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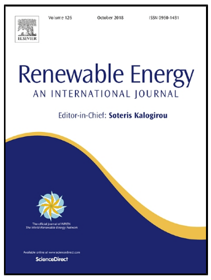

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A Study of the Flow Field of an Axial Flow Hydraulic Turbine with a Collection Device in an Open Channel

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Abstract

Axial flow hydraulic turbine with a collection device aims to improve the output using an open channel and concentrating/increasing the volume and velocity of flow. The flow field of this turbine is extremely complex because it has a free surface, and its internal and external flows are mixed. Several such hydraulic turbines are occasionally placed in series against a flow. Thus, it is of utmost importance to elucidate the flow structure downstream of the hydraulic turbine. The proposed study aims to elucidate the flow field of this hydraulic turbine in a shallow open channel by the means of PIV measurement, multiphase flow analysis considering the free surface, and single-phase flow analysis considering uniform flow as the premise. As a result, the characteristics of the flow field of the hydraulic turbine considered herein in an open channel are clarified. Especially, in terms of the slipstream characteristics, it is clarified that due to the influence of free surface and channel bottom, the type of vortexes that occur downstream of the hydraulic turbine are different, and the process and distance of velocity recovery differ depending on the vortex.

Keywords: Small Hydro Power, Hydraulic Turbine, Collection Device, Flow Field, Free Surface, Slipstream

1. Introduction

In recent years, there has been an increase in the environmental and energy problems. From the viewpoint of reducing carbon dioxide emissions, further utilization of renewable energy is expected. In particular, hydraulic energy is the most powerful renewable energy source, and by 2035, it is predicted that the usage capacity of hydraulic energy will exceed 1400 GW [1]. To realize this goal, active usage of hydraulic energy, which has been overlooked due to its low output and difficulty in use, is important. Among hydraulic turbines, those with open channels [2, 3] require little incidental equipment to supply water and are able to generate electricity with a relatively low-pressure head. In recent years, the number of available construction sites with sufficient head and low impact on the surrounding ecosystem has been decreasing; thus, attention has increased in regard to hydraulic turbines for open channels. However, many hydraulic turbines in open channels require an intake weir and have low rotational speeds; this increases the size of a practical turbine. Therefore, open-channel hydraulic turbines are fixed to the site, meaning that the installation sites are limited. In recent years, a hydraulic turbine [4-6] capable of generate electricity by simply being installed in the flow water of an open channel has been developed, but the turbine output per water-receiving area is small.

Under such circumstances, the authors developed a new portable hydraulic turbine for open channels, such as rivers and canals, that does not require an intake weir and can utilize the flow of an open channel without modification [7, 8]. This hydraulic turbine uses the principle of brimmed-diffuser wind turbines [9, 10] and includes a collection device with a constant-height diffuser on the axial flow runner. Therefore, the outer diameter of the runner can be increased to the same size as the water depth, and by collecting and accelerating the flow, this collection device increases the turbine output. Moreover, as it employs a high-speed rotational axial flow runner, its size and weight is smaller than that of common open channel hydraulic turbines, which helps it match better with generators. In previous studies, the performance characteristics and flow field of this hydraulic turbine were studied using single-phase flow analysis, in which constant flow was used as the premise without considering the free surface [7, 8, 11], and its performance was improved [12]. In addition, its effectiveness was examined by conducting a verification test [8, 12]. Furthermore, the performance characteristics of this hydraulic turbine in an open channel were clarified by conducting a model experiment in an open circulating water tank using a scale model and multiphase flow analysis considering the free surface [13].

The flow field associated with the present hydraulic turbine has mixed internal and external flows and both strongly impact the performance of the hydraulic turbine. Furthermore, considering that several of these hydraulic turbines can be operated in series in the channel, the structure of the flow downstream of the hydraulic turbine must be understood. Although several studies have examined the downstream flow field of a brimmed-diffuser wind turbine via numerical analysis and particle image velocimetry (PIV) measurements [14, 15], none have examined a model with diffusers that spread in the direction of the width, as they do in this hydraulic turbine. Furthermore, the flow field of the present hydraulic turbine installed in an open channel is strongly impacted by the free surface and the bottom and side surfaces of the channel; thus, it would likely differ dramatically from the flow field of a brimmed-diffuser wind turbine.