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Development of Pumping-type for Turgo Impulse Micro Hydroelectric System in Emergency Power Supply

***Abstract**. In this work, the turgo impulse micro hydroelectric system was developed by using water flow in natural pipeline for preparing to energy emergencies of disaster sites. The motorized ball valve was used experimentally to control the water volume for changing to output voltage under different conditions of water head, including 4.5 m, 6.0 m, and 8.0 m. For the results, the influence of water head was investigated concentratedly with the relationship of water flow rate, number of rotations, and output voltage. Note that the number of rotations has a significant effect to the power generator. There have been found that the load power generation will be variation to the load resistance. Mentioned, when the number of rotations is increasing, the output voltage will be risen, which is presented the maximum voltage of 78 V, rotations of 1035 min $^{-1}$, and water flow of 583.3 x 10 $^{-3}$ m ^{3}/s following to the 8.0 m of water head. And, the set water head of 4.5 m and 6.0 m were shown the output voltage by 53 V and 63 V, respectively. Consequently, the optimum result was illustrated by water head of 8.0 m, which showed the highest power of about 5.0 W resulting to use for charging cell phones.*

Streszczenie.** W tej pracy opracowano mikroelektrownię wodną impulsową turgo, wykorzystując przepływ wody w naturalnym rurociągu do przygotowania zasilania w sytuacjach awaryjnych w miejscach katastrofy. Zawór kulowy z napędem zastosowano eksperymentalnie do kontrolowania objętości wody przy zmianie na napięcie wyjściowe w różnych warunkach słupa wody, w tym 4,5 m, 6,0 m i 8,0 m. W celu uzyskania wyników zbadano wpływ spadku ciśnienia wody w zależności od natężenia przepływu wody, liczby obrotów i napięcia wyjściowego. Należy pamiętać, że liczba obrotów ma znaczący wpływ na generator prądu. Stwierdzono, że wytwarzana moc obciążenia będzie się zmieniać w zależności od rezystancji obciążenia. Wspomniano, że wraz ze wzrostem liczby obrotów wzrośnie napięcie wyjściowe, które prezentuje maksymalne napięcie 78 V, obroty 1035 min -1 i przepływ wody 583,3 x 10-3 m3/s po 8,0 m słupa wody. A dla ustawionego słupa wody na 4,5 m i 6,0 m pokazano napięcie wyjściowe odpowiednio 53 V i 63 V. W rezultacie optymalny wynik uzyskał słup wody wynoszący 8,0 m, który wykazał największą moc około 5,0 W przy zastosowaniu do ładowania telefonów komórkowych.* (Ptojekt typu pompowego dla mikroelektrowni hydroelektrycznej Turgo Impulse do zasilania awaryjnego***)

Keywords: turgo impulse, micro-hydroelectric, water flow, disaster
Słowa kluczowe: impuls turgo, mikroelektrownia wodna, przepływ wody, katastrofa

Introduction

Recently, we have observed some great earthquake in Japan such as the Great East Japan Earthquake in 2011 and Kumamoto Earthquake in 2016, which led to tremendous damage on lifeline and infrastructure from many human disasters and collapse of buildings [1-3]. With that, many disaster victims took refuge at evacuation centers and emergency power source was required for a great number of people. The stable power sources to charge cell phones such as smartphones were particularly necessary as a communication method to confirm the safety of people. Promptly securing evacuation centers and stable emergency power sources are urgent tasks for local governments [4-6]. Presently, local governments have been installing solar panels on the roof of the buildings that serve as evacuation centers so that the renewable energy can be used as emergency power sources at time of emergency. However, such measures are still quite insufficient as a measure to secure power at the evacuation centers for the capacity of people the centers can accept.

In this study, we developed a compact, easy-to-install and portable turgo impulse micro hydroelectric system that can generate power as an emergency power source for evacuation centers of the disaster sites [7-9]. The system can generate power using the drop in height so that it can be installed in the places such as school buildings that can serve as evacuation centers and be managed by local governments. The volume of water can be controlled with motorized ball valves to automatically adjust the voltage to the set voltage (for charging cell phones). The system can generate power when power is required at time of emergency.

We developed the turgo impulse micro hydroelectric system that can adjust the water volume and flow rate with motorized ball valves, on which we performed no-load/load characteristic test and confirmed the generation of the power of about 5.0 W with the water freely falling from the height of 8.0 m. This paper reports the design policy of the system and the confirmation of the power generation with this system.

Experimental & setup

Fig. 1 shows the exterior of the turgo impulse micro hydroelectric system. We used a DIY-Ⅱ-TurgoKIT (Izumi Co.) in the generator section and we can verify the rotation of the waterwheel from the observation port on the water outlet section. The generator and rectifier elements are housed in the black section connected above the observation port. The water used to generate power is stored in a transparent container under the generator and pumped [10-12]. The path of the water from the pump can be switched with the three-way valve. With a flowmeter and a pressure gauge installed, the flow rate and pressure of the water can be measured as required. The drop height of the water is an important parameter for generating power. We used the height of the stair landing of the building and set three patterns of the drop height: 4.5 m, 6.0 m, and 8.0 m. These are the standard height from the second floor, third floor, and the roof of public-school buildings from the ground.

Fig. 2 shows the structure of the turgo impulse micro hydroelectric system we developed in this study. As shown in the figure, this is a pumping system that pumps up the water used to generate power to be able to generate power infinitely with the limited volume of water. The upper dam and the generator are connected with a hose, and one end of the water-filled hose is submerged in water on the dam side, which will pull down the water with the pressure difference and water drops naturally with the siphon action [13-15].

Fig. 3 shows the measurement circuit used in no-load/ load characteristic test to verify the characteristic of the generator in the turgo impulse micro hydroelectric system. In the no-load characteristic test, we measured the voltage of the power generated and the number of rotations of the generator without connecting the generator to a load. We used an Arduino Uno Rev3 to autonomate the operation of two types of motorized ball valves, which are 2-way valve and 3-way valve, to adjust the opening of the valves mounted to the water intake section and the flow rate. The 2-way valve adjusts the water flow rate, and the 3-way valve adjusts the water flow from the pump. In the load characteristic test, we used an adjustable resistor as the load. We used DC voltmeter to measure the output voltage of the generator, and DC ammeter to measure the load current every time the voltage was reduced by 2.0 V. We also measured the number of rotations of the generator with a tachometer.

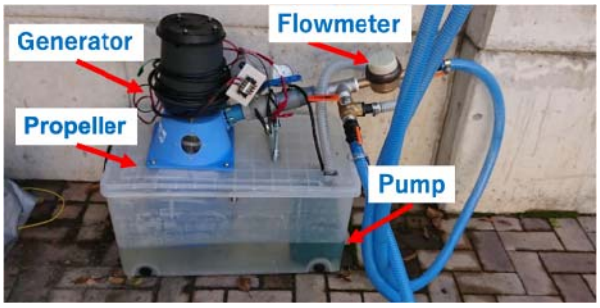

Fig.1. Outline on system for pumping-type for turgo impulse micro hydroelectric system

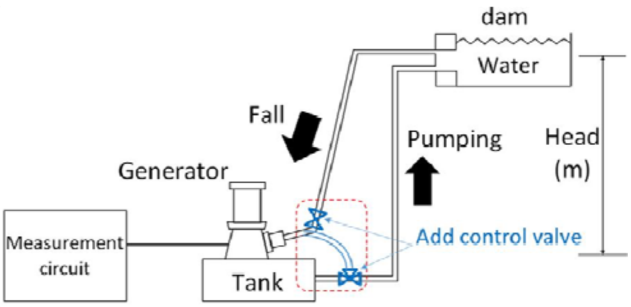

Fig.2. Structure of system for pumping-type for t turgo impulse micro hydroelectric system

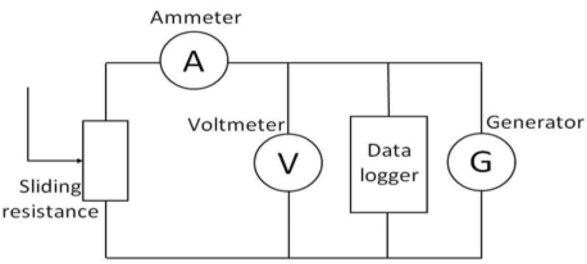

Fig.3. Circuit of no-load/ load characteristic test

Fig. 4 shows the diagram of the motorized ball valve control circuit. As seen in the figure, the control circuit consists of signal input section to receive input signals, and signal output section to drive valves. When the output voltage from the generator is 15 V, the input voltage to Arduino Uno Rev3 will be 5.0 V. The Arduino Uno Rev3 uses the output voltage of the generator and a carbon-film resistor of 10 kΩ to separate pressure with the rate of 2:1 to use it as the input. This is because applying the voltage of 5.5 V or higher to the I/O pin of Arduino Uno Rev3 will stress the elements, leading to deterioration. The forward voltage at D1 (connected to +5.0 V on side Arduino Uno Rev3) and D2 diodes is approximately 0.5 V. If the partial voltage is below 5.5 V, the voltage will be input as signal as it is. However, if the generator voltage rises during the process of control operation or for some reason and the partial voltage reaches 5.5 V or higher, there will be voltage difference of 0.5 V or higher between the partial voltage and +5.0 V, causing the D1 to be conductive. For this reason, the input pin will not have the voltage of 5.5 V or higher applied and thus the Arduino Uno Rev3 will be protected m [16-17]. The control signal will be output from 4 pins. Each signal controls the opening/ closing of the 2-way valve and opening direction of the 3-way valve. In this system, output pins are not directly connected to the valves but via LEDs and relay circuit to allow us to verify which signal is output from the microcomputer.

Fig. 5 shows the flow chart of the program installed in the Arduino Uno Rev3 to operate the control circuit of the motorized ball valves in the turgo impulse micro hydroelectric system. As seen in the figure, it is a simple infinite loop [18-19]. The operation is determined by the calculated voltage of the power generated. There is no power generated at the voltage of 0 V and the starting operation is performed by opening the three-way valve to the waterwheel side. There is a delay of 7.0 s after the starting operation. The three-way valve is not activated instantly after the control signal is output from the Arduino Uno Rev3 and it will take about 5.0 s until the operation will be completed. In order to be sure that the generator will be started, there is a process to pause the operation of the program. As soon as the generator starts rotating and power is generated, the three-way valve is switched to the pump side [20]. From that point, the voltage of the power generated is constantly measured. When the voltage is lower than 12 V, the 2-way valve will be opened. When it is 13 V or higher, then the 2–way valve will be closed. We also studied accurate operation and incorporated a program with the delay of 0.1 s for every loop.

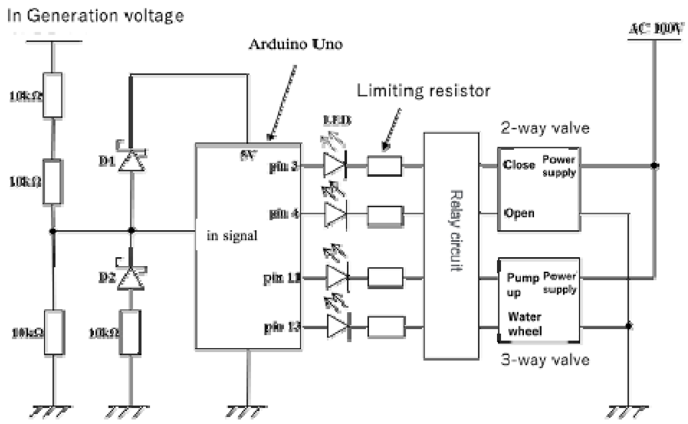

Fig.4. Circuit of control circuit for electric boll valve

Results & discussions

Table 1 shows the relation among voltage of the power generated, the number of rotations, and the flow rate when water drops naturally from the height of 4.5 m, 6.0 m, and 8.0 m with no load. We can see that as the drop height increases, the flow rate per 1.0 s of the water flown into the waterwheel increases and accordingly, the number of rotations of the generator and the voltage of the power generated increases. In the experiment, we maintained the rotation of the waterwheel stable with no load. Then, the waterwheel is braked and the resistance is changed gradually from low resistance just like brake is loosened gradually.

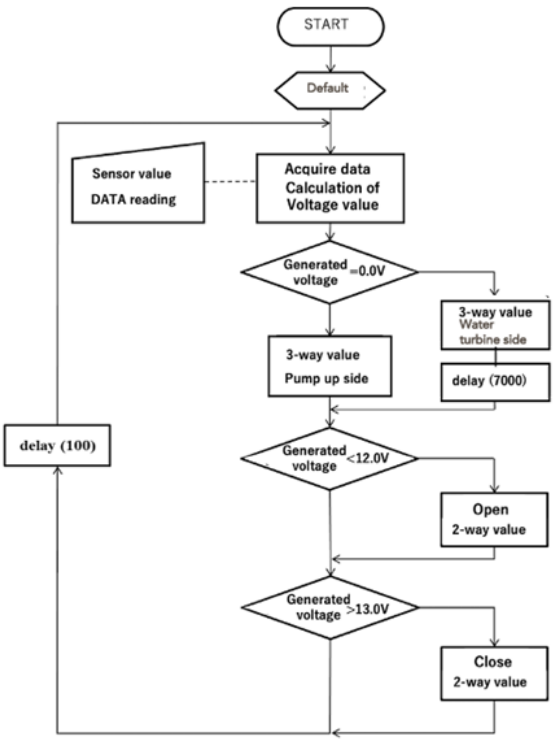

Fig.5. Control circuit for flowchart

Table 1. Relationship water fall between number of rotation and output voltage.

Water head [m]	Water flow [m^3/s]	Number of rotation [min^{-1}]	Output voltage [V]
4.5	455.8×10^{-3}	709	53
6.0	515.0×10^{-3}	819	63
8.0	583.3×10^{-3}	1035	78

Fig. 6 shows the result of the load characteristic measurement when the generator is operated with the adjustable resistor connected to it. The figure shows the relation between the load resistance and the power generated as the resistance changes for each drop height of 4.5 m, 6.0 m, and 8.0 m. The X-axis shows the resistance of the adjustable resistor, and Y-axis shows the calculated power generated by the generator. We can see that the power generated increases as the resistance of the load connected to the generator increases. However, the power generated does not increase proportionally. We found out that the increment gradually decreases and saturates at a certain value.

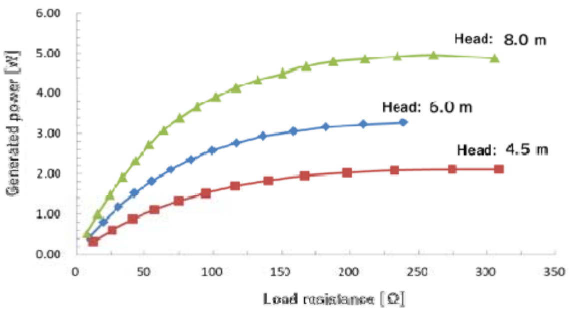

Fig.6. Results of load characteristic test (in slide resistance)

Fig. 7 shows the relation between the voltage of the power generated and the power generated for the number of rotations of the generator for each drop height. As shown in the figure, the blue line represents the relation between the number of rotations of the generator and the voltage of the power generated, and the red line shows the relation between the number of rotations of the generator and the power generated.

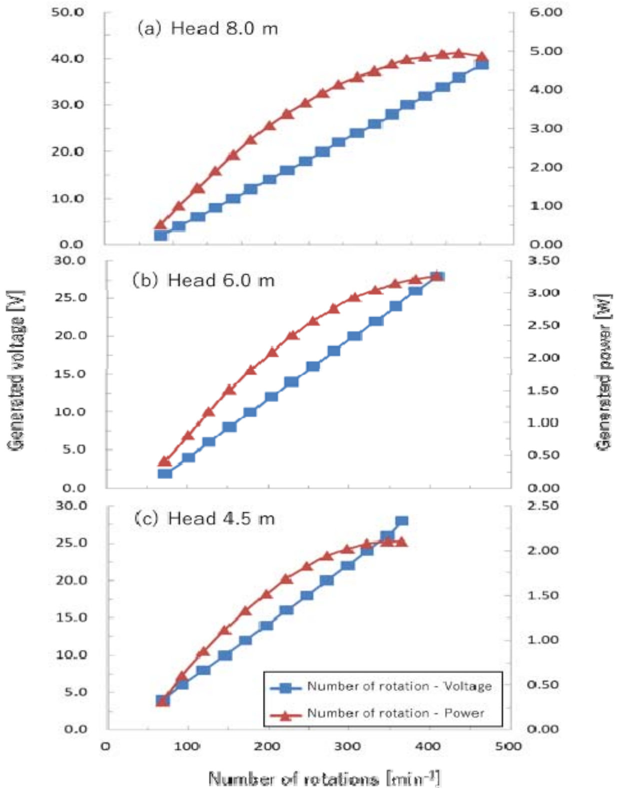

Fig.7. Relationship number of rotation between output voltage and load resistance (in waterfall)

From these results, we can see that the relation between the number of rotations and the voltage of the power generated is constant regardless of the drop height. We confirmed that the power generated increases as the number of rotations increases, though the increment gradually decreased and eventually saturated. This saturation power is greater when the drop height is greater. The blue line shows the relation between the load resistance and the voltage of the power generated, and the red line the relation between the load resistance and load current.

Fig. 8 shows the relation between the voltage of the power generated and load current when the load resistance changes. The blue line shows the relation between the load resistance and voltage of the power generated, and red line the relation between the load resistance and load current. From these results, we can confirm that the voltage of the power generated increases and the load current decreases as the load resistance increases. However, the amount of change is not constant and we can figure out that the amount of change gradually decreases in either case. We also found out that the output voltage is about 5.0 W when the water drop height is 8.0 m.

As the experiments, the power generated (P) was found to be about 3.0 W with the drop height of 6.0 m, which requires the flow rate (q) of 500 ml/s. For example, let's think about the water capacity required in order to continue to operate the micro hydroelectric system for 2.0 hours [t]. We need to store 500 ml ($500 \times 10^{-3} m^3$)of water for every t =1.0 s as equation (1)

(1) $$P = q \times t = 500 \times 10^{-3} \times 10^{-3} \times 7{,}200 = 3.6\ m^3$$

For that, we will need a tank with the capacity of about 4.0 m^3.

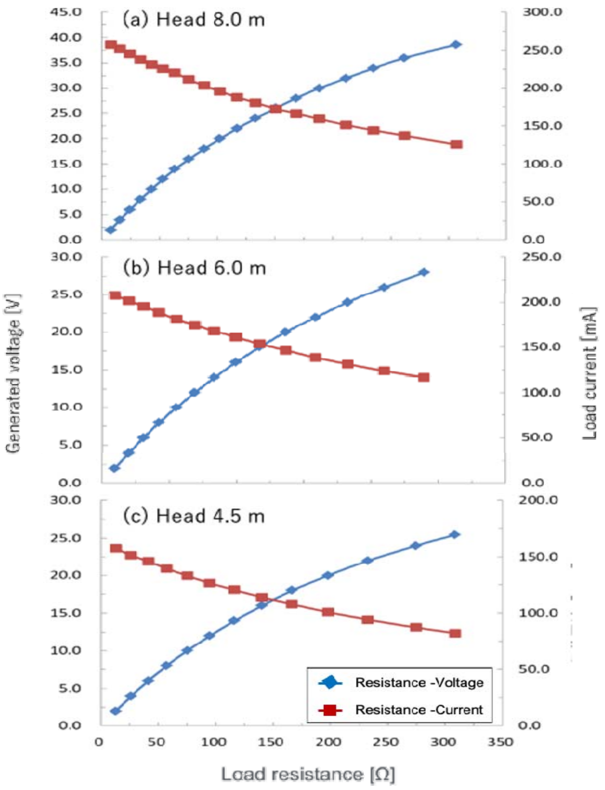

Fig.8. Relationship output voltage number of rotation and load resistance (in waterfall)

Conclusion

In this study, we developed a compact, easy-to-install, and portable turgo impulse micro hydroelectric system that can generate power as an emergency power source. The system automatically adjusts the water volume by controlling motorized 2-way ball valve and 3-way ball valve installed to the water intake port to adjust the opening and flow rate to the set voltage. By adding a pumping function, the system can generate power when power is needed urgently. The non-load and load characteristic tests confirmed that the flow rate per 1.0 s of the water flown into the waterwheel increases as the natural drop height increases, and accordingly, the number of rotations of the generator and the voltage of the power generated increase. Similarly, the load characteristic test allowed us to obtain the output of 5.0 was the power generated *P* when the drop height is 8.0 m, and this turgo impulse micro hydroelectric system permitted the generation of power sufficient for the charging capacity of devices such as cell phones.

In the future, we are going to further improve the efficiency of the generator in the turgo impulse micro hydroelectric system we developed, improve the water resistance, and make the parts lighter to pursue development of the practical product.

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