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Analysis and processing of index tests results at double-adjust hydraulic turbines with a computer-aided design software

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Abstract. The paper presents a method developed and used by the CCHAPT researchers for the graphic plotting of the index tests results for hydraulic turbines, the comparison of the efficiency curves resulted from testing to those obtained by the model transposition [1] i.e. the determination and comparison of the existing combinatory cam with that obtained from tests.
The method presented in the paper was born from the need for processing and presenting the results of index tests within the shortest delay and eliminating the errors that might occur in the results plotting.

Introduction

When a hydro unit is commissioned, before and after the refurbishment works, it is subjected to a set of tests to quantify both the efficiency gain and electric power produced, as well as its general condition. One of the most important dimensions measured during these tests is the discharge. There are several methods for measuring the debit at hydraulic turbines, but most of them require expensive, lengthy measurements and they block the hydro unit exploitation for a period of time unfavourable for the beneficiaries. The simplest and most efficient methods from the economical point of view for flow measurement, currently used in the field, is the Winter – Kennedy method [2, 3, 4].

The index tests, as defined in [5], represent the totality of tests performed in the hydro electro power plant on the hydro unit for determining the flow and efficiency as relative dimensions (the Winter-Kennedy method [2]), and are used on the commissioning of a hydro unit or after a capital repair and are performed by specialised personnel with high-precision measuring tools. Beside flow and efficiency, within the index tests, at the beneficiary's request one may also check the combinatory link implemented in the hydro unit governor.

The paper presents the way this method was used for the graphic plotting of the index tests, the determination of the combinatory link resulted from the tests and the comparison with the implemented link and that resulted from the model transposition, tests performed on a 19.5 MW Kaplan turbine.

Index tests on hydraulic turbines

Theoretic considerations. As defined according to [5], an index value is an arbitrary value, measured with non-gauged instruments with primary methods. For instance, the index efficiency is calculated from the specific hydraulic energy, power and debit, measured with non-gauged tools by primary methods.

For the double-adjust turbines the index tests procedure for a head requires two sets of measurements: measurements on cam and measurement outside the combinatory cam.

The cam measurements start from minimum power and progress to maximum power, and are performed in minimum 5 points, with equal power steps.

The measurements outside the cam preferably start from the maximum power, for a preset number of angular positions of runner blades. The measuring procedure is graphically illustrated in [6] and described in detail in [7].

Actually, in most cases, the start point on the cam does not correspond to the maximum efficiency point on the helicoidal curve determined from index tests, and the optimum cam point for the prescribed runner blades opening.

For a better understanding of the problem, the article will present the graphic results of the index tests obtained on a 19.5 MW Kaplan turbine for a measured head.

Index tests performed on a 19.5 MW Kaplan turbine. The index tests presented below were performed for the verification of the unit condition after capital repairs.

The turbine technical data subjected to testing are:

- maximum power at maximum net head: 19.5 MW;
- nominal number of revolutions: 93.75 rpm;
- maximum net head: 14 m;
- net head: 13.25 m;
- minimum net head: 11 m;
- maximum discharge: 156 m^3/s.

In order to determine flow and efficiency, one measured the following dimensions:

- upstream level after grate;
- downstream level at the exit from turbine;
- pressure gap on Winter-Kennedy taps on the spiral chase;
- the stroke of the wicket gate servomotor piston;
- stroke of runner servomotor;
- active power at the generator terminals.

From the measured dimensions one determined:

- *net head*:

$$H_n = z_i - z_e - 1{,}0965 \cdot 10^{-5} Q^2 \qquad (1)$$

where: z_i is the upstream level in the turbine entry section (placed after grate); z_e - downstream level in the turbine exit section; Q - discharge.

- *turbine hydraulic power*:

$$P_T = \rho \cdot g \cdot H_n \cdot Q \cdot \eta_h = \frac{P_A}{\eta_G}. \qquad (2)$$

where P_A is the active power measured on the generator terminals, η_G generator efficiency grunted by the supplier, given by the relation:

$$\eta_G = -0.000329538046847169 P_A^2 + 0.0130884353741485 P_A + 0.845000000000009. \qquad (3)$$

- *discharge measured by Winter-Kennedy method*:

$$Q = k_{WK} \cdot \sqrt{\Delta h}\ . \qquad (4)$$

where: k_{wk} coefficient of Winter-Kennedy debitmetry, Δh the pressure gap measured at the Winter-Kennedy taps on the spiral chase.

- *the turbine efficiency*:

$$\eta_T = \eta_h = \frac{P_T}{\rho \cdot g \cdot H_n Q}\,. \tag{5}$$

- *opening of wicket gate blades*:

$$a_0 = -0.00000075 \cdot S_{AD}^3 + 0.00107592 \cdot S_{AD}^2 + 0.41008942 \cdot S_{AD} - 0.11235177\,. \tag{6}$$

where S_{AD} *represents* the measured stroke of the wicket gate servomotor.
- *runner blades opening*:

$$\varphi = -0.00000008 \cdot S_R^3 - 0.00002698 \cdot S_R^2 + 0.14132199 \cdot S_R - 9.99497792. \tag{7}$$

where S_R is the measured servomotor stroke.

From the measured dimensions and taking into account relations (1) – (7), one obtained the values of head, turbine efficiency, flow, runner blades opening angle and the opening of the runner blades.

As we may remark, for the 13.44 m head, 4 angular positions of the runner blades φ we measured, obtaining four sets of helicoidal curves whose envelope represents the turbine efficiency curve for the given head, curve which is compared to that resulted from scaled up from model at the same head.

Instruments for graphic plotting and value extraction with the help of the CAD Microstation software

In order to plot the results of the tests performed, we decided to import the calculated values into the CAD Microstation software because, beside the precision of determining value differences between curves in the CAD environments, the application offers, for interpolations, a „b-spline" curve [8], [9] and also a higher easiness in utilisation.

Thus, for the rapid data import into Microstation we developed a sequence of commands grouped in a „macro" which takes over the points coordinates from a „.csv" file exported from Excel, and transposes them into the CAD environment together with the afferent curves. Fig. 2 presents the window of developed macro, named „*curve settings*".

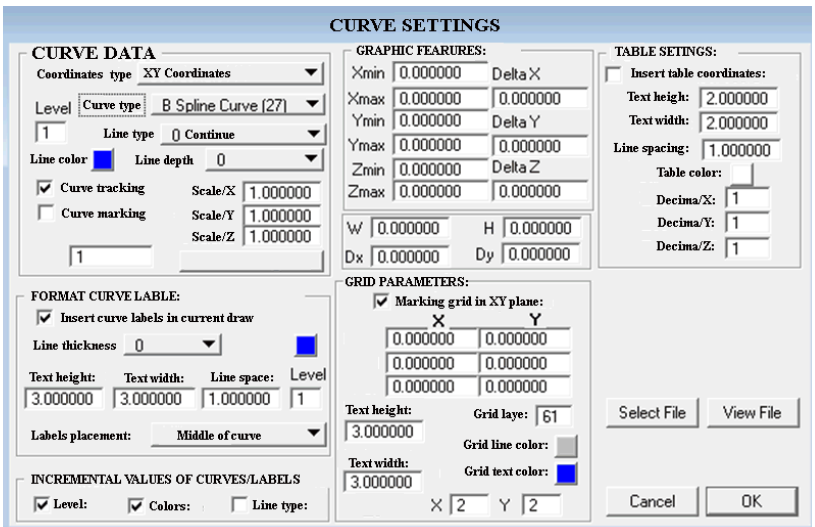

Fig. 2. The window of the „macro" for the curve import and plotting

The macro allows the user to define the parameters from a plot such as: type of plot curve, type of line, thickness, colour, tagging and other CAD options such as layers where plots and grid are to be placed.

There is however certain conditions imposed to source files providing the points for plotting. The Excel structure of a datafile for exemplification is presented in the figure below:

	A	B	C	D
1	4			
2	fi1	12		
3	fi2	10		
4	fi3	13		
5	fi4	13		
6				
7	fi1			
8	1	89.2295	9.74	
9	2	88.84	9.72	
10	3	89.0422	9.61	
11	4	88.7511	9.62	
12	5	90.727	9.88	
13	6	93.0421	10.06	
14	7	95.661	10.1	
15	8	95.1212	10.13	
16	9	87.1004	9.39	
17	10	86.8739	9.37	
18	11	82.9513	8.82	
19	12	83.1833	8.83	

Fig. 3. Example of file structure for importing

The file presented in fig. 3 represents the value of the points calculated for the runner blades opening angle against debit, φ = f(Q) at a certain head. In fig. 3, cell A1 represents the number of curves to be plotted from this file, cells A2-A5 bear the tags to be placed on the plot, cells B2-B5 show the number of points defining the curve for each opening, A7 sets the start location of the first curve, A8-A19 the current point number, B8 - B19 the values of the flow (Q) for the ordinate (x axis), C8 – C29 values of the runner blades opening angle (φ) for the abscissa (y axis). The same structure was followed for the other three curves.

With this type of tests however most of the times the beneficiaries desire comparisons and value comparisons. In order to realise this type of comparisons during tests or immediately after their finalisation we developed another macro, called „*Table settings*”, which takes over points from Microstation and transposes them into Excel values. The dialog box of this macro is presented in figure 4 below.

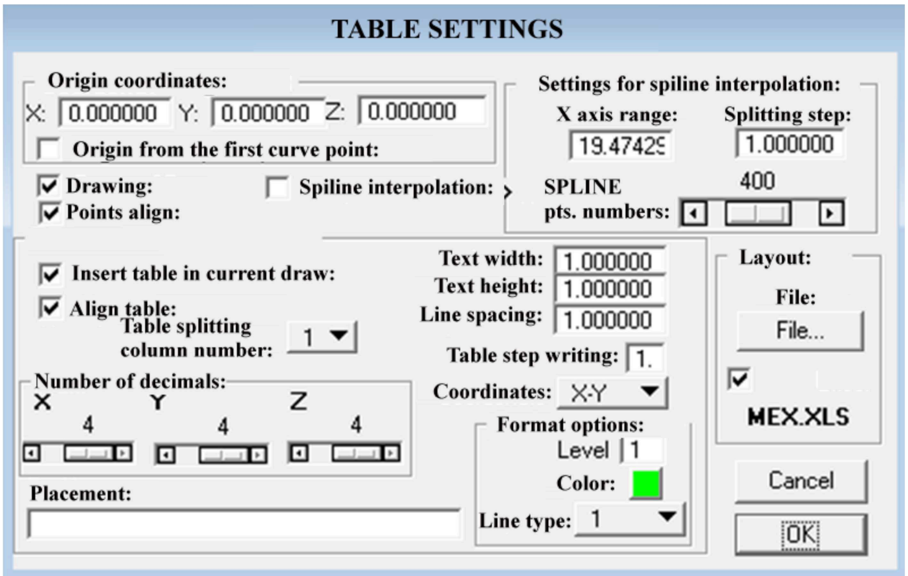

Fig. 4. The window of the point export „macro”

The macro reads the coordinates of the points marked on the existing plot with the command „Place active points” from Microstation framed by a „Fence” block. Additionally, for getting the point we need two files: an intermediate file called „file1.txt” and an Excel file called „MEX.xls” which have to be open when pressing the OK button. The only thing the operator has to do is to place the selected points for value extraction.

Presentation of graphic results of index tests results with Microstation

With the results obtained, presented in table 1 and with the help of the „curves" macro and the previous procedure we obtained the plot of the representative dimensions from the index tests performed on the aforementioned hydro unit, for the 13.44 m head.

The points marked by red triangle on the figure 5 plot represent the operation on the combinatory cam implemented in the hydro unit governor on the test moment. As it can be remarked, it does not always correspond with the maximum efficiency point obtained from the index tests, and the blue line dropped for the maximum efficiency obtained by intersecting the plotted curves for the opening of the blade of wicket gate and runner does not have values measured in these points. The marking of the intersection between the optimum efficiency obtained from tests and the curves of the two adjustment parts (wicket gate and runner) with „active point" from Microstation and the use of the „*Curve settings*" macro allowed the comparison of the adjustment parts curves obtained from index tests, resulted from scaled up from model and implemented in the governor presented in fig. 6.

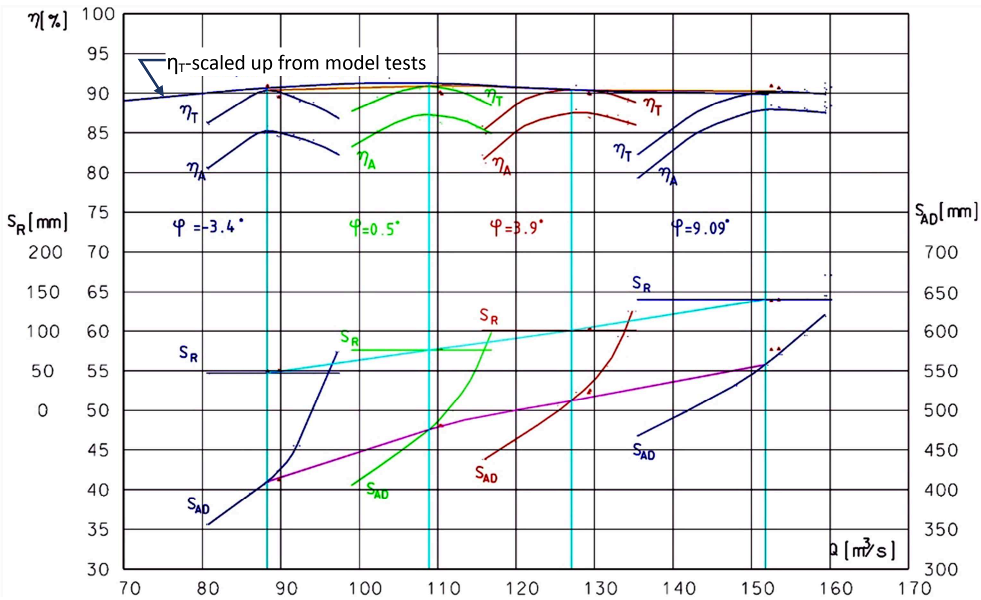

Fig. 5. Index tests graphical results for Hn=13.44 m

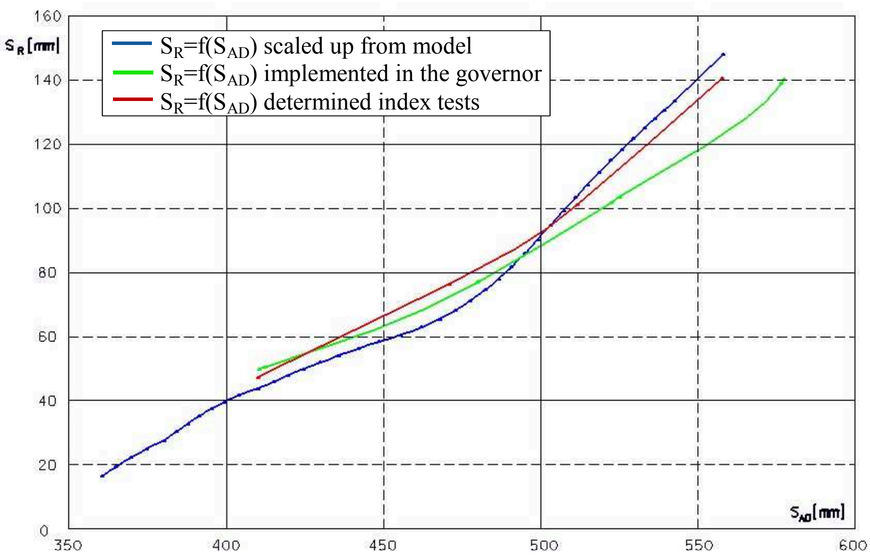

Fig. 6. Combinatory cams $S_R = f(S_{AD})$ for Hn=13.44 m

Conclusions

This method, used for graphic plotting of index tests results and verifications of combinatory cams with the help of the Microstation CAD software and the two developed macros, was applied for the test performed on 16 hydro units, before and after the refurbishment works or capital repairs and was accepted by the beneficiaries. The method allows the almost total elimination of errors that may occur in the graphic transmission of numeric results, as the 3D design environments are very precise.

As regards index tests, beside the possibility of import, export and short-time comparison of the curves obtained, the spline curve implemented in Microstation allows the best approximation used up to the present by the authors of the efficiency helilcoidal curves obtained for a given head and their envelope for comparison with the efficiency curve resulted from the model transposition.

Beside the benefits highlighted above, this methods presents an additional use of the CAD software which may be utilised in other engineering fields.

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References

[1] ********** „Determination of the prototype performance from model acceptance tests of hydraulic machines with consideration of scale effects”, Standard international IEC 995, Publication 1991.

[2] I.A. Winter, Improved Type of Flow Meter for Hydraulic Turbines, Proceedings of the ASCE, 1933.

[3] N. I. Zubarev, Index method for determination of turbine efficiency during full-scale tests, Gidrotekhnicheskoe Stroitel’stvo, 4, (2010), 27 – 29.

[4] Z.G. Yan, L.J. Zhou, Z.W. Wang, Turbine efficiency test on a large hydraulic turbine unit, Science China Press and Springer-Verlag Berlin Heidelberg, 2012.

[5] ********** „Hydraulic turbines, storage pumps and pump-turbines – Model acceptance tests”, International Standard IEC 60193, Second edition, 1999-11, International Electrotechnical Commission.

[6] C.V. Câmpian, D. Nedelcu, V. Barbu, C. Dumbravă, A. Cuzmoş, V. Suciu, Index tests performed on hydro unit no. 6 at CHE Iron Gates I before and after refurbishment, CCHAPT Technical Report no. U-02-400-23, August, 2012.

[7] C.V. Câmpian, Index tests performed on hydro unit no.6 at CHE Iron Gates I before refurbishment, Annals of the University „Eftimie Murgu” of Reşiţa, Year IV, no. 1, ISSN 1453-7394, Reşiţa, (1999), 63-72.

[8] R.H. Bartels, J.C. Beatty, B.A. Barsky, An Introduction to Splines for Use in Computer Graphics & Geometric Modeling, Morgan Kaufmann Publ., Los Altos CA 94022, 1987.

[9] C. de Boor, A Practical Guide to Splines, (Revised Edition), Springer-Verlag, New York, 2001.