A REMOTELY DEPLOYED LASER SYSTEM FOR VIEWING/METROLOGY*

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ABSTRACT

A metrology system is being developed for in-vessel inspection of present day experimental, and next generation fusion reactors. It requires accurate measuring capability to verify sub-millimeter alignment of plasma-facing components in the reactor vessel. A metrology system capable of achieving such accuracy for next generation reactors must be compatible with the vessel environment of high gamma radiation, high vacuum, elevated temperature, and magnetic field. This environment requires that the system must be remotely deployed. A coherent, frequency modulated laser radar system that is capable of correcting for environmental vibration meets 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 the harsh environment. The deployment mechanism configured for a next generation reactor was telescopic-mast positioning system. This paper identifies the requirements for the metrology/viewing system having precision ranging and surface mapping capability, and discusses the results of various environmental tests.

1. Introduction

The International Thermonuclear Experimental Reactor (ITER) was the next generation fusion reactor that was the basis for establishing the design requirements for the metrology system. 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 was being developed to periodically verify the condition of the ITER in-vessel components and measure surface erosion. These requirements are highlighted below, however, the use of this inspection system in present day fusion experiments does not require radiation hardening, and most likely will not require operation in magnetic fields. This 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. Figure 1 shows the inspection system deployed in the reactor vessel.

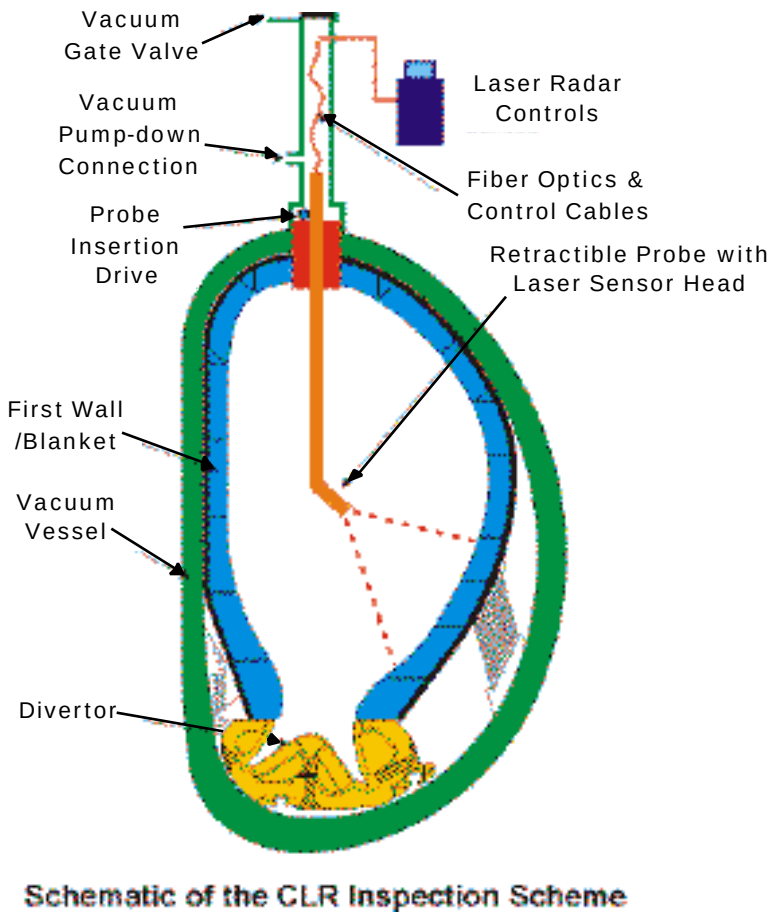


Figure 1. The laser metrology/viewing system deployed in the reactor vessel.

2. Design Requirements

The interior surface area of the ITER vessel was approximately 1500 m^2. In order to achieve acceptable mapping times, ten metrology systems were required; however, as few as three may be sufficient to map all surfaces for smaller present day reactors. Each system had to be capable of acquiring in-vessel dimensional data accurately under harsh environmental and radiological conditions for ITER, and the test results indicated that these could be met, however, the requirements are significantly relaxed for present day machines. For ITER, the equipment would have to withstand gamma radiation levels of 3×10^4 Gy/h, operating in a 200°C environment, in vacuum conditions. The undeployed system will be subjected to a cyclic magnetic field that peaks at 0.15 Tesla (T). In addition, there was a requirement to deploy the system into a constant magnetic field of 6.2 T. And the system also had to function during scheduled maintenance activities when the vessel was to be at atmospheric pressure.

3. Laser Radar Metrology System

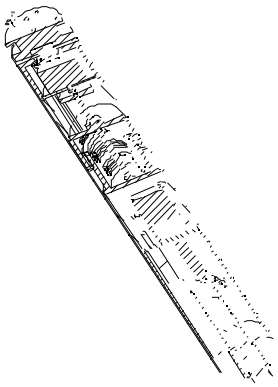
3.1. Design Description

A lightwave signal from the laser source sweeps linearly in frequency with time. Lightwave signals which have traveled to the target or through the local oscillator fiber optic loop will have a delay which results in a constant beat frequency when the two signals are mixed at the detector. This beat frequency is proportional to the path length difference between the target path and the local oscillator path.

This laser metrology system is designed to interface with a deployment mechanism, probably in the form of a telescoping boom. Fiber optic connections, cooling fluid, and power signals will be provided through the deployment system to the laser scanner interface. The scanner package will be completely self contained with all umbilical connections vacuum rated. The connection of the scanner package to the deployment mast will be designed for hands-on maintenance and handling, for a rad-worker wearing anti-contamination clothing.

The laser scanner is based on a frequency modulated, coherent laser radar (CLR) system under development by MetricVision (formally Coleman Research Corporation), with modifications by Oak Ridge National Laboratory (ORNL).[1] MetricVision's previous work in this area yielded a precision laser radar system with a wide field of view, extremely high range resolution, and a high degree of programmability. ITER requirements however, demanded that a totally different sensor head and additional components be added to the current computer system in order to meet the ITER operational scenarios.

An additional challenge was to develop the metrology system for operation in a magnetic field inside the reactor vessel. The sensor was to be used with the reactor field coils energized, hence electromagnetic devices such as electric motors for driving the system could be used in the vicinity of the sensor head. Operation in the magnetic field requires that electric drive motors must be placed remotely from the CLR, and position sensors also must not be electro-magnetically based, or they must be placed remotely from the sensor. Figure 2 shows a design configuration that meets the requirements of the laser scanning system.



SECTION C-C

3.3. Radiation Effects on Sensor Components

Little data exists on the compatibility of certain key components of the CLR system in a high radiation environment. The AO scanner and the polarization maintaining fiber fall into this category. In the AO device, the effect of high gamma radiation on the TeO_2 crystal was not known. Samples of the TeO_2

4.2 Vibration Measurements

The MetricVision CLR system incorporates a proprietary feature that allows range data to be instantly corrected for Doppler frequency shifts. These could be caused by motion of the target, or motion of the deployment mast. Hence, the effects of vibration can be corrected for in real time. This feature could eliminate the effects on the system from building vibrations without resorting to complicated, mechanical schemes. Laboratory testing was done in July 1998 to assess the data-correction feature for the “moving” target case and the “moving” mast case.[3]

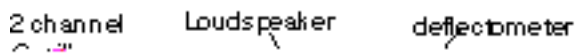


Figure 3. Schematic of the vibration test setup.

In its most basic form, the CLR produces an RF signal whose frequency is related to both the target's range and its velocity. For a stationary target, an upsweep and a downsweep measurement produces the same frequency. For a moving target, the upsweep measurement consists of a frequency associated with the target's range plus a component caused by the Doppler shifting of the light due to the velocity of the object. In the downsweep case, this component reduces the range component. Therefore, by taking the frequency difference between an upsweep and a downsweep measurement and dividing by 2, the frequency component caused by the velocity generated Doppler shift is obtained. Range and velocity measurements are made at a rate of 250 measurements/s, the limit of the CLR-100 Model. The Doppler shift in frequency, Df , due to the target moving at a velocity V, is given by:

$$f = 2V/L$$

where L is the wavelength of the laser beam (1550 nm).

The range data obtained with MetricVision's built-in Doppler correction function was found to be the same as that manually calculated from uncorrected data, obtained without Doppler correction, at low frequencies (Figures 4 and 5 were taken at about 1 Hz). If the Doppler correction is not performed, however, the range information is not accurate, as can be seen in the data of Figure 5 compared to that of Figure 4. Actual speaker deflection was a few millimeters, not the centimeters that the uncorrected data indicate. Figures 6, 7, and 8 show Doppler corrected data for 2, 4, and 8 Hz, respectively. At higher frequencies a software problem within the Doppler correction function corrupted the range data, but velocity measurements could be made at frequencies up to 20 Hz. Figures 9 and 10 show velocity measurements of the loudspeaker target with input signals of 10 and 20 Hz, respectively. In principle, the correction limits in the amplitude/frequency domain are determined by the design of the CLR. For the ITER conceptual design, these limits are shown in Figure 11. The "signal broadening limit" determines the upper limit in frequency.

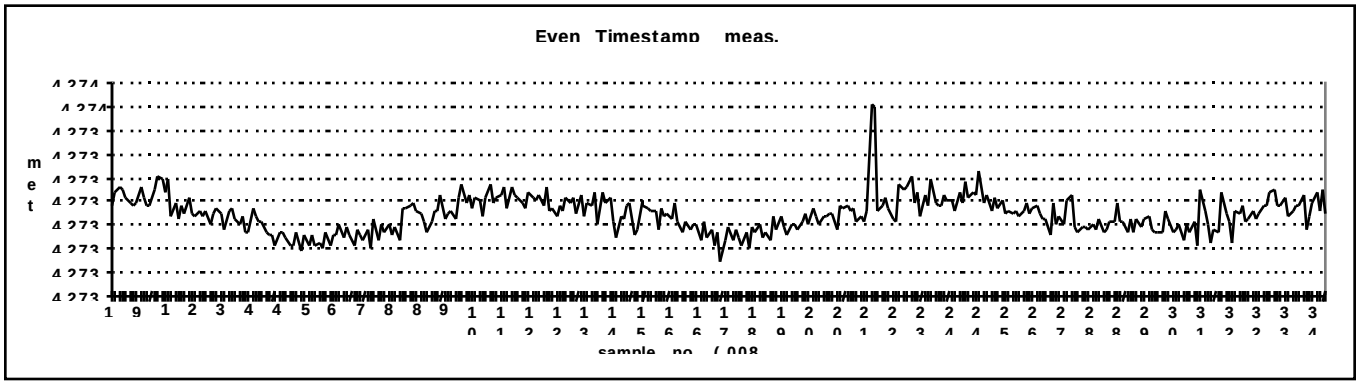


Figure 4. Doppler Corrected Range Measurements from a loudspeaker with a 1Hz input signal.

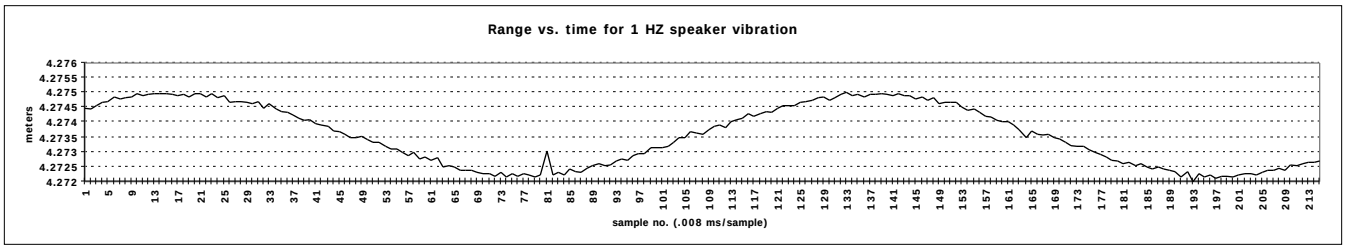


Figure 5. Range Measurements from a loudspeaker with a 1Hz input signal (no Doppler correction).

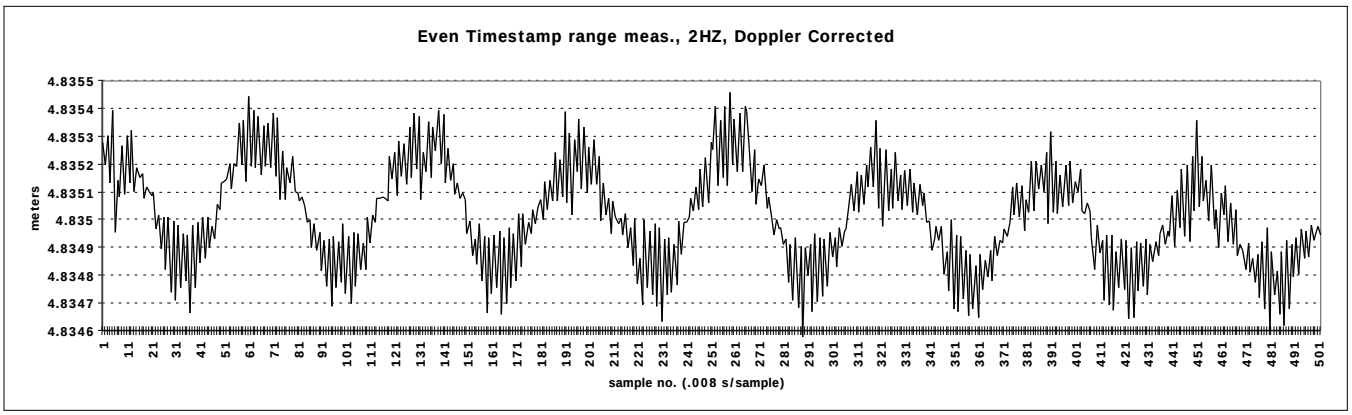


Figure 6. Range measurements from a loudspeaker with a 2Hz input signal and Doppler correction.

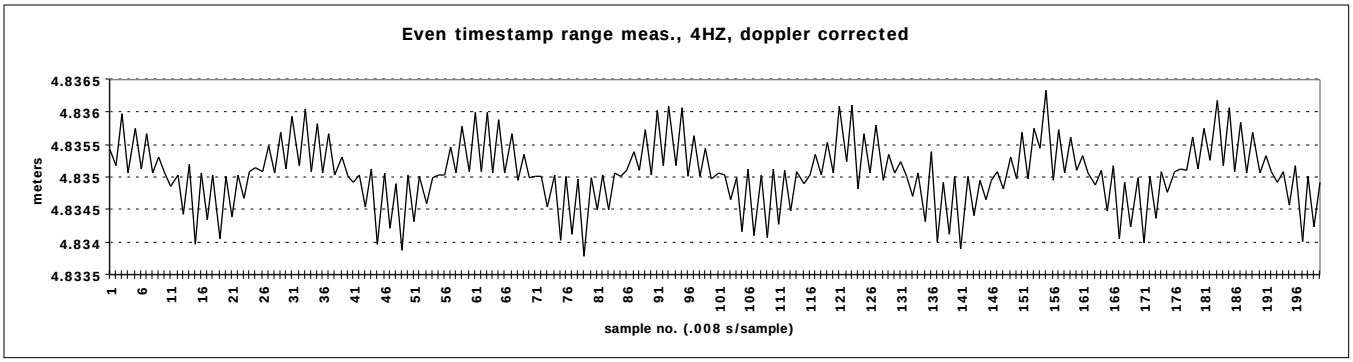
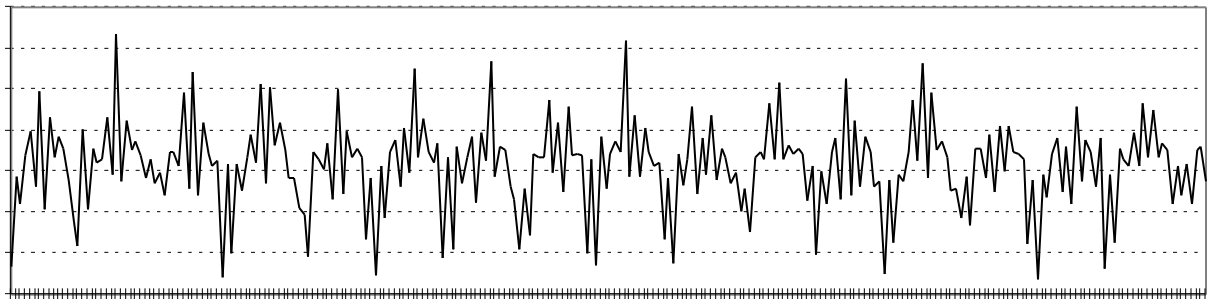


Figure 7. Range measurements from a loudspeaker with a 4Hz input signal and Doppler correction.



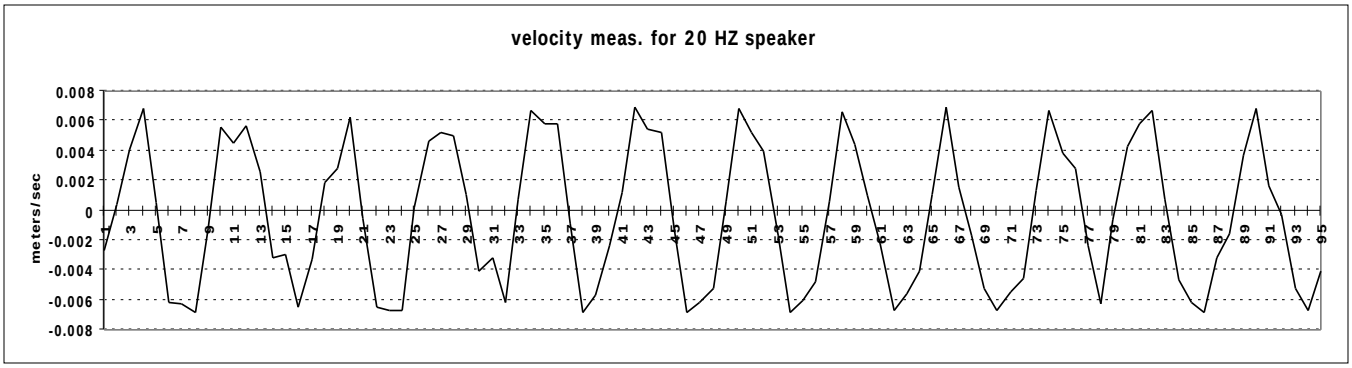
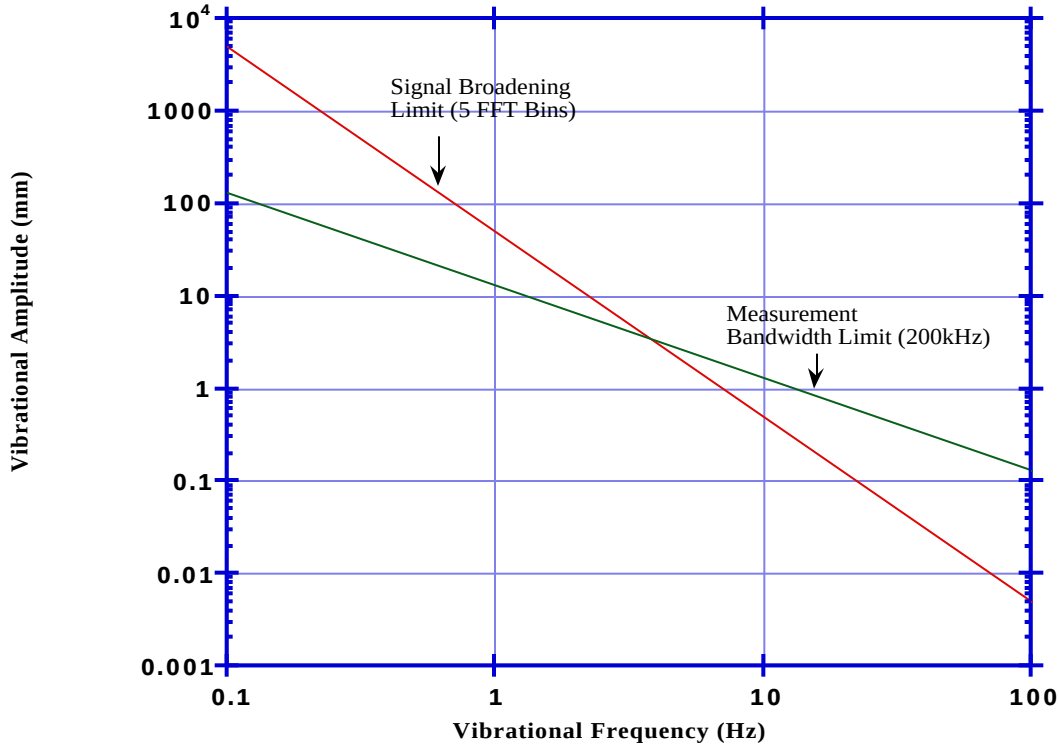


Figure 10. Velocity Measurements from a loudspeaker with a 20 Hz input signal.

These results show that the CLR could be utilized to study the motion of PFCs in real time, during plasma disruptions. And from such measurements, the forces acting on the PFCs during disruptions can be estimated.



Mast Vibration

A mock-up of the mast designed for ITER application was constructed. The mock-up consisted of a 433.5 in long "schedule 10" stainless steel pipe. The natural frequency of this mast is given by:

$$f_n = (1.732/2\pi)\ [(E.I.g)/0.236\ w\ l^4)^{0.5}\ \text{Hz},$$

where, $E = 3.0 \times 10^7$ psi, $I = 8.43\ in^4$, $w = 0.63$ lb/in, and $g = 386.4\ in/s^2$

For the dimensions mentioned above, the natural frequency is calculated to be 1.18 Hz.

The natural frequency of the mast was measured using the CLR. The mast was deflected by nudging its tip by 1 cm, and the deflections were measured as a function of time using the CLR. Doppler corrections were applied to the data to take into account the movement of the mast. The data, shown in Figure 12 yields a natural frequency of 1.04 Hz [1/(120 samples × .008 sec/sample)], which is in good agreement with the calculated value.

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