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Corner Machining System for Protective Coating

Dae-Eun Ko
Department of Naval Architecture & Ocean Engineering, Dong-Eui University, Busan, KOREA

ABSTRACT: *In the hull structure, a large number of color plates are used for shear reinforcement of slot holes. The shipyard should perform grinding so that the corners of the color plate are sufficiently smooth in accordance with the International Maritime Organization's performance standards for protective coating. However, manual grinding for this can cause many problems in terms of work environment and productivity. In this study, we designed an automatic corner machining system for protective coating. To establish the corner machining process, we introduced shape recognition and processing path generation algorithms. Once this automation system is established, it is expected to not only meet IMO regulations but also contribute to productivity improvement.*

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I. INTRODUCTION

The International Maritime Organization made the regulation, performance standards for protective coatings, mandatory to minimize hull corrosion and improve structural stability. This regulation applies to the water ballast tanks of all newly constructed ships with 500GT or more and the double hull structure of bulk carriers with the entire vessel length of more than 150m. However, for application, various related technical issues, such as hull surface pretreatment, paint selection, painting process and inspection, must be addressed effectively [1]. In particular, for hull surface pretreatment, there are technical issues that the sharp corners of collar plates, which are installed for shear reinforcement of slot holes must be rounded to the minimum radius of 2mm (2R), or the corners must be subjected to 3-pass (3P) grinding [2].

Most shipyards rely on manual labor to use a general grinder for corner processing of color plates, performing only one pass operation. Therefore, the significant increase in the intensity of work to meet the traditional 2R or 3P regulations has raised concerns for workers about the occurrence of musculoskeletal diseases and poor pretreatment quality. To address this, it is necessary to develop and apply fully automated or partially automated corner processing systems instead of manual work.

Studies on grinding automation include studies related to cutting force as well as cutting conditions and studies related to the creation and optimization of processing paths. Zhu et al.[3] conducted computer simulations and cutting experiments to establish a mathematical model for predicting the cutting force of cotton milling. Kim et al.[4] determined the optimal cutting conditions through complex experimental design in the milling process using conventional machine tools. Studies on the creation and optimization of processing paths include simulation of manufacturing based on cutting paths and experimental studies conducted by Wang et al.[5]. These prior studies focused on in-depth research topics such as cutting power, cutting conditions, and cutting paths of commercial milling machine tools or milling tools based on existing experimental devices.

In this study, an automatic corner machining system was designed for collar plates, and a manufacturing process was established by applying the shape recognition and process path generation algorithm. It is expected that an automation system capable of meeting IMO regulation will be constructed and productivity will be improved at the same time.

II. SYSTEM DESIGN

Collar plates, which are the processing target of this study, have 100-500mm lengths, 100-400mm widths, and 7-25mm thicknesses. Figure 1 shows the schematic diagrams of the 2R and 3P grinding, which are the corner machining standards.

The mechanical unit of the machining automation system to meet the 2R or 3P regulations on collar plate corners can be divided into a clamping module for fixing collar plates, a high-speed spindle module for processing, and a drive module for moving the high-speed spindle along the processing path. The clamping module is composed of the upper and lower jig to fix collar plates with various thicknesses. The upper jig pressurizes collar plates using a hydraulic cylinder, and the lower jig fixes them using an electromagnet. The high-speed spindle module directly rotates the milling tool and its rotation speed was set to the range between 1,000 and 10,000[rpm].

The drive module consists of X-axis, Y1-axis, Y2-axis, Z1-axis, and Z2-axis as shown in Figure 2 for the corner machining of collar plates. Y1-axis and Y2-axis had gantry synchronous drive structures, Z1-axis was used for the height adjustment of the milling tool, and Z2-axis was used for the automated focus adjustment of the shape-recognition camera. The camera was used to measure the shapes of collar plates. It had the high resolution of 2,400×2,050[pixel] and could use backlit lighting for higher quality.

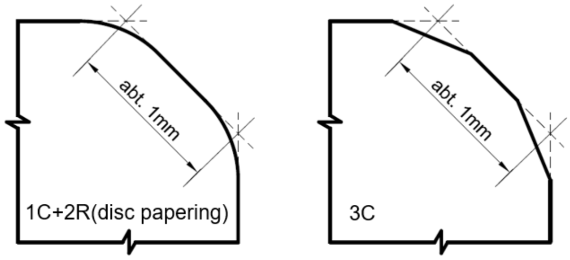

Figure 1: Corner machining standards

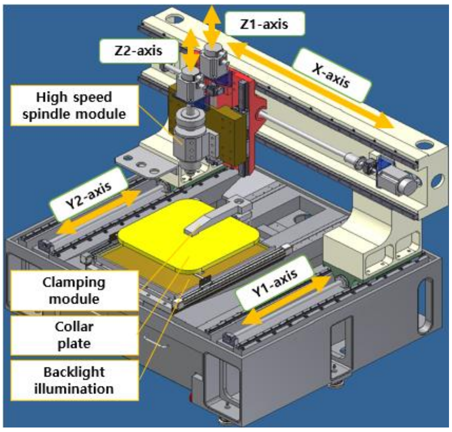

Figure 2: Concept of corner machining system

The computer-based motion controller consists of a CPU and servo integrated circuits (ICs) that give commands to the motor or receive feedback. The CPU checks the status of the controller in real time using the watchdog timer and enables the system to maintain the best condition by checking the control routines, servo update, hardware, and software over travel limit. There are two servo ICs in the control unit. Each servo IC can control four axes by providing analog commands to the DC servo drive of each axis. In addition, for precision operation, closed loop control was implemented using the feedback signals of the encoder that detects the rotation amount of the motor. In the existing control systems, the control method is set to serial or parallel method for drive synchronization [6]. However, since such control methods may cause synchronous errors, it is difficult to apply them to the gantry system requiring high precision and high speed. Therefore, the cross-coupling control method was applied so that the feedback information of both control loops could be shared using the cross-coupling control method [7] for the synchronous drive of the Y1-axis and Y2-axis of the system.

III. PROCESS ALGORITHM

A collar plate is loaded onto the clamping module, and the collar plate model is selected from the database. The selected collar plate information is compared with the collar plate information recognized through the camera to determine shape matching. Shape matching can be determined based on the length, width, and thickness information of the collar plate. Shape matching is important because the painting and welding design information of the collar plate to be accurately selected and reflected to the processing path. When the collar plate shapes are determined to be matching, the processing path reflecting the painting section and the welding section is generated automatically to begin machining. Finally, when machining is complete, the milling tool is returned to the starting point.

To recognize the shape of a collar plate, the images captured by the camera converted into 8-bit gray scale images. In addition, the commonly used Sobel operator [8] was used to detect the corners of a collar plate. Based on the detected corner image, the processing path can be generated by extracting the straight line or circle information through Hough transformation [9]. In the case of straight line information, numerous straight lines passing through the one detected point are marked in the Hough space by converting each straight line into a function expressed with θ, the angle between the line and x-axis, and r, the shortest distance from the origin to the line. When crossing curves are found among the curves marked in the Hough space, it can be seen that the points corresponding to such curves lie on one straight line. Based on this, the straight line information can be extracted from the corner image. In the case of the circle information, circles that use the point coordinates detected from the radius and corner image within the given range as their center points can be generated.

The circle information can be derived by finding the coordinates with the highest cross frequency from the generated circles and setting this point as the center point of the corner circle shape. The straight lines and circles extracted through Hough transformation generate crossing points, and each interval is defined as the machining region requiring painting or as the non-machining region requiring welding, based on the selected standard collar plate information. Processing coordinates corresponding to the machining region are generated as the primary coordinates for processing. Later, processing coordinates are added to a crossing point between straight lines for 2R processing. For crossing points between a line and a circle, processing coordinates are added depending on whether the number of crossings is one or two. Furthermore, the processing degree can be improved by evenly dividing a circle into two or three depending on its size and additionally generating processing coordinates.

The shape recognition and processing path generation algorithm developed in this study is shown in Figure 3. This algorithm can implement corner machining considering the characteristics of each collar plate by recognizing the shape of the collar plate using the high-resolution camera and by generating Hough transformation and then the processing path based on the recognized shape. In addition, since the collar plate shape information with the completed cutting process is directly used, processing errors that may occur during the cutting process can be automatically solved during corner machining.

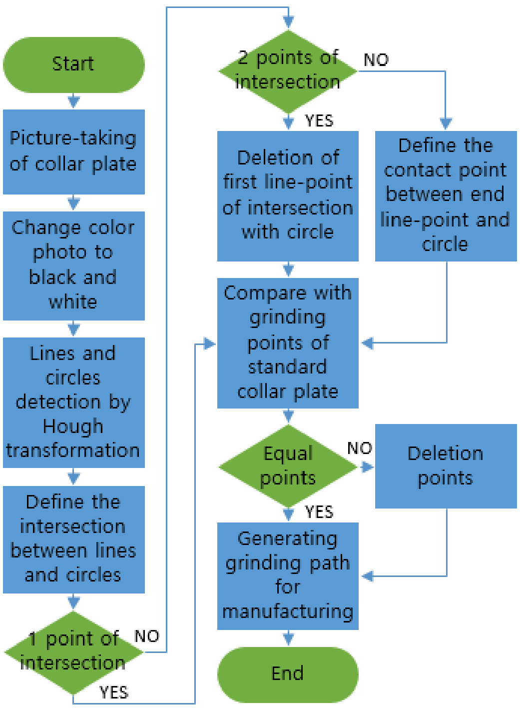

Figure 3: Process algorithm

IV. CONCLUSION

In this study, an automatic corner machining system for collar plates was designed to effectively meet the IMO regulation. The results derived are summarized as follows.

- Based on the various shapes of collar plates and the 2R or 3P regulation review results, the five-axis synchronous drive mechanical unit capable of effectively performing automatic corner machining work was designed. The efficiency of the drive system was improved by placing the mechanical unit for the rotation and feed of the milling tool and the camera position adjustment mechanical unit for accurately recognizing the shape of a collar plate in the integrated drive system without mutual interference.
- The precision of the automation system was improved by applying the cross-coupling control method to prevent the occurrence of synchronous drive errors, and a gantry system enabling the high-speed rotation of the milling tool was constructed.

- To consider the characteristics of collar plates for which the painting region and welding region must be divided for machining unlike the general materials, an corner machining process was newly established using both the shape recognition information and design information.
- High-resolution image shooting and an image conversion algorithm were applied to generate a more accurate processing path, and the processing degree was improved compared to manual work by developing a stepwise processing path generation algorithm composed of Hough transformation, crossing point generation, non-machining region definition, and 2R or 3P processing coordinate generation.
- It is expected that an automatic corner machining system capable of meeting IMO regulation will be constructed and productivity will be improved at the same time.

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