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TPX IN-VESSEL REMOTE MAINTENANCE TOOLING

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ABSTRACT

The Tokamak Physics Experiment (TPX) has used the lessons learned from successful remote maintenance and remote handling facilities to develop both a concept and philosophy for incorporation of remote design from the earliest phases of the project. Initiation of mockup testing during the conceptual design phase leads to significant improvements in the basic maintenance equipment configuration. In addition, remote handling features and capabilities have been incorporated into the design of the plasma-facing components (PFCs) as part of the total PFC design effort.

INTRODUCTION

Historically, remote repair and maintenance operations of complex systems have proven to be difficult and expensive. Failure to include the provisions for remote maintenance in the earliest stages of planning and design of such systems has been the major cause of these problems. The Tokamak Physics Experiment (TPX) project has successfully taken this lesson and implemented it with several substantive directives. Including remote handling considerations in the early design of in-vessel components and diagnostics has resulted in features that will better optimize remote operations. The result being an early development of remote handling concepts, incorporation of maintenance-specific features in components designated for remote handling, and the development and execution of a comprehensive full-scale mockup test program. In all these areas, the early and comprehensive consideration of remote handling has yielded benefits in the maintenance system and the TPX facility, including the plasma-facing components (PFCs) and diagnostics.

The PFCs used in the TPX vessel will range in weight from 45 to 360 kg (100 to 800 lb) and are individually water cooled because of the anticipated heat loads. The PFCs are classified maintenance "category I," which includes items expected to require replacement during the life of the machine. At some point in the operation of TPX, the tokamak will become activated by the generated fusion neutrons and contaminated by generated tritium. Because of this, remote maintenance systems for use inside the vessel become a necessity. Implementing remote maintenance functions requires dealing with the tools and handling devices necessary to remove fasteners, cut and weld cooling lines, and handle weighty components.

REMOTE MAINTENANCE SYSTEM CONCEPTS

The TPX remote maintenance system has evolved significantly since the completion of the conceptual design. This system is based on the integration of a rail system permanently mounted in the vessel. Alternate rail systems were considered which would accommodate both vertically and horizontally oriented vehicles and would support necessary manipulators and tools for positioning in the various vessel locations. Design studies and analysis of the anticipated maintenance and tool requirements led to the development of vehicles mounted on horizontal rails rather than the originally conceived vertical rails. The new configuration proved to be less complex, was easier to install, and provided better access to the PFC components.

Fig. 1 shows an overall view of the TPX in-vessel maintenance system. The in-vessel system is composed of two primary elements; a transfer system to move components into and out of the vessel and an in-vessel assembly based on a two-vehicle, track-mounted system designed to handle both the heavy PFC modules, while also offering the flexibility and dexterity to perform tooling and unusual functions. The transfer system interfaces with the maintenance port to provide access to the vessel interior. A cut-away quarter segment of the vessel is shown with in-vessel maintenance system in place.

Fig. 2 shows the transfer system that will be permanently installed in the TPX test cell. During maintenance operations Port "A" will be opened, the port plug removed, and the transfer system moved into place. A telescoping boom along with isolation chambers provide the means of moving tools, equipment, and components in and out of the vessel. The remote system in-vessel vehicles provide a platform for remote manipulators, remote maintenance tools, vision and lighting, and they must be installed in the vessel before maintenance operations can proceed.

IN-VESSEL OPERATIONS

The in-vessel vehicle assembly is shown in Fig. 3 with a lower outer divertor handling tool installed. The vehicle system consists of two powered tractor type vehicles each with a multi-degree of freedom manipulator mounted to its upper

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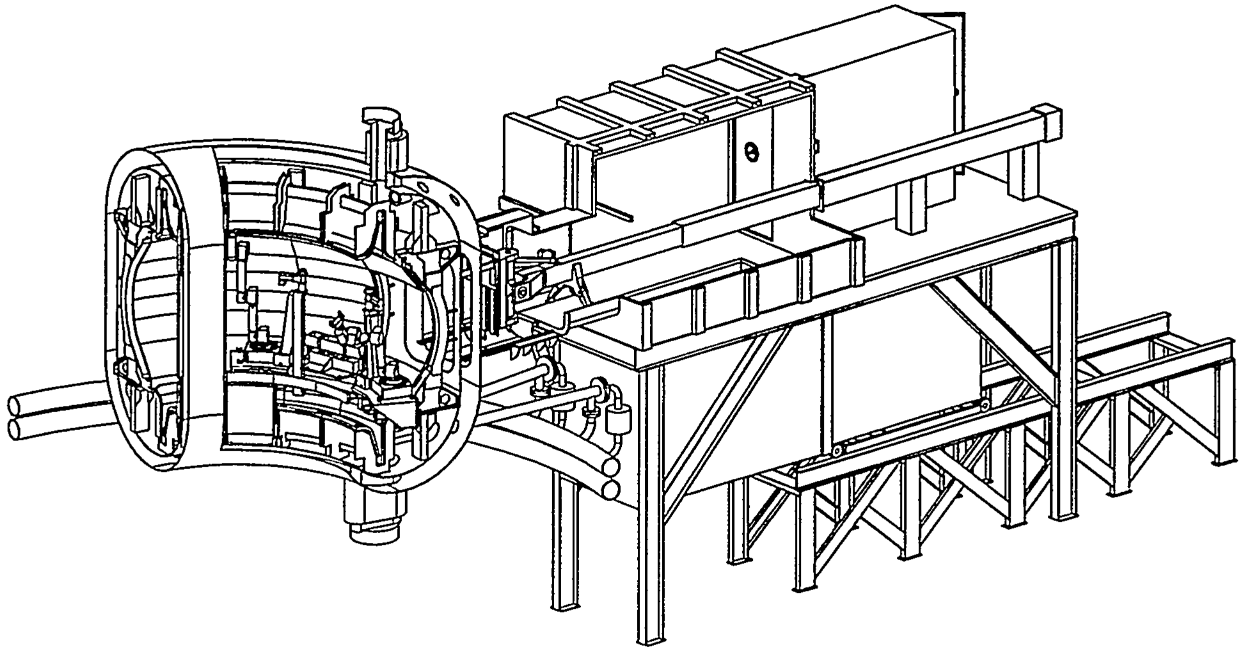

Fig. 1 General arrangement of TPX maintenance system

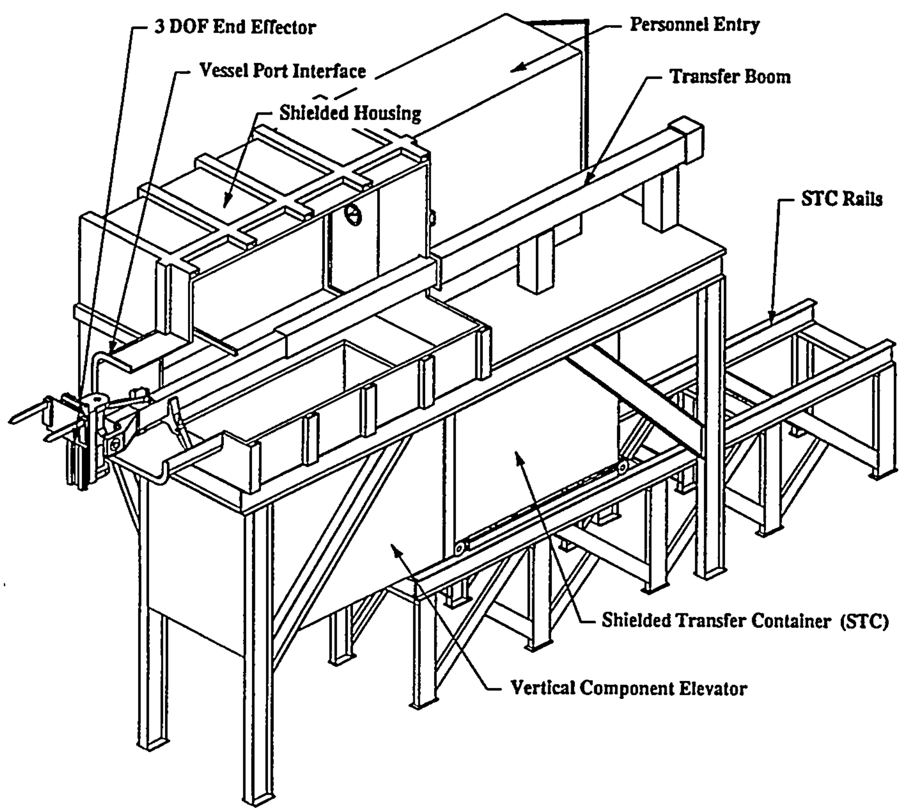

Fig. 2 Transfer system

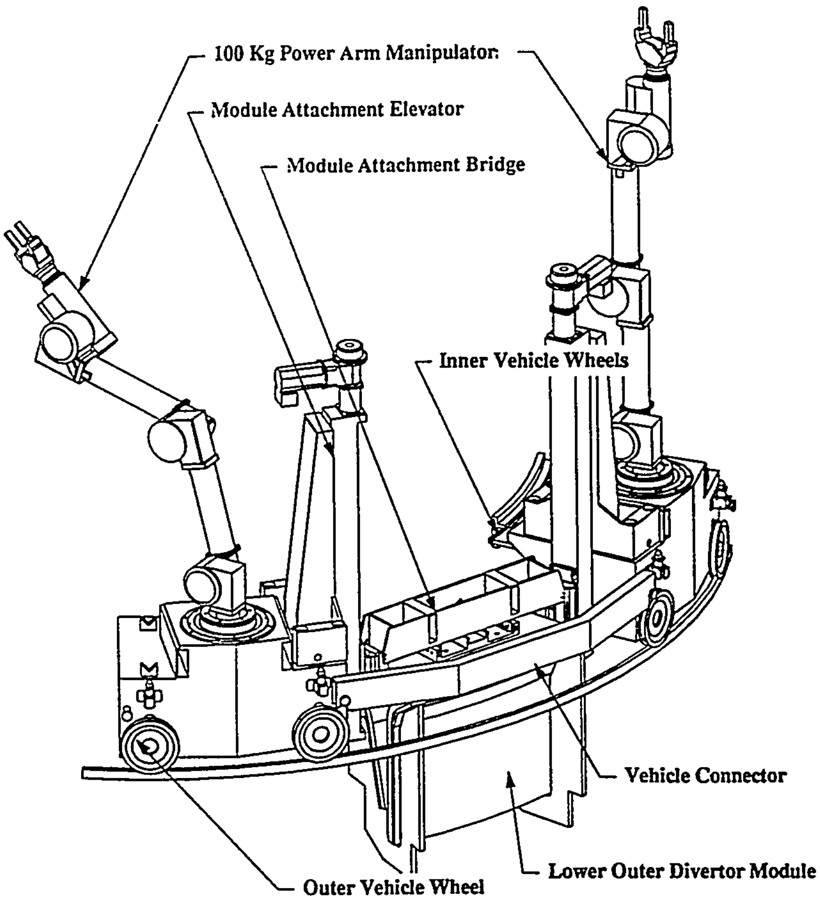

Fig. 3 In-vessel vehicles with module handling fixture

platform. The two tractors straddle and support special handling tools for each type of module. The composite assembly with all attachments will be configured inside the vessel by transferring modules in through Port "A." The tractors with manipulators are first installed on the in-vessel rail system. These power arm manipulators are then available to provide assistance in assembly of the other attachments and fixtures.

Table I lists the PFC components that require handling within the TPX vessel. Due to the weight and size of these components and the special handling requirements, a unique attachment fixture is planned for each component. These fixtures will mount to the tractor arrangement utilizing a common interface. As an example, Fig. 4 shows a detail of the lower outboard divertor module handling fixture assembled to the lower outer divertor. This fixture includes grapples that interface with the divertor assembly to provide a fail-safe grip for lifting. A combination of drive motions and fixture compliance is utilized to accommodate tolerance limits and normal out-of-position conditions. Before attachment of the fixture, a manipulator mounted torque tool is used to loosen fasteners securing the module to the vessel, a dedicated cutting tool severs the cooling line, and procedures are implemented to disconnect affected diagnostics.

Table I
TPX PFC characteristics

Description	Quantity	Estimated weight [kg (lb)]
Outboard divertor	32	360 (800)
Inboard divertor	32	150 (330)
Inboard passive plate	16	320 (700)
Outboard passive plate	32	300 (660)
Toroidal break (half section)	2	300 (660)
Poloidal limiter/vertical plate	2	310 (680)
Line of sight shield	TBD	50 (110)
Bolted tiles	TBD	1 (2)

The maintenance tooling system is being designed to implement the fundamental aspects of simplicity and reliability. In the design considerations one objective is to provide equipment based on proven technology and to implement this with a minimum number of components and mechanisms. In keeping with this design philosophy, many of the operations required for functioning of handling tools will be powered by the manipulator wrist rotary drive. Positioning and verification of action taken is made using the CCTV system. This

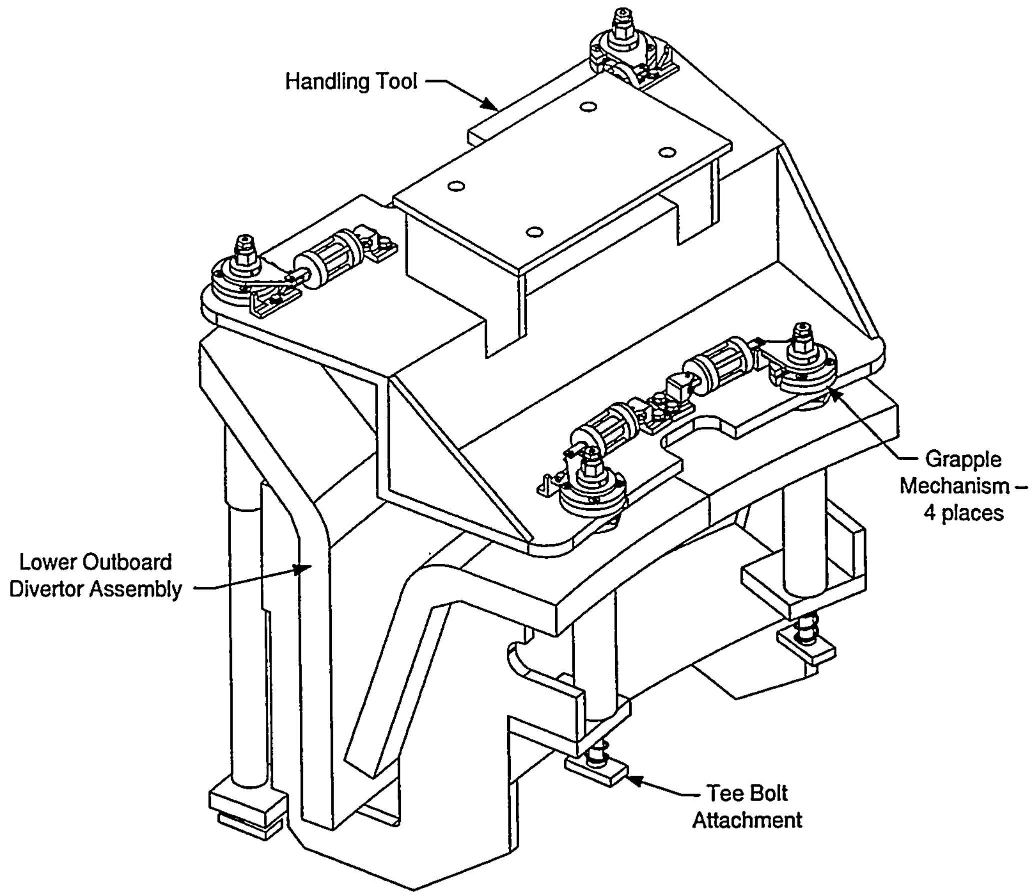

Fig. 4 Module handling fixture

approach will minimize electrical controls and powered mechanisms necessary on all of the individual handling tools.

MOCKUP TESTING

Mockup testing is the foundation of successful remote handling facilities; consequently, all components designated to be remotely maintained will be verified at each stage of design in a series of full-scale test facilities. The first mockup facility has been constructed at Oak Ridge National Laboratory and is being used to demonstrate key elements of the proposed TPX maintenance system design. These elements include the viewing and lighting system, a compact high-torque wrench, the in-vessel vehicles, and many dummy models used to evaluate fit and handling inside the confined TPX volume. A second mockup, to be located at Princeton Plasma Physics Laboratory, will include a sector of the vessel and functional features such as piping and feedthroughs. It will be operational throughout the life of the project and be used for operator training and unusual event analysis as well as verification of the final designs of the component modules and in-vessel maintenance systems.

CONCLUSION

Focused attention to the remote maintenance of in-vessel components early in the TPX program has ensured that features necessary to maintain elements are integral to the design and arrangement of the components. Building on many years of remote tooling development practices such as modular packaging, standardized pipe connections, and remote fasteners has improved the efficiency of the design effort and the reliability of the maintenance operations. The use of an in-vessel rail and vehicle system ensures a mobile, stable, and reliable platform from which remote maintenance tasks can be performed. Where special purpose handling fixtures are required, designs take advantage of manipulator drive and handling features to replace distributed on-board powered operators and controls. A full-scale mockup program will provide necessary verification of design concepts.