ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

METHODOLOGY FOR HYDRAULIC MICROTURBINES TESTING

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Abstract. *The principal objective of this work is to make the description of the test about a hydraulic microturbine and explained the entire methodology, from the assembly of the laboratory bench until final result (characteristics curves).For the test, firstly, it is needed a laboratory bench able to simulate and measure the flow characteristics, and also measure the turbine's own data. The bench used, basically, has a pump to simulate the flow, a flow meter, a Francis microturbine, flow and pressure sensors for flow's characteristics and rotation sensor for the turbine shaft's characteristics. After the test it was possible to find the point where the microturbine works with the best efficiency, it also called of best operation point.*

Keywords: *microturbine, Francis, methodology, laboratory bench.*

1. INTRODUCTION

Now a day with the necessity of expansion and diversification of energy's sources, it's common to use smaller hydroelectric plants. One of the most important type of small plant is the micro-hydroelectric plant, which the principal objective is to produce electric energy in small quantities for supply small consumer or even the own producer.

As in any hydroelectric plant the most important equipment is the hydraulic turbine,so there is a big necessity to know how the turbine works and to plan a methodology to test and characterize a microturbine.

This paper has as main objective to make the description of a hydraulic testing of a micro turbine, it will be explaining the whole methodology, from assembling the experimental bench until the final results (turbine's characteristic curves).

2. METHODOLOGY

2.1 Physic model

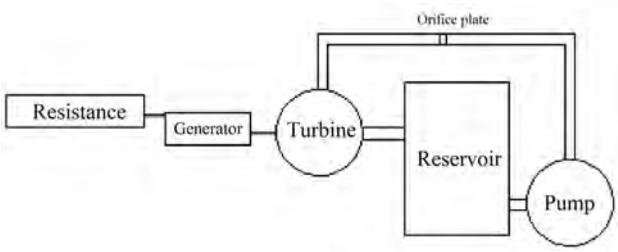

Figure 1: Diagram of laboratory bench

The Fig. 1 shows the system utilized for the test in the Francis turbine type, it is basically a group of equipment whose order to simulate and monitor various flow rates and obtaining the characteristic curves of the turbine.

First, the flow rate is generated when the centrifugal pump is activated, the starter is done via a frequency inverter connected to the pump, the purpose of the inverter is to generate a variation in rotation of the pump with the intention to change the flow rate of the simulation.

After exiting the pump, the fluid flows to an orifice plate, which is a head loss device that blocks the flow and causes a pressure drop, which can be use to measure the flow rate. The orifice plate follows the Bernoulli obstruction theory, governed by the Eq. 1

$$Q = C_d A_0 \sqrt{\frac{\frac{2\Delta p}{\rho}}{1-\beta^4}} \tag{1}$$

$$\beta = \frac{D_0}{D_1} \tag{2}$$

In the Eq. (1), "Q" is the flow rate, "Δp" is the variation of the pressure "C_d" is an adjustment factor,"A_0" is the area on point 0,"ρ" is density and "β" is the diameter ratio between point 0 and 1.

Figure 2: Centrifugal pump

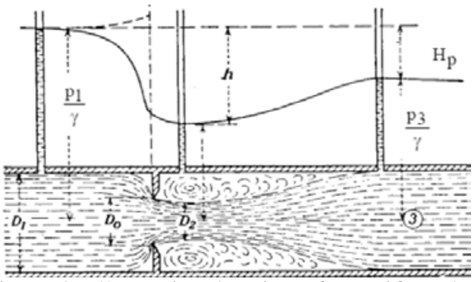

Figure 3: Illustrative drawing of an orifice plate

For this orifice plate, the pressure drop is measure by a differential manometer installed after and before the plate.

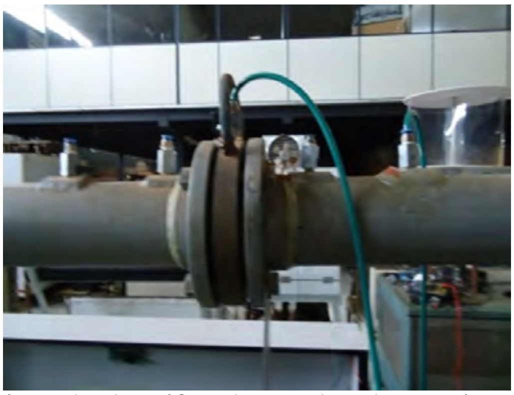

Figure 4: The orifice plate used on the experiment

After pass in the orifice plate, the flow goes to Francis turbine, where part of the fluid energy changes in shaft work. This turbine has a control of the wicket gate.

There is two pressure taps near to the turbine, one is before and other is after the turbine, them serves to measure the energy that fluid give to the shaft, the energy can be calculate by different between the two pressure taps dividing by fluid specific mass.

The flows returns to reservoir after go out the turbine, completing the cycle.

On this bench, the turbine shaft is connecting on a DC electric generator and the generator is connecting on a resistance, this system serves to get the electric potency curve, witch is giving by the product between the current "i" and potential difference "U":

$$P_{ele} = Ui \tag{3}$$

Utilizing the Ohm law, the potency can be calculate utilizing only the potential difference and some resistance, if the resistance "R" stay constant, the potency can be measure utilized only one potential difference sensor, like as:

$$U = Ri \tag{4}$$

$$P_{ele} = \frac{U^2}{R} \tag{5}$$

ISSN 2176-5480

Figure 5: DC generator and resistance used

The mechanical potency in the shaft is given by the product between the angular velocity and the torque.

$$P_{mec} = \omega T \tag{6}$$

In this bench, there is a indirect way to measure the shaft potency, for this there are an angular velocity sensor and Prony brake (Torque sensor).

Figure 6: Angular velocity sensor

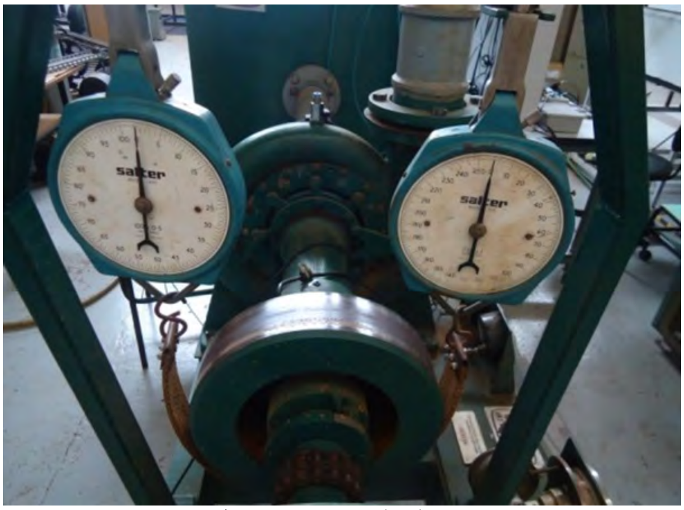

Figure 7: Prony brake

The microturbine efficiency is given by the Eq. (7),

$$\eta = \frac{P_{mec}}{P_{mec}} \tag{7}$$

2.2 Experimental procedure

For the first part of the experiment it was necessary to gauge the calibration on the differential manometer utilized on the orifice plate, because it was an unknown sensor, for this procedure it was used water column to get different points to do the calibration, resulting the Fig. 8.

For finding the calibration polynomial, it was used the arithmetic mean of the points and after it was used one fist order adjust utilizing the Ordinary Least Squares.

The most important thing to do on the test is to plot the real curves, theoretically these curves depend on the flow rate, but the flow rate can vary with the movement of the wicket gate, so to get the curves it is important to fix the angle of the wicket gate.

The firstly step to start the test is to turn on the frequency inverter that is connect to pump. After do this step, it is necessary to increase the frequency of the inverter, in order to increase the pump rotation.

ISSN 2176-5480

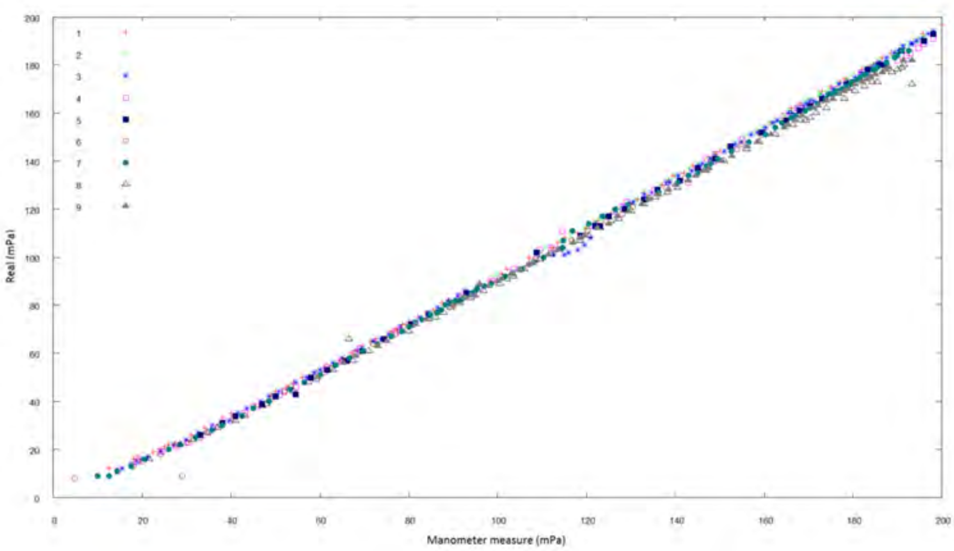

Figure 8: Manometer calibration

When the turbine has been working, it is time to get the measurements, for this work it used the flow rate measure (it is given by drop pressure in the orifice plate), hydraulic potency (it is measured by drop pressure in the turbine) and the electric potency (it is given by the potential difference).

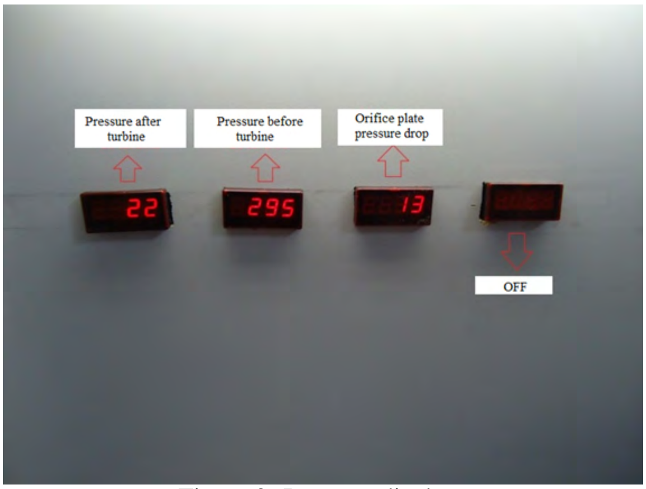

Figure 9: Pressure displays


Figure 10: Voltage display

The test starts when the turbine starts to move and goes until the maximum pump rotation, it was measure all the steps between these limits, after do all the point it is possible to do the potency and efficiency curves. It is done tree test utilizing tree different positions of the wicket gate.

ISSN 2176-5480

3. DATA ANALYSIS

It was possible to get the potency and efficiency graphics, and with that to find the best point work, witch is the point of maximum efficiency in the microturbine tested.

How were expected, the graphs show a behavior close to a second order curve, so it was made an adjustment using the Ordinary Least Squares method on the experimental points in order to obtain the polynomials for the potency and efficiency for each angle tested of the wicket gate.

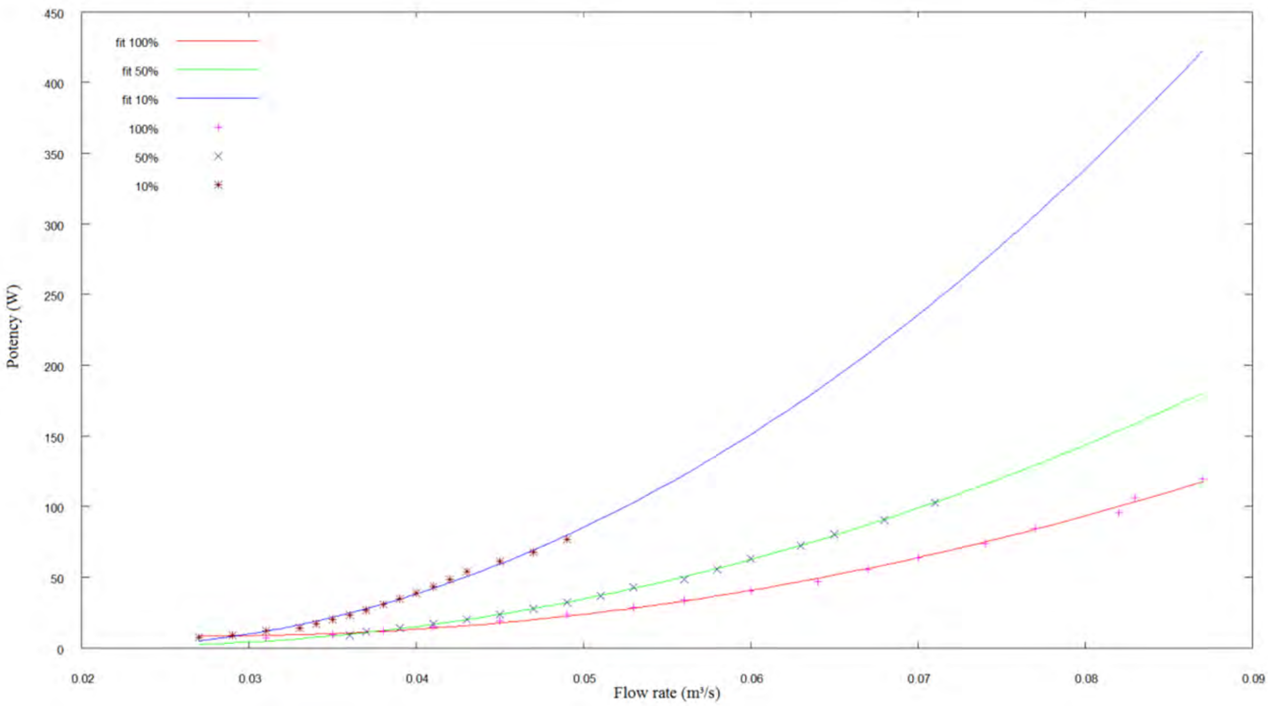

Figure 11: Potency versus flow rate

The polynomials found for the potency, utilized 100% of the wicket gate open, 50% of the wicket gate open and 10% of the wicket gate open, were:

$$Pot_{100\%}(Q) = 31453.4Q^2 - 17773.6Q + 33.7 \quad (8)$$

$$Pot_{50\%}(Q) = 40650.4Q^2 - 1699.9Q + 17.7 \quad (9)$$

$$Pot_{10\%}(Q) = 96055.5Q^2 - 3978.7Q + 42.8 \quad (10)$$

The polynomials found for the efficiency, utilized 100% of the wicket gate open, 50% of the wicket gate open and 10% of the wicket gate open, were:

$$\eta_{100\%}(Q) = -340.7Q^2 - 50.8Q + 1.3 \quad (11)$$

$$\eta_{50\%}(Q) = -817.1Q^2 - 105.4Q + 2.7 \quad (12)$$

$$\eta_{10\%}(Q) = -1098.1Q^2 - 123.0Q + 2.6 \quad (13)$$

In each case, the flow rate which efficiency is maximum is given when the derivative of the polynomial is zero, like the formulation below.

$$\dot{\eta}(Q) = 0 \quad (14)$$

After find the flow rate, it just put them again on the polynomial for finding the maximum efficiency. These flow rates and efficiency are very important because with them we can plan all the turbine operation. The Table 1 show all the cases calculate in this experiment.

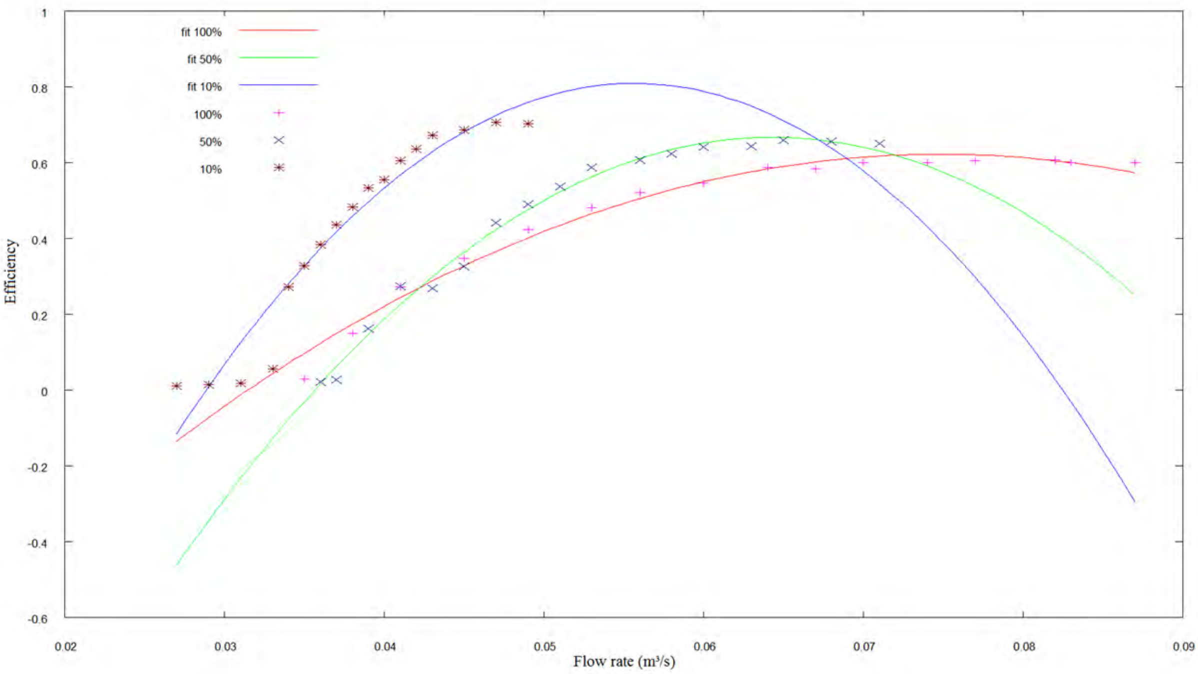

Figure 12: Efficiency versus flow rate

Table 1: Experimental results for maximum efficiency.

Angle of the wicket gate	Maximum efficiency	Flow rate(m^3/s)
10%	0.73	0.0560
50%	0.66	0.0644
100%	0.62	0.0745

4. CONCLUSION

The turbine test, realized on the experimental bench, shows the turbine behaves and the characteristic curves in each situation.

It was observed that a single turbine can have more than one behavior depend on the angle of the wicket gate, as seen in the example of microturbine analysis in this paper. When the angle changes there is, necessarily, a change in the angle of the turbine inlet and remembering that the power can be written in function of the tangential velocity input.

For this turbine geometry, it was noted that the turbine works better with a lower degree of opening, because the efficiency becomes higher than other configuration.

$$\eta_{max10\%} > \eta_{max50\%} > \eta_{max100\%} \tag{15}$$

In this experiment it was used only the hydraulic and electric data, because of the lack of some sensors, the ideal for the test is to consider the power shaft turbine, since it deletes the influence of the generator efficiency in the calculus leaving the result closest to the theoretical.

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