High frequency acoustic microscopy imaging of Pellet/Cladding interface in nuclear fuel rods

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Abstract

Pressurized Water Reactor (PWR) fuel rods are made of ceramic pellets (UO_2, $(U,Pu)O_2$ or gadolinium fuel) assembled in a zirconium alloy cladding tube. By design, an initial gap exists between these two elements. During irradiation, they both undergo transformations leading progressively to the closure of this gap. A local and non-destructive examination of the pellet/cladding interface could constitute a useful help to identify the zones where the two materials are in contact, particularly at high burnups when a strong chemical bonding occurs under nominal operating conditions in PWR fuel rods. The evolution of the pellet/cladding bonding during irradiation is also an area of interest.

In this context, the Institute of Electronic and Systems (IES - UMR CNRS 5214), in collaboration with the Alternative Energies and Atomic Energy Commission (CEA), is developing a high frequency acoustic microscope adapted to the control and imaging of the pellet/cladding interface. Because the geometrical, chemical and mechanical nature of the contact interface is neither axially nor radially homogeneous, the ultrasonic system must allow the acquisition of 2D images of this interface by means of controlled displacements of the sample rod along both its axis and its circumference.

In the present communication, the first prototype of this microscope will be presented and the first results of the pellet/cladding interface examinations will be analyzed in order to highlight the potentials of the system, whose final objective is to be introduced in hot cells of the LECA-STAR facility in CEA-Cadarache.

Keywords: Pellet/Cladding interface, Ultrasound, High-Resolution imaging, High-frequency acoustic microscopy, Fuel rod, Non Destructive Testing.

1. Introduction

In a pressurized water reactor (PWR), the fission of uranium atoms produces heat which transforms the water into steam and drives a turbine connected to a generator that produces electricity. The pressurized water (in a liquid state) is both coolant and moderator. This type of reactor is the most widespread in the world, representing approximately 55% of installed reactor. EDF has 58 PWRs in France [1]. Reactor cores where fission takes place may contain up to 11 million ceramic pellets [2] of UO_2, MOX or gadolinium fuel stacked inside a zirconium alloy cladding tube that form fuel rods (see Figure 1 (a) and (b)).

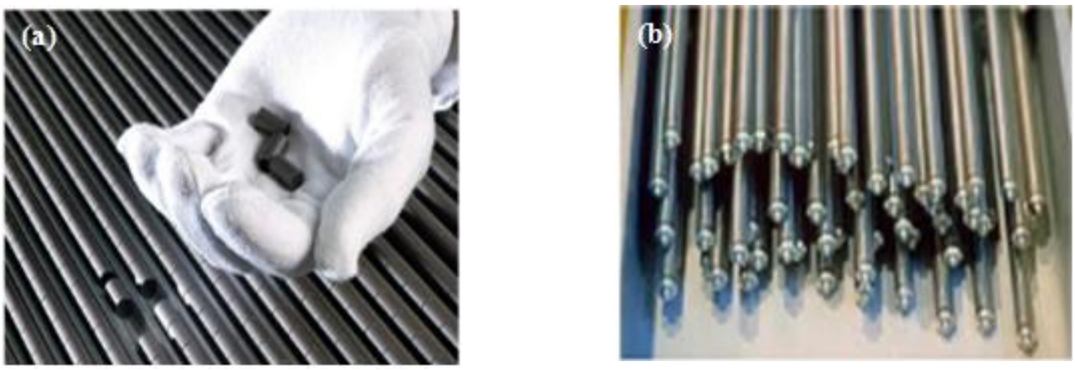

Figure 1: (a) Pellets (b) assembled in a Zirconium alloy cladding [3].

By design, a gap, filled with helium, exists between the pellets and the cladding forming the first containment barrier for nuclear fuel [4]. The several transformations undergone by the fuel rod during the irradiation lead to a reduction of this initial gap until its closure [5]. The control and/or characterization of the pellet/cladding interface should then allow an additional understanding of the fuel rod behavior at different burnups.

In the present paper, we propose to describe a High-resolution Acoustic Microscope allowing a non-destructive investigation of the pellet/cladding interface.

2. High-resolution Acoustic Microscopy

The general principle of acoustic microscopy is presented in figure 2 [6]. An electrical signal is sent to a piezoelectric element in contact with a silica delay line generating a high-frequency ultrasonic wave. This latter propagates to an acoustic lens that focuses through a coupling medium the ultrasonic field onto the sample. The reflected waves are then sent back to the piezoelectric element where they are converted, by reciprocity, into electrical signals. By controlling the sensor manufacturing, and in particular, the focusing lens, the system may allow the acquisition of surface and in-depth echoes. The Acoustic Microscope developed in the present study operates with a 150 MHz center frequency leading to acquire 2D images with resolutions in the order of several tens of microns.

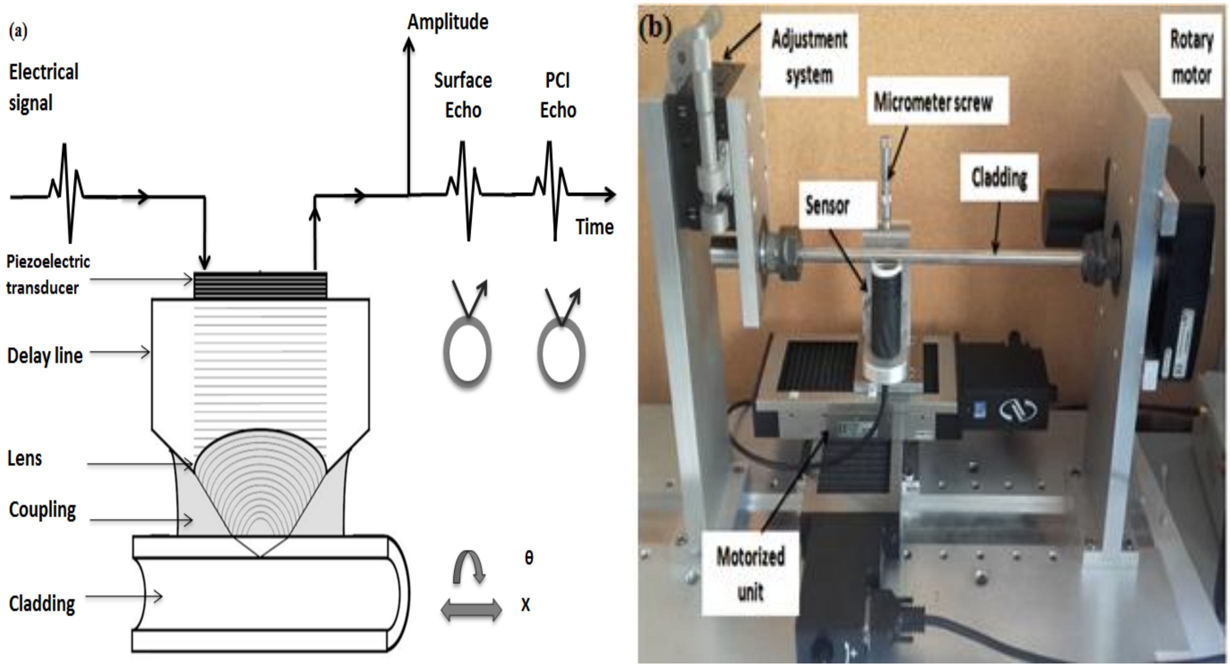

Figure 2: (a) General principle of Acoustic Microscopy (b) Laboratory prototype implemented in a mechanical bench.

3. Description of the ultrasonic device

a- Mechanical bench

The acoustic sensor is designed to be connected to a motorized unit allowing its horizontal movement along the length of the rod. Moreover, the rotation of the latter is achieved via a rotary motor to acquire the data along the entire circumference. To realize the image of the inner face of the cladding, a micrometer screw is attached to the sensor allowing the variation of its altitude and then the optimization of its focusing position.

b- Acquisition system

The acquisition system possesses the following components:

- A Dual channel digitizer Agilent Acqiris DC152 with 2 GHz of bandwidth that provides synchronous sampling of 2 GS/s on both input channels. In single-channel applications this doubles to 4 GS/s. This acquisition board is characterized by a resolution of 10 bits.
- An electronic board designed and produced by IES to improve the excitation signal of the transducer.
- Two softwares developed specifically for signal acquisition and processing.

4. Results

In the present section are exposed the results obtained during a first experiment performed on an empty zirconium alloy tube. To evaluate the sensitivity of the device to a modification of the inner surface, some glue was introduced inside the cladding. Figure 3 presents the ultrasonic signals acquired by the device when the focusing point of the sensor is positioned in the wall thickness in order to simultaneously visualize the outer (a) and inner surface (b) echoes.

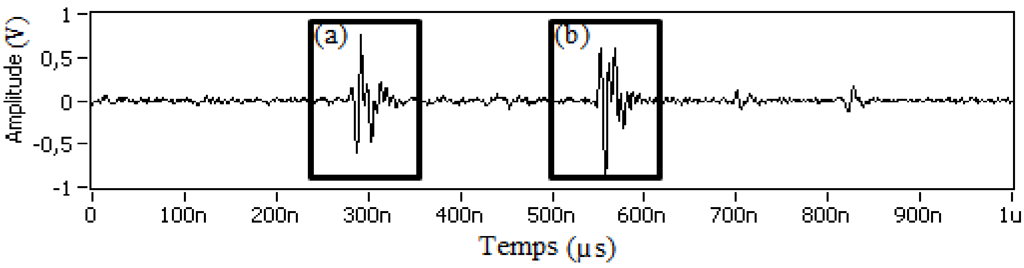

Figure 3: Signal collected by a piezoelectric transducer (a) outer surface echo (b) inner surface echo.

Moreover, combined with full rotations of the rod, the system allows the reconstruction of 2D images of the outer and inner surfaces of the tube (see Figure 4 (a) and (b)).

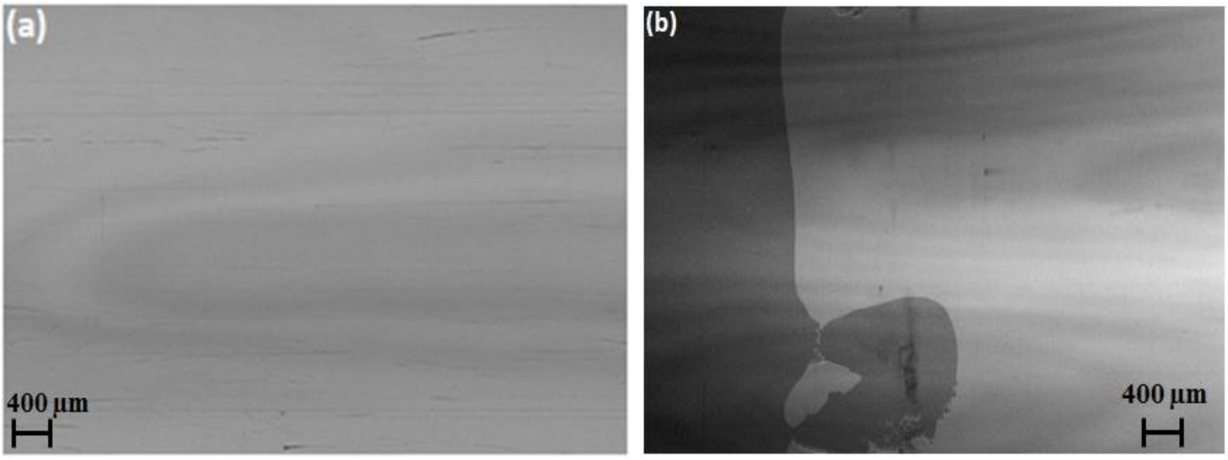

Figure 4: Images of (a) outer surface and (b) the inner surface of the tube including a glue layer.

The darkest part of figure 4 (b) corresponds to areas where the glue has been deposited. During reflection, the ultrasound energy is transmitted into this absorbing layer yielding lower reflection coefficients. On the right part of the image, the ultrasound energy is fully reflected at the interface between the zirconium alloy tube and air.

In a way to evaluate the resolution of the device at the inner surface, a second image has been acquired on a 1 mm thick aluminum tube where the name of the Institute “IES” has been engraved. Results are presented in Figure 5.

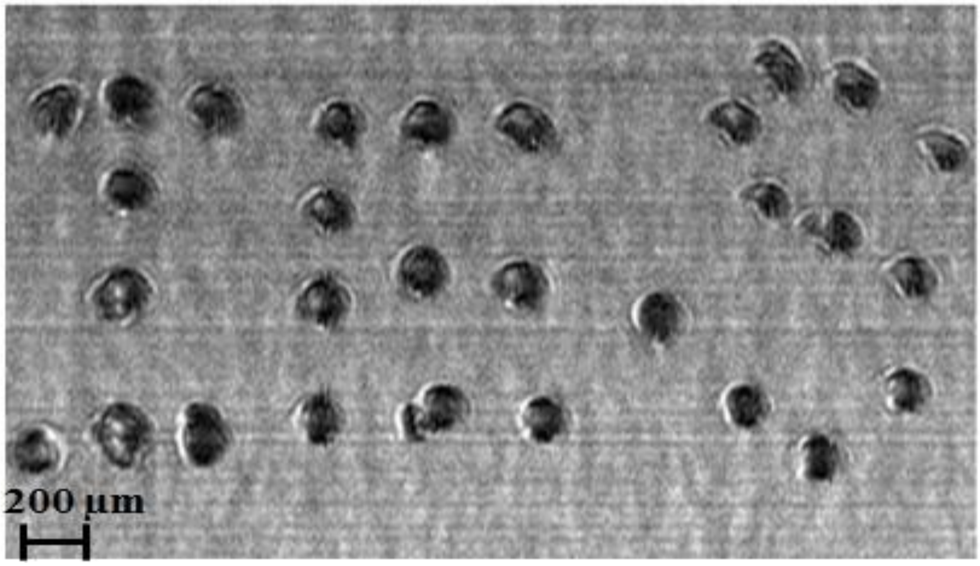

Figure 5: Image of the inner surface of an aluminum tube with an “IES” engraving.

5. Conclusion

In the present paper, acoustic microscopy which is a non-destructive technique is employed to investigate the pellet/cladding interface of the fuel rod. A high frequency ultrasound device connected to an electronic acquisition instrument allowed image acquisitions with a 30 µm resolution at the inner face of the cladding. The first results clearly demonstrated the ability of the system to detect interface modifications in terms of contact or defect identifications. Future work will deal with the optimization of the mechanical part of the device as well as the signal processing to increase the image resolutions. A radiation reliability study will then be performed in a way to propose the system as a standard control tool in the hot cells of the LECA-STAR facility in CEA-Cadarache.

Acknowledgments

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