

# EXAMPLES OF BENEFITS FROM EFFICIENCY EVALUATION USING COMPARATIVE TESTS

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## ABSTRACT

Traditionally, most field efficiency measurements are made to verify guarantees for a new project, which have led to that this issue is well covered by standardization guidelines. There are however several other situations where information from field efficiency measurements contributes with value. Depending on issue and site characteristics, there are several feasible options, that are not described in current standards of primary methods.

A comparative test is here defined as a test where efficiency is evaluated at the same flow conditions but with modified or changed turbine or water conduits. At an efficiency evaluation of a comparative test, many systematic uncertainties will cancel, and the overall evaluation of uncertainty will be at a very useful level.

This paper presents experiences of the hydropower producer Vattenfall, from several efficiency tests, where different types of comparative tests settings have been used.

## INTRODUCTION

Efficiency tests may have other objectives than to verify guaranteed performance. In such cases, depending on objective and situation, there are alternatives to the methods covered in existing standards, describing primary flow testing methods.

To get the required information on performance *differences* between different units, or regarding a single unit before and after a rehabilitation, a comparative test is adequate. A comparative test compares performances between two different equipment situations at the same operational condition. The methods used for measuring flow, head and power may be chosen for the best repeatability and small uncertainties at minor changes of operational settings.

An advantage with comparative tests is that many systematic uncertainties cancel in the evaluation of relative values. For some methods this will give less uncertainty on relative values than comparing two different tests performed with primary methods to obtaining flow. An example of an analysis showing the difference is displayed in Andersson et al., 2010.

Please observe the difference between index tests and comparative tests. Index tests compare the same equipment at different operational conditions, whereas a comparative test considers the performance difference after an equipment change in a unit or between different units in the same plant. The term “comparative test” has been used before (Lévesque and Néron 1996), but then referring to comparisons between different measurement methods used simultaneously.

A comparative test may e.g. be useful in following common situations:

- to evaluate the change in efficiency and/or power of the machine resulting from wear, repair or modification. When using a comparative test for this purpose, it must be assessed whether the modifications may affect flow patterns in the measuring sections;
- to optimize the operation of a power station with several units. This can be done where there is a common water passage available for discharge measurement;
- to check changes in other types of unit characteristics compared to a reference test, such as cavitation or pulsations.

In this paper we present experiences of the hydropower producer Vattenfall, from four different cases where different types of comparative tests have been used. We discuss benefits from these cases and uncertainties in the measurements.

## 1. FIRST EXAMPLE

The first case is from a plant with three identical 100 MW Francis units, with a long common intake channel. The intake channel ends in a small head pond before the intake to each unit, cf. Figure 1.

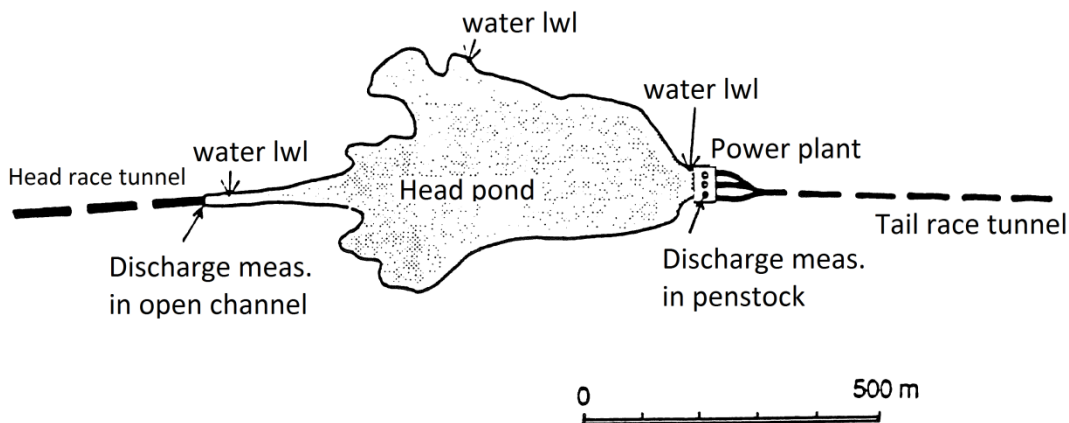


Figure 1 – Water ways of the power plant considered in the first example.

A measurement site with the possibility to measure water velocities by acoustic transit time was established in the last part of the intake channel. Four vertical girders with rails for small carriages carrying acoustic transducers were placed near the channel walls. The blasted rock walls are irregular in shape and there will therefore be a space between the girders and the walls, see Figure 2. The channel is around 13 m deep and 15 m wide. Maximum discharge for one unit is  $100 \text{ m}^3/\text{s}$ . The carriages makes it possible to traverse and obtain velocity measurements by crossed acoustic paths at several vertical positions. Figure 3 shows a photograph of the measurement site.

This measurement site introduce several uncertainties if used as an absolute test. The “leakage” outside the vertical girders, i.e. outside the measuring sections, is unknown. The velocity profile near channel bottom has to be estimated. The integration of velocities to an overall flow introduce uncertainty. The cross correction for possible angles in the flow direction gives uncertainty due to long measurement paths.

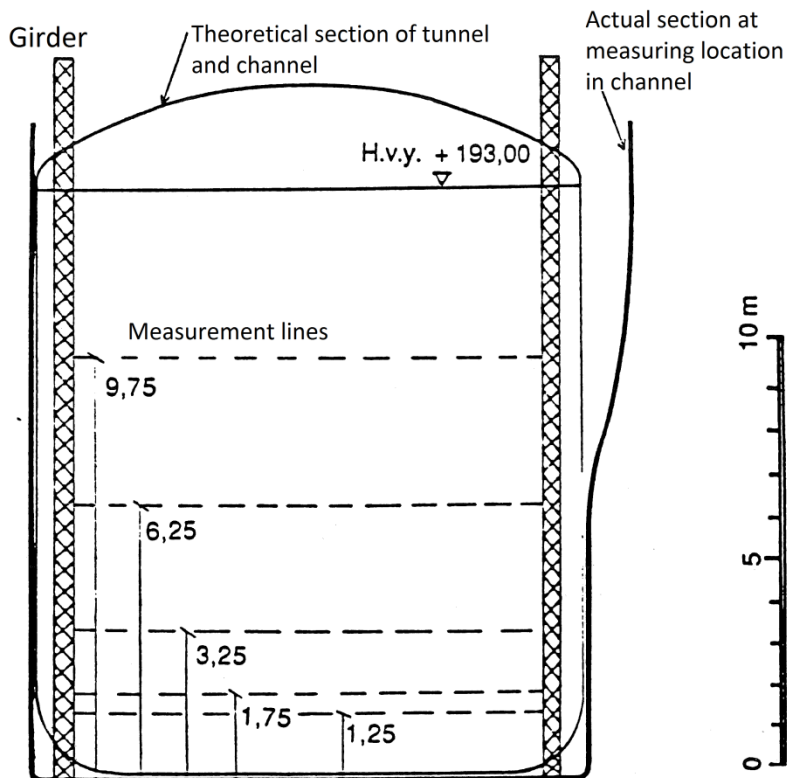


Figure 2 – Theoretical and actual sections at site for velocity measurement in the open channel of the first example.

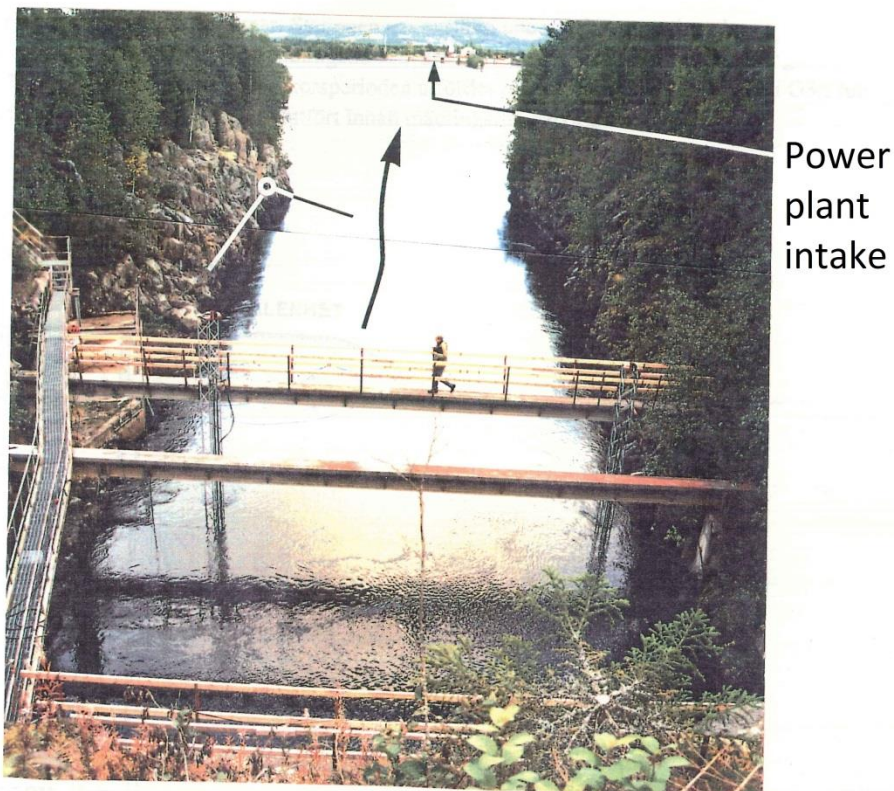


Figure 3 – Measurement site for velocity measurements of first example. The power plant intake is visible in the background.

When the same measurement section is used for comparative tests, geometrical values that give rise to uncertainties in flow will cancel. And in addition, when using the same flow at different tests, several uncertainties related to the flow situation will diminish. Examples of such are leakage flow and integration effects.

The remaining uncertainties will be due to natural random variations in the flow. The uncertainty from this may be further reduced by using long enough measuring time, but at the same time keeping track of the small possible storage effect in the pond.

In this plant, a test series was performed with the same flow, near best efficiency, passing through each of the three units one at a time, while the other two units had closed intake gates. A thorough measurement analysis resulted in uncertainties in comparisons of less than 0.4 %. As the resulting measured efficiencies had a spread in a band of 1.2%, a conclusive result could be obtained in ranking the units.

The value of yearly production in correct ranking units in start order is considerable even with a small efficiency difference, since only one or two units are in operation most of the time. In addition, the ranking information is highly valuable when going into reinvestment prioritizations. The payoff time for the test cost showed to be close to one year.

## **2. SECOND EXAMPLE**

The next example also concerns discharge measurements in a common intake channel. This time in a plant where a major refurbishment project had been performed. All of the plant flow passes through a head race channel under a bridge section with vertical concrete walls and a mid pier for the bridge. As the section was dried out for a longer period during the construction of a new unit in parallel with the old plant, there was an opportunity to accurately mount rails in the walls. These were later used for traversing acoustic transducers.

After completion of the new unit, discharge measurements were performed using 16 traversable acoustic transit time paths, 8 in each section under the bridge. The acoustic paths were coordinated in pairs to be able to compensate for velocity angles deviating from the main channel direction. By traversing the transducers into different vertical positions, a good estimate of the velocity profile was achieved. For the comparative tests, four representative measurement planes were chosen.

After refurbishment, the plant consisted of five old units with a 80 year old design, and one new unit about three times the capacity of one old unit. A test series was performed with the flow matching best efficiency of one of the old units. This flow was repeatedly used for generation at one of the six units one by one, with all other units closed with intake gates. The tested point at each unit was later complemented by index tests, based on relative discharge measurements.

An analysis of the comparative uncertainty resulted in a value less than 0.4 %. The spread between the older units exceeded 2.5 % in efficiency (see Figure 4), and the new unit had almost 7 % higher efficiency than the mean of the old units.

These relative efficiency measurements between units gave a good ground for a total optimization of the production in the plant at every possible plant flow. The correct start order between old units

improve the yearly plant production by 0.5% and would have improved the yearly production in the situation before refurbishment by more than 1%. The payback time of the tests turned out to be less than one year, despite the extra costs due to the complicated setup and assembly.

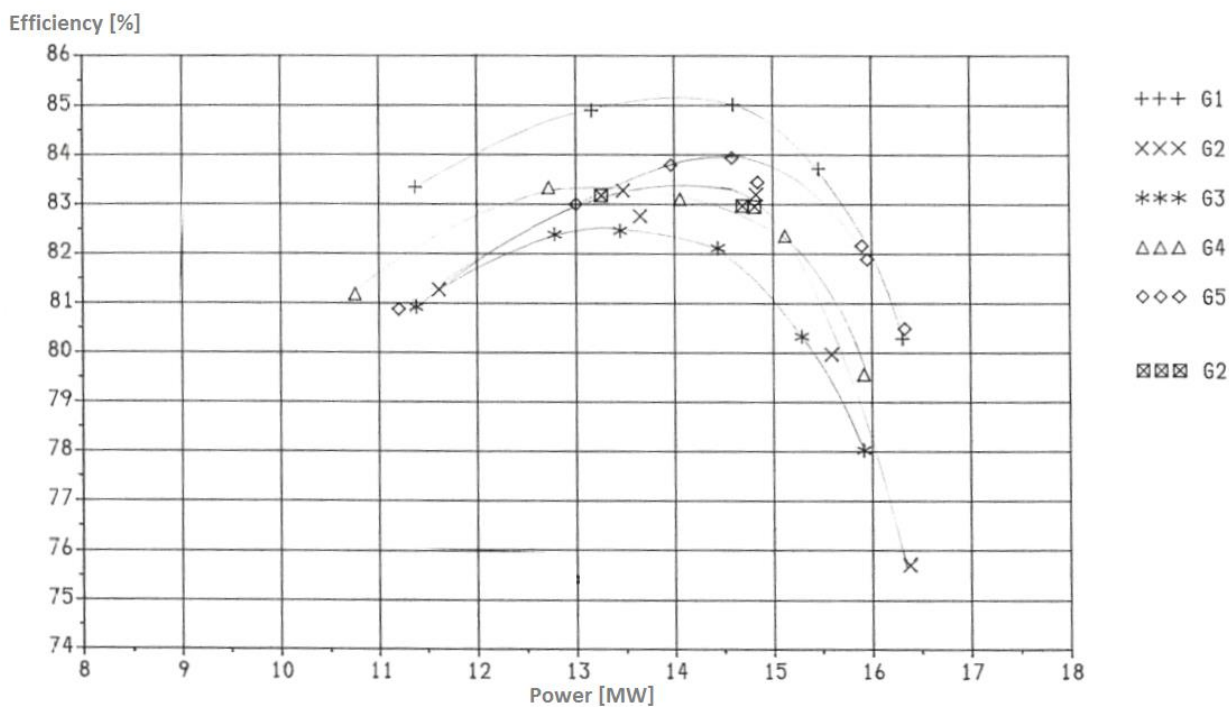


Figure 4 – Efficiency measurements on the five old units in second example. The measurement on unit G2 is repeated.

### 3. THIRD EXAMPLE

In some situations, there is a change in equipment near the runner or a runner adjustment, that may affect the efficiency of a unit. A comparative test may then be needed to evaluate the consequences for operational economy. An example of this type was examined in a 105 MW Francis unit where air admission through the shaft was possible, intended to damp effects of hydraulic transients. However, the benefits/cost of this function was still to be examined. A measurement set up of acoustic transit time transducers in the penstock was already established, to test the absolute efficiency of the unit. The same measurement site was tested to compare the efficiency with and without air admission.

As most of the systematic uncertainties due to geometrical measures and integration method will cancel, a very good resolution on the comparisons was expected. An analysis estimated the uncertainty to be 0.21 % in comparative test. Figure 5 shows the resulting efficiency curves and Figure 6 shows the air inflow measurement. It is visible that the air admission has an adverse effect on efficiency at high loads but a positive effect on efficiency in part load. The efficiency changes are also very consistent with the amount of air inflow, indicating that the result has a resolution in accordance with the low uncertainty estimated.

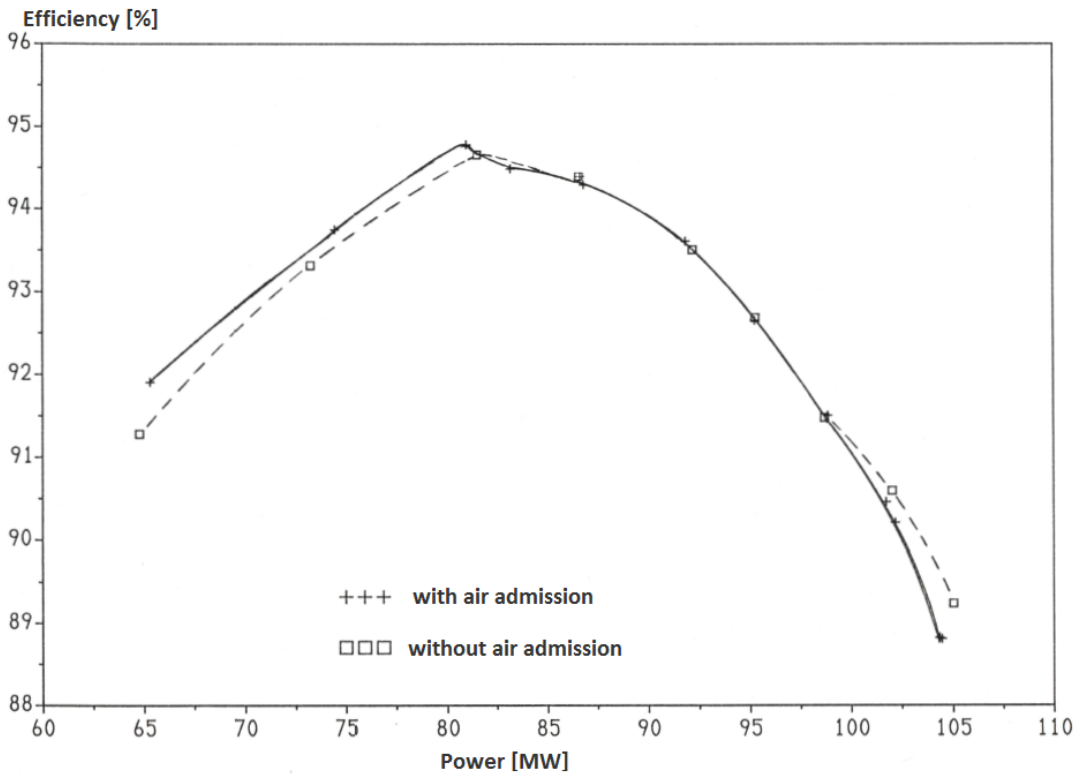


Figure 5 – Efficiency measurements of the third example, with and without air admission through the shaft.

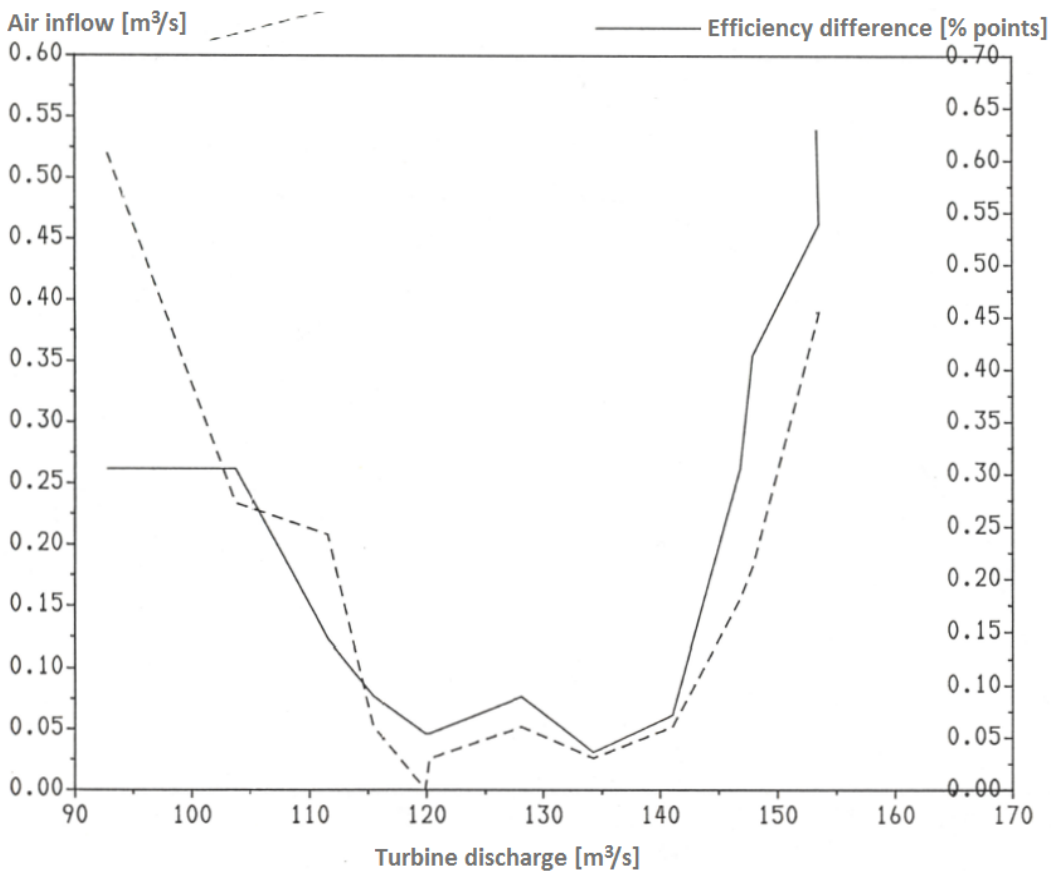


Figure 6 – Air inflow measurement of third example, and difference (absolute value) between efficiency measurements with and without air admission.

Before the tests, there was a discussion if an alternative way to do a comparison test in this case could have been using relative discharge measurement via Winter Kennedy taps. This was however rejected due to the uncertainty if the flow conditions with/without air would affect results using pressure taps. Please note that in such a case, this would still had been called a comparison test and not an index test, since the latter uses the same test object at different flow situations. A comparison test uses the same test situation, also regarding discharge level, for different test object setups.

#### **4. FOURTH EXAMPLE**

At a redesign of a fifty year old runner, a change in the draft tube geometry was investigated. During a period in 1945-1960, the sharp heel draft tube was frequently used in design, and in these cases it is a clear option to make adjustments of draft tubes at refurbishments. Model tests with different draft tube adjustments showed some dependency on model test head, why the expected outcome in prototype was unclear.

A comparison test before and after draft tube adjustment, without replacing the runner, was performed to complement model test results. The flow measurement site was not ideal. A relatively wide gravel channel section downstream was used with acoustic transit time path lines. The width of the channel was 50 m. Still, good measurement series were achieved and the results were usable. An analysis of compative uncertainty ended up in 0.6 %. This was less than the change in efficiency detected. A more detailed description of the overall project is found in ref. Andersson and Dahlbäck 1998 and Andersson 2009.

The results gave insight on how to evaluate model tests in reshaping draft tubes more generally. The efficiency gain in the specific plant was 0.7 %, which gives considerable value.

#### **5. GENERAL DISCUSSION**

In the examples above, acoustic transit time measurements have been used for comparative tests. The reason for this choice is that the test equipment is robust in time. Other methods for relative discharge may be used, as long as uncertainties introduced by changes in test object do not affect the measurement site. Especially for refurbishment work with a long outage and construction works in between, it is more robust to rely on stable geometrical measures and time measurements than e.g. the condition of a pressure tap before and after refurbishment.

We have tried to show the potential in using comparative tests. High values may be achieved for operational purposes, but there are also possibilities to evaluate performance of equipment changes. The forthcoming update of IEC standard 60041 will introduce the term “comparative test” and some general guidance. However, as situations depend very sensitively on the setup of specific cases, it will be difficult to have a specific standard, rather than a guide on general methodology. A continued communication of examples and experience sharing will be a way forward to increase the use of this methodology.



## REFERENCES

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