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THE INTEREST OF EFFICIENCY MODEL TESTS

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1. INTRODUCTION

Upgrading and refurbishment projects have been constantly more common in these last few years. In many cases it is the only way to increase the electrical production. Not only financial problems but also ecological objections make the construction of new power plants difficult.

In case of a powerhouse refurbishment an important question always arises: are the turbines and especially the runners in relative good condition? Is it economical to change the runner or any other components, to modify the geometry of the draft tube, in order to obtain a better efficiency level and, if possible, increase the power? The answer to such questions is not so easy due to the fact that the old runner's efficiency is usually not known with a good accuracy.

Usually at the time of first commissioning of the plant, model testing was not so common. Even if a model test was performed, the accuracy was certainly quite poor. It is to be noted that a relatively small efficiency difference, some percents, can have a very important effect on the issue of the project from an economical point of view. The measurement accuracy plays a major role.

2. AIM OF THE PAPER

The aim of this paper is to propose a standard procedure for performance measurement and analysis applied on a refurbishment project.

In this type of project the usual procedure was to build an homologous model. The characteristic of the new prototype runner was calculated from model test results. Geometrically, the model was fully homologous with the prototype. Test results were stepped-up using standard formulas for the control of guaranteed performances [1], [2], [3].

With increasingly accurate field flow-rate measurements, prototype efficiencies are better known and discrepancies were evidenced between prediction and reality.

These discrepancies for the upgraded runner mainly come from the surface roughness of the rest of the water passages. The model is hydraulically smooth while the prototype, eroded/corroded by years of operation, has often a poor surface finish. Sometimes, riveted construction of the spiral case increases the wall roughness.

Under these circumstances, the best solution would be, to perform a prototype test before the model comparative tests in order to evaluate the real step-up value.

In the case of the existing runner characteristic measurement, the discrepancies between model and prototype tests are mainly due to:

- The conditions of the prototype surface roughness which is much higher than hydraulically smooth.

- The leakage through larger clearances of the labyrinth.

- The cast runners as which made until the end of the years 60 are also often different from the original design. The main deviations are observed at the trailing edge with more than 10 % of difference between the larger opening and the smaller.

3. EXAMPLE

The previous remarks are illustrated below in the case of the rehabilitation of an existing power plant:

- The existing runner in model size was manufactured in full homology with the original design;

- The model hill chart was measured;

- A field test was also performed.

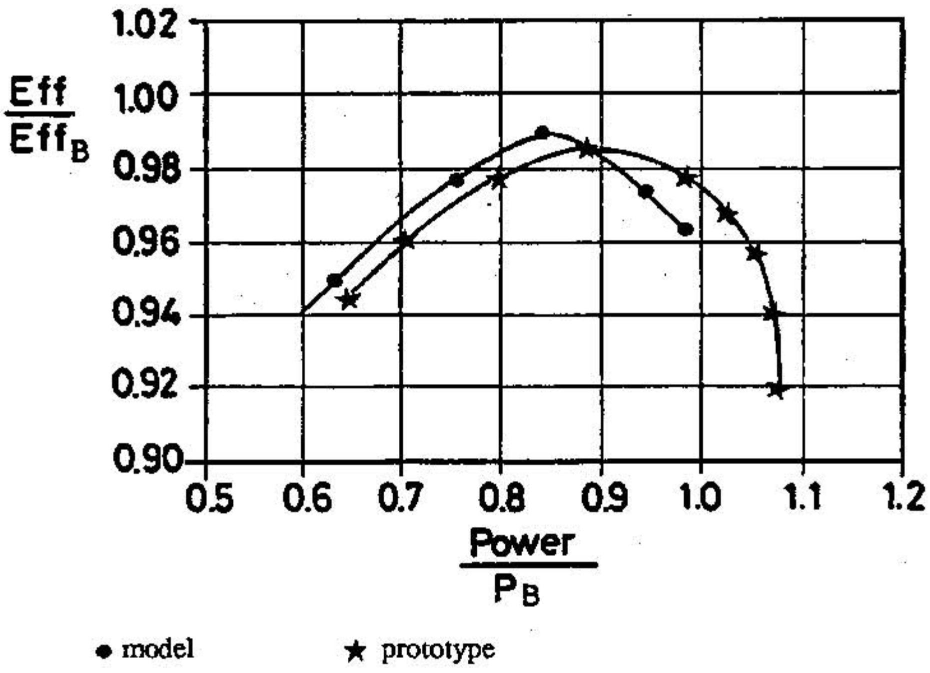


Figure 1 Efficiency curve from the field test superposed to a section of the model hill chart at the corresponding energy. (the scale of the diagram is given by the relative efficiency and power of the new model runner).

The geometry difference between the prototype and the model of the existing runner, due to the higher consistence of the model runner construction gives generally a better characteristic for the model. It is of course impossible to predict it. This increase can be assimilate to a sort of step-up. as a margin of security

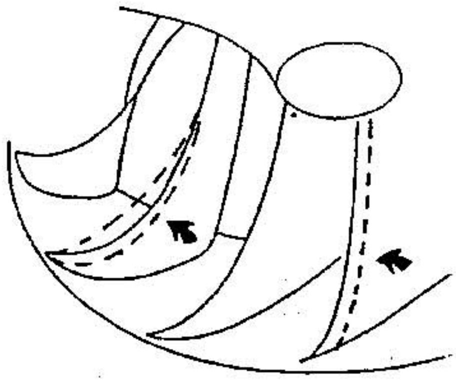
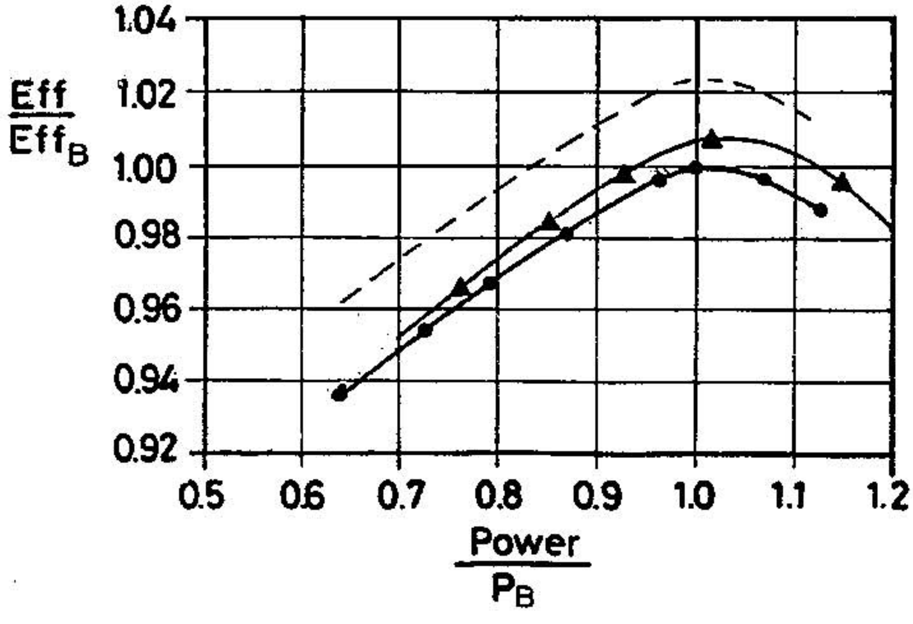


Figure 2 Location where the most important geometrical deviations were noted on the prototype runner.

In the case of the new runner construction, both model and prototype are build with the same technology and the same geometrical accuracy. The measurement results are illustrated below in the case of an old power plant, the efficiency level of the prototype is influenced by the roughness of the turbine components.

- The model hill chart was measured;
- A field test was performed to check the guaranties.



● Model ▲ Prototype ---- Model with step-up

Figure 3 Efficiency curve from the field test superposed to a section of the model hill chart at the corresponding energy, the scale of the diagram is given by the relative efficiency and power of the new model runner. The predicted step-up is added for comparison.

The curves shown above clearly demonstrate the good accuracy of model tests when the full homology is respected. Even if the step-up can not be fully applied, it is of course possible to estimate the roughness influence on the prototype efficiency. However, as roughness is not always uniform, computational results are not very accurate and can be contested.

4. LOSS DISTRIBUTION

Now considering the losses measured in the prototype at best operating conditions for both runners, they can be distributed in four types:

- Roughness influence, function of the Reynolds number
- Singularities, determined by the hydraulic passage geometry
- Mechanical losses
- Volumetric losses

Mechanical and volumetric losses are eliminated by comparing the old and new prototype losses. The losses related to singularities follow exactly the same behavior as with the model and are diminished of the same amount. On the opposite, as the prototype is operated at higher Reynolds values than the model, the friction losses should diminish. The efficiency must therefore be increased with the step-up formula, defined in the IEC and presented below.

The transposition between the model measurements and the prototype values is done with:

$$\Delta\eta = \zeta_{ref} \cdot \left[\left(\frac{Re_{u\,ref}}{Re_{u\,essai}} \right)^{0.16} - \left(\frac{Re_{u\,ref}}{Re_{u\,P}} \right)^{0.16} \right]$$

with

$$\zeta_{ref} = \frac{1 - \eta_{h\,opt\,M}}{\left(\frac{Re_{u\,ref}}{Re_{u\,opt\,M}} \right)^{0.16} + \frac{1 - V_{ref}}{V_{ref}}}$$

where

- Re_u	REYNOLDS number	- Re_u tests	Re_u during the tests
- Re_u opt M	Re_u at best operating conditions	- Re_u P	Re_u prototype
- Re_u ref.	Reference Re_u (7.10^6)	- ηh opt M	peak efficiency
- $V_{ref.}$	loss distribution coefficient (0.7)		

Taking into account measuring accuracy, controls conducted in power plants offer similar results to those calculated with this step-up formula, when applied to a new prototype with smooth and uniform surface roughness in the entire turbine.

This situation is not anymore true when refurbishing an old turbine. Surfaces are damaged on all components of the prototype and the roughness is not necessarily uniform. A surface roughness of a more than 30 year old spiral casing induce new friction losses which can eliminate the step-up effect or even diminish the prototype efficiency below the value measured on the model.

5. TESTS

The efficiency and power differences observed between a new runner design and an older one of less power can be defined with extremely good accuracy (nearby ± 0.1 %) in model tests. Both runners are of course tested in the same turbine casing and in the same conditions.

The best operating conditions coordinates of the two models, in a (φ,ψ) diagram, are very close one to the other. In the case of a power increase, at constant head coefficient ψ, the discharge coefficient φ is roughly increased by 10%. Friction losses, related to Reynolds number, will therefore increase when losses related to singularities should diminish as the new design is optimized.

A similar remark can be applied to the prototype.

For all these reasons, for any refurbishment and power increase of a power plant, we feel that comparative tests between the old and the new designs of the runner should be conducted [4].

These tests would have the following advantages:

- The customer has a strong experience of his runner. He knows how much power and in which conditions it can supply it, has a good knowledge of its efficiency, if field tests were done, of cavitation effects, and so on... An important data base is therefore available for the existing prototype and can easily be compared to measurements obtained from its model tests.
- Using this database, the measurements obtained with the new runner can be easily analyzed.
- According to the loss distribution described earlier, the efficiency and power differences are very similar between both model runners and both prototype runners.

These considerations would thus imply:

- A higher security for the customer who will not be awaiting unrealistic guaranteed efficiencies but a measured efficiency increase which is to be added to the prototype efficiency of the old runner.
- A higher security for the constructor who would not be anymore imposed an absolute efficiency value but an efficiency increase in comparison to the old runner. This efficiency increase is to be demonstrated in comparative tests.

An important difference is observed between the stepped-up model efficiencies and the prototype efficiencies. The step-up formula is thus ineffective in this case.

The comparison between the efficiency versus power increases for the model and prototype each tested under identical conditions, clearly demonstrate the usefulness of this test procedure proposed. Than both supplier and purchaser have an objective evaluation of the proposed runner which is not influenced by external conditions.

However, a power increase of an hydraulic machine implies a discharge increase. The cavitation risk is therefore higher and special attention must be paid to it.

6. PROPOSED PROCEDURE

The following procedure can be proposed for plant refurbishment's in which fully homologous model tests are required:

The first step is to perform a field test in order to know the level of existing performances.

The second step is perform a geometrical survey at site of the runner in order to avoid the use of the original design drafts.

The third step is to reproduce a reduced scale model of the existing runner. The turbomachines specialist will reproduce as close as possible a model of the existing runner.

The fourth step is to conduct a comparative model test with the original and the new runners

The analysis of the field and model tests for the original runner will give the possible step-up if no other modifications are made on the water passages.

The fifth step is to check the guarantees based on the increase in power output and efficiency measured on the model. This, according to our experience, gives an accurate $\Delta\eta$ without step-up uncertainty.

At this stage of project progress an evaluation of the expected pay back can be made in order to reorientate the project.

Finally, a field acceptance test on the upgraded runner must be performed in conclusion to the project.

This procedure could avoid an overbidding tendency of competing manufacturers and could improve the predictability of operating conditions.

Increasing the power of an existing turbine by changing the runner also raises the risk of cavitation and thus of a possible efficiency drop. Also the accurate location of the critical σ (σ_0) in the $\eta-\sigma$ diagram is mandatory. It is therefore very important to investigate carefully the cavitation behavior of the new runner using the new cavitation test procedure put forward by IMHEF. This procedure is set in the draft of IEC code 193 (which was accepted in the plenary meeting of IEC TC4, in May 93, in Tokyo) as an option to the basic cavitation tests. It consists in an analysis of effects of injection of cavitation nuclei (micro bubbles) in the test water. To achieve similitude of cavitation conditions, the degassed model test water must be seeded with a proper amount of nuclei.

Testing the existing runner is important not only to ascertain the efficiency or power of the new runner, but also to correlate cavitation damages on the old runner with the cavitation behavior of the old design model runner.

7. CONCLUSION

As a conclusion, during refurbishment projects, it appears that the following procedure can be followed:

- Manufacture a runner model of the existing runner and test it as a reference.

- In the same time conduct a field test with the existing turbine and use it as a prototype reference, analyzing the model and prototype references a prediction can be made about the possible step-up.

- Specify guarantees as an efficiency increase in reference to the old runner and not as an absolute efficiency value. These guarantees must be checked on model tests.

- When the new design is selected on the base of the model test, conduct a new field test on the upgraded prototype.

- As power is increased, control the cavitation influence and behavior in both runners by injecting nuclei.

This procedure will provide a better evaluation of the efficiency and the cavitation behavior of the new runner with much less possibilities of dispute for both the supplier and the purchaser of hydraulic turbines.

8. REFERENCES

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