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Analysis of the main methods used in determining the discharge at low head small hydro power plants

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Abstract. Low head hydro power plants are generally plants equipped with Kaplan or bulb turbines.They can process a discharge of the order of tens of m^3/s (Fughiu HPP, Zăneşti HPP, Golesti HPP) or hundreds of m^3/s (Ipoteşti HPP, Robeşti HPP) and have a gross head generally between 10 ... 30 m. In order to make a good determination of the efficiency of a hydro unit that equips a low head hydro power plants, it is necessary to perform performance tests periodically by measuring the actual operating parameters of the hydro unit in situ. Among the parameters of a hydro power or hydro-unit, the parameter whose measurement poses the most difficult problems is the turbine discharge. Determining the turbine discharge requires a complex measurement methodology. The present paper aims to present and analyze the main methods of determining the discharge that can be used in the case of low head small hydro power plants.

Keywords: discharge measurement, efficiency testing, refurbished, hydro unit.

1. Introduction

Hydro power plants represent a large part of the portfolio of electricity production in Romania and provide about 25% of the electricity needs. Most of the hydraulic turbines that equip the hydro power plants were built a few decades ago and need refurbishment. A substantial increase in electricity production and an adaptation to new market requirements can be achieved by using renewable energy sources [1,2] but also by refurbished process. The technologization is also stimulated through the system of certification of electricity from renewable energy sources. In the last decades, the Winter-Kennedy method has been one of the most used methods to verify through in situ performance tests performed before and after the refurbished,

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the improvements obtained after the refurbished process. In some cases, the results obtained were unpredictable. In order to increase the accuracy of the performance tests performed in situ, it is necessary to develop effective methodologies/methods for determining the discharge. Within the paper are presented and analyzed the main methods of discharge determination at low head hydro power plants.
The international codes of measurements in which the absolute methods of determining the discharge of a hydro unit are described are ASME PTC 18/2002 [3]; IEC 60041/1991 [4]; IEC 62006/2010 [5], ISO 3354/2008 [6].

2. Methods for determining the turbine discharge at low head small hydro power plants

The reasons for carrying out the discharge determinations at the small hydro power plant stations are multiple.
Some of these reasons are:
• performance tests, including acceptance tests for new or upgraded turbines, assessment of turbine status in the planning phase of the upgrading or cam optimization projects;
• calibration of the devices used in the case of the Winter-Kennedy method or of other devices for determining the pressure difference for permanent discharge measurement;
• water management in river systems, determining consumption characteristics;
• adjusting the level of rivers in the context of navigation or tourism.
However, such discharge measurements are rarely performed in low head hydro power plants. Many of these hydro power plants, which have been in operation for decades, have never been tested with quantitative discharge measurements. Often the effort to make such measurements is considered too high. One of the reasons why no absolute discharge measurements are made is that an optimal correlation of the cams with double regulated turbines can be adapted without knowing the absolute discharge.
The contracts for new hydro-technical projects or refurbishment projects are based, for the most part, on tests carried out on the turbine model, on smaller hydro units, or even on the numerical simulation of the discharge.
However, for a more accurate determination of the discharge, but also of other parameters of a hydropower arrangement in situ measurements are required [7]. The reasons presented above justify the need to obtain methods for determining the discharge rate in situ as accurately as possible.
The main methods for determining the discharge that can be used in the case of low head hydro power plants are presented below.

2.1. The velocity area method

The velocity area method is also known as the current meter method, the principle of the current meter method is the placement in a measuring section of circular (forced conduit), rectangular or trapezoidal (upstream slot gate or free surface channel) a certain number of measurement translators (current meter, Pitot tubes or acoustic translators) with which the velocity of the water at the respective points is determined. Based on the values obtained from the measurements and applying an integration method [8], (Simpson method, trapeze method, Spline function or others) the average normal velocity is determined in the measurement section used and the discharge is determined based on the fact that it is directly proportional to the velocity in a uniform measurement section.

This type of discharge determination method has been used in an in-situ measurement campaign recently conducted at the Vaduri HPP a small hydro power plant on the Bistriţa river in Romania [9].

The current meters were moved on a mobile frame and placed in the slot gate after the tracks upstream of the hydro power plant and adjusted in the main direction of the water flow.

Fig. 1. Mobile frame for locating current meter.

According to IEC 60041/1991 measurement code number of measuring points required to determine the punctual velocities of the turbine discharge section measuring 18.25 m^2, Vaduri HPP was between 63 and 94.

In order to comply with this provision of the code of measurements, measurements were made on 10 levels with 9 current meter placed on a mobile frame, resulting in a total number of 90 measurement points of the punctual velocities.

The average location angle of the current meter (β) in the measurement section was 15^0.

The angles (α) between normal at the measurement section and the tangent at the current flow lines for the 10 measurement levels were: α_1 - 15^0; α_2 - 13^0; α_3 - 11^0; α_4 - 9^0; α_5 - 8^0; α_6 - 8^0; α_7 - 7^0; α_8 - 7^0; α_9 - 6^0; α_{10} - 5^0 this angles were graphically represented in figure 2.

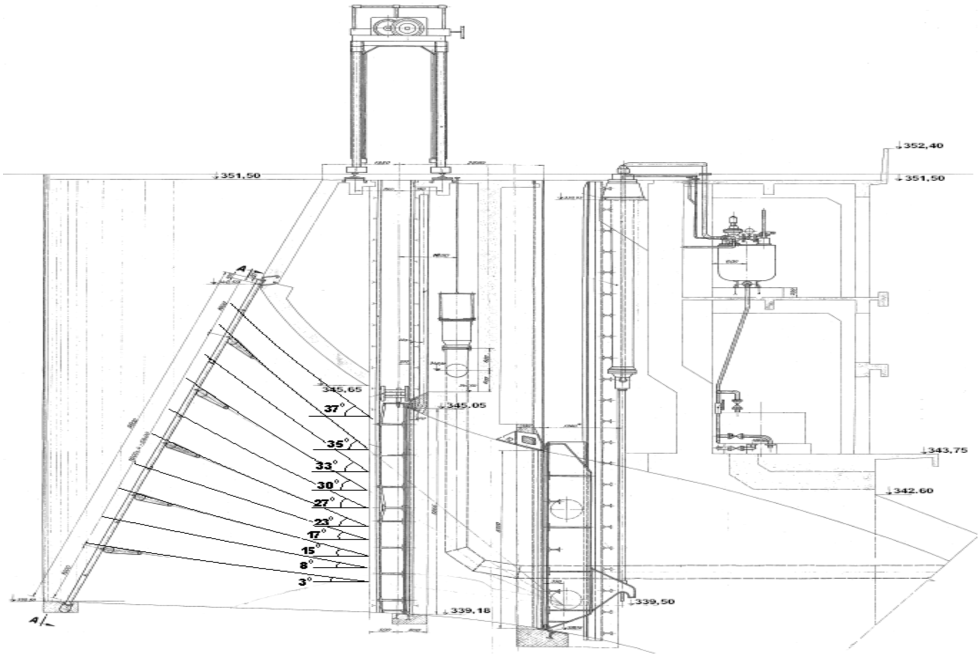

Fig. 2. Cross-section through Vaduri HPP and representation of the measurement angles for the ten measurement levels.

Each Vaduri HPP turbine is equipped with two slot gate. Due to the positioning of the mobile frame on 10 levels in slot gate, the measurement duration for an operating regime lasted 1.5 hours. Minor variations in power and head were offset by weighting velocities for each position of the mobile frame.

For each measurement regime, for the discharge integration, a total of 90 local velocities were used in each inlet (slot gate) and a number of 180 local velocities for each turbine.

Because the measurement sections were rectangular, the integration was performed according to ISO 3354/2008 with cubic spline interpolation and the Simpson method [10]. The uncertainty of the discharge determination with the velocity area method did not exceed 1.3%.

The results obtained in the in-situ tests were used to draw the real performance characteristics of the hydro units from Vaduri HPP.

In the measurement code, IEC 60041/1991 the velocity area method is the only recommended method for determining the absolute discharge in short convergent measurement sections as is the case of low head hydro power plants.

2.2. The acoustic of transit time method

International Codes of Measurements describe in detail the procedures required for applying the acoustic method of multi-way transit time (ATT).

However, the application of the method is limited to circular and rectangular sections in straight penstock.
In low head hydro power plants, there are usually no straight sections, often converging sections. In principle, the installation of acoustic sensors in convergent sections is possible, but a standard method for discharge assessment is not available. A theoretical approach to measurements performed with the acoustic method in power stations with variable sections is described in [11].
For the application of the acoustic method of transit time at the Wettingen hydro power plant (HPP) on the Limmat River in Switzerland, the only possible location of the acoustic sensors was in the convergent section, even upstream of the inlet butterfly valve [11], (Fig. 3). The main challenge was that the shape of the cross-section changed from rectilinear to circular along acoustic paths.
Within the Wettingen hydro power plant, all three hydro units have been equipped with measuring devices with acoustic sensors, and the combinatorial cam can be optimized for each turbine / hydro unit. The flowmeters with permanent acoustic sensors will also allow the quantitative determination of the increase of the operating efficiency with the replacement of the old turbines with new ones in the case of a refurbishment project.

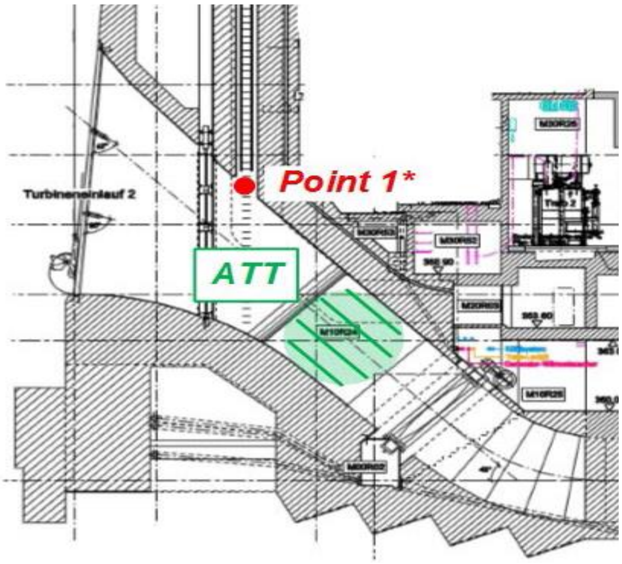

Fig. 3. Application of the acoustic method of transit time in short convergent measurement sections.

One of the advantages of using the acoustic method is that such a discharge meter with acoustic sensors can be used permanently, and the operator of the hydro power plant is able to continuously monitor the performance of the hydro units in the hydro power plant.
The test time to determine the optimal correlation of the combinatorial cams is much shorter compared to the measurements made with current meter. Typically, the duration for obtaining data for an operating point takes only about 5 minutes.

2.3. Pressure-time method

Pressure-time method, also known as the Gibson method is based on Newton's laws of mechanics and fluid, giving the relationship between the strength of the corresponding change in the difference in pressure between the two sections (section 1-1 and section 2-2, Fig. 4) and acceleration or deceleration of the body of water between the two sections.

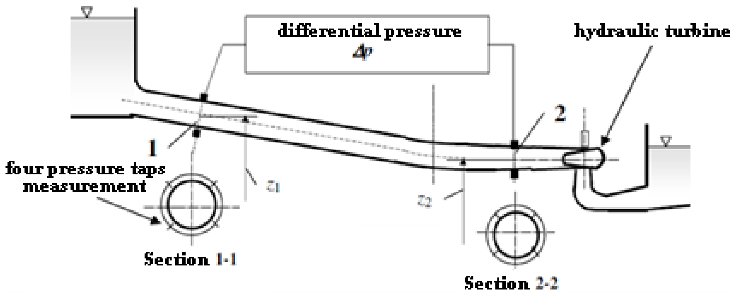

Fig. 4. Pipeline segment with marking the measurement sections for applying the pressure-time method [12].

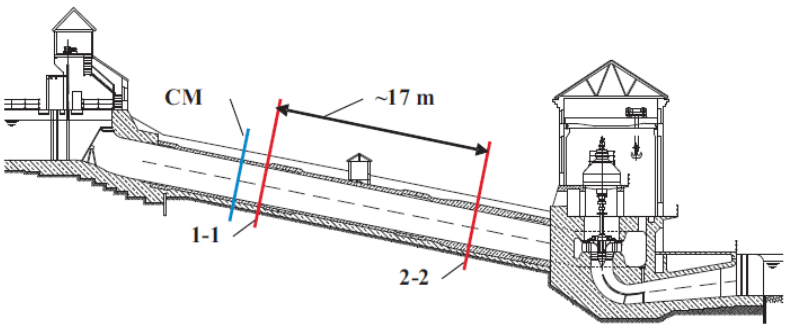

Fig. 5. Longitudinal section through Zur HPP with marked hydrometric sections measurement [14].

The method is based on the following principle - in a frictionless fluid flowing through a cross-section pipe *A*, the variation of the velocity *dv/dt* of a fluid mass ($m = \rho L A$), can lead to a pressure difference (called and differential pressure) Δp between the upstream cross-section and the downstream cross-section of a penstock section of length L

$$\rho LA\frac{dv}{dt} = -A\Delta p, \tag{1}$$

where

$$\Delta p = p_{am} - p_{av}. \tag{2}$$

p_{am} is the pressure in the upstream cross-section,
p_{av} – the pressure in the downstream cross-section.

The method was applied to the Zur HPP low head hydro power plants , equipped with two vertical Kaplan units of 4.3 MW capacity each and 15 m head, in Fig. 5. Current-meter and pressure-time method were applied simultaneously here to measure discharge under previously optimized operating conditions [13]. Both the supporting cross with 26 current meters and the pressure-time method instrumentation with hermetic differential pressure transducer were installed inside a penstock of 4 m diameter and 31 m length.

From the results of tests carried out at Zur HPP, results o excellent consistency between measurement results exists under the full load conditions. However, the discrepancy rises systematically with falling discharge. At the lower edge of the guaranteed range, the pressure-time method data fall by 2% below those attained by means of the velocity-area methods.

Due to the limited amount of instrumentation needed, the pressure-time method shows sometimes advantages when compared with the current meter technique (CM). However, the method is not quite typical for small low-head schemes as a straight pressure conduit segment of sufficient length is required.

Also, the application of the pressure-time method demands a series of conditions to must be met as listed in [4], but these conditions are rarely fulfilled for low head hydro power plants.

3. Conclusions

Although recent progress has been made in the development of new methods for turbine discharge determination (for example acoustic methods - Acoustic Scintillation Flow Meter ASFM method), the current meter method remains a basic method for determining the discharge at hydro power plants, often being used as a standard method of comparison for other flowmeters.

Also in the last period can be noticed in the specialized literature numerous methods of velocity integration, methods used in practice by different teams of specialists over the years. Some of these integration methods have performed better than the methods recommended by the main international measurement codes ASME PCT 18/2002, respectively IEC 60041/1991. This shows that some recommendations and provisions of the current standards, even if they are met, are not sufficient to provide an outcome in line with reality and expectations.

There are proposals that in the next revision of the IEC code 60041 the acoustic method of time (ATT) of transit will be considered an absolute method of determining the discharge and the method of acoustic scintillation will be introduced in the code as a relative method of determining the discharge.

Discharge determinations in low head hydro power plants are possible and the involved efforts are, in most cases, economically justifiable. The chosen method to perform the tests has to be fitted to the individual goals of the measurement campaign and to the local situation in each of the hydro power plants. Depending on the chosen method, the accuracy of the discharge measurement to be expected will be in the order of one or two percent, if conditions match the requirements mentioned in the measurement codes.

A general finding of this paper is that at present the modern measurement theory and technique allow the determination of the individuality of each hydro unit, which creates the necessary premises for the knowledge and use of both the internal reserves resulting from the coverage of the project with respect to the hydro unit, as well as those represented. by the differences between the hydro units of the same hydro power plant, orienting the exploitation towards the optimal differentiated use of the hydro units.

The optimal functioning of a hydro unit, a hydro power plant, or a cascade of hydro power, is equivalent to an increase of energy or the existence of (theoretical) arrangements that would have an additional electricity production of at least 2%.

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