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A LASER SCANNING SYSTEM FOR METROLOGY AND VIEWING IN ITER

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ABSTRACT

The construction and operation of a next-generation fusion reactor will require metrology to achieve and verify precise alignment of plasma-facing components and inspection in the reactor vessel. The system must be compatible with the vessel environment of high gamma radiation (10^4 Gy/h), ultra-high-vacuum (10^{-8} torr), and elevated temperature (200°C). The high radiation requires that the system be remotely deployed. A coherent frequency modulated laser radar-based system will be integrated with a remotely operated deployment mechanism to meet these requirements. The metrology/viewing system consists of a compact laser transceiver optics module which is linked through fiber optics to the laser source and imaging units that are located outside of a biological shield. The deployment mechanism will be a mast-like positioning system. Radiation-damage tests will be conducted on critical sensor components at Oak Ridge National Laboratory to determine threshold damage levels and effects on data transmission. This paper identifies the requirements for International Thermonuclear Experimental Reactor metrology and viewing and describes a remotely operated precision ranging and surface mapping system.

KEYWORDS: laser radar metrology, remote maintenance, gamma radiation environment, surface mapping

INTRODUCTION

The International Thermonuclear Experimental Reactor (ITER) is a fusion device planned to be built early in the next century. The performance and survival of plasma-facing components (PFC) located within the reactor's vacuum vessel depend on precise alignment and positioning with respect to the plasma edge. A remotely deployed and controlled three-dimensional metrology system is being developed to periodically verify the condition of in-vessel components in ITER. This metrology system has two basic

functions: (1) frequent inspection to establish the dimensional status of in-vessel components and (2) extensive checking of in-vessel components and plasma-facing surfaces during scheduled maintenance shutdowns.

DESIGN REQUIREMENTS

The interior surface area of ITER is approximately 1500 m^2. In order to achieve acceptable mapping times, up to ten metrology systems will be required. Each system must be capable of acquiring in-vessel dimensional data accurately, under harsh environmental and radiological conditions. It must withstand gamma radiation levels that are expected to reach 3×10^4 Gy/h, while operating in a 200°C environment, in vacuum conditions. The undeployed system will experience a cyclic magnetic field that peaks at 0.15 T. In addition, an alternative requirement which is being investigated is the feasibility of deploying the system in a constant magnetic field of 6 T. The system must also function during scheduled maintenance activities when the vessel will be at atmospheric pressure. Because of the severity of the ITER environment, further development is required to adapt any commercially available range imaging systems. A survey of available mapping technologies[1] identified frequency modulated (FM) coherent laser radar (CLR) as a promising approach for ITER remote metrology.

THREE-DIMENSIONAL METROLOGY SYSTEM

The design concept for a precision measuring device for ITER is based on an FM CLR produced by Coleman Research Corporation.[2] A prototype model of the FM CLR has demonstrated submillimeter range accuracy at more than 10 m. The prototype showed very little sensitivity to surface type, color, and angle of incidence in tests performed at Oak Ridge National Laboratory (ORNL).

Range is determined by measuring the frequency difference between an FM laser beam reflected from a target surface and a local oscillator reference. The accuracy of the range is determined by the linearity of the FM over the counting interval. A prototype Coleman-CLR system that was developed for a joint Department of Energy/National Aeronautics and Space Administration project was tested at ORNL in June 1994. The results indicated that the basic technique is accurate enough to meet the ITER requirements. Since that time, the accuracy of the ranging system has been further improved by Coleman researchers.[3]

- Results show that the unit was able to measure absolute range from 4 to 12 m and accurately track 0.127-mm (0.005-in.) increments.

- Signal attenuation is well within the capability of the instrument's resolution.

- The instrument was able to obtain range data at near grazing angles on most surfaces, indicating low angular sensitivity.

In the ITER application, automated beam deflection techniques will be used to provide a scanning capability for fast mapping of the large surface areas of the vacuum vessel.

Figure 1 shows a schematic configuration with a one-dimensional acousto-optical (AO) beam deflector and a nodding mirror. This allows the radar to have a two-dimensional scanning capability with only one moving part.

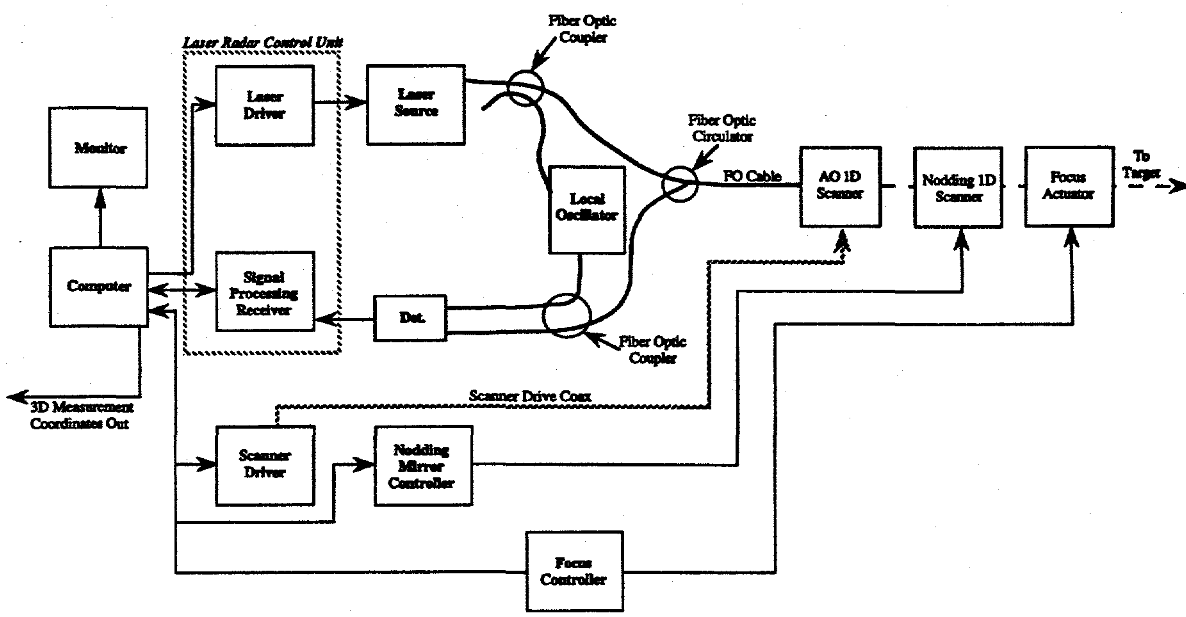

Figure 1. Schematic of the FM CLR with a two-dimensional scanner.

The "viewing" capability of the CLR system was also investigated.[3] A metrological map of a surface with features can be converted into a "picture quality" image that helps to make a visual assessment of surface patterns. The CLR can be used to acquire images in a wide range of formats and resolutions. The prototype version has a pointing accuracy of 0.01° and can be programmed to scan areas up to ±40° in azimuth and elevation. Scan patterns can be set up for raster-type, serpentine, or discrete point scans. The data may then be used to produce high-quality surface images. The image of a dime obtained by precision range scanning of its surface is shown in Figure 2.

IN-VESSEL DEPLOYMENT SYSTEM

A conceptual design effort is under way to develop a deployment mechanism mounted to a top port of the vacuum vessel. Two viewing/metrology deployment systems are being evaluated. A one-piece 150-mm-diam, 11-m-long mast to ensure positioning accuracy and minimize deflection and vibration would use a linear actuated drive (ball screw) and high-precision bearing guides to deploy it through the top port opening. The other system would use a telescopic mast that extends into the vacuum vessel. Both concepts will utilize an airlock housing mounted on top of the vacuum vessel. The amount of out-of-vessel storage space required by both systems represents an important design consideration. For example, in its retracted position the telescopic mast will require approximately one-third of the storage space needed by the single mast design. Figure 3 is a sketch of the deployment system mounted above the reactor.[2]

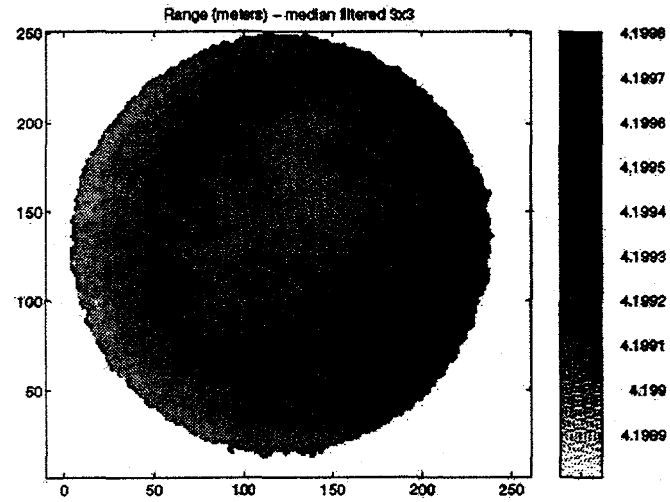

Figure 2. Image of dime developed from range measurements.

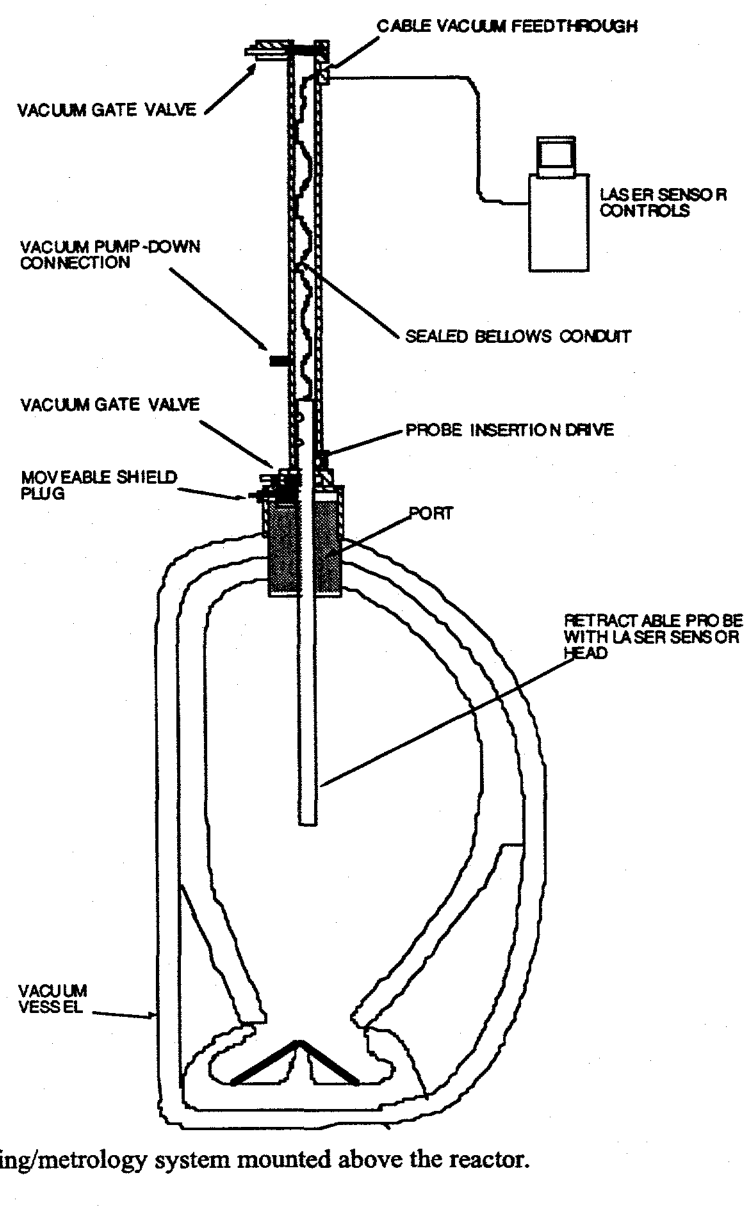

Figure 3. Viewing/metrology system mounted above the reactor.

The design concerns associated with the telescopic mast are also significant. For example, achieving the same extended stiffness and deflection resistance as the one-piece mast will be difficult. In addition, the stepped-down diameter will have a reduced cross-section of the mast at the lower end, which may limit the cabling and coolant lines that can feed through the system. Coolant lines will be needed to support a differential environment inside the mast to protect cables, motors, and sensors. For this configuration, special shielding at each sliding joint may have to be designed to maintain a temperature of <150°C inside the mast.

Either system must penetrate two boundaries: the vacuum vessel and the cryostat wall. This penetration scheme will allow quick access to the deployment system for removal and installation. Isolation valves will be used to seal the opening and maintain the boundary separation between the vacuum vessel and the cryostat. A movable neutron-gamma shield plug protects the stored system and provides access through the cryostat and vacuum vessel. A special feedthrough connection will be used for power and control cables, fiber-optic lines, and coolant lines. Both deployment system designs are presently envisioned to have 2 degrees of freedom (DOF), namely vertical travel and 360° rotation. All system motions will operate at constant velocity to meet the scanning and resolution requirements of the viewing/metrology sensor equipment.

To ensure quick deployment into the vacuum vessel, the viewing system will be permanently mounted to the top ports of the vacuum vessel at ten locations. Nuclear shielding will be required to prevent neutron and gamma radiation streaming. A special shielding mechanism mounted at the vacuum vessel port will allow deployment of the probe. The present concept is a key-lock mechanism that is being evaluated by the ITER central design group. The viewing/metrology mast and key-lock system will operate together as one mechanism.

RADIATION TESTING OF SENSOR COMPONENTS

The performance of two crucial components of the metrology system will be established under the radiation conditions anticipated in ITER. These components are (1) the polarization maintaining (PM) fiber and (2) the AO scanner. The latter is a complex device involving several active and passive components. The basic AO crystal planned to be used in the ITER metrology scheme is TeO_2.

The gamma radiation dose in proximity to the spent fuel rods in the High Flux Isotope Reactor at ORNL, soon after they are removed from the active reactor, is $\sim 10^6$ Gy/h. This dose decays with time, exhibiting a characteristic e-folding decay time of ~8 days. Thus, cumulative doses of $\sim 10^7$ Gy can be imparted to test objects if they can be introduced into the test region. The axial length of the test piece for which the radiation dose will be uniform within ±10% is about 0.2 m.

Plans are under way to test the effect of radiation on the transmission characteristics of a 1550-nm laser beam through the PM fiber and the TeO_2 crystal. If these tests prove promising, the scanning performance of an entire AO scanning device will be evaluated. Several meters of the PM fiber will be wound on a short spool (<0.2 m) and introduced to the test region. The physical size of the AO device (maximum dimension 45 mm) appears to fit in the experimental region although the details of the test itself are yet to be finalized.

CONTINUING WORK

An important aspect of the design work is to evaluate the time required for mapping PFCs. This is being done using three-dimensional modeling computer simulation. A model of the ITER vacuum vessel was created with access ports, blanket/shield components, and divertor components.[3] It included the sensor head with 2 DOF positioning the laser scanner device. This simulation is being updated and will be used to scan plasma-facing surfaces, particularly the divertors, from the top port locations. Modeling will be expanded to verify that ten ports are necessary for full surface coverage of the divertors, as well as other surfaces. Time and motion studies will be conducted to assess various operating scenarios. Preliminary modeling results have shown that a rough scan of the entire in-vessel surface can be completed in less than 8 h if all probes are utilized simultaneously. Metrology tests using the prototype sensor equipment will be repeated on PFC candidate material surfaces such as beryllium, tungsten, and carbon fiber composites.

CONCLUSIONS

A remotely deployed metrology system based on coherent FM laser radar is being designed for ITER in-vessel inspections. Experiments using a prototype system show that the technique has the capability to map complex surfaces to submillimeter accuracy from distances of ~20 m. The quality of the metrological image obtained by this technique also demonstrates that the system can be utilized for in-vessel viewing of reactor internals without the need for an illuminating source. The modifications necessary for adopting this system for use in the harsh ITER environment are being studied, along with development of a mast-like deployment system.

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