

EVALUATION OF THE VOLUMETRIC METHOD

WITH APPLICATION TO LOW HEAD HYDRAULIC MACHINES

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Abstract

The present work presents an evaluation of a flow measuring method known as the volumetric method. The method consists in running a turbine at a constant load during an extended period of time which depends upon the reservoir geometry. The flow rate through the turbine is determined from the volume change in the reservoir(s) by measuring the water level change. Through a pilot study in a full scale machine it is shown that the method reproduces reasonable results. The measured flow rate deviates by less than 3% from the value reported in the hydropower plant. The accuracy of the reported flow rate and the one measured in here is however difficult to determine and left unconsidered in this work. For future studies of the method it is recommended to more thoroughly investigate how accurately the rate of change of water level along with the reservoir area can be determined.

Introduction

Hydraulic turbines owner seek accurate efficiency measurements after the construction of a new power plant or a turbine refurbishment. Several methods based on different principles are today available: thermodynamic, pressure-time, current meter, ultrasound and dilution. Most of the available methods can be found in the IEC41 standard [1]. An accuracy below 0.5% may be achieved for hydraulic machines with large heads ($H > 100$ m). However, efficiency measurements in low head hydraulic turbines ($H < 50$ m) is challenging as the flow rate is difficult to

estimate due to the shortness and variation in the water passages. The other parameters such as head and power are accurately determined without any difficulty. The Winter-Kennedy method is often used to verify efficiency step ups after refurbishments [2]. The method consists in measuring the pressure across the spiral, which deliver the flow to the runner. The method is sensitive to modifications in stay vanes, guide vanes and runner that may alter the pressure distribution in the spiral casing and thus the method itself. Difficulties related to the method have been reported for renewals of several units of both Francis and Kaplan type. The problems are not isolated but have been an important issue for many years. The hydropower industry is looking for alternative measuring methods.

The volumetric method is attractive since there is no need to shut down the power plant for geometrical measurements and sensor installations. Furthermore, no obstacles have to be installed in the waterways which might disturb the flow and the method does not suffer from potentially altered measurement conditions such as renovated waterways, modified surface conditions, refurbished pressure taps etc. This method was mainly use some decades ago. Because of the favourable properties mentioned above and some unpredictable results of the Winter-Kennedy method, new interest in the method has been initiated.

Method description

Measuring turbine flow rate with the volumetric method is based upon relating changes in

$$Q_T = Q_t + Q_u - Q_L = A \cdot \frac{\Delta h_p}{\Delta t_p} \quad (3)$$

With Q_L being the *total* leakage in the power plant under study and index p indicates a perturbation flow measurement. The magnitude of the guide vane leakage is often specified and can otherwise be estimated as explained in [3]. The total perturbation flow was estimated the day before the turbine flow measurement by stopping the discharge in Turinge and upstream power plant Rätan. The rate of change of water level was estimated by fitting a linear least squares function as illustrated in figure 2 (a). This resulted in a perturbation flow $Q_T=3.16 \text{ m}^3/\text{s}$ which corresponds to $Q_t=2.97 \text{ m}^3/\text{s}$. As a comparison, the reported flow was calculated to $Q_{tr}=3.19 \text{ m}^3/\text{s}$.

Estimation of the turbine flow rate

The pilot study lasted during twelve hours with the actual flow rate measurement confined to seven of those as outlined below:

- t=0 h; data acquisition started. The power plants ran according to schedule,
- t=1 h; the discharge in Turinge and Rätan were abruptly stopped,
- t=3 h; one unit in Turinge was started at a discharge of about $Q_s=50 \text{ m}^3/\text{s}$,
- t=10 h; both units in Rätan were started at a discharge of about $Q_u=100 \text{ m}^3/\text{s}$,
- t=12 h; the logging equipment stopped recording data, measurement ended.

The acquired water level data is presented in figure 2 (b). Note that the deployed transmitters measured the water depth and not absolute water level elevation as the fixed sensors which are illustrated in figure 2 (a). To enable a presentation of data in the same plot, approximately 288 m was subtracted from the fixed sensor readings. The water level drops at a fairly constant rate during the seven hours in which the flow rate measurement was confined. This is true for the data of each transmitter in the sense that each seems to follow linear trends. Furthermore, the slope among the lines is similar which implies a quite constant rate of change of water level around the basin. Note that the data acquired from the second transmitter shows a peculiar behaviour with spikes occurring at some instants together with rather noisy data. The quality of this data is

questionable but was still used due to lack of other more reliable sources of data.

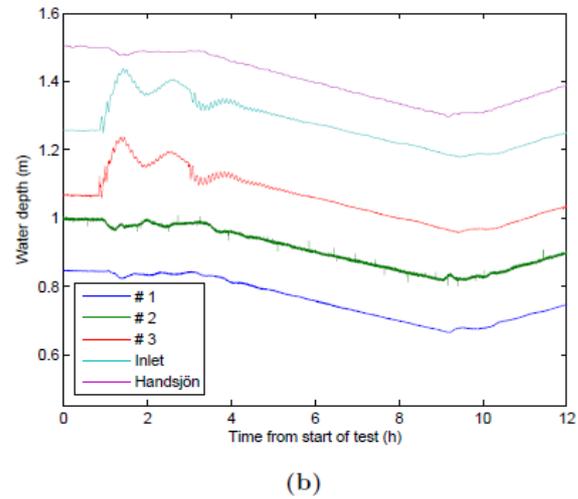
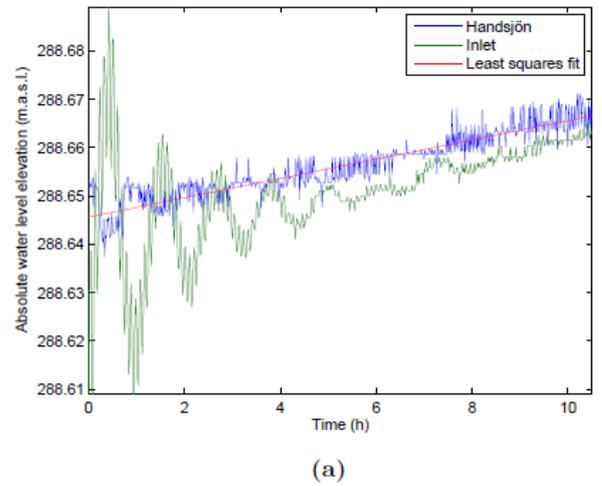


Figure 2 – (a) Result from measurement of perturbation flow entering the reservoir of power plant Turinge by stopping the turbines in Turinge and upstream power plant Rätan. (b) Acquired water level readings during turbine flow rate measurement in Turinge. Note that the data recorded by transmitter two acts strange with spikes showing up at some instants.

Unexpected load changes were realized about six hours into the turbine flow measurement. All analyses were therefore restricted to between four and a half and six hours into the test when the load was fairly constant. The flow rate during the experiment was calculated through use of a slightly modified version of equation 1

$$Q_s = Q_T + Q_{ls} - A \frac{\Delta h}{\Delta t} \quad (4)$$

Where Q_{ls} is the guide vane leakage in the running unit. The rate of change of water level was calculated by fitting linear least squares functions to the data of each deployed transmitter. These were averaged which

resulted in a mean change of water level $\Delta h/\Delta t = -8.14 \times 10^{-6}$ m/s. The mean basin area was extracted from data sheets, $A = 5.77 \times 10^6$ m². As outlined in the previous section, the perturbation terms were bunched together and measured to 3.16 m³/s, the guide vane leakage was specified to 0.19 m³/s.

The flow calculated from equation 4 was accomplished by the steps and data presented above which resulted in $Q_s = 50.32$ m³/s. This value can be compared with the mean flow reported from the power plant; $Q_{rs} = 48.90$ m³/s, i.e. a difference of about 3%. The reported flow was calculated by

$$Q_{rs} = \frac{P}{\rho \cdot g \cdot H \cdot \eta} \quad (5)$$

Where P , ρ , g , H and η are the power, density, acceleration of gravity, head and efficiency respectively. η was extracted from the turbine Hill chart while P and H were measured in the power plant with a temporal resolution of 60 s. The accuracy of the reported flow rate is however uncertain and should only be used as a guidance; the efficiency is based upon earlier flow rate measurements or model tests with unknown accuracy.

From uncertainty analyses of equation 1 and 2 it is readily shown that [3] the reservoir area and mean rate of change of water level have the greatest relative influence in an absolute flow rate measurement. The accuracy of relative measurements is shown to be dependent only upon the mean rate of change of water level.

Conclusion

A pilot study has shown that the volumetric method possesses potential as an absolute flow rate measurement method. There is however some aspects which must be further investigated. The reservoir area is a parameter which is associated with uncertainty [3] and the accuracy of the available methods for areal determination must be tested. Furthermore, the accuracy of measured rate of change of water level should be more thoroughly investigated by measuring with more sensitive pressure transmitters and fixed measurement conditions. There is also unclear how much uncertainty which is introduced, or cancelled, by averaging

the slope among the transmitters around the reservoir. There was a difference of about 4% among the slope of the deployed transmitters in the present study. By including the fixed transmitters the difference is raised up to 12%. Absolute measurements might suffer from problems with stopping neighbouring power plants as desired because of potential conflicts among different owners of the involved power plants. Finally; laws that controls by how much the water level may differ and possible requirements of minimum power plant flow rates might complicate absolute measurements.

The method might therefore be best suited for comparative measurements since these are independent of the exact reservoir area and requires measurement of the water level in only one point. Furthermore, the potential problem of controlling the schedule of neighbouring power plants is somewhat relaxed since these can be operated at constant load.

References

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