

Guide for field measurement of vibrations and pulsations in hydraulic machines (turbines, storage pumps and pump-turbines)

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National foreword

This British Standard has been prepared under the direction of the Machinery and Components Standards Policy Committee and is the English language version of EN 60994:1993 *Guide for field measurement of vibrations and pulsations in hydraulic machines (turbines, storage pumps and pump-turbines)*, published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 994:1991 published by the International Electrotechnical Commission (IEC).

For graphical, symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to:

- IEC Publication 27: *Letter symbols to be used in electrical technology*;
- IEC Publication 617: *Graphical symbols for diagrams*.

The symbols and signs contained in the present publication have either been taken from IEC Publications 27 or 617, or have been specifically approved for the purpose of this publication.

For general terminology, readers are referred to IEC Publication 50: *International Electrotechnical Vocabulary (IEV)*, which is issued in the form of separate chapters each dealing with a specific field, the General Index being published as a separate booklet. Full details of the IEV will be supplied on request.

The terms and definitions contained in the present publication have either been taken from the IEV or have been specifically approved for the purpose of this publication.

Some Sections and Parts of BS 4727 are identical with or technically equivalent to IEC Publication 50. All Parts of BS 3939, except for Part 1, are identical with IEC Publication 617.

Additional information. ISO 2041 referred to in the text was the 1975 edition of the standard. This edition has now been superseded by ISO 2041:1990. BS 3015:1991 is identical with ISO 2041:1990.

In 2.2, paragraph 1, line 2 and 10.2, line 3, reference is made to “IEC Publication 000”. This publication has now been published as IEC 41:1991 and it is envisaged that, if it is accepted as a European Standard, it will be published in the BS EN series.

EN 60994 was produced as a result of international discussion in which the United Kingdom took an active part.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 60, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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English version

Guide for field measurement of vibrations and pulsations in hydraulic machines (turbines, storage pumps and pump-turbines)

(IEC 994:1991)

Guide pour la mesure in situ des vibrations et
fluctuations sur machines hydrauliques
(turbines, pompes d'accumulation et
pompes-turbines)
(CEI 994:1991)

Leitfaden für die Messung von Schwingungen
und Druckpulsationen an hydraulischen
Maschinen (Turbines, Speicherpumpen und
Pumpturbinen) in Kraftwerken
(IEC 994:1991)

This European Standard was approved by CENELEC on 1992-09-15. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The CENELEC questionnaire procedure, performed for finding out whether or not the International Standard IEC 994:1991 could be accepted without textual changes, has shown that no common modifications were necessary for the acceptance as European Standard.

The reference document was submitted to the CENELEC members for formal vote and was approved by CENELEC as EN 60994 on 15 September 1992.

The following dates were fixed:

- latest date of publication
of an identical national
standard (dop) 1993-09-01
- latest date of withdrawal
of conflicting national
standards (dow) 1993-09-01

Annexes designated “normative” are part of the body of the standard. In this standard, Annex ZA is normative.

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Introduction

On a machine in service, pulsations and vibrations which cannot be avoided and which do not affect by themselves the service life of the plant where they occur, can always be observed. Their values depend on many factors, among which are the flow pattern in the water passages under different operating conditions of the unit, peculiarities of the design as well as the thoroughness of manufacture, erection and maintenance. Such pulsations and vibrations can be considered as detrimental only when certain parts of the machine or of the plant are subject to forces that may impair its resistance or when unacceptable disturbances are carried to its environment.

In extreme cases, vibrations in hydraulic machines can result in the formation of cracks and even in fracture of components due to fatigue¹⁾.

Excessive vibration in hydraulic machines not only can reduce their trouble-free service life but can also affect operation of governing systems and instruments, the behaviour of the attached structures and the health of personnel.

Measurement of pulsation and vibration characteristics or, preferably, of their effects is to be carried out in accordance with this guide which also gives the information necessary to derive the value of the physical quantities from the readings of the measuring instruments.

Given the present state of knowledge, it can only be hoped that measurements made in compliance with this guide will reveal a basic characteristic making it possible to relate pulsations and vibrations to their effects statistically, with an acceptable confidence level.

Vibration studies of a hydraulic machine represent a long and difficult operation and hence are expensive (particularly as regards the non-availability of the machine) and therefore should be undertaken only if a limited number of measurements of stresses or movements indicates the possibility of a real danger. The purpose of such work is, if possible, to eliminate the source of detrimental loadings after having identified it or, should this not be practicable, to define an operating procedure reducing such loadings to an acceptable level. There are many sources of disturbances but a very small number of them, and even one only, may create a real problem on a given machine.

As a rule, the vibrational state of a hydraulic machine is assessed from tests in which the vibration is measured at individual characteristic points of the structure. A standard experimental set-up, designed on the basis of good practice and experience, should already yield sufficient indications about the general vibrational conditions of the machine. However, examination of results thus acquired can sometimes point to strong local amplification (resonance) in some vital parts of the machine; if such is the case, the affected part(s) should be more closely investigated by means of an appropriate experimental arrangement. Flow pattern in the water passages may have important effects on the vibrations of hydraulic machines. In order to obtain an accurate vibration analysis, it is common practice to relate appropriately located measurements of vibrations (see 5.2.1 and 5.2.2) with appropriately located measurements of pulsations²⁾ of other important quantities, such as:

- pressure pulsations (see 5.2.3);
- pulsations of local strains and corresponding stresses (see 5.2.4);
- shaft torque pulsations (see 5.2.5);
- rotation speed pulsation (see 5.2.6);
- power pulsations (see 5.2.7);
- guide vane torque pulsations (see 5.2.8);
- radial thrust pulsations measured at guide bearings (see 5.2.9);
- axial thrust pulsations measured at thrust bearing (see 5.2.10);

and, if need be, also other quantities.

It is in no way intended that all the measurements listed in this guide should be carried out in every case.

¹⁾ In previous years fatigue failures in hydraulic machines were few in number. However, the current tendency to increase specific loads and to save material in the design of hydraulic machines can lead to lowering of dynamic rigidity of the structure, which may increase the risk of vibration in newly designed machines. Also the increase in geometrical dimensions stemming from increasing unit capacity can lead to a lowering of characteristic vibration frequencies of the machine or of some parts thereof (guide vanes, etc.). Thus the frequencies in question could more easily interact with the frequencies of hydraulic and/or electrical oscillations in the system (or harmonics thereof).

²⁾ In this guide, the term "pulsation" is understood to mean any periodic (or quasi-periodic) fluctuation, irrespective of its frequency.

Section 1. General

1 Scope and object

1.1 Scope

1.1.1 This guide applies to any type of reaction or impulse turbine, as well to any type of pump-turbine and storage pump, coupled to an electric generator or motor.

1.1.2 The guide covers the field of vibration and pulsation tests referred to as standard tests.

The objectives of the tests are as follows:

- Assessment of hydraulic machine design, manufacture and quality of erection from the viewpoint of vibration³⁾.
- Assessment of the changes of vibration behaviour during the machine life.
- Provision of recommendations applying to operation of unit (for instance, choice of the most appropriate transient sequences).
- Aid in analysing faults and break downs.

1.1.3 If it is not possible to apply the recommendations of the guide because of the construction of the hydraulic machine, or if it is not necessary to conduct some of the measurements, such items may be omitted on prior agreement between the manufacturer and the user.

1.2 Object

1.2.1 To establish uniform rules to be applied when carrying out vibration and pulsation tests. To establish methods of measuring and of test data processing.

1.2.2 To indicate criteria for a unified approach to the comparison of vibrations and pulsations of different hydraulic machines of the same class (see 2.4).

1.2.3 To ensure the possibility of accumulating actual data of sufficient homogeneity on different hydraulic machines.

1.3 Excluded topics

1.3.1 The guide excludes all matters of purely commercial interest.

1.3.2 The guide is not concerned with special vibration and pulsation tests for research purposes, although it is recommended that the methods described in the guide be applied to usual vibration and pulsation tests.

1.3.3 Laboratory model vibration and pulsation tests and tests of separate full-sized parts in the workshop are not dealt with in this guide.

However, if pulsation tests on a model are available, they should be taken into consideration.

1.3.4 The problems related to the vibrations of civil engineering works and of parts of the electrical machine other than bearing(s) or the shaft, as well as the pressure pulsations in the waterways external to the machine⁴⁾, are not dealt with in the guide.

However, in specific cases, when the causes of excessive vibration of a hydraulic machine are uncertain or might be influencing other parts of the plant, it may be appropriate to inspect the civil engineering work structures and/or the electrical machine as well as the waterways external to the machine.

1.3.5 The guide excludes recommendations on identifying and eliminating causes of vibrations.

1.3.6 Although quite often noise measurements and noise analysis, if adequately performed, can be a useful diagnostic tool to assess vibratory troubles of a hydraulic machine, this guide considers only mechanical vibrations to the exclusion of acoustical effects (noise).

1.3.7 Regulation systems may interact with phenomena of “pulsations” of hydraulic, mechanical and electrical quantities in a hydroelectric power plant. However, treatment of such interactions or guidelines for conducting artificial-excitation test by injecting a sine signal in the governor loop (as is often done e.g. to determine the frequency response of the system) are outside the scope of this guide.

³⁾ Recommendations on assessment of the vibrational and pulsatory state of the machine will not be prepared until systematic data have been accumulated in accordance with this guide and have been properly interpreted.

⁴⁾ In the case of absence of valves and/or gates, the machine is understood to include waterways between high pressure/low pressure reference sections, as specified for guarantees [see IEC Publication 000 (see footnote 5 on page 7)].

2 Terms, definitions, symbols and units

2.1 Units

The International System (SI) is used throughout this guide.

2.2 Terms

The terms, definitions and symbols relating to hydraulic turbines, storage pumps and pump-turbines are in compliance with the IEC Publication 000⁵⁾. The terms not defined in 2.3 can be found in the publication just mentioned.

The terms, definitions and symbols relating to vibrations and pulsations as well as mathematical terms are in compliance with ISO Standard 2041 and IEC Publications 184 and 222.

2.3 List of terms specific to this guide

Tabulated below are the terms, symbols and units relating to vibrations and pulsations adopted throughout this guide.

	Terms	Definitions	Symbols	Units
2.3.1	Terms relating to description of vibrations and pulsations as functions of time^a			
2.3.1.1	Dynamic absolute displacement	(see IEC 184)	$u(t)$	m
2.3.1.2	Dynamic absolute velocity	(see IEC 184)	$v(t)$	m/s
2.3.1.3	Dynamic absolute acceleration	(see IEC 184)	$w(t)$	m/s ²
2.3.1.4	Dynamic relative displacement between two parts e.g. the shaft and the part on which the proximity transducer is fixed ($d = 0$ when the shaft touches the transducer)		$d(t)$	m
2.3.1.5	Pressure pulsation	Oscillatory variation of the pressure of the liquid referred to its mean value during a time interval Δt previously selected	$\tilde{p}(t)$	Pa
2.3.1.6	Strain pulsation	Oscillatory variation of the strain referred to its mean value during a time interval Δt previously selected	$\tilde{\varepsilon}(t)$	m/m
2.3.1.7	Stress pulsation	Oscillatory variation of the stress referred to its mean value during a time interval Δt previously selected	$\tilde{\sigma}(t)$	N/m ²
2.3.1.8	Shaft torque pulsation	Oscillatory variation of the shaft torque referred to its mean value during a time interval Δt previously selected	$\tilde{M}(t)$	N · m
2.3.1.9	Rotational speed pulsation	Oscillatory variation of the rotational speed referred to its mean value during a time interval Δt previously selected	$\tilde{n}(t)$	rev/s
^a For the definitions of vibrations and pulsations see 2.3.2.				

⁵⁾ At present Document 4(Central Office)48.

	Terms	Definitions	Symbols	Units
2.3.1.10	Power pulsation	Oscillatory variation of the power referred to its mean value during a time interval Δt previously selected	$\tilde{P}(t)$	W
2.3.1.11	Guide vane torque pulsation	Oscillatory variation of the guide vane torque referred to its mean value during a time interval Δt previously selected	$\tilde{M}_{GV}(t)$	N · m
2.3.1.12	Radial pulsation measured at guide bearing	Oscillatory variation of the radial load on the guide bearing referred to its mean value during a time interval Δt previously selected	$\tilde{R}(t)$	N
2.3.1.13	Axial pulsation measured at thrust bearing	Oscillatory variation of the axial load on the thrust bearing referred to its mean value during a time interval Δt previously selected	$\tilde{T}(t)$	N
2.3.2	General terms relating to parameters used to describe vibrations and pulsations^a			
2.3.2.1	Vibration	The variation with time of a quantity, which is descriptive of the motion or position of a mechanical system, when the magnitude is alternately greater and smaller than some average value of reference		
2.3.2.2	Periodic vibration or pulsation	A quantity whose values recur at equal intervals of the independent variable (time) NOTE A periodic quantity $X(t)$ which is a function of time t , and can be expressed as $X = f(t) = f(t + nT)$ where n is an integer, T is a constant interval of time and t is the running time		
2.3.2.3	Fundamental period (period)	The smallest interval of time for which a periodic function of time repeats itself (see 2.3.2.2) NOTE If there is no ambiguity, the fundamental period is called the period	T	s
2.3.2.4	Frequency	The reciprocal of period	f	Hz
2.3.2.5	Harmonic (of a periodic quantity)	A sinusoidal component (of a composite periodic function of time) whose frequency is an integer multiple of the fundamental frequency		
2.3.2.6	Angular frequency (circular frequency)	The product of the frequency of a sinusoidal phenomenon by the factor 2π	ω	rad/s

^a The definition of “pulsation” is the same as that of “vibration”, with the difference that the quantity involved is not descriptive of the motion or position of a mechanical system.

	Terms	Definitions	Symbols	Units
2.3.2.7	Simple harmonic quantity; sinusoidal quantity	A periodic quantity that is a sinusoidal function of time. Thus $X = A \sin(\omega t + \varphi)$ where $X(t)$ is the simple harmonic quantity. A is the amplitude, ω is the angular frequency (see 2.3.2.6), t is the running time, φ is the phase angle of the oscillation (radians)		
2.3.2.8	Simple harmonic motion or pulsation	A motion or pulsation that is a sinusoidal function of time		
2.3.2.9	Phase angle; Phase (of a sinusoidal quantity)	If a sinusoidal quantity has advanced through mT units of time (T being the period) as measured from a value of time taken as reference, the phase angle is $m2\pi$	φ	rad
2.3.2.10	Amplitude	The maximum value of a sinusoidal quantity $X(t)$	A	[X] (different units according to the physical nature of X)
2.3.2.11	Peak-to-peak value of an oscillating quantity^a	The algebraic difference between the extreme values of the quantity. In the case of a sinusoidal quantity the peak-to-peak value is twice the amplitude, i.e. $2A$	ΔX_{pp}	[X]
2.3.2.12	Compound vibration or pulsation	Vibration or pulsation consisting of the super-position (sum) of several simple harmonic vibrations or pulsations NOTE In cases when the ratio of each of the frequencies of simple harmonic vibrations to fundamental frequency is an integer, compound vibration is called polyharmonic vibration		
2.3.2.13	Resonance	Resonance of a system in forced oscillation exists when any change, however small, in the frequency of excitation causes a decrease in the response of the system		
2.3.2.14	Random vibration or pulsation	A vibration or pulsation, of which the magnitude cannot be precisely predicted for any given instant of time		

^a Peak value ($\Delta X_p[X]$) of an oscillating quantity (as opposed to peak-to-peak value) is the maximum absolute value of the deviation from the mean value (see 2.3.3.1) of the oscillating quantity.

	Terms	Definitions	Symbols	Units
2.3.3	Mathematical terms			
2.3.3.1	Average value; mean value; algebraic mean value	a) The average value of a number of homogeneous discrete quantities is equal to the algebraic sum of the quantities divided by the number of quantities. The average value is equal to: $\bar{X} = \frac{\sum_{n=1}^N X_n}{N}$ where X_n is the value of nth quantity: N is the total number of discrete quantities b) The average value of a continuous function, $X(t)$, over a time interval between t_1 and t_2 is equal to: $\bar{X} = \frac{\int_{t_1}^{t_2} X(t) dt}{t_2 - t_1}$	$\bar{X}$	[X]
2.3.3.2	Standard deviation effective value referred to the mean	The root-mean-square (r.m.s.) value of the deviation of a set of numbers (or a function) from the mean value a) For a set of numbers $X_1, X_2, \dots, X_N$ $\tilde{X}_{\text{eff}} = \sqrt{\frac{\sum_{n=1}^N (X_n - \bar{X})^2}{N}}$ where the subscript n refers to the n-th value. N is the total number of discrete quantities in the set, $\bar{X}$ is the mean value of the set (see 2.3.3.1)^a b) If the quantity $X(t)$ is a continuous function of t, its effective value over an interval between t_1 and t_2 is: $\tilde{X}_{\text{eff}} = \sqrt{\frac{\int_{t_1}^{t_2} [X(t) - \bar{X}]^2 dt}{t_2 - t_1}}$	$\tilde{X}_{\text{eff}}$	[X]
2.3.3.3	Root-mean-square value: r.m.s. value (effective value)	a) The root-mean-square (r.m.s.) value of a set of numbers is the square root of the average of their squared values. The r.m.s. value of the set of numbers can be represented as: $X_{\text{rms}} = \sqrt{\frac{\sum_{n=1}^N X_n^2}{N}}$	X_{rms}	[X]

^a Sometimes the standard deviation for the data of a sample is defined with $(N - 1)$, replacing N in the denomination because the resulting value represents a better estimate of the standard deviation of a population from which the sample is taken. For larger values of N (i.e. $N > 30$) there is practically no difference.

	Terms	Definitions	Symbols	Units
		where the subscript n refers to the n-th value and N is the total number of discrete homogeneous quantities b) The root-mean-square (r.m.s.) value of a continuous function, $X(t)$ over an interval between t_1 and t_2, is equal to the square root of the average of the squared values of the function over the interval. The r.m.s. value of a continuous single-valued function, $X(t)$ over an interval between t_1 and t_2 is: $X_{rms} = \sqrt{\frac{\int_{t_1}^{t_2} [X(t)]^2 dt}{t_2 - t_1}}$ NOTE In vibration theory the average or mean value of the vibration is equal to zero. In this case the r.m.s. value X_{rms} is equal to the standard deviation $\tilde{X}_{eff}$ (see 2.3.3.2) and the mean square value X_{rms}^2 is equal to the variance $\tilde{X}_{eff}^2$ (see 2.3.3.4). In the case of a sinusoidal quantity of amplitude A its effective value is $A/\sqrt{2}$		
2.3.3.4	Variance	The square of the standard deviation NOTE When the mean value of a variable is zero, the variance is the mean square value of the variable (see Note 2 under Mean square value, 2.3.3.5)	$\tilde{X}_{eff}^2$	$[X^2]$
2.3.3.5	Mean square value	The mean square value of a function (or set of numbers) over a given interval is equal to the mean of the squared values of the function (or set of numbers) over that interval NOTE 1 The mean square value is the square of the r.m.s. value NOTE 2 When the mean value $\bar{X}$ is zero the mean square value is equal to the variance (see 2.3.3.4) NOTE 3 If the mean value $\bar{X}$ is not zero then: $X_{rms}^2 = \tilde{X}_{eff}^2 + \bar{X}^2$	X_{rms}^2	$[X^2]$
2.3.4	Other terms utilized			
2.3.4.1	Number of guide or diffuser vanes (reaction machines), or number of Pelton nozzles		Z_0	
2.3.4.2	Number of runner impeller blades (reaction machines), or number of Pelton buckets		Z_2	
2.3.4.3	Flow velocity	The relative velocity of flow over a part to be investigated, at a point P, outside the thickness of the boundary layer, to be specified (see Figure 1)	v_w	m/s

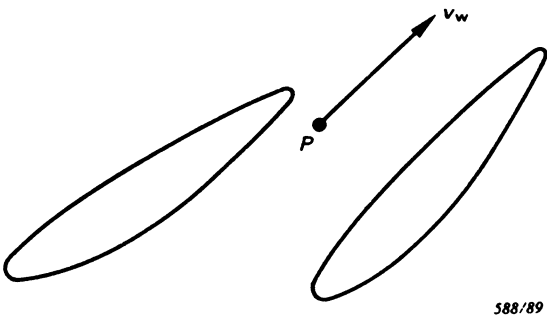


Figure 1 — Definition of flow velocity^a

^a These definitions are only a rough suggestion to evaluate the order of magnitude of frequency through the Strouhal number (see 6.1.1).

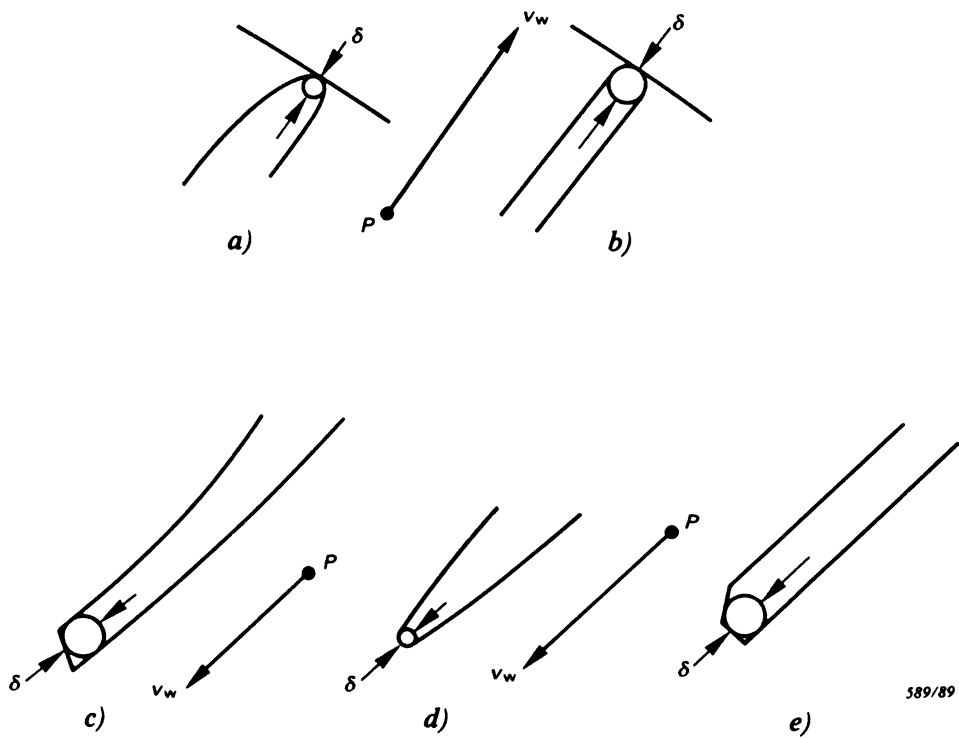


Figure 2 — Definition of thickness of trailing edge of a hydraulic profile^a

^a These definitions are only a rough suggestion to evaluate the order of magnitude of frequency through the Strouhal number (see 6.1.1).

	Terms	Definitions	Symbols	Units
2.3.4.4	Thickness of trailing edge of a hydraulic profile (guide vane, runner blade, etc.)	Maximum diameter of a sphere tangent to the two opposite surfaces of the profile near the trailing edge (see Figure 2)	δ	m
2.3.4.5	Limit frequency (lower, upper)	The lower and upper frequency values of the frequency range of the process under investigation	f_L, f_U	Hz
2.3.4.6	Lower/upper limit frequency of measuring channel	Actual lower/upper limit of frequency of measuring channel, where amplification is reduced by 3 dB with respect to the flat portion of the amplification versus frequency response curve	f_{Lr} f_{Ur}	Hz
2.3.4.7	Power spectral density	The power spectral density is the mean square value of that part of the quantity, passed by a narrow band filter of centre frequency f , per unit bandwidth in the limit as the bandwidth approaches zero and the averaging time approaches infinity	$G(f)$	$[X^2] \cdot s$ where $[X]$ is the unit in which the oscillating quantity X is measured
2.3.4.8	Constant relative (percentage) bandwidth of an analyzer	The ratio $\beta = \frac{f_1 - f_2}{\sqrt{f_1 \cdot f_2}} \times 100$ where f_1, f_2 = frequency values at 3 dB drop points of the analyzer frequency response curve	β	%
2.3.4.9	Upper cut-off frequency of pressure transducer installation	Maximum frequency at which pressure transducer amplitude distortion caused by transducer installation (see Figure D.1) does not exceed 3 dB	f_c	Hz
2.3.4.10	Volume of pressure transducer chamber (see Figure D)	Volume of the chamber where the pressure transducer is mounted	V_c	m ³
2.3.4.11	Cross-sectional area and length of the pressure transducer pipe (see Figure D)	Cross-sectional area and length of the connecting pipe connecting the pressure transducer to the water passage of the hydraulic machine	A_c L_c	m ² m
2.3.4.12	Wave propagation velocity in pressure line	Velocity of propagation of pressure waves in the pressure line (see 2.3.4.11)	a_c	m/s
2.3.4.13	Recording velocity	Velocity of recording beam or pen movement with respect to the recording paper	v_s	m/s

	Terms	Definitions	Symbols	Units
2.3.4.14	Signal recording time	Period of time during which a signal from a transducer is recorded	t_r	s
2.3.4.15	Vibration component frequency	Frequency of recorded component to be investigated	f_i	Hz
2.3.4.16	Number of cycles recorded	Number of component cycles to be recorded	N_r	
2.3.4.17	Tape or paper speed	Tape or paper speed during recording	v_r	m/s
NOTE Other terms and symbols, not listed here, are defined in the text as the necessity arises.				

2.4 Classification of hydraulic machines

Hydraulic machines are classified into their types on the basis of the future “Guide for the Nomenclature of Hydraulic Turbines, Storage Pumps and Pump-Turbines”.

Designs of hydraulic machines and their parameters are highly different. To facilitate the comparison of vibrations and pulsations of different machines the various designs are subdivided into a number of different classes.

2.4.1 The following features are used as the basis for classification⁶⁾:

— *Type of hydraulic machine*

Turbines: Pelton, inclined jet, cross flow, Francis, diagonal flow (Deriaz), propeller, Kaplan, bulb, rim-generator (straight-flow), S-type.

Pumps: centrifugal (single stage, multistage), diagonal flow, axial flow.

Pump turbines: Francis (single stage, multistage not regulated and regulated), diagonal flow, axial flow.

— *Arrangement of the shaft* (vertical, horizontal, inclined).

— *Number and position of bearings*.

— *Arrangement of the machines*: suspended type, umbrella type supported on the lower bearing bracket, umbrella type supported on the head cover, thrust bearing at lower end of the machine in relation to the position of the thrust bearing.

2.4.2 As a function of the arrangement of the shaft and of the number and position of bearings the following principal classes of hydraulic machines are formed (some examples of arrangements are shown in Figure 3).

2.4.2.1 The class of vertical machines includes:

- suspended machines (Figure 3a)
- umbrella type machines (Figure 3b and Figure 3c)
- machines with the thrust bearing at the lower end of the shaft (Figure 3d).

2.4.2.2 The class of horizontal machines includes:

- machines with two bearings (Figure 3e and Figure 3g)
- machines with three bearings
- machines with four bearings (Figure 3f).

2.4.3 The class of bulb machines includes:

- machines with cantilever arrangement of runner and generator (Figure 3h);
- machines with additional radial support located on an outlet stayring (Figure 3i).

Figure 3k gives an example of S-type machines.

⁶⁾ This classification is not intended to be exhaustive, but to cover only the more widely used types: besides, the figures are intended only as indicative schemes for easy reference to the list of arrangements and parts on page 15.

The general description of the figures and a list of the numbers used for the identification of the main parts within the arrangements is summarized in the following

- Figure 3a: vertical suspended machine.
- Figure 3b: vertical umbrella-type machine.
- Figure 3c: vertical umbrella-type machine.
- Figure 3d: vertical machine supported at the lower end shaft.
- Figure 3e: horizontal machine with two bearings.
- Figure 3f: horizontal machine with four bearings.
- Figure 3g: pair of horizontal machines with two bearings.
- Figure 3h: bulb machine with cantilever arrangement.
- Figure 3i: bulb machine with additional radial bearing.
- Figure 3k: S-type machine.

List of parts and reference numbers:

- 1 Runner/impeller.
- 2 Shaft.
- 3 Generator/motor.
- 4 Head cover.
- 5 Lower bearing bracket.
- 6 Upper bearing bracket.
- 7 Thrust bearing support.
- 8 Turbine (pump/pump-turbine) guide bearing.
- 9 Generator/motor guide bearing.
- 10 Thrust bearing.
- 11 Guide and thrust bearing combined.
- 12 Coupling.
- 13 Gear box.

Figure 3 — Some arrangements of hydraulic machines (See following pages)

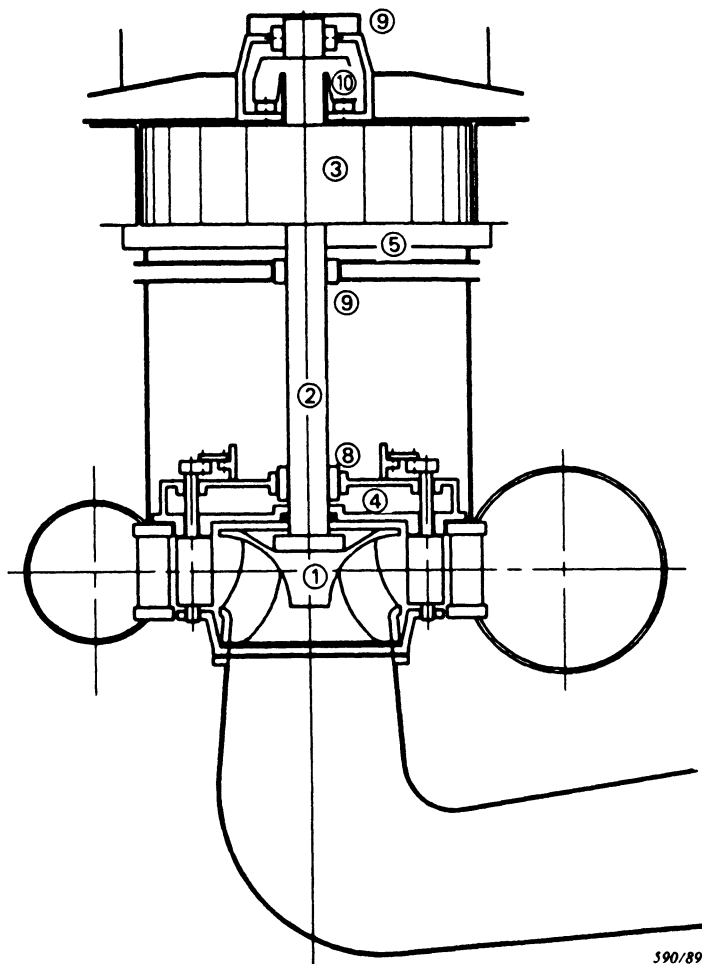


Figure 3a — Example of a vertical suspended machine (Francis turbine) with three guide bearings

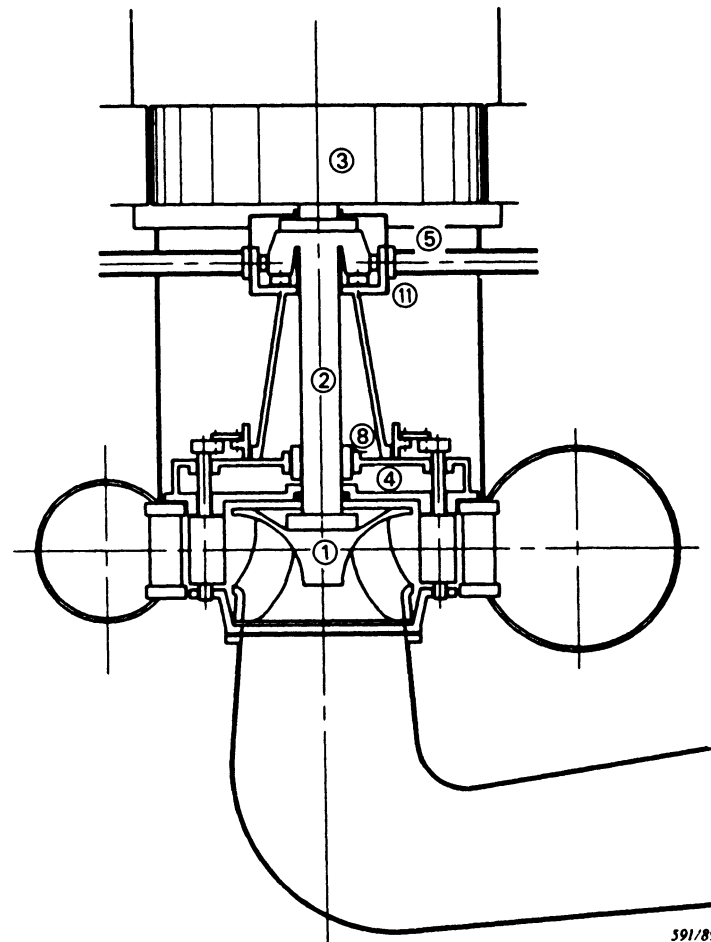


Figure 3b — Example of a vertical machine (Francis turbine) of umbrella type with the bearing on the turbine head cover and cantilever arrangement of the generator

(List of reference numbers, see general description of Figure 3, page 15)