The 5th International Symposium on Robotics in Construction June 6-8, 1988 Tokyo, Japan

"RESEARCH AND DEVELOPMENT OF ROBOT FOR REACTOR DISMANTLEMENT"

— Current Status and Perspective of Development of Robot through JPDR Decommissioning Program —

M. Ishikawa
Japan Atomic Energy Research Institute
Tôkai-mura, Ibaraki-ken, 319-11, Japan

ABSTRACT

Robot systems to be applied to the actual dismantlement of the Japan Power Demonstration Reactor (JPDR) have been developed* in the Japan Atomic Energy Research Institute (JAERI) since 1981 as a part of the technical development for reactor decommissioning. The development has been carried out through the steps of the fundamental and mock-up tests of the robots not only to meet the technical functions required to each cutter but also to match with the supporting equipments by taking the whole dismantling system into consideration. This paper describes the results of the multifaceted evaluation of the design philosophy of the dismantling robots. The dismantlement of the core internals of JPDR started in January, 1988, using the robot developed in JAERI. Various data on these robots will be obtained through their applications to JPDR, which are required to design a dismantling system for the future decommissioning of commercial nuclear power plants.

1. Introduction

There are 35 commercial nuclear power plants operating in Japan at the end of March, 1988. All of these reactors except one are light water reactors (LWRs) and it is scheduled that further commercial LWR plants will be continuously constructed by the middle of the next century. Since the operating period of a nuclear power plant is estimated to be 30 to 40 years, safe and economical decommissioning of those power plants is a matter of great importance to be successfully solved for future nuclear industry in Japan.

It is widely understood in Japan that a nuclear power plant shall be dismantled after its final shutdown to reuse the site for the next power plant. There are, however, few experiences in the world in dismantling a nuclear power plant completely. Consequently, it becomes necessary to demonstrate that a nuclear power plant can be dismantled in a safe and economical manner.

---

* This program is being performed by JAERI under contract from the Science and Technology Agency (STA) of Japan.

Since some structures of a nuclear power plant were irradiated by neutron and/or were contaminated with radioactive materials during reactor operation, these structures are very difficult of access by working personnel for dismantling in certain cases. Remote control devices to drive cutters for dismantling (i.e. dismantling robot) are, thus, needed to reduce radiation exposures to workers as low as reasonably achievable (ALARA).

Meanwhile, a lot of maintenance and inspection robots have been already developed and play an active part in the high radiation area of an operating nuclear power plant. However, since dismantling robots have to supply much larger mechanical energy than the maintenance and inspection robots, an innovated technique to cope with this requirement should be developed to realize the robot for automating the dismantlement. In addition, proper measures have to be taken into consideration to meet the following requirements when developing the dismantling robot.

- To minimize consequential waste such as by-products during the dismantling work and to collect them efficiently
- To decrease dismantlement costs (including personnel expenses) reasonably
- To optimize the development costs for dismantling systems economically from the viewpoint of cost-benefit analysis

These design requirements for the dismantling robots are conceptually shown in Fig.1, being arranged from the viewpoint of a level of automation. The figure suggests that there seems to be the most optimum point in the design of automation (i.e. robotization).

Robots for dismantling JPDR have been developed in JAERI since 1981 on the basis of the above-mentioned design requirements. In this paper, the robots developed in each dismantling technique are evaluated from various points of view, and moreover, the current status and the future perspective of the development of dismantling robots for nuclear power plants are described.

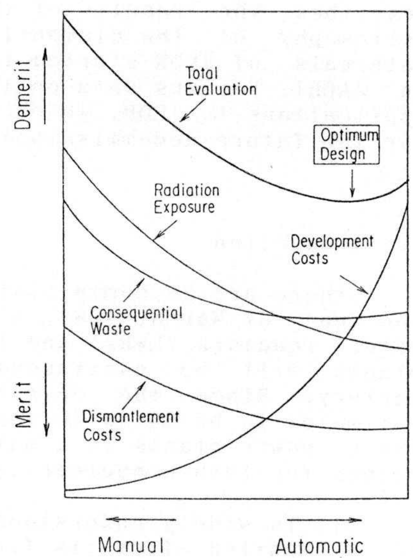

Fig.1 Variation of Design Requirements

2. Process of Dismantling System Development

2.1 Nuclear Structure

Main radioactive components of light water reactors are a reactor pressure vessel, core internals, a biological shield, a containment vessel, and piping connected to the reactor.

Figure 2 shows the reactor composition of JPDR (BWR, 90MWt, operation in 1963-76). The reactor vessel is made of low alloy steel of about 73mm in thickness, 2.1m in inside diameter, 8.2m in height, and is surrounded by biological shield concrete of 1.5 to 3m in thickness. Core internals made of stainless steel have various shape and size, and are either welded or bolted in the reactor vessel. Piping such as the recirculation pipe and the feedwater pipe are connected to the reactor vessel, penetrating biological shield. These components are rigidly constructed, to support fuel assembly even in serious seismic period. It is, therefore, absolutely necessary to develop special cutters to dismantle those components. In addition, those components are radioactive, more or less, after reactor operation of about 17,000 hours. The values shown in Fig.2 are radiation dose rates in JPDR at present. These values indicate that dismantling operations for the core internals and the reactor vessel have to be performed underwater using remote control devices to reduce radiation exposures to workers.

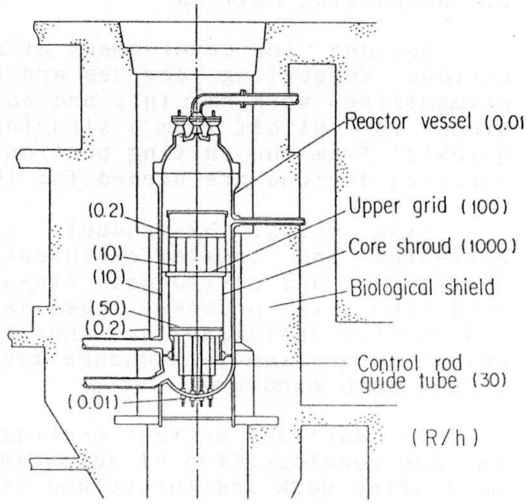

Fig.2 JPDR Reactor Composition

2.2 Cutters for Dismantlement

Actual dismantlement of reactor components is carried out by cutting them into pieces of suitable size in site to put into containers, before taking them out. Various cutters have been developed in JAERI as shown in Table 1 (indicated in the last leaf). They have been produced and tested so as to get the best cutting performance, taking into consideration material, shape and size of the object to be dismantled.

2.3 Design Conditions for Dismantling Robot

Dismantling robots are designed and fabricated depending on cutters and materials to be dismantled. When developing dismantling robots, a mechanism which is capable of supporting cutter, approaching to a cutting position and driving it for cutting, has to be developed as well as the cutter itself. The design conditions for dismantling robots are determined, taking into account the following items.

- The necessary rigidity against mechanical energy such as compressive and rotatory power when cutters are operated.
- Controllability such as velocity and accuracy for driving a cutter with pre-programmed action
- Utilities such as electric power, water, gas, abrasive, etc. to be supplied to a cutter
- Both geometrical restriction and radiation dose rate of cutting objects as well as working atmosphere such as in-air and in-water

2.4 Supporting Devices

Besides the development of a cutter and a robot for dismantling, various supporting devices are required to execute remote operated dismantling work smoothly and safely. For example, when one piece of block is cut off from a structure, it has to be removed safely and quickly from the cutting portion for the next cutting. Cutting block carrying devices are needed for this process.

Fine chips, by-products in dismantling operation, have to be collected and treated efficiently depending on their shape, state (solid/gas) and environment (in-air/in-water). Fine chip separators are used in this process. These devices work to prevent the spread of radioactive contamination, thus reducing worker's radiation exposures. Automatic and remote exchange devices of cutters may be needed also to reduce such exposures.

In addition, surface coating and sealing mechanism may be derived in due consideration of decontamination, so that the robot can be re-used after work and the volume of consequential waste can be reduced.

3. Practice of Dismantling Robot

3.1 Remote Control

Since the major reactor structures are cylindrical, the remote control mechanism with cylindrical coordinates enables easier access to such structures. In addition, a reactor is generally designed so as to be approached from the upper part of the core for fuel handling. A remote control mechanism for dismantling these structures, therefore, may be a mast-type or a wire-type moving mechanism, as shown in Figs.3 and 4, respectively. The moving mechanism equipped with a cutter is hung down into the core using either mast or wire. And the outriggers of the moving mechanism are stretched against the inner surface of cylindrical structure —reactor vessel, biological shield concrete— to fix it at the designated position and angle, so that the cutter can easily obtain access to the cutting portion. In the following sections, six types of robots developed in JAERI will be described.

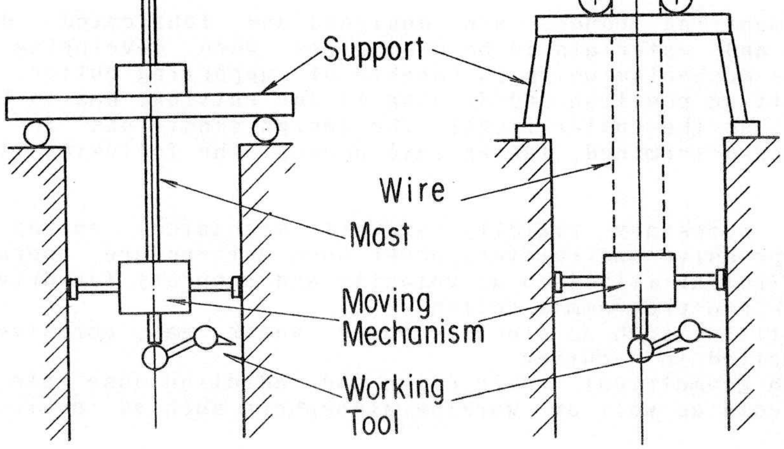

Fig.3 Mast-type Moving Mechanism   Fig.4 Wire-type Moving Mechanism

3.2 Mechanical Power Supply

Mechanical power and its reaction supplied by and to the robot are considerably large, because reactor components consist of rigid steel/concrete structures. The robots supplying large mechanical power have been developed in JAERI, such as the abrasive water jet cutting robot, the diamond sawing and coring robot and the underwater arc saw cutting robot, as shown in Figs. 5, 6 and 7, respectively.

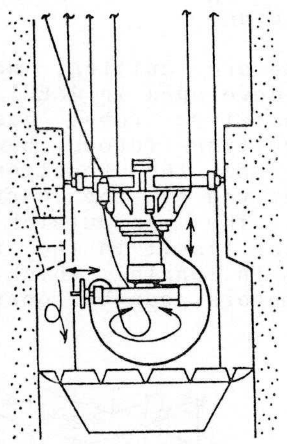

Fig.5 Abrasive Water Jet Cutting Robot

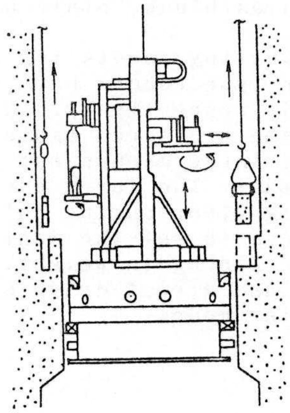

Fig.6 Diamond Sawing & Coring Cutting Robot

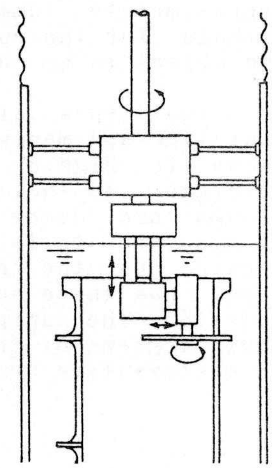

Fig.7 Arc Saw Cutting Robot

The abrasive water jet cutting robot can cut biological shield concrete into blocks while operating high pressure (2000kg/cm^2) water jet skillfully regardless of the jet reaction of about 100kg. The slurry fluid including abrasive is caught at a funnel form installed below the cutting portion, thus transferring to a slurry separator. Separated blocks can be collected by falling down into a bucket hung from the upper part.

The diamond sawing and coring robot can also cut biological shield concrete into blocks by driving a diamond-tipped disk of 1.1m in diameter into the concrete while rotating it at 800rpm. The cutting portion is sprayed with water in order to prevent the spread of fine concrete chips. Separated blocks can be removed by carrying them up with a handling device.

The underwater arc saw cutting robot can cut a reactor vessel into blocks of rectangular shapes by arcing between the vessel and a 460rpm blade saw. The arc cutting is performed underwater to restrict generated by-products (such as dross and fine particles) in water. The moving mechanism is so rigidly designed that it can drive the blade stably regardless of the irregular force by the intermittent arc. The blocks separated from the vessel are treated in the same manner as the diamond sawing and coring robot.

3.3 Position Control

The dismantling robots are designed to cut the object into blocks and take them out from the site as previously stated so that they can be handled to put into containers easily. Though the precise separation of a block from the structure is not a matter of consideration, the accurate moving of the cutter is required for cutting complicated structure. In the underwater plasma arc cutting robot for core internals, for instance, plasma arc has to be driven so that the distance between the object and plasma arc torch can be kept approximately 10mm so as to make the arc stable. Various positioning methods for the cutting torch are prepared depending on the shape of the object to be cut such as block, plate and piping.

Two types of dismantling robots for plasma arc cutting, namely mast-type and manipulator-type robots have been developed in JAERI, as shown in Figs.8 and 9, respectively. The mast-type robot has no outrigger to hold plasma arc torch against cutting force, because plasma arc doesn't need large mechanical power and the reaction of plasma arc is fairly small. The torch can be driven by the carriage located on the refueling floor during cutting. The manipulator-type robot has three outriggers to set the manipulator itself in the right position. The manipulator (250kg in weight, 1.8m in length), which has seven degrees of freedom and direct-drive servomotors, can be operated in master-slave or computer modes.

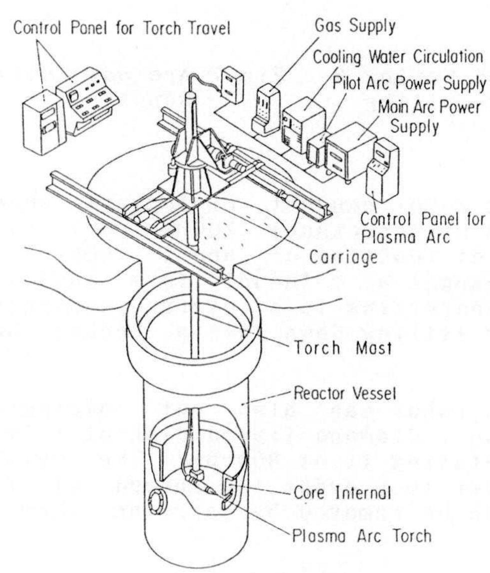

Fig.8 Mast-type Plasma Arc Cutting Robot

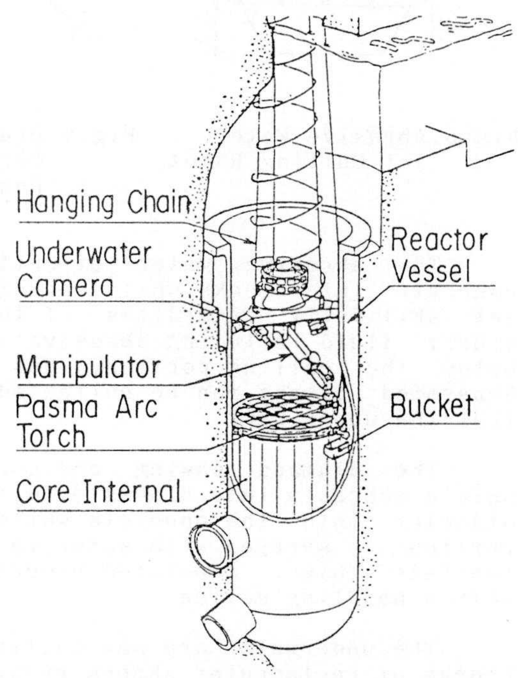

Fig.9 Manipulator-type Plasma Arc Cutting Robot

3.4 Velocity Control

On the other hand, cutting velocity of dismantling robot is governed by the performance of each cutter. In general, the velocity of the cutter during dismantlement is relatively slow, within the range of 1 to 5mm/s, and the velocity control is not very severe regarding dismantling robot. Moreover, what is very important, the dismantling work using robot is quite time-consuming, because the work is accompanied by complex procedure. The procedure of dismantling work by manipulator-type robot is typically shown in Fig.10. The figure indicates the the actual cutting time is slight as compared with the period for dismantling, which is a part of whole schedule. The cutting velocity itself is, therefore, almost negligible from the point of view of the whole schedule of decommissioning.

PREPARATION		ASSEMBLY		ADJUSTMENT		DISMANTLING		RESTORATION
54 days	===>	10 days	===>	18 days	===>	23 days	===>	11 days
						Total cutting time: 32 min.		

Fig.10 Procedure of Dismantling Work by Manipulator-type Robot (Sept. 1987 through Mar. 1988)

3.5 Confined Working Area

The space around the cutter is almost always limited and is also far apart from the control booth. A series of cutting/dismantling works ought to be executed in the limited space without trouble. Personnel access is not allowed at all even in case of trouble. The remote pipe cutting system using shaped explosives, for instance of the robot for confined area, has been developed in JAERI. In the system, a small sized vehicle, called "mouse-robot", can be driven inside a pipe to carry and put shaped explosives in a designated and remote position as shown in Fig.11. Since visual observation inside a pipe cannot be allowed in the automotive system, the reliability of the system is thoroughly required regarding the automotive control and the installation of explosives.

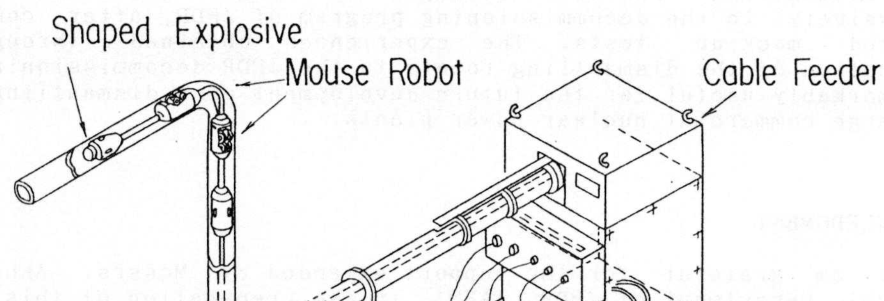

Fig.11 Moving Mechanism for Shaped Explosive (Mouse Robot)

4. Actual Dismantlement with Manipulator Robot

The dismantlement of core internals of JPDR using manipulator type robot (already shown in Fig.9) was successfully performed in early 1988 as the first step of the dismantlement of highly radioactive components of JPDR. In the cutting sequence, firstly, the manipulator equipped with plasma arc torch was operated in master-slave mode to determine the cutting path, while an operator was watching the torch through four sets of underwater cameras. After that, the torch was driven automatically according to the preprogrammed action. Then three species of core internals could be successfully cut underwater with arc current up to 500A. The separated pieces were collected by cutting down into a bucket hung from the upper part or by carrying up with a handling device. The period of 116 days was required for the whole work, as shown in Fig.10.

5. Future Perspective of Dismantling Robot

Most of the elemental techniques used in the dismantling robots developed in JAERI are such conventional ones as had been improved or scaled up.

It would be the future direction of the development of a dismantling robot that the reliability of the whole system of the robot developed so far has to be increased in a balanced manner, though there seems to be no need to develop innovative cutting techniques and moving mechanism newly in most cases.

In addition, when optimizing the level of automation in a dismantling system, It might be important that dismantling work has to be properly shared between manual and automated operations. For this purpose, cost-benefit analysis of the improvement of the robot is indispensable to make the system more efficient. Moreover, the dismantling robot which enables a few cutters to be operated by turns would be required to reduce dismantling costs in the future.

6. Conclusion

Dismantling robots developed in JAERI will be applied successively in the decommissioning program of JPDR, after completing required mock-up tests. The experiences obtained through the application of the dismantling robots to the JPDR decommissioning must be remarkably useful for the future development of a dismantling robot for large commercial nuclear power plants.

ACKNOWLEDGMENT

I am grateful for the support extended by Messrs. Ashida and Toraishi, Department of JPDR, JAERI, in the preparation of this paper.

Table 1 Cutters Developed in JAERI

Cutting Method	Content of Cut	Developed Cutter	Material to be cut
Mechanical cutting	shave off or press off with mechanical power	Abrasive water jet cutting	Concrete
		Diamond sawing & coring	Concrete
		Rotary Disk knife cutting (not described in this paper)	Piping
Thermal cutting	melt and exclude with heat of arc	Plasma arc cutting	Core Internal
		Arc saw cutting	Reactor Vessel
Explosive cutting	demolish with explosion of powder	Shaped explosive	Piping
		Controlled blasting (not described in this paper)	Concrete