Laser Vibrometer PFC Health Monitoring System

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Introduction

Fusion power offers the prospect of an inexhaustible source of clean energy for future generations. To achieve safe, successful, and reliable operation of fusion reactors, an in situ diagnostic method is required for structural health monitoring of Plasma Facing Components (PFCs) to identify specific damage mechanisms including cracking and erosion. Non-destructive evaluation or testing (NDE/NDT), an effective method to estimate the location, severity, and type of damages of materials, has been widely used in various applications. However, current existing NDE techniques are not suitable for the structural health monitoring of PFC due to the harsh environment of fusion reactors. There is clear need for a PFC structural health monitoring system that can operate at elevated temperatures in the presence of high magnetic fields and neutron fluence, immune to RF noise, and ultimately compatible with high performance plasma operation.

Laser Vibrometer for SHM

Luna Innovations proposed a novel NDE technique based on laser vibrometer for SHM of PFCs used in fusion reactors, as shown in Figure 1.

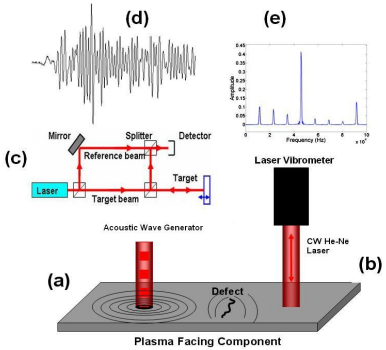

Figure 1: Conceptual drawing of the Laser Vibrometer based PFC health monitoring system.

In other research programs, Luna has developed and demonstrated an alternative technique for SHM in which the generation and detection of acoustic waves were enabled through an all-fiber optic method.

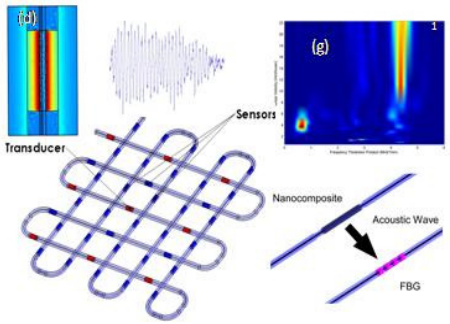

Figure 2: Conceptual drawing of the all-fiber optic ultrasonic SHM system.

Table 1: Non-contact NDE techniques for SHM of PFCs

Techniques	measurement velocity/frequency	erosion/deposition (depth) (resolution)	crack defect	Temperature	stress	material identity	Non-Contact
Ellipsometry		X (30nm)		X	X		X
Thermography			X	X		X	X
Displacement Interferometry (Static)		X (sub nanometer)		X	X		X
All-Fiber sensing	X	X(30um)	X	X	X	X	
Vibrometry	X	X(30um)	X	X	X	X	X

Defect Detection

The physical properties of the materials will change after damaged. The acoustic detection of physical parameter changes is enabled via modal evaluation. A depiction of acoustic waves undergoing multiple reflections within the thickness of the plate is shown in Figure 3. Only the acoustic modes that replicate themselves upon multiple reflections within the thickness of the plate or along the surface of the plate will survive to be evaluated due to resonance phenomena.

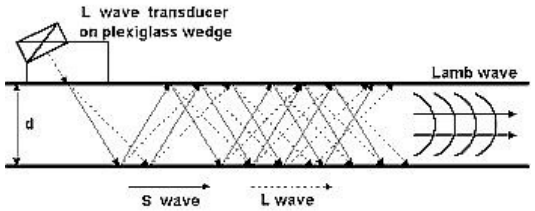

Figure 3: Cross-section of propagating acoustic waves in a plate.

Defect information can be obtained through acoustic mode dispersion analysis. The acoustic signals are measured originally in the time domain and then transformed into the time-frequency domain via short time Fourier transforms. A major aspect of the problem is the identification of the reflection, mode conversion and scattering of the Lamb waves due to damages. Figure 4 shows two examples of the acoustic detection based on the time-frequency analysis.

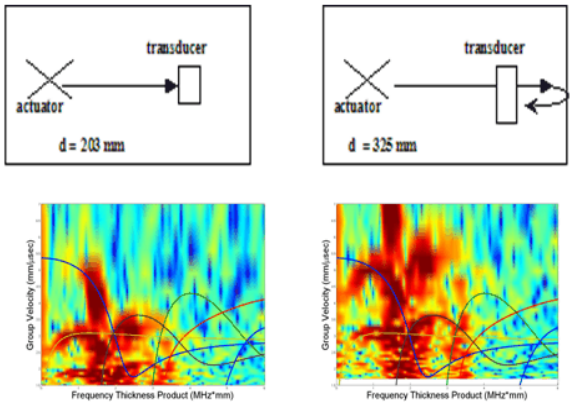

Figure 4: Best fit of modal data to theoretical dispersion curves. 203 mm (left) and 325 mm (right) path length.

Figure 5 shows the COMSOL modeling of Tungsten samples with and without crack in an acoustic resonance pattern.

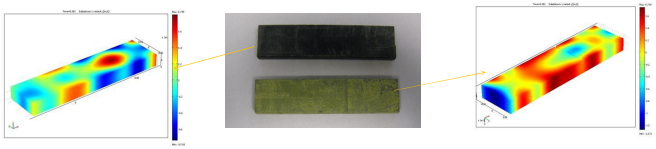

Figure 5: Tungsten samples and simulated acoustic resonance pattern.

Figure 6 presents an example of defect detection of a Tungsten sample. For both COMSOL modeling and experiment, a frequency shift in the excited "lamb" (plate) modes yields the plate thickness change.

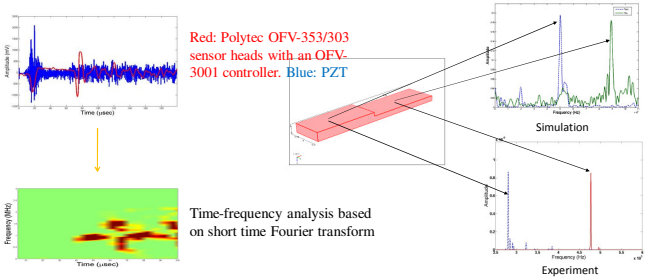

Figure 6: Defect detection of a Tungsten sample.

Luna has demonstrated thermal induced error by using room temperature parameters to analyze the signal obtained from a high temperature measurement as shown in Figure 7.

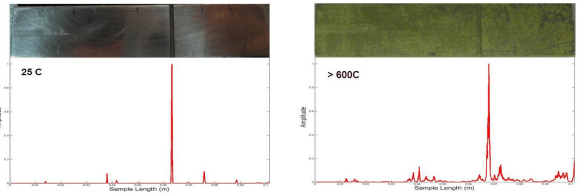

Figure 7: Thermal effect on data analysis.

Conclusion

The Laser vibrometer based PFC health monitoring technology offers an all-optical, non-contact method, which enable efficient in-situ, non-destructive-evaluation for PFCs experiencing elevated temperatures in the presence of high magnetic fields and neutron fluence while remaining immune to RF noise. Luna developed a novel solution based on laser vibrometry for in situ structure health monitoring of PFC in fusion reactor environments (potentially at temperatures > 800 °C, heat flux > 15 MW/m^2). Demonstration testing was performed upon PFC samples heated in excess of 600 ºC at a distance more than one meter.

Acknowledgements

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