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Impulse Turbine for Wave Power Conversion with Air Flow Rectification System

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ABSTRACT

In order to develop a high-performance impulse turbine for wave power conversion with an airflow rectification system, the impulse turbine has been designed and investigated experimentally by model testing. A computer simulation, taking account of the energy conversion efficiency of the oscillating water column (OWC), then clarified the running and starting characteristics in irregular ocean waves. As a result, a suitable choice of design factors is suggested for the setting angle of the guide vane and rotor profile.

INTRODUCTION

Several of the wave energy devices being studied under any wave energy program make use of the oscillating water column (OWC) principle. In such wave energy devices, an OWC due to wave motion is used to drive an oscillating air column, whose energy is converted into mechanical energy. The energy conversion from the oscillating air column can be achieved by using a self-rectifying air turbine such as the Wells turbine (Gato and Falcao, 1990; Inoue et al., 1986, 1988; Setoguchi et al., 1998; Takao et al., 2001) and other newly proposed turbines (Inoue et al., 1989; Kaneko et al., 1991; Sarmento et al., 1987; Setoguchi et al., 1996, 2000a, 2000b; Takao et al., 1997). In general, however, the self-rectifying turbine—because of its symmetrical configuration with respect to the plane perpendicular to the rotor axis, in order to operate in a bidirectional reciprocating flow—has the inherent disadvantages of relatively low efficiency and poor starting characteristics.

On the other hand, researches and proposals on the wave energy devices using a system of nonreturn valves for rectifying the airflow, together with a conventional turbine such as the Francis turbine, have been reported (Katsuhara et al., 1987; Neal, 1993; Tan et al., 1995; Ueki et al., 2000). This is because the peak efficiency of the conventional turbine is higher than that of the self-rectifying turbine, though such a system is complicated and difficult to maintain. The representative wave energy converter using the rectification valve system is the wave-activated generator used as a light beacon invented in Japan, and it has been used in some countries besides Japan. According to previous study, however, the efficiency of an impulse-type turbine adopted in the generator seems to be comparatively low (Katsuhara et al., 1987). This may be because the turbine configurations are not optimized in the design. But because the rectification valve system seems to be a promising technique for the use of wave energy with small wave height, it is important to achieve the optimization of turbine geometry in order to develop a high-performance generator. Although the design technique of rotor blades for the impulse turbine is established for a high-pressure stage of both steam and gas turbines, this design method cannot be used directly for a turbine for wave energy conversion, as the total efficiency of the wave energy device (Setoguchi et al., 2000a, 2000b) depends not only on the turbine efficiency (i.e., secondary conversion efficiency) but also on the efficiency of the air chamber (i.e., primary conversion efficiency).

In this study, in order to develop a high-performance turbine for wave power conversion with an airflow rectification system, some specific impulse turbines have been designed and manufactured. The turbine characteristics were investigated experimentally by model testing under both steady and periodically reciprocating flow conditions. Further, a computer simulation, taking account of the OWC energy absorption efficiency, has clarified the running and starting characteristics under irregular wave conditions. As a result, a suitable choice of design factors has been suggested for the setting angle of the guide vane and rotor profile.

TURBINE DESIGN

In order to clarify the suitable turbine geometry, experiments are performed for some typical rotor profiles. Hamajima's design method (1973) for an axial-flow gas turbine is adopted for the present rotor profiles. The procedure is as follows. First, the angular velocity of the rotor ω_d and the output P_d are decided at the

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