

INTERNATIONAL STANDARD



Hydraulic turbines, storage pumps and pump-turbines – Rehabilitation and performance improvement



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2017 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.

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

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
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 corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub

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 It also gives information on projects, replaced and withdrawn publications.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 also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions 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

65 000 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.

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: csc@iec.ch.

INTERNATIONAL STANDARD



Hydraulic turbines, storage pumps and pump-turbines – Rehabilitation and performance improvement

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.140

ISBN 978-2-8322-4340-4

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	7
INTRODUCTION.....	9
1 Scope.....	10
2 Normative references	10
3 Terms, definitions and nomenclature	10
4 Reasons for rehabilitating.....	12
4.1 General.....	12
4.2 Reliability and availability increase.....	14
4.3 Life extension and performance restoration.....	14
4.4 Performance improvement	14
4.5 Plant safety improvement.....	14
4.6 Environmental, social and regulatory issues.....	15
4.7 Maintenance and operating cost reduction	15
4.8 Other considerations.....	15
5 Phases of a rehabilitation project.....	15
5.1 General.....	15
5.2 Decision on organization.....	17
5.2.1 General	17
5.2.2 Expertise required	17
5.2.3 Contract arrangement.....	17
5.3 Level of assessment and determination of scope	18
5.3.1 General	18
5.3.2 Feasibility study – Stage 1.....	19
5.3.3 Feasibility study – Stage 2.....	19
5.3.4 Detailed study.....	19
5.4 Contractual issues	23
5.4.1 General	23
5.4.2 Specification requirements.....	24
5.4.3 Tendering documents and evaluation of tenders	24
5.4.4 Contract award(s)	25
5.5 Execution of project	25
5.5.1 Model test activities	25
5.5.2 Design, construction, installation and testing	25
5.6 Evaluation of results and compliance with guarantees.....	26
5.6.1 General	26
5.6.2 Turbine performance evaluation.....	26
5.6.3 Generator performance evaluation.....	27
5.6.4 Penalties and/or bonuses assessment	27
6 Scheduling, cost analysis and risk analysis	27
6.1 Scheduling.....	27
6.1.1 General	27
6.1.2 Scheduling – Assessment, feasibility and detailed study phases.....	28
6.1.3 Evaluating the scheduling component of alternatives	28
6.1.4 Scheduling specification and tendering phase	29
6.1.5 Scheduling project execution phases	29
6.2 Economic and financial analyses	29

6.2.1	General	29
6.2.2	Benefit-cost analysis.....	30
6.2.3	Identification of anticipated benefits.....	31
6.2.4	Identification of anticipated costs and benefits	32
6.2.5	Sensitivity analysis	33
6.2.6	Conclusions.....	34
6.3	Risk analysis.....	34
6.3.1	General	34
6.3.2	Non-achievement of performance risk.....	34
6.3.3	Risk of continued operation without rehabilitation	35
6.3.4	Extension of outage risk	35
6.3.5	Financial risks	35
6.3.6	Project scope risk	36
6.3.7	Other risks.....	36
7	Assessment and determination of scope of the work.....	37
7.1	General.....	37
7.2	Assessment of the site.....	37
7.2.1	Hydrology	37
7.2.2	Actual energy production	38
7.2.3	Environmental, social and regulatory issues	38
7.3	The assessment of the turbine	39
7.3.1	General	39
7.3.2	Turbine integrity assessment.....	39
7.3.3	Residual life.....	52
7.3.4	Turbine performance assessment.....	61
7.4	The assessment of related equipment.....	83
7.4.1	General	83
7.4.2	Generator and thrust bearing	84
7.4.3	Turbine governor	84
7.4.4	Turbine inlet and outlet valves, pressure relief valve.....	85
7.4.5	Auxiliary equipment	85
7.4.6	Equipment for erection, dismantling and maintenance	86
7.4.7	Penstock and other water passages	86
7.4.8	Consequences of changes in plant specific hydraulic energy (head)	86
7.4.9	Grid integration.....	87
8	Hydraulic design and performance testing options	87
8.1	General.....	87
8.2	Computational hydraulic design	88
8.2.1	General	88
8.2.2	The role of CFD	88
8.2.3	The process of a CFD cycle.....	89
8.2.4	The accuracy of CFD results.....	89
8.2.5	How to use CFD for rehabilitation	90
8.2.6	CFD versus model tests.....	91
8.3	Model tests	91
8.3.1	General	91
8.3.2	Model test similitude	92
8.3.3	Model test content	93
8.3.4	Model test application.....	93

8.3.5	Model test location	95
8.4	Prototype performance test	96
8.4.1	General	96
8.4.2	Prototype performance test accuracy	97
8.4.3	Prototype performance test types	97
8.4.4	Evaluation of results	98
9	Specifications	99
9.1	General	99
9.2	Reference standards	99
9.3	Information to be included in the tender documents	100
9.4	Documents to be developed in the course of the project	101
Annex A (informative)	Check-list for evaluation of existing turbine	103
Annex B (informative)	Assessment examples	136
B.1	General	136
B.2	Runner (applicable to Francis, Kaplan, propeller and Pelton)	136
B.2.1	Documentation – available data	136
B.2.2	Design review	137
B.2.3	Inspection items	137
B.2.4	Assessment of inspection results	138
B.2.5	Current condition assessment	140
B.2.6	Scope of work	140
B.3	Stay ring	142
B.3.1	Documentation – available data	142
B.3.2	Design review	142
B.3.3	Inspection items	142
B.3.4	Assessment of inspection results	143
B.3.5	Current condition assessment	143
B.3.6	Scope of work (possible action to be taken)	144
B.4	Guide vanes	144
B.4.1	Documentation – Available data	144
B.4.2	Design review	145
B.4.3	Inspection items	145
B.4.4	Assessment of inspection results	146
B.4.5	Current condition assessment	147
B.4.6	Scope of work	147
B.5	Real life example: Pelton runner with severe crack	148
B.5.1	Data of the Pelton runner	148
B.5.2	Fatigue analysis	148
B.5.3	Fracture-mechanics analysis	150
B.5.4	Results for the Pelton runner	150
Annex C (informative)	Checklist for evaluation of related equipment	152
Bibliography	156
Figure 1	Flow diagram depicting the logic of the rehabilitation process	16
Figure 2	Critical zones for cracks “A” and “B” in Pelton runner buckets	51
Figure 3	Bathtub curve	53
Figure 4	Process of residual life estimation	54
Figure 5	Schematic behaviour for the different stages in the fatigue process	55

Figure 6 – Start-up and full load strain gauge signal on Francis blade.....	60
Figure 7 – Relative efficiency versus relative output – Original and new runners.....	63
Figure 8 – Relative efficiency versus output – Original and new runners – Outardes 3 generating station	64
Figure 9 – Efficiency and distribution of losses versus specific speed for Francis turbines (model) in 2005	65
Figure 10 – Relative efficiency gain following modification of the blades on the La Grande 3 runner, in Quebec, Canada.....	67
Figure 11 – Potential efficiency improvement for Francis turbine rehabilitation.....	71
Figure 12 – Potential efficiency improvement for Kaplan turbine rehabilitation	72
Figure 13 – Cavitation and corrosion-erosion in Francis runner.....	74
Figure 14 – Back side erosion of the entrance into a Pelton bucket.....	75
Figure 15 – Leading edge cavitation erosion on a Francis pump-turbine caused by extended periods of operation at very low loads.....	76
Figure 16 – Severe particle erosion damage in a Francis runner	78
Table 1 – Expected life of a hydropower plant and its subsystems before major work	13
Table 2 – Typical routine inspections	41
Table 3 – Example of a rating system for the inspection results	58
Table 4 – Example of a typical list of turbine components for Francis and Kaplan with different weight factors X_1 to X_7 based on relative importance.....	59
Table 5 – Example of rating of a single component assessment including three assessment criteria.....	59
Table 6 – Francis turbine potential efficiency improvement (%) for runner profile modifications only	66
Table 7 – Potential impact of design and condition of runner seals on Francis turbine efficiency with new replacement runner or rehabilitated runner (%).....	69
Table 8 – Potential total gain in efficiency from the replacement of a Francis turbine runner including the blade profile improvements, the restoration of surface condition and the reduction of seal losses.....	69
Table 9 – Potential additional efficiency improvement by rehabilitation/replacement of other water passage components on a Francis turbine (%)	70
Table A.1 – Assessment of turbine embedded parts – Stay ring	103
Table A.2 – Assessment of turbine embedded parts – Spiral or semi-spiral case	104
Table A.3 – Assessment of turbine embedded parts – Discharge ring	105
Table A.4 – Assessment of turbine embedded parts – Draft tube	107
Table A.5 – Assessment of turbine non-embedded, non-rotating parts – Headcover	109
Table A.6 – Assessment of turbine non-embedded, non-rotating parts – Intermediate and inner headcovers	112
Table A.7 – Assessment of turbine non embedded, non-rotating parts – Bottom ring	113
Table A.8 – Assessment of turbine non embedded, non-rotating parts – Guide vanes.....	115
Table A.9 – Assessment of turbine non embedded, non-rotating parts – Guide vane operating mechanism.....	117
Table A.10 – Assessment of turbine non embedded, non-rotating parts – Operating ring	118
Table A.11 – Assessment of turbine non embedded, non-rotating parts – Servomotors.....	119
Table A.12 – Assessment of turbine non embedded, non-rotating parts – Guide bearings.....	120

Table A.13 – Assessment of turbine non embedded, non-rotating parts – Turbine shaft seal (mechanical seal or packing box)	122
Table A.14 – Assessment of turbine non embedded, non-rotating parts – Thrust bearing support.....	122
Table A.15 – Assessment of turbine non embedded, non-rotating parts – Nozzles	123
Table A.16 – Assessment of turbine non embedded, non-rotating parts – Deflectors and energy dissipation	124
Table A.17 – Assessment of turbine rotating parts – Runner	125
Table A.18 – Assessment of turbine rotating parts – Runner	128
Table A.19 – Assessment of turbine rotating parts – Runner	130
Table A.20 – Assessment of turbine rotating parts – Turbine shaft.....	131
Table A.21 – Assessment of turbine rotating parts – Oil head and oil distribution pipes	132
Table A.22 – Assessment of turbine auxiliaries – Speed and load regulation system (governor).....	133
Table A.23 – Assessment of turbine auxiliaries – Turbine aeration system.....	134
Table A.24 – Assessment of turbine auxiliaries – Lubrication system (guide vane mechanism)	135
Table C.1 – Assessment of related equipment – Governor	152
Table C.2 – Assessment of related equipment – Generator and thrust bearing.....	153
Table C.3 – Assessment of related equipment – Penstock and turbine inlet valves	154
Table C.4 – Assessment of related equipment – Civil works.....	155
Table C.5 – Assessment of related equipment – Crane, erection equipment	155

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**HYDRAULIC TURBINES, STORAGE PUMPS AND PUMP-TURBINES –
REHABILITATION AND PERFORMANCE IMPROVEMENT**

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 62256 has been prepared by IEC technical committee 4: Hydraulic turbines.

This second edition cancels and replaces the first edition published in 2008. This edition constitutes a technical revision.

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

- Tables 2 to 23 modified, completed and moved to Annex A;
- 7.3.2:
 - subclauses moved with text changes;
 - new subclauses on temperature, noise, galvanic corrosion, galling and replacement of components without assessment;
- 7.3.3: complete new subclause on residual life;
- Tables 29 to 32 moved to Annex C;

- new Annex B with assessment examples.

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

FDIS	Report on voting
4/323/FDIS	4/326/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.

A bilingual version of this publication may be issued at a later date.

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

Hydro plant owners make significant investments annually in rehabilitating plant equipment (turbines, generators, transformers, penstocks, gates etc.) and structures in order to improve the level of service to their customers and to optimize their revenue. In the absence of guidelines, owners may be spending needlessly, or may be taking unnecessary risks and thereby achieving results that are less than optimal. This document is intended to be a tool in the optimisation and decision process.

Edition 1 of this International Standard was based on the IEA document *Guidelines on Methodology for Hydroelectric Francis Turbine Upgrading by Runner Replacement*.

HYDRAULIC TURBINES, STORAGE PUMPS AND PUMP-TURBINES – REHABILITATION AND PERFORMANCE IMPROVEMENT

1 Scope

This document covers turbines, storage pumps and pump-turbines of all sizes and of the following types:

- Francis;
- Kaplan;
- propeller;
- Pelton (turbines only);
- bulb turbines.

This document also identifies without detailed discussion, other powerhouse equipment that could affect or be affected by a turbine, storage pump, or pump-turbine rehabilitation.

The object of this document is to assist in identifying, evaluating and executing rehabilitation and performance improvement projects for hydraulic turbines, storage pumps and pump-turbines. This document can be used by owners, consultants, and suppliers to define:

- needs and economics for rehabilitation and performance improvement;
- scope of work;
- specifications;
- evaluation of results.

This document is intended to be:

- an aid in the decision process;
- an extensive source of information on rehabilitation;
- an identification of the key milestones in the rehabilitation process;
- an identification of the points to be addressed in the decision processes.

This document is not intended to be a detailed engineering manual nor a maintenance document.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and nomenclature

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>