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Sloshing Risk Reduction in Membrane Tanks of FLNG by Interchanging Liquid Cargo Between Tanks

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The Floating Liquefied Natural Gas (FLNG) Production, Storage, and Offloading Unit and the Floating Storage and Regasification Unit (FSRU) have appeared in the offshore liquefied natural gas (LNG) chain recently. Large-scale membrane tanks are expected to be used in some such facilities; however, special attention should be paid to partial loading in the membrane tanks because of the risk of sloshing. A distribution control method by which LNG is distributed and interchanged between the tanks to reduce the sloshing risk was proposed by Yokohama National University. In this operation, the sloshing risk is reduced by shortening the period spent in the partially-filled condition as much as possible. In this study, the operation was optimized through the use of a genetic algorithm (GA). Several cases involving different charging operations were examined, and the flexibility of this method was demonstrated. It was shown that a considerable decrease of the sloshing risk was achieved.

INTRODUCTION

Interest in the production of liquefied natural gas (LNG) at offshore locations has grown remarkably, and the development of related technologies has accelerated. The floating liquefied natural gas (FLNG) production, storage, and offloading unit is one of the related technologies to be applied in retrieving natural gas from the ocean (Arai et al., 2012). FLNG has advantages such as its lower initial cost and shorter construction time than conventional natural gas facilities, and it can be widely applied to several types of gas fields in the sea. For these reasons, such systems have gained considerable attention, and some engineering companies are starting to design and build these new facilities, e.g., Shell's Prelude FLNG (Shell Global, n.d.). Large-scale membrane tanks are expected to be used in some of the FLNGs because of their good space efficiency. However, it is necessary to avoid partially-filled conditions as much as possible in membrane tanks in order to minimize the sloshing risk. In particular, the charging operations in LNG tanks take a long time, and there is a possibility of sloshing during the operations.

Sloshing refers to the violent movement of liquid with a free surface inside a liquid storage tank that is caused by tank motion. Since membrane tanks have almost no internal structures, the liquid in the tank can move freely. Moreover, violent sloshing loads may occur at the corners of the tanks if the tanks have a prismatic or almost-square shape. A severe sloshing phenomenon is caused by the matching of the natural frequency of the free surface motion with that of the ship motion. In ships with very large tank breadths such as FLNGs, the rolling motion frequency is likely to match the free surface natural frequency. One way to avoid the occurrence of resonance is simply to prevent these frequencies from matching. The free surface motion's natural frequency mainly depends on the tank breadth and liquid height.

In the previous study, therefore, we proposed a distribution control method that focuses on controlling the liquid height to reduce the sloshing risk (Matsuo and Arai, 2013). In this method, the LNG distribution is appropriately controlled among multiple tanks to reduce the sloshing risk. The proposed process operates by interchanging LNG among multiple tanks in order to accelerate the charging speed of the liquid in the target tank so that the time spent at the dangerous filling level is minimized. We also proposed the introduction of "slack tanks" that are usually small tanks with little or no sloshing risk. The slack tank can be used as a buffer, and the stored liquid cargo can be transferred to the main storage tanks from the slack tanks to accelerate the filling speed in the main tanks.

Rokstad et al. (2010) tried to reduce the sloshing risk in the tanks of floating storage and regasification units (FSRUs) on the basis of a similar concept without slack tanks using time-discretized integer programming. In our research, the genetic algorithm (GA) optimization method was used to establish more realistic distribution control, and we defined the sloshing risk as a function of the filling level.

In this paper, we tried to improve the performance of the GA in finding a solution by using Gray codes. An effective operation process was obtained by GA analysis. Computational fluid dynamics (CFD) simulation was also carried out to confirm the effectiveness of the process.

DISTRIBUTION CONTROL METHOD

Concept

The distribution control method that we proposed in the previous paper intended to reduce the sloshing risk by controlling the fill levels and accelerating the speed of the fill level change in LNG tanks (Matsuo and Arai, 2013). The fill levels are controlled through the use of pumps to transfer liquid between the tanks that are connected by pipelines. The LNG distribution is determined by solving an optimization problem to reduce the sloshing risk.

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KEY WORDS: FLNG, FSRU, sloshing, risk reduction, membrane tank, genetic algorithm, gray codes.