HYDRO TURBINE FLOW MEASUREMENT BY THE GIBSON METHOD (TIME – PRESSURE)

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Gibson method (or pressure-time method) is one of the main turbine flow measurement methods specified in IEC 41/1991 (classic version) as well as IEC 62006/2010 (modern version). This method is suitable for all hydropower plants equipped with pipes. This method was not used in Romania but it is used internationally, particularly in Canada and USA.

In 2011 ICEMENERG has developed a methodology for calculating the flow methods Gibson IEC 41 and IEC 62006 and based on this methodology have been made to flow measurements and Valsan HPP efficiency.

The paper summarizes the method of measurement, the results obtained from the measurements by the Gibson method, which are compared with the results of measurements with ultrasonic method (method considered indicative IEC 41) and the dilution method.

Keywords: Turbine, time-pressure, efficiency, discharge, pressure, wicket gates, runner

1. Introduction

The Gibson method (pressure - time flow measurement in closed conduits) was proposed in 1923 by Gibson Rothwell Normal [1]. It is based on the second law of motion and Newton's laws of fluid mechanics derived giving relationships between the strength of the variation of the pressure difference between the two sections or braking and accelerating water column between these sections due to a closure device for closing. Although this method is theoretical by valid both for turbine and pump operation and closure or opening of the gate, in practice it is used only in case of discharge cut-off in turbine operation.

Because of the reliability of its results, the method is recommended in the main international standards [2], [3], it is suitable for measuring water flow in hydraulic turbine efficiency tests.

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Many authors have contributed to the method by solving the existing problems in the conventional method, like Adam Adamkowski [4]. He has developed a computer program called Gib – Adam, which calculates the flow by means of pressure signals from a differential pressure transducer. Flow results obtained with this program were mostly validated in the laboratory and in site conditions (in years 2003 - 2010 the method Gibson was successfully applied in determining energy efficiency on many hydropower units in Poland as well as in Mexico).

Following measurements yielded measured values of turbine efficiency uncertainties caused by conditions tested, usually between 1.2 % and 1.5 % .

Another important contribution is of Petr Sevcik [5]. It has benefited from excellent method for Gibson to PSHP Dalesice. These conditions have enabled additional experiments to measure flow in both directions (turbine, pump) avoiding significant systematic errors. Author chose standard IEC 62006 recording from these measurements as an example for future standard.

2. Gibson method principles

2.1. Preliminary remarks on the Gibson method

This method, was developed to measure the flow of hydraulic turbines. The method is based on water hammer phenomenon that occurs in a closed pipe. Gibson method measures a static pressure difference between two cross sections of a penstock due to impulse changes caused by rapid closure of the turbine guide vanes. Flow is obtained by integrating, within a period of about 4 to 10 s. When this method is used, the closing time of the guide vanes is greater than the time required by penstock crossing the shock wave. The fig.1 is a schematic diagram for applying the Gibson method.

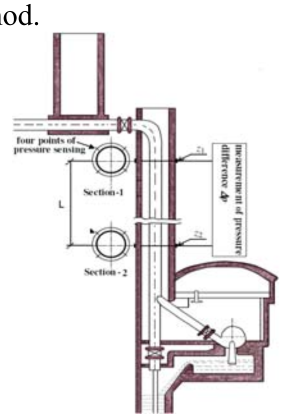

Fig. 1. Segment of a pipeline with marks needed to explain the theoretical basis of the pressure-time method.

2.2. Mathematical relationships

To obtain a relation for calculating the flow Q between two cross sections (see fig.1) of a penstock sections with length L and flow section area S several calculation assumptions are necessary:
- It is assumed that the velocity and pressure distributions in cross sections of penstock segment considered are constant;
- It is assumed that the working fluid density and flow sectional area remain constant after hammer effect that takes place in closed guide vanes.

Applying the above mentioned assumptions, one can get a relationship between unstable flow parameters between two cross sections of a penstock. His equation can be written with his relationship to one-dimensional unsteady flow Bernoulli [7].

$$\alpha_1 \frac{\rho Q^2}{2S_1^2} + p_1 + \rho g z_1 = \alpha_2 \frac{\rho Q^2}{2S_2^2} + p_2 + \rho g z_2 + \Delta P_f + \rho \frac{dQ}{dt}\int_0^L \frac{dx}{A(x)} \quad (1)$$

where:
-ρ means liquid density,
-p_1 and p_2 present static pressures in pipeline sections 1 and 2, respectively
- z_1 and z_2 are elevations of 1 and 2 hydrometric pipeline section weight centers,
- α_1, α_2, are the Coriolis coefficients (kinetic energy correction coefficients) for 1 and 2 sections, respectively,
-Q is total discharge of the turbine before wicket gate closure,
-g means gravity acceleration and, finally,
- ΔP_f is the pressure drop caused by friction losses between sections 1 and 2.

For simplification we use the following notation:
- ΔP is the static pressure difference between pipeline sections 2 and 1 related to the reference level:

$$\Delta \mathrm{P} = (p_2 + \rho g z_2) - (p_1 + \rho g z_1) \quad (2)$$

- ΔP_d is the dynamic pressure difference between pipeline sections 2 and 1:

$$\Delta P_d = \rho Q^2 \left(\alpha_2 \frac{1}{2S_2^2} - \alpha_1 \frac{1}{2S_1^2} \right) \quad (3)$$

-C is the geometrical modulus of the penstock segment of a length L given by the following equation :

$$C = \int_0^L \frac{dx}{A(x)} \quad (4)$$

Substituting the above notations in equation (1), one obtains:

$$\rho C\frac{dQ}{dt} = -(\Delta p + \Delta p_d + \Delta p_f) \tag{5}$$

In equation (5), the term $\frac{dQ}{dt}$ is the unsteady term which depends on the rate of change of the volumetric flow $Q = VA$, recorded during transient flow. This volumetric flow is liquid inertia effect in the considered penstock.

Integrating this equation between time interval (to, tk), and grouping terms we get the following equation:

$$\mathrm{Q}_0 = \frac{1}{\rho F}\int_{t_0}^{t_k}\left(\Delta p(t) + \Delta p_d(t) + \Delta p_f(t)\right)dt + q_k \tag{6}$$

Of the integrating result equation (6) above can be obtained by planimetration. If we consider that the surface area resulting from planimetration is A_T the equation (6) can be written in the following from:

$$\mathrm{Q}_0 = \frac{g}{F}A_T + q_k \tag{7}$$

In equation (7) q_k is the leakage flow past the closing device; the flow rate in the final conditions (q_k), if different from zero due to leakage in the closing device, has to be measured or assessed using a separate method.

The above integral formula (6) reveals that in order to determine the flow rate Q_0, the pressure drop ΔP_f caused by hydraulic loss in the examined pipeline segment and the dynamic pressure difference Δp_d in the hydrometric sections of the pipeline should be extracted from the measured static pressure difference Δp between these sections. The values of the last two quantities should be calculated using their dependence on the flow rate square (see eq. (3) and eq. (8)).

$$\Delta P_f = kQ^2 \tag{8}$$

The hydraulic losses calculated in accordance with equation (8) do not depend on flow direction (both are always of the same sign). This type of calculation may lead to the generation of additional error while determining the flow value in the Gibson method. This results from the fact that, under certain conditions, especially in the case of the pump test, temporary significant change direction of fluid flow occurs.

3. Application to a central downturn equipped with Francis turbines

The hydroelectric power high head Valsan is located upstream of the dam on the stream Vidraru on the Valsan river. Valsan HPP is equipped with a horizontal Francis turbine double runner manufacturing Gant Rpu.

In 2011 the SAHME team form ICEMENERG carried out experimental measurements at Valsan HPP. The hydraulic circuit diagram in this section hydroelectric and placement of pressure transducers used to make the tests is shown in fig. 2.

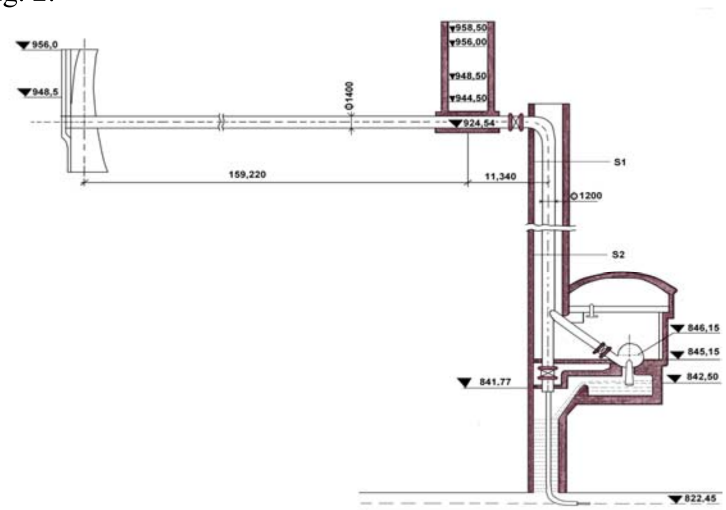

Fig 2. Hydraulic circuit diagram of the HPP Valsan

The Gibson method was chosen for the turbine flow measurement, but for the verification flow was measured simultaneously with ultrasonic method using an ultrasonic flow meter is available in house plant.

A variant with two different sections of measurement was chosen. The tests used two Siemens type pressure transducers, placed in sections S_1 and S_2 in fig. 2.

The tests were carried for several values of load power plant. In Table 1, the values obtained during measurements are given.

Table 1

Nr.crt	P[MW]	Q_{Gib}[mc/s]	H_{av}[m.d.M]	H_{am}[m.d.M]	H_{br}[m]	η[%]
1	0,95	1,23	842,5	954,27	111,77	0,726
2	2,01	2,31	842,5	952,53	110,03	0,818
3	3,44	3,63	842,5	949,68	107,18	0,891
4	4,03	4,21	842,5	947,74	105,24	0,900
5	4,41	4,7	842,5	947,34	108,56	0,882

The data obtained from measurements were used to plast the pressure-time diagram in fig.3, presented for a power of 2 MW generator terminals, a net drop of 108.5 m and a share in the upstream lake 954 mdM.

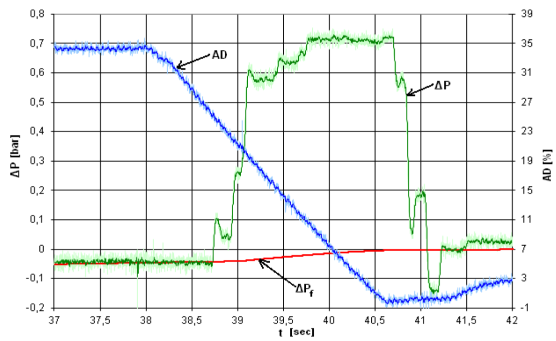

Fig. 3. Diagram of pressure - time to HPP Valsan

Following the calculation by the Gibson method, the flow value was 2.31 [m^3/s], value across power of 2 MW generator. Ultrasonic flowmeter showed a flow value, 2.44 [m^3/s].

The diagram in fig. 3 has been obtained based on a methodology developed at ICEMENERG. The calculation is based on international standards IEC 41 and IEC 62006, respectively, in the previous paragraph formulae. The ΔP_f line of the diagram represents, the pressure loss due to friction; determination on of the lines according to IEC 41 is based on the fact that at some point ther pressure loss is given by:

$$c_i = c(1 - r_i)^2 \tag{9}$$

where:

c is the pressure loss before closing

r_i is a parameter which is determined by the relation: $r_i = \frac{a_i}{A_T + A_L}$

A_T - is the total net area of the diagram for all given segmental areas
a_i - is the net area measured up to a given segment area
A_L - is the area of the diagram corresponding to leakage flow

Also the ΔP_f line can be obtained starting from the prerequisite that pressure losses due to friction and kinetic energy varies with the square of the flow (eq. 8); to simplify calculation of this line, it can be approximated by a straight line [6].

Flow leakage losses determined based on volumetric flow, are calculated using the formulae:

$$q_i = \frac{dV}{dt} = \frac{A \cdot \Delta z}{\Delta t \cdot \sin \alpha} \quad (10)$$

$$q_k = q_i \sqrt{\frac{H_1}{H_2}} \quad (11)$$

where :
- q_k is the loss of flow due to leakage
- q_i is the initial loss of flow (volume flow)
- α is the slope of the pipe
- Δt is the time when the measurement takes place
- Δz level changes recorded in the time Δt
- H_1 is static plant fall
- H_2 is the current fall while making measurements of leakage flow
- A is cross-section area

The flow losses due to leakage were less than 5% of the turbine flow, in accordance with the IEC 41.

A comparison of the flow measured by Gibson method, ultrasonic method and dilution method, is shown in fig. 4.

With this flow, efficiency of the turbine in the three cases was calculated using the following relationship:

$$\eta = \frac{P}{\rho g H Q} \quad (12)$$

A comparison between the results of efficiency corresponding to the three cases is made in Fig. 5.

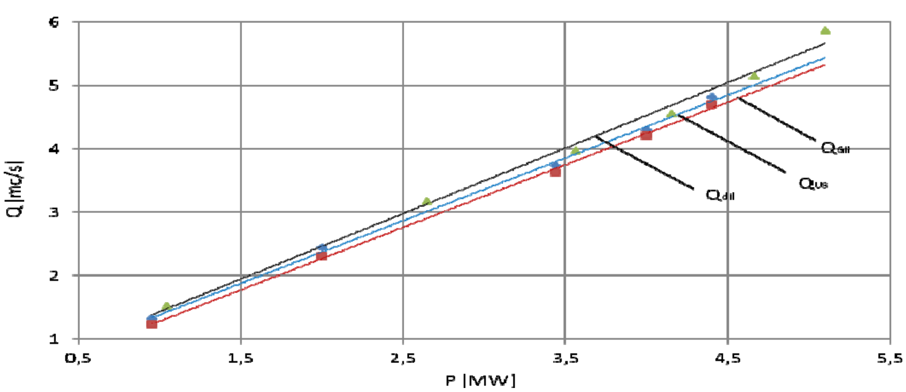

Fig. 4. Comparison between the measured flow time method - pressure (Q_{Gib}) method with ultrasound (Q_{US}) and dilution method (Q_{dil})

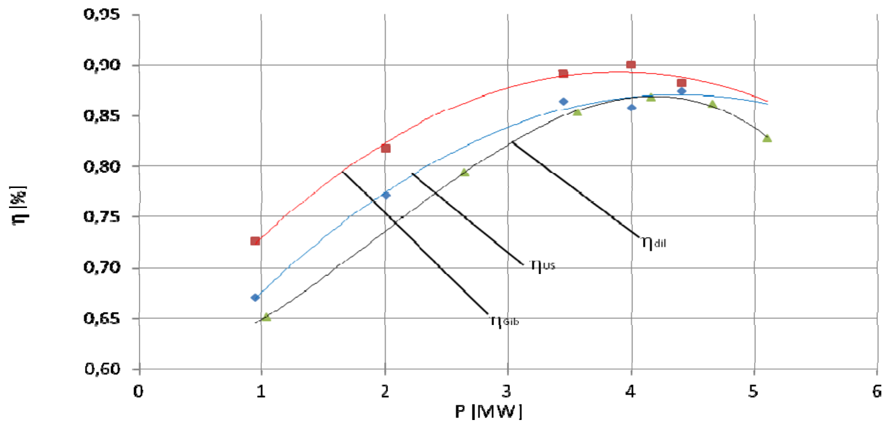

Fig. 5. Comparison of efficiency corresponding measured flow Gibson method (η_{Gib}), ultrasound method ($\eta_{U.S.}$), and dilution method (η_{dil})

The flow values obtained from the measurements by the three methods are presented in table 2. This table was calculated as the average flow Q_{med} between the three-flow measured values Q_{Gib} Gibson method, ultrasonic method Q_{us}, Q_{Dil} dilution method. In the last three columns of the table were calculated deviations from the average flow value of flow values measured by the three methods, flow deviation method ΔQ_{Gib} Gibson, flow deviation method ΔQ_{us} ultrasound, flow deviation method nnn dilution ΔQ_{dil}

For better understanding the table functions $Q_{Gib} = f\ (Q_{us})$, $Q_{Gib} = f\ (Q_{Dil})$, were plotted respectively

Table 2

Nr. crt	Q_{Gib}	Q_{US}	Q_{dil}	Q_{med}	ΔQ_{Gib}	ΔQ_{us}	ΔQ_{dil}
1	1,23	1,32	1,41	1,320	-0,068	0,000	0,068
2	2,31	2,44	2,47	2,407	-0,040	0,014	0,026
3	3,63	3,74	3,95	3,773	-0,038	-0,009	0,047
4	4,70	4,82	4,97	4,830	-0,027	-0,002	0,029
5	4,21	4,30	4,52	4,343	-0,031	-0,010	0,041

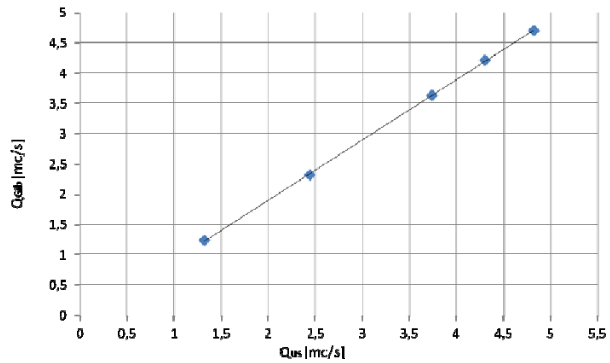

Fig. 6. Graphic representation of the flow measured by Gibson method depending on the flow measured by ultrasonic method Q_{Gib} = f (Q_{us}).

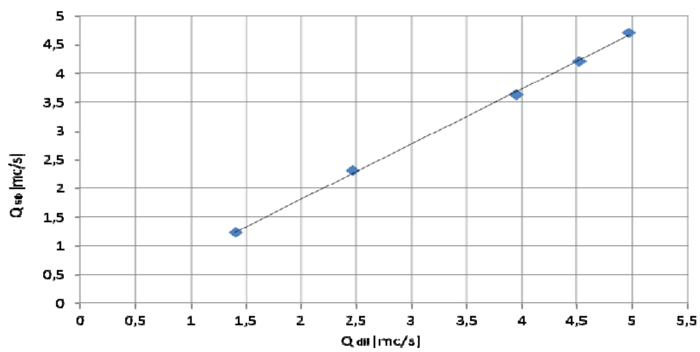

Fig. 7. Graphical representation of flow measured by Gibson method depending on the flow measured by ultrasonic method Q_{Gib} = f (Q_{dil}).

4. Conclusions

Currently, the classical methods used to measure flow turbine Gibson method are most commonly used. Precision electronic devices used in the method for measuring pressure and pressure difference between the two measuring sections, together with the availability of computer software used for recording and processing of measurement makes this method more attractive than the techniques used in the classical method.

Unfortunately not all theoretical aspects of the Gibson method have been addressed comprehensively. An unresolved issue is related to the calculation of friction losses during unstable fluid flow in closed conduits. The method adopted for calculating such losses is justified for flow in equilibrium, and it must be checked in unstable flow conditions. However the Gibson method has proven to be a reliable method for determining the efficiency of hydropower plants.

The advantages of the Gibson method, compared with the other methods are: low cost method and easy installation of the measuring system; measurement accuracy as good as that of other conventional methods used to determine efficiently; low operating restrictions for conducting hydro test for efficiency; •short duration of time efficiency tests; ability to determine temporal variation in flow.

Disadvantages of the Gibson method are:
• low accuracy of assessment or measurement of leakage flow closures; require quick closing guide vanes for each measurement which lead to water hammer.

R E F E R E N C E S

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