Study on the Development of High Transfer Robot Additional-Axis for Hot Stamping Press Process

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***Abstract*—High transfer additional-axis of robot plays important role in processes that require shorter transfer times, such as hot stamping press process. The intention of this study is to develop a robot additional-axis model which is smaller in size than existing high transfer robot additional-axis, and has the same or better durability and main performance. Dynamic analysis and structural analysis are carried out in the design stage to verify structure stability of drive mechanism according to material and shape.**

***Index Terms*— Hot-stamping, Robot additional-axis, High transfer, Structure analysis, Dynamic analysis**

I. Introduction

Recent trends of lightweight and environment friendly in automobile manufacturing technology is hot stamping that produce lightweight and strong steel sheets. Hot stamping process is a technique of heating the material to a high temperature of 900 ℃ or higher and then quenching the forming and molding at the same time, and it can achieve around 25% of automobile weight reduction. This hot stamping process is a manufacturing process that requires high temperature and quenching. As shown in Fig. 1, technology of moving products between processes using robot additional axis is regarded as an important factor

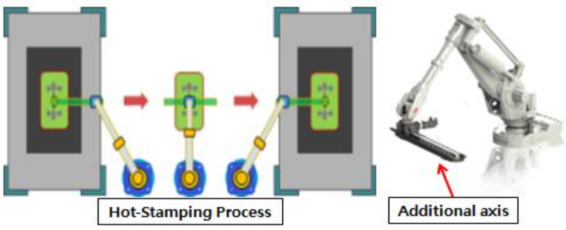

Figure 1. Hot stamping process using robot additional-axis.

It is the purpose of this study to develop a robot additional axis model which is smaller in size than existing high transfer robot additional axis, with same or better durability and main performance. Also, dynamic analysis and structural analysis are carried out in the design stage to verify structure stability of drive mechanism according to material and shape.

II. Structure of High Transfer Robot Additional-axis

As shown in Fig. 2, high transfer robot additional axis is composed of 1 servo motor, main frame, cover and rail. Currently developed additional axis model's maximum payload is 50 kg. First, design stability of main frame, rail and cover by their material and shape is verified through structure analysis. Second, design verification is performed for servo motor specification according to payload, speed, etc. through dynamics analysis.

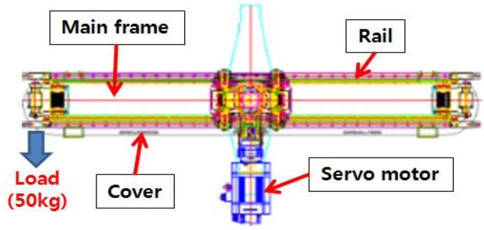

Figure 2. Main block diagram of high transfer robot additional-axis.

III. Structure Analysis of Robot Additional-Axis

Structure analysis was performed to find the stable structure of high transfer additional axis in two cases of different material and shape – main frame and cover material is different as in Fig. 3 (a), and integrated main frame and cover with same material as in Fig. 3 (b). Material values used in the analysis are shown in Table I, and the analysis software is MSC Nastran.

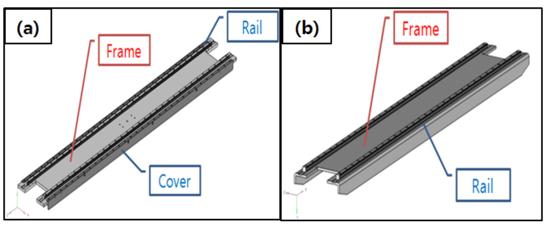

Figure 3. Main frame condition of high transfer robot additional axis.

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TABLE I. MATERIAL VALUES USED IN THE ANALYSIS

Unit Name	Material	Young's Modulus (MPa)	Poisson's Ratio	Density (kgf/m3)	Yield Stress (MPa)
Rail, Cover	SM45C	210,000	0.30	7.85	569
Frame	AL6061	70,000	0.33	2.70	275

A. Constraints and Analysis Condition

When the object is separated from the outside in order to understand the behavior of any object in contact with the outside, the influences from the outside should be reflected in the boundary conditions. Boundary conditions play a very important role, even for objects of the same shape and material, because their behavior varies greatly with boundary conditions. Which of the influences from the outside is included as a boundary condition depends on the type of behavior of the object to be analyzed. Structure analysis[1,2] conditions for 2 model types of high transfer robot additional axis are shown in Fig. 4. Its boundary conditions are that rail is fixed on the upper part, and 50 kg of load is applied to the center of the rail end while considering self-weight.

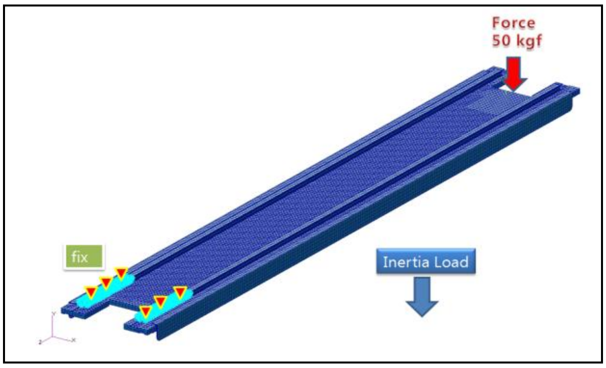

Figure 4. Analysis condition of high transfer robot additional axis.

B. Results of Structure Analysis

Structure analysis result when main frame and cover material are different is shown in Fig. 5. Analysis shows that its peak stress is 108 MPa where rail and main frame is jointed, and maximum displacement is 12.8 mm at the end of rail. Structure analysis result for integrated main frame and cover is shown in Fig. 6. Analysis shows that its peak stress is 97.5 MPa where rail and main frame is jointed, and maximum displacement is 10.0 mm at the end of rail. From the analysis result, it is found that one body integrated model using aluminum as main frame has less peak stress and maximum displacement. The stress is concentrated on the rail where the system is fixed, and the safety factor considering the yield stress is about 5.3 (= 569/108). Therefore, the structure of the system is expected to be stable.

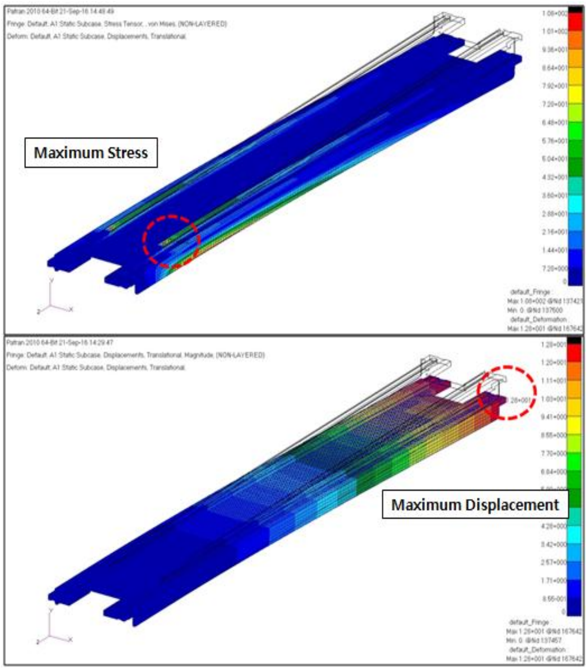

Figure 5. Analysis result of high speed additional axis (when main frame and cover material are same).

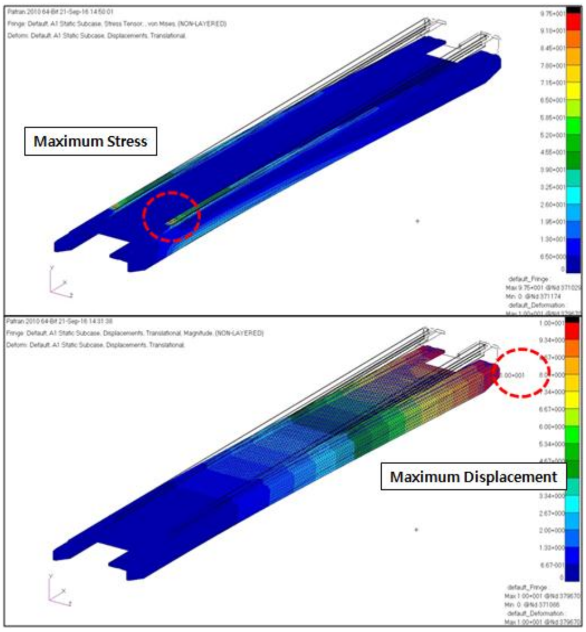

Figure 6. Analysis result of high speed additional axis (when main frame and cover material is integrated type).

C. Analysis Results of Main Frame Optimization

High transfer robot additional axis moves between both ends of main frame with high speed and 50 kg of payload. So, structure stability and main frame's maximum displacement can have critical influence to robot's position repeatability. Therefore, to find more stable structure from main frame and cover integrated model, we performed structure analysis for 4 types of main frame rib thickness as shown in Fig. 7, and surveyed most stable structure. Same criteria of boundary condition and load condition as previous condition were applied for structure analysis according to main frame rib thickness change. Self weight condition when rib thickness is changed is applied considering the weight of raw material as shown in Table II.

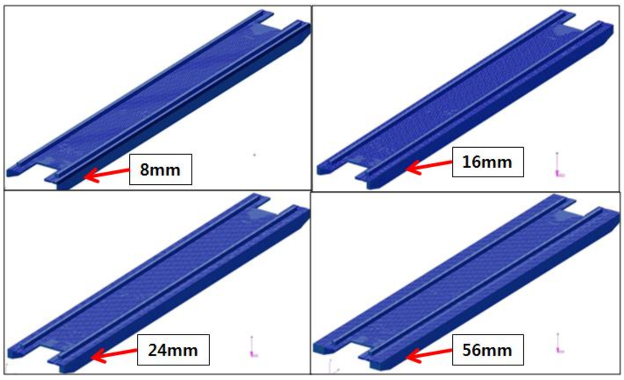

Figure 7. Main block diagram of high transfer robot additional-axis.

TABLE II. WEIGHT OF MAIN FRAME USED FOR ANALYSIS

Rib-Thickness	8mm	16mm	24mm	56mm
Weight(kg)	12.52	17.29	21.64	39.00

Table III and Fig. 8 shows the structure analysis result according to change of main frame rib thickness. As shown in the analysis results, thicker the rib thickness[3], displacement at the ends of main frame decrease and maximum stress[4] also decrease, which is expected to have more stable structure. However, due to the characteristics of the hot stamping process, weight of the robot additional axis are important variables. In this study, the development was carried out by applying the rib thickness of 16 mm considering the weight, displacement and maximum stress of the additional axis.

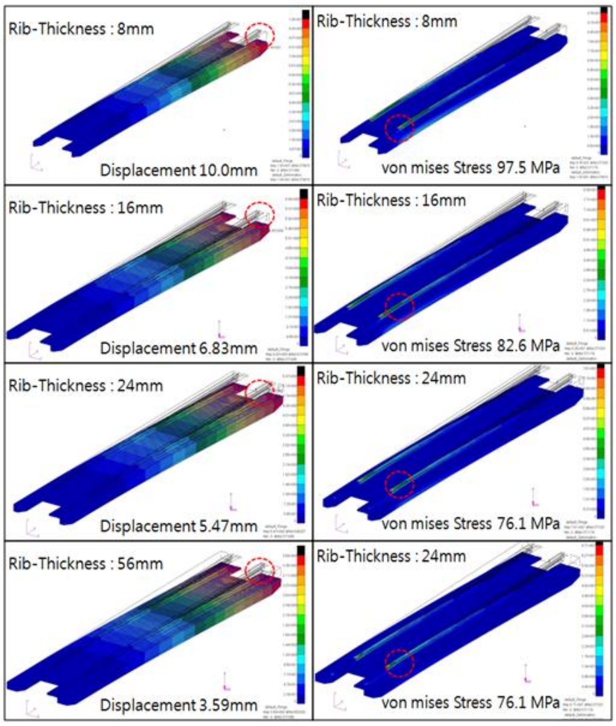

Figure 8. Result of structure analysis for rib-thickness change

TABLE III. MATERIAL VALUES USED IN THE ANALYSIS

Rib-Thickness (mm)	8	16	24	56
Displacement (mm)	10.0	6.83	5.47	3.59
Von-mises Stress (MPa)	97.5	82.6	76.1	67.1

IV. DYNAMICS ANALYSIS OF ROBOT ADDITIONAL AXIS

Since high transfer robot additional axis has long transfer distance and requires high speed, it is essential to verify the design of applied motor, reducer and pulley. Dynamics analysis is mainly used for this design verification[5]. Payload of currently developing model is 50kg, and the maximum travel distance is 700mm on both sides. Fig. 9 shows the dynamic analysis model of high transfer robot additional axis, and RecurDyn V8R1 is used as analysis software[6,7]. The high transfer robot additional axis is driven by the linear motion of the motor through the timing belt. At this time, the weight of the additional axis is 37.8 kg.

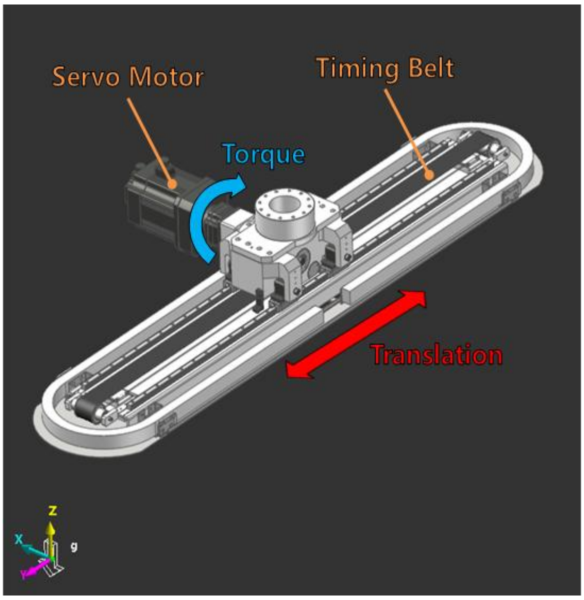

Figure 9. Dynamics analysis model of robot additional axis

A. Dynamics Analysis Criteria

As shown in Fig. 10, the rotation axis of the driving motor is defined as Revolute Joint. The LM block and the rail of the auxiliary plate are restrained by the Translate Joint, and the LM block and the rail of the plate are restrained by the Translate Joint. The dynamic friction coefficient of is set to 0.08 and static friction coefficient to 0.1. In addition, s-curve type motion profile was created through step function of motion input of translation joint constraint condition of additional axis. Assuming that additional axis is at the center, the total stroke of additional axis is about 1,400mm, which can transfer about 700mm to each side. Fig. 11 shows definition of motion profile command function which defines the feed position and direction of additional axis.

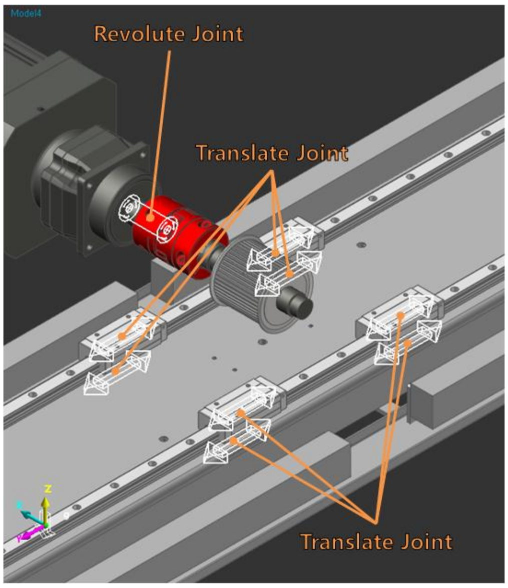

Figure 10. Boundary conditions for dynamic analysis

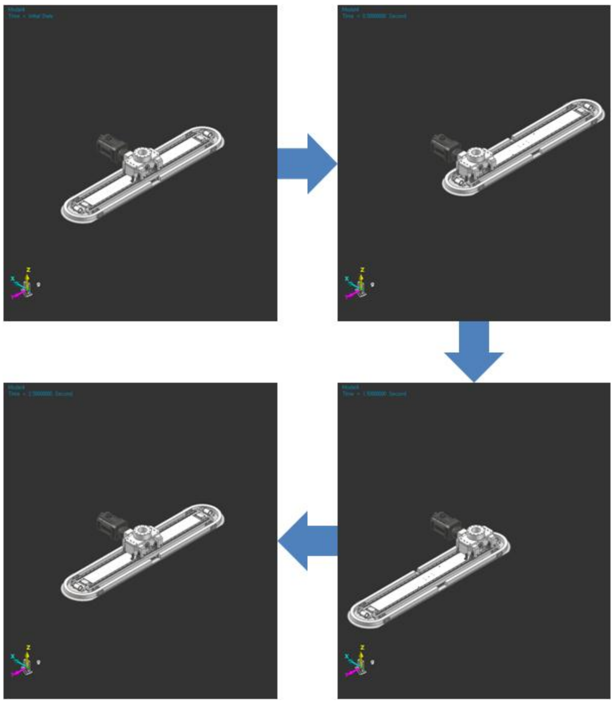

Figure 11. Definition of motion profile command function for dynamics analysis

B. *Results of Dynamics Analysis*

Fig. 12 shows motion profile analysis result of robot additional axis. As shown in Fig. 13, maximum speed at the end of robot additional axis at no load condition is 3 m/sec according to analysis result. Especially as shown in Fig. 14, driving thrust of additional axis required to achieve maximum speed is maximum of 611.7N and average of 205.8N according to analysis result. As a result of analyzing the types and specifications of motors to be applied to the development model of the robot additional axis, the average torque output from 5KW servo motor is 15.9 Nm and maximum torque is 47.7 Nm. Also, when the reduction gear ratio of 4: 1 is applied, it becomes 63.6 Nm and 190.8 Nm, respectively, which is higher than the thrust and torque required for the dynamic analysis. Since additional axis changes movement direction while moving at high speed, it is expected to cause high load to drive motor, and it will be advantageous to select the motor with high inertia product.

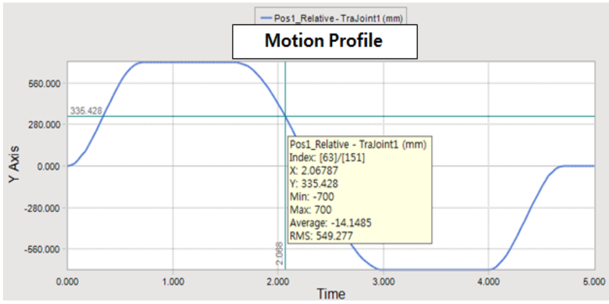

Figure 12. Result of Dynamics Analysis (Motion profile of robot additional axis)

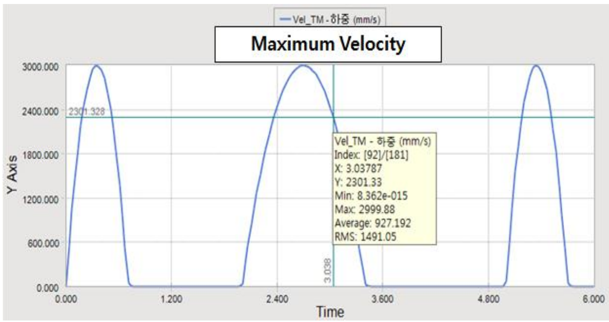

Figure 13. Result of Dynamics Analysis (Motion profile of robot additional axis)

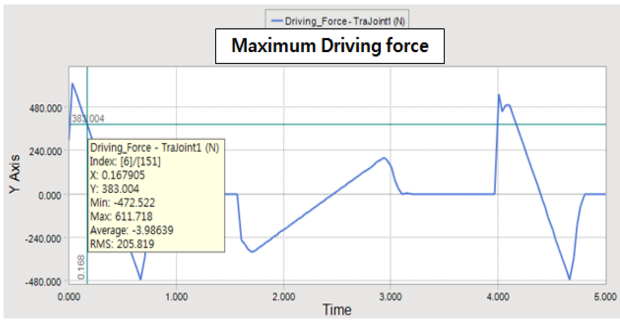

Figure 14. Result of Dynamics Analysis (Motion profile of robot additional axis)

V. Field Test of Robot Additional Axis

After design verification is completed, prototype of high transfer robot additional axis is constructed, and test devices are constructed to test major performances of high transfer robot additional axis, and configured test bed for performance evaluation as shown in Fig. 15. Major performance evaluation items are max. speed of additional axis, payload and repeatability. Performance evaluation is carried out using precision measurement laser tracker device (FARO ION, Accuracy：4 ㎛)[8].

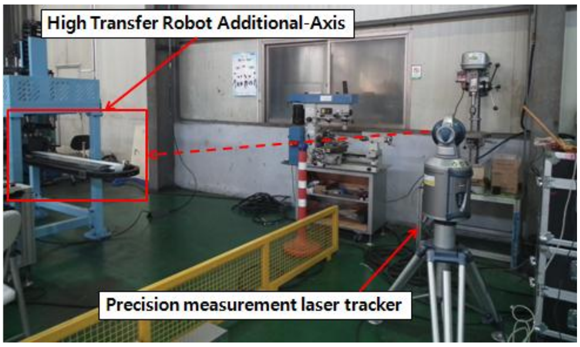

Figure 15. Test environment for robot additional axis performance evaluation

A. *Test of Maximum Speed(without load)*

SMR measurement sensor is attached to transfer area as shown in Fig. 16 to measure no-load max. speed of high transfer robot additional axis, and collected data using precision measurement laser tracker by operating additional axis in reciprocating motion for 10 times at max. speed.

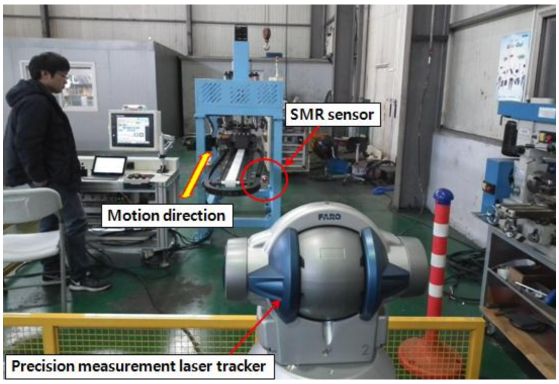

Figure 16. Max. Speed Measurement of Robot Additional Axis

Fig. 17 shows the measurement results of robot additional axis at its max. speed (no-load). Average max. speed for 10 times of measurement is 4.79 m/s.

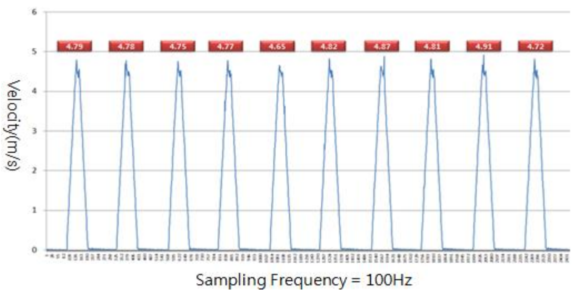

Figure 17. Result of maximum speed for robot additional axis

B. *Test of Payload for Robot Additional Axis*

In order to measure payloads of high transfer robot additional axis, 50 kg weight is loaded to the bottom of additional axis as shown in Fig. 17, and checked its transferability using precision measurement laser tracker. Fig. 18 shows the graph of robot additional axis test results for 50 kg weight payload. As shown in the figure, the result graph shows normal and uniform waveform when carrying out reciprocating motion with 50 kg load.

Figure 18. Payload measurement method for robot additional axis

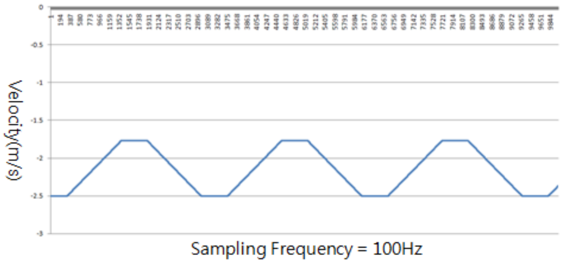

Figure 19. Result of payload test for robot additional axis

C. *Test of repeatability (without load)*

Repeatability of high transfer robot additional axis is measured using precision measurement laser tracker with 30 times of reciprocating movement for specified distance according to Korea Industrial Standard for Robot, KS B ISO 9238. Fig. 17 shows the raw measurement data of additional axis repeatability test (30 times), and its measurement result using distribution and standard deviation between reference and measurement point is found as ±0.061 mm[9].

No.	First point			Second point		
	X1	Y1	Z1	X2	Y2	Z2
1	-2,203.182	-1,990.104	-435.790	-2203.202	-1990.182	-435.787
2				-2203.209	-1990.148	-435.782
3				-2203.260	-1990.170	-435.776
4				-2203.288	-1990.110	-435.778
5				-2203.226	-1990.131	-435.781
6				-2203.263	-1990.154	-435.784
7				-2203.242	-1990.218	-435.779
8				-2203.263	-1990.185	-435.778
9				-2203.290	-1990.148	-435.768
10				-2203.218	-1990.180	-435.765
11				-2203.235	-1990.146	-435.768
12				-2203.183	-1990.123	-435.767
13				-2203.252	-1990.199	-435.770
14				-2203.267	-1990.122	-435.764
15				-2203.282	-1990.140	-435.739
16				-2203.242	-1990.128	-435.767
17				-2203.207	-1990.188	-435.772
18				-2203.297	-1990.115	-435.773
19				-2203.278	-1990.134	-435.750
20				-2203.266	-1990.205	-435.771
21				-2203.233	-1990.162	-435.771
22				-2203.232	-1990.151	-435.777
23				-2203.226	-1990.114	-435.772
24				-2203.202	-1990.180	-435.778
25				-2203.209	-1990.214	-435.785
26				-2203.201	-1990.128	-435.781
27				-2203.225	-1990.195	-435.785
28				-2203.229	-1990.212	-435.779
29				-2203.204	-1990.136	-435.778
30				-2203.236	-1990.219	-435.769

Figure 20. Result of repeatability for robot additional axis

VI. Conclusion

High transfer additional-axis of robot plays important role in processes that require shorter transfer times, such as hot stamping press process. In this study, to develop a robot additional-axis model which is smaller in size than existing high transfer robot additional-axis, and to equip same or better durability and main performance, dynamic analysis and structure analysis are carried out for main frame and key driving module's mechanical parts. In addition, design verification completed high transfer robot additional axis is constructed, and performance analysis is carried out for major specifications through field test and derive following conclusions.

- As a result of structure analysis, it is expected that main frame and cover of robot additional axis are structurally stable when the same material is applied as an integrated structure.
- According to analysis, displacement at the end of frame is minimized when main frame rib is thicker, and product feed repeatability using robot additional axis is expected higher. Even though structure stability can be secured when frame-rib thickness increases, interference condition between main frame of high transfer robot additional axis and the other equipment shall also be taken into consideration sufficiently when the robot loads and unloads the product in hot-stamping process.
- According to dynamics analysis results, 5 Kw class servo motor and reducer with 4:1 reduction ratio are expected to satisfy thrust and torque value required by analysis.
- According to the field test and performance test results for developed high transfer robot additional axis prototype, it shows that max. speed (no-load) is 4.79m/s, repeatability is ±0.061 mm, and payload satisfies max. 50 kg.

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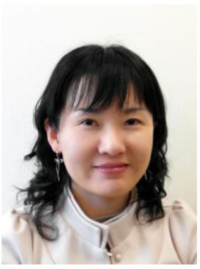

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