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

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

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

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17.160	Vibracije, meritve udarcev in vibracij	Vibrations, shock and vibration measurements
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CORRIGENDUM 1

Page 6 - AVANT-PROPOS

Dans la liste des publications citées de la CEI, à la cinquième ligne, au lieu de

*** Actuellement document 4(Bureau Central)48

lire:

CEI 41 (1991): Essais de réception sur place des turbines hydrauliques, pompes d'accumulation et pompes-turbines en vue de la détermination de leurs performances (troisième édition)

Page 7 - PREFACE

In the list of other IEC publications quoted, fifth line, instead of

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

read:

IEC 41 (1991): Field acceptance tests to deter- mine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines (third edition)

Corrections en anglais uniquement

Page 17 – Subclause 2.3.2.7

In the definitions column, third line, instead of ...quantity, *A* is... *read* ...**quantity, *A* is**... (comma instead of full stop) *

Page 19

In the footnote, at end of first line, instead of ...*N* in the denomination... *read* ...*N* in the denomin**ator**...

Page 21

In the definitions column, fifth line, instead of ...function, *X*(*t*) over... *read* ...**function *X*(*t*) over**... (no comma)

Page 25 – 2.3.4.11

In the definitions column, first and second line, instead of ...length of the connecting pipe connecting the pressure transducer... *read* ...**length of the pipe connecting the pressure transducer**...

Page 41 – 4.1.1

In item d), second and third line, instead of ...unbalance; also and if... *read* ...**unbalance and also if**...

4.1.3 - *In the first line, instead of* ...to the machine water passages... *read* ...**to the water passages**...

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* Bold types are for clarity only

Corrections en anglais uniquement

Page 49 – 5.2.3

In the eighth line, instead of ...in the draft tube at a distance of 0.5 D_5 to 1.0 D_5 from... *read* ...**0.5 to 1.0 times the suction diameter of the runner (D_S) from**...

Tenth line, instead of ...0.2 D_5 – 0.8 D_5 from... *read* ...**0.2 D_S – 0.8 D_S from**...

Eleventh line, instead of ...D_5 being... *read* ...**D_S being**...

Twelfth line, instead of ...outer contour of the elbow, *read* ...**outer side of the elbow.**

Page 51 – 5.2.10

Item b), instead of ...thrust bearing load pulsations, by means of strain measurements on every bearing element; *read* ...**thrust bearing load pulsations, on every bearing element by means of strain measurements;**

Page 53 – 5.6.1

In item b), first line, instead of ...and runner blade angle... *read* ...**and runner/impeller blade angle**...

Page 55 – 5.7.4

In the second line, instead of ...position of a runner vane or nozzle and/or guide blade... *read* ...**position of a guide vane or nozzle and/or runner blades**...

Page 58 – 6.1.1

Au point b), au lieu de

Limite supérieure de fréquence**:
— turbines Pelton:

lire **Limite supérieure de fréquence:
— turbines Pelton****

Corrections en anglais uniquement

Page 59 – 6.1.1

In item b), instead of Upper frequency**:
— for Pelton turbines:

read **Upper frequency:
— for Pelton turbines****

In the first footnote (*), end of first line, instead of ...lower than the vortex rope... *read* ...**lower than the suction vortex**...

Page 65 – 6.3.5

In the second line, instead of ...any measuring point. *read* ...**any measuring operating condition.**

Page 71 – Clause 6.8

In the seventh line (second dash), remove the words ...(see Figure 7)... *and place them in next line so as to obtain* ...**are eliminated (see Figure 7).**

Page 85 – 8.3

In the seventh line, instead of ...A/D conversion... *read* ...**A/D (analog to digital) conversion**...

Page 95 – 9.2.4

Ninth line, instead of Only in the last case is phase information preserved, *read:* **Only in the last case phase information is preserved.**

Page 99 – 10.3

In the second line, instead of ...should be agreed with the concerned parties,... *read* ...**should be agreed between the concerned parties,**...

Page 103 – Clause A2.

In the last but one line, instead of ...conversion of the signals from the three signals... *read* ...**conversion of the three signals**...

Page 108 – Article B2.

Dans la dernière formule de la page, ajouter un signe moins à la suite du second signe égale (= −)

Page 109 – B2.

In the last formula of the page, add a minus sign just after the second equal sign (= −)

Corrections en anglais uniquement

Page 115 – C7.

In the fifth line (third dash), instead of (...recorder or plotter, output)... *read* **(...recorder or plotter output)**... (no comma)

Page 117 – Figure C1.

In the heading of the table, last column, instead of Conditions test/... *read* **Test conditions/...**

Page 118 – Figure C2.

Sous le tableau, à la cinquième ligne (4ème tiret), au lieu de

– rendement de la pompe ou de la turbine,

lire

– rendement de la pompe ou de la turbine, **etc.**

Page 119 – Figure C2.

Below the table, fifth line (4th dash), instead of

– turbine or pump efficiency,

read

– turbine or pump efficiency, **etc.**

Page 132 – Figure D1.

Dans le schéma, au lieu de II_B *lire* **II**

Page 133 – Figure D1.

In the diagram, instead of II_B *read* **II**

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.
2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.
3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as posssible, be clearly indicated in the latter.

PREFACE

This standard has been prepared by IEC Technical Committee No. 4: Hydraulic turbines.

The text of this standard is based on the following documents:

Six Months' Rule	Report on Voting
4(CO)45	4(CO)50

Full information on the voting for the approval of this standard can be found in the Voting Report indicated in the above table.

Other IEC Publications quoted in this standard:

Publication Nos.
- 184 (1965): Methods for specifying the characteristics of electro-mechanical transducers for shock and vibration measurements.
- 222 (1966): Methods for specifying the characteristics of auxiliary equipment for shock and vibration measurement.
- *** At present Document 4(Central Office)48.

Other publications quoted:

ISO standards
- 2041 (1975): Vibration and shock — Vocabulary. Bilingual edition.
- 3945 (1985): Mechanical vibration of large rotating machines with speed range from 10 to 200 tr/s — Measurement and evaluation of vibration severity *in situ*.
- 5347-0 (1987): Methods for the calibration of vibration and shock pick-ups — Part 0: Basic concepts.
- 5348 (1987): Mechanical vibration and shock — Mechanical mounting of accelerometers.
- 7919-1 (1986): Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation — Part 1: General guidelines.
- 8042 (1988): Shock and vibration measurements — Characteristics to be specified for seismic pick-ups.

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

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* 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.

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* 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.

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* 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.