Modern Environmental Science and Engineering (ISSN 2333-2581)
May 2018, Volume 4, No. 5, pp. 439-444
Doi: 10.15341/mese(2333-2581)/05.04.2018/005
Academic Star Publishing Company, 2018
www.academicstar.us

Educational Renewable Energy Screw Wheel Technologies for Pico Hydropower Generation*

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Abstract: A laboratory-scale integrated inclined axis Screw Turbine System simulating pico hydroelectric generation has been constructed in ASPETE, under the supervision of the Austrian B.O.K.U. University and used in the educational curriculum of Renewable Energy Programme at the M.Sc. in "Management Technologies of Waters, Soft Energy Systems and Environmental Mechanics (M.T.W.-S.E.S.E.M.)". The mainlines of the small integrated Screw Turbine System simulating pico hydropower generation construction and the measurement procedure are described in the present manuscript. The apparatus is simple to make and uses inexpensive components, most of which can be found in standard science laboratories. From the "Management Technologies of Waters, Soft Energy Systems and Environmental Mechanics" M.Sc. courses experimental results, the turbine was found to have a good maximum mechanical efficiency for small water flow rates. The small scale hydraulic screw turbine and apparatus demonstrate the principles of hydropower and are well suited for educational purposes in renewable and soft energy.

Key words: renewable energy sources, small hydropower, screw turbine, environmental and renewable energy education

1. Introduction

Hydropower represents a reliable source of renewable energy with majority of global renewable energy production contributing over 16% of the global electricity generation and accounting for 76% of the total renewable electricity supply. However, only a third of the total world hydropower capacity has been developed and most of this growth and development is concentrated in developed countries especially in Europe [1]. Small hydropower is an eco-friendly and non-polluting renewable source of energy. Large scale hydropower potential being mostly developed, the focus is now shifted to small scale hydropower [2]. Within the small scale hydropower sector, very low head sites below 4-5 m, formerly disregarded considered uneconomical for developing hydropower, are recently getting renewed interest [3]. In order to develop these underutilized energy resources, conventional highly efficient low head hydraulic turbine technologies such as Cross-Flow and Kaplan turbines are not economically viable because of the large size of the turbine required for very low head installations, requirement of special flow control mechanism and the risk they impose on the environment [4]. Efforts have been made to develop Archimedean Screw Water Wheels technologies that suitably harness the very low head energy source [5, 6, 7]. Technological development is therefore required to harness this very low head energy potential. During the last years, the inverse use of the classical Archimedean screw, as a kind of inverse screw pump-turbine, is under discussion within the hydropower scientific community [8]. The screw renaissance taking place actually throughout the world

*This paper is dedicated to the memory of our wonderful son and brother, George Stergiopoulos, Biosystem Engineer and M.Sc. in Waste Treatment, who recently passed away.

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in the promotion and construction of renewable energy valorizes Archimedean Screw Turbines for low, ultra-low and zero-head small hydro plants. Some cochlear inclined axis small hydro plants were installed during the last decade in Central Europe by various industrial companies, which were based on the inversion of the energy flow in their pumps operation and turning the old screw pumps into new screw turbines [3]. Low, ultra-low and zero-head cochlear hydropower plants are developing very slowly, due to the fact that recent Archimedean screws are a new type of turbines in all countries throughout the world. For sites with relative greater heads, and relative greater water flows, the cascades of two or more similar energy spiral rotors in series and in parallel could give efficient Archimedean hydropower solutions.

2. Educational Laboratory-Scale Screw Wheel Materials & Methods for Pico Hydropower Generation

ASPETE is a higher education institution offering through the Civil Engineering Educators Department a three-semester M.Sc. course in M.T.W.-S.E.S.E.M. (Management Technologies of Waters, Soft Energy Systems and Environmental Mechanics). Established in 2015, the M.Sc. in M.T.W.-S.E.S.E.M. formally commenced its operations in July 2015, through a series of declarations of cooperation with universities and research centers in Greece and various European countries, and other institutions and renewable energy and water engineering firms. The multidisciplinary post university Master-level degree programme offers a 90 ECTS credit M.Sc. degree in M.T.W.-S.E.S.E.M. with various renewable energy and water science directions, covering wind energy, hydropower, geothermal, wave energy, rational use of terrestrial and maritime waters and indigenous resources including oil and natural gas, environmental technologies, geopolitics, aesthetics, development policies etc. Each area of specialization at M.T.W.-S.E.S.E.M. consists of a series of intensive 13 week modules per semester. Each series of modules includes and field trips to sites related to renewable resources activities. Students take an exam following the completion of each module and a final exam at the end of the semesters. The final degree requirement is a 30 credit Master's Thesis. Teaching staff of MTW-SESEM are professors and researchers from Greece, energy experts from engineering and energy consulting firms, and various international experts from research centers and universities in Europe. Tuition for the M.Sc. programs is 3.300€ for the full three-semester program. Many multidisciplinary important and compulsory components of the curriculum are combinations of theoretical and laboratory courses which aim to provide students with an understanding of the physical principles involved in renewable energy generation. To this end, laboratory-scale hydroelectric experiments were devised to develop and to demonstrate the hydropower and the Archimedean technologies of water screw turbines in low-head pico hydropower plants. The first step towards the creation of Laboratory-Scale Screw Wheel for Pico Hydropower Generation in Renewable Energy M.Sc. Education is made by designing and constructing a series of inclined axis Archimedean Screw Wheel under the supervision of the Austrian B.O.K.U. University and used in Austria and Greece, following the mainlines fixed from BOKU University by A. Stergiopoulou. Fig. 1 shows information about such three Archimedean pico scale screw rotors.

The present effort deals with the design, construction and operation of a low head educational Archimedean Screw Wheel for Pico Hydropower Generation. The main aim of this effort is to bring a robust, easy-to-build and affordable screw technology. To achieve this objective, the present effort investigates the one-blade Archimedean Screw Wheel for its potential to be used as a good educational example of power converter and probably to be applied in bigger scales in the irrigation canals. The conception of the integrated

Laboratory-Scale Screw Wheel for Pico Hydropower Generation is also due to A. Stergiopoulou. A photorealistic artistic view of the Laboratory-Scale Screw Wheel for Pico Hydropower Generation in Renewable Energy M.Sc. Education is given in Fig. 2.

The Laboratory-Scale Screw Wheel for Pico Hydropower Generation in Renewable Energy M.Sc. Education is built with locally simple materials based on PVC and cables. A steel axis was used in order to finish building of the screw rotor. Information about constructing the one blade Archimedean screw rotor and its characteristic dimensions is given in the Fig. 3.

Some characteristic views of the construction progress steps', including the introduction of a Led lamp, for making sure that pico-hydropower electricity is really generated by this Laboratory-Scale Screw Wheel for Pico Hydropower Generation device are given in Fig. 4.

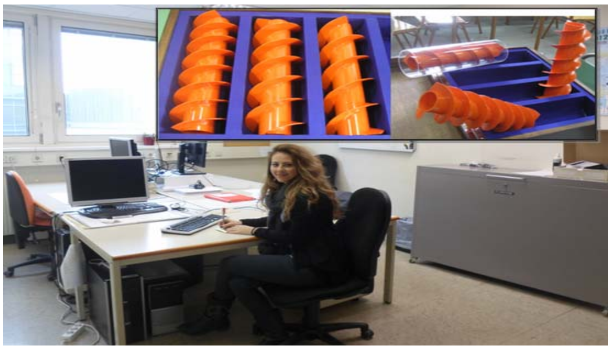

Fig. 1 Three laboratory-scale inclined axis Archimedean Screw Rotors (photo authors own).

Fig. 2 A photorealistic artistic view of the Laboratory-Scale Screw Wheel for Pico Hydropower Generation made by A. Stergiopoulou (photo authors own).

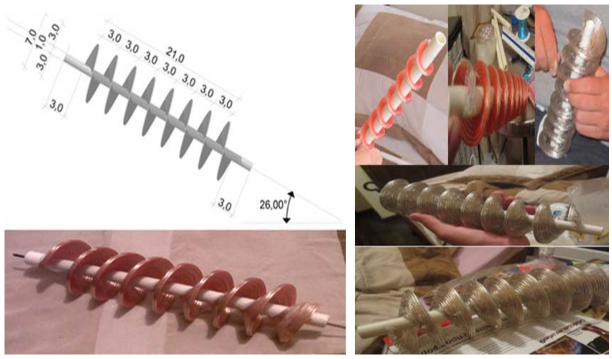

Fig. 3 Information about constructing the Archimedean screw rotor and its characteristic dimensions (photos authors own).

Fig. 4 Characteristic views of the construction progress including the Led lamp (photos authors own).

Views of the used pump plastic and of the shroud of the rotor and of are given in Fig. 5.

Fig. 5 Plastic shroud of the rotor and views of the pump (photos authors own).

A bicycle generator was used and connected to the Archimedean screw through a simple gear-box made by gears from children toys. The flume tank of the whole system was build following GRP techniques. Views of the whole system flume tank and details concerning the various components including efforts for a better bleu aesthetic view of the flume infrastructure are given in Fig. 6.

An overall view of the complete Laboratory-Scale Screw Wheel System for Pico Hydropower Generation in Renewable Energy M.Sc. Education, with details for the power house is given in Fig. 7.

Fig. 6 Views of the whole system flume tank and details concerning its various components (photos authors own).

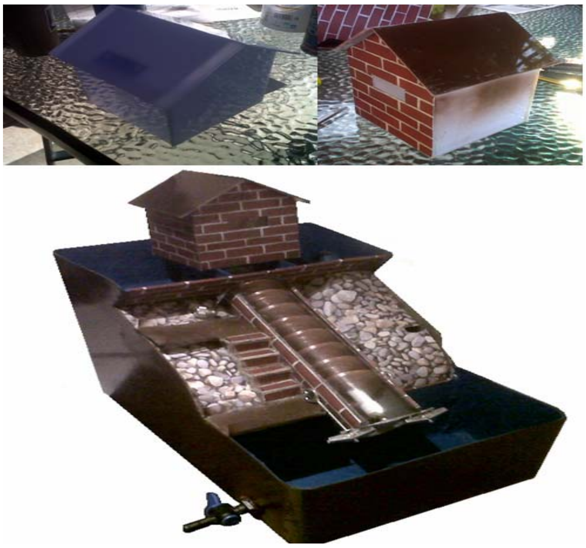

Fig. 7 The Laboratory-Scale Screw Wheel for Pico Hydropower Generation in Renewable Energy M.Sc. Education (photos authors own).

3. Hydrodynamic Performance Results of the Laboratory Scale Screw Wheel

The main components of the whole system acting as a real test rig are a pump, an overhead tank, pipelines, the Archimedean screw rotor, the side coverings, the shroud, the flume, the tail race tank. The dimensions of the whole system are 49 cm $\times$ 34 cm $\times$ 29 cm. The weight of the whole system is 5.50 kg. The max volume capacity of the upper tank is 4,752 l. The max volume capacity of the lower tank is 3,960l. The maximum volume of the flowing water that the test set up could safely handle was around 6.5l. The diameter of the rubber pipe of the pump is 1.50 cm. The angle of orientation of the screw axis is 26^o. The diameter of the screw rotor is 3.50 cm. The length of the screw rotor is 30 cm. The diameter of the shroud is 3.75 cm. The length of the shroud is 32 cm. Water flow was supplied through a pump having a satisfying nominal power capacity. To make sure that pico hydropower electricity is really generated by this educational renewable energy screw wheel device, not only a led lamp is installed on bicycle generator is on, but also pico hydropower electricity is measured by using two polymeters to show how much current and voltage are generated. The rotation speed measurements were made with an electronic handle rotation meter (Fig. 8).

Fig. 8 Current and voltage measurements with two polymeters and rotation speed measurements with an electronic handle rotation meter (photo authors own).

Views of typical measurements in the M.T.W.-S.E.S.E.M. M.Sc. classroom of the produced voltage and current with two polymeters are given in Fig. 9.

A series of pico hydropower performances measurements was realized in the classroom of M.T.W.-S.E.S.E.M. M.Sc. By using a water volume 7500 ml, as an example of these experiences, with measurement of rotation with tachometer get 187 RPM on turbine. This educational pico hydro turbine can generate power 6.36 mW, which consist of 5.3 mA current and voltage 1.2 volt. Results of these educational experiments are very promising because better installing of this turbine should increase its performance. Fig. 10 gives the evolution of the measured rotation speeds N (RPM) following increase and diminution of water flow V (ml).

Fig. 9 Measuring voltage and current (photo authors own).

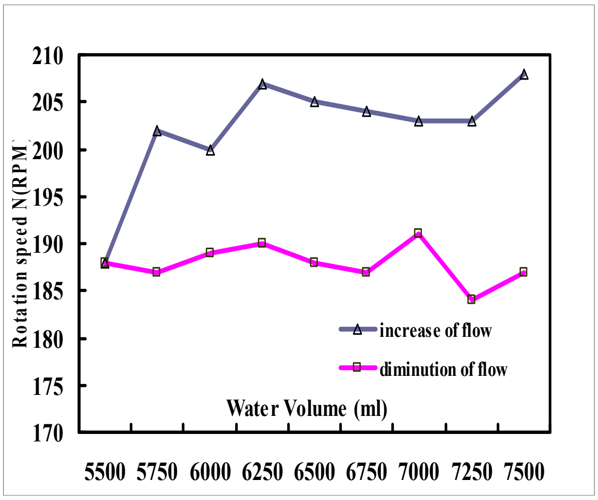

Fig. 10 Evolution of the measured rotation speed N (RPM).

Fig. 11 gives the obtained results of the measured, with the polymeters, intensity I(A) and voltage V(V), following increase (upper curve) and diminution (lower curve) of water volume V (ml).

In Fig. 12 is given the obtained hydrodynamic torque T (N.m) in function of the increase and diminution of water flow V (ml).

The measured evolution of the hydrodynamic power P (mW) in function of the increase and diminution of water flow V (ml) is given in Fig. 13.

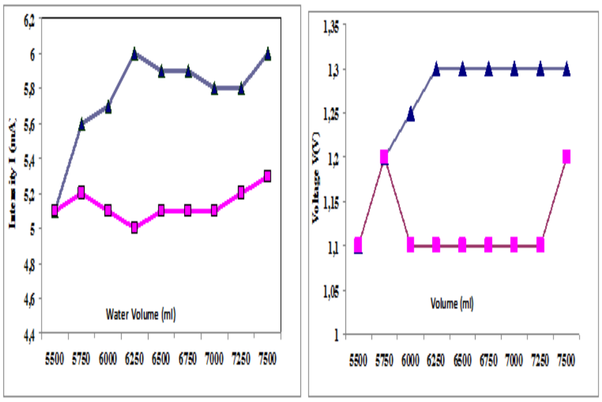

Fig. 11 Evolution of the measured intensity and voltage.

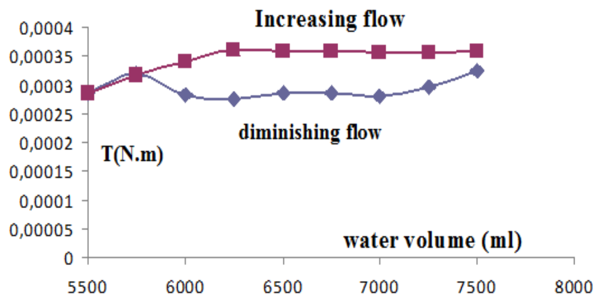

Fig. 12 Evolution of the hydrodynamic torque T (N.m).

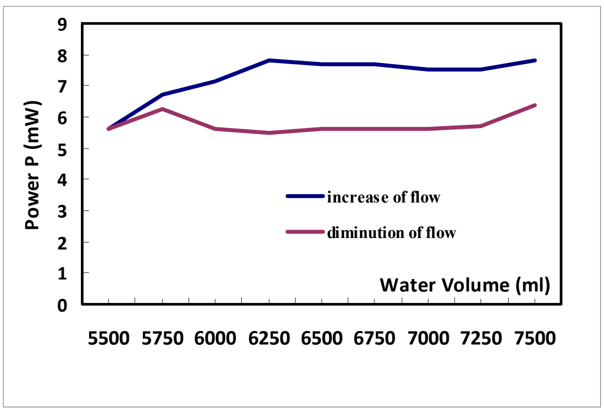

Fig. 13 Evolution of the hydrodynamic power P (mW).

4. Conclusions

The laboratory-scale integrated inclined axis Screw Turbine System simulating pico hydroelectric generation, constructed in ASPETE, under the supervision of the Austrian B.O.K.U. University and used in the educational curriculum of Renewable Energy Programme at the M.Sc. in "Management Technologies of Waters, Soft Energy Systems and Environmental Mechanics (M.T.W. - S.E.S.E.M.)" had given valuable experimental information about its hydrodynamic performance characteristics. This small scale hydraulic screw turbine and apparatus demonstrate the principles of hydropower and are well suited for further educational purposes in renewable and soft energy. The preliminary educational results obtained are very promising to be continued. More research needs to be done, including the hysteresis in the performance curves observed during the classroom measurements, before this educational pico hydropower screw turbine and other future similar turbines, made by using the turbo machinery similitude theory, are used in low head sites in natural or technical watercourses. The used here new Archimedean small hydropower philosophy should attract an increasing amount of interest in Greece mainly to the fact that such Archimedean small hydro plants are relatively easy to develop, and they can make an important contribution to the energy supply in remote and rural areas, they can play an important role in the regional and national energy scenarios and satisfy different other requirements following a multipurpose philosophy.

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