ISA-RP31.1-1977

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Recommended Practice

Specification, Installation, and Calibration of Turbine Flowmeters

ISA-RP31.1 — Specification, Installation, and Calibration of Turbine Flowmeters

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Preface

(This preface is included for informational purposes and is not part of Recommended Practice RP31.1.)

This Recommended Practice has been prepared as part of the service of ISA toward a goal of uniformity in the field of instrumentation. To be of real value, this document should not be static, but should be subject to periodic review. Toward this end, the Society welcomes all comments and criticisms, and asks that they be addressed to the Standards and Practices Board Secretary, ISA, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, NC 27709, telephone 919-549-8411, e-mail: standards@isa.org.

The ISA Standards and Practices Department is aware of the growing need for attention to the metric system of units in general, and the International System of Units (SI) in particular, in the preparation of instrumentation standards. The Department is further aware of the benefits to USA users of ISA standards of incorporating suitable references to the SI (and the metric system) in their business and professional dealings with other countries. Toward this end, this Department will endeavor to introduce SI and SI-acceptable metric units as optional alternatives to English units in all new and revised standards to the greatest extent possible. *The Standard for Metric Practice*, which has been published by the American Society for Testing and Materials as ANSI-Z210.1 (ASTM E 380-76; IEEE 268-1975) and future revisions will be the reference guide for definitions, symbols, abbreviations, and conversion factors.

The ISA Standards Committee on Turbine Flowmeters, SP31, operates within the ISA Standards and Practices Department, L. N. Combs, Vice-President. The men listed below serve as members of this committee.

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The assistance of others who aided in the preparation of RP31.1 by answering correspondence, attending many committee meetings, and in other ways is gratefully acknowledged. In particular, the assistance of Robert L. Galley, previously of General Dynamics, McDonald-Douglas, Bechtel, United Nations, and presently with Hallanger Engineers and his committee who prepared ISA Recommended Practice RP31.1, and of George J. Lyons of Pratt & Whitney Aircraft and his committee who prepared drafts of Recommended Practice RP31.1 (not published) is acknowledged.

In addition to the SP31 committee members, the following have served as a Board of Review for this Document.

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Contents

1 Purpose

This document establishes the following for turbine flowmeters, especially those 2-inch diameter and smaller.

1.1 Recommended minimum information to be specified in ordering.

1.2 Recommended acceptance and qualification test methods including calibration techniques.

1.3 Uniform terminology and drawing symbols.

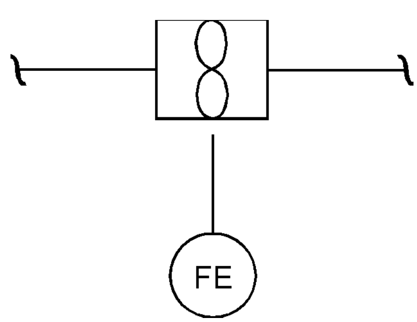
1.4 Recommended installation techniques.

2 Scope

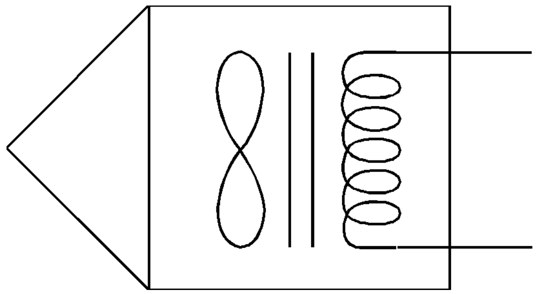
2.1 These recommendations cover volumetric turbine flowmeters having an electrical output. The flowmeters are used to measure either flow rate or quantity of liquids, and can be either self-generating or modulating. Their use in cryogenic fluids will require special considerations, which are not fully described herein.

3 Drawing symbols

3.1 The flow diagram symbol for a turbine flowmeter is shown below, in accordance with ISA-S5.1



3.2 The electrical diagram symbol for a turbine flowmeter is shown below.



4 Specifications

Terminology used is defined either in ISA-S37.1 or 4.3 Specific Terminology. An asterisk appears before these terms defined in ISA-S37.1; the terms defined in 4.3 Specific Terminology appear in italics.

4.1 Design characteristics

4.1.1 The following mechanical design characteristics shall be specified.

1) *Measured Fluids

The liquids to be in contact with the wetted parts, e.g., JP-4 fuel, hydrochloric acid, etc.

2) Configuration and Dimensions

a) For flared tubing (MS 33656) the nominal tube size, overall length, and equivalent fittings.

b) For flanged types the nominal pipe size, and length between flanges.

c) For male pipe-threaded flowmeters the nominal pipe size and overall length.

3) Mountings and Mounting Dimensions

Unless the process connection serves as a mounting, the outline drawing shall indicate the method of mounting with hole sizes, centers and other pertinent dimensions, including thread specifications for threaded holes, if used.

4) The weight of the flowmeter.

5) The following information shall be permanently marked on the flowmeter housing.

a) Manufacturer

b) Part or Model No.

c) Serial No.

d) Flow Direction

e) Nominal Tube or Pipe Size

4.1.2 Supplemental mechanical design characteristics

The following mechanical design characteristics shall be specified at the option of the purchaser.

1) Minimum and maximum temperatures

The minimum and maximum temperatures of the measured liquid, and of the surrounding environment.

2) Pressure

The maximum pressure of the measured liquid.

3) Speed

The maximum output frequency which the flowmeter can produce without physical damage.

4.1.3 Required electrical design characteristics

The following electrical characteristics shall be specified.

1) ***Excitation** (modulating type only).

Expressed as "___volts at___hertz."

2) ***Electrical output**

a) Output voltage

Expressed as "___volts" minimum peak-to-peak at any flow within the operating range.

b) Frequency at maximum rated flow expressed as "___Hz."

4.2 Performance characteristics

The pertinent performance characteristics of turbine flowmeters should be specified in the order shown. Unless otherwise stated, they apply at *Room Conditions, as defined in ISA-S37.1 and are expressed in SI units. (Equivalent units may be substituted.)

4.2.1 *Range

Expressed as "___to___meter^3 per second."

4.2.2 Linear range

Expressed as "___to___meter^3 per second."

4.2.3 *Sensitivity

The sensitivity (K factor) is expressed as "___cycles per meter^3." Often used as $\overline{K}$, which is the average sensitivity across the flow range of interest to the user. Average is used here in the sense of (Kmax + Kmin)/2.

4.2.4 *Linearity

The normal presentation of the calibration data is in cycles per meter^3 vs. frequency, which is the slope of a curve of flow vs. frequency. Linearity is then expressed as "±___% of the average sensitivity (K factor)." (See *Linearity* in 4.3 Specific Terminology.)

4.2.5 Pressure drop

The pressure drop across the flowmeter at maximum rated flow, expressed as "___differential pascals at ___meter^3 per second" when used with specific measured liquid.

4.3 Specific terminology

Actual flow: Refers to the actual volume of liquid passing through the flowmeter in a unit time as computed by applying all necessary corrections for the effects of temperature, pressure, air buoyancy, etc. to the corresponding readings indicated by the calibrator.

Air buoyancy: The lifting effect or buoyancy of the ambient air which acts during a "weighing" procedure with open gravimetric calibrations. This is caused by displacement of air from the measuring vessel during the calibration run. The standard air (50% R.H.) for correcting to "weights" in vacuum has a density of 1.217 kg/m^3 at 288.7 K and 1.013 250E+05 Pa. When "weighings" are made against "weights," the buoyancy force on these must also be considered. For brass "weights" the net effect of air buoyancy in air at standard conditions is about 0.015%. Exact values can be determined by procedures outlined in paragraphs 3059 and 3060 of API Standard 1101, 1960 Editions, and NBS Handbook 77, Volume III, Pages 671-682.

Apparent flow: The uncorrected volume flow as indicated by the calibrator.

Back pressure: The absolute pressure level as measured four pipe-diameters downstream from the turbine flowmeter under operating conditions, expressed in pascals.

***Calibration curve:** A graph of the performance of a turbine flowmeter, showing sensitivity as the ordinate and volume flow, flowmeter frequency, or frequency divided by kinematic viscosity as the abscissa, for a liquid of specified density, viscosity, and temperature.

Calibration system: A complete system consisting of liquid storage, pumps, and filters; flow, pressure, and temperature controls; the quantity measuring apparatus; and the associated electronic instruments used to calibrate turbine flowmeters.

Correlation check: A procedure whereby the performance and accuracy of a calibration system is checked against another calibration system using "Master Flowmeters" as the standards.

Density: The mass of a unit volume of a liquid at a specified temperature. The units shall be stated, such as kilograms per meter^3. The form of expression shall be: Density ___kg/m^3 at ___Kelvin.

Dynamic calibration: A calibration procedure in which the quantity of liquid is measured while liquid is flowing into or out of the measuring vessel.

Flow: the rate of flow of a liquid expressed in volume units per unit of time. Examples are: meter^3/second (m^3/s).

Flow straightener: A supplementary length of straight pipe or tube, containing straightening vanes or the equivalent, which is installed directly upstream of the turbine flowmeter for the purpose of eliminating swirl from the fluid entering the flowmeter.

Gravimetric: A descriptive term used to designate an instrument or procedure in which gravitational forces are utilized. However, the results or indications of such procedures are not necessarily influenced by the magnitude of the acceleration of gravity. See discussion on mass, weight, and weighing (5.4.1 (1) Mass, Weight, and Weighing).

Linear range of a turbine flowmeter: the flow range over which the output frequency is proportional to flow (constant K factor) within the limits of linearity specified.

Linearity of a turbine flowmeter: the maximum percentage deviation from the average sensitivity ($\overline{K}$) across the linear range.

Master flowmeter: Flowmeter used as an inter-laboratory standard in correlation checks of calibration systems.

Measuring vessel: The container in which the liquid metered by the turbine flowmeter during calibration interval is collected and measured. In a direct-gravimetric calibration system, this is a tank on a weigh scale and the exact dimensions are not significant. In indirect-gravimetric systems and volumetric systems the cross-sectional area or actual volume, respectively, must be known to a precision compatible with the desired accuracy of calibration.

Pressure drop: the differential pressure in pascals at a maximum linear flow measured between points four pipe diameters upstream and four pipe diameters downstream from its ends, using a specified liquid, and using pipe size matching the fittings provided.

The *sensitivity of a turbine flowmeter is designated by the letter "K" and is expressed in cycles per meter^3, under the following specified conditions:

1) Calibration Liquid
   - a) Density (kg/m^3)
   - b) Viscosity (m^2/s)
   - c) Downstream Temperature (K)
   - d) Back pressure (Pa abs)
   - e) Flow (m^3/s)

2) Line Configuration
   - a) Length of straight line upstream
   - b) Length of straight line downstream
   - c) Configuration of flow straightener

Reference flowmeter: Flowmeter used as a transfer standard for in-system and comparison calibrations of turbine flowmeters.

Static calibration: A calibration procedure during which the quantity of liquid is measured while the liquid is not flowing into or out of the measuring vessel.

Swirl: A qualitative term, describing tangential motions of liquid flow in a pipe or tube.

Thermal expansion: The increase in a volume of liquid caused by an increase in temperature.

Turbine, turbine supports(s), housing and transduction coils: the preferred names for the major parts of a turbine flowmeter.

Turbine flowmeter with an electrical output: a flow measuring device in which the action of the entire liquid stream turns a bladed turbine at a speed nominally proportional to the volume flow, and which generates or modulates an output signal at a frequency proportional to the turbine speed.

Two-phase: A fluid state consisting of a mixture of liquid with gas or vapors.

Vapor pressure: The pressure of a vapor corresponding to a given temperature at which the liquid and vapor are in equilibrium. Vapor pressure increases with temperature.

Vapor pressure, Reid: The vapor pressure of a liquid at 100°F (311K) as determined by ASTM Designation D 323-58, "Standard Method of Test for Vapor Pressure of Petroleum Products (Reid Method)."

Viscosity, absolute: The property by which a fluid in motion offers resistance to shear. Usually expressed as newton-seconds/meter^2.

Viscosity, kinematic: The ratio of absolute viscosity to density. The SI unit is the meter^2/s.

Weigh-scale: A device for determining either the mass or the weight of a body depending upon the apparatus and procedure employed.

Weighing: The process of determining either the mass or weight of a body depending upon the apparatus and the procedure employed.

Weight: The force with which a body is attracted by gravity. The newton is the unit force in this Standard.

Weights: Reference units of mass such as counterpoise "weights" used with lever balances and dead "weights" used in calibrating balances, scales, and pressure gauges.

4.4 Tabulated characteristics vs. test requirements

The table on the following page is intended for use as a quick reference for design and performance characteristics and tests of their proper verification as contained in this Standard.

5 Individual acceptance tests and calibrations

5.1 Calibration methods

Methods suitable for the calibration of turbine flowmeters may be classified as:

1) Gravimetric (direct or indirect)

2) Volumetric

3) Comparison

Each of these methods has advantages and disadvantages depending upon the liquid being metered and the type of operation. The gravimetric methods require that the density of the liquid be determined accurately to provide a basis for converting mass to volume. The effect of the gas added to the "weigh" tank in closed gravimetric calibrators must also be considered. The buoyancy factor for air, in open gravimetric calibrators, as a function of liquid density is shown in Figure 1. (See also 4.3 Definitions, air buoyancy.) The volumetric method is more direct in that conversions from mass to volume are not required.

The calibrator may be of either the open-type for use with low vapor pressure liquids only, or the closed-type in which a back pressure greater than atmospheric is maintained to prevent liquid loss from the measuring vessel by evaporation. Calibration methods are further classified as Static or Dynamic.

5.1.1 Static method

In this method, "weighing" or measurement of volume occurs only while the liquid is not flowing into or out of the measurement vessel. This method is capable of high accuracy under proper conditions and should include static checks against reference units of mass or volume traceable to the National Bureau of Standards.

5.1.2 Dynamic method

In this method, the measurement of volume or mass occurs while the liquid is flowing into or out of the measuring vessel. Although more suitable for many applications, it may involve dynamic errors which cannot be detected through static checks with reference units of mass or volume. Therefore, it is important that each new dynamic calibrator of a different type or size be checked carefully by correlation or other suitable means to prove that significant dynamic errors do not exist.

Two procedures for conducting a turbine flowmeter calibration are the running start-and-stop and the standing start-and-stop. The procedure which more closely duplicates the type of service anticipated in the application of the flowmeter should be selected whenever possible.

5.1.3 Running start-and-stop

The running start-and-stop requires that a reasonably constant flow be maintained through the flowmeter prior to, during, and immediately after the collection of the liquid in the measuring vessel. This is accomplished by using a stream diverter, whose motion is synchronized with the starting and stopping of the electronic counter.

		Design Characteristic		Verified During	
Characteristics	**Paragraph**	**Basic**	**Supplemental**	**Individual Acceptance Test**	**Qualification Test**
Configuration, Dimensions, Mountings and Mounting Dimensions	4.1.1 (2) through 4.1.1 (3)	x		5.3.1	Special Test
Weight	4.1.1 (4)				6.2
Identification	4.1.1 (5)	x		5.3.1	
Materials in contact with measured fluid	4.1.1 (1)		x		5.3.1
Minimum & Maximum Temperatures	4.1.2 (1)		x		6.3
Pressure	4.1.2 (2)		x		6.4
Speed	4.1.2 (3)		x		6.5
Output Voltage	4.1.3 (2) (a)	x		5.3.3	
Frequency	4.1.3 (2) (b)	x		5.3.4	
Linearity	4.2.4	x		5.3.4	
Sensitivity (K factor)	4.2.3	x		5.3.4	
Linear Range	4.2.2	x		5.3.4	

5.1.4 Standing start-and-stop

This procedure requires that a "no-flow" condition exist at the flowmeter prior to the beginning and at the end of the calibration run and that at least 95% of the total throughput be at the desired flow. This is accomplished by using solenoid valves synchronized with the action of the electronic counter.

5.2 General precautions

General precautions which should be considered in the design of a calibration system for turbine flowmeter include the following:

5.2.1 System piping

The piping between the flowmeter and the measurement vessel should be short, of small volume compared to the measured volume and designed to eliminate all air, vapor, and temperature gradients. It should be constructed to assure that all of the liquid and only that liquid passing through the flowmeter is measured.

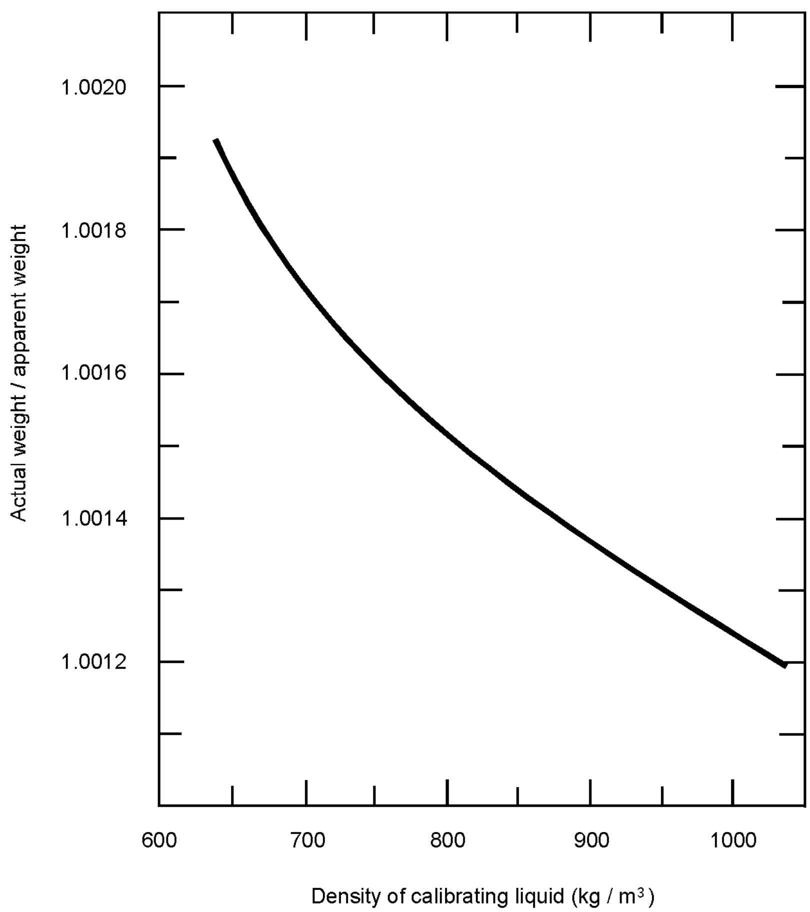


Figure 1 — Air buoyancy factor for standard air of (1.217 kg/m^3)

5.2.2 Throttling or flow control

Throttling or flow control valves should be located downstream of the flowmeter to reduce the possibility that two-phase flow may occur within the flowmeter under test. When this is not practical, a back-pressure regulator or similar device should be installed downstream to maintain the required back pressure.

5.2.3 Leak indicators

Positive methods, visual if possible, should be provided to assure that shut-off valve action is positive and that no leakage occurs during the calibration interval.

5.2.4 Measuring vessel capacity

The minimum permissible capacity of the measuring vessel is dependent upon the precision required of the calibration procedure and the resolution of the readout and the flowmeter under test.

5.2.5 The liquid used in performing a calibration should be the same as that with which the flowmeter is to be used in service, and the operating conditions should be duplicated.

5.2.6 A substitute calibration medium may be employed when it is impractical to use the operating liquid. The kinematic viscosity and specific gravity of this liquid should be within 10% of those of the operating liquid. The lubricity of a liquid cannot be as well defined as viscosity and specific gravity, but this parameter should be considered when using substitutes, and should be duplicated as closely as possible.

5.2.7 Filtration shall be provided to protect the flowmeter against damage or malfunction from foreign matter. The degree of filtration required is a function of flowmeter size. A 50 micron or less filter should be employed for general usage on a calibration stand where various size flowmeters are to be calibrated.

5.2.8 Install the flowmeter as indicated by the flow direction arrow marked on the flowmeter.

5.2.9 If flow straighteners or straight sections of pipe are used as an integral part of tile flowmeter service installation, the calibrations shall be performed with the same configuration. If the flowmeter must be used immediately downstream of pipe elbows or other swirl-producing pipe fittings, the calibration should be performed with the same plumbing configuration, but this arrangement does not guarantee a good calibration.

5.2.10 The flowmeter shall normally be calibrated in a horizontal position with the transduction element vertically upward since this is the usual attitude for service installations. However, when the service installation is other than horizontal, a difference in axial thrust balance may cause a change in the calibration factor. The transduction element orientation may also cause an error due to the relationship of magnetic drag and gravitational forces in some types of flowmeter. If these effects are not known to be negligible for the flowmeter being used the unit should be calibrated in the attitude in which it will be installed. When a flowmeter is equipped with two or more transduction elements, the flowmeter must be calibrated with all such elements installed.

5.3 Calibration and test procedure

Results obtained during the calibration and testing shall be recorded on a data sheet in 7 DATA PRESENTATION. Calibration and Testing shall be performed under *room conditions as defined in ISA-S37.1 unless otherwise specified.

The definitive paragraph under 4 SPECIFICATIONS is listed beside each of the parameters for which the test results are to be compared.

5.3.1 The flowmeter shall be inspected visually for applicable mechanical characteristics of 4.1.1 Required Mechanical Design Characteristics:

Configuration and Dimensions	4.1.1(2)
Mounting and Mounting Dimensions	4.1.1(3)
Identification	4.1.1(5)

By the use of special equipment or by formal verification of production methods and materials used, it can be determined that the materials are compatible with the measure liquids specified in 4.1.1(1).

5.3.2 The flowmeter shall be "run-in" for a period of at least five minutes at a reasonable flow prior to calibration.

5.3.3 During the run-in period, the peak voltage output shall be measured and recorded at the rated minimum and maximum flow. The wave shape of the output signal shall also be observed on a cathode-ray oscilloscope to check flowmeter for malfunctions.

5.3.4 The number of calibration points shall not be less than five and should include the minimum and maximum flow as specified by the manufacturer.

The number of runs at each calibration point shall not be less than two and shall be taken with the flow increasing and decreasing. The sensitivity, linearity, and linear range are determined from this data.

5.3.5 The back pressure shall be measured and should preclude a change in the calibration factor due to two-phase conditions. This pressure shall be measured four pipe-diameters downstream of the flowmeter. The required back pressure may be determined by specific tests, (8.3.1 Liquid Pressure), but in the absence of the exact data it may be set at a pressure equal to the sum of the vapor pressure of the liquid at the operating temperature plus three times the measured pressure drop across the flowmeter.

5.3.6 The temperature of the calibrating liquid at the flowmeter should be measured approximately four pipe-diameters downstream. If it is necessary to install the temperature sensor upstream of the flowmeter, it should be installed one pipe-diameter upstream of the straightening vanes of a supplementary flow straightener. In all installations, the temperature sensor must be immersed to a sufficient depth to minimize thermal conduction error.

5.3.7 The total number of cycles accumulated for each calibration point is dictated by the flow measurement accuracy requirement. Since the usual electronic counter has an inherent error of ±1 cycle, a sufficient number of cycles should be accumulated to make that error negligible.

5.3.8 The total count method does not require that flow be maintained absolutely constant when calibrating in the region in which the calibration factor is essentially independent of flow. Variations in flow of ±4% should not introduce significant error. However, in the laminar and transition regions, the calibration factor is affected significantly by both flow and liquid viscosity. Thus, in calibrating in these regions, flow should be maintained constant to ±1% or better; or the duration of the calibration run as well as the total pulse count should be measured, so that the exact average frequency existing during the run can be determined.

5.3.9 All gravimetric calibration methods require an accurate basis for converting mass to volume. The density of the liquid at the flowmeter temperature and pressure, should be determined to an uncertainty of ±0.05% or less. The effect of air buoyancy must also be considered (Air Buoyancy in 4.3 Specific Terminology).

5.3.10 Correlation of calibration system with NBS

1) The National Bureau of Standards, or suitable calibration facilities which maintain current correlation checks with NBS, may be used as reference calibrating laboratories. To promote flow calibration standardization and agreement, the National Bureau of Standards maintains facilities for the calibration of flowmeters at the following maximum flows.

Hydraulic & Lubricating Oils	30 GPM (1.9 E-03 m^3/s)
MIL-F-7024A, Type II	200 GPM (1.3 E-02 m^3/s)
Water	9000 GPM (5.7 E-01 m^3/s)

2) Correlation checks shall be made using flowmeters of proven repeatability as transfer standards. These are termed "*Master Flowmeters*" as defined above, and shall have supplementary flow straighteners connected directly upstream.

3) Identical calibration liquids and flow shall be agreed upon and used at both the reference facility and the user's calibration facility during the correlation check.

4) To the extent that the reference facility permits, it is suggested that no less than three nor more than five flows covering the full range of each measuring vessel in the user's system be selected as calibration points.

5) The number of test runs at each calibration point shall be 8 to 10. The allowable standard deviation of the repeat observations shall be set by agreement between the user and the reference facility.

6) The *Master Flowmeters* may be used to check the errors of the user's calibration facility periodically as necessary and must be submitted to the reference facility for recalibration when significant shifts in their performance are suspected.

5.4 Specific calibration systems

5.4.1 Gravimetric systems

1) Mass, weight, and "weighing"

In the calibration and application of liquid flowmeters, it is essential that a definite distinction be made between mass and weight. This is especially true in the aeronautical and aerospace industries, with their exacting requirements, where operations are frequently conducted under conditions in which the acceleration of gravity does not have a constant value. Mass, as used herein is a direct measure of the quantity of matter. Weight will be used only as a measure of the force with which a body is attracted by the acceleration of gravity, never as a measure of the quantity of matter.

In this document, the selected unit for mass is the kilogram. This unit is used as a direct measure of the exact quantity of matter in a body. So long as no material is added to nor taken from the body its mass remains constant and is independent of all ambient conditions including the acceleration of gravity.

The selected unit of force herein is the newton. Force will only be used as a measure of pressure or weight, never as a measure of the quantity of matter. The use of the local gravitational conversion factor will be required in computing weights as:

Weight = (kg)(g) = newtons

where kg is mass and g is the local acceleration of gravity. "Weighing" is the process of determining either the mass or weight of a body depending on the apparatus employed. Weighing on a lever balance is a comparison between an unknown mass and selected standards of mass (commonly called "weights"). Effects of variations in the acceleration of gravity are self-negating and the mass, not weight, of the unknown is determined directly. In precise work spring or load cells are usually calibrated at their place of installation with standard units of mass. Thus, these scales also read out directly in mass if they have been so calibrated. See NBS Handbook 77, Volume III, "Design and Test of Standards of Mass," page 615-706 for a detailed discussion of Mass and Weight, and Air Buoyancy.

2) Component errors

The individual components which are suggested in this section are based on the premise that the uncertainty of calibration is to be no greater than 0.5% of flow. When the desired uncertainty differs materially from this, the individual components should be modified accordingly.

a) "Weights"

Scale counterpoise "weights" for the gravimetric calibrators shall conform to the tolerances for Class C Commercial Test Weights as stated in Circular 3 appearing in Volume III, Handbook 77 of the National Bureau of Standards, the acceptance tolerances (applicable to new or newly adjusted "weights") being one-half the tabular tolerances.

b) Weigh scale

The weigh scale shall be installed and its ratio and sensibility reciprocal checked in accordance with NBS Handbook 44 - 2nd Edition. The ratio test shall be performed with certified test weights applied in approximately equal increments throughout the nominal capacity range of the scale under conditions of both increasing and decreasing loads. It is suggested that the performance of the scale be such that the uncertainty in weighing will not exceed ±0.05% of the smallest net batch sample to be collected during a calibration run.

c) Pressure sensing devices (indirect gravimetric calibrator)

The intervals between electrical contacts in the manometer type pressure sensing instrument shall be measured by means of shadowgraph, cathetometer or other optical techniques.

Consideration must be given in the application of these techniques to the possibility of error introduced by image distortion when viewing the contacts through the transparent manometer wall. The measurements shall be made in a temperature controlled area, and at the same temperature as that to which the manometer is normally exposed. Other pressure sensing devices such as differential pressure transducers shall be calibrated at the location of the standpipe, with precision "Deadweight" testers omitting corrections for the local value of g normally applied, so that the standpipe will measure in units of mass rather than weight. Further, they shall be temperature compensated or temperature controlled. The uncertainty in pressure measurement should not exceed ±0.05% of the smallest increment of pressure used in calibration run.

d) Temperature measurement

The instrument used for measurement of liquid temperature at the flowmeter shall have sufficient sensitivity and accuracy so that this temperature measurement error will not affect the density determination by more than ±0.025%.

e) Density determination

The hydrometer, pycnometer, or other density determining instrument shall have sufficient sensitivity and accuracy to determine liquid density to within ±0.05% of actual. The temperature of the liquid at the time of density determination must be precisely known so that proper corrections can be applied to obtain the density at the operating temperature of the flowmeter.

f) Viscosity determination

Viscosity measurement uncertainties within ±5% of actual are adequate when calibrating in a flow region in which the calibration factor is essentially independent of flow, otherwise the viscosity should be determined to an uncertainty of ±2% of value.

g) Pressure measurement

Pressure measuring instrumentation used to determine operating pressure level of the flowmeter and the pressure drop across it should be within ±5% of actual when calibrating with conventional liquids at pressure levels where compressibility is not a factor. When compressibility is significant the pressure measurement shall be made with sufficient accuracy so that this measurement uncertainty will not affect the density determination by more than ±0.025%.

3) Typical flow diagrams

Figures 2 through 7 show the operation of typical calibration systems. Readings from all systems must be corrected for air buoyancy and the further precautions described above must be observed in each case.

In the static methods, the flow is first adjusted to a suitable value with the flow regulator (FCV). After draining the weigh tank and obtaining the tare weight, the diverter or solenoid valve is opened for an appropriate time, during which the counter records the flowmeter pulses.

In the dynamic methods, the counter is actuated by the weighing system (WI, WC), operating between selected low and high weight settings. Operation must be compensated for dynamic effects of liquid entering or leaving the weigh tank, and for any inertia in operation of weighing device. The pressurized system must also be corrected for the weight of the pressurizing gas.

In the indirect gravimetric calibrator, Figure 6, gravity corrections need not be applied providing that the mass of the measured liquid is balanced by the mass of mercury in the manometer used to measure differential pressure. Contacts on the manometer start and stop the counter to establish the calibration interval.

The mass of liquid passed through the flowmeter is:

$$M = k\left(\frac{\rho_l}{\rho_l - \rho_a}\right) A_l \times H_m\left[\rho m\left(1 + \frac{A_t}{A_w}\right) - \rho_a\left(1 + \frac{A_t}{A_l}\right) - \rho_l\left(\frac{A_t}{A_w} - \frac{A_t}{A_l}\right)\right]$$

H_m= Change in elevation of manometer meniscus, i.e., distance between contacts used, in meters.

ρm = Density of manometer liquid at manometer temperature, kg/m^3.

ρ_a = Density of atmospheric air, which is assumed constant at 1.2250 kg/m^3.

ρ_l = Density of calibrating liquid in standpipe, kg/m^3.

A_l = Cross section area of standpipe, in mm^2.

A_t = Cross section area of manometer tube, in mm^2.

A_w = Cross section area of manometer well, in mm^2.

k = 10^{-9} m^3/mm^3

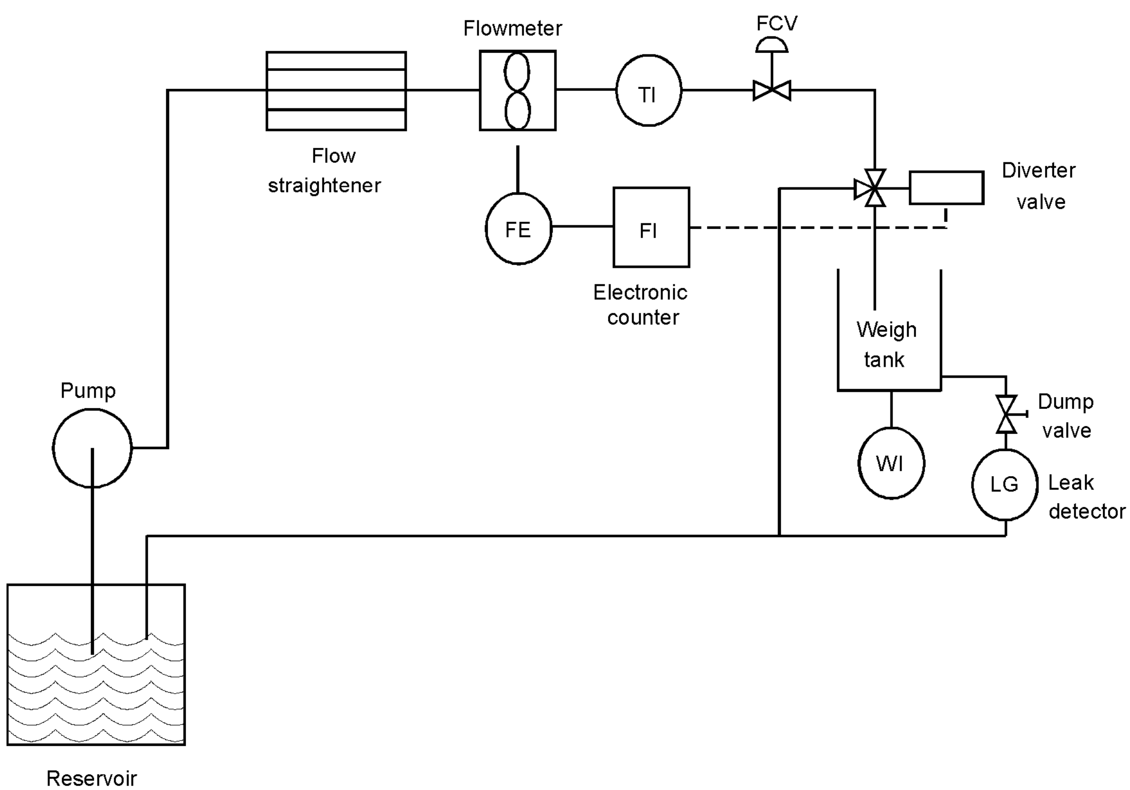


Figure 2 — Direct gravimetric, open, static calibrator — running start - stop

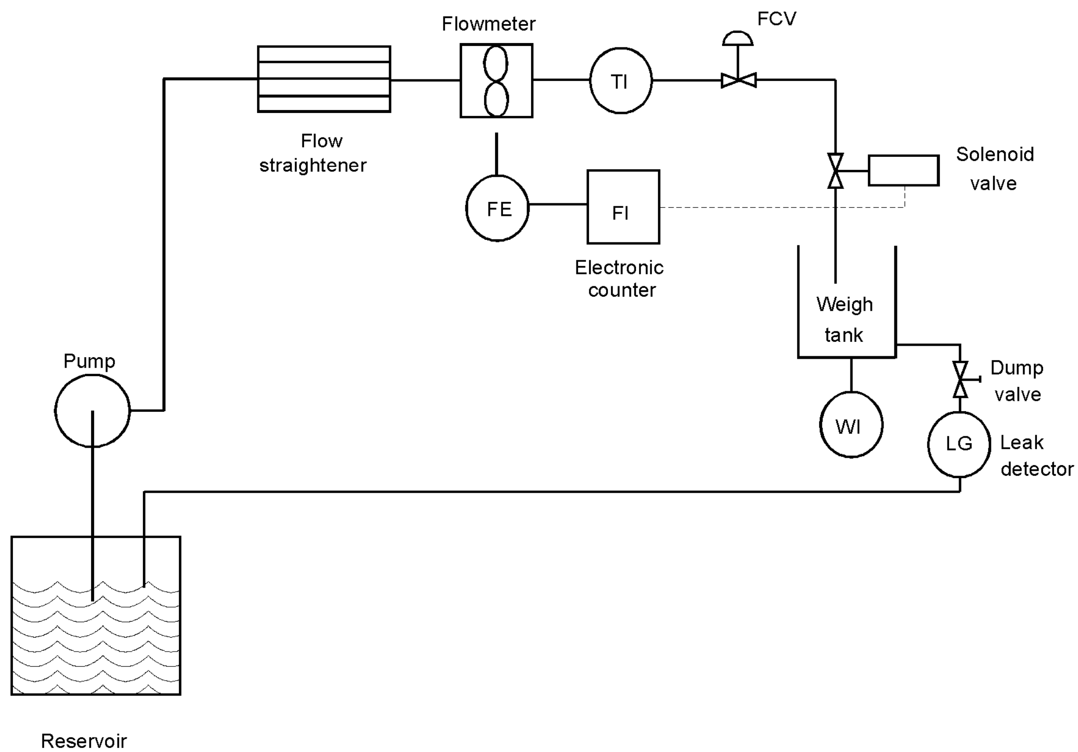


Figure 3 — Direct gravimetric, open, static calibrator — standing start - stop

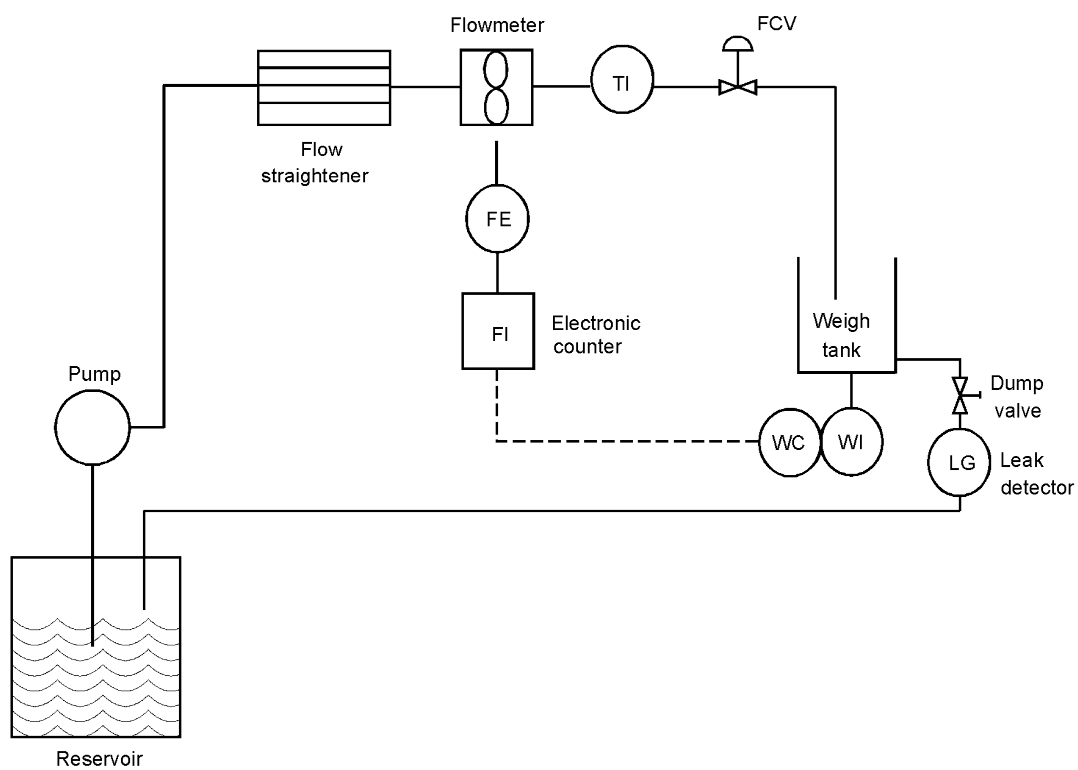


Figure 4 — Direct gravimetric, open, dynamic calibrator

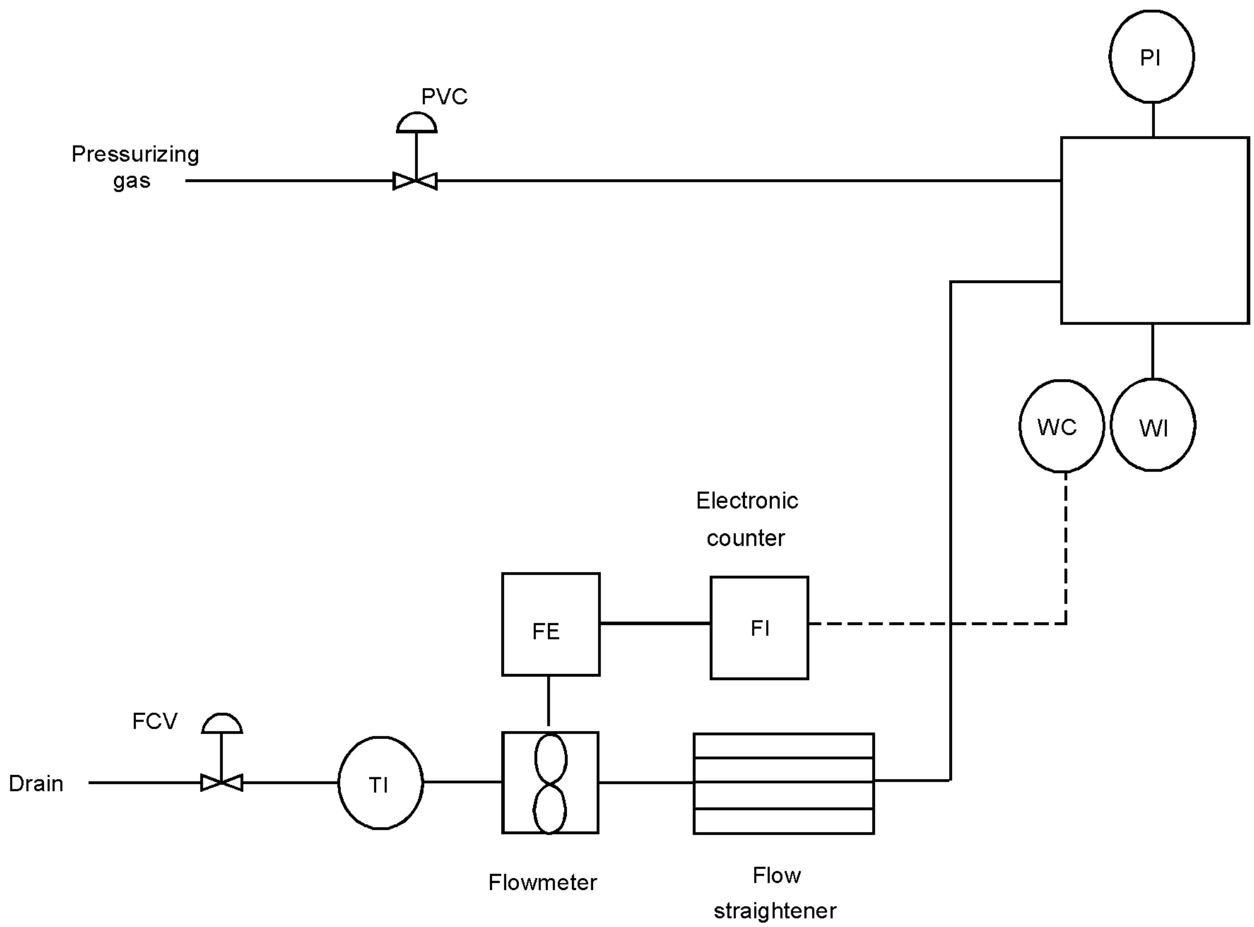


Figure 5 — Direct gravimetric, closed dynamic calibrator

Possible sources of error with this system are: (1) the rate of rise of the liquid in the standpipe and in the manometer must be constant during the counter period; (2) the standpipe walls must be allowed to drain completely before each calibration run; and (3) correction must be made for the thermal expansion of the standpipe, the measured liquid, and the manometer liquid.

5.4.2 Volumetric calibrators

In any of the systems described in 5.4.1 (3), a calibrated volume may be substituted for the weigh tank. In such systems, correction must be made for volume changes in the containers, and fluids with pressure and temperature.

1) Mechanical displacement calibrator

The system shown in Figure 7 is also called a "ballistic" or "piston" calibrator. It is particularly suitable for use with high-vapor-pressure liquids because it is a constant volume closed system. It is the only calibrator suitable for large flowmeters. The electronic counter is gated by the passage of the piston (usually a liquid-filled elastomer spheroid) across detectors at the ends of the calibrated section of the container.

This calibrator is widely used in the petroleum industry, and is fully discussed in API 2531 and APE 2534.

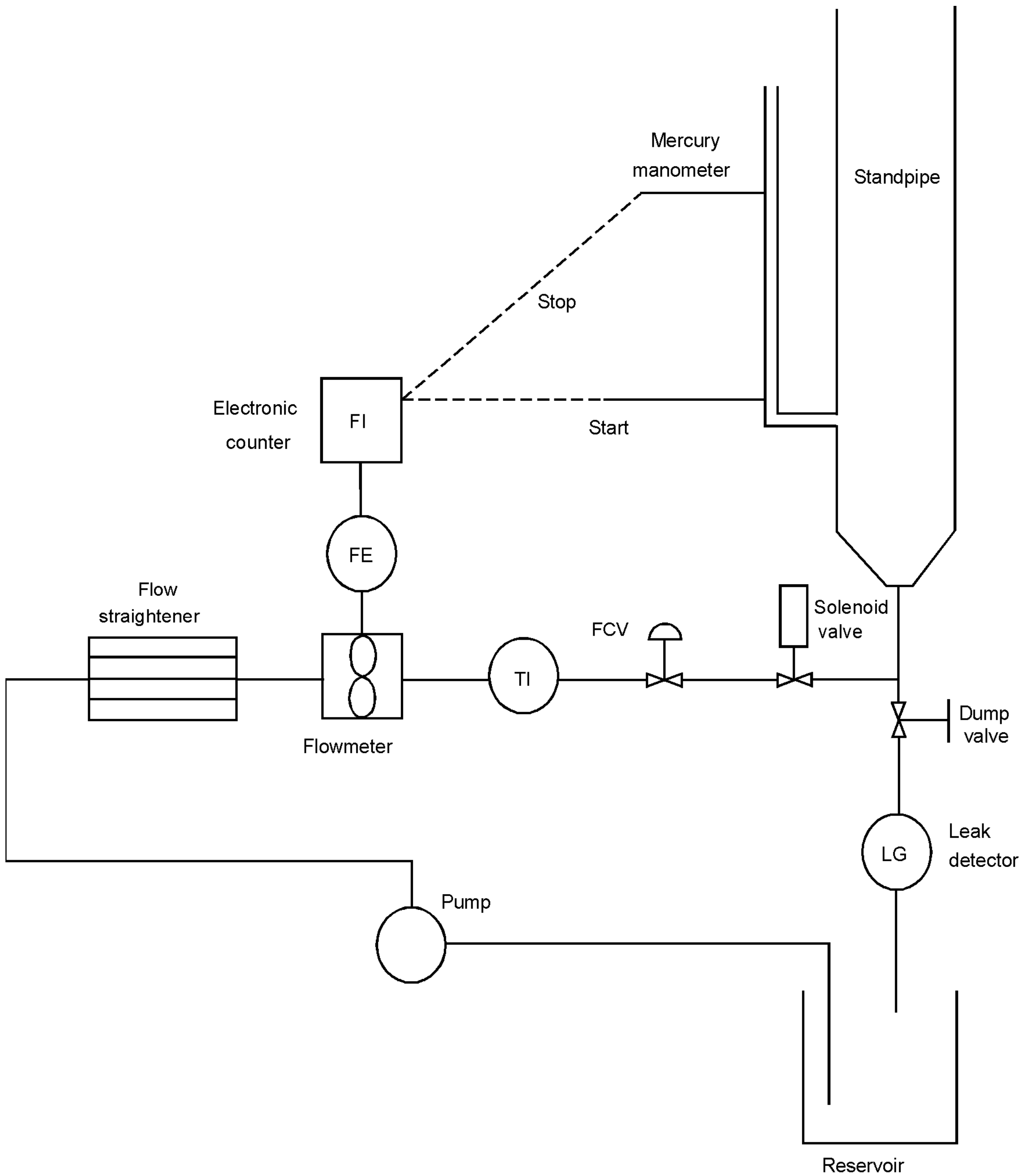


Figure 6 — Indirect, gravimetric, dynamic calibrator

5.4.3 Comparison calibration

This method requires a minimum amount of equipment and is convenient for routine calibration of turbine flowmeters. Since a secondary standard is employed in this technique, it should be recognized that the total uncertainty may increase. In operation, a reference turbine flowmeter is installed in series with the flowmeter to be calibrated and the proper steps taken to reduce pulsation and swirl at the inlet of both units. The flow points are set by the frequency output of the reference flowmeter and the flow is held constant using a frequency meter, electronic counter or cathode-ray oscilloscope for indication of flow variation.

Cycles per unit volume are used as the basis for the comparison of indicated quantity as follows where:

K_1 = cycles per meter^3 of reference flowmeter

K_2 = cycles per meter^3 of flowmeter being calibrated

f_1 = cycles per time "t" of reference flowmeter

f_2 = cycles per time "t" of flowmeter being calibrated

The time base of the two counters used should be synchronous. If the temperature of the liquid is different at the two flowmeters, then a correction must be made for the difference in density.

Then:

$$K_2 = K_1 \times \frac{f_2}{f_1} \times \frac{\rho_2}{\rho_1}$$

where: ρ_1 = density of liquid at reference

ρ_2 = density of liquid at flowmeter being calibrated.

NOTE: The comparison calibration method is strictly valid only when the reference flowmeter is being operated under the identical conditions, including flow, under which it was calibrated by a primary method. It should be realized that the operation of this flowmeter at other conditions represents extrapolation of the data; the amount of the extrapolation being the extent to which the operating conditions deviate from the primary calibration conditions.

The reference flowmeter should be checked before and after a series of calibrations against either; a) a primary standard, or b) a master flowmeter to verify its repeatibility.

The reference flowmeter should be calibrated in accordance with 5.3 Calibration and Test Procedure and the check calibration should not deviate from the previous calibration by more than ±0.1%.

The reference flowmeter may be of the positive displacement type or other provided that the error requirements are met. Conversion of the output data may be necessary to effect the correlation noted above.

1) Frequency ratio calibration

Better precision can be achieved in certain calibrations by the use of frequency ratio methods. Similar turbine flowmeters are plumbed together in series with the usual flow straightening sections of pipe. These two flowmeters are calibrated simultaneously using one of the primary methods. During this calibration, the ratio of the frequencies of the two flowmeters is noted for each flow. When these flowmeters are used as reference flowmeters, if this ratio remains the same, it can be assumed that their calibrations have not changed.

In subsequent operation, these reference flowmeters and flow straighteners are installed in series with the flowmeter to be calibrated. The signals from the reference flowmeters are compared by a ratio counter that has a long counting time (20 to

30 s). The signal from the flowmeter under test is similarly compared with that from one of the reference flowmeter. In these comparisons the output of one referenced flowmeter is used as the "time base" for the other and later for the test flowmeter. This eliminates the need for a precise measurement of the counting intervals of separate calibrations. A less precise timer records the time during which the ratio count is determined. This technique is useful in several applications: two master flowmeters used as interlaboratory transfer standards can be used to check the calibration facility, with greater confidence, or a working flowmeter can be calibrated against a reference flowmeter with better precision as explained above.

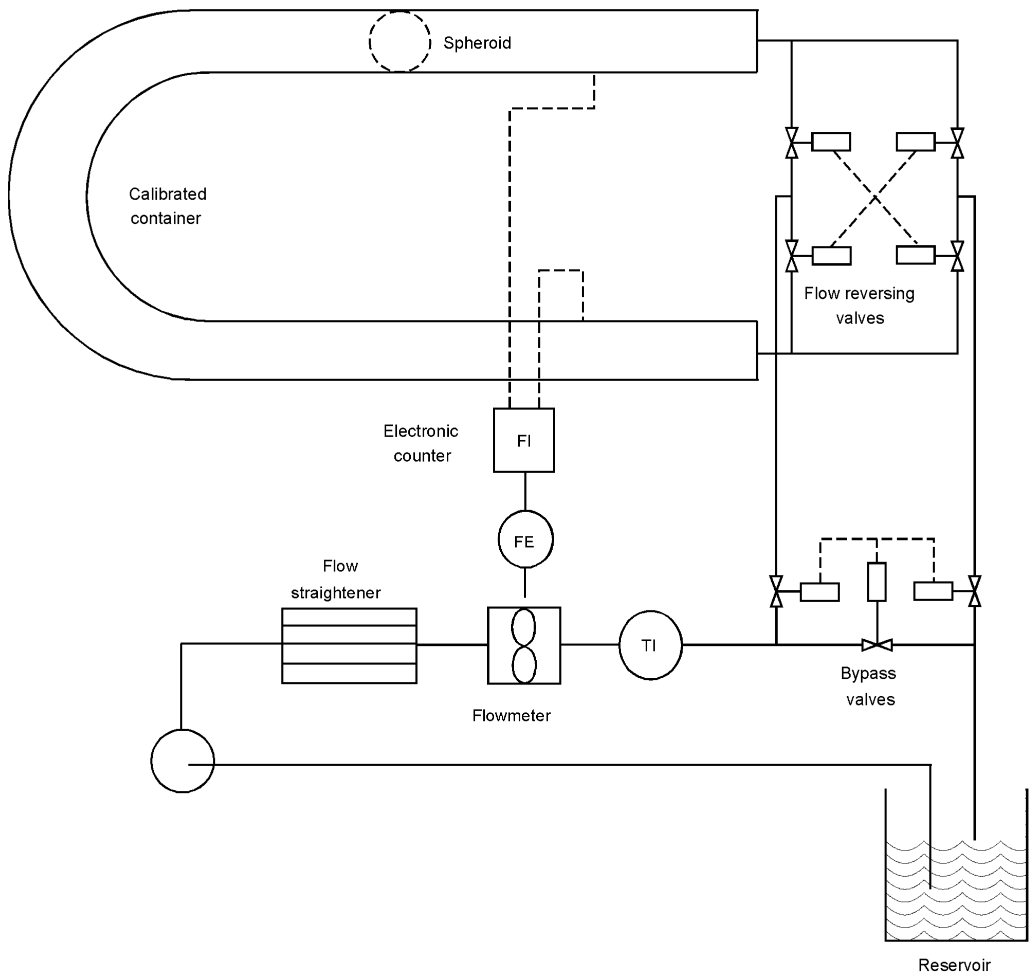


Figure 7 — Mechanical displacement volumetric calibrator

6 Qualification test procedures

Qualification tests shall be performed as applicable using the test forms of 7 DATA PRESENTATION as required. Upon completion of testing the form of Figure 8 shall be used to summarize all testing.

6.1 Initial performance tests

The tests and procedures of 5 INDIVIDUAL ACCEPTANCE TESTS AND CALIBRATIONS, individual acceptance tests and calibration, shall be run to establish reference performance during increasing and decreasing steps of 0, 20, 40, 60, 80, and 100 percent of range as a minimum.

6.2 Weight test

The flowmeter shall be weighed on an appropriate balance or scale to establish compliance with 4.1.1 (4).

6.3 Temperature test

The flowmeter shall be placed in a suitable temperature chamber. To establish compliance with 4.1.2 (1) Minimum and Maximum Temperatures, two calibration cycles shall be run at each combination of measured liquid temperature limits and environmental temperature limits specified therein.

NOTE: The temperature rating of the flowmeter may not in all cases be compatible with the vapor pressure of the measuring liquid used. Generally, the user is advised to test within the limitations of the intended measured liquid.

6.4 Pressure test

During the temperature test above, at the maximum measured temperature, the liquid pressure shall be raised to the pressure limit specified in 4.1.2 (2) Pressure.

6.5 Speed test

The flowmeter shall be operated at a flow which produces the maximum rotor speed specified in 4.1.2 (3) Speed, without regard to linearity.

7 Data presentation

A suggested format for recording calibration data is shown on Figure 8. This format is specifically directed toward the Direct Gravimetric Static Method but with modification could be used for all types of calibrators. Since the turbine flowmeter is a volumetric device, the calibration data should be presented in volume units. The standard format should be a plot of cycles/meter^3 vs. frequency. Cycles/meter^3 is designated by the letter "K." For convenience to the user, it is also correct to present the data in a number of other ways such as: meter^3/cycle, or kilograms/cycle. When a flowmeter is calibrated with a number of liquids with various kinematic viscosities, it is sometimes useful to plot the data as cycles/meter^3 ("K") versus frequency divided by the kinematic viscosity in meter^2/s.

TURBINE TRANSDUCER CALIBRATION TEST NO.___

DIRECT-GRAVIMETRIC METHOD

Location________________; Date___________________; Calibrator________________

Flowmeter Manuf.__________; Model_________________; Serial #_________________

Test Liquid: Type____________; Density________________kg/m^2 at_______________K.

Viscosity_______________m^2/s at________________K.

Back Pressure_________Pascals; Pressure Drop__________Pascals at___________m^3/s.

Electrical Output:Max:_______________mv rms at______________Hz.

Min:_______________ mv rms at______________Hz.

TEST MEASUREMENT DATA	Run 1	Run 2	Run 3
1. Nominal Frequency, Hz			
2. Transducer Temperature, K			
3. Density, kg/m^3			
4. Total count, cycles			
5. Time, s.			
6. Tare Reading, kg			
7. Gross Reading, kg			
8. Apparent Net, kg(7 - 6)			

CALCULATIONS

9. Air Buoyancy Factor

10. Actual Net, kg(8 x 9)

11. Actual Vo., m^3 (10/3)

12. K, cycles/m^3, (4/11)

13. Actual Freq., Hz (4/5)

14. f/v, (13 ÷ kinematic viscosity)

Operator:________________________

Figure 8 — Format for recording calibration data

8 Installation

8.1 Environmental considerations

A number of environmental conditions may affect the operation of a turbine flowmeter. Of these, moisture is the most common cause for malfunction. The electrical components should be waterproof to eliminate trouble from this source. The temperature of the flowmeter is largely determined by the temperature of the flowing liquid. However, the temperature of the transduction coil and connector may be influenced by the environment. Low temperatures do not usually cause malfunction, but high temperatures may result in failure of the insulation. Mechanical vibration will shorten the service life of a flowmeter and may also bias the data obtained. Magnetic fields in the proximity of the flowmeter or transmission cable may introduce spurious signals, if the circuit is not adequately shielded. Pulsation of the flow may produce errors or damage the flowmeter. Precautions should be taken to ensure that the operating conditions are within the limits set forth in the specification (4.1 Design Characteristics). Other special conditions such as a nuclear environment should be given consideration.

8.2 Piping configuration

The turbine flowmeter is affected by upstream and downstream line configuration. This is caused primarily by swirl of the flowing liquid and, therefore, upstream configuration is much more influential than downstream. Rules specifying a certain number of pipe diameters of straight line upstream and downstream, which have been determined for orifice-type flowmeters, are generally conservative when applied to turbine flowmeters. However, lacking specific tests to establish the validity of less conservative configurations, these rules should be applied. These rules are well treated in API-2534, Appendix C, and in ASME, "Fluid Meters - Their Theory and Application." Without such analysis, a minimum of 20 diameters upstream and 5 diameters downstream should be used. A flow straightener is effective in eliminating swirl, and the upstream rotor support of a turbine flowmeter acts, to some extent, as a straightener. The turbine flowmeter should be located with most of the available straight line upstream. Unusual downstream disturbances, such as a pump inlet, may require a straight line downstream or in extreme cases a downstream straightener may be necessary. Care should be taken not to allow piping to impose excessive stresses on the flowmeter housing.

8.2.1 Flow direction

Install a turbine flowmeter in accordance with the flow direction arrow or wording marked on the flowmeter.

8.2.2 Flow straighteners

Various designs of straighteners have been proposed. Tube bundles and sections of honeycomb have been found effective. In addition to effectiveness, the pressure drop and durability should be considered.

8.2.3 Attitude of flowmeter

Turbine flowmeters should be installed in the same position as they were calibrated, usually in a horizontal position (5.2.10). When installed in a position other than horizontal, a difference in axial thrust balance may cause a change in the calibration factor. For small flowmeters, the angular position of the transduction coil should be similarly considered.

8.2.4 Filtration

The measured liquid should not contain solid particles having a maximum dimension more than half the clearance between turbine blade tip and bore of the housing. The service life of the flowmeter will be extended by filtering the measured liquid. As a guide, the following U.S. Standard sieve mesh sizes are recommended:

Flowmeter Nominal Size	Mesh Size	Particle Size
3/8 - inch	170	88 microns
1/2 - inch	120	125 microns
3/4 - inch	45	350 microns
1 - inch	45	350 microns
1-1/2 - inch	18	1000 microns

8.3 Operation precautions

8.3.1 Liquid pressure

A minimum back pressure for any flowmeter installation should be maintained to preclude a change in the calibration factor due to two-phase conditions. The minimum absolute back pressure is a function of the vapor pressure of the liquid and the presence of dissolved gases. The minimum back pressure can be experimentally determined under actual test conditions and is defined as the back pressure at which the calibration factor at 125% of the nominal maximum flow increases 1/2% over the corresponding calibration factor obtained at the same flow but with a 7.0E + 04 Pa higher pressure. The minimum back pressure should be measured four pipe-diameters downstream of the flowmeter.

8.3.2 Prevention of over-speeding

A number of conditions may cause the turbine to turn at a speed higher than its rated value. Whether such over-speeding causes damage to the flowmeter depends upon the degree and duration. Improper selection of the flowmeter or excessive flow due to failure of some component of the system can cause over-speeding. Depletion of the metered liquid in a pressurized feed system will usually cause ruinous over-speeding as the gas passes through the flowmeter. Perhaps the most frequent cause of severe over-speeding of a liquid flowmeter is gas in the line. Gas may be introduced during assembly of the system, or may result from a two-phase condition of the metered liquid. Over-speeding can be prevented by care in design and operation of the system. Proper location of the flowmeter with respect to valves can minimize risk. Finally, provision and use of means for limiting flow or bleeding gas from a liquid system is essential. Different types of over-speed protection devices are available for specific application, including mechanical and electromagnetic brakes.

8.4 Electrical installation

8.4.1 A two-conductor or three-conductor shielded cable should be used for the electrical output. Wire size should be based on allowable signal attenuation. Avoid installation in a conduit containing power cables.

8.4.2 The cable shield is to be grounded at one point only. Normally it should be grounded at the flowmeter end, but some experimentation may be necessary in troublesome cases.

8.4.3 Excessive installation torque may damage the transduction coil.

8.5 Checkout

8.5.1 System check

The type of check procedure will depend largely upon the flowmeter application. In some instances it may be possible and most expedient to establish test flow to check functionally the complete measuring system, with no serious consequences if proper operation is not obtained on first attempt. In other instances it may be of paramount importance that proper operation be obtained every time test flow is established so that one or more of the following pre-test checks may be justified.

8.5.2 Rotor spin check

The most comprehensive check that may be made of a turbine flowmeter, associated circuitry, and readout equipment, short of actually establishing flow, is to spin the rotor by tangential impingement of a jet of fluid. When such a check is desired, a pressure connection for this purpose must be provided on the housing. Any fluid that will not contaminate the system may be used. Extreme care must be exercised in making a spin check to avoid over-speeding. Even if excessive speeds are avoided, bearing lubrication may be inadequate so that prolonged checks should be avoided.

8.5.3 Induced signal check

The transduction coil, associated circuitry, and readout equipment of a self-generating flowmeter may be checked by an induced signal. A small coil, connected to an ac power source should be held near the transduction coil so as to effect an energy transfer. This functionally checks the circuit without breaking any connections and can be used.

8.5.4 Applied signal check

The associated circuitry and readout equipment of a self-generating flowmeter may also be checked by applying the signal directly. An oscillator can be connected in parallel with transduction coil to accomplish a check similar to that of 8.5.3 Induced Signal Check. Note, however, that the transduction coil is not checked by this method. Care must be exercised so that circuit characteristics are not altered or continuity disturbed by connection and disconnection of the oscillator.

9 Signal conditioning and systems considerations

The data signal is transferred and converted in the following general manner. The electrical output from the flowmeter is sent to the signal conditioning equipment by means of a signal transmission system. After the signal has been properly conditioned, it is sent to a data presentation system, which consists of a display or recording system. The display and recording can be a combination of analog and digital readouts.

9.1 Signal conditioning

In addition to the basic operations of amplification or attenuation, certain signal conditioning may be done to obtain data in a different form.

9.1.1 A rate-type signal conditioner counts, for repetitive short time intervals, the number of cycles of flowmeter signal produced in each of those intervals. By the choice of a suitable time interval, desired units of volumetric flow may be indicated. Flow may be indicated even in mass units if the density is constant.

9.1.2 A totalizer accumulates the number of cycles proportional to the total volumetric flow which has passed through the flowmeter.

9.1.3 An integrator provides a dc voltage level proportional to the signal frequency.

9.1.4 A scaler multiplies or divides the flowmeter output frequency by some selected factor. It is generally used to facilitate presentation and reduction of data.

9.2 Data presentation

9.2.1 Monitor display

Display is divided into two general categories, digital and analog. Both rate and total quantity data are easily displayed digitally, while rate can also be displayed in analog form.

9.2.2 Recorded data

To obtain a permanent record of the data, it is usually recorded by means of an electric typewriter, counter printer, graphic recorder, oscillograph or magnetic tape system. There are numerous combinations of recording systems, the detailed discussion of which is beyond the scope of this Standard.

9.3 Supplemental data

In many applications, the measurement of one of more additional variables may be necessary for complete interpretation of the flow data. Such supplemental data are generally limited to the following:

9.3.1 Temperature

Temperature of the measured liquid has an effect on the performance of the turbine flowmeter. Any one or more of the following effects may produce errors and must be considered. There is a mechanical effect caused by thermal expansion or contraction of the housing and turbine when the operating temperature materially differs from calibration temperature (See 9.4.1 (1) Temperature). An elevated or depressed operating temperature changes the physical properties of the liquid being measured, specifically its vapor pressure, viscosity and density. (See 9.4 Data Interpretation, 9.3.2 Viscosity, and 9.3.3 Density).

9.3.2 Viscosity

Kinematic viscosity measurement is desirable when operating over a wide temperature range or near the low end of the flowmeter's range, and when high accuracy is important. Liquid viscosity is usually determined indirectly by measuring the liquid temperature at a point four pipe diameters downstream of the flowmeter. The measured temperature information is used to obtain the liquid viscosity from known temperature vs. viscosity data for the particular liquid being measured. Available data on the viscosity-temperature relationship of the liquid being measured may be supplemented by analysis of samples from the actual batch to determine the viscosity at operating temperatures. Alternatively, a viscosimeter can be used for direct measurement.

9.3.3 Density

It is necessary to know the density of the liquid at the flowmeter when mass flow data are desired. This may be determined from a temperature measurement in the same manner as described for viscosity. Alternatively, a densitometer may be used. In some systems, the densitometer is arranged to compensate the volumetric flow measurement automatically so that flow and total quantity are presented in mass units. This approach often increases the uncertainty in the density correction.

9.3.4 Pressure

Where compressibility is an important factor, liquid pressure is measured. The pressure should be measured four pipe diameters downstream of the flowmeter.

9.4 Data interpretation

This section deals only with the analytical factors which affect the flow data acquired. It is presumed that factors such as two-phase flow, pulsation, and electrical interference have been minimized to a degree consistent with the accuracy desired.

9.4.1 Volumetric flow measurement

Regardless of whether the signal conditioning equipment provides a measurement of flow rate or total quantity the readings must be divided by the calibration factor "K" (See 4.3 Specific Terminology) to obtain volumetric data. As noted in that section the factor is a function of several independent variables for which corrections may be applied according to accuracy requirements. For totalization, a mean effective calibration factor must be determined based on representative values of these variables. If the signal conditioning equipment introduces a scaling factor, it must also be applied to the data at this time. The flow through a turbine flowmeter is torsionally deflected by the rotor due to bearing friction and signal generation torque. In a properly functioning flowmeter, this effect is small and is incorporated in the calibration factor. The magnitude of the effect, however, varies inversely with the density of the flowing liquid and size of flowmeter. Consequently, if the density of the operating liquid differs from that of the calibrating liquid, an error is introduced. Even a change in density, due to temperature or pressure variation, affects the factor. Because the magnitude of this error is related to the flowmeter design, no generalized correction can be given. Fortunately, the error is small, but even so, it is desirable to calibrate with a liquid of approximately the same density as the operating liquid. Corrections, if applied at all are usually for one or more of the following:

1) Temperature

The flowmeter temperature is usually assumed to be that of the flowing liquid. When operating temperature differs from that noted during calibration, an error is introduced by dimensional changes in the housing and turbine. A correction based on the thermal coefficient of expansion may be approximated as follows:

$$K_O = \frac{K_C}{1 + 3a(T_O - T_C)}$$

where:

K_O = calibration factor at operating temperature

K_C = calibration factor at calibrating temperature

a = thermal coefficient of linear expansion

T_O = operating temperature

T_C = calibration temperature (in same units as T_O)

Note that K_O decreases as operating temperature increases and that correction applies only when housing and turbine have the same thermal coefficient.

2) Flow

The sensitivity "K" is usually expressed as a constant. When a wide range of flow is to be covered, error can usually be reduced by expressing the factor as a linear function of flow, either with or without temperature correction. In some cases a non-linear expression of calibration factor may be justified.

3) Viscosity

If viscosity of the operating liquid differs from that of the calibrating liquid, or if it varies during operation due to temperature change, it may be necessary to obtain calibration at more than one viscosity. These data are best utilized as a single relationship of K factor vs. Reynolds number if the flowmeter characteristics enable such a presentation. For simplification, the quantity f/ν (output frequency divided by kinematic viscosity) which is approximately proportional to Reynolds number, may be used instead. If the flowmeter characteristics are such that a single relationship is not obtained, the data must be utilized as a family of constant viscosity relationships of K vs. flow. In either case, these relationships may be expressed as linear or non-linear functions.

9.4.2 Mass flow measurement

When flow data obtained with a turbine flowmeter are desired in mass units, the volumetric rate or total quantity must be multiplied by the density of the metered liquid at operating conditions (See Par. 9.3.3).

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