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Operating Characteristics of a Bladeless Turbine for Irrigation Purposes

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Abstract

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Irrigation and pumping systems are still important issues in agriculture. There are many places on the Earth where water needs to be pumped, however no energy sources are available to power the pumps. The bladeless turbine offers a possible solution. This machine can utilize even low-potential sources of water-borne energy working as autonomous energy sources. The turbine has been developed only recently and therefore no comprehensive operating characteristics has existed as yet. The article summarizes the results of experimental measurements carried out on the SETUR DVE 120, a commercially available bladeless turbine sold in a monoblock together with an electricity generator. "User" characteristics have been created from the measured data: dependence of output electrical power and the efficiency of the set on speed, etc.

Keywords: efficiency; power; SETUR DVE 120; water gradient

Lack of irrigation water is a serious perennial problem in dry-climate areas and underdeveloped countries (Kazim 2003). A localized irrigation system offers unique agronomic, agritechnical, and economic advantages for efficient use of water and labour (Kuklík & Hoang 2014). For this reason micro-irrigation systems (MIS) are ever more frequently being introduced in areas with limited water sources. The size of such irrigated areas is gradually growing: from 1.1 million ha in 1986 to approximately 3 million ha in 2000. Nowadays more than 70 countries use micro-irrigation on a total area exceeding 6 million ha (Zamaniyan *et al.* 2014). On the other hand, there are many cases of inefficient water utilization – such as Iran which has a dry climate (average annual precipitation of 240 mm) but efficiently uses only 35% of the total amount of water designated for agriculture (Ebrahimian & Liaghat 2011).

A lack or complete absence of energy needed for water pumping is yet another frequent pressing problem. Reports say that there are 1.6 billion people living in rural areas without access to electricity (IEA 2006; Lahimer *et al.* 2012). This number will not drop in the future unless there are solutions available, especially for less-developed countries. The use of the energetic potential of small water streams by means of a microturbine is a possible solution in some cases. This alternative is becoming very attractive in the field of local renewable energy sources for electricity generation (Bhusal *et al.* 2007). The newly developed bladeless turbine is one of them. It is a machine that converts hydraulic energy of flowing water into the mechanical energy of a rotor without the use of blades (Maršík *et al.* 2010). Designed on the vortex principle (Figure 1), it is very much suitable for operation in a closed loop, i.e. in "island operation" together with a generator (Beran *et al.* 2013).

The bladeless turbine is structurally a very simple unit featuring only a minimum number of moving parts and thus minimum operation requirements. In addition to this, it can handle even very small hydrotechnical potentials that would be unusable for conventional types of turbines. The monoblock bladeless turbine can then be used for the direct pro-

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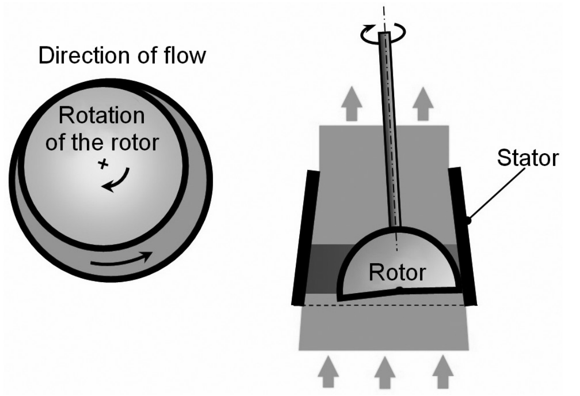

Figure 1. Principle of bladeless turbine (Polák *et al.* 2013)

pelling of irrigation pumps or electricity generation as an autonomous source. A practical application of both can be seen in Figure 2 in the bottom left-hand part of which connection of the bladeless turbine to a wing pump can be seen as well as its connection to an electricity generator in the right-hand part. The water flows in through an open trough equipped with baffle plates and both turbines operate on a water gradient of mere dozens tenths of meter.

As the operating principle has been discovered only recently (1995), there is still not enough information available on the characteristics of the technology that utilizes it. That is why the measuring of operating characteristics has been performed in a closed hydraulic testing circuit in the Faculty of Engineering, Czech University of Life Sciences Prague, which is conducting research on the bladeless turbine. The measurements have been made on a commercially available SETUR DVE 120 bladeless turbine equipped with an electricity generator.

Constant water flow rates of Q = 8, 10, and 12 l/s have been applied. The research focused predominantly on turbine utility for end customers and operators.

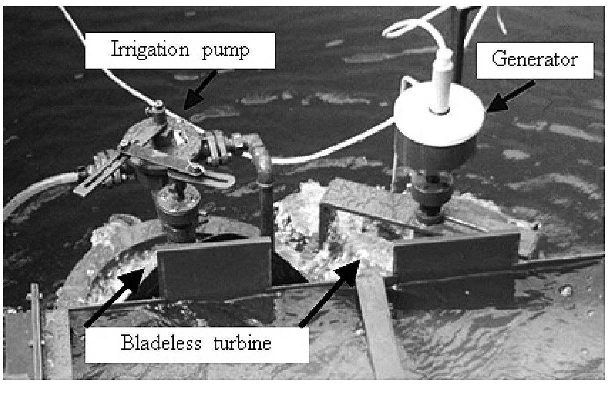

Figure 2. Bladeless turbine in conjunction with an irrigation pump and an electric generator (Hostin *et al.* 2005)

MATERIAL AND METHODS

The measuring has been performed on a SETUR DVE 120 miniturbine (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 circuit (Figure 3) includes a storage tank located below the floor level. Water is pumped from it to the delivery piping by a centrifugal pump (1). This creates the hydraulic potential that is processed by the turbine. The discharge pipe is provided with a control valve (2) and a bypass with control valve (3) through which flow can be changed and the drop in height. The inlet manifold is equipped with pressure gauges (5) for measuring the pressure and the ultrasonic flow meter (6) for measuring flow rate.

The feeding line ends with a flexible hose (the vertical part prior the turbine) featuring an input diameter reduction and a flange for connecting to the turbo-set (i.e. this section has been built the same way as in real installations). The DVE 120 unit, i.e. the turbine (7) and a generator (8) on a concrete

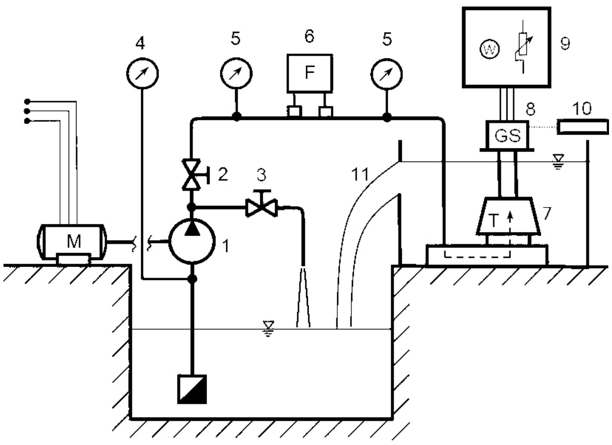

Figure 3. Diagram of the hydraulic circuit for measuring the DVE 120 miniturbine (Dlabal *et al.* 2015)
1 – pump, 2 – control valve, 3 – valve for bypass, 4 – vacuum gauge, 5 – pressure gauge, 6 – flow meter, 7 – turbine, 8 – generator, 9 – electrical circuit (detail in Figure 4), 10 – speedometer, 11 – overflow discharge.

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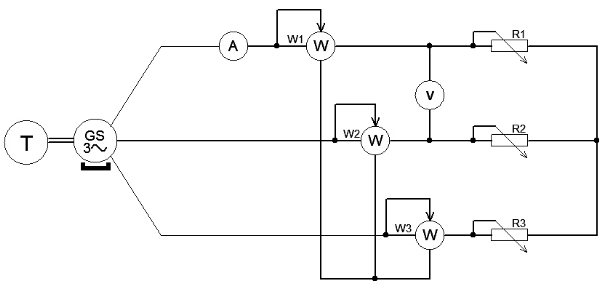

Figure 4. Electrical circuit wiring
T – turbine, GS – synchronous generator, A – ammeter, W – wattmeter (W1, W2, W3), V – voltmeter, R1, R2, R3 – loading rheostats

foundation is located in a plastic tank the purpose of which is to maintain the correct water level necessary for proper functioning of the equipment. There is an overflow chute (11) in the tank wall through which water returns to the reservoir. In addition, turbine speed was measured with an infrared contactless sensor (10) during the operation (Dlabal & Polák 2013; Polák *et al.* 2013).

The generator (8) generates three-phase AC voltage (9). As it is equipped with permanent magnets, the set can run autonomously in "island mode". Electrical output (Figure 4) from the synchronous generator (GS) has been connected to an infinitely adjustable resistance load (rheostats R1, R2, R3) for the purpose of making measurements. Wattmeters HEWa-2 (Ganz Instruments Ltd., Budapest, Hungary) (W1, W2, W3) have been inserted in individual phase lines to metre the output power. The total output power has been calculated by the corresponding formula. Measuring of the interlinked voltage (V) and electric current (A) was crucial for proper setting up the metering range of the wattmeters (W1, W2, W3).

Measuring took place at a defined water gradient and load, and a constant flow rate. The following parameters have been recorded:
– pressure at the turbine input,
– flow rate in the feeding line,
– turbine speed,
– interlinked voltage and current in the selected phase for proper setting up of the wattmeter,
– output power at terminals of the three-phase generator

Based on these values, the following has been determined:
– water gradient,
– water flow power at the turbine input,
– generator electric output,
– overall efficiency of the generating set

This resulted in graphically expressed relationships of different parameters, mainly as functions of the power, efficiency, water gradient. The final characteristics (Figures 4–6) are presented in the following text including brief comments.

Determining hydraulic input power of the turbine. The hydraulic input power (the water flow power) that the turbine processes is determined by the flow rate and the usable water gradient h_{us}, which can be calculated from the measured parameters using Bernoulli's equation (Bollrich *et al.* 1989; Munson *et al.* 2006). The usable water gradient is defined as the gross (geodetic) gradient minus the hydraulic height loss of the turbine, i.e. the difference between the corresponding specific energies (see Eq. (1)):

$$g \times h_{us} = g \times h_1 + \frac{p_1}{\rho} + \frac{v_1^2}{2} - e_z \quad \text{(J/kg)} \tag{1}$$

where:
g – acceleration due to gravity (Earth) (m/s^2)
h_{us} – 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 (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 (m/s)
$v_1^2/2$ – specific kinetic energy (J/kg)
e_z – specific energy loss (J/kg)

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

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

where:
Q – flow rate (m^3/s)
π – Ludolphian number (–)
d_1 – diameter of feeding line (m)

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

$$e_z = \sum e_{zT} + \sum e_{zM} \quad \text{(J/kg)} \tag{3}$$

The power of the water flow entering the turbine P has been determined based on the usable water gradient (Eq.(1)) calculated in equation (Mays 2001):

$$P = Q \times \rho \times g \times h_{us} \text{ (W)} \tag{4}$$

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The total output power P_{el} of the set under a symmetrical load can be calculated by the following formula (Fiala *et al.* 1981):

$$P_{el} = P_1 + P_2 + P_3 \text{ (W)} \tag{5}$$

where:

P_1, P_2, P_3 – output powers of individual phases (W)

Output power and efficiency characteristics are the most important from the user's perspective. The total efficiency of the set is expressed as the ratio of electric output power of the turbine to its hydraulic input power (Date *et al.* 2013):

$$\eta = \frac{P_{el}}{P} \text{ (–)} \tag{6}$$

Bladeless turbine characteristics. The operating characteristic measurements took place in a closed circuit, in which the hydrotechnical potential was created by a centrifugal pump. This arrangement can differ from natural streams in some respects as the usable water gradient usually drops with growing flow rate in natural water courses. The character of the hydraulic potential that the turbine had to handle in the laboratory is simulated by the constant flow curves: Q = 8; 10 and 12 l/s in the relationship of the usable water gradient and the turbine speed (Figure 5). Another turbine feature (monitored earlier) needs to be mentioned in this respect: the turbine "throttles down", i.e. reduces the water flow with decreasing speed (Polák *et al.* 2013).

The diagram in Figure 6 illustrates the dependence of the set DVE 120 output electrical power on

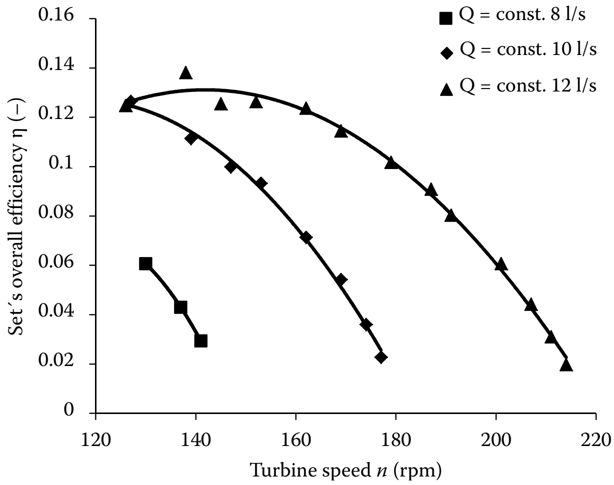

Figure 6. Dependence of output power on turbine speed at different flow rates

turbine speed at three different flow rates: Q = 8, 10, and 12 l/s. The maximum power at a given flow rate always corresponds to a particular speed, which, however, is different for different flow rates. In the case of 12 l/s, the maximum output power is achieved between 150 and 160 rpm. The speed range generating the maximum output power narrows with the declining flow rate. It is also apparent from the diagram that the turbine generates the lowest output power at the highest speed. This state is similar to the runaway speed at which the turbine runs under minimum load, thus supplying only minimum power.

The characteristic describing the dependence of the efficiency of the set on the turbine speed is crucial for the optimum utilization of the energetic

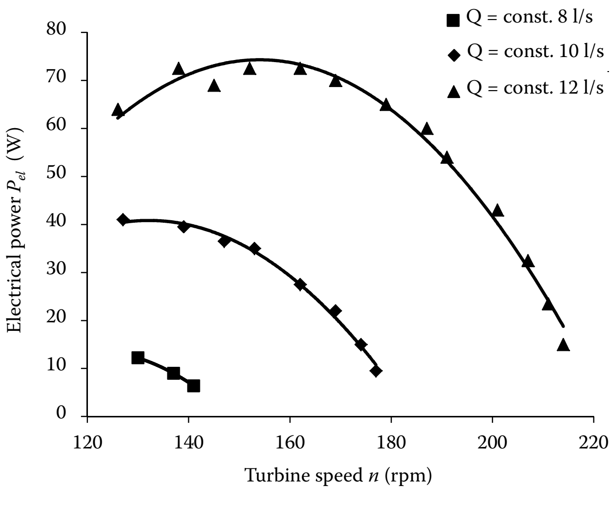

Figure 5. Dependence of usable water gradient on turbine speed

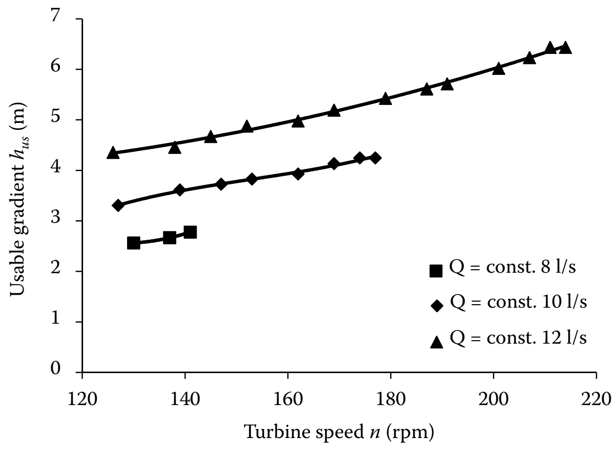

Figure 7. Dependence of overall efficiency of the set on turbine speed at different flow rates

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potential of water course. It is the overall efficiency combining the turbine and generator efficiencies. The generator efficiency is approximately 60%. These characteristics have also been created for the same flow rates of Q = 8, 10, and 12 l/s, and are presented in Figure 7. The maximum efficiency of the set varies at values above 12% at the flow rates of 10 and 12 l/s and a speed around 140 rpm. The unit reached only minimum efficiency at the minimum flow rate (8 l/s). Dropouts of the vortex effect, which is essential for turbine operation, occurred in this mode. The set ran unevenly resulting in rotor stoppage.

DISCUSSION AND CONCLUSION

The experimental objective was to determine bladeless turbine operating characteristics, which are still not known for this machine. The performed laboratory measurements detected the highest overall efficiency of the set of 6% at a flow rate of 8 l/s; 12.6% at 10 l/s, and 12.5% at 12 l/s on a DVE 120 turbine. The usable water gradient varied between 2.5 and 6.4 m. The turbine worked within a speed range of 126 to 214 rpm (see measurement at Q = 12 l/s). Under these conditions, the maximum generated electrical output power was 12.2 W at a flow rate of 8 l/s and a usable water gradient of h_{us} = 2.6 m; or 41 W at 10 l/s and h_{us} = 3.3 m; or 72.5 W at 12 l/s and h_{us} = 4.5–5 m.

Based on the above characteristics, it is possible to evaluate and classify the correctness of functionality of the set under particular local installation conditions, i.e. adjusting the load and the corresponding speed as important parameters of operation control. In addition to this, a system malfunction or a need for servicing can be assumed from parameter changes (output power, efficiency).

The DVE 120 set is equipped with a generator featuring permanent magnets. It is therefore suitable for electricity generation in "island mode", i.e. independently of electrical infrastructure. The turbine can also be directly connected to a pump as part of a micro-irrigation system (MIS), as in Figure 2. Due to relatively low turbine speeds, mostly slow-running hydrostatic pumps are suitable for applications such as a wing (vane) pump.

Currently there is a new competitor to the bladeless turbine: its structural alternative called the precessional turbine (Sedláček *et al.* 2009). Its operating principle is identical; the main difference is that the precessional turbine can handle even lower hydrotechnical potentials and runs at higher speeds, which is welcome in technical applications. This design is the subject of further research.

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