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Measurement of fluid flow in closed conduits — Guidelines on the effects of flow pulsations on flow-measurement instruments

Mesurage du débit des fluides dans les conduites fermées — Lignes directrices relatives aux effets des pulsations d'écoulement sur les instruments de mesure de débit

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Foreword

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

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This document was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

This fourth edition of ISO/TR 3313:2018 is a technical revision of ISO/TR 3313:1998, which was withdrawn in 2013.

Measurement of fluid flow in closed conduits — Guidelines on the effects of flow pulsations on flow-measurement instruments

1 Scope

This document defines pulsating flow, compares it with steady flow, indicates how it can be detected, and describes the effects it has on orifice plates, nozzles or Venturi tubes, turbine and vortex flowmeters when these devices are being used to measure fluid flow in a pipe. These particular flowmeter types feature in this document because they are amongst those types most susceptible to pulsation effects. Methods for correcting the flowmeter output signal for errors produced by these effects are described for those flowmeter types for which this is possible. When correction is not possible, measures to avoid or reduce the problem are indicated. Such measures include the installation of pulsation damping devices and/or choice of a flowmeter type which is less susceptible to pulsation effects.

This document applies to flow in which the pulsations are generated at a single source which is situated either upstream or downstream of the primary element of the flowmeter. Its applicability is restricted to conditions where the flow direction does not reverse in the measuring section but there is no restriction on the waveform of the flow pulsation. The recommendations within this document apply to both liquid and gas flows although with the latter the validity might be restricted to gas flows in which the density changes in the measuring section are small as indicated for the particular type of flowmeter under discussion.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

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

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

3.2
pulsating flow
flow in which the flowrate in a measuring section is a function of time but has a constant mean value when averaged over a sufficiently long period of time, which depends on the regularity of the pulsation

Note 1 to entry: Pulsating flow can be divided into two categories:

— periodic pulsating flow;

— randomly fluctuating flow.

Note 2 to entry: For further amplification of what constitutes steady or pulsating flow see 5.1 and 5.2.

Note 3 to entry: Unless otherwise stated in this document the term “pulsating flow” is always used to describe periodic pulsating flow.

4 Symbols and subscripts

4.1 Symbols

A	area
A_d	area of the throat of a Venturi nozzle
A_{R}	turbine blade aspect ratio
a_r, b_r, c_r	amplitude of the r^{th} harmonic component in the undamped or damped pulsation
B	bf_{p}/q_V, dimensionless dynamic response parameter
b	turbine flowmeter dynamic response parameter
C	turbine blade chord length
C_{c}	contraction coefficient
C_{D}	discharge coefficient
C_v	velocity coefficient
c	speed of sound
D	internal diameter of the tube
d	throat bore of orifice, nozzle or Venturi tube
E_{R}	residual error in time-mean flowrate when calculated using the quantity $\sqrt{\Delta p}$
E_{T}	total error in the time-mean flowrate
f	turbine flowmeter output signal, proportional to volumetric flowrate
f_{p}	pulsation frequency
f_{r}	resonant frequency
f_{v}	vortex-shedding frequency
H	harmonic distortion factor
Ho	Hodgson number
I	moment of inertia
I_{R}, I_{F}	moments of inertia of turbine rotor and fluid contained in rotor envelope respectively
k/D	relative roughness of pipe wall
L	turbine blade length
L_{e}	effective axial length
l	impulse line length for differential pressure (DP) measurement device

$m = \beta^2$	orifice or nozzle throat to pipe area ratio
N	number of blades on turbine rotor
p	pressure (absolute)
q_m	mass flowrate
q_V	volume flowrate
R	turbine blade mean radius
Re	Reynolds number
r_h, r_t	turbine blade hub and tip radii respectively
Sr	Strouhal number
Sr_d	Strouhal number based on orifice diameter
t	time
t_b	turbine blade thickness
U	axial bulk-mean velocity
U_d	bulk-mean velocity based on orifice diameter
V	volume
X	temporal inertia term for short pulsation wavelengths
α	U'_{RMS} / U
β	orifice or nozzle throat to pipe diameter ratio
γ	ratio of specific heat capacities (c_p/c_V)
Δp	differential pressure
$\Delta\varpi$	pressure loss
$\varepsilon_{\mathrm{ss}}$	expansibility factor for steady flow conditions
η	blade "airfoil efficiency"
θ	phase angle
κ	isentropic exponent (= γ for a perfect gas)
μ	damping response factor (see 6.1.4.1.3)
ρ	fluid density
ρ_b	turbine blade material density
$\tau = p_2/p_1$	pressure ratio

φ	maximum allowable uncertainty in the indicated flowrate due to pulsation at the flowmeter
ψ	maximum allowable relative error
$\omega = 2\pi f_p$	angular pulsation frequency

4.2 Subscripts and superscripts

o	pulsation source
p	measured under pulsating flow conditions, possibly damped
po	measured under pulsating flow conditions before damping
RMS	root mean square
ss	measured under steady flow conditions
$\bar{\ }$ (over-bar)	the time-mean value
1,2	measuring sections
'	fluctuating component about mean value, e.g. U'

5 Description and detection of pulsating flow

5.1 Nature of pipe flows

Truly steady pipe flow is only found in laminar flow conditions which can normally only exist when the pipe Reynolds number, *Re*, is below about 2 000. Most industrial pipe flows have higher Reynolds numbers and are turbulent which means that they are only statistically steady. Such flows contain continual irregular and random fluctuations in quantities such as velocity, pressure and temperature. Nevertheless, 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 such standards as ISO 5167 (all parts) apply.

The magnitude of the turbulent fluctuations increases with pipe roughness, and this is one of the reasons why ISO 5167 (all parts) stipulates a maximum allowable relative roughness, k/D, of the upstream pipe for each type of primary device covered by ISO 5167 (all parts).

ISO 5167 (all parts), however, cannot be applied to flows which contain any periodic flow variation or pulsation.

5.2 Threshold between steady and pulsating flow

5.2.1 General

If the amplitude of the periodic flowrate variations is sufficiently small there should not be any error in the indicated flowrate greater than the normal measurement uncertainty. It is possible to define amplitude thresholds for both differential pressure (DP) type flowmeters and turbine flowmeters without reference to pulsation frequency. It is also possible to do this for vortex flowmeters but extreme caution is necessary if even the smallest amplitude is known to be present in the flow.

For DP-type flowmeters, the threshold is relevant when slow-response DP cells are being used. In the case of turbine flowmeters, the threshold value is relevant when there is any doubt about the ability of the rotor to respond to the periodic velocity fluctuations. In the case of a vortex flowmeter the pulsation frequency relative to the vortex-shedding frequency is a much more important parameter than the velocity pulsation amplitude.

5.2.2 Differential pressure (DP) type flowmeters

The threshold can be defined in terms of the velocity pulsation amplitude such that the flow can be treated as steady if

$$\frac{U'_{\mathrm{RMS}}}{\bar{U}} \leq 0{,}05 \quad (1)$$

where U is the instantaneous bulk-mean axial velocity such that

$$U = U' + \bar{U} \quad (2)$$

where

U' is the periodic velocity fluctuation;

$\bar{U}$ is the time-mean value.

The threshold in terms of the equivalent DP pulsation amplitude is

$$\frac{\Delta p'_{\mathrm{p,RMS}}}{\overline{\Delta p}_{\mathrm{p}}} \leq 0{,}10 \quad (3)$$

where Δp_{p} is the instantaneous differential pressure across the tappings of the primary device such that

$$\Delta p_{\mathrm{p}} = \overline{\Delta p}_{\mathrm{p}} + \Delta p'_{\mathrm{p}} \quad (4)$$

where

$\overline{\Delta p}_{\mathrm{p}}$ is the time-mean value;

$\Delta p'_{\mathrm{p}}$ is the periodic differential pressure fluctuation.

To determine the velocity pulsation amplitude it is necessary to use one of the techniques described in 5.5 such as laser Doppler or thermal anemometry. To determine the DP pulsation amplitude it is necessary to use a fast-response DP sensor and to observe the rules governing the design of the complete secondary instrumentation system as described in 6.1.3.

Theoretical considerations are covered in Annex A.

5.2.3 Turbine flowmeters

At a given velocity pulsation amplitude a turbine flowmeter tends to read high as the frequency of pulsation increases and exceeds the frequency at which the turbine rotor can respond faithfully to the velocity fluctuations. The positive systematic error reaches a plateau value depending on the amplitude and thus the threshold amplitude can be defined such that the resulting maximum systematic error is still within the general measurement uncertainty. For example, if the overall measurement uncertainty is greater than or equal to 0,5 % then it can be assumed that a systematic error due to pulsation of 0,1 % or less has negligible effect on the overall measurement uncertainty.