On the Leakage Flow Measurement in Gibson Method Applied for Hydro Power Plants

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Abstract: - This work presents a methodology developed for the leakage flow measurement when using Gibson method in hydro power plants. A mathematical modeling is presented and field tests were applied. The obtained results shows the efficiency of the method that considers the existence of a downstream valve that can be operated later on the guide vanes closing.

Key-Words: - Flow Measurement, Gibson Method, Pressure-Time Method, Hydro Power Plants.

1 Introduction

The Gibson method, or pressure-time method, for flow measurements in closed conduits was proposed in 1923 by Normal Rothwell Gibson [1]. The method is based on the Newton's Second Law of Motion. The force on a mass of water is related to the change in momentum as the mass desaccelerates.

To apply the method, the difference in pressure between two cross sections is measured during an over pressure transient that occur when the flow is continuously reduced while the hydraulic turbine guide vanes is closed. The most common implementation is to measure the difference in pressure existing between two piezometer rings on the penstock.

Due to the reliability of its results, the method is recommended in the main standards [2-4] being suitable for application in water measurement for efficiency test of hydraulic turbines. Many authors have been contributing with the method since its conception. In order to optimize its application, as long as possible, the use of modern information technology tools is accounted for [5-7].

Despite of the ingenious theory behind the method, the identification and considering of the leakage flow has been one of the great challenges to spread its application. The leakage flow appears when the guide vanes of the turbine do not closes at all or when the complete shut-off is not guaranteed.

In general the leakage flow is very small, assuming maximum values of about 1.5% of the rated flow. However this low value is not negligible, mainly in front of commercial disputes where very closed contractual requirements imposes low uncertainties in the efficiency calculation.

This way, this work presents a new conception of the test, applying Gibson method for flow measurements in hydro power plants, considering the leakage flow. The existence of a valve located on the hydraulic turbine upstream that could be closed in a few seconds after guide vanes closing is considered.

2 Description of Gibson Method

Consider a steady flow as showed in fig. 1, with mean speed v (m/s) and flow Q (m^3/s) in the interval with length L (m) between the piezometer rings 1 and 2 of a straight conduct, internal diameter D (m) and cross section area A (m^2).

Operating the valve V during a closing time t_V (s) while the speed droops from v_i to v_f (m/s), originates the so called *water hammer*. This phenomenon is characterized by a considerable differential pressure rising Δp (m) between points 1 and 2, with the point 2 at the higher pressure, represented by the line (A,B,F). This differential pressure is proportional to the desired flow value.

From the Newton's Second Law of Motion one can obtain [7]:

$$\Delta p \cdot \gamma \cdot A = -\rho \cdot L \cdot A \cdot \frac{dv}{dt} \quad (1)$$

$$v_i - v_f = \frac{g}{L} \cdot \int_0^{t_v} \Delta p \cdot dt = \frac{g \cdot A_d}{L} \quad (2)$$

And,

$$Q = \frac{g \cdot A_d \cdot A}{L} + q \quad (3)$$

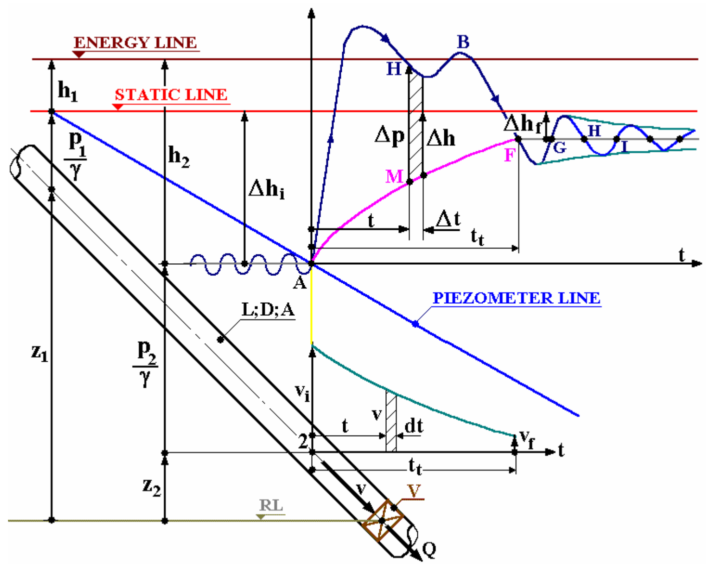


Fig. 1 – Geometrics, kinematics and dynamics characteristics of Gibson method.

When friction losses *Δh* (m) and leakage flow *q* (m) are properly accounted for, the area of the differential pressure with respect to time diagram, delimited by the (A,B,F,A) segment, is directly proportional to the flow. The line AF, representing the friction losses, would be obtained considering that the friction losses and the kinetic energy varies with the square of the flow [7]. Thus, the steady-state flow rate can be obtained by solving for flow in an algebraic impulse equation [6].

A critical aspect during the calculus is the determination of the limits of the integral. This is a source of confusion and divergence since different standards establishes different procedures. Nevertheless, after successive study cases, it has been observed that there is a certain freedom while choosing these limits.

The main objective is to calculate the area of the diagram. When working with mean values, it can be observed that oscillations which results in positive areas over the mean static pressure line are compensated by oscillations that produce negative areas under this line.

The fact is that only the area under the over pressure will be significant, auto excluding undesired areas. Thus, the initial and final limits of integration may be anyone regarding they would be as apart as possible, at left and at right, from the differential overpressure diagram.

One of the most important issue is the leakage flow determination. The knowing of its correct value is of capital importance, since it influences directly on the final flow value.

Nevertheless, its identification is not trivial, and depends on physical installation and on the power plant arrangement. The factors of influence are, sometimes, non controllable variables. An alternative way for the leakage flow identification applying Gibson method is showed as follows.

3 Proposed methodology

As described, the determination of the leakage flow is of fundamental importance to the success of employing Gibson method for flow measurements in power plants.

This leakage flow appears when the complete shut-off is not guaranteed when the guide vanes of the turbine (controlled by the speed governor) is closed. In general, the complete shut-off is achieved by acting in an existing upstream valve, normally a butterfly or globe valve.

It is important to note that this valve or other gate device is designed to bear overpressures in extreme conditions like that found in an emergency closing. The operational proceeding, however, proposes the flow shut-off by a prior acting of the guide vanes for a subsequent operation of valves or gates, after a couple of seconds, when the flow assumes minimum values of about the leakage flow.

The flow reduces from the steady value (v_0) till zero in two stages. The first reduction is reached by the guide vanes closing and the former is done by operating the upstream valve. These actions are time coordinated in t_0 and t_2, respectively, as showed in figure 2.

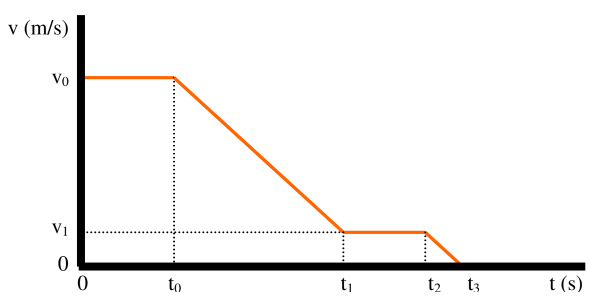


Fig. 2 – Speed decay in two steps.

This two stages speed reduction will product two differential pressure diagrams, a primary and a secondary, according to (2), with areas proportional to the speed reduction, conducting to (4) and (5).

$$v_0 = (v_0 - v_1) + (v_1 - 0) = \frac{g}{L} \cdot \left(\int_{t_0}^{t_1} \Delta p \cdot dt + \int_{t_2}^{t_3} \Delta p \cdot dt \right) \tag{4}$$

The resultant flow is:

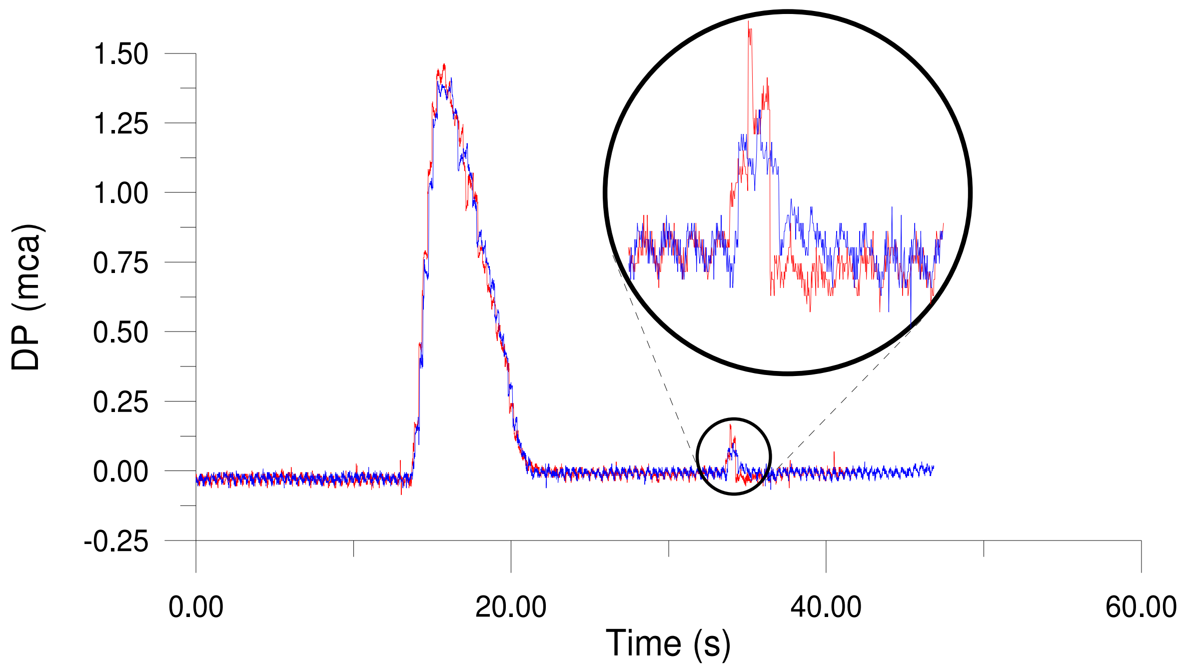
$$Q = v_0 \cdot A = \frac{g}{L} \cdot (A_{d1} + A_{d2}) \cdot A \tag{5}$$

Where A_{d1} (m.s) and A_{d2} (m.s) are areas under differential pressure curve.

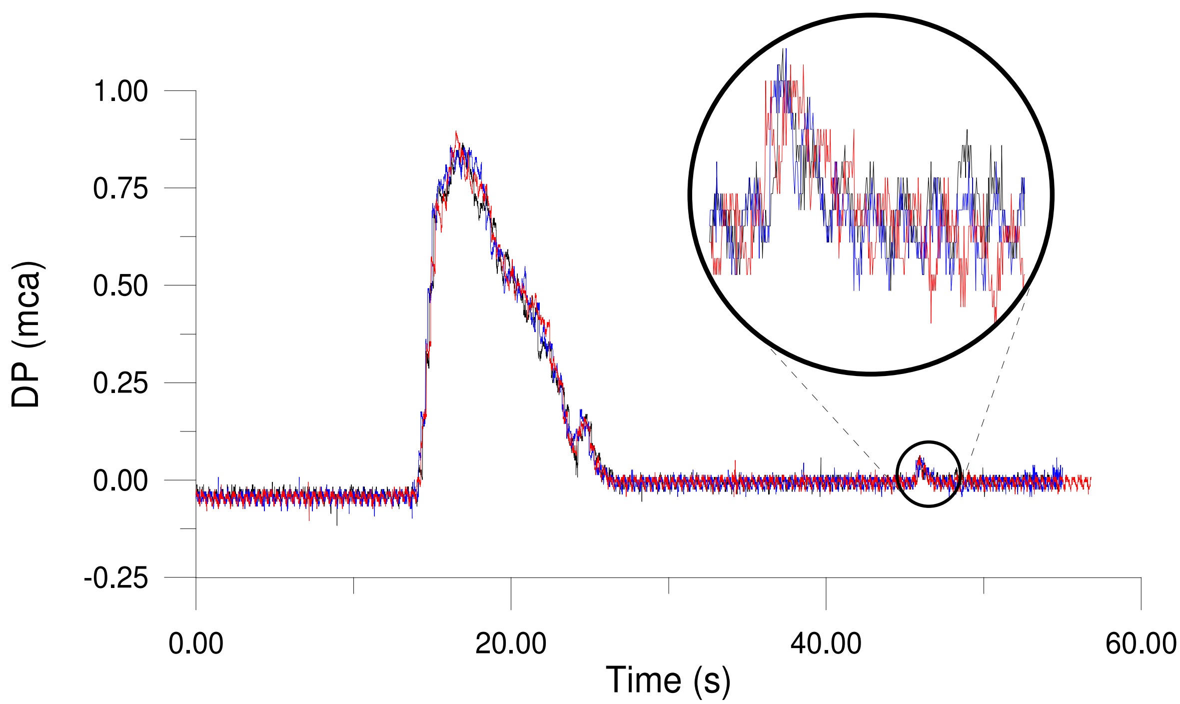
4 Study case

The proposed methodology was applied during the reception tests of Alto Jauru small power plant, owned by Arapucel S/A [6]. Figure 3 shows the arrangement of the test, depicting the penstocks prepared for the differential pressure measurement. The internal diameters and the distance between the pressure intakes are 3.2 (m) and 19.97 (m) respectively. The local gravity acceleration was obtained 9.783 (m/s^2).

Fig. 3 – Field setup to the Gibson method for flow measurement.



(a)



(b)

Fig. 4 – Pressure-time diagrams

Pressure time records for specific conditions were made applying a portable computer based PCMCIA data acquisition system. Figures 4(a) and 4(b) shows the obtained diagrams for 90% load conditions for machines #1 (two recorders) and #2 (three recorders), respectively.

These pictures shows the primary overpressure due to the hydraulic turbine guide vanes closing, as so as the secondary overpressure, with smaller intensity, showed in the details, due to the closing of a butterfly valve, about twenty seconds later on the guide vanes operation.

The areas under these curves are proportional to the steady state flow to be determined. The minor area in relation to the total area gives an idea of the percentile value of the leakage flow.

The results presented in Tables 1 and 2 summarize the analysis and were obtained applying these data to developed software that implements the proposed methodology.

Table 1 – Analysis of pressure-time diagram - Unit #1

Unit #1	**A_{d1} (m.s)**	**A_{d2} (m.s)**	**q (m^3/s)**	**Q (m^3/s)**	**q (%)**
Record 1	5.6885	0.0573	0.2260	22.6716	1.008
Record 2	5.5680	0.0491	0.1936	22.1638	0.873
Mean	**5.6283**	**0.0532**	**0.2098**	**22.4177**	**0.936**
Std Dev	**0.0852**	**0.0058**	**0.0229**	**0.3591**	**0.096**

Table 2 – Analysis of pressure-time diagram - Unit #2

Unit #2	**A_{d1} (m.s)**	**A_{d2} (m.s)**	**q (m^3/s)**	**Q (m^3/s)**	**q (%)**
Record 1	5.3473	0.0372	0.1467	21.2463	0.690
Record 2	5.5037	0.0307	0.1213	21.8378	0.555
Record 3	5.5937	0.0287	0.1130	22.1848	0.509
Mean	**5.4816**	**0.0322**	**0.1270**	**21.7563**	**0.584**
Std Dev	**0.1247**	**0.0044**	**0.0176**	**0.4745**	**0.094**

5 Discussion of the results

The International Standard Commission establishes a minimum speed-length product value of 50 (m^2/s) [3]. No attention is made from where this value comes. Nevertheless, the following simple formula can be used to estimate the maximum differential pressure to be observed while applying Gibson Method.

$$\Delta P_{\max} = \frac{L \cdot u_{\max}}{g \cdot t_v} \quad (6)$$

Looking at this formula, it is clear that the higher the product u.L, the higher will be the differential pressure. Considering that the mean flow speed in a steel pipe of power plants is about 3 (m/s), t_V of 10 (s) and the minimal length of 10 (m), results in a maximum differential pressure of about 0.3 (m). If the value 50 (m^2/s) is applied the value increases to 0.5 (m). These differential pressure values can easily be read by modern differential sensors.

Sometimes, even with a small u.L product, a high differential pressure can be reached when the closing time is very short, in such way that an update of the standard procedure should include the closing time to proper consider its effect in the differential pressure value. This issue is particularly important regarding to the secondary pressure diagram, where a fast closing time guarantees pressures of the same order of the most of primary diagrams even with a small leakage flow.

6 Conclusions

The presented methodology allows the determination of the leakage flow in hydro power plants using pressure-time records obtained while applying the Gibson method. The existence of a valve that could be closed after the turbine guide vanes is considered.

The method showed to be highly precise as a function of the presented repeatability. A great accuracy can be obtained increasing the distance between the piezometer rings or reducing the time of closing of the valve. These actions enlarge the amplitude of the differential pressure during the primary and secondary hydraulic transients.

The power plant arrangement, regarding to the design of its dam, hydraulic path, surge tank and other, will have a decisive influence over the time interval between the guide vanes closing and the valve closing, necessary to obtain reliable results.

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