DEVELOPMENT OF THE SPECIAL EQUIPMENT FOR UNDERWATER CUTTING OF HIGHLY ACTIVATED COMPONENT IN THE DECOMMISSIONING OF KRR-1&2

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ABSTRACT

Two Korean Research Reactors, KRR-1 (TRIGA Mark-II) and KRR-2 (TRIGA Mark-III), were shut down for their decommissioning in the end of 1995. The decontamination and decommissioning project of KRR-1&2 was started in January 1997 and will be completed in December 2008 when a national repository for the disposal of low and intermediate level waste will be expected to operate. The Rotary Specimen Racks (RSRs) were highly activated and then classified intermediate level radioactive waste for the decommissioning of KRR-1&2. To reduce the volume of intermediate level radioactive waste, underwater cutting is needed to separate stainless steel parts from RSR because of high radioactivity. A milling machine was designed and manufactured for underwater cutting of RSRs used in the KRR-1&2. The machine was designed to be operated in four directions of X, Y, Z axes and a rotation upon Z axis. A waterproof system was developed to cope with emergencies such as an electricity failure. Structural analyses were carried out to estimate stability and precision for a main frame and spindle using a FEM tool. The results showed that the developed machine has a sufficient stability and precision for cutting RSRs. Before the practical cutting is carried out, the cutting of the imitation of RSR was carried out to verify the reliability of a new machine and finally underwater cutting of RSRs will be achieved using the developed machine. The remote-control cutting test was carried out using submarine cameras.

INTRODUCTION

KRR-1, the first research reactor in Korea (TRIGA Mark-II), has operated since 1962, and KRR-2, the second one (TRIGA Mark-III), since 1972. The operation of both of them was phased out in 1995 due to reaching their life-time and operation of the new and more powerful research reactor, HANARO (High-flux Advanced Neutron Application Reactor) at the site of the Korea Atomic Energy Research Institute (KAERI) in Daejeon. Both are TRIGA pool type reactors in which the cores are small self-contained units sitting in tanks filled with cooling water. The KRR-1 is a TRIGA Mark II, which went through the first criticality in May of 1962 and could operate at a level of up to 250 kW. The second one, the KRR-2 is a TRIGA Mark III, which could operate at a level of up to 2,000 kW.[1]

The decommissioning project of these two research reactors was started in January 1997 and will be completed by 2008. The aim of the decommissioning activities is to decommission the KRR-1&2 and to decontaminate the residual building structures and the site to release them as unrestricted areas.

According to the schedule, the practical decommissioning activities were started in June 2001 by cleaning first the radioisotope production equipment and experimental laboratories in the KRR-2. Cleaning of more seriously contaminated areas such as the lead hot-cell and concrete hot-cell, then followed. The reactor of KRR-2 is being dismantled starting in 2003.

All the dismantled materials are classified in the three following categorises: 1) non-contaminated; 2) radioactive material lower than the free release level; and 3) material higher than free release level.[2] The non-contaminated wastes will be disposed of like industrial waste. The second type of waste will be temporarily stored on the site then disposed of after permission is received from the Minister of the Ministry of Science and Technology. The third type of waste, radioactive wastes, will be further volume reduced by decontamination by proper techniques such as washing, cutting, compacting etc., and put into 4m^3 containers for temporary storage on the site. These will then be transported to the national LILW repository when it is operational, probably in 2008.

Proper management of radioactive waste is of utmost importance for successful fulfillment of the project. Radioactive wastes arising from decommissioning work are very diverse not only in size (it is sometimes very difficult to reduce the volume), but also in radioactivity and physical type. Most solid wastes, except some parts of the reactor structure, have low-levels of radioactivity. It is anticipated that intermediate level waste will be comprised of the stainless steel parts of the three Rotary Specimen Racks (two for KRR-1 and one for KRR-2) and some other stainless steel components from the two reactor cores vicinity. However, the Rotary Specimen Racks (RSRs) can be classified as low level radioactive waste after removing the highly activated stainless steel parts. Due to size and radioactivity, the underwater cutting is required to remove these stainless steel parts from the RSR.

In this study, the underwater cutting equipment, used to cut the RSR in the water, was developed and testing was carried out. The stress and displacement of main frame and spindle were simulated by using a structural analysis tool and from the results it was concluded that the equipment would be stabile and accurate enough to cut the RSR. A waterproof system was developed to cope with emergencies such as an electricity failure and the remote controlling method was suggested. The waterproof and cutting tests were conducted and it was determined that the equipment can be safely disassemble stainless steel parts of RSR under water.

CHARACTERISTICS OF THE ROTARY SPECIMEN RACK

The RSR is composed of many components like an aluminum rack which is used to fix the specimen, a floating tank which is used to move vertically, bearings etc. The RSR is a ring type with outer diameter of 115 cm and a height of 46 cm.

The weight of a RSR is 118 kg including 3.4 kg of stainless steel and 114.6 kg of aluminum. The stainless steel parts are 2 dowel pins, 8 screws, 14 washers, 2 roll pins, 47 split lock washers, 23 hexagonal nuts, 40 assorted screws, 1 bearing, 1 chain and 1 drive gear.

For KRR-1 RSR, the total activity is 3.93×10^{10} Bq and the total activity of Co-60 in a KRR-1 RSR would be 2.38×10^{10} Bq giving a dose rate of 8.725 mSv/h at a distance of 1 m from the unshielded RSR. This calculation result shows that the KRR-1 RSR could be considered as low-level radioactive waste.

For KRR-2 RSR, the total activity is 1.28×10^{12} Bq and the specific activity of Co-60 in the stainless steel is 1.98×10^{8} Bq/g. So the KRR-2 RSR is estimated to have approximately 6.75×10^{11} Bq of Co-60 giving a dose rate of 248.2 mSv/h at a distance of 1 m from the unshielded RSR. The result of the calculation shows that the KRR-2 RSR could be considered as intermediate-level radioactive waste.

As a precaution, all of the stainless steel parts from the three RSRs will be treated as intermediate-level radioactive waste. Therefore the three RSRs should be disassembled under water to prevent any radiation exposure to the worker.

DESIGN AND STRUCTURAL ANALYSIS OF THE EQUIPMENT

Concept and Design Requirements

The equipment is a underwater cutting tool to remove stainless steel parts from the RSR using special cutter and end mill. The RSR will be fixed on turntable using clamping devices, and the turntable can be moved X and Y axial direction.

The design requirements of the underwater cutting equipment are as follows:

- because of space limit, the equipment must be as small and light as possible,
- since the disassemble work will be conducted in the water, the equipment must be remotely controlled, and must be waterproof and corrosion resistant,
- the equipment must be operated without any trouble or malfunction during underwater work,
- to prevent secondary contamination, the reliability of cutting tools and components must be verified.

Design of the Equipment

The equipment was designed for four-axes (X, Y, Z axis and a rotation upon Z axis) and was capable of three-axes (X, Y, Z axis) simultaneous-control. It was composed of a bed, five servo motors, linear motion guides, ball screws, a CNC (Computer Numerical Control) unit and a balance weight, which was equal to the weight of a spindle system.[3] Its material was chosen as stainless steel (SUS316L) to prevent rust and corrosion. Operating ranges of axes are X 900mm, Y 640mm, Z 1400mm and its table can be turned 360 degrees upon Z axis. The spindle system was designed to be rotatable and it enables the equipment to cut RSR in both vertical and horizontal directions. Figure 1 shows a drawing and photograph of the equipment.

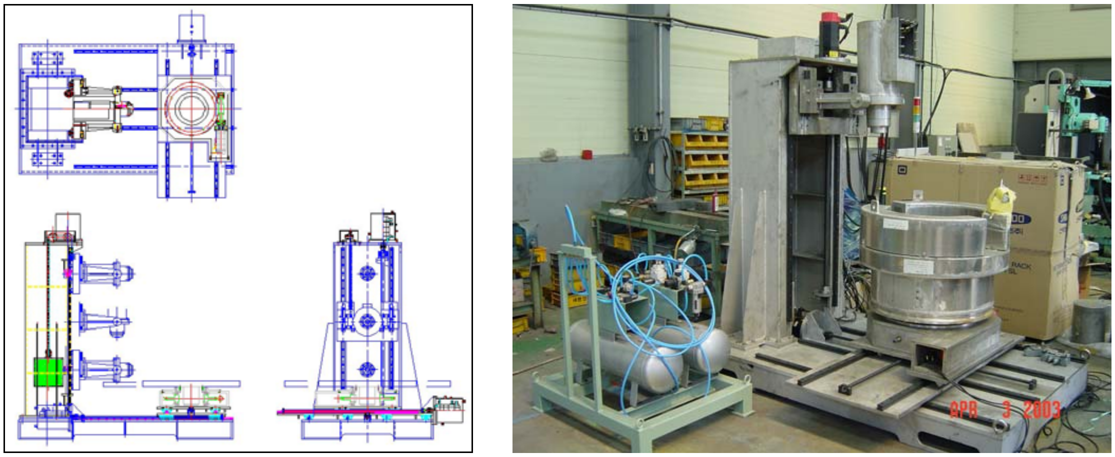

Fig. 1 Drawing and figure of the underwater cutting equipment

For stable and strong clamping of RSR, a special clamping device was designed. The device is composed of four clamping actuators, which are operated by the air pressure system, four clamping jaws and a guide plate. The function of clamping jaws is to transfer force of clamping actuators to a guide plate uniformly. A guide plate makes the force to clamp RSR and prevents the clamping parts of RSR to be deformed by the cutting force.

To protect servo motors under water, continuous compressed air, with a pressure higher than that of the surrounding water, will be supplied to servo motor cases and safe sealing devices are used. The developed equipment used mechanical sealing devices, which are dynamic sealing devices and have characteristics of no wear of motor axes, no generation of heat and long life. The system always supplies continuous compressed air (0.6bar) to servo motor cases. If supply of compressed air stops because of emergencies such as an electricity failure, compressed nitrogen gas will be supplied instead.

Structural Analysis

The structural analysis of the equipment was carried out for a main frame, a spindle system and a clamping device to verify strength and stability of equipment. For the main frame, when the force of 500N was loaded, maximum equivalent stress was 2.24MPa and maximum displacement was 0.02mm. The value of maximum equivalent stress was much less than the tensile yield strength of a main frame (207MPa) and thus it was verified that a main frame had a sufficient strength.

The structural analysis of a spindle system was conducted for two cases of horizontal and vertical cutting states when the force of 500N was loaded to three-directions (X, Y, Z). For horizontal cutting, the maximum equivalent stress was 5.73MPa and occurred at a tool insert part, hinge axes and frame connected parts. This value was much less than the tensile yield strength of a spindle system (207MPa) and thus it is thought that stable cutting is possible. The maximum displacement was 0.038mm and it satisfies requested accuracy for cutting RSR. For vertical cutting, the maximum equivalent stress was 7.14MPa and occurred at a tool insert part, hinge axes and frame end parts. Alike horizontal cutting state, this value was much less than 207MPa and thus stable cutting will be possible. The maximum displacement was 0.015mm and RSR will be cut enough accurately enough. Table I shows the results of structural analysis for a main spindle in horizontal and vertical cutting states.

Table I Results of structural analysis for main spindle in horizontal and vertical cutting states

Cutting State	Loading Direction (500N)	Maximum Equivalent Stress (Mpa)	Maximum Displacement (mm)	Displacement of Tool Insert Part (mm)
Horizontal Cutting	X	4.98	0.002	0.002
	Y	7.12	0.02	0.012
	Z	5.73	0.038	0.038
Vertical Cutting	X	6.43	0.034	0.013
	Y	7.14	0.015	0.015
	Z	5.54	0.02	0.011

To calculate a proper fixing force to stabilize the RSR at a turntable without causing displacement and fracture of RSR, structural analysis of RSR was carried out.[4] The pressure from the clamping jaws was 5.75MPa and the maximum displacement of RSR was 0.9mm when equivalent stress became same as the tensile yield strength of RSR (280MPa). Thus it is recommended that the maximum pressure of clamping jaws be 5.75MPa.

REMOTE CONROL METHOD

For automatic remote cutting processes, a CAM (Computer Aided Manufacturing) system is employed. A computer inputs NC (Numerical Control) codes to the controller, which are based on CAM model, and the controller indicates the equipment to process according to NC codes automatically.

The cutting equipment works under about 4m of water and thus it is difficult to visually observe the cutting process from the surface. When the cutting equipment is driven by hand, it causes instability of cutting speed and leads to tool breakage, vibration and a drop of cutting accuracy. Therefore a remote control method for underwater cutting was suggested. The main spindle and feed servo motors of the cutting equipment can be driven by a controller. A NC (Numerical Control) code is generated as input to the controller to allow remote control. NC codes have functions for controlling cutting speed, feed speed, tool paths etc. There are two methods to generate NC code. One is a method that measures a target's shape and generates NC codes by hand. The other is where NC codes are generated automatically using CAM program. In the case of RSR, the NC codes were generated automatically because there are many and various cutting processes. To generate NC codes automatically using computer, a CAM model of RSR is needed. CAM model means a model that includes tool shape, workpiece information etc. to CAD model. The generated NC codes are transmitted and inputted to a controller and checked to prevent collisions during movement. Lastly, the checked NC codes are transmitted to the cutting equipment and automatic cutting work is carried out. Fig. 2 shows the CAM system for underwater remote-control.

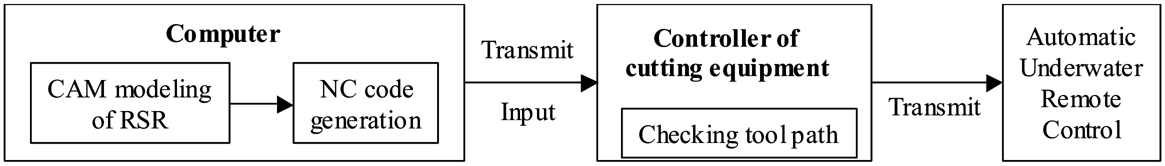

Fig. 2 Block diagram of the CAM system for underwater remote-control

Also two cameras will be put in waterproof cases and fixed at the developed equipment for monitoring of the cutting process.

TEST AND RESULTS

Before the practical cutting is carried out, the cutting of the imitation of RSR was carried out to verify the reliability of the developed equipment in the air and under water. And then finally underwater demolition of RSR will be achieved using the developed equipment. The waterproof and cutting tests were conducted to assess capability of the equipment.

The waterproof capability was assessed by investigating the time for a pressure drop in the motor case. The initial pressure was 3 bar and the time was measured until the pressure dropped to 0.4 bar.
The pressure drop time was more then 2 hours for the five motor cases. Therefore it was expected that the servo motors could be operated properly during under water cutting without water intrusion.

The cutting test was conducted for 2000, 2500 and 3000 rpm of rotating speed and for 100, 125 and 150 mm/min of feeding speed. The optimal cutting condition was selected through the measuring of cutting force.

The results of cutting force measurement are shown Fig. 3. As shown Fig. 3 cutting force increases with increasing feeding speed and with decreasing rotating speed. Actually the cutting can be made more stable by decreasing the cutting force. From the test results, the optimal cutting condition chosen was a 3000 rpm rotating speed and a 100 mm/min feeding speed. The imitation of RSR was successfully demolished using the selected cutting condition.

From the test results, it was concluded that the developed equipment could be used to remove stainless steel parts of RSR under water to protect radiation exposure of workers.

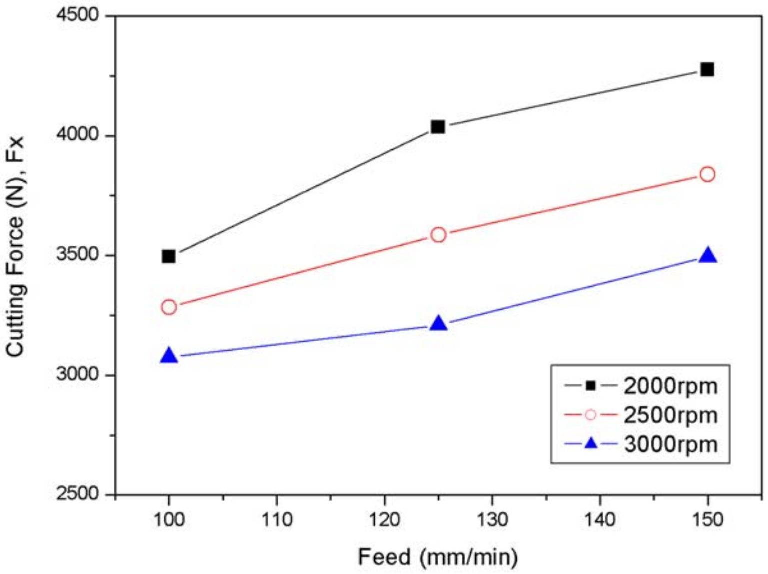

Fig. 3 The results of cutting force measurement

CONCLUSION

The four-axes cutting equipment was developed for underwater cutting of RSRs for the decommissioning of KRR-1&2. SUS316L was used as material of each axis and a turning system considering anti-rust nature and hardness and the mechanical sealing unit was mounted to each servo motor for smooth and safe drive in hydrospace. An exclusive-use clamping device was devised for stable setting of RSR. From structural analysis results of a main frame and a spindle system, it was verified that a equipment had a sufficient strength and stability. A waterproof system was developed to protect servo motors in underwater cutting. Remote-control cutting will be carried out using submarine cameras and a CAM system was employed for automatic cutting processes. The waterproof and cutting tests were conducted and the optimal cutting condition was selected for the purpose of stable cutting. It is concluded that the developed cutting equipment can be successfully used to decompose RSR under water.

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