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Conversion of lowland river flow kinetic energy

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ABSTRACT

This paper presents the analysis of possibilities and feasibilities of the extraction of kinetic energy from lowland rivers, which are slow and shallow and their water may contain organic fibres of water vegetation and solid particles of soil. In these rivers the existing hydrokinetic energy converters are not optimised for use because at small flow velocity the efficiency of such converters is very low. The depth of a shallow river flow may be not deep enough to install the converters. The latter are sensitive to jamming by water plant fibres. To overcome the difficulties in developing river flow kinetic energy the structures, the advantages and disadvantages of commonly used converters have been analysed A conveyor type converter has been found to be the most suitable for use in shallow rivers. Results of our field and laboratory studies of hydrokinetic energy converters have confirmed the anticipated difficulties when applying the commonly used converters in lowland rivers. The validity of our proposed method has allowed to reduce the number of mobile elements and friction couples in our novel converter and to increase its reliability. A particular approach to the principle of kinetic energy extraction from a river flow has been developed and a novel converter has been invented. To increase the efficiency of the river flow kinetic energy conversion a new conveyor technology has been proposed. This converter allows the extraction of kinetic energy from the river flow almost without affecting the river and the surrounding environment.

Contents

1. Introduction

The possibility to extract energy from a river flow without the construction of a dam, the arrangement of a pond and flooding of a valley make kinetic energy of flowing water a very attractive energy source. For this reason, the interest in river flow kinetic energy is currently increasing, but until recently its technological deployment has been negligible [1,2]. The majority of publications

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about the possibilities of water flow kinetic energy development examine marine systems [3,4] and only a few of them examine river systems [5,6]. The authors of some publications analyse both marine and river technologies and the equipment applied [7,8], but almost nobody has studied the peculiarities of the development of lowland river kinetic energy.

A vertical cross flow turbine was tested in a deep (6–7 m) Swedish river site with the velocity ranging between 0.4 and 1.4 m/s in order to prove the concept, to validate the simulation tools and gain experience in operating the unit in various conditions [9].

To facilitate the design of axial hydrokinetic turbines, a numerical method for the analysis of their operating conditions was developed based on a series of laboratory tests [10]. The shape of a similar type turbine was designed by CFD, then its model (rotor diameter of 150 mm) was tested in a wind tunnel and a prototype (rotor diameter of 1 m) was installed in a river in Germany [11].

A series of tests on several Darrieus type cross flow hydrokinetic turbines were conducted by mounting each turbine in front of a barge and motoring through still water at a speed ranging from lower than 1 m/s to up to 5 m/s [12]. Differences in the coefficient of the performance of a number of turbine configurations ranging from lower than 0.1 to 0.25 were revealed, while the turbine associated with ducts could increase the coefficient by a factor of 2 or 3 and, consequently, the power output too.

A specific floating energy converter, containing an in-plane axis cross flow turbine, which can be used in shallow rivers, was designed with a purpose to utilise the streams with slow flow velocities (down to 1.0 m/s); its laboratory experiments and field tests were performed [13]. Impacts on the flow velocity, backwater, changes in the river morphology were revealed and the measurement results were used as the input data for a 3D numerical model to simulate the power output as well as further impacts on the environment.

Numerical modelling of a fixed pitch cross flow hydrokinetic turbine to maximise its performance and smooth operation was carried out by Lazauskas and Kirke [14].

A river is rather sensitive to human activity. Sustainability and possibilities to develop kinetic energy of a river without damming it and with minimal impact on the environment are recognised as significant advantages. It should be accepted that kinetic energy is not intensively distributed in the river flow. Its level determines the ease of using the energy of this type in practice.

Let us consider this kind of kinetic energy and try to estimate the real possibilities of utilising this energy source for human needs. Currently, as rivers have become strictly protected by ecologists and environmentalists from any disruption, any obstacle in the fish migration path is considered to cause harm to the environment. Here, we will analyse the real intensity of kinetic energy in lowland alluvial river flows and the possibilities of converting and utilising it for our needs.

2. River flow kinetic energy

An approximate magnitude of river flow power P is expressed by the following simple well known formula:

$$P=\rho gQH, \tag{1}$$

where $\rho=1000\ \mathrm{kg/m^3}$ is water density; $g=9.81\ \mathrm{m/s^2}$ is acceleration of gravity; Q is flow discharge; and H is pressure head. Last parameter H is used to express relative power in units of length, and it consists of relative potential and kinetic energies, i.e.

$$H=h+\alpha v^2/(2g) \tag{2}$$

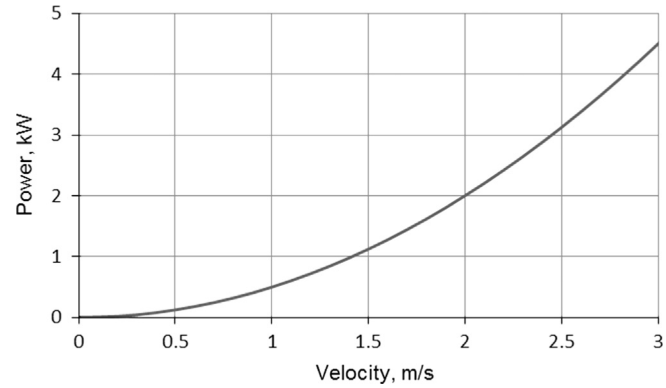

Fig. 1. P–v plot for $Q=1\ \mathrm{m^3/s}$.

here, h is flow depth (potential energy); $\alpha v^2/(2g)$ is velocity head (kinetic energy), where α is Coriolis coefficient and v is mean flow velocity. These two parts of energy are closely inter-related. An increment in flow velocity v leads to a decrement in both flow depth h and the cross-sectional area.

Expressing river flow discharge $Q=Av$, where A is the area of the river flow cross section, and assuming that $\alpha=1$ in $H=\alpha v^2/(2g)$, Eq. (1) takes the following form of kinetic energy power:

$$P=0.5\rho Qv^2 \tag{3}$$

or

$$P=0.5\rho Av^3 \tag{4}$$

When the dependence of kinetic power on velocity is analysed, it should be taken into account that at Q=constant any change of velocity v causes the change in flow cross-sectional area A. Therefore, it is more correct to use the quadratic Eq. (3) instead of cubic Eq. (4) P–v relationship for the analysis and illustration of kinetic energy resources. A rapid increase in kinetic energy occurs with the growth of velocity due to its quadratic relationship with velocity in Eq. (3). This is shown in Fig. 1, where the P–v relationship graph is given for $Q=1\ \mathrm{m^3/s}$=constant Similar plots, primarily in the form of power density ($\mathrm{kW/m^2}$), are used to illustrate the promising future of the use of kinetic energy sources [1,15], but in these cases Q=var. A potentially large amount of power from kinetic energy promise bright future for the development of river kinetic energy sources. We will consider what type of the development of kinetic energy sources can be actually achieved.

The value of 4.5 kW for each $\mathrm{m^3/s}$ of water flow at velocity of 3 m/s is a very good power concentration. However, other issues should be considered before determining the potential development of kinetic energy sources. Let us analyse water flow velocities in lowland alluvial rivers.

The river flow velocity never exceeds non-scouring velocity of the soil forming the river bed. If this condition is violated, bed scour and river meandering begin. It proceeds until the length of the river has sufficiently increased and its hydraulic gradient and velocity have decreased to restore the equilibrium in the interaction between the water flow shear action and the resistance of a river bed to that shear. The mean water flow velocity in alluvial rivers usually varies within the range of 0.3–0.8 m/s and seldom exceeds 1.0 m/s.

The stream velocity in the middle of the river may reach up to 1.5–2.0 m/s; however, such high velocities occur during spring or storm floods and last only for some days or even hours. Thus, in the analysis of the lowland river flow kinetic energy resources their velocities should be considered not to exceed 1.5 m/s.