Design Method and Dynamic Response of Floating Ocean Thermal Energy Conversion (OTEC) Plant

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（浮体式海洋温度差発電施設の動的応答と設計手法）

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論 文 内 容 の 要 旨

An Ocean Thermal Energy Conversion (OTEC) is the system which utilizes a temperature difference between surface seawater and deep seawater to drive a heat engine. Since sea temperatures do not change significantly in the short term, this energy source is expected to be operate with a high stability and a high capacity factor among natural energy sources. Because of this main characteristic, an OTEC plant could have a large potential to contribute as a base-load power in tropical island countries, such as Indonesia. Furthermore, to utilize the advantage of scale, a 100 MW floating plant has frequently been studied for a commercial-scale deployment. However, the estimated levelized cost of energy of OTEC is still higher than existing base-load powers, and its evaluation also involves many uncertainties.

A commercial scale OTEC plant requires a large amount of seawater to drive the heat engine from only a 20 ℃ of temperature difference. For a 100 MW plantship, a Cold Water Pipe (CWP) with the diameter of 12 m and the length of 800 m will be required to intake deep seawater. Comparing to an offshore Oil & Gas riser, the mechanical characteristics of CWP are that (i) the diameter is significantly large, (ii) it contains a large mass flow rate, (iii) it is always hanged off even during operation, and thus (iv) the lower end is open in underwater. Currently, a design method has been developed for individual projects, and there seems to be no systematic analysis and design methodology that focuses on these mechanical characteristics.
The overall objective of this thesis is to clarify the design methodology of a floating OTEC plant and its mechanical characteristics through a preliminary design of a 100 MW plantship. This thesis is divided into 6 chapters as follows.

Chapter 1, general introduction, firstly introduces the general overview of OTEC. Subsequently, the development history and current status of a floating OTEC with regard to offshore engineering are reviewed to clarify the position and the overall objective of this study.

In chapter 2, the environmental conditions, hull geometry, mooring system and CWP are configured for analysis model. An analysis model of the plantship is designed from KVLCC2M and the CWP is assumed as made of FRP. The environmental conditions for Indonesia seas are assumed for the extreme analysis. A spread mooring system is considered preferable as a position keeping system. Preliminary designs by several combinations of a flexible joint, a clump weight for the CWP, taut mooring system and catenary mooring

system are compared on their dynamic behavior by using OrcaFlex. Two kinds of models which are calculated by direct coupled system and only CWP under the forced oscillation obtained by the moored ship without CWP are compared in order to examine those interactions. As a result, it is found that the interaction is significant and thus should not be ignored around the resonant frequency of the CWP and the slowly-varying drift motion of the plantship.

The aim of chapter 3 is to construct a simplified analysis model/method to easily comprehend the coupled responses characteristics of the floating platform, CWP and mooring system for the preliminary design stage. The equations of equilibrium and motion are derived based on simplifying a floating OTEC plant to a two-dimensional floating body and an elastic pendulum. This model is compared with time domain analysis from chapter 2, in order to verify the applicability for a practical design and limitation of this present model. It is observed that the present model has predicted the coupled response with practically sufficient accuracy for the early design stage. Subsequently, the influence of the design parameters for CWP to the coupled responses is also clarified by a parametric study combining the bending stiffness, the linear density, and the boundary conditions, as a preliminary design methodology using the present model.

As a critical phenomenon for the design, there are concerns about a self-induced vibration due to large momentum of internal flow. However, our knowledge of the dynamics of such pipes is based on limited experimental studies and the dynamics would seem to be not definitely established. This issue is considered to be an important outstanding question in the dynamics of the CWP and pursued it experimentally and theoretically in chapters 4 and 5.

Chapter 4 reports a tank experiment using a polycarbonate pipe with 4 m length. As first configuration, the free vibration with internal flow is measured by a set-up in which possible disturbances is removed. As a result, a flutter is not observed at a maximum flow velocity of 1.66 m/s. In addition, the observed free vibration seems to be essentially nonlinear and three-dimensional. As second configuration, the behavior at a range of high intaking flow velocity generated by a centrifugal vacuum pump is measured. As a result, a typical flutter is not observed at the maximum flow velocity of 4.1 m/s, while only long-period behavior of less than 5% of the diameter is observed at the tip of the pipe. The existing theory and simulation predicted that a self-induced vibration occur at this flow velocity. Therefore, the experiment reveals the necessary to improve the theory.

In chapter 5, a new model of the inlet flow field, which plays an important role on stability, considering the flow separation and jet formed inside of the pipe entrance is presented based on a CFD analysis. This equation is solved by FEM for time integration and eigenvalue analysis, and the results reproduce the experimental observations. The model also suggests that an aspirating pipe submerged in water does not flutter up to the practically reachable flow velocity.

Chapter 6, concluding remarks, states the general conclusions obtained above and future works.