SLOVENSKI STANDARD
SIST EN 60994:2002

01-julij-2002

Nadomešča:
SIST IEC 60994:1999

Vodilo za terenske preskuse vibracij in pulzacij za vodne naprave (turbine, akumulacijske črpalke in črpalne turbine) (IEC 60994:1991)

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

Leitfaden für die Messung von Schwingungen und Druckpulsationen an hydraulischen Maschinen (Turbinen - Speicherpumpen und Pumpturbinen) in Kraftwerken

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

Ta slovenski standard je istoveten z: EN 60994:1992

ICS:

17.160	Vibracije, meritve udarcev in vibracij	Vibrations, shock and vibration measurements
27.140	Vodna energija	Hydraulic energy engineering

SIST EN 60994:2002 **en**

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 60994

October 1992

UDC 534.6:534.83:621.22:621.65

Descriptors: Hydraulic machine, turbine, pump, measuring, vibration, test, test conditions

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 (Turbinen, 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.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

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

Central Secretariat: rue de Stassart 35, B-1050 Brussels

Ref. No. EN 60994 : 1992 E

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.

CONTENTS

GUIDE FOR FIELD MEASUREMENT OF VIBRATIONS AND PULSATIONS IN HYDRAULIC MACHINES (TURBINES, STORAGE PUMPS AND PUMP-TURBINES)

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 fatigue*.

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

* 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).

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 pulsations* 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.

SECTION ONE — 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 vibration**.
— 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.

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

** 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.

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 machine*, 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.

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 000***. The terms not defined in 2.3 can be found in the publication just mentioned.

---

* 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***).

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

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**			
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
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

* For the definitions of vibrations and pulsations see 2.3.2.

	Terms	Definitions	Symbols	Units
2.3.2	*General terms relating to parameters used to describe vibrations and pulsations**			
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
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**	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 superposition (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		

* 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.

** Peak value (ΔX_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
2.3.2.13	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		
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: $$\overline{X} = \frac{\sum_{n=1}^{N} X_n}{N}$$ 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: $$\overline{X} = \frac{\int_{t_1}^{t_2} X(t)\,dt}{t_2 - t_1}$$	$\overline{X}$	[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 $X_1, X_2, \ldots X_N$ $$\tilde{X}_{eff} = \sqrt{\frac{\sum_{n=1}^{N} (X_n - \overline{X})^2}{N}}$$ where the subscript n refers to the n-th value. N is the total number of discrete quantities in the set, $\overline{X}$ is the mean value of the set (see 2.3.3.1)* *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: $$\tilde{X}_{eff} = \sqrt{\frac{\int_{t_1}^{t_2} [X(t) - \overline{X}]^2\,dt}{t_2 - t_1}}$$	$\tilde{X}_{eff}$	[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: $$X_{rms} = \sqrt{\frac{\sum_{n=1}^{N} X_n^2}{N}}$$	X_{rms}	[X]

* 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^2_{rms} is equal to the variance $\tilde{X}^2_{eff}$ (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)	$\tilde{X}^2_{eff}$	[X²]
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 *Notes 1.* — The mean square value is the square of the r.m.s. value *2.* — When the mean value $\overline{X}$ is zero the mean square value is equal to the variance (see 2.3.3.4) *3.* — If the mean value $\overline{X}$ is not zero then: $X^2_{rms} = \tilde{X}^2_{eff} + \overline{X}^2$	X^2_{rms}	[X²]
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
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

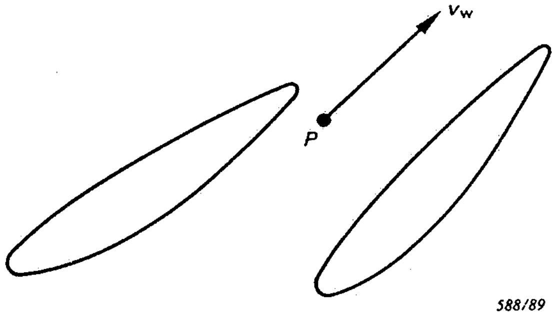

FIG. 1. — Definition of flow velocity*.

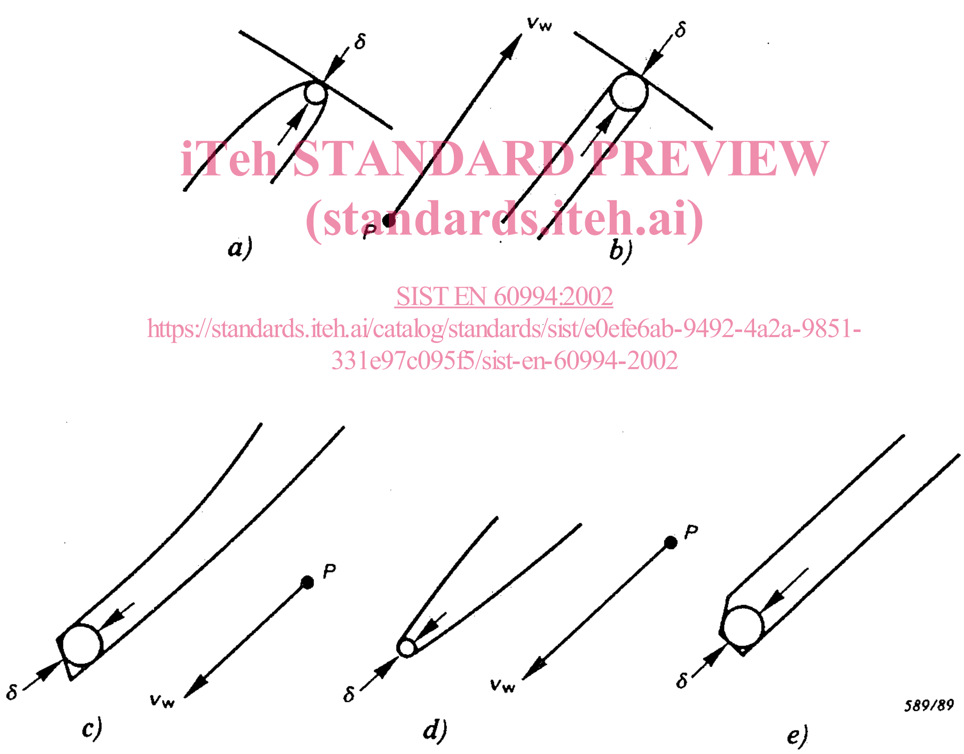

FIG. 2. — Definition of thickness of trailing edge of a hydraulic profile*.

* 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
2.3.4.6	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 D1) 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
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.