Development of Heavy-Duty and High-Precision Hydraulic Manipulator for Inspection, Maintenance and Decommission of Nuclear Power Plants

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1. Introduction

Robotic manipulators have been used for inspection, maintenance and decommission of nuclear power plants because nuclear power plants have high radiation and human workers cannot easily access the plants. And also, to inspecting, maintaining and decommissioning nuclear power plants require various manipulators. However, several required tasks cannot work by using single manipulator. Only one manipulator cannot response to many required tasks. The existing manipulators that was used at nuclear power plants can only operate only focused specific task and cannot be used at several tasks. Therefore, several manipulators are necessary, depending on the payload capacity, their number of axes and their dexterity.

The actuators used at manipulators are varied and many companies sell actuators depending on power, torque and speed. However, the commercial product is not standardized. Therefore, the development of manipulator is time consuming and expensive. The essential item of a manipulator is an actuator module. If actuator module is standardized, it's easier to develop a manipulator and also maintain a manipulator.

Recently, manipulator having high-radiation, high-duty and high-precision is necessary to inspection, maintain and decommissioning of nuclear power plants. Hydraulic actuator has been used to development high-duty manipulator. But control performance of a hydraulic actuator is not better than that of an electric actuator so that hydraulic manipulator cannot easily satisfy the required precision.

In this paper, we developed high-duty and high-precision actuator modules and hydraulic manipulator using the developed actuator modules. The developed hydraulic manipulator have a payload of 250kg and a precision of ±1mm.

2. Design of Actuator Modules

An actuator module is important to design manipulator. Generally, the specification of an actuator module comes from the requirement of the manipulator. Most of the manipulators used at a nuclear power plant handle non-destructive inspection equipment having a weight of less than 30kg for inspection. However, to maintain and decommissioning a nuclear power plant, the weight of the tool that manipulator must handles is increasing by tasks. For example, for decommissioning, a manipulator must be utilized in the maintenance of a cutting system as well as a cutting operation. A payload of 250kg is necessary to handle the parts of the cutting system. Moreover, a precision of ±1mm is necessary to a cutting operation using water-jet and laser.

Most of the manipulators used at a nuclear power plants are working at the underwater because high-radiation or facility with high humidity. Therefore, manipulators should have water-proof. Thus, the actuator module that used at manipulator must be water-proof.

To develop and maintain a manipulator, actuator modules should be developed. If a manipulator is out of work, the whole of a manipulator is generally decomposed to repair the broken part of a manipulator. Therefore, to repair broken manipulator is time consuming. To improve the assembly property and maintainability, actuator modules should be developed.

Therefore, we developed hydraulic actuator modules to satisfy the requirement that the hydraulic manipulator using the developed actuator modules have a payload of 250kg and a precision of ±1mm.

2.1 Analysis of Hydraulic Manipulator

Based on the scenario for decommissioning the reactor pressure vessel of Gori-1 nuclear power plant [1], the hydraulic manipulator is designed to dismantle the components of reactor pressure vessel using water-jet, hydraulic cutter and etc.

The designed manipulator has 6 degree-of-freedom and R-P-R-R-R-R structure as shown in Fig.1.

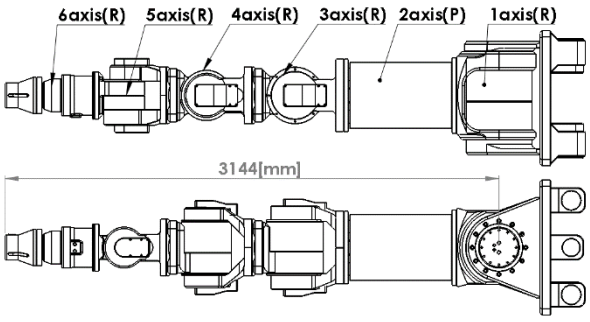

Fig. 1. The figure of designed hydraulic manipulator

To obtain the required torque/force of actuator module, the torque of the joints is simulated using a commercial dynamic analysis program [2]. When the hydraulic manipulator having the payload of 250kg is operated according to the shoulder joint's velocity of 0.125rpm and the wrist joint's velocity of 0.25rpm, the maximum torques and force of the joints are listed as in Table 1.

Table 1 : Maximum torque and force of joints

1 axis	2 axis	3 axis	4 axis	5 axis	6 axis
4,285 [Nm]	1,877 [N]	7,407 [Nm]	4,580 [Nm]	2,325 [Nm]	84 [Nm]

To obtain the control accuracy of actuator module, the control accuracy of end-effector of the hydraulic manipulator is calculated using the jacobian matrix of the manipulator and the accuracy of actuator module. If the minimum accuracy of actuator module have $\Delta\theta = \frac{360}{32768} = 0.01[deg]$, the maximum and minimum accuracy of end-effector of the manipulator is shown in Table 2, which shows that the accuracy of end-effector satisfies the requirement that the manipulator have a precision of $\pm$1mm. Therefore, the accuracy of actuator module should has a precision of ±0.01deg.

Table 2 : The accuracy of the end-effector

	Max	Min
X axis	0.7393mm	0.2297mm
Y axis	0.5906mm	0.0005mm
Z axis	0.5049mm	0.0002mm

2.2 Hydraulic actuator modules

From the analysis of the hydraulic manipulator, the requirements of actuator modules is defined as follows. The torques and force of actuator module should be satisfied as like as Table 1. The control performance of actuator modules should be controlled in the range of ±0.01deg.

We select the hydraulic actuator instead of electric actuator because the torques and force requirements. But hydraulic actuator that is satisfied the torques of Table1 cannot easily selected because the torques of Table 1 is extremely large so that the size of hydraulic actuator is increased. And also, it is very difficult to control hydraulic actuator in the range of ±0.01deg because the nonlinearity of hydraulic system. Therefore, we select harmonic reducer with 100:1 gear ratio to satisfy the requirements.

We design the hydraulic actuator modules as all-in-one type. The hydraulic actuator module has two rotation resolver sensors which one is on the input side of that modules (the input side of hydraulic actuator) and the other is on the output side of that modules. The sensor of input is used to control that modules and the sensor of output is used to sense the absolute rotation angle. To detect the joint limit, the limit sensor is installed on the inside of modules.

As the condition of required torques and force, four hydraulic actuator modules (three revolute modules and one prismatic modules) are designed respectively. Three revolute joint modules consist of large, medium and small revolute module. The large revolute module is designed to be attached to base frame. The medium revolute module is designed to be used as the shoulder joint of the manipulator. The last small revolute module is designed to be used as the wrist joint of the manipulator and to connect a gripper. The prismatic modules is designed for prismatic moving of the manipulator.

The draft of the large revolute module is shown in Fig. 2. As shown in Fig. 2, the hydraulic actuator module is designed as all-in-one type, which consists of hydraulic motor, reducer, two resolver and limit sensor.

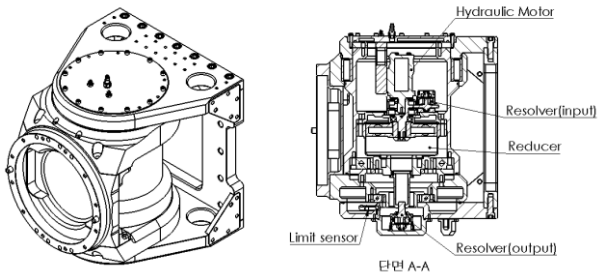

Fig. 2. The draft of designed hydraulic actuator module (large revolute module)

3. Hydraulic Manipulator

The developed hydraulic actuator modules allow us to easily develop the hydraulic manipulator because the developed module is modularized. Using the developed hydraulic actuator modules, we develop the hydraulic manipulator for dismantling nuclear power plants as shown in Fig. 3.

Fig. 3. The picture of the developed hydraulic manipulator using the developed hydraulic actuator modules for dismantling the reactor pressure vessel of nuclear power plants

4. Conclusions

Four modularized hydraulic actuator modules were developed for inspection, maintenance and decommission. Using the developed actuator modules, the manipulator for decommissioning is easily developed. And also, various manipulators having different kinematic structure for specific tasks will be easily developed by using hydraulic modules.

REFERENCES

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