

Characteristics of bladeless turbine

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Abstract

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The project objective was to perform laboratory tests of the SETUR DVE 120 bladeless turbine and to analyse its measured parameters. Operating characteristics were then determined based on the measured values. The measurement was performed in a closed hydraulic testing circuit in a laboratory of the Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences Prague. The first part of the article describes the workplace and the method of measurement of the main and the auxiliary parameters. The second part deals with the turbine characteristics. The characteristics describe the relationship between the water flow rate and the usable water gradient and between the water flow rate and the electrical power output of DVE 120, which is important from the user's point of view. The conclusion features a comparison of the bladeless turbine operating characteristics (dependency of the overall efficiency on the waterpower) and the characteristics of the Francis turbine.

Keywords: Setur DVE 120; irrigation; water gradient; water flow rate; efficiency

Today, the issue of alternative energy sources is ever more important. Use of the energy potential of water streams has a significant and irreplaceable position in it. The bladeless turbine, invented as recently as 1995, is intended for the smallest water streams. Due to the newness and uniqueness of its design, there is still not enough data for determining its operating and technical parameters (SEDLÁČEK, HOSTIN 1998; SEDLÁČEK, BERAN 2008). Its ability to run in “island mode” is a great benefit further extending the variability of its use. Apart from the electricity generation, the turbine may be used for powering other machinery, especially irrigation pumps, etc. (POLÁK et al. 2013).

Bladeless turbine characteristics have not yet been accurately specified. Users of currently operated sets tend to rely on empirically acquired experience. Yet, it is important to know and to predict the operating

features of equipment sets to design and size them. Similarly, users must be aware of the operating parameters to create conditions for efficient operation.

The experiment resulted in determining relations between the main and auxiliary operating/technical parameters of a set. Such acquired parameters can then be used for the selection of a powered machine such as a small pump for irrigation. A small pump connected to the bladeless turbine can irrigate parched areas, for example. Lack of water still represents a major problem in dry or underdeveloped areas (KAZIM 2003).

MATERIAL AND METHODS

A water turbine based on the rolling principle can use the energy potential of very small water

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streams, which is suitable especially for closed production or other electrical systems or for powering irrigation pumps (BERAN et al. 2013).

The measurement was performed on a SETUR DVE 120 mini-turbine (Mechanika Králův Dvůr s.r.o., Králův Dvůr, Czech Republic) within a closed testing hydraulic circuit in a laboratory of the Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences Prague. The circuit design provides for the necessary measuring and modelling of different operating states of the tested turbine. The measuring circuit (Fig. 1) consists of a reservoir, installed under floor level, from which the water is pumped with an impeller pump into a feeding line (the horizontal part beyond the pump), thus simulating the water gradient and flow rate of a water source feeding the turbine. The feeding line has a control valve, which can change the flow rate and the water gradient height. In addition, it features measuring equipment – pressure gauges and an ultrasound flow meter. The feeding line ends with a flexible hose (the vertical part in front of the turbine) featuring an input diameter reduction and a flange for connecting to the turbo-set (i.e. this section was built the same way as in real installations). The DVE 120 unit, i.e. the turbine and a generator on a concrete foundation is located in a plastic tank the purpose of which is to

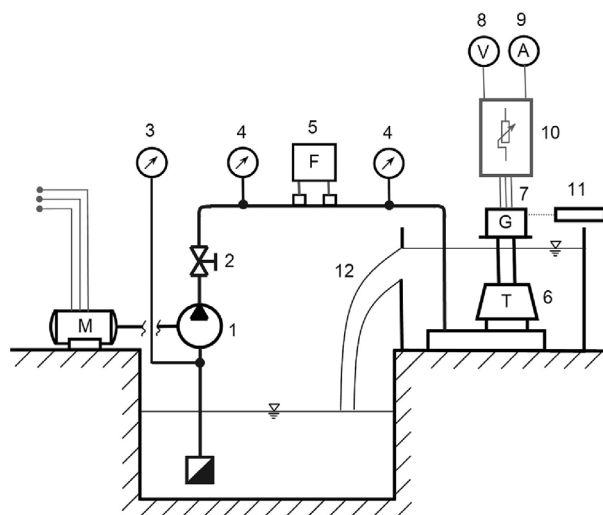


Fig. 1. Diagram of the hydraulic circuit for the measurement of the DVE 120 mini-turbine characteristics

1 – pump; 2 – control valve; 3 – vacuum gauge; 4 – pressure gauge; 5 – flow meter; 6 – turbine; 7 – generator; 8 – voltmeter; 9 – ammeter; 10 – fluently variable resistance load; 11 – speedometer; 12 – overflow discharge; A – ammeter; F – flow meter; G – generator; M – electric motor; T – turbine; V – voltmeter

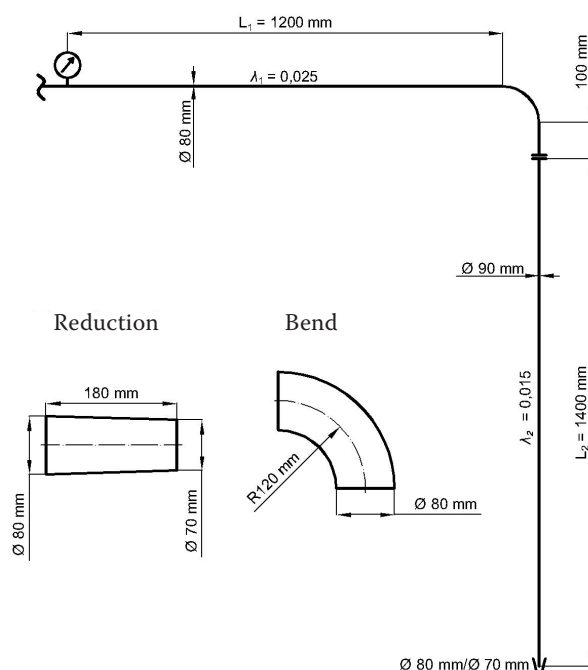


Fig. 2. Technical description of the hydraulic circuit for the measurement of mini turbine

λ_1, λ_2 – coefficient of friction losses in pipeline; L_1, L_2 – tube length

maintain the correct water level necessary for proper functioning of the equipment. There is an overflow chute in the tank wall through which water returns to the reservoir.

Three-phase electricity can be drawn from the generator's terminals and as it is equipped with permanent magnets, the set can run autonomously in "island mode". For the purpose of measurement the generator output was connected to a fluently variable resistance load. Current in individual phases and interfacial voltage was measured in order to determine the output power, which was then calculated based on the applicable relations. In addition, turbine speed was measured with an infrared contactless sensor during the operation. (POLÁK et al. 2013).

Fig. 2 presents the technical layout of the measuring loop including its dimensions.

Measurement took place at a defined water gradient, flow rate and load. The following parameters were recorded:

- pressure at the turbine input,
- flow rate in the feeding line,
- turbine speed,
- voltage and current at the generator terminals.

Based on these values, the following parameters were determined:

- water gradient,
- water flow power at the turbine input,
- generator electric output,
- generating set's overall efficiency.

It should be stressed that all the presented turbine parameters were measured at a constant speed of $n = 200$ rpm. This resulted in graphically expressed relationships of different parameters, mainly as functions of water gradient, flow rate, power, speed and load. The final characteristics are presented in the following text including brief comments (POLÁK et al. 2013).

Determining the turbine's input hydraulic power. The turbine characteristics were created based on the measured and calculated values. The values measured in the turbine include: pressure at the input, flow rate and speed. In addition, electric current and voltage produced by the generator were measured. The usable water gradient h_u was calculated from the measured values by means of the Bernoulli's equation (BOLLRICH 1989; MUNSON et al. 2006). The usable water gradient is defined as the gross (geodetic) gradient minus the turbine's hydraulic height loss, i.e. the difference between the corresponding specific energies:

$$g \times h_u = g \times h_1 + \frac{p_1}{\rho} + \frac{v_1^2}{2} - e_z \quad (\text{J/kg}) \quad (2)$$

where:

- g – acceleration due to gravity (Earth) (m/s^2)
- h_u – usable water gradient (m)
- $g \times h_1$ – specific potential energy (J/kg)
- h_1 – height between the lower water level and the feeding pipe centre, $h_1 = 0.55$ m
- p_1 – pressure on pressure gauge (Pa)
- ρ – density of water (kg/m^3)
- p_1/ρ – specific pressure energy (J/kg)
- v_1 – speed in the tube (diameter of feeding line $d_1 = 0.08$ m) (m/s)
- $v_1^2/2$ – specific kinetic energy (J/kg)
- e_z – specific energy loss (J/kg)

The v_1 speed was calculated from the Q flow rate by means of the continuity equation:

$$v_1 = \frac{4 \times Q}{\pi \times d_1^2} \quad (\text{m/s}) \quad (3)$$

where:

- d_1 – diameter of feeding line, see above ($d_1 = 0.08$ m)

The specific energy loss e_z is the sum of friction losses e_{zT} and local losses e_{zM} :

$$e_z = \sum e_{zT} + \sum e_{zM} \quad (\text{J/kg}) \quad (4)$$

$$e_{zT} = \frac{v_1^2}{2} \times \lambda_1 \times \frac{L_1}{d_1} + \frac{v_2^2}{2} \times \lambda_2 \times \frac{L_2}{d_2} \quad (\text{J/kg}) \quad (5)$$

$$e_{zM} = \zeta_K \times \frac{v_1^2}{2} + \zeta_R \times \frac{v_2^2}{2} + \zeta_Z \times \frac{v_2^2}{2} \quad (\text{J/kg}) \quad (6)$$

where:

- ζ_K – coefficient of local losses in the bend ($\zeta_K = 0.169$)
- ζ_R – coefficient of local losses in the sudden broadening ($\zeta_R = 0.23$)
- ζ_Z – coefficient of local losses in the sudden narrowing ($\zeta_Z = 0.1$)
- λ – coefficient of friction losses in pipeline ($\lambda_1 = 0.025$, $\lambda_2 = 0.015$)
- L_1, L_2 – tube length ($L_1 = 1.200$ m, $L_2 = 1.400$ m)

The v_2 speed was calculated analogically to the speed v_1 (flexible hose, $d_2 = 0.09$ m).

Once these relationships Eqs (3–6) for calculating energy losses are inserted in Bernoulli's equation (Eq. 2), the equation for calculating the usable water gradient acquires the following form:

$$g \times h_u = g \times h_1 + \frac{p_1}{\rho} + \frac{v_1^2}{2} - \left[\frac{v_1^2}{2} \times \left(\lambda_1 \times \frac{L_1}{d_1} + \zeta_K \right) + \frac{v_2^2}{2} \times \left(\lambda_2 \times \frac{L_2}{d_2} + \zeta_R + \zeta_Z \right) \right] \quad (\text{J/kg}) \quad (7)$$

The power of the water flow entering the turbine was determined based on the usable water gradient calculated in Eq. (7) (MAYS 2001; LAHIMER 2012):

$$P = Q \times \rho \times g \times h_u \quad (\text{W}) \quad (7)$$

where:

- Q – flow rate (m^3/s)
- ρ – density (kg/m^3)
- g – acceleration due to gravity (Earth) (m/s^2)
- h_u – usable water gradient (m)

From the user's perspective, output power and efficiency characteristics are more important. The electrical power supplied by the generator can be determined based on the measured current and voltage values. The set's efficiency is expressed as

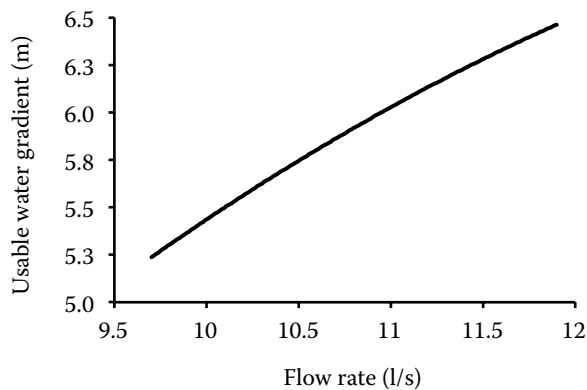


Fig. 3. Usable water gradient and flow rate relationship

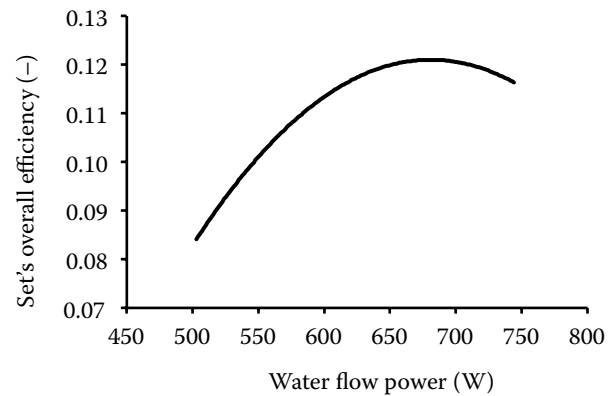


Fig. 4. Bladeless turbine working characteristics

the ratio of the turbine's electric output power to its hydraulic input power (i.e. the water flow power)

$$\eta = \frac{P_{el}}{P} \quad (-) \quad (8)$$

where:

P_{el} – electric power (W)

P – water flow power (W)

RESULTS AND DISCUSSION

The first mentioned characteristic is the relationship between the usable gradient and the flow rate (Fig. 3). It clearly indicates that the flow rate increases together with the usable water gradient, which confirms the presumption. The curve is nearly linear.

Knowledge of the turbine's working characteristics is crucial for its proper operation. This concerns mainly the relationship between the power and the efficiency. The following diagram (Fig. 4)

presents the dependency of the set's efficiency on the waterpower. Max. efficiency is achieved at a certain value of power. Further increase of the waterpower reduces the efficiency. This feature is typical also for conventional turbines. For illustration, Fig. 5 presents the Francis turbine's characteristics (ŠTOLL et al. 1977). A similar trend of the dependence between efficiency and power follows from comparison of both characteristics.

The following characteristic (Fig. 6) is useful for users of this system. It describes the dependence of the electric output power on the flow rate. This characteristic is beneficial especially for streams with variable flow rates during the year.

The flow rate through the turbine varied from 9.5 to 12 l/s at a gradient height of 5 to 6.5 m during the laboratory tests. The overall system (i.e. turbine, transmission and generator) efficiency varied between 9 and 12% during the electricity generation. The greatest overall efficiency of 12% was achieved at a waterpower of 650 W, which corresponds to approximately 80 W of electric power generated. The set's electrical output power varied between 42 and 87 W.

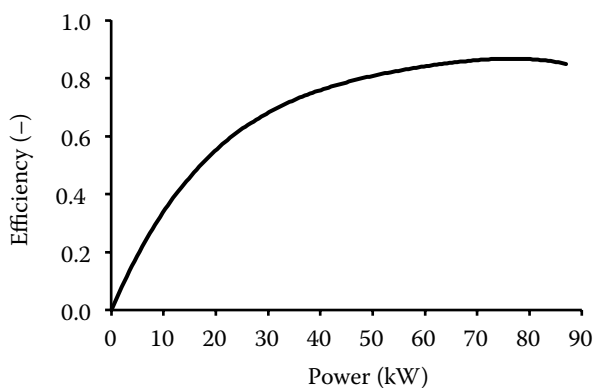


Fig. 5. Francis turbine operating characteristics

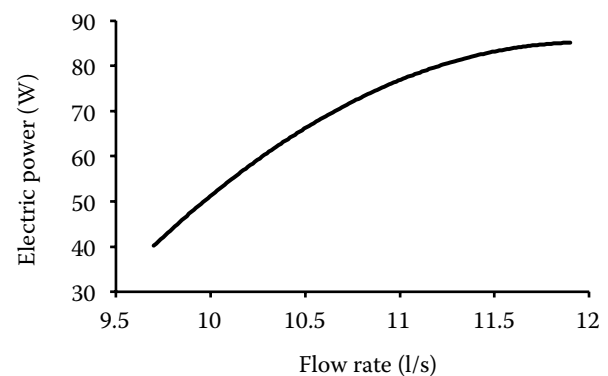


Fig. 6. Electric power and flow rate relationship

CONCLUSION

Following the experiment's evaluation, bladeless turbine parameters were defined determining its operating characteristics. These make it possible to predict its behaviour under different loads. Water flow rates of 9.5 to 12 l/s were measured during laboratory tests at a gradient height of 5 to 6.5 m, which corresponds to a small mountain creek. The max. overall set's efficiency reached 12%, which corresponds to approximately 80 W of generated electricity.

Mini-turbines are expected to have a typical application in local "household" conditions. Yet, industrial use can also be considered as a supplement to small hydraulic power plants or in agricultural irrigation systems if connected to a pump, for example. Further potential for the bladeless turbine use is in water aeration (oxygenation), air humidification, etc.

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