

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Hydraulic machines – Guidelines for dealing with hydro-abrasive erosion
in kaplan, francis, and pelton turbines**

**Machines hydrauliques – Lignes directrices relatives
au traitement de l'érosion hydro-abrasive des turbines kaplan, francis et pelton**



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2019 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC -

webstore.iec.ch/advsearchform

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

Electropedia - www.electropedia.org

Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 000 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 16 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary

67 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Hydraulic machines – Guidelines for dealing with hydro-abrasive erosion
in kaplan, francis, and pelton turbines**

**Machines hydrauliques – Lignes directrices relatives
au traitement de l'érosion hydro-abrasive des turbines kaplan, francis et pelton**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 23.100.10; 27.140

ISBN 978-2-8322-6286-3

**Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	8
2 Terms, definitions and symbols.....	8
3 Prediction of hydro-abrasive erosion rate.....	12
3.1 Model for hydro-abrasive erosion depth	12
3.2 Reference model.....	13
3.3 Simplified hydro-abrasive erosion evaluation	14
4 Design.....	15
4.1 General.....	15
4.2 Selection of materials with high resistance to hydro-abrasive erosion and coating.....	16
4.3 Stainless steel overlays	16
4.4 Water conveyance system	16
4.5 Valve	17
4.5.1 General	17
4.5.2 Protection (closing) of the gap between housing and trunnion.....	17
4.5.3 Stops located outside the valve	17
4.5.4 Proper capacity of inlet valve operator	18
4.5.5 Increase bypass size to allow higher guide vane leakage	18
4.5.6 Bypass system design	18
4.6 Turbine	18
4.6.1 General	18
4.6.2 Hydraulic design.....	18
4.6.3 Mechanical design.....	20
5 Operation and maintenance.....	26
5.1 Operation.....	26
5.2 Spares and regular inspections.....	28
5.3 Particle sampling and monitoring	28
6 Materials with high resistance to hydro-abrasive erosion	29
6.1 Guidelines concerning relative hydro-abrasive erosion resistance of materials including hydro-abrasive erosion resistant coatings	29
6.1.1 General	29
6.1.2 Discussion and conclusions.....	30
6.2 Guidelines concerning maintainability of hydro-abrasive erosion resistant coating materials	30
6.2.1 Definition of terms used in this subclause	30
6.2.2 Time between overhaul for protective coatings	30
6.2.3 Repair of protective coatings	31
7 Guidelines on insertions into specifications.....	32
7.1 General.....	32
7.2 Properties of particles going through the turbine	33
7.3 Size distribution of particles	34
Annex A (informative) <i>PL</i> calculation example.....	35
Annex B (informative) Measuring and recording hydro-abrasive erosion damages	37
B.1 Recording hydro-abrasive erosion damage	37

B.2	Pelton runner without coating.....	37
B.3	Needle tip and mouth piece without coating	38
B.4	Pelton runner with hardcoating.....	38
B.5	Needle tip, seat ring and nozzle housing with coating	38
B.6	Francis runner and stationary labyrinth without coating	39
B.7	Francis runner with coating and stationary labyrinth.....	39
B.8	Guide vanes and facing plates without coating.....	39
B.9	Guide vanes and facing plates with coating.....	40
B.10	Stay vanes.....	40
B.11	Francis labyrinth seals uncoated.....	40
B.12	Kaplan uncoated.....	40
B.13	Kaplan coated.....	41
B.14	Sample data sheets	41
B.15	Inspection record, runner blade inlet.....	42
B.16	Inspection record, runner blade outlet.....	43
B.17	Inspection record, runner band	44
B.18	Inspection record, guide vanes	45
B.19	Inspection record, facing plates and covers	46
B.20	Inspection record, upper stationary seal.....	47
B.21	Inspection record, upper rotating seal	48
B.22	Inspection record, lower stationary seal	49
B.23	Inspection record, lower rotating seal.....	50
B.24	Inspection record, runner bucket.....	51
B.25	Inspection record, Pelton runner splitter.....	52
Annex C (informative) Monitoring of particle concentration and properties and water sampling procedure		53
C.1	General.....	53
C.2	Sampling before building a power station	53
C.3	Sampling in existing power stations	54
C.4	Logging of samples.....	54
Annex D (informative) Procedures for analysis of particle concentration, size, hardness and shape		55
D.1	General.....	55
D.2	Particle concentration	55
D.3	Particle size distribution	55
D.4	Mineralogical composition	55
D.5	Particle geometry.....	55
Annex E (informative) Frequency of sediment sampling.....		58
Annex F (informative) Typical criteria to determine overhaul time due to hydro-abrasive erosion		59
F.1	General.....	59
F.2	Parameters which are observable while the unit is in operation.....	59
F.3	Criteria that require internal inspection of the unit.....	60
Annex G (informative) Example to calculate the hydro-abrasive erosion depth.....		61
Annex H (informative) Examples to calculate the TBO in the reference model.....		63
Annex I (informative) Background for hydro-abrasive erosion depth model		66
I.1	Model background and derivation.....	66
I.2	Introduction to the <i>PL</i> variable.....	67
I.3	Calibration of the formula.....	69

Annex J (informative) Quality control of thermal sprayed WC-CoCr.....	71
J.1 Specification	71
J.2 Quality control	71
Bibliography.....	72
Figure 1 – Estimation of the characteristic velocities in guide vanes, W_{gv} , and runner, W_{run} , as a function of turbine specific speed	13
Figure 2 – Simplified evaluation of risk of hydro-abrasive erosion for first assessment.....	15
Figure 3 – Example of protection of transition area	17
Figure 4 – Runner blade overhang in refurbishment project	19
Figure 5 – Example of cavitation on runner band due to thicker blades	20
Figure 6 – Example of design of guide vane trunnion seals.....	21
Figure 7 – Example of fixing of facing plates from the dry side (bolt to the left)	23
Figure 8 – Head cover balancing pipes with bends.....	24
Figure 9 – Step labyrinth with optimized shape for hardcoating	26
Figure 10 – Sample plot of particle concentration versus time.....	28
Figure D.1 – Typical examples of particle geometry	57
Figure I.1 – Example of flow pattern in a Pelton injector at different load	68
Table 1 – Values of K_f and p for various components	13
Table 2 – Overview over the feasibility for repair C on site.....	31
Table 3 – Form for properties of particles going through the turbine.....	33
Table 4 – Form for size distribution of particles.....	34
Table A.1 – Example of documenting sample tests	35
Table A.2 – Example of documenting sample results	36
Table B.1 – Inspection record, runner blade inlet form	42
Table B.2 – Inspection record, runner blade outlet form	43
Table B.3 – Inspection record, runner band form.....	44
Table B.4 – Inspection record, guide vanes form.....	45
Table B.5 – Inspection record, facing plates and covers form.....	46
Table B.6 – Inspection record, upper stationary seal form.....	47
Table B.7 – Inspection record, upper rotating seal form	48
Table B.8 – Inspection record, lower stationary seal form	49
Table B.9 – Inspection record, lower rotating seal form.....	50
Table B.10 – Inspection record, runner bucket.....	51
Table B.11 – Inspection record, Pelton runner splitter	52
Table G.1 – Calculations.....	62
Table H.1 – Pelton turbine calculation example.....	63
Table H.2 – Francis turbine calculation example	64
Table I.1 – Analysis of the calibration constant K_f and p	70
Table J.1 – Recommended items to include in HVOF inspection	71

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**HYDRAULIC MACHINES –
GUIDELINES FOR DEALING WITH HYDRO-ABRASIVE
EROSION IN KAPLAN, FRANCIS, AND PELTON TURBINES****FOREWORD**

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 62364 has been prepared by IEC technical committee 4: Hydraulic turbines.

This second edition cancels and replaces the first edition published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) the formula for TBO in Pelton reference model has been modified;
- b) the formula for calculating sampling interval has been modified;
- c) the chapter in hydro-abrasive erosion resistant coatings has been substantially modified;
- d) the annex with test data for hydro-abrasive erosion resistant materials has been removed;
- e) a simplified hydro-abrasive erosion evaluation has been added.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
4/351/FDIS	4/366/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The number of hydro power plants with hydro-abrasive erosion is increasing worldwide.

An overall approach is needed to minimize the impact of this phenomenon. Already at the start of the planning phase an evaluation should be done to quantify the hydro-abrasive erosion and the impact on the operation. For this, the influencing parameters and their impact on the hydro-abrasive erosion have to be known. The necessary information for the evaluation comprises among others the future design, the particle parameters of the water, which will pass the turbine, the reservoir sedimentation and the power plant owner's framework for the future operation like availability or maximum allowable efficiency loss, before an overhaul needs to be done.

Based on this evaluation of the hydro-abrasive erosion, an optimised solution can then be found, by analysing all measures in relation to investments, energy production and maintenance costs as decision parameters. Often a more hydro-abrasive erosion-resistant design, instead of choosing the turbine design with the highest efficiency, will lead to higher revenue. This analysis is best performed by the overall plant designer.

With regards to the machines, owners should find the means to communicate to potential suppliers for their sites, their desire to have the particular attention of the designers at the turbine design phase, directed to the minimization of the severity and effects of hydro-abrasive erosion.

Limited consensus and very little quantitative data exists on the steps which the designer could and should take to extend the useful life before major overhaul of the turbine components when they are operated under severe hydro-abrasive erosion service. This has led some owners to write into their specifications, conditions which cannot be met with known methods and materials.

HYDRAULIC MACHINES – GUIDELINES FOR DEALING WITH HYDRO-ABRASIVE EROSION IN KAPLAN, FRANCIS, AND PELTON TURBINES

1 Scope

This document gives guidelines for:

- a) presenting data on hydro-abrasive erosion rates on several combinations of water quality, operating conditions, component materials, and component properties collected from a variety of hydro sites;
- b) developing guidelines for the methods of minimizing hydro-abrasive erosion by modifications to hydraulic design for clean water. These guidelines do not include details such as hydraulic profile shapes which are determined by the hydraulic design experts for a given site;
- c) developing guidelines based on “experience data” concerning the relative resistance of materials faced with hydro-abrasive erosion problems;
- d) developing guidelines concerning the maintainability of materials with high resistance to hydro-abrasive erosion and hardcoatings;
- e) developing guidelines on a recommended approach, which owners could and should take to ensure that specifications communicate the need for particular attention to this aspect of hydraulic design at their sites without establishing criteria which cannot be satisfied because the means are beyond the control of the manufacturers;
- f) developing guidelines concerning operation mode of the hydro turbines in water with particle materials to increase the operation life.

It is assumed in this document that the water is not chemically aggressive. Since chemical aggressiveness is dependent upon so many possible chemical compositions, and the materials of the machine, it is beyond the scope of this document to address these issues.

It is assumed in this document that cavitation is not present in the turbine. Cavitation and hydro-abrasive erosion can reinforce each other so that the resulting erosion is larger than the sum of cavitation erosion plus hydro-abrasive erosion. The quantitative relationship of the resulting hydro-abrasive erosion is not known and it is beyond the scope of this document to assess it, except to suggest that special efforts be made in the turbine design phase to minimize cavitation.

Large solids (e.g. stones, wood, ice, metal objects, etc.) traveling with the water can impact turbine components and produce damage. This damage can in turn increase the flow turbulence thereby accelerating wear by both cavitation and hydro-abrasive erosion. Hydro-abrasive erosion resistant coatings can also be damaged locally by impact of large solids. It is beyond the scope of this document to address these issues.

This document focuses mainly on hydroelectric powerplant equipment. Certain portions can also be applicable to other hydraulic machines.

2 Terms, definitions and symbols

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: