

## Development of semi-automatic painting system for longitudinal stiffeners in double Hull blocks

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**Abstract:** Painting works in double hull blocks are very difficult and dangerous because working space is isolated and narrow. The structure in double hull blocks is too complex to apply automatic painting equipments. For these reasons, every shipyard still applies manual painting process which causes delay in ship construction and low quality. Therefore, the purpose of this study is to develop the semi-automatic painting system inside double hull blocks. It consists of two main equipments. One is the semi-automatic painting machine to paint structure members inside double hull blocks and the other is the supplement machine to install and move the former. By applying the developed system, productivity and painting quality can be increased and workmen's accident and injuries can be reduced.

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### 1. INTRODUCTION

Due to the recent trend of putting into statute double hull construction requirements regarding new ships, the role played by closed areas in ship building is increasing. As shown in Fig. 1, double hull blocks are constructed by complex structural members in order to satisfy a ship's strength requirements, and thus the internal areas of a double hull block can only afford to have a space enough to fit a person. This means a worker's movement is restricted, and leads to a worker having to bend over to carry out most of his work, causing spinal injuries.

Although many automated equipments have been developed and applied in ship building such as welding robots, any automatic paints system for ship structure has not been applied yet. So almost every major shipyards still apply manual painting process. But it is very difficult, danger and dirty process so most workers tend to avoid. And, painting quality is unstable due to manual work depending on worker's experience.

In order to overcome this circumference, this study develops the semi-automatic painting system which consists of painting equipment and supplement equipment. The former is used to paint structural members inside double hull blocks such as longitudinal stiffeners. And the latter is used to move and install the former inside double hull blocks.



Fig.1 Inner of double hull blocks

### 2. WORK PROCESS

Standard painting process for ship blocks is shown in Fig. 2. Painting process is divided into blasting and painting activity. And the latter is divided into main spray and touch-up activity. Touch-up activity is done by paint roller for region that main spray cannot form enough painting thickness such as inner side of longitudinal stiffeners, flange edge, scallop, collar plate and etc. This is the main culprit behind the exacerbation of worker fatigue due to him or her having to bend over to carry out their work. Fig.2 shows a painting process inside double hull blocks after development has completed

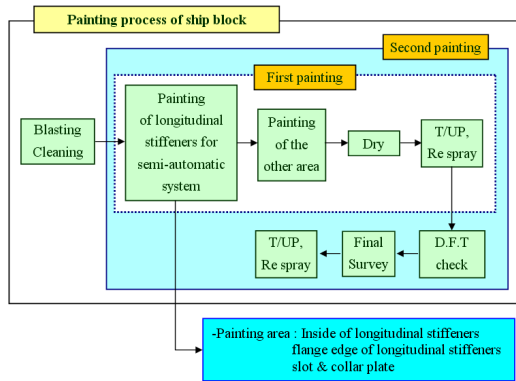


Fig.2 Painting process of ship blocks after developed system has applied

### 3. SYSTEM PERFORMANCE REQUIREMENTS

Table 1 shows the major criteria to be followed for developing the equipment. Actually there are so many variables such as size, shape, and the number of stiffeners, space between stiffeners, and etc to develop painting system in double hull block. And all variables are changed by type of ship. So, the most severe condition is selected out of those cases. There are areas where automated machines cannot reach because the working region, double hull block, is so complex. Therefore setting the right goals following system performance requirement will play an important role in applying the equipment after developing.

Table 1 System Performance Requirements

Item		Requirements
Ship block	Frame Space (mm)	3400
	Space between stiffeners (mm)	720~850
	Angle web height (mm)	200~400
	Angle flange width (mm)	90~100
Painting equipment	Velocity (mm/s, degree/s)	Driving : 600 Pivot : 270
	Axis	Driving : 1 Pivot : 1
	Weight (kg)	20
Supplement equipment	Velocity (mm/s)	Vertical : 200 Horizontal : 600
	Axis	Vertical : 1 Horizontal : 1
	Weight(kg)	15
	Additional load (kg)	25

### 4. SYSTEM DESIGN

#### 4.1 Mechanical system design

The painting equipment is moving on the flange and painting inner side of longitudinal stiffeners automatically. After finishing painting for one longitudinal stiffener, it moves to adjacent longitudinal stiffener by supplement equipment. As shown in Fig. 3, painting equipment can be divided into fixed and moving part. The moving part moves on longitudinal stiffener in the long direction of longitudinal stiffener while having the spray gun that sprays paint that is attached to it to paint the inner side of longitudinal stiffener. The moving part and fixed part are connected by scissors type structure to guarantees straightness of moving part during running on flange. The moving part has a front area identification sensor that enables it to stop at the end of longitudinal stiffener. The moving part moves forward (first round), stops, and automatically moves backward (second round), so painting is done second time to ensure proper painting thickness 150 microns. As soon as the first round is complete, in case of it stopping on the end of longitudinal stiffener's location, a tilting motor rotate the spray gun to cover end region. After second round, moving part and fixed part join together. At that time, the spray gun rotates 90 degrees to prevent interruption when moving between longitudinal stiffeners.

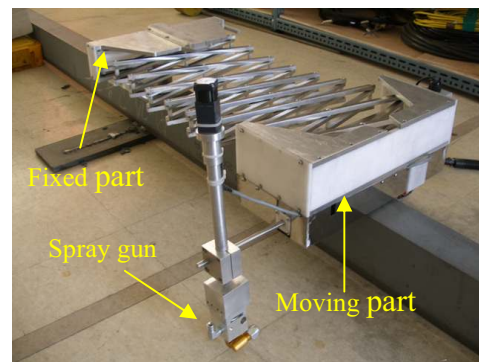


Fig.3 A prototype of painting equipment moving on longitudinal stiffener

As shown in Fig. 4, supplement equipment can be largely divided into main body, transportation part and horizontal rack. Transportation part is combined with the side of the main body and horizontal rack is positioned in a long bar. And the fixed part of painting equipment is connected to the main body of supplement equipment. When the moving part of painting equipment finishes the painting and joins with fixed part, transportation part and horizontal rack move up by lead screw installed on main body. And then, horizontal rack moves transverse direction to adjacent longitudinal stiffener by horizontal motor installed on transportation part. When it reaches adjacent stiffener, it moves down on stiffener and is fixed on adjacent stiffener by pneumatic rubber pad. After

horizontal rack settle down on stiffener, main body and painting equipment moves transverse direction along horizontal rack by similar mechanism. In the bottom end part of the horizontal rack mentioned above, a pneumatic rubber pad exists which firmly fixes one end of the horizontal rack to the longitudinal stiffener. There is also a rotator system in the main body part which allows horizontal rack to rotate among longitudinal stiffeners which differ in height. Fig. 5 shows how painting system can move to adjacent longitudinal stiffener by supplement equipment automatically.

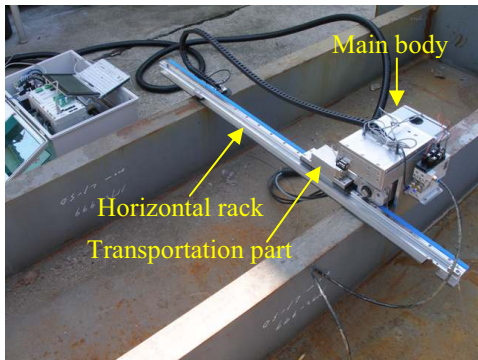


Fig.4 A prototype of supplement equipment moving to adjacent stiffener

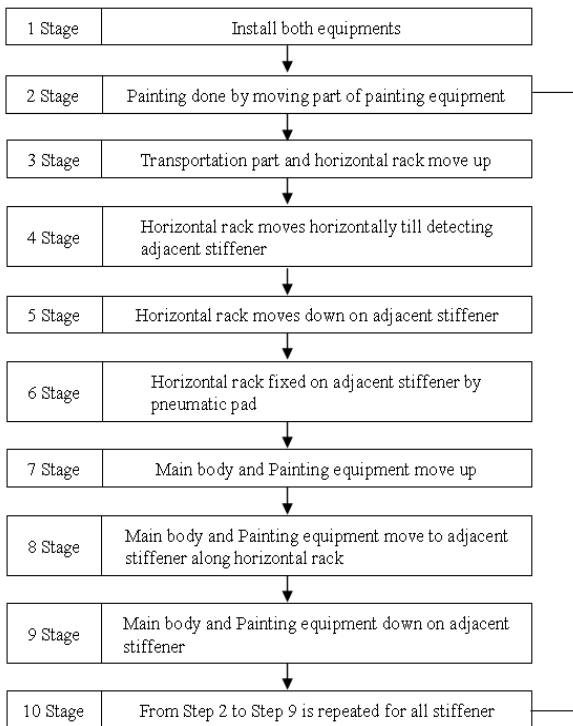


Fig.5 Sequence of working of developed system

#### 4.2 Control unit design

Fig. 6 shows the control mechanism for the painting and supplementary equipment. The four analogue commands which come out of the motion controller control each servo motor and Closed Loops are controlled with the encoder feedback. Communication of host (PC) and devices using the blue tooth is properly configured system which immediately sends feedback when happen a wrong signal. Additionally, CPU runs a real-time check on the status of the controller using watchdog timer, servo update and hardware and software over-travel limit in order to maintain the working condition of the system. Using ultrasonic wave sensor, Motion that transferred and backed as well as designated distance is saved on buffer in advance, which considers better responsiveness for system.

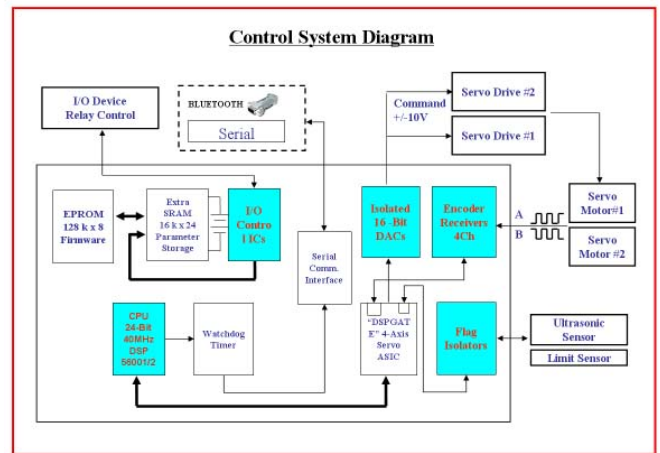


Fig.6 Motion control diagram

#### 4.3 Performance tests

The following tests were conducted on the two equipment designed according the system mentioned above.

- 1) Structural strength test
- 2) Capacity tests for the motors used
- 3) Capacity tests for pneumatic and magnetic force
- 4) Performance test of sensors
- 5) Straightness test for moving part of painting equipment on stiffener
- 6) Motion test between adjacent stiffeners that differ in height

After conducting the tests, we made some modifications and decided on the final design for the system. Fig. 7 shows the concept design for two parts joined together.

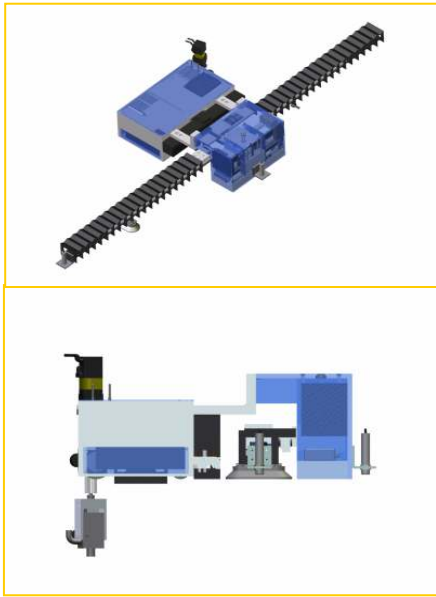


Fig.7 Concept design for semi-automatic painting system

### 5. PAINTING SPRAY CAPABILITY ENHANCEMENTS

Even if the automated system is constructed, actual usage of the equipment will be challenged if the painting quality is not satisfactory. To derive proper painting conditions such as tip size of nozzle, painting velocity, distance of object and input pressure, painting experiments were done. To enhance the reliability of the experiments, five axes reciprocator was manufactured and used as shown in fig.8.



Fig.8 Painting reciprocator with five axes

Table 2 presents painting conditions and their range used in the coating assessment experiment. The data from Table 2 was carefully selected from the information acquired from consulting actual field workers. It is notable that SVR was chosen to investigate the coating thickness by types of coating materials. By applying empirical formula used SVR factor, we can predict the most appropriate coating requirements regardless of coating materials. Fig. 9 shows a

painting test for investigate painting conditions with five axes reciprocator in laboratory.

Table 2 Painting conditions (experiment)

Conditions	Range
Tip size	523, 527, 531
Distance of object (mm)	350~550
Velocity (mm/s)	500~700
Input pressure (bar)	4~6
Solid Volume Ratio (%)	57~68



Fig.9 Experiment of painting conditions

Fig. 10 presents the coating profile of A/C painting material as one of variety of results of experiment. The requirements for the best coating profile are velocity of 600~700mm/s, distance of 400~500mm, tip size 527, and input pressure of 4~6 bars. Using the result of painting conditions mentioned above, painting defects such as sagging, orange peel and pinhole may not occur during the painting.

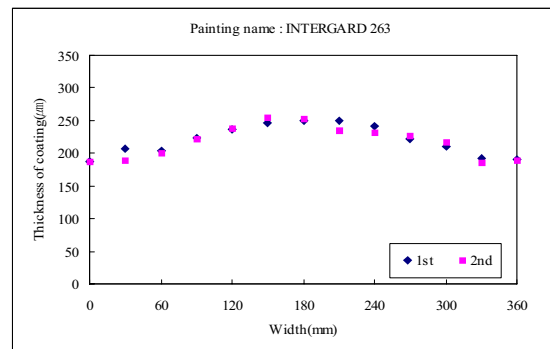


Fig.10 Coating profile (Tip size: 527, Velocity: 600mm/s, Distance: 450mm, Input pressure: 6bar)

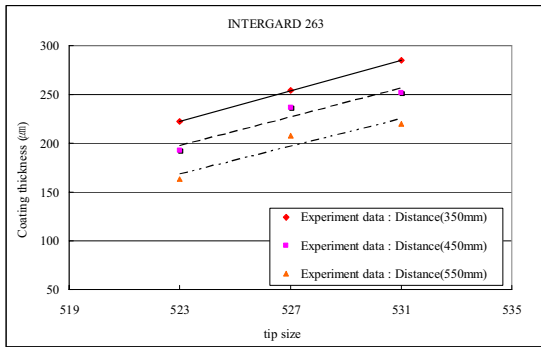


Fig.11 A comparison of thickness of coating, varying the distance of object (Velocity: 500mm/s, Pressure: 5bar, Tip size: 527)

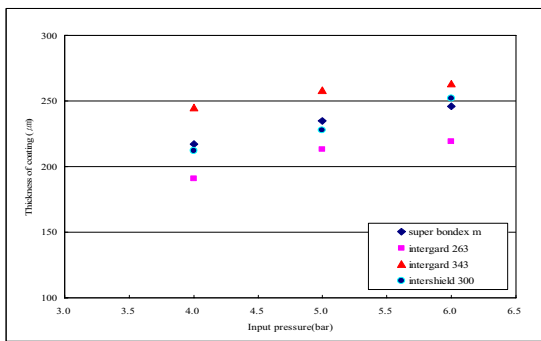


Fig.12 A comparison of thickness of coating, varying the input pressure (Velocity: 500mm/s, Distance: 450mm, Tip size: 527)

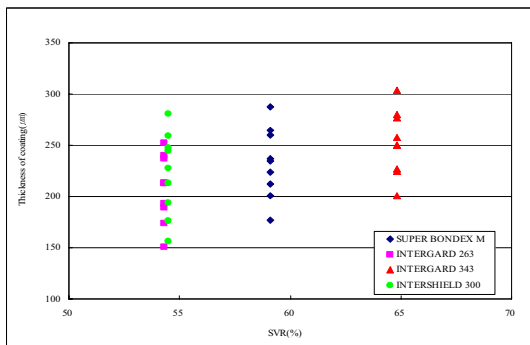


Fig.13 A comparison of thickness of coating, varying SVR for painting materials (Velocity: 500mm/s, Pressure: 5bar, Tip size: 527, Distance: 450mm)

Fig 11 shows the variations of thickness of coating as a function of the tip size and distance of object, respectively. This is the very important factors affected thickness of coating. On the other hand, it is found that input pressure is not influential parameter to coating thickness. Fig.12 and fig.13 show the effect of factor of input pressure and SVR for

coating thickness. The final prediction formula (1) was developed through regression analysis of data obtained from experiments mentioned above.

$$Pt = \{1.8413 \times (S/100) + 0.0723\} \times \left[ \{0.3594 \times (P/5) + 0.6406\} \times \left[ \{(-0.000009 \times V + 0.001) \times D \times N\} + \{(0.0055 \times V + 6.5197) \times N\} + \{(0.005 \times V - 0.9918) \times D\} + (-3.1185 \times V - 2964.4) \right] \right] \quad (1)$$

Where,

Pt : Thickness of coating (µm),

V : Painting velocity (mm/s),

D : Distance of object (mm),

T : Tip size of nozzle,

S : Solid volume ratio (%),

P : Input pressure (bar)

Fig. 14 shows correlation of experimental values and empirical values. As illustrated in the graph, the experiment results and predicted values show a highly positive correlation. The final painting prediction formula will be used in painting guide for workers and painting database for the software of automated system.

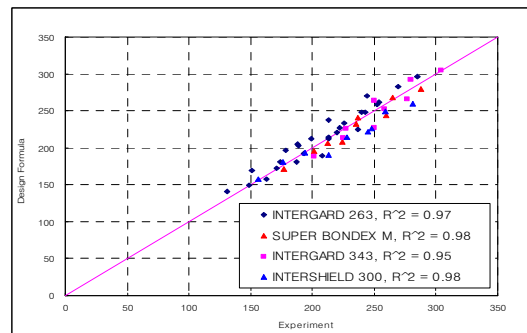


Fig.14 Correlation of experimental values and empirical values

## 6. CAPACITY TEST AND PROBLEMS

Following the test on various functions including the control algorithm test, we conducted painting test on the testing blocks as shown in the Fig. 15. Table 3 shows painting conditions used in experiment with painting machine. As results of test, it was possible to obtain the desired coating thickness and profile provided in the Fig. 16 and Fig. 17.

However, it is shown that over-spraying can happen if the nozzle tip's angle is not properly controlled. Therefore, it is necessary that ability of prevention from painting pollution for the sake of the better application of the field.

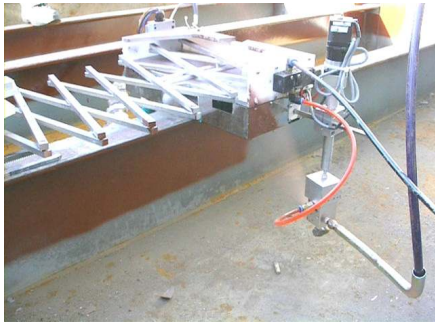


Fig.15 Painting test using a prototype of painting equipment

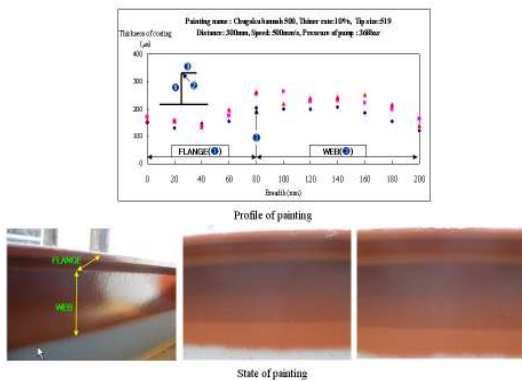


Fig.16 Result of painting test (Distance: 300mm, Tip size: 519, Painting velocity: 500mm/s, Input pressure: 5bar)

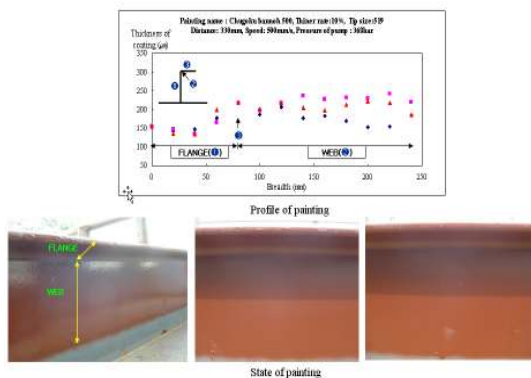


Fig.17 Result of painting test (Distance: 330mm, Tip size: 519, Painting velocity: 500mm/s, Input pressure: 5bar)

Table 3 Painting conditions used in experiment with painting machine.

Conditions	Range
Tip size	523, 527, 531
Distance of object (mm)	300, 330
Velocity (mm/s)	500
Output pressure (bar)	340
Angle of tip size (%)	30~35

## 7. CONCLUSION

In this study, we develop the semi-automatic painting system which consists of painting equipment and supplement equipment. The former is used to paint structural members inside double hull blocks such as longitudinal stiffeners. And the latter is used to move and install the former inside double hull blocks. Along with the development of automatic system to derive proper painting conditions such as tip size, painting velocity, distance of object, input pressure and etc, painting experiments were done. Based on the experiment data, equation for predicting painting quality was derived and clarified.

Finally using developed system and condition, painting test was done on sample block. It showed good results. Through this study, the following benefits are expected.

- 1) An automatic process can be applied for painting in shipbuilding which is very dirty, dangerous and difficult.
- 2) By applying the developed system, productivity and painting quality can be increased and workmen's accident and injuries can be reduced.

## EPILOGUE

This work has been carried out by authors within the framework of the Ministry of Commerce, Industry and Energy (MOCIE) project, entitled "Development for automated painting and blasting system in inner double hull blocks."

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