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Analysis of the Mini Turgo Hydro Turbine Performance for different Working Regimes

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Abstract

Many countries, especially in rural zones, have serious problems in supplying electrical energy. In order to fulfil such requirements, and obvious solution is the installing of mini hydro turbines due to their simplicity in manufacturing, installing, lower prices and wide potential.

During the exploitation of hydro turbines in different periods of the year, there are cases where they cannot generate electricity due to the low water flow, which is a characteristic of Kosovo rivers. In order to generate energy which corresponds to the changing flow of water, a mini Turgo hydro turbine by different working regimes has been designed and manufactured.

For analysing mini Turgo hydro turbine efficiency, a test bench must be used. The test bench consists of a water steel tank from which a centrifugal pump draws the water into the Turgo turbine, therefore creating a suitable water head. An inductive generator is connected directly to the turbine runner, which converts the hydraulic energy into electric energy. The test bench has several installed measuring devices, such as flow meters, pressure gauges, ampere meters, voltage, etc.

Mini Turgo turbines have four manual ball valves with four different diameters of nozzle. Valves are operated manually, creating several working regimes by changing the water head and flow. For each working regime, the results have been presented graphically and numerically in order to determine turbine efficiency and other characteristics.

The aim of this paper is to make a comprehensive analysis of the efficiency obtained by theoretical and experimental methods for Turgo hydro turbines in different working regimes.

Keywords: Turgo turbine; Flow; Pressure; Power; Efficiency

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1. Introduction

Energy in general, and electricity in particular, are key elements and very important factors in everyday life and the development of society. Considering the increasing demands for electricity and problems with pollution coming from coal-fired power plants, its production from Renewable Energy (RE) sources is among of the alternative solutions.

The hydropower plants represent an example of renewable energy sources through which it is possible to produce electricity by using the hydro potential of water. In addition, electricity production in hydropower plants is particularly important when considering its positive impact on environmental protection. On the other hand, the hydro turbine produces power during the day and night, and they are better than other alternative sources of energy such as wind, solar, etc. [1-2].

The first hydropower plant in Kosovo was built in the town of Prizren in 1929 with an output power of 160 kVA, with its energy mostly used for the lighting of the several streets. Another hydropower plant was built in Mitrovica on the river Iber in 1930.

After the Second World War several locations in Kosovo began construction of Small Hydropower plants (SHPP). In 1948 a plant was built in Istog with a generation capacity of 0.5 MW, while in 1957 in Kozhnjer – Deçan two generators with capacity 8 MW were installed. Another SHPP was built in Dikanc with a capacity of 1.4 MW in 1956. The biggest Hydropower Plant in Kosovo started work in 1981 on the River Iber. It was called “Gazivoda” and had a capacity of 34 MW [3].

According to Directive 2009/28/EC of the European Council, the Republic of Kosovo has taken the obligation up to undertake the following activities by 2020:

- 20% of electricity generation to be from RE,
- 20% reduction of CO_2, and
- 20% increasing energy efficiency.

In order to meet EC directive requirements, the government of the Republic of Kosovo has prepared a strategy for the period 2013-2020 for building new capacities from RE sources, such as water, wind, sun and biomass by approving feeding tariffs. In 2013 the generation energy from RE was 47.56 MW, while the government target up to 2020 is 765.2 MW [4].

According to some statistics, the hydro potential in Kosovo is very limited and can meet only 10% of the requirements of domestic consumption of electricity. The largest percentage of electricity generation can be obtained from wind, sun, biomass, etc.

Due to poor water flow of rivers in the Republic of Kosovo, generation of energy from water is also limited, and thus the alternative is the building of hydropower plants with low generation. In order to use these rivers' potential, the installing of the mini hydropower plants due to their simplicity in manufacturing and low costs is a very viable option [5].

The literature [6] details several Kosovo rivers flows; for example, the water flow in Mirusha river varies from a minimum of 0.02, an average 1.21 and a maximum 23.30 [m^3/s].

Given the great change of flow within the year, it was necessary to choose mini hydropower plants to suit different working regimes. For this purpose, a testing device at the Faculty of Mechanical Engineering in Prishtina, funded by the Ministry of Education, Science and Technology of the Republic of Kosovo was created [7].

The Turgo turbine is a hydroelectric impulse turbine suitable for medium to high head application ($50<H<250$ m). It has gained renewed attention in research due to its potential application, because it is easy to produce and it has a low cost [8-9]. Under the best conditions, the Turgo turbine efficiency was observed to be over 80%, which is quite good for pico-hydro-scale turbines [10].

The purpose of this study is to analyse the performance of a developed mini Turgo Turbine for 15 different working regimes to determine its efficiency.

2. Testing bench of the mini-hydropower plant

The Testing Bench has been designed for students in order to understand the basic working principles of the mini hydroelectric power station. It is a complete system like in a real hydro power plant, only that the water regulated from the pump instead of a waterfall. The testing bench consists of a water steel tank (1) from which a centrifugal pump (2), which draws the water into the Turgo turbine (3), creating a suitable water head (H). An inductive generator (4) is connected directly to the turbine runner, which converts the hydraulic energy into electric energy, Figure 1 [7].

A test bench (mini Turgo turbine) has four manual ball valves with different diameters of nozzle. Valves are operated manually which create several working regimes by changing the water head and flow. Each working regimes is presented with graphic and numeric results in order to determine turbine efficiency.

The turbine power is dependent from the water head (H) and flow rate (Q). These parameters determine runner pitch diameter (d_p), rotational speed (N), turbine power (P_{turb}), numbers, diameter of nozzles and number of spoons of runners are in the function of pump characteristic, Figure 2.

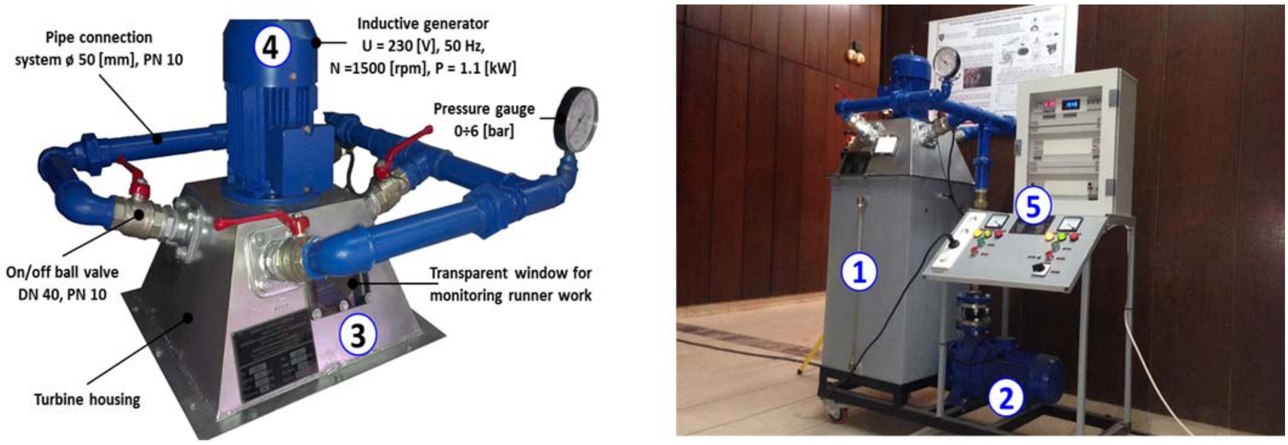

Figure 1. Test bench of the mini hydropower plant [7]

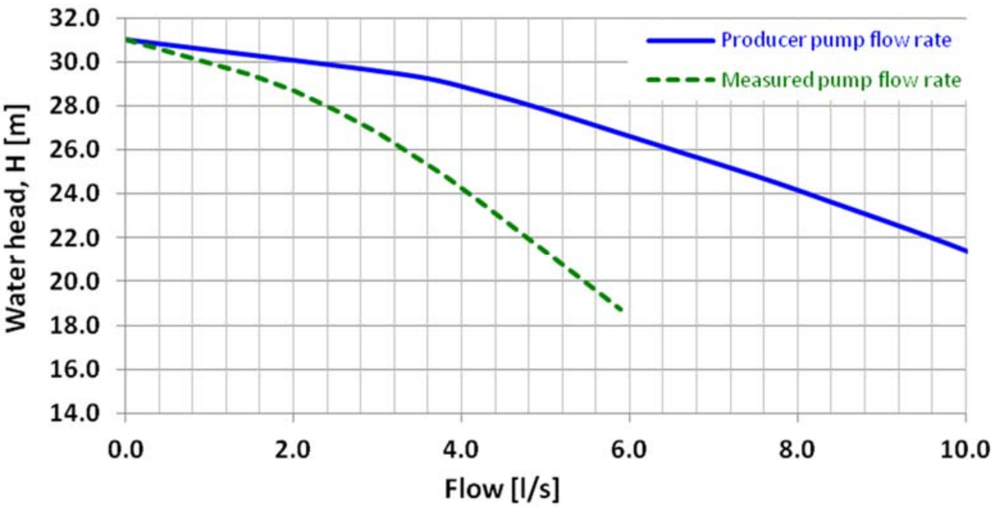

Figure 2. Pump curves of producer and measured flow rate in test bench

Figure 3. Measuring instruments for determining turbine efficiency

From Figure 2 we can see that the curves of pumps taken from the producer and measuring are different. This difference is a result of using available bulk water meters with a small size in the output of pump as well as pipe fittings, ball valves which create additional losses and reflect in the decreasing flow and water head.

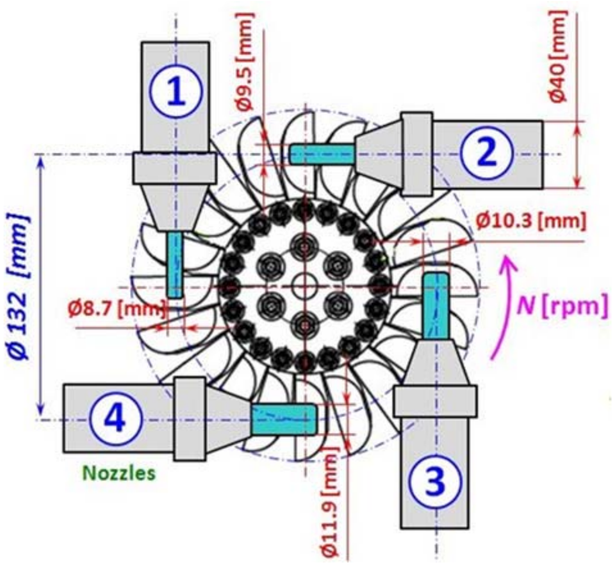

Figure 4. Configuration of nozzles in test bench

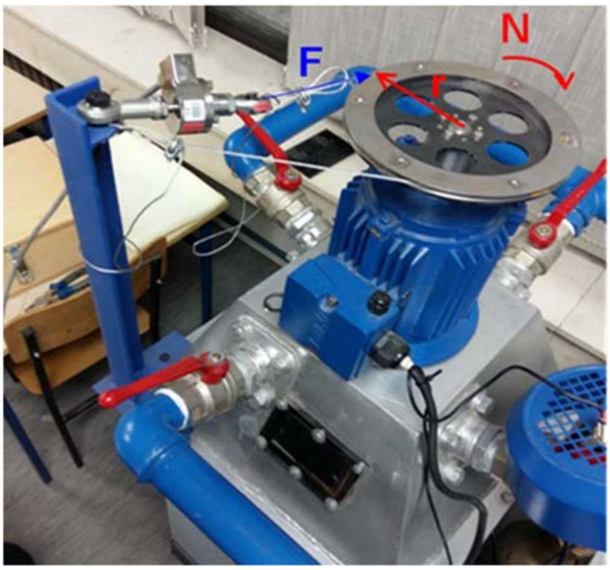

Figure 5. Method for measuring of force in steel rope through pulley

Table 1: Possible combination of nozzles

Working Regimes	Combination of nozzles	Cross section of nozzles [mm^2]	Diameter of equivalent nozzles [mm]
1	1	59.86	8.73
2	2	71.33	9.53
3	3	83.65	10.32
4	4	111.41	11.91
5	1+2	131.19	12.92
6	1+3	143.50	13.52
7	1+4	171.26	14.77
8	2+3	154.98	14.05
9	2+4	182.74	15.25
10	3+4	195.05	15.76
11	1+2+3	214.83	16.54
12	1+2+4	242.60	17.58
13	1+3+4	254.91	18.02
14	2+3+4	266.38	18.42
15	1+2+3+4	326.24	20.38

The measuring instruments which are used in the test bench are: ampere meters, voltage meters, a digital tachometer, water flow meter, pressure gauge and a dynamometer, which allows us to determine turbine efficiency during the different working regimes, Figure 3.

3. Methodology for analysis of working regimes

A testing bench has four ball valves with four different sizes of nozzles (Figure 4), which gives 15 possible operation points of turbine (the 16 is the trivial zero-flow maximal head point on the pump curve), Table 1.

The output power in the shaft of a hydro turbine (P_{turb}) is a function of the head and flow and is written by the following expression:

$$P_{turb} = \rho \cdot g \cdot H_n \cdot Q \cdot \eta_t \; [W] \tag{1}$$

In the other side, the turbine's power output (P_{turb}) is the product of the torque (T) and rotational velocity (ω), which is determined by the following expression, Figure 5:

$$P_{turb} = T \cdot \omega = F \cdot r \cdot \omega \; [W] \tag{2}$$

$$\omega = \frac{\pi \cdot N_{Turb}}{30} \left[s^{-1}\right] \tag{3}$$

A turbine's experimental efficiency is:

$$\eta_t = \frac{P_{turb}}{\rho \cdot g \cdot H_n \cdot Q} \cdot 100 \, [\%] \tag{4}$$

where:

$\rho = 1000$ [kg/m^3] – water density,

$g = 9.81$ [m/s^2] – gravity acceleration,

η_t [%] – turbine efficiency,

T [Nm] – torque in shaft of turbine,

F [N] – force in steel rope,

$r = 0.1$ [m] – pulley radius,

N [rpm] – rotation speed of generator shaft.

Measurement of turbine power (P_{turb}) is done through a pulley with a radius (r) which is fixed in the shaft of the generator. In the pulley is an open trapeze channel in which is located a steel rope. One side of the steel rope is fixed for the beam, while the other has a dynamometer which measures tensile force (*F*). During measurement, the rotational speed of the generator (*N*) should be constant (1500 rpm).

4. Determining of turbine efficiency

In this paper we analyse six working regimes of the mini Turgo hydro turbine.

The *first* working regime is when the first ball valve is open by the nozzle diameter Ø8.7 mm, while the *second* regime is only when the second ball valve with nozzle diameter Ø9.5 mm is open. These cases present a situation where the water flow rate has a lower value but the water head gets large values, Figure 6.

Figure 7 presents the output power obtained in a shaft of the turbine for the first and second working regimes.

The turbines efficiency for the *first working* regime is:

$$\eta_{1turb} = \frac{P_{1turb}}{\rho \cdot g \cdot H_{1n} \cdot Q_1} = 0.845 \tag{5}$$

The turbines efficiency for the *second working* regime is:

$$\eta_{2turb} = \frac{P_{2turb}}{\rho \cdot g \cdot H_{2n} \cdot Q_2} = 0.838 \tag{6}$$

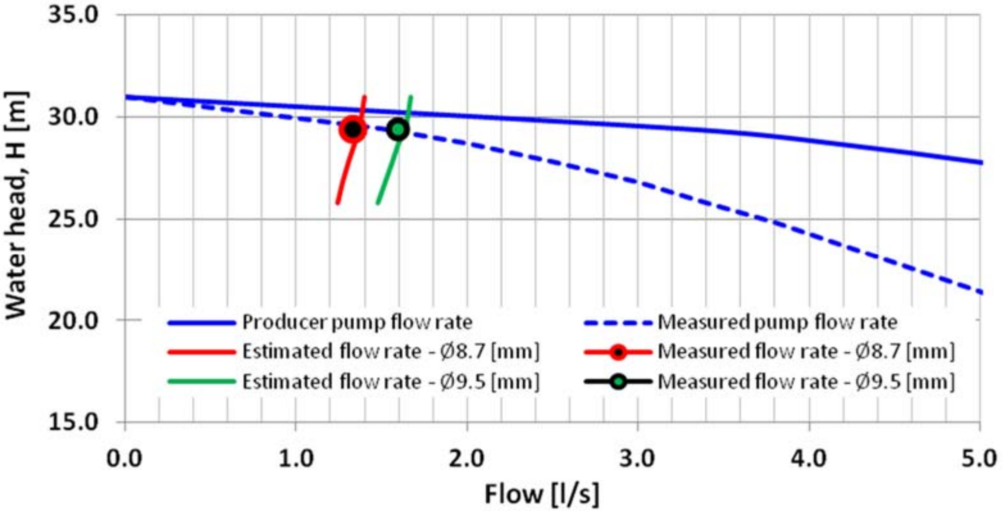

Figure 6. Flow rate vs. water head for first and second working regimes

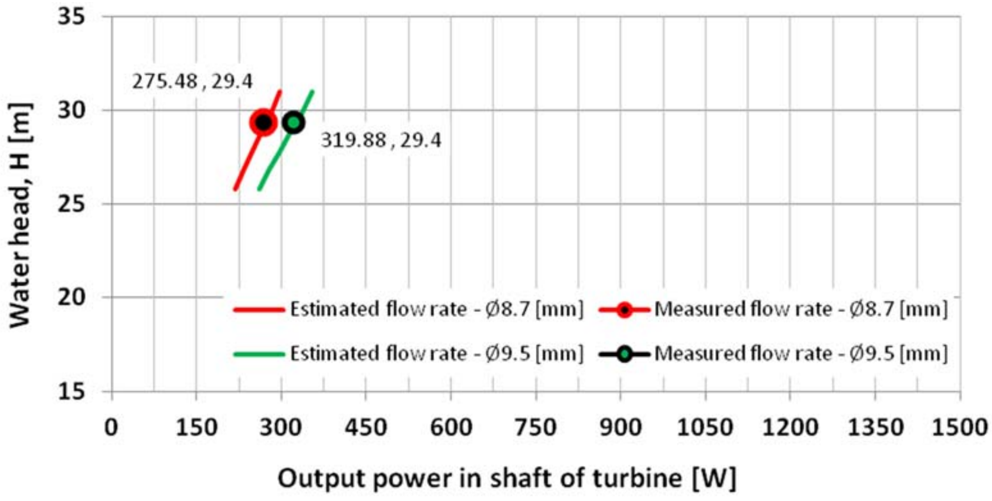

Figure 7. The output power of turbine vs. water head for the first and second working regimes

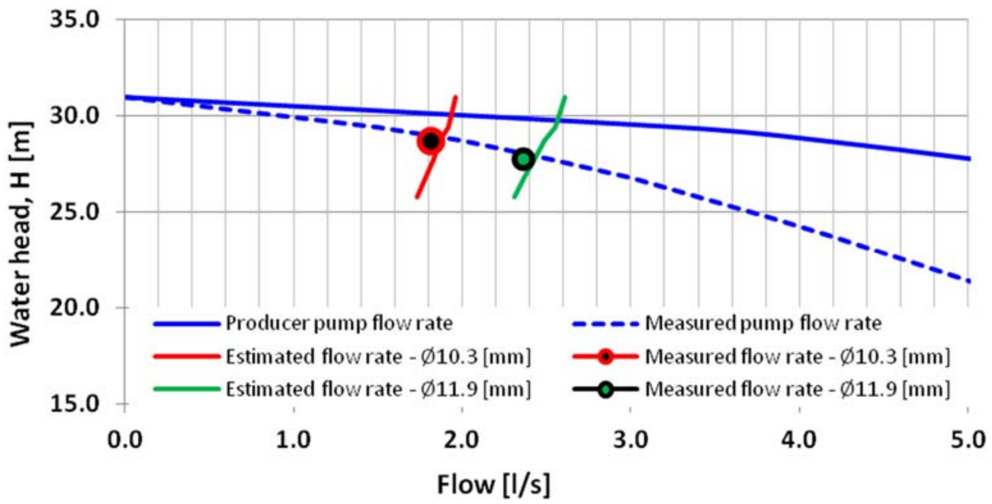

Figure 8. Flow rate vs. water head for third and fourth working regimes

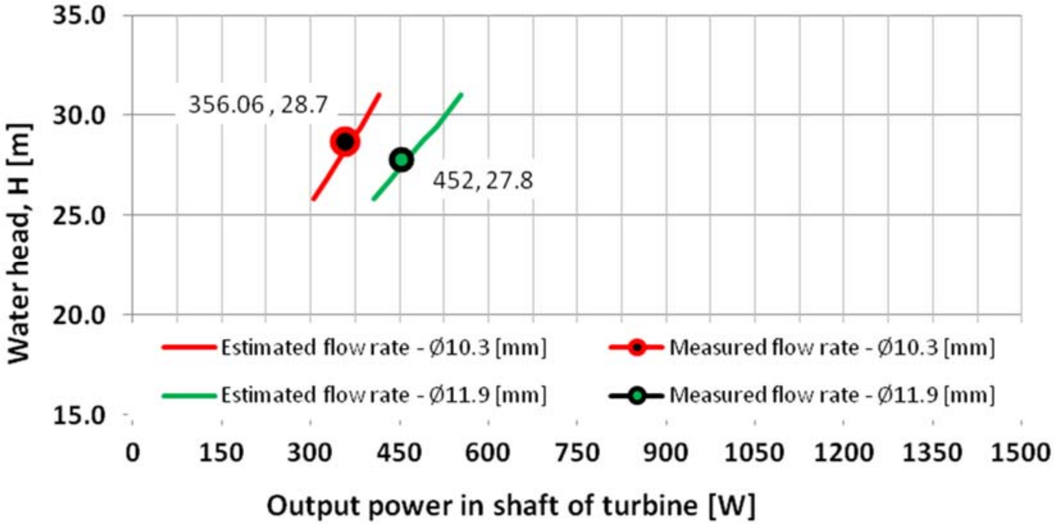

Figure 9. The output power of turbine vs. water head for third and fourth working regimes

From Figure 6 and Figure 7 we see the increasing diameter of nozzles from Ø8.7 to 9.5 mm, where the water flow is significantly increased while the water head is the same. The output power of the turbine is increased by 16% while the efficiency is reduced from 84.5 to 83.8%.

The *third* working regime is when the third ball valve is open by a nozzle diameter of Ø10.3 mm, while the *fourth* regime is when the fourth ball valve, with a nozzle diameter of Ø11.9 mm, is open exclusively. These cases are presented in Figure 8.

Figure 9 presents the output power obtained in the shaft of the turbine for the third and fourth working regimes.

The turbines efficiency for *third working* regime is:

$$\eta_{3turb} = \frac{P_{3turb}}{\rho \cdot g \cdot H_{3n} \cdot Q_3} = 0.835 \tag{7}$$

The turbines efficiency for fourth working regime is:

$$\eta_{4turb} = \frac{P_{4turb}}{\rho \cdot g \cdot H_{4n} \cdot Q_4} = 0.832 \tag{8}$$

In Figure 8 and Figure 9 it is shown that with an increasing diameter of nozzles from Ø10.3 to 11.9 mm water flow significantly is increased while the water head is dropped from 28.7 to 27.8 m. The output power of turbine is increased to 27% while efficiency is reduced from 83.5% to 83.3%.

The fourteen working regimes happen when the second + third + fourth ball valves are open (nozzles diameter Ø9.5 + Ø 10.3 + Ø 11.9 mm), while the fifteen regimes is when all ball valves are open (nozzle diameter Ø8.7 + Ø9.5 + Ø 10.3 + Ø 11.9 mm). These cases present a situation where water flow rate gets the largest value but the water head gets lower values, Figure 10.

The turbines efficiency for fourteen working regime is:

$$\eta_{14turb} = \frac{P_{14turb}}{\rho \cdot g \cdot H_{14} \cdot Q_{14}} = 0.825 \tag{9}$$

The turbines efficiency for fifteen working regime is:

$$\eta_{15turb} = \frac{P_{15turb}}{\rho \cdot g \cdot H_{15} \cdot Q_{15}} = 0.805 \tag{10}$$

In Figure 11 are presented the output powers obtained in the shaft of the turbine for the fourteen and fifteen working regimes.

From Figure 10 and Figure 11 we can see that with an increasing numbers of nozzles from 3 to 4 pieces, water flow significantly is increased while the water head is dropped from 21.4 to 18.7 m. The output power of turbine is increased 2.5%, while efficiency is reduced from 82.5 to 80.5%.

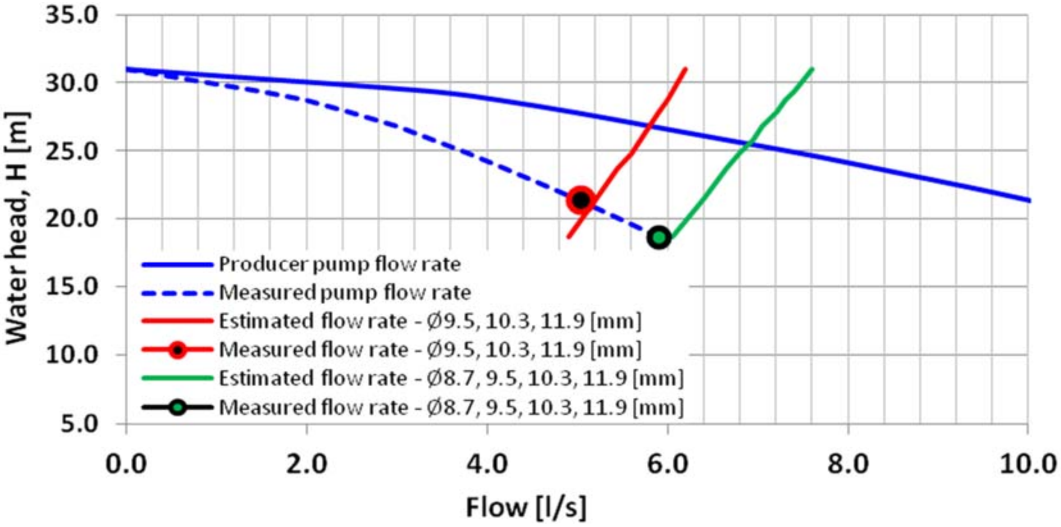

Figure 10. Flow rate vs. water head for fourteen and fifteen working regimes

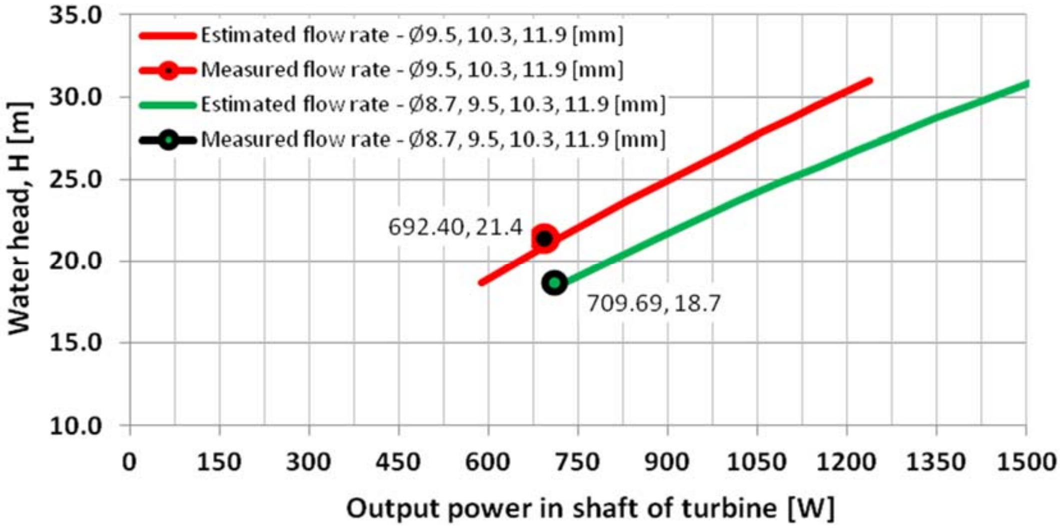

Figure 11. The output power of turbine vs. water head for fourteen and fifteen working regimes

5. Conclusion

Based on the comprehensive analysis of the working regimes of a developed mini Turgo turbine through a test bench, we can conclude that:

- For a higher water head (around 30 m), the turbine efficiency is better (~ 84%), while for lower head the efficiency significantly dropped (81%), although water flow increased. This fact confirm the Turgo turbine gives better efficiency

in medium and higher head application 50<H<250 m;
- By decreasing of the water flow, the number of nozzles should be reduced in order to maintain higher water head respectively efficiency;
- Each working regime has a slightly different peak power and rpm, which significantly influences fluctuation tension and frequency in the generator;
- In order for the test bench to be more suitable for a mini Turgo turbine for medium and higher head application, it is necessary to replace the existing pump with a higher head in order to maintain efficiency, voltage and frequency.

Based on the findings outlined above on river hydrology and configuration of Kosovo rivers, the authors recommend the installing of Turgo turbines.

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