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**Abstract**

In ITER, the in-vessel components such as blanket are to be maintained or replaced remotely since they will be activated by 14 MeV neutrons, and a complete exchange of shielding blanket with breeding blanket is foreseen after the Basic Performance Phase. The blanket is segmented into about seven hundred modules to facilitate remote maintainability and allow individual module replacement. For this, the remote handing equipment for blanket maintenance is required to handle a module with a dead weight of about 4 tonne within a positioning accuracy of a few mm under intense gamma radiation. According to the ITER R&D program, a rail-mounted vehicle manipulator system was developed and the basic feasibility of this system was verified through prototype testing. Following this, development of full-scale remote handling equipment has been conducted as one of the ITER Seven R&D Projects aiming at a remote handling demonstration of the ITER blanket. As a result, the Blanket Test Platform (BTP) composed of the full-scale remote handling equipment has been completed and the first integrated performance test in March 1998 has shown that the fabricate remote handling equipment satisfies the main requirements of ITER blanket maintenance.

## 1. INTRODUCTION

Remote maintenance is an essential technology of the International Thermonuclear Experimental Reactor (ITER) since in-vessel components such as blanket are scheduled to be replaced remotely. A blanket structure made up of modules, which are installed individually in the vacuum vessel and whose total number is about seven hundred, has been adopted in the ITER design to facilitate remote maintainability. This requires reliable remote operations to install a blanket module wish a dead weight of about 4 tonne within a few mm positioning accuracy in the restricted vacuum vessel space. A new concept of rail-mounted vehicle manipulator system [1] has been developed for maintenance and replacement of blanket modules, as shown in Fig.1. This system consists of vehicle manipulators working on a rail transporter formed into a toroidal ring structure in the in-vessel region and supported at every 90-degree port, resulting in stable handling of heavy components and quick maintenance with parallel operation of manipulators. The rail and manipulator, which are initially stored in the maintenance cells located at the 0-degree and 180-degree ports, are deployed into the in-vessel region for maintenance operation. A module receiver is installed in the 90-degree and 270-degree ports so as to receive a module removed by the vehicle manipulator and to transport it to a transfer cask which is docked to the port for delivery to the hotcell building for repair. A new module or repaired module is also supplied to the vehicle manipulator for installation using the transfer cask and receiver in the reverse sequence. As a development step, prototypes of vehicle manipulator[2]and rail transporter [3] were fabricated and tested so as to assess the basic feasibility of this concept and to define the detailed specifications for fabrication of the full-scale remote handling equipment. Following the prototype tests, development of the full-scale remote handling equipment has been conducted as one of the ITER Seven Large R&D Projects by the joint efforts of the Japan and EU Home Teams in a close collaboration with the ITER Joint Central Team.

This includes development of the associated equipment/tools such as welding, cutting and inspection tools for blanket cooling pipes, shield plug handling equipment, transfer cask with double-seal door, as well as the vehicle manipulator system. In this Project, the maintainability

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of the blanket module is tested in the Blanket Test Platform (BTP) which is installed in the Japan Atomic Energy Research Institute (JAERI). This paper describes the major results obtained in the first integrated performance test of the full-scale vehicle manipulator system in the BTP.

## 2. BLANKET TEST PLATFORM

The BTP for the verification of blanket replacement was installed in the experimental building at JAERI by the end of February 1998. Figures 2 and 3 show the overall layout of the BTP with the deployed rail and the vehicle manipulator handling a dummy blanket module for replacement, respectively. The BTP reproduces the physical environment of the 180-degree, in-vessel region, including maintenance ports at 0, 90 and 180 degrees. In addition, two dummy blanket modules weighing about 3 and 4 tonne are installed on the mockup structure which is located between 0 and 90-degree ports. The full-scale remote handling equipment, which has also been installed in the BTP, are composed of a vehicle manipulator with 13 degrees of freedom, multi-joint rail for deploying into the 180-degree in-vessel region, rail deployment and storage device at the 0-degree port, rail support and module receiver at the 90-degree port, rail to rail docking device at the 180-degree port, and measurement and control systems.

## 3. INTERGRATED PERFORMANCE TEST

After the component tests in the factory, the first integrated performance test was carried out at the end of March 1998 so as to verify the feasibility of remote handling equipment under manual and/or semi-automatic modes from the control room. The performance test includes the main operations such as rail deployment, module replacement and module transfer by the receiver.

### 3.1 Loading test of vehicle manipulator

In order to verify structural integrity and measure the mechanical characteristics of the manipulator including all mechanisms such as traveling, telescoping and rotation, the loading test was performed prior to the module handling demonstration. In this test, the loads are applied in the radial, toroidal or vertical direction to the manipulator axis or to the gripping axis, and the displacements of various positions of the manipulator were measured as a function of the applied loads. In the vertical direction, the measured average stiffness is about 1.2 tonne/mm due to flexibility of the rotating mechanism while the stiffness of the manipulator arms and telescoping mechanism is over 10 tonne/mm which roughly meets the design value. The radial and toroidal stiffness measured is about 0.08 tonne/mm which is also dominated by the rotating mechanism since the stiffness of manipulator arms and traveling mechanism is

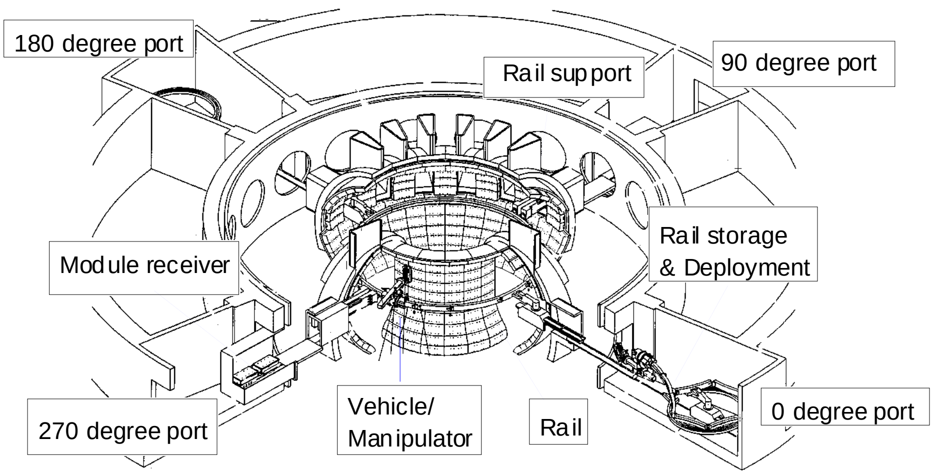


*FIG.1 Rail-mounted vehicle manipulator system for blanket remote maintenance*

over 3 tonne/mm equivalent to the design value. The measured backlash in the vertical, radial and toroidal directions is 2 mm, 8 mm and 3 mm, respectively. These values can be represented from clearances and backlashes of the gear mechanisms. As a whole, it has been verified that the fabricated manipulator and end-effector satisfy the module handling capability and the mechanical characteristics including nonlinear behavior of the mechanisms are quantitatively evaluated under the design loads.

### 3.2 Rail deployment/storage test

During plasma operation, the rail with vehicle manipulator is wound and stored in the maintenance cell for minimizing the storage space. The rail is a 8-linked structure to allow deployment through a narrow maintenance port and form a toroidal ring structure in the 180-degree in-vessel region. During the maintenance operation, the deployed rail has to support all of the loads so that the high reliability and mechanical stiffness are inevitably required for handling heavy blanket module. Therefore, it is essential for the vehicle manipulator system to verify the feasibility of rail deployment and storage operations by fully automatic control. In the first performance test, the rail deployment and storage operation were carried out by manual and semi-automatic means to verify the mechanical feasibility of the integrated equipment and to obtain the optimum control parameters, such as positions and speeds of the respective mechanisms. These operations are based on a sequential control so as to synchronize the toroidal movement by the vehicle traveling mechanism and the radial movement by the rail deployment device [1]. As a result, the rail has been successfully deployed and stored by the sequential control which basically involves 12 steps based on the teaching-playback control along with the teaching points of 636 and 587,respectively. The operation time for rail deployment and storage was about four days each, including measurement, adjustment and teaching operation. To reduce the operation time below one day as the target, optimizing the procedures and teaching points is being carried out. In this test, rail deflections during the deployment were also measured at the 90 and 180-degree ports. The result assures the structural integrity of the rail since the maximum deflection measured was below the design value of 100 mm, except for the vertical deflection of 260 mm at the 90 degree port: this is due to mainly the backlash of the swing arm which is a cantilevered structure to fix the vehicle manipulator and rail at the 0-degree port. It has also been verified that the guide and docking mechanisms at the 90 and 180-degree ports can correct the deflected rail to the correct position and fix the rail as the toroidal ring structure.

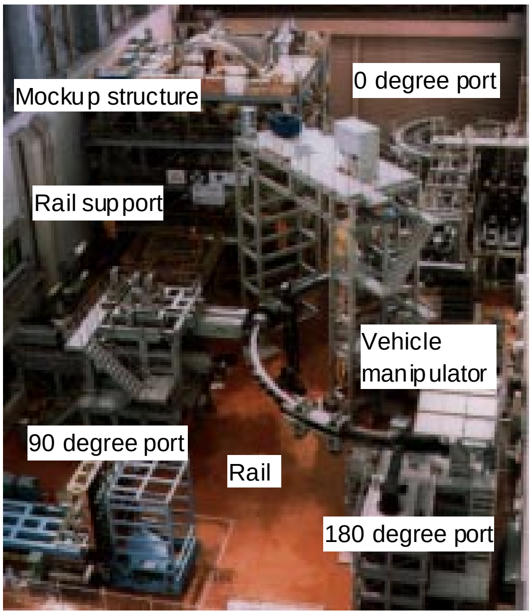


*FIG.2 Blanket test platform*

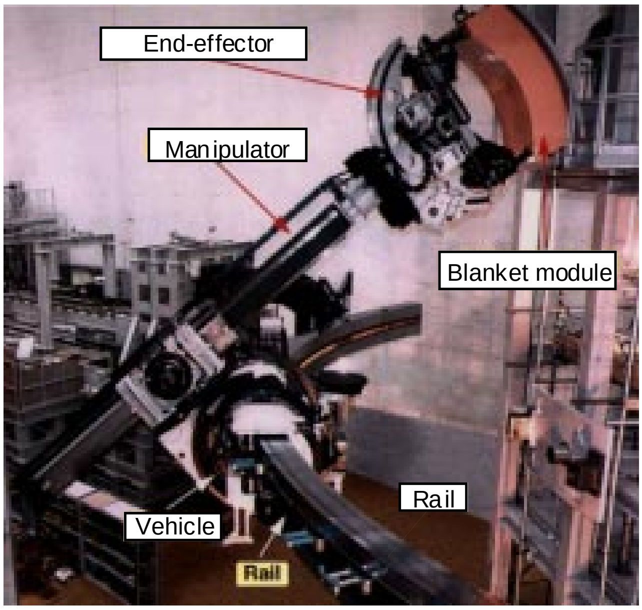


*FIG.3 Module replacement by manipulator*

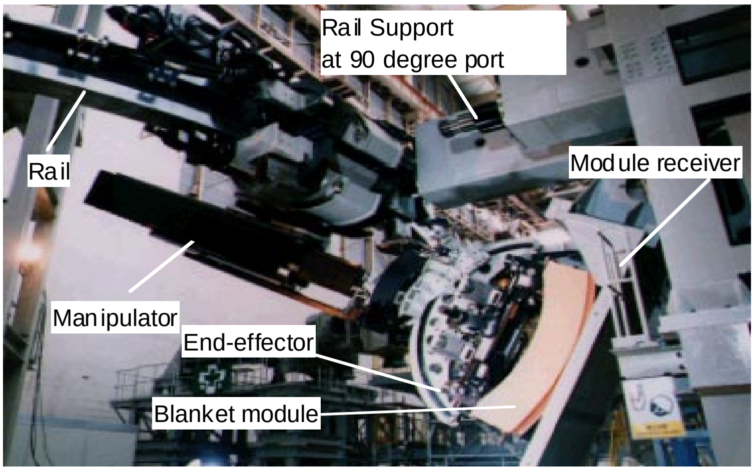


*FIG.4 Module transfer from manipulator to receiver*

### 3.3 Module replacement and transfer test

After deployment of the rail, the module replacement and transfer test was carried out using the dummy modules in the BTP. Figures 3 and 4 represent typical operations of the vehicle manipulator handling the dummy module for replacement and transferring it to the receiver at the 90-degree port, respectively. These operations were successfully performed under manual and semi-automatic means based on the teaching-playback control in the same way as the rail deployment and storage test. In this test, the positioning error and deflection of the manipulator were measured during the replacement and transfer operations. The measured positioning accuracy was about 1 mm as repeatability: this satisfies the ITER requirement of 2 mm accuracy for module installation. The maximum deflection of about 60 mm was observed when the module deadweight was suddenly transferred and loaded to the manipulator for module removal. However, this dynamic deflection was successfully solved and became almost zero by applying the modified control scheme, in which the module deadweight was gradually loaded to the manipulator while gripping before removal. As a whole, the basic operations required for module replacement have been fully demonstrated although optimizing the procedures and control method is needed.

## 4.CONCLUSION

The full-scale remote handling equipment for blanket maintenance was fabricated and assembled into the BTP for demonstration of the ITER blanket replacement. Through the performance tests of the fabricated equipment, feasibility for handling 4-tonne blanket module was fully verified, together with the quantitative assessment on mechanical characteristics under the design loads. In addition, the integrated performance test demonstrated the critical operations of rail deployment/storage, module replacement and transfer, so that the vehicle manipulator system satisfies the maintenance scenario for the ITER blanket. Based on these results, it is concluded that the fundamental technology for blanket maintenance has been well established and further extended performance tests, including optimization, rescue, and radiation hardness, are required for practical use under normal and abnormal conditions.

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