, the etoile type flow straightener could have very low pressure loss characteristics.

NBS type

This type of flow straightener is constructed as shown in Figure 8. This shape has resulted from a series of numerical computations of fluid flows through a variety of similar shapes and has been shown to give good conditioning performance. However, it is to be considered neither as an optimal design nor as a standard conditioner. The correcting action is based upon the fact that the flow is turned through a series of 90° bends, passes through a perforated cylinder, and then a last 90° turn to resume the original flow direction. Through this tortuous path and the mixing produced by the perforated cylinder and the divergence to the original flow cross-sectional area, a very repeatable flow profile is produced in which the swirl and skewness of the flow profile is considerably reduced.

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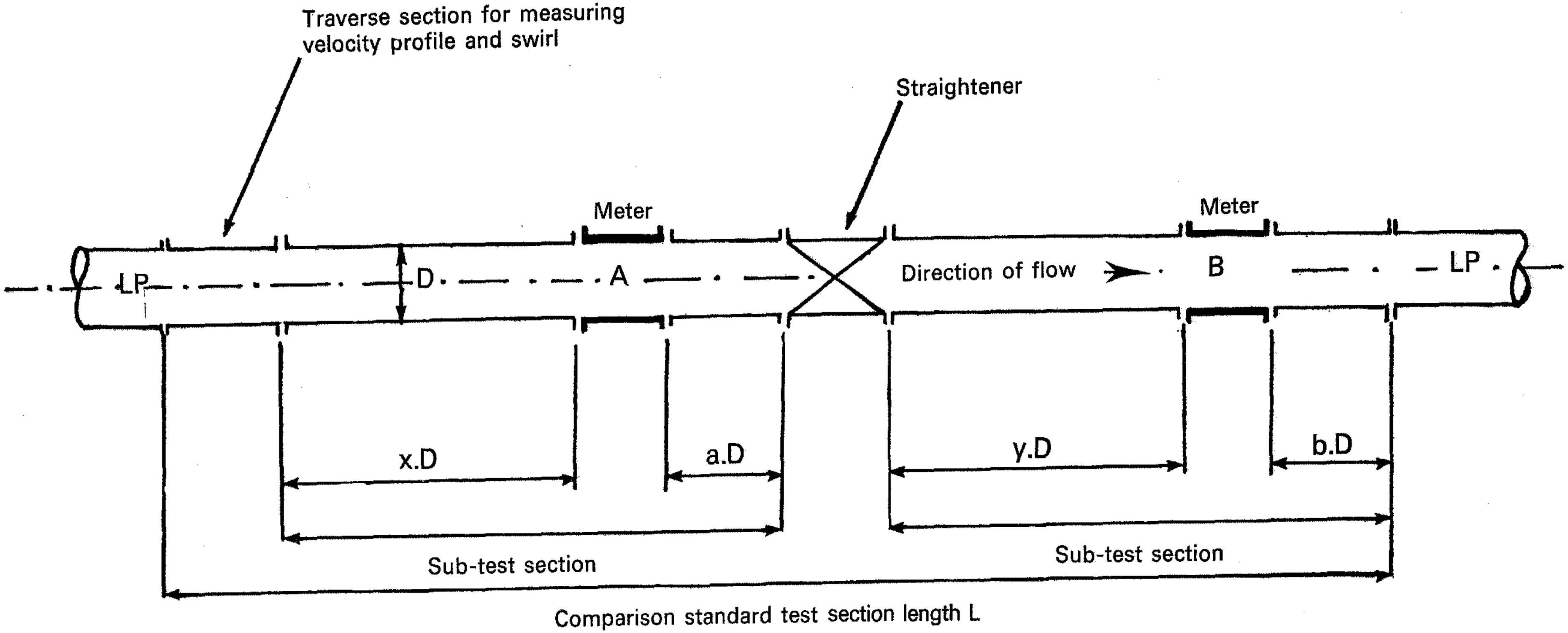

Figure 1

PREFERRED SCHEMATIC ARRANGEMENT OF COMPARISON STANDARD TEST SECTION

A, B : Similar meters
LP : Laboratory pipework

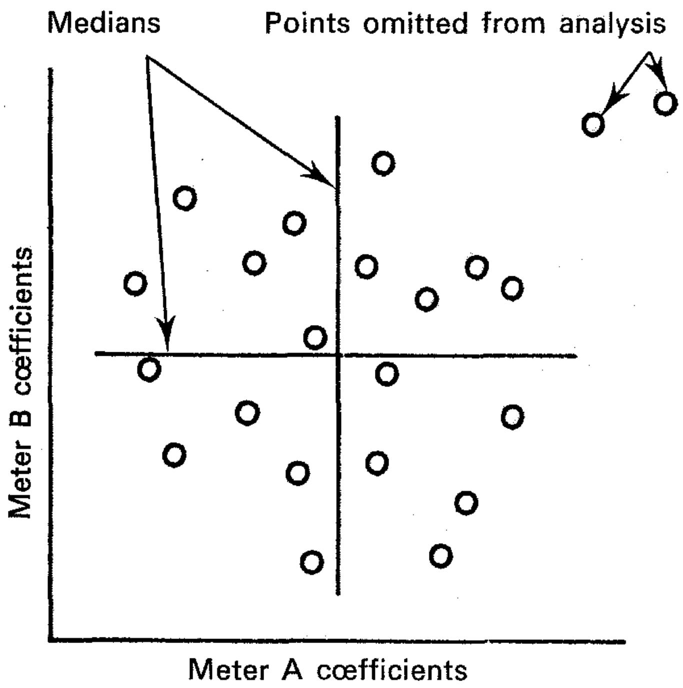

Figure 2

PLOT SHOWING IDEAL PATTERN

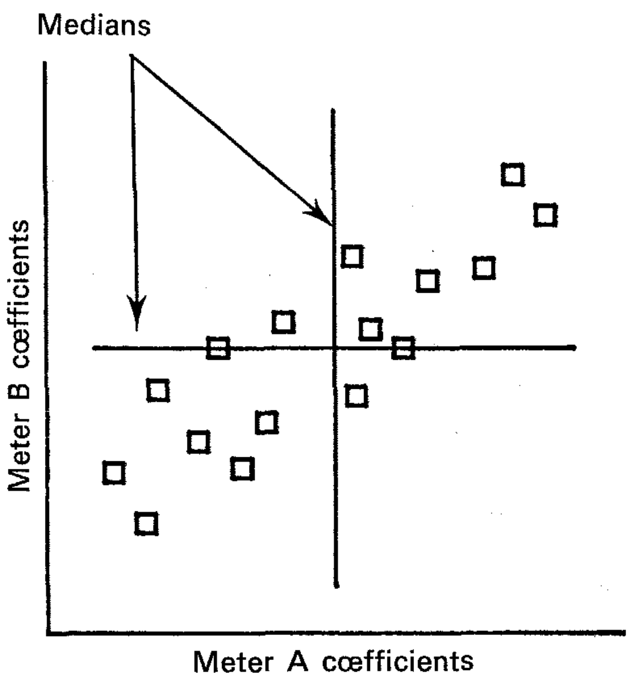

Figure 3

PLOT SHOWING SYSTEMATIC BIAS

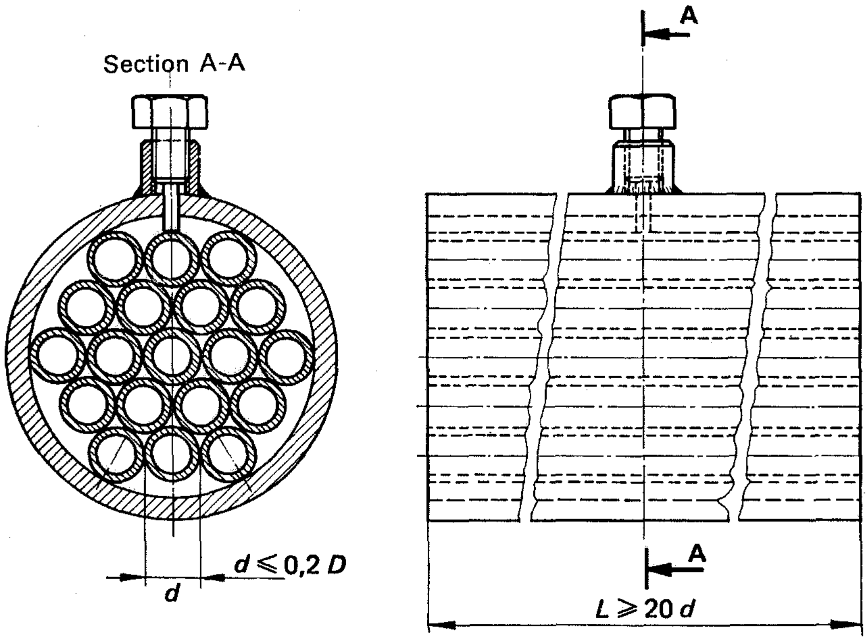

Figure 4

TUBE BUNDLE STRAIGHTENER

Note — In order to decrease the pressure loss the entrance of the holes may be bevelled at 45°.

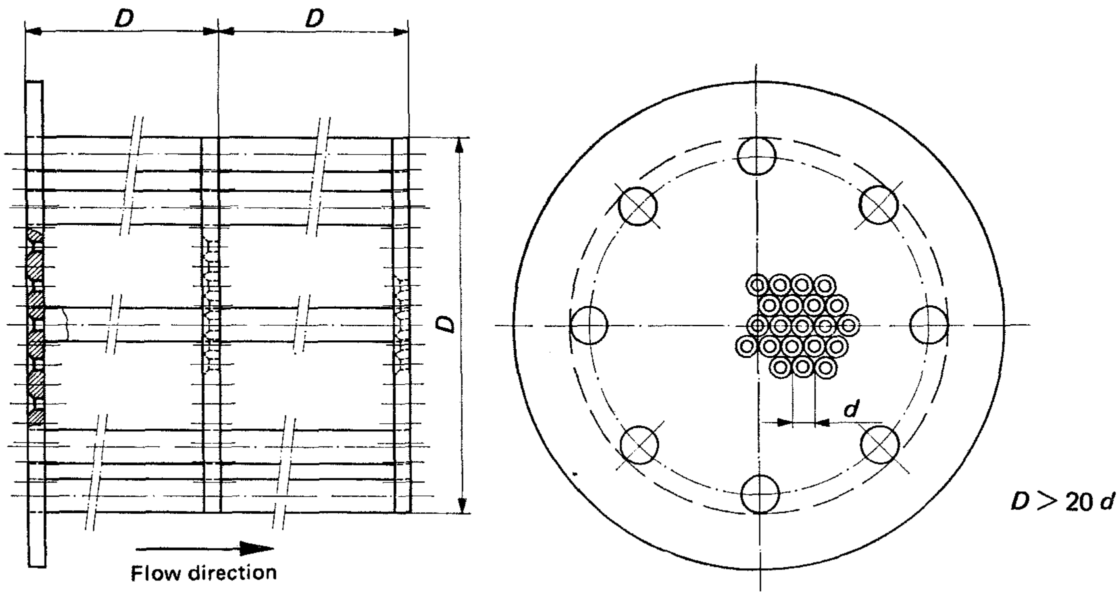

Figure 5

PERFORATED PLATE STRAIGHTENER

BIML note : the Figures 4, 5 and 6 are extracts from the International Standard ISO 5167-1980, Figure 1, reproduced with the authorization of ISO, the International Organization for Standardization. Copies of this standard may be obtained from the ISO Central Secretariat, Case postale 56, 1211 Genève 20, Switzerland.

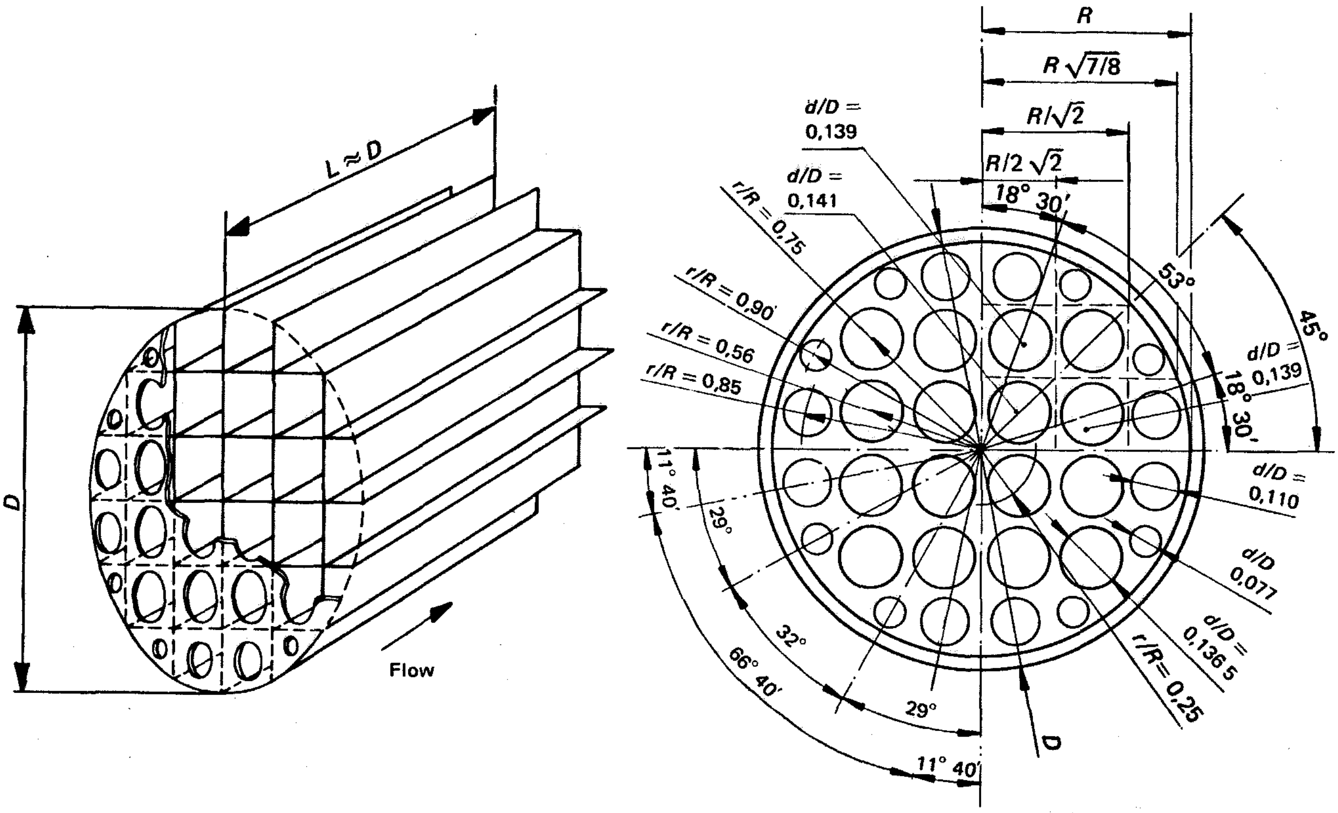

Figure 6
ZANKER TYPE STRAIGHTENER

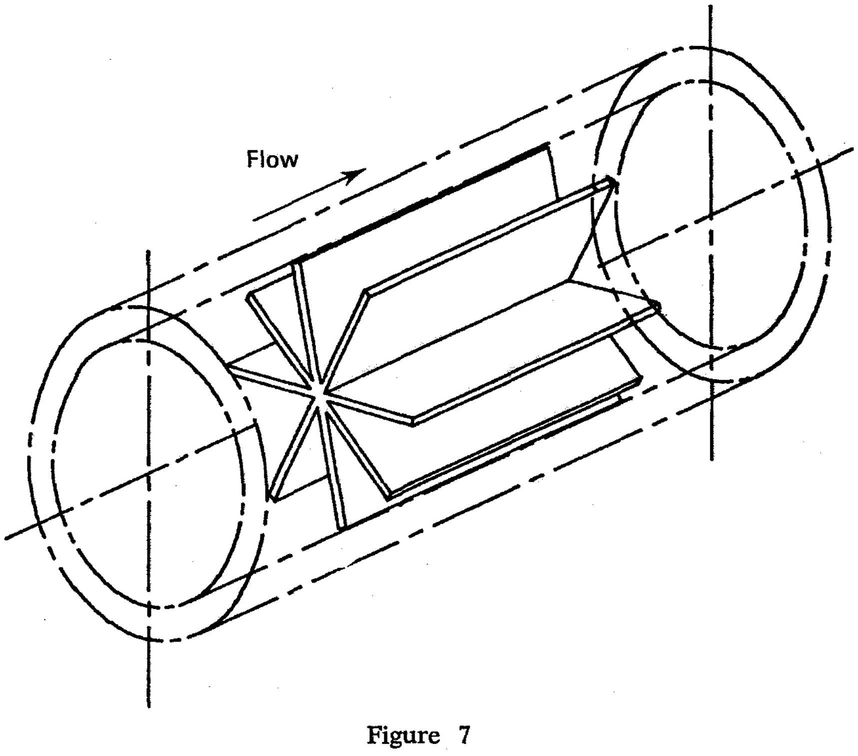

Figure 7
ETOILE (STAR) TYPE STRAIGHTENER

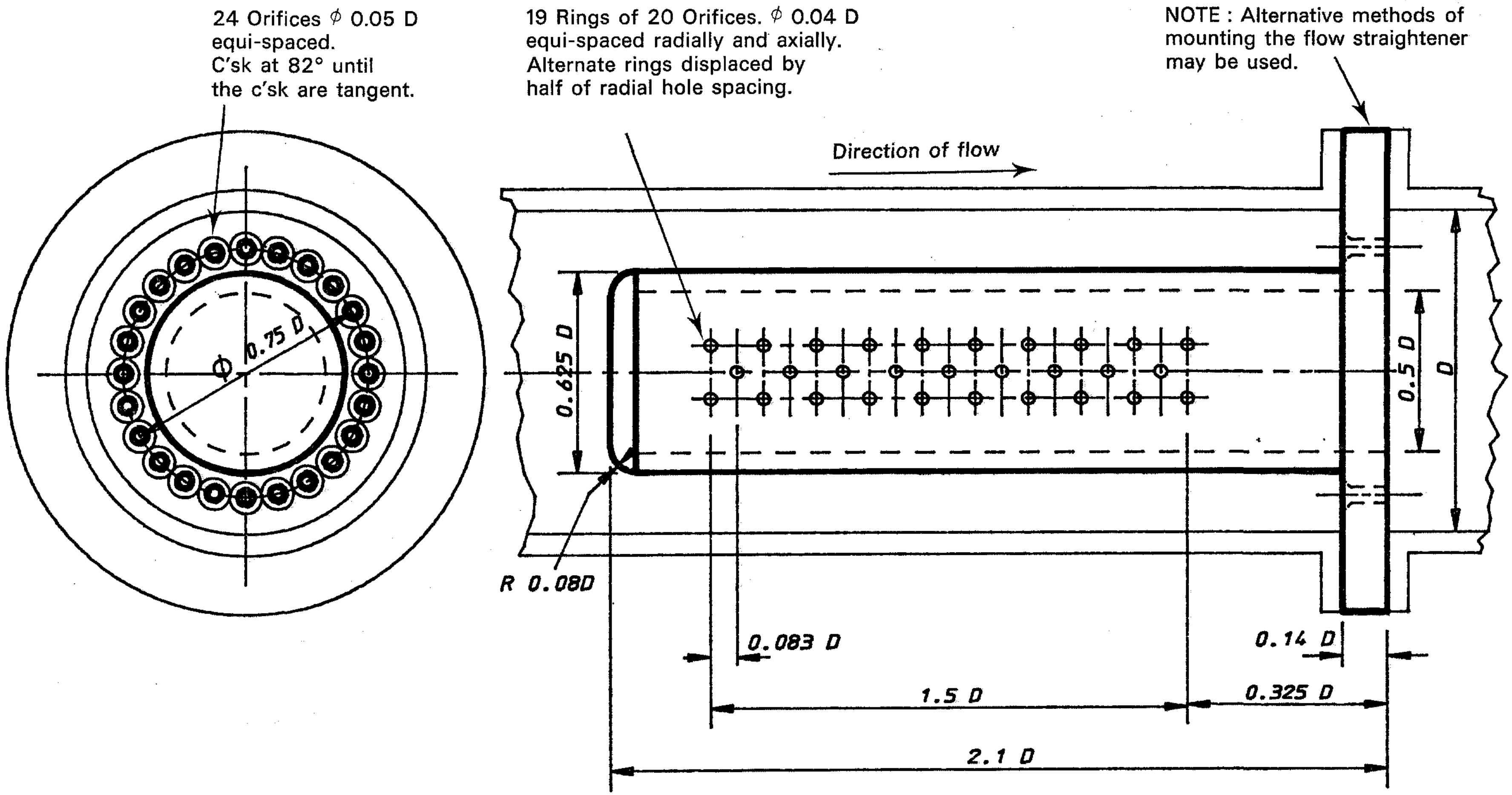

Figure 8

NBS FLOW STRAIGHTENER

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