

**BS 1042 :
Section 1.6 :
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ISO TR 3313 :
1992**

Measurement of fluid flow in closed conduits

Part 1. Pressure differential devices

**Section 1.6 Method of measurement of
pulsating fluid flow in a pipe, by means
of orifice plates, nozzles or Venturi tubes**

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Industrial-process Measurement and Control Standards Policy Committee (PCL/-) to Technical Committee PCL/2, upon which the following bodies were represented:

British Compressed Air Society
British Gas plc
Department of Energy (Gas and Oil Measurement Branch)
Department of Trade and Industry (National Engineering Laboratory)
Electricity Industry in United Kingdom
Energy Industries Council
GAMBICA (BEAMA Ltd.)
Institute of Measurement and Control
Institute of Petroleum
Institute of Trading Standards Administration
Institution of Gas Engineers
Institution of Mechanical Engineers
Society of British Gas Industries
Water Services Association of England and Wales

The following bodies were also represented in the drafting of the standard through subcommittees and panels:

Engineering Equipment and Materials Users' Association
Institution of Water and Environmental Management
United Kingdom Offshore Operators' Association

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National foreword

This Section of BS 1042 has been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee. It is identical with ISO TR 3313 : 1992 *Measurement of pulsating fluid flow in a pipe by means of orifice plates, nozzles or Venturi tubes*, published by the International Organization for Standardization (ISO).

This is Section 1.6 of a series of Sections of BS 1042 on the measurement of fluid flow in closed conduits by pressure differential devices, as follows:

Section 1.1 *Specification for square-edged orifice plates, nozzles, and Venturi tubes inserted in circular cross-section conduits running full*

Section 1.2 *Specification for square-edged orifice plates and nozzles (with drain holes, in pipes below 50 mm diameter, as inlet and outlet devices) and other orifice plates*

Section 1.3 *Method of measurement of gas flow by means of critical flow Venturi nozzles*

Section 1.4 *Guide to the use of devices specified in Sections 1.1 and 1.2*

Section 1.5 *Guide to the effect of departure from the conditions specified in Section 1.1*

Section 1.1 specifies the geometry and method of use of orifice plates, nozzles and Venturi tubes inserted in a conduit running full, to measure the flow rate of the fluid in the conduit. It is identical with ISO 5167-1 : 1991 published by the International Organization for Standardization (ISO). It should be noted that guidance on the effects of departure from the conditions specified in Section 1.1 can be found in Section 1.5.

An index to Sections 1.1, 1.2 and 1.4 is provided in Section 1.4 to facilitate the rapid cross-referencing of subject matter.

Cross-references

International standard	Corresponding British Standard
ISO 5167-1 : 1991	BS 1042 <i>Measurement of fluid flow in closed conduits</i> Section 1.1 : 1992 <i>Specification for square-edged orifice plates, nozzles, and Venturi tubes inserted in circular cross-section conduits running full</i> (Identical)

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Introduction

Methods of measuring fluid flow in a pipe by means of orifice plates, nozzles or Venturi tubes are described in ISO 5167-1. However, it is stipulated that the rate of flow shall be constant or, in practice, vary only slightly and slowly with time (see ISO 5167-1:1991, 6.3.1). ISO 5167-1 does not provide for the measurement of pulsating flow.

The reasons for the publication of this document in the form of a Technical Report are the following:

- the restricted field of application of the document;
- the lack of available data on the relationship between measuring installation parameters and errors in measurement;
- if no appropriate action is taken, pulsation can cause very large errors.

Measurement of pulsating fluid flow in a pipe by means of orifice plates, nozzles or Venturi tubes

1 Scope

This Technical Report defines pulsating flow, compares it with steady flow, and indicates the requirements that allow accurate measurement of the mean rate of flow by means of orifice plates, nozzles and Venturi tubes in pipes where pulsations are present.

This Technical Report applies to flow in which the pulsations are generated at a single source which is situated either upstream or downstream of the flowmeter's primary element. Its applicability is restricted to conditions where the flow direction does not reverse in the measuring section. It includes recommendations which apply to liquid flows and gas flows in which the density changes in the measuring section are small (expansibility factor $\varepsilon \geq 0,99$ and density fluctuation ratio $\rho_{rms}/\bar{p} \leq 1/40$). Critical flow Venturi nozzles are treated as special cases.

There is no restriction on the wave-form of the flow pulsation, but the pulsation wavelength must be long compared with the dimensions of the flowmeter.

This Technical Report gives practical criteria for ensuring that flow pulsations are damped to such an extent that systematic errors in the indicated time-mean flow rate do not exceed a specified value. Recommendations concerning the appropriate design of the differential pressure secondary device are also given.

Finally, this Technical Report describes how uncertainty in the measurement of mean flow rate under pulsating flow conditions can be established.

Annex A of this Technical Report defines the theoretical and experimental basis for the determination of the total measuring error.

Annex B gives the criteria for adequate damping.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this Technical Report. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 5167-1:1991, *Measurement of fluid flow by means of pressure differential devices — Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full*.

3 Definitions

For the purposes of this Technical Report, the following definitions apply.

3.1 steady flow: Flow in which parameters such as velocity, pressure, density and temperature do not vary significantly enough with time to affect the required uncertainty of measurement.

3.2 pulsating flow: Flow in which the flow rate in a measuring section is a function of time but has a constant mean value when averaged over a sufficiently long period of time.

Pulsating flow can be divided into:

- periodic pulsating flow, and
- randomly fluctuating flow.

Unless otherwise stated in this Technical Report, the term “pulsating flow” is always used to describe periodic pulsating flow.

4 Symbols and indices

4.1 Symbols

A	Area
A_*	Area of the throat of a Venturi nozzle
a_r, c_r, b_r	Amplitude of the r^{th} harmonic component in the damped or undamped pulsations
$\bar{B}$	Time-mean value of quantity B (see B.3)
B'	Fluctuation of quantity B such that $B = \bar{B} + B'$
b	The amplitude of pulsations of density
C_c	Contraction coefficient
c	Speed of sound
D	Internal diameter of the tube
d	Internal diameter of orifice or throat bore
E_T	Total error in the indicated time mean flow-rate
f	Pulsation frequency (Hz)
H	Harmonic distortion factor
L, L_e, l_e	Effective axial lengths
$m = \beta^2$	Orifice area/pipe area ratio
p	Pressure (absolute)
q_m	Mass flow-rate
q_V	Volume flow-rate
t	Time
U	Axial velocity
V	Volume
X	Temporal inertia term for short pulsation wavelengths
β	Orifice diameter/pipe diameter ratio
γ	Ratio of specific thermal capacities
Δp	Differential pressure
$\Delta \varpi$	Pressure loss
θ	Phase angle
κ	Isentropic index
ρ	Fluid density
$\tau = p_2/p_1$	Ratio of pressure

ϕ Maximum permissible fluctuation in density

ψ, ψ_1 Maximum allowable percentage error

$\omega = 2\pi f$ Angular frequency

4.2 Indices

0 Index for the pulsating source

1, 2 Index for measuring sections

rms Root mean square

5 General

5.1 The nature of pipe flows

In practice, the flow observed in pipes is mostly a statistically steady flow. When the pipe Reynolds Number is sufficiently high, the flow is always turbulent and is, therefore, a fluctuating flow as there are irregular and random variations in quantities such as flow rate, pressure, density and temperature. If the conditions are similar to those which are typical of fully developed turbulent pipe flow and there is no periodic pulsation, the provisions of ISO 5167-1 apply.

The presence of pulsations is also very common in industrial pipe flows. Pulsating flows are generated by both rotary and reciprocating positive displacement engines, compressors, blowers and pumps. Hydrodynamic oscillations such as vortex shedding can also be a source of pulsation.

It is possible that the damping effect of the flow system between the pulsation source and the flow meter is so great that flow pulsation in the metering sections cannot be detected. In such a situation, the flow is regarded as steady and the methods of ISO 5167-1 are applicable. When flow pulsations in the metering section have an amplitude above the threshold value, however, ISO 5167-1 does not apply and the procedure outlined in this Technical Report should be followed.

As a guideline, the threshold between steady and pulsating flow can be defined in terms of the velocity pulsation amplitude such that if

$$U'_{\text{rms}}/\bar{U} < 0,05$$

and if the recommendations given in 6.4 are correctly followed,

$$\Delta p'_{\text{rms}}/\bar{\Delta p_p} \leq 0,10$$

U is the axial velocity component, such that

$$U = \bar{U} + U'$$

where U' is the velocity fluctuation,

Δp_p is the differential pressure in the primary element, such that

$$\Delta p_p = \overline{\Delta p_p} + \Delta p'$$

where $\Delta p'$ is the differential pressure fluctuation.

The barred quantities, $\overline{U}$ and $\overline{\Delta p_p}$ are time mean values.

5.2 The detection of pulsations

There is often no obvious indication of the presence of pulsations at the flowmeter. The secondary device used in industrial flowmeter installations is usually a slow response heavily damped instrument which may not show any oscillation. The best method of detecting flow pulsations is to place a hot wire anemometer or similar device on the axis of the pipe upstream of the measuring section. If this is not possible, a fast response differential pressure transducer may be connected across the primary element, provided that the recommendations given in 6.4 are strictly followed.

6 Determination of the mean flow rate of a pulsating flow

6.1 Pulsation effects on the primary device

The most important effect is due to the square root relationship between flow and differential pressure. In pulsating flow, the time-mean flow rate should be computed from the mean of the instantaneous values of the square root of differential pressure.

The practice of using slow, large displacement secondary devices for pulsating flow, and averaging by damping before taking the square root, results in an indicated flow rate greater than the true value. The amount greater depends on the ratio of the root-mean-square amplitude of the flow rate fluctuation to the mean value ($q'_{V,rms}/\overline{q_V}$).

Modern, fast, small displacement differential pressure transmitters with square root circuits and subsequent averaging exist. These can theoretically provide a more accurate output, but there is insufficient data to establish the magnitude of the improvement.

The recommended procedure for measuring the mean flow rate of a pulsating flow involves the installation of sufficient damping into the flow system such that the pulsation amplitude of the flow rate in the measuring section will be reduced to such a level that the square root error is less than a given allowable value.

The flow rate is calculated in the same way as for steady flow, using the discharge coefficients given in ISO 5167-1. When the amplitude of the residual

damped pulsation can be measured, the discharge coefficient may possibly be reduced to compensate for the calculated square root error which is always a positive systematic error. Methods for error calculation are given in clause 8.

6.2 Determination of pulsation amplitude

When damping of the flow stream is required, it is necessary to determine the r.m.s. amplitude of the undamped flow pulsation, $q'_{V0,rms}$, at the pulsation source, in order to calculate the required damping or throttling volume using the criteria described in 6.3.

There are a number of methods which can be used to obtain the amplitude. These are, in order of preference.

- Direct measurement using a linearized hot wire anemometer or similar device and r.m.s. voltmeter. The r.m.s. value of the fluctuating component of the voltage output must be measured on a true r.m.s. meter. Mean sensing r.m.s. meters must not be used as these will only read correctly for sinusoidal waveforms.
- Use of a linearized hot wire anemometer or similar device and computing $q'_{V0,rms}$ from a recorded time trace.
- Estimation of $q'_{V0,rms}$ from the action of the pulsation generator (this method is possible when a positive displacement compressor or motor is situated near the meter location).
- If the methods described in a), b) or c) cannot be used, the maximum probable value of $q'_{V0,rms}$ can be approximately inferred from a measurement of $\Delta p'_{p0,rms}$ using one of the following two inequalities:

$$\frac{q'_{V0,rms}}{\overline{q_V}} \leq \frac{1}{2} \frac{\Delta p'_{p0,rms}}{\Delta p_{ss}}$$

$$\frac{q'_{V0,rms}}{\overline{q_V}} \leq \left\{ \frac{2}{1 + [1 - (\Delta p'_{p0,rms}/\Delta p_{p0})^2]^{1/2}} - 1 \right\}^{1/2}$$

where

Δp_{ss} is the differential pressure that would be measured across the primary element under steady flow conditions with the same time-mean flow rate;

Δp_{p0} is the time-mean differential pressure that would be measured