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Ship block assembly sequence planning considering productivity and welding deformation

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Abstract

The determination of assembly sequence in general mechanical assemblies plays an important role in terms of manufacturing cost, duration and quality.

In the production of ships and offshore plants, the consideration of productivity factors and welding deformation is crucial in determining the optimal assembly sequence. In shipbuilding and offshore industries, most assembly sequence planning has been done according to engineers' decisions based on extensive experience. This may result in error-prone planning and sub-optimal sequence, especially when dealing with unfamiliar block assemblies composed of dozens of parts.

This paper presents an assembly sequence planning method for block assemblies. The proposed method basically considers geometric characteristics of blocks to determine feasible assembly sequences, as well as assembly process and productivity factors. Then the assembly sequence with minimal welding deformation is selected based on simplified welding distortion analysis. The method is validated using an asymmetric assembly model and the results indicate that it is capable of generating an optimal assembly sequence.

Keywords: Assembly sequence planning; Simultaneous welding; Productivity; Welding deformation

1. Introduction

For a better competiveness in manufacturing ships and offshore structures, good quality which satisfies customer needs is very important. In particular, higher-quality manufacturing of offshore structures is now required. Ship and offshore structures are usually manufactured by dividing dozens of blocks where each block is composed of dozens or hundreds of plates.

For the enhancement of productivity and quality, many researchers focused on efficient welding distortion prediction method, optimal welding sequence problems, as well as their impact on the production schedule. Simplified welding distortion prediction methods have been developed by many researchers, and some researches considered the constraining effects (Kim et al., 2014a,b). Most of the simplified analysis methods are based on inherent strain concept and provide comparatively faster than 3D thermos-elasto-plastic analysis with reasonable analysis accuracy. Hetero-Layered Approach (HLA) is a simple thermal elasto-plastic analysis (Kim et al., 2014a,b). It is intended to simulate T-joint model and imposes heat loads in the multi-layer shell elements. Another simplified welding distortion analysis method is Improved Equivalent Strain Method (Improved ESM) and it is described as three-dimensional tri-axial restraint model considering temperature gradient (Kim et al., 2014a,b). This method was applied to evaluate the reduction of welding distortion during the cooling stage by external restraints imposed normal to the plate. In addition, elasto-plastic-based strain as directed boundary method (SDB) was proposed and applied to simple butt joint (Ha, 2011). In order to be available to consider both flange and

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web distortion in fillet joint, a composite layered shell is applied in the conventional SDB (Kim et al., 2015a,b). However, they focused on the welding itself and did not applied to the determination of welding sequence problems. Some other researches focused on the optimal load balancing and scheduling problems (Cheng et al., 1996; Kim et al., 2000; Mula et al., 2006). They emphasized the impact of assembly sequence (precedence constraint) as one of the most critical constraints in their formulation. However, they assumed that the optimal assembly sequence is regarded as a priori, not the parameter to determine.

Assembly sequence planning is one of the most important tasks with regard to the quality and productivity in manufacturing structures. It affects many aspects including fixture design, crane and dock schedule and so on. Correct assembly sequence planning can provide a good quality of assembly and reduce manufacturing cost and time. However, an incorrect assembly sequence may increase the complexity of the manufacturing process and require substantial rework to fit structures within allowable tolerances.

In order to determine a feasible assembly sequence, constraints between parts in a block and several manufacturing processes in the working area should be carefully considered at a basic level. For the assembly sequence planning, a method using a liaison graph containing vertices and edges to express parts and connection relationships among them based on questions and answers was previously reported (Bourjault, 1984). Its limitation was that the number of questions and answers increased exponentially with increasing of the number of parts. Additional studies reported on reducing the number of questions and answers by applying a net graph (Defazio and Whitney, 1987) or rules based on engineers' experience (Bourjault, 1984) However, the more complex a structure become, the more limited its application because it depends completely on the engineers' experiences.

With the advancement of computing systems, methods for assembly sequence planning using artificial intelligence methods or heuristic algorithms have been proposed (Zhang et al., 2002; Chen et al., 2008; Yasin et al., 2010; Su, 2014). Even though these are relatively easy to apply to determine the optimal assembly sequences, they cannot guarantee a globally optimal solution.

Recently, a method for determining an assembly sequence automatically was introduced (Shipeng et al., 2013). It determined the preference relations between parts in the assembly using case-based reasoning and represented logical and physical relations between parts in matrix form so that feasible assemblies that consider geometric constraints could be obtained. However, the main challenge of this method is that it does not reflect the real manufacturing environment in ship and offshore manufacturing.

In ship and offshore manufacturing procedures, most parts are assembled and joined by welding. Basically, the welding process causes residual deformation in the assembled part owing to local heating and cooling processes in the assembly. In order to fit the dimensions of the assembled part, a rework process is required which causes additional manufacturing cost and manufacturing time. Therefore, welding deformation should be considered in determining the optimal assembly sequence since an incorrect assembly sequence may increase the amount of welding deformation and is closely related to assembly quality manufacturing cost and manufacturing period.

When several parts are assembled by welding, the stiffness between parts varies before and after welding. Because of this, different amount of deformation appear for different assembly sequences. Considering the amount of deformation is desirable since it is directly related to the quality and productivity of the final assembly. Therefore, many studies have been performed to analyze the effects of welding sequences in manufacturing-related fields. Most of studies selected specific unit assembly from a target entire assembly and conducted experiments and thermal elasto-plastic analysis. In addition, a simplified analysis method based on inherent strain has sometimes been applied for analysis of welding deformation effects (Hardikar et al., 2012; Park et al., 2013; Wang, 2013). In order to consider welding deformation in the assembly process more practically, the post-sequence method which places the most influential joint welding in terms of welding deformation in the last sequence was introduced to consider welding deformation in welding sequence planning and was applied for tack-welded assemblies (Ha, 2011, 2013). But he did not include the productivity-related factors, such as turning-over, parallel welding, and the likes.

This paper proposes an assembly sequence planning method considering productivity and welding deformation in ship and offshore manufacturing in order to achieve higher quality and better productivity. The proposed method defines the part types for all parts in the target assembly based on case-based reasoning and takes into account constraints like part movement, part location, welding type and simultaneous welding conditions. In addition, welding deformations of different magnitudes in accordance with different assembly sequences are considered.

2. Assembly sequence planning method

As a preliminary step in the manufacturing of ships and offshore blocks, the determination of the assembly sequence has a significant impact on manufacturing cost, duration and quality. The efficient work process flow, the amount of rework, the scheduling of equipment and the number of operators required may all depend on the assembly sequence. For efficient process flow, the shape of each part and assembly relation between parts should be analyzed. On the basis of this analysis, productivity factors for minimizing the occurrence of bottlenecks regarding equipment and workers should be considered. Additionally, the amount of rework is closely related to the degree of welding deformation affecting production cost and duration as well as dimensional quality of the structure. Therefore, the influences of welding deformation for different assembly sequences should also be considered.

The proposed assembly sequence planning method in this paper considers productivity factors and the amount of

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