CONF-871195--3

EX-VESSEL REMOTE MAINTENANCE FOR THE COMPACT IGNITION TOKAMAK*

CONF-8711195--3

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P. T. Spampinato
Fusion Engineering Design Center/Grumman Corporation
P. O. Box Y
Oak Ridge, TN 37831

D. Macdonald
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37831

Abstract

The use of deuterium-tritium (D-T) fuel for operation of the Compact Ignition Tokamak (CIT) requires the use of remote handling technology to carry out maintenance operations on the machine. These operations consist in removing and repairing such components as diagnostic modules by using remotely operated maintenance equipment. The major equipment being developed for maintenance external to the plasma chamber includes a bridge-mounted manipulator system for test cell operations, decontamination (decon) equipment, hot cell equipment, and solid-radiation-waste-handling equipment. Wherever possible, the project will use commercially available equipment. Several areas of the maintenance system design were addressed in fiscal year (FY) 1987, including conceptual designs of manipulator systems, the start of a remote equipment research and development (R&D) program, and definition of the hot cell, decon, and equipment repair facility requirements. R&D work included preliminary demonstrations of remote handling operations on full-size, partial mock-ups of the CIT machine at the Oak Ridge National Laboratory (ORNL) Remote Operations and Maintenance Development (ROMD) Facility.

Introduction

The CIT, located at the Princeton Plasma Physics Laboratory, will be the next experimental machine in the U.S. Fusion Program. Its use of D-T fuel requires the implementation of remote handling technology for maintenance and disassembly operations. The machine will be surrounded by a close-in nuclear shield designed to permit personnel access into the test cell 24 h after shutdown. With the shield in place, certain maintenance activities in the cell may be hands-on operations. Maintenance on the tokamak will be accomplished remotely with a boom-mounted manipulator system after shield modules are disassembled. Maintenance within the plasma chamber will be accomplished with two articulated-boom manipulators operating in a vacuum environment [1].

The machine will operate initially in a nonactivated hydrogen phase for approximately one year. This will permit verification of the integrity of the total system and allow hands-on repair of any equipment that fails during shakedown or early operation. In addition, the operation of installed maintenance equipment in the test cell will be demonstrated. Once deuterium-deuterium operations begin, device maintenance is expected to require remote handling techniques. The design activities for FY 1987 focused on establishing equipment interfaces with the facility design, developing manipulator system requirements, and using mock-up demonstrations to support the tokamak configuration design. These activities are described in the following sections.

Facility Features

The maintenance philosophy for the test cell is influenced by the close-in neutron-gamma shield surrounding the machine, which allows personnel access into the test cell. Hence, maintenance operations can be hands-on in the test cell with the shield intact but must be remotely performed when the shield is disassembled for machine access. The shield has a modular construction so that removal of a shield module exposes a segment of the machine for maintenance work. Figure 1 is an isometric view of the tokamak with the shield structure partially removed. A bridge-mounted master-slave manipulator system and the overhead crane are used to maintain or replace equipment modules that interface with the machine. A second, floor-based mobile manipulator is used for operations in the area underneath the machine.

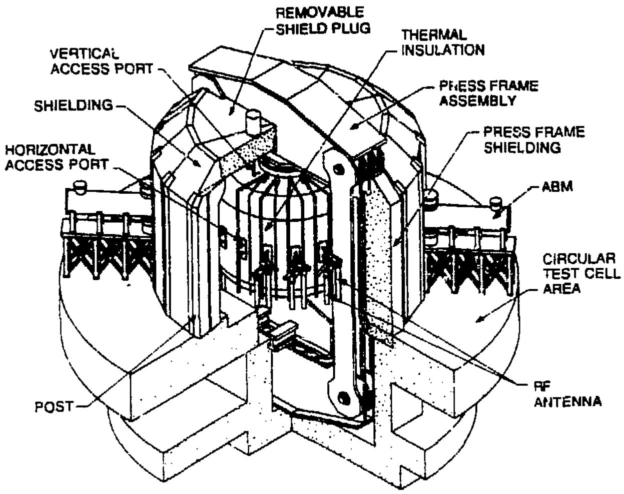

Fig. 1. Compact Ignition Tokamak with the nuclear shield partially removed.

The shielded test cell is adjacent to an air-lock transfer area, leading into the decon cell. After decon, highly activated components are remotely loaded into a shielded cask for transport to the hot cell. Nonactivated components are transferred to the warm cell in an unshielded containment structure. The hot cell and warm cell are located in an existing shielded building at the Princeton site; this building will be modified to meet the CIT needs. The hot cell will also contain the equipment for solid-radiation-waste handling.

Maintenance Concept Development

The CIT maintenance concept relies primarily on remote means to repair and replace failed equipment on the tokamak

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

machine. Highly irradiated and contaminated auxiliary components of the fusion device, such as diagnostics, rf heating, and fueling systems scheduled for repair or replacement, will be removed from the test cell through shielded doors on a cart transfer system. The general sequence of operations for component maintenance is shown in Fig. 2. The main path for failed components is remote removal and transport to a shielded facility for decon, followed by transfer to the hot cell for repair. If repairs cannot be made, the component will be scrapped. The radioactive components will be remotely processed by special tools to reduce the volume of scrap before it is placed in sealed containers, which are then stored to await possible off-site shipment.

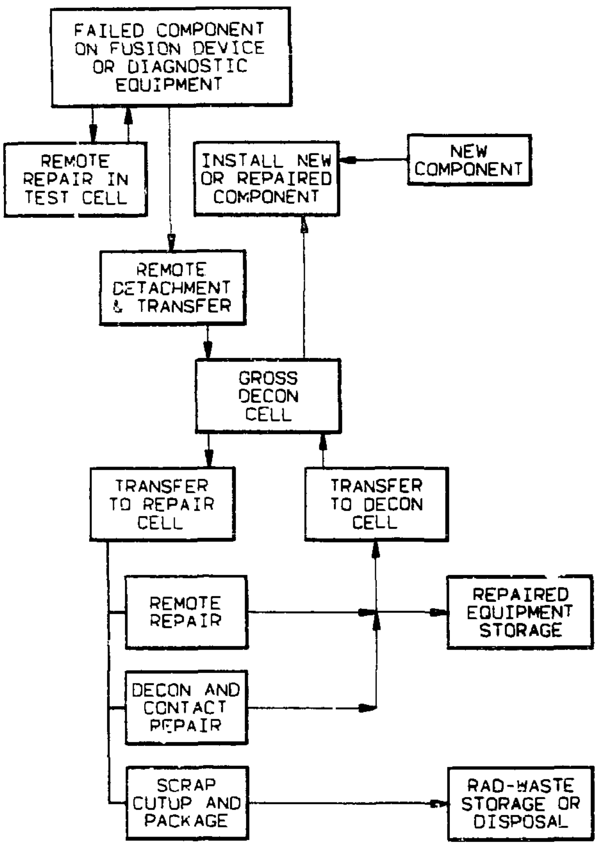

Fig. 2 Equipment maintenance sequence.

The major thrust of the work for FY 1987 was to define maintenance requirements to a degree sufficient to identify major impacts on the facility configuration. These studies included evaluation of remote handling and manipulator transport system arrangements, access to machine components requiring remote maintenance, and requirements for transport, decontamination, and repair or disposal of failed components. The progress of this work is described here.

Assessment of Manipulator Systems

Remote handling and manipulator transport systems have a major impact on cell configuration and equipment layout. This study investigated the best way to provide manipulator coverage of the tokamak and associated cell equipment. Alternatives included overhead systems with either a telescoping boom or a rigid mast and floor-based systems including fixed-mount and mobile manipulators.

The prime candidates evolving from these studies were the bridge-mounted manipulator with telescoping mast (Fig. 3) and a floor-mounted system with an articulated boom (Fig. 4). The overhead system was selected for the baseline configuration. This resulted from a comparison of the two systems and also the modification of the arrangement of the igloo shield to provide unrestricted manipulator access. The overhead system provides full test cell coverage without interference from floor-mounted machine components.

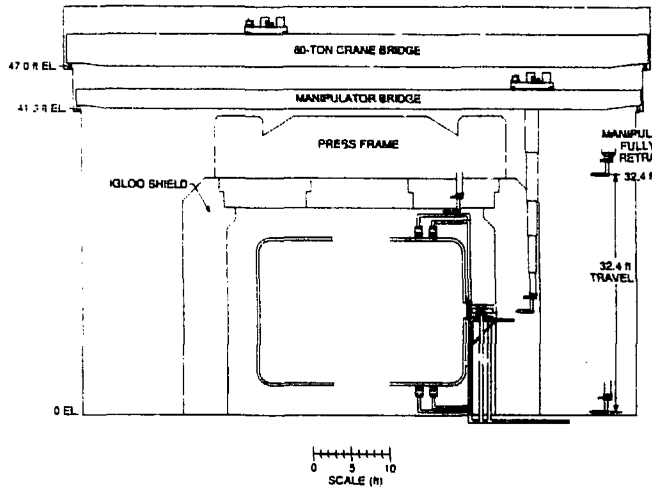

Fig. 3. Bridge-mounted manipulator for CIT test cell.

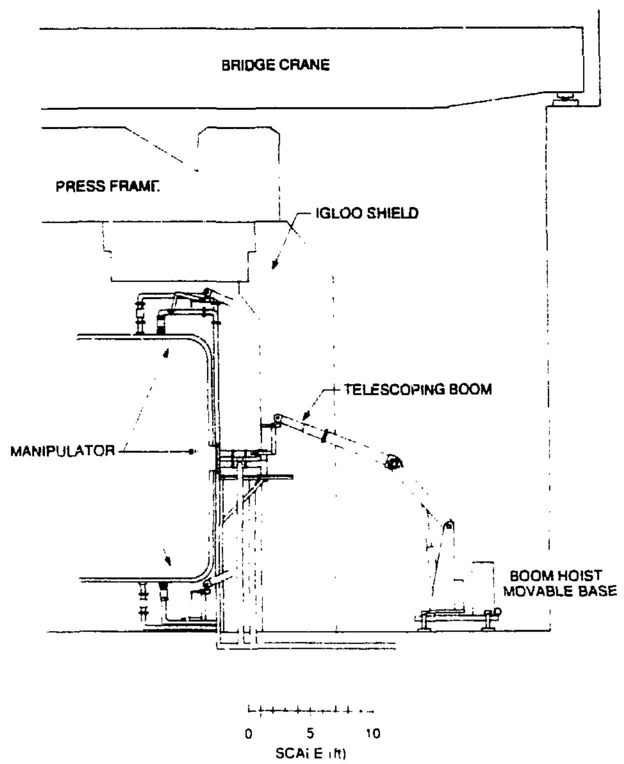

Fig. 4. Elevation view of CIT cell with typical floor-mounted manipulator positions.

Computer Modeling of Manipulator Tasks

The repair of the ex-vessel auxiliary machine components involves gaining access to the vertical ports on top of or beneath the machine and to the 18 midplane ports on the side of the machine. Each of these tasks requires insertion of the manipulator slave with its TV viewing cameras and auxiliary hoist into the opening made by removing a shield module. Three-dimensional, CATIA-developed kinematic models of manipulators and solid models of the upper diagnostic and midplane port areas of the CIT machine are proving to be a powerful tool to evaluate access and reach requirements. Figures 5 and 6 are examples of the CATIA system models. In these models, it was shown that the original shield limited lateral movement of the manipulator to essentially a head-on radial approach to each port. This created remote handling problems for the component designer and imposed some abnormal requirements for the slave-arm configuration and motions. Severe restraints were also imposed on the viewing systems and the means for providing auxiliary hoisting assistance.

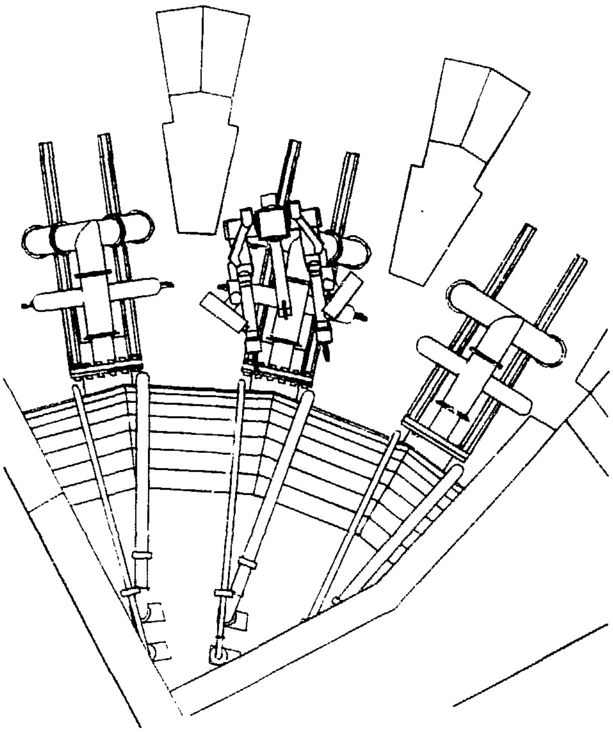

Fig. 5. CATIA plan view of upper ports and manipulator system.

As a result of this study, the shield designers revised the igloo design to provide acceptable manipulator access. The bridge-mounted manipulator now has free access to all the ports except those underneath the machine. The overhead transport system can position the manipulator slave arms and viewing equipment in and around each diagnostic port and rf heating port to perform the intricate tasks of disconnecting and replacing vacuum, electrical, and cooling interfaces. Additional CATIA modeling is planned for FY 1988.

Remote Maintenance Demonstrations

Demonstrations of CIT ex-vessel maintenance tasks have been under way to determine capabilities and equipment requirements for the ex-vessel maintenance system. These demonstrations are conducted on full-scale, partial mock-ups of the CIT machine at ORNL's ROMD Facility with a Central Research Laboratory model M-2 manipulator. The first demonstration simulated various tasks required to maintain diagnostic hardware and associated vacuum piping located on the upper surface of the CIT. The mock-up demonstration investigated vision requirements (camera locations) and manipulator access to this equipment. Conventional, bolted vacuum flanges were used. The vacuum pipe flange now being considered for CIT use is the "Cefilac" coupling, manufactured by the Helicoflex Company, and is specifically designed for remote handling. It is the type specified for use on the Joint European Torus (JET) in the European Fusion Program. Methods and procedures for remotely assembling these vacuum joints will be tested and refined during FY 1988.

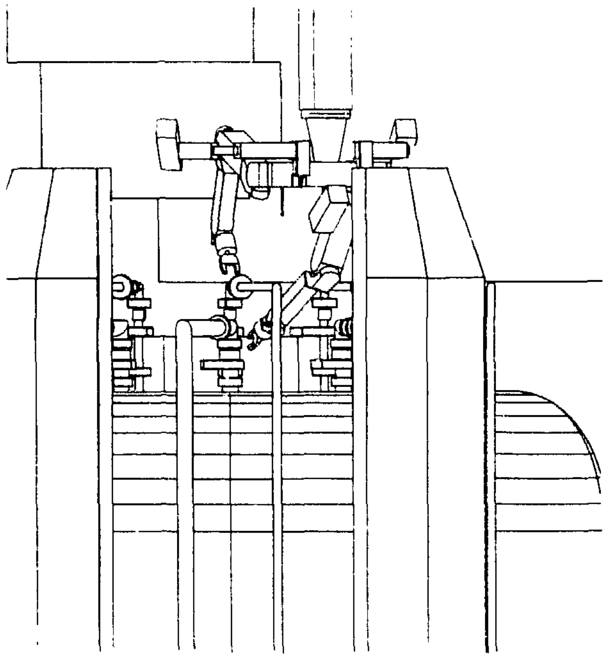

Fig. 6. CATIA elevation view of upper ports and manipulator system.

A second demonstration is under way to help in understanding the viewing needs for maintaining the upper and midplane diagnostics. Because of the compact, complex arrangement of the diagnostics and their associated vacuum piping and the physical constraints of the igloo shield and the press frame, there is not much space for TV cameras. Ideally, the operator would prefer a belly-mount view as well as upper right and left views. It is not apparent that all of these views can be provided, since the location of cameras could interfere with machine components.

A third mock-up has been designed to demonstrate the removal and installation of the rf module, which is mounted in several midplane ports. The ex-vessel maintenance system will be required to remotely detach and remove the rf module from the CIT device for refurbishment in the hot cell. Tasks that will be performed remotely in FY 1988 include:

- Removing and installing the igloo shield sections.
- Aligning and supporting the rf coaxial pipes during removal and installation.
- Making and breaking connections at the rf coaxial pipes and midplane port (flange bolts, electrical connectors, and coolant connectors).

- Pushing and pulling the rf module into and out of the midplane port.

Remote Maintenance Design Guide

A manual that provides basic guidelines for the design of equipment to be remotely maintained is being developed for issuance to equipment designers responsible for such systems as the diagnostic, fueling, and rf heating systems. The guidelines will be based on proven techniques used at other facilities for design of similar equipment. Designs specific to CIT will be incorporated from the remote maintenance demonstration mock-ups of the CIT machine components conducted at ORNL.

Activities for FY 1988

The work planned for FY 1988 focuses on R&D activities to support the development of a manipulator system prototype; the manipulator transporter; inspection and viewing equipment; and various fasteners, flanges, and connectors for remote handling. Some work will be done on cutting and welding equipment. In addition, work will be started for designing a full-scale quadrant mock-up of the machine, to be located at the Princeton site. The design-related work will be more limited and will concentrate on the preliminary design of decon and waste-handling equipment, the hot cell equipment, and the remote maintenance control room.

Upgrading the existing mock-ups at ORNL to reflect the final machine configuration will be a priority activity. The mock-up of the upper vacuum pipes was based on an early version of the machine size and the igloo structure. The rf mock-up will be modified to study access and reach for various diagnostic modules. A new mock-up of the vacuum pipes under the machine is planned for the second half of 1988.

Conclusions

The CIT is providing the impetus to apply existing remote handling technology to fusion device maintenance and to develop new approaches where needed. The activities for the past year focused on developing maintenance requirements and conceptual designs of maintenance equipment. The early use of partial mock-ups has been invaluable in studying problems of access and reach and has had an impact on the development of the machine configuration. The work for FY 1988 will emphasize manipulator system development, preliminary design of facilities-related equipment, and the continued use of full-size mock-ups.

Acknowledgments

The authors wish to acknowledge the contributions to the work presented in this paper by our colleagues K. C. Bills, R. E. DePew, and J. D. Snider of the Remote Systems Engineering Group at ORNL, led by D. P. Kuban.

Reference

[1] F. Puhn, R. Gallix, and E. Hager, "Conceptual Design of the Plasma Chamber and Remote Maintenance System for the Compact Ignition Tokamak," paper presented at the 12th Symposium on Fusion Engineering, Monterey, California, October 1987.