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Virtual reality applications in remote handling development for tokamaks in India

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HIGHLIGHTS

- Evaluation of Virtual Reality (VR) in design and operation phases of Remote Handling (RH) equipment for tokamak.
- VR based centralized facility, to cater RH development and operation, is setup at Institute for Plasma Research, India.
- The VR facility system architecture and components are discussed.
- Introduction to various VR applications developed for design and development of tokamak RH equipment.

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ABSTRACT

A tokamak is a plasma confinement device that can be used to achieve magnetically confined nuclear fusion within a reactor. Owing to the harsh environment, Remote Handling (RH) systems are used for inspection and maintenance of the tokamak in-vessel components. As the number of in-vessel components requiring RH maintenance is large, physical prototyping of all strategies becomes a major challenge. The operation of RH systems poses further challenge as all equipment have to be controlled remotely within very strict accuracy limits with minimum reliance on the available camera feedback. In both design and operation phases of RH equipment, application of Virtual Reality (VR) becomes imperative. The scope of this paper is to introduce some applications of VR in the design and operation cycle of RH, which are not available commercially. The paper discusses the requirement of VR as a tool for RH equipment design and operation. The details of a comprehensive VR facility that has been established to support the RH development for Indian tokamaks are also presented. Further, various cases studies are provided to highlight the utilization of this VR facility within phases of RH development and operation.

1. Introduction

A tokamak is a toroidal machine that uses high power superconducting magnets to confine high density and high temperature plasma. It is one of the most promising fusion reactor configurations to generate electricity using controlled nuclear fusion reactions. Research and development work on this concept is being pursued worldwide. In the Indian fusion road map [1], Aditya tokamak and Steady-State Superconducting Tokamak 1 (SST-1) are already operational at Institute for Plasma Research (IPR) and it is envisaged that medium sized fusion reactor will be realized in the next two decades [2].

The in-vessel components of the tokamak primarily include, plasma divertors, plasma control coils, various plasma diagnostics, shielding blankets and tritium breeding blankets. Typically, these components weigh in order of a few kilograms for diagnostics to a few thousands of kilograms for blankets and divertors. During the plasma operation, the in-vessel components will be subjected to a surface heat flux of ~4–5 MW/m^2 [1], depending upon their location within the tokamak and the type of plasma operation. Thus, these components will vitiate over the lifetime of the tokamak and scheduled maintenance cycles are needed for each component. Maintenance cycles of tokamak involve crucial operations like periodic visual inspections, tritium dust cleaning, replacements of tiles and diagnostics, up-gradation of in-vessel coil systems etc. [3]. The in-vessel components in the tokamak and some locations within the hot-cell (a component maintenance area adjoining the tokamak building) will become inaccessible to humans. This is essentially to limit the radiation dose uptake on the human workers post Deuterium-Tritium (DT) plasma campaign. Thus all the inspection and maintenance activities are carried out remotely using specialized robotic equipment that are controlled by an operator(s) from

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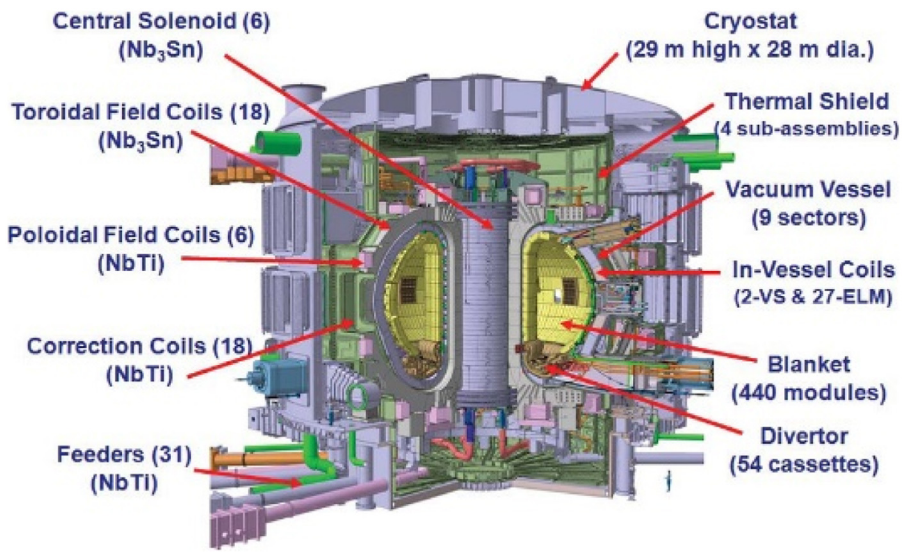

Fig. 1. ITER tokamak showing various in-vessel components for reference.

a control room located far away from the reactor building. Fig. 1 shows a 3D model of International Thermonuclear Experimental Reactor (ITER) tokamak for reference.

The RH operations in tokamak face two major challenges. Firstly, to maintain a low shutdown time and high availability of the tokamak, it is imperative to follow a strict design, testing and operation cycle of the RH equipment. The RH equipment features required for each component is different. These include structural design of RH equipment, payload capability, reach, component access, deployment procedure of RH equipment, accuracy of operation, control requirements, space constraints, allowable radiation dosage and time to complete a maintenance operation. Meticulous planning, optimizing and preparation of the RH operations is imperative to minimize any failure during the operation. Due to a large number of such in-vessel components, 1:1 scale prototyping and demonstration for each RH operation, becomes intensive in terms of cost and time. Secondly, owing to the complexity and criticality of the tasks involved, crucial decisions during RH operations are relied on the intelligence and intuition of a trained operator. Thus, all RH operations in a tokamak follow 'man in the loop' control. To make an informed decision, it is essential to provide sufficient details of the task environment, robot pose and location, possible outcomes of a decision, etc., to the operator. Visual feedback using cameras are limited, as cameras can only be installed at certain locations in the tokamak or on the RH equipment. This limitation is essentially to control the nuclear dosage on the camera electronics.

Virtual Reality (VR) is extensively used to tackle both these challenges. The feasibility of using VR based approach to assist the RH design and operation cycle of tokamak has been successfully demonstrated in the Joint European Torus [4–6]. This paper presents the Indian scenario for the utilization of VR in RH needs for existing and future tokamaks. Section 2 of this paper explains the use of VR in the RH design and operation cycle. Section 3 describes the established VR facility at IPR. Section 4 details some of the major VR enabled development activities and their results, that have been accomplished to support RH design and operation cycle. Section 5 gives a discussion of the future requirements.

2. VR assistance for RH in tokamak

Virtual Reality is described "as a computer-synthesized, three-dimensional environment in which a plurality of human participants, appropriately interfaced, may engage and manipulate simulated physical elements in the environment and, in some forms, may engage and interact with representations of other humans, past, present or fictional or invented creatures" [9]. With the advancements in graphic processing capabilities in the last decade, VR has emerged as a medium for rapid prototyping in manufacturing and a tool for interactive gaming in entertainment industries. However, the application VR in RH is significantly wide and critical. Fig. 2 shows the utilization of VR in various phases of the RH design and operation cycle. As mentioned in Section 1, the assistance of VR can be broadly categorized into – utilization during design, testing and qualification of RH equipment and during control and monitoring of RH equipment. Here, we elaborate and discuss these requirements.

Remote Handling (RH) is an approach to perform manual inspection and maintenance tasks at remote locations without being physically present at the workspace. Unlike conventional industrial robotic systems, which are pre-programmed to do a certain task, the RH activities of a tokamak are much complex. All RH equipment of a tokamak work in a toroidal workspace with a space limitation of ~2 m. The RH equipment for tokamak have a long reach (~5–10 m) and handle heavy payload (100–2000 kg) with an accuracy of <5 mm. In many cases, the RH equipment has to enter constrained spaces (<0.2 m) for inspection and maintenance. Also, the in-vessel environment changes slightly after every plasma operation, thus the RH operations are dynamic.

The evaluation of RH maintenance and inspection schemes for major in-vessel components begin with the conceptual design of the tokamak. These include, assessment of accessibility to components, payload-handling constraints, typical time requirement for maintenance and inspection, etc. Integration of RH equipment design into the design process of a tokamak and its component is imperative as the impact of any particular RH scheme may alter the design of the tokamak and the component. For instance, a vertical replacement scheme of the blankets requires a large upper port for the tokamak but can sustain higher blanket payload with low maintenance time. However, a horizontal handling of blankets demands lower payload capacity of RH equipment, leading to a longer maintenance time, see Refs. [7,8]. Also, the design process of components is itself an iterative process thus constant improvisation to RH schemes is required through out the design phase. Full scale prototyping for demonstration of RH schemes for individual components is thus extremely difficult.