DEVELOPMENT OF LIGHTWEIGHT DUAL ARM ROBOT BY USING HOLLOW SHAFT SERVO ASSEMBLY

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Abstract: Studies on dual arm robots have been continually carried out because the robots provide human-like flexibility of movement. In previous study, the dual arm robot with solid shafts had been designed. However, the robot has some defects in its heavy weight and big shape. In this study, a hollow shaft servo assembly for lightweight robot arm has been developed. And then, the dual arm robot (AUTOMAN) has been designed using a hollow shaft servo assembly.

1 INTRODUCTION

Single arm industrial robots are applied in the process where the simple repetitive operation is much like the automotive industry and the semiconductor industry. There are many tasks that are difficult or impossible to do with the single arm robots. The dual arm robot is able to solve these problems (University of Texas at Austin, DLR, Yaskawa Co.). In the previous study, the dual arm robot with solid shafts had been developed as shown in Figure 1 (Park, 2008). The robot with solid shafts is easily implemented. However, as the degree of freedom of a robot rises, when implementing the complicated motion, some problems are appeared such as kink and abrasion of cables. As to the dual arm robot with hollow shafts, the inside of an arm and a motor shaft are empty. It is free from a constraint by the electrical wire in the implementation of complicated motion in comparison with the robot with solid shafts (Han, 2008). Also, the load to weight ratio of a robot is improved. Accordingly, basic researches on the hollow shaft servo assembly had been carried out in the previous studies (Han, 2008; Lee, 2008; Go. 2009).

The goal of this study is to develop a dual arm robot with the hollow shaft servo assembly. Firstly, the hollow shaft servo assembly for applying to the dual arm robot is developed. Secondly, the performance of the completed servo assembly is evaluated. Finally, the industrial hollow shaft articulated dual arm robot (called as AUTOMAN) tries to be developed.

Figure 1: Dual arm robot developed in previous study.

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2 HOLLOW SHAFT SERVO ASSEMBLY

In order to apply hollow shaft to industrial dual arm, the specifications of each axis have to be determined. The payload of the robot is set as 20kg. The specifications of the each hollow shaft servo assembly are determined by analyzing the maximum torque and the steady state torque under tracking trajectories at full reach within given time like Figure 2. The capacity, torque and maximum velocity of each axis are finally obtained by applying a safety factor to analyzing value as shown in Table 1 (Lee, 2008).

The assembly drawing of the hollow shaft servo assembly for the dual arm robot is shown in Figure 3. The key components comprising the servo assembly are the hollow shaft servo motor, the hollow shaft multi-turn absolute encoder, the hollow shaft brake, and, the hollow shaft harmonic drive. Table 2 shows the axis specification of the developed hollow shaft servo assembly.

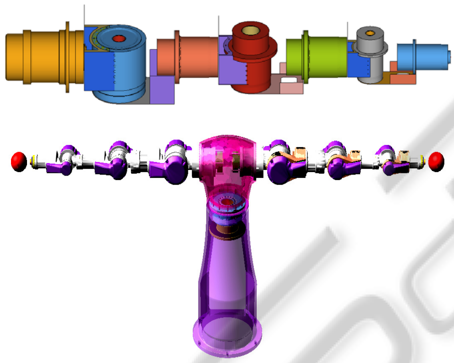

Figure 2: Dynamic critical conditions of dual arm robot.

Table 1: Specifications of servo motors.

Axis	Capacity	Torque	Velocity
1, 2	2.0 kW	6.8 Nm	3,000 RPM
3, 4	0.9 kW	2.9 Nm	3,000 RPM
5	0.6 kW	1.9 Nm	3,000 RPM
6, 7	0.4 kW	1.3 Nm	3,000 RPM

Table 2: Specifications of hollow shaft servo assembly.

Axis	Capacity [kW]	Torque [Nm]	Velocity [rpm]	Reduction gear ratio	Weight [kg]	Length [mm]
1	2.0	6.8	3,000	120	23.5	270
2				120	23.9	270
3	0.9	2.9		120	11.6	236
4				120	12.5	236
5	0.6	1.9		80	5.1	237
6	0.4	1.3		80	4.9	213
7				80	4.3	213

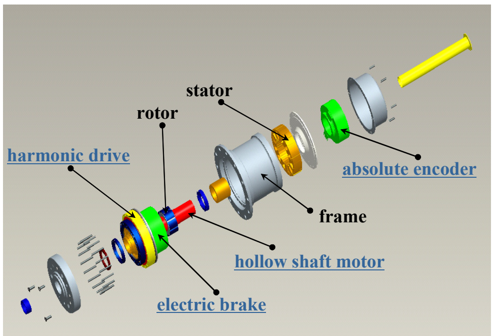

Figure 3: Hollow shaft servo assembly.

2.1 Hollow Shaft Servo Motor

As to the development of the hollow shaft servo motor, because all cables enter into the hollow shaft, the inner diameter of hollow shaft is as big as possible and it should not have a problem in an assembly between the hollow shaft encoder and the hollow shaft brake. Moreover, because the hollow shaft rotates, the protecting duct in which it protects the cable has to be installed and the axis of motor has to be designed by considering the connection with the axis of a reduction gear.

Accordingly, the hollow shaft servo motor was developed in consideration of the hollow size and the axis capacity of the motor. Figure 4 shows the developed hollow shaft servo motor. The cores of stator and rotor used the Si-steel S18 and S30 respectively. And the magnets of these used Nd-Fe-B and N-35SH.

Since being the servo system, sensors such as a resolver or a hollow shaft absolute encoder is essential. Accordingly, the hollow shaft absolute encoder is selected as shown in Table 3 (Tamagawa Seiki Co.).

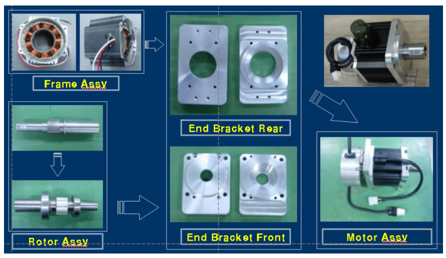

Figure 4: Hollow shaft servo motor.

Table 3: Specifications of applied encoder.

Axis	Resolution [bit]	Revolution [RPM]	Weight [kg]
1,2	33	1,500	2.1
3~7		3,000	1.2

2.2 Hollow Shaft Brake

The development of the hub shape type brake is needed, because the hollow shaft of the servo motor can be penetrated. The excitation functional type brake stops a rotator when a current is electrified in a coil. Therefore, this brake is suitable to the machine with horizontal motion. On the other hand, as to the electro-magnetic operable brake, when a current is electrified in a coil, the braking power loses and a rotator is free. This type brake is usually applied by the machines with vertical motion. In this research, since the vertical motion had to be possible in the small and narrow place, the hollow shaft brake of the non-excited operation type is developed by considering the required torque and dimension of each axis. Figure 5 shows the developed hollow shaft brake and the specifications are shown in Table 4.

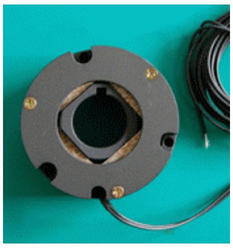

Figure 5: Hollow shaft brake.

Table 4: Specifications of developed hollow brake.

Axis	Frictional Torque [Nm]	Weight [kg]	Outer Dia. / Inner Dia. / Thickness
1,2	6.86	2.77	147 / 51 / 38.3
3,4	2.94	1.18	104 / 41 / 36/2
5,6,7	2.45	0.54	74.8 / 26 / 29/8

2.3 Hollow Shaft Harmonic Drive Unit

The reduction gear applied to the dual arm robot has to be fitted the hole size of the hollow. And not only the high-torque and but also the high precision are needed. The hollow shaft harmonic drive made by Harmonic Driver Systems in Japan is applied (Samick HDS). The motor shaft and the axis of reduction gear are connected as shown in Figure 6. The test results of eccentricity and torsion stress are satisfied the required specifications as shown in Table 5. The specifications of developed hollow shaft harmonic drive are presented by Table 6.

2.4 Performance Test of Hollow Shaft Servo Assembly

After making one side of the dual arm robot as Figure 7, the test of repeatability carried out. Table 7 shows the specifications of the developed hollow shaft robot arm. In the performance evaluation about the robot arm, the repetition precision about the location tracking was verified according to the KS 7082 standard (KS B 7082,) After from P1 to P5 designated the coordinate in which a robot has to follow according to the three-dimensional space-phase like Figure 8, the repetition tracking was performed by 30 time series. The laser tracker was used to measure the positions. Results of repeatability test are as shown in Figure 9. The average repeatability about each site is ± 0.05 mm within and it is satisfactory.

Figure 6: Hollow shaft harmonic drive.

Table 5: Performance test results of the unit.

	Spec.	Test 1	Test 2
Concentricity1	0.02 and less	0.0103	0.0122
Concentricity2		0.0047	0.0185
Diameter[mm]	50 + 0.015	50.0144	49.9985
Length[mm]	300 ± 0.3	300.0625	300.1394
Torque[Nm]	More than 4.7	274.5	246.37

Table 6: Specifications of the hollow harmonic drive.

Axis	Ratio	Torque [Nm]	Speed [RPM]	Weight [kg]	Outer/Inner [mm]
1,2	120	523	3,000	6.9	190 / 52
3,4	120	178	3,000	3.1	142 / 36
5,6,7	80	44	3,000	0.89	90 / 21

Table 7: Specifications of developed hollow Shaft robot arm.

	Weight	Length	Payload
Specification	94kg	1,574mm	20kg

Figure 7: Developed hollow-type robot arm.

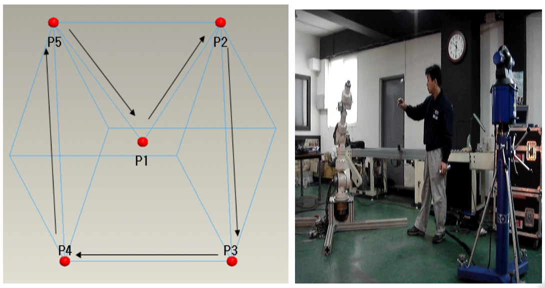

Figure 8: Reference trajectory.

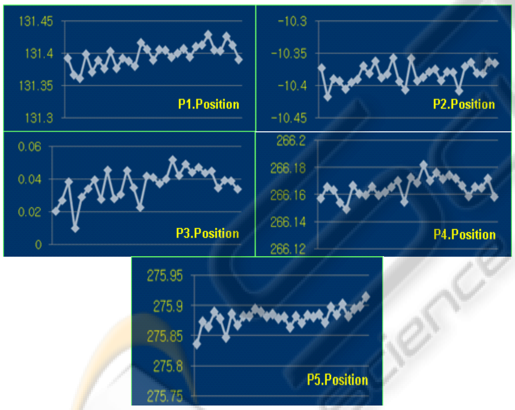

Figure 9: Results of repeatability test. [unit : mm].

3 DESIGN OF DUAL ARM ROBOT

In the previous research, the solid type dual arm robot like Figure 1 had been developed (Park, 2008). The dual arm robot developed in the previous research has the both arms of 6 degree of freedoms with the payload 20 kg, and the body (torso) of 2 degree of freedom. However, as to the developed dual arm robot, some problems have occurred such as the overweight compared with payload, the increase of the servo motor capacity due to a volume and weight enlargement, a kick and an abrasion of cables. In order to solve these problems, the hollow shaft servo assembly is developed. In the development of the robot, it tried to lighten through the stress analysis and optimal design. The servo control systems like servo drivers and controller are used by commercial controller.

3.1 Design and Fabrication of Robot

The dual arm robot makes to put an emphasis on the improvement of the weight and movement. Housing, frame, cover and the key element parts of robot are developed by considering the design specifications as shown in Figure 10. Especially, in the case of the housing, in order to satisfy the maximum allowable deflection 3 mm at full reach of the horizontal direction, the target rigidity is obtained by the CAE analysis (Lee, 2008). Figure 11 shows the dual arm robot (AUTOMAN) in which it makes in this research. It can show the reduction of weight and the improvement of design. AUTOMAN is composed of two arms and one twist joint. Each arm has 7 DOF. Therefore, AUTOMAN totally has 15 DOF. The robot can be designed so that cables can pass through the central part of a robot. The length of the arm is about 1,500 mm. Table 8 shows the specification comparison with the solid type dual arm robot.

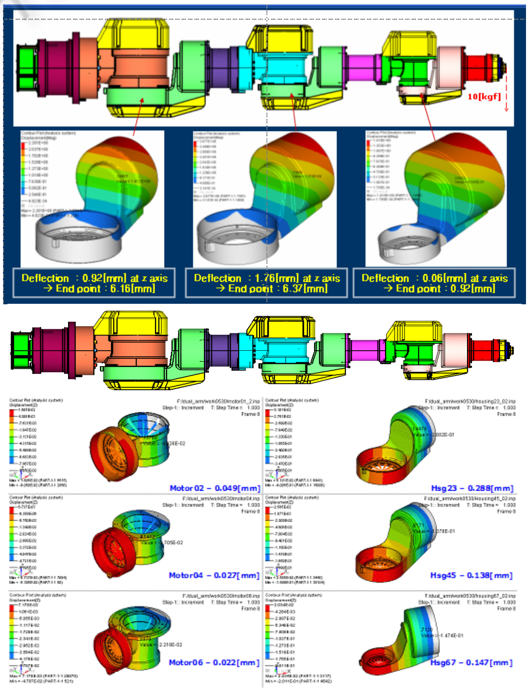

Figure 10: Design of motor frame and housing.

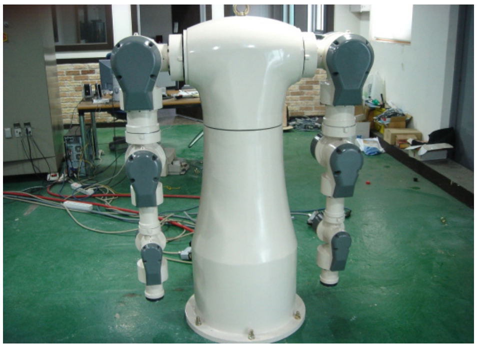

Figure 11: AUTOMAN.

Table 8: Specifications of developed dual arm robot.

Item	Solid type dual arm robot (Fig. 1)	AUTOMAN
Controlled axes	14(Right 6, left 6, rotate 2)	15(Right 7, left 7, rotate 1)
Payload	20 kg	20 kg
Mass	500 kg	300 kg
Repeatability	±0.7 mm	±0.1 mm
Maximum Speed	100 °/s	100 °/s

3.2 Development of Control System

The robot control system is designed for considering convenience of developing environment, powerful computing, real-time operation ability. Figure 12 shows the control system of the robot. The MEI ZMP controller (The Motion Engineering) and PMAC controller (DELTA TAU) were examined in order to select the controller in which it is suitable for the dual arm robot (MEL, DELTA TAU). It is altogether able to use with these controllers in case the moving track of a robot is predetermined.

Figure 12: Control system of AUTOMAN.

However PMAC controller has evaluated that it could not be guaranteed a real-time ability in case the moving track of a robot is determined in real time such as a visual servoing control and a force control. Accordingly, in order that the target platform of the control system was determined, the ZMP board (DELTA TAU), that is the commercial controller in which a performance is verified, was selected as the controller of the dual arm robot.

4 CONCLUSIONS

This research tried to be comprised the light weight of the dual arm robot by the hollow shaft servo assembly, and a miniaturization and highly-rigid in order to solve a problems reflected in the previous developed dual arm robot. The hollow shaft servo assembly is developed by designing and fabricating the hollow shaft servo motor, the hollow shaft brake, and so on. And the dual arm robot (AUTOMAN) for the flexible package operation is designed and made. The control system is made in consideration of a convenience and operation processing speed of the development environment. The performance of the arm is confirmed that the average repeatability is measured by ± 0.05 mm within and it is satisfactory. Moreover, by installing in the cable, kink and friction problems were solved. It is finally remarked that the comparison between the solid type robot and the developed hollow type robot will be undertaken as a second phase of this work.

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