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NORME INTERNATIONALE

Hydraulic machines, radial and axial – Performance conversion method from model to prototype

Machines hydrauliques, radiales et axiales – Méthode de conversion des performances du modèle au prototype

IEC 62097:2009

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

HYDRAULIC MACHINES, RADIAL AND AXIAL – PERFORMANCE CONVERSION METHOD FROM MODEL TO PROTOTYPE

FOREWORD

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International Standard IEC 62097 has been prepared by technical committee 4: Hydraulic turbines.

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

FDIS	Report of voting
4/242A/FDIS	4/243/RVD

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

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

This publication contains attached files in the form of Excel file. These files are intended to be used as a complement and do not form an integral part of this publication.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result data indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- recommended;
- withdrawn;
- replaced by a revised edition;
- or amended.

INTRODUCTION

0.1 General remarks

This International Standard establishes the prototype hydraulic machine efficiency from model test results, with consideration of scale effect including the effect of surface roughness.

Advances in the technology of hydraulic turbo-machines used for hydroelectric power plants indicate the necessity of revising the scale effect formula given in 3.8 of IEC 60193. [1][1] The advance in knowledge of scale effects originates from work done by research institutes, manufacturers and relevant working groups within the organizations of IEC and IAHR. [1 - 7]

The method of calculating prototype efficiencies, as given in this standard, is supported by experimental work and theoretical research on flow analysis and has been simplified for practical reasons and agreed as a convention. [8 – 10] The method is representing the present state of knowledge of the scale-up of performance from model to a homologous prototype.

Homology is not limited to the geometric similarity of the machine components, it also calls for homologous velocity triangles at the inlet and outlet of the runner/impeller. [2] Therefore, compared to IEC 60193, a higher attention has to be paid to the geometry of guide vanes.

According to the present state of knowledge, it is certain that, in most cases, the formula for the efficiency step-up calculation given in the IEC 60193 and earlier standards, overstated the step-up increment of the efficiency for the prototype. Therefore, in the case where a user wants to restudy a project for which a calculation of efficiency step-up was done based on any previous method, the user shall re-calculate the efficiency step-up with the new method given in this standard, before restudying the project of concern.

This standard is intended to be used mainly for the assessment of the results of contractual model tests of hydraulic machines. If it is used for other purposes such as evaluation of refurbishment of machines having very rough surfaces, special care should be taken as described in Annex B.

Due to the lack of sufficient knowledge about the loss distribution in Deriaz turbines and storage pumps, this standard does not provide the scale effect formula for them.

An excel work sheet concerning the step-up procedures of hydraulic machine performance from model to prototype is indicated at the end of this Standard to facilitate the calculation of the step-up value.

0.2 Basic features

A fundamental difference compared to the IEC 60193 formula is the standardization of scalable losses. In a previous standard (see 3.8 of IEC 60193:1999 [1]), a loss distribution factor V has been defined and standardized, with the disadvantage that turbine designs which are not optimized benefit from their lower technological level.

This is certainly not correct, since a low efficiency design has high non-scalable losses, like incidence losses, whereby the amount of scalable losses is about constant for all manufacturers, for a given type and a given specific speed of a hydraulic machine.

This standard avoids all the inconsistencies connected with IEC 60193:1999. (see 3.8 of [1]) A new basic feature of this standard is the separate consideration of losses in specific hydraulic energy, disc friction losses and leakage losses. [5], [8 – 10]

[1] Numbers in square brackets refer to the bibliography.

Above all, in this standard, the scale-up of the hydraulic performance is not only driven by the dependence of friction losses on Reynolds number Re, but also the effect of surface roughness Ra has been implemented.

Since the roughness of the actual machine component differs from part to part, scale effect is evaluated for each individual part separately and then is finally summed up to obtain the overall step-up for a complete turbine. [10] For radial flow machines, the evaluation of scale effect is conducted on five separate parts; spiral case, stay vanes, guide vanes, runner and draft tube. For axial flow machines, the scalable losses in individual parts are not fully clarified yet and are dealt with in two parts; runner blades and all the other stationary parts inclusive.

The calculation procedures according to this standard are summarized in Clause 7 and Excel sheets are provided as an Attachment to this standard to facilitate the step-up calculation.

In case that the Excel sheets are used for evaluation of the results of a contractual model test, each concerned party shall execute the calculation individually for cross-check using common input data agreed on in advance.

HYDRAULIC MACHINES, RADIAL AND AXIAL – PERFORMANCE CONVERSION METHOD FROM MODEL TO PROTOTYPE

1 Scope

This International Standard is applicable to the assessment of the efficiency and performance of prototype hydraulic machine from model test results, with consideration of scale effect including the effect of surface roughness.

This standard is intended to be used for the assessment of the results of contractual model tests of hydraulic machines.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60193:1999, *Hydraulic turbines, storage pumps and pump-turbines – Model acceptance tests*

3 Terms, definitions, symbols and units

3.1 System of units

The International System of Units (SI) is used throughout this standard. All terms are given in SI Base Units or derived coherent units. Any other system of units may be used after written agreement of the contracting parties.

3.2 List of terms

For the purposes of this document, the terms and definitions of IEC 60193 apply, as well as the following terms, definitions, symbols and units.

3.2.1 Subscripts' list

Term	Symbol	Term	Symbol	
model	M	component	CO	
prototype	P			
specific energy	E	spiral case	SP	in general term represented by CO
volumetric	Q	stay vane	SV	
torque or disc friction	T	guide vane	GV	
reference	ref	runner	RU	
hydraulic diameter	d	draft tube	DT	
velocity	u	stationary part	ST	
hydraulic	h			
optimum point	opt			
off design point	off			

3.2.2 Terms, definitions, symbols and units

Term	Definition	Symbol	Unit
Radial flow machines	Francis turbines and Francis type reversible pump-turbines	-	-
Axial flow machines	Kaplan turbines, bulb turbines and fixed blade propeller turbines	-	-
Reference diameter	Reference diameter of the hydraulic machine (see Figure 3 of IEC 60193)	D	m
Hydraulic diameter	4 times sectional area divided by the circumference of the section	d_h	m
Sand roughness	Equivalent sand roughness [11]	k_S	m
Arithmetical mean roughness	Deviation of the surface profile represented by the arithmetical mean value	Ra	m
Acceleration due to gravity	Local value of gravitational acceleration at the place of testing as a function of altitude and latitude (see IEC 60193)	g	$m\ s^{-2}$
Density of water	Mass per unit volume of water (see IEC 60193)	ρ	$kg\ m^{-3}$
Dynamic viscosity	A quantity characterizing the mechanical behaviour of a fluid	μ	Pa s
Kinematic viscosity	Ratio of the dynamic viscosity to the density of the fluid. Values are given as a function of temperature. (see IEC 60193)	ν	$m^2\ s^{-1}$
Discharge	Volume of water per unit time flowing through any section in the system	Q	$m^3\ s^{-1}$
Mass flow rate	Mass of water flowing through any section of the system per unit time	$(\rho\ Q)$	$kg\ s^{-1}$
Discharge of machine	Discharge flowing through the high pressure reference section	Q_1	$m^3\ s^{-1}$
Leakage flow rate	Volume of water per unit time flowing through the runner seal clearances	q	$m^3\ s^{-1}$
Net discharge	Volume of water per unit time flowing through runner/impeller. It corresponds to Q_1-q in case of turbine and Q_1+q in case of pump.	Q_m	$m^3\ s^{-1}$
Mean velocity	Discharge divided by the sectional area of water passage	v	$m\ s^{-1}$
Peripheral velocity	Peripheral velocity at the reference diameter	u	$m\ s^{-1}$
Rotational speed	Number of revolutions per unit time	n	S^{-1}
Specific hydraulic energy of machine	Specific energy of water available between the high and low pressure reference sections 1 and 2 of the machine taking into account the influence of compressibility (see IEC 60193)	E	$J\ kg^{-1}$
Specific hydraulic energy of runner/impeller	Turbine: Net specific hydraulic energy working on the runner Pump: Specific hydraulic energy produced by the impeller	E_m E_m	$J\ kg^{-1}$ $J\ kg^{-1}$
Specific hydraulic energy loss in stationary part	Specific hydraulic energy loss in stationary part which includes both friction loss and kinetic loss	E_{Ls}	$J\ kg^{-1}$
Specific hydraulic energy loss in runner/impeller	Specific hydraulic energy loss in runner/impeller which includes both friction loss and kinetic loss	E_{Lm}	$J\ kg^{-1}$
Friction loss of specific hydraulic energy	Specific hydraulic energy loss caused by the friction on the surface of water passages	E_{Lf}	$J\ kg^{-1}$

Term	Definition	Symbol	Unit
Kinetic loss of specific hydraulic energy	Specific hydraulic energy loss caused by the hydraulic phenomena other than surface friction, such as turbulence, separation of flow, abrupt change of water passage, etc.	E_{lk}	J kg^{-1}
Turbine net head or pump delivery head	H = E / g	H	m
Turbine output or pump input	The mechanical power delivered by the turbine shaft or to the pump shaft, assigning to the hydraulic machine the mechanical losses of the relevant bearings and shaft seals (see Figures A.1 and A.2)	P	W
Hydraulic power	The power available for producing power (turbine) or imparted to the water (pump) $P_h = E\ (\rho Q_1)$	P_h	W
Mechanical power of runner/ impeller	The power transmitted through the coupling between shaft and runner (impeller).	P_m	W
Power of runner/impeller	Turbine: Power produced by the runner corresponding to $E_m\ (\rho Q_m)$ or $P_m + P_{Ld}$ Pump: Power produced by the impeller represented by $E_m(\rho Q_m)$ or $P_m - P_{Ld}$	P_r P_r	W W
Disc friction loss	Loss power caused by the friction on the outer surface of the runner/impeller	P_{Ld}	W
Bearing loss power	Loss power caused by the friction of the shaft bearing and shaft seal	P_{Lm}	W
Runner/impeller torque	Torque transmitted through the coupling of the runner/impeller and the shaft corresponding to the mechanical power of runner/impeller, P_m	T_m	N m
Hydraulic efficiency	Turbine: $\eta_h = P_m/P_h$ Pump: $\eta_h = P_h/P_m$	η_h	-
Specific hydraulic energy efficiency	Turbine: $\eta_E = E_m/E_h$ Pump: $\eta_E = E_h/E_m$ (see Figures A.1 and A.2)	η_E	-
Volumetric efficiency	Turbine: $\eta_Q = Q_m/Q_1$ Pump: $\eta_Q = Q_1/Q_m$ (see Figures A.1 and A.2)	η_Q	-
Power efficiency (disc friction efficiency)	Turbine : $\eta_T = P_m/P_r$ Pump : $\eta_T = P_r/P_m$ (see Figures A.1 and A.2)	η_T	-
Mechanical efficiency	Turbine: $\eta_m = P/P_m$ Pump: $\eta_m = P_m/P$ (see Figures A.1 and A.2)	η_m	-
Efficiency step-up	Difference between efficiencies at two hydraulically similar operating conditions	$\Delta\eta$	-
Efficiency step-up ratio	Ratio of efficiency step-up against model efficiency $\Delta = \frac{\Delta\eta}{\eta_M}$	Δ	
Reynolds number	Reynolds number of the machine $Re = D\ u / \nu$	Re	-
Reynolds number of component passage	$Re_d = d_h\ v / \nu$	Re_d	-
Friction loss coefficient for pipe flow	Friction loss coefficient for a pipe. $\lambda = \frac{E_{Lf}}{\frac{L}{d}\frac{v^2}{2}}$ where d pipe diameter (m) L pipe length (m)	λ	-

Term	Definition	Symbol	Unit
Friction loss coefficient for a flat plate	Friction loss coefficient for a flat plate. $$C_f = \frac{E_{Lf}}{\frac{BL}{Q}\ \frac{w^3}{2}}$$ where B width of a flat plate (m) L length of a flat plate (m) Q discharge passing by the plate (m^3/s) w relative flow velocity (m/s)	C_f	-
Disc friction loss coefficient	Friction loss coefficient for a rotating disc $$C_m = \frac{P_{Ld}}{\frac{\pi^4}{8}\rho n^3 D_d^5}$$ where D_d diameter of the rotating disc (m)	C_m	-
Relative scalable hydraulic energy loss	Scalable specific hydraulic energy loss divided by E, which is dependent on Reynolds number and roughness (in most cases, it is represented in %) $\delta_E = E_{lf}/E$	δ_E	-
Relative non-scalable hydraulic energy loss	Non-scalable specific hydraulic energy loss divided by E, which remains constant regardless of Reynolds number and roughness $\delta_{ns} = E_{lk}/E$	δ_{ns}	-
Reference scalable hydraulic energy loss	δ_E value for a model with smooth surface operating at a reference Reynolds number Re = 7 × 10^6	δ_{Eref}	-
Reference scalable hydraulic energy loss in component passage	δ_{Eref} for each component passage	δ_{ECOref}	-
Relative disc friction loss	Disc friction loss P_{Ld} divided by P_m $$\delta_T = \frac{P_{Ld}}{P_m}$$	δ_T	-
Reference disc friction loss	δ_T value for a model with fairly smooth surface operating at a reference Reynolds number Re = 7 × 10^6	δ_{Tref}	-
Flow velocity factor for each component passage	Ratio of the maximum relative flow velocity in each component passage against the peripheral velocity u $$\kappa_{uCO} = \frac{v_{CO}}{u}$$	κ_{uCO}	-
Dimension factor for each component passage	Ratio of the hydraulic diameter of each component passage against the reference diameter $$\kappa_{dCO} = \frac{d_{hCO}}{D}$$	κ_{dCO}	-

Term	Definition	Symbol	Unit
Dimension factor for disc friction loss	Ratio of the diameter of the runner crown or runner band against the reference diameter $\kappa_T = \frac{D_d}{D}$ D_d: diameter of the runner crown or the runner band, whichever larger	κ_T	-
Scalable hydraulic energy loss index for each component passage	$d_{ECOref} = \frac{\delta_{ECOref}}{1 + 0{,}351\left(\kappa_{uCO} \times \kappa_{dCO}\right)^{0{,}2}}$	d_{ECOref}	-
Scalable disc friction loss index	$d_{Tref} = \frac{\delta_{Tref}}{1 + 0{,}154\ \kappa_T^{\ 0{,}4}}$	d_{Tref}	-
Loss distribution factor	Ratio of scalable loss to total loss $V = \frac{\delta}{1 - \eta_h}$	V	-
Specific speed	$N_{QE} = \frac{nQ_1^{\ 0{,}5}}{E^{0{,}75}}$	N_{QE}	-
Speed factor	$n_{ED} = \frac{nD}{E^{0{,}5}}$	n_{ED}	-
Discharge factor	$Q_{ED} = \frac{Q_1}{D^2 E^{0{,}5}}$	Q_{ED}	-
Power factor	$P_{ED} = \frac{P_m}{\rho_1 D^2 E^{1{,}5}}$	P_{ED}	-
Energy coefficient	$E_{nD} = \frac{E}{n^2 D^2}$	E_{nD}	-
Discharge coefficient	$Q_{nD} = \frac{Q_1}{nD^3}$	Q_{nD}	-
Power coefficient	$P_{nD} = \frac{P_m}{\rho_1 n^3 D^5}$	P_{nD}	-

4 Scale-effect formula

4.1 General

4.1.1 Scalable losses

The energy flux through hydraulic machines and the various losses produced in the energy conversion process in a hydraulic machine can be typically illustrated by the flux diagrams shown in A.1. [4]

As a consequence, one of the main features of the new scale up formula as stated in this standard is the separate consideration on three efficiency components. They are specific