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Block turnover simulation considering the interferences between the block and wire ropes in shipbuilding

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A R T I C L E I N F O

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A B S T R A C T

Ship and offshore plants are constructed with cranes on the dock by joining several blocks, which are basic units for design and production in shipbuilding. In the joining process, the erection and turnover operation of a block can cause interference between the block and the wire ropes on the cranes. To identify such a possibility in advance, lifting simulation, which is a kind of dynamic simulation, can be used based on multibody system dynamics. At this time, it is necessary to calculate the contact forces exerted on the block because the block can be damaged or structurally deformed if the contact forces become larger than the allowable value. However, if the lifting simulation is performed with the traditional wire rope model modeled by an incompressible spring, it is difficult to check whether the block and the wire ropes interfere with each other, and to calculate the contact forces exerted, if any. To perform a realistic lifting simulation, a wire rope model that takes interference into consideration is adopted in this study. In addition, a contact algorithm that consists of four steps is proposed to check contacts and to calculate the contact forces. First, the Möller algorithm, which is generally known as the fastest algorithm for triangle-ray intersection, is applied to detect the contacts. Second, the contacted wire rope is divided to cope with the contacts. Third, the contact forces are calculated with the sum of the tensions in the wire rope segments including a contact point. To verify the efficiency and applicability of the proposed method, it is applied to block turnover simulation. It can be seen that the contacts can be accurately checked, and the corresponding contact forces can be calculated if there are contacts between the block and the wire ropes on the crane.

1. Introduction

1.1. Background

A block is a basic unit for design and production in shipbuilding, and a ship or an offshore plant is divided into several blocks then constructed by joining the blocks on the dock [14]. In the joining process, erection and turnover operations that lift and rotate the blocks with cranes are necessary. Recently, various dynamic simulations for shipbuilding operations have been performed to analyze dynamic responses such as block motion, tension acting on wire ropes, interference, and so on. To achieve this, some methods have been used such as the quasi-static method [15], multibody system dynamics [3], and so on. As shown in Fig. 1, a floating crane lifting a block with some wire ropes is a kind of multibody system. Here, a multibody system consists of multiple bodies joined together with joints or wire ropes. For example, *Body* 1 and *Body* 2 are connected with a fixed joint, which constrains relative translational and rotational movement. *Body* 2 and *Body* 3 are connected with wire ropes, which generate elastic force when stretched. Therefore, to evaluate the dynamic response of the crane and the block, multibody system dynamics can be effectively used.

Meanwhile, during the turnover operation presented in Fig. 2, interference between a block and the wire ropes on the crane can occur. If the force exerted on the block by the wire ropes exceeds the allowable value, the block and the wire ropes can be damaged or structurally deformed. To avoid such interference, attached points called lug points for the wire ropes on the block or the construction method can be changed. If interference is inevitable despite these changes, structural analysis of the block should be performed. At this time, block turnover simulation before the actual operation can be performed to evaluate whether the block and the wire ropes interfere with each other or not, and to calculate the contact forces when the interference occurs. However, the interference cannot be detected and calculated with the traditional wire rope model. To solve this problem, the wire rope model that takes interference into account is adopted, and the contact algorithm is proposed to check contacts from the interference and to calculate the contact forces in this study.

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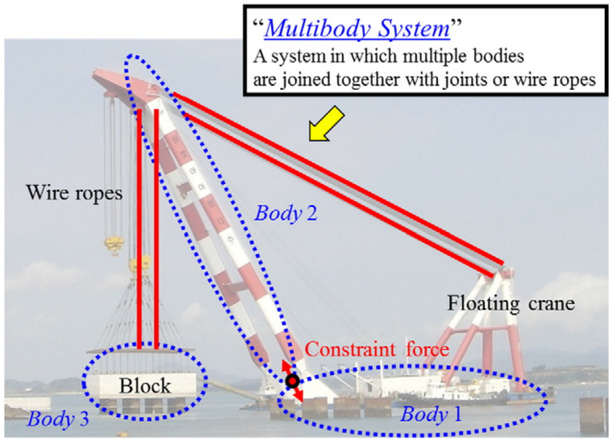

Fig. 1. Example of the multibody system: floating crane that lifts a block.

1.2. Related works

Cha et al. [2,3]) analyzed the dynamic motion of a floating crane that lifts a heavy load based on multibody system dynamics. Through the simulation, the motion of the crane and the heavy load was estimated for the given operating condition. However, the interference between the block and the wire ropes was not considered despite its importance in the lifting simulation. Jo et al. [9]) performed a block turnover simulation including the interference using a simplified block model. In their study, the motion of the wire ropes in the event of interference was analyzed and the contact forces were calculated through the proposed contact algorithm. However, as the wire ropes were modeled with incompressible springs, dummy mass points, which correspond to contact points between the block and the wire ropes, should be inserted into the block and the wire ropes to calculate the contact forces. Also, to find the accurate positions of the contact points, pre-simulation was required. In addition, it is difficult to determine the interference for blocks with a complicated shape. Ku and Roh [10]) performed dynamic response simulation of an offshore wind turbine suspended by a floating crane. For this, they supposed that the motion of the floating crane and the wind turbine has 14 degrees of freedom and considered the interactions among them with constraints. In addition, hydrostatic and hydrodynamic forces were considered external forces acting on the floating crane. Through the simulation, they estimated the motion of the floating crane and the offshore wind turbine, and also calculated the tension acting on the wire ropes between the two. However, the interference between the offshore wind turbine and the wire ropes on the crane was not calculated. Ha et al. [17]) performed block turnover simulation with two Goliath cranes. In their study, wire ropes were modeled with incompressible springs. Therefore, the interference between a block and the wire ropes during the operation could not be detected and calculated. Also, since the wire ropes used in shipyards have a large spring coefficient, the highly oscillated motion during the simulation could be caused by numerical instability, and this numerical instability is usually due to the stiffness of the ODE (ordinary differential equation). Ham et al. [7]) analyzed the dynamic motion of a floating crane that lifts a heavy load. In their study, the discrete Euler–Lagrange equation (DELE) was used for stability of the simulation and the constraint-based wire rope was adopted to reflect various properties of the wire rope. However, the interference between the block and the wire ropes was not considered despite its importance in the lifting simulation. Vorhölter et al. [15] performed a time-domain analysis of typical lifting operations for the offshore wind industry with the quasi-static method. Three different vessels and two different load variations of the lifting operations were considered in the analyses. For this, they supposed that the motion of the vessel and the lifted structure has 8 degrees of freedom. Through the analysis, the dynamic motion of the vessel and the structure was derived; however, the contact forces acting on the wire ropes and the interference between the structure and the wire ropes were not calculated.

In this study, a lifting simulation taking into consideration the interference between the block and the wire ropes was studied and applied to the block turnover operation in the shipyard. For this, the contact

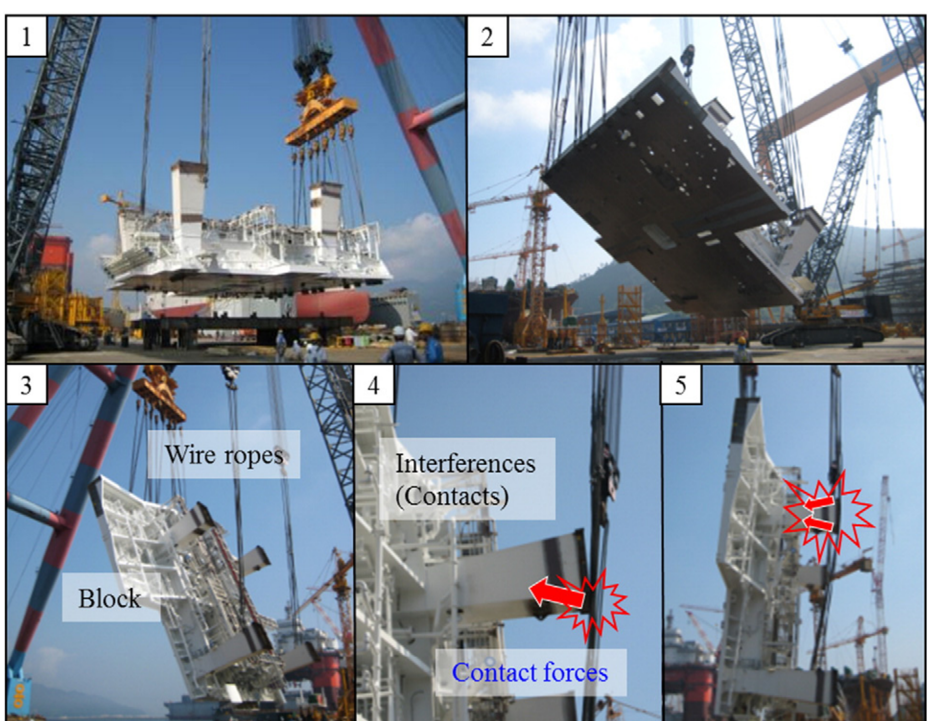

Fig. 2. Example of the block turnover operation and the interference between the block and the wire ropes.