Detection of Fatigue Damage by Using High Frequency Nonlinear Laser Ultrasonic Signals

Seung-Kyu Park [a*], Nak-Kyu Park [a], Sung-Hoon Baik [a], Yong-Moo Cheong [a] and Byung-Heon Cha [a]

[a]*Korea Atomic Energy Research Institute, 150 Dukjin-Dong, Yuseong, Daejeon 305-353, Rep. of Korea*

[*] skpark4@kaeri.re.kr

1. Introduction

The detection of fatigue damage for the components of a nuclear power plant is one of key techniques to prevent a catastrophic accident and the subsequent severe losses. Specifically, it is preferred to detect at an early stage of the fatigue damage. If the fatigue damage that is in danger of growing into a fracture is accurately detected, an appropriate treatment could be carried out to improve the condition. Although most engineers and designers take precautions against fatigue, some breakdowns of nuclear power plant components still occur due to fatigue damage. It is considered that ultrasound testing technique is the most promising method to detect the fatigue damage in many nondestructive testing methods.

Laser ultrasound has attracted attention as a non-contact testing technique. Especially, laser ultrasonic signal has wide band frequency spectrum which can provide more accurate information for a testing material [1-3].

The conventional linear ultrasonic technique is sensitive to gross defects or opened cracks whereas it is less sensitive to evenly distributed micro-cracks or degradation. An alternative technique to overcome this limitation is nonlinear ultrasound. The principal difference between linear and nonlinear technique is that in the latter the existence and characteristics of defects are often related to an acoustic signal whose frequency differs from that of the input signal. This is related to the radiation and propagation of finite amplitude, especially high power, ultrasound and its interaction with discontinuities, such as cracks, interfaces and voids. Since material failure or degradation is usually preceded by some kind of non-linear mechanical behavior before significant plastic deformation or material damage occurs [4].

The presence of nonlinear terms in the wave equation causes intense acoustic waves to generate new waves at frequencies which are multiples of the initial sound-wave frequency. The nonlinear effect can exert a strong effect on the structure and interaction of solids, making intense ultrasound applicable in material characterization. These effects are enormous in damaged material but nearly un-measurable in undamaged materials, hence the interest in applying nonlinear ultrasound. Those are expected to be much more sensitive to micro-damage than the conventional linear characteristics of ultrasonic wave.

In this paper, we have investigated a detection technique to detect fatigue damage by using nonlinear components of high frequency laser ultrasonic signals. A detection technique and experimental results based on the nonlinear laser ultrasound are described in this paper.

2. Configuration of a Detection System for Fatigue Damage and Experiments

A block diagram and a photo of a detection system for fatigue damage are shown in Fig. 1 and Fig. 2, respectively. The system consists of a pulse laser to generate high frequency laser ultrasound, a receiving transducer to receive longitudinal ultrasound, an oscilloscope to digitize data and a computer for signal processing.

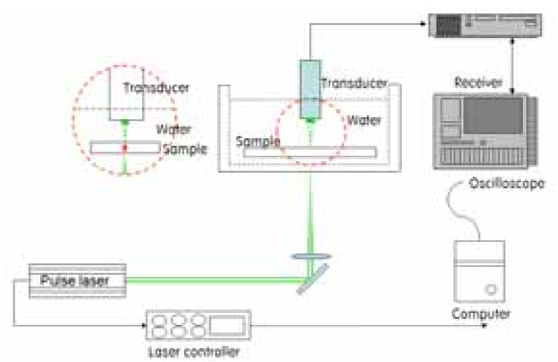

Fig. 1. Block diagram of a configured laser ultrasonic system to detect fatigue damage.

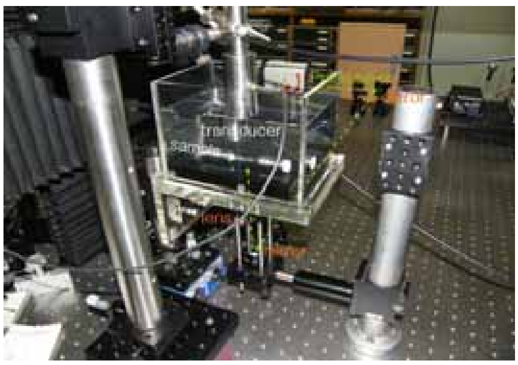

Fig. 2. Photo of a configured laser ultrasonic system to detect fatigue damage.

Six specimens of a circle type of SUS316, fatigue rates of 0%, 50%, 60%, 70%, 80% and 90% of a fracture cycle of N_f, were prepared for experiments. We used multiple power longitudinal laser ultrasounds generated by four levels of pulse laser beams as shown in Fig. 3. Two averaged nonlinear components, harmonic nonlinear components and mixed frequency components of two signals, were used to detect fatigue damage because laser ultrasound having wideband frequency components is generated by one pulse laser beam. The frequency spectrums corresponding to the four L_2 signals of Fig. 3 are shown in Fig. 4.

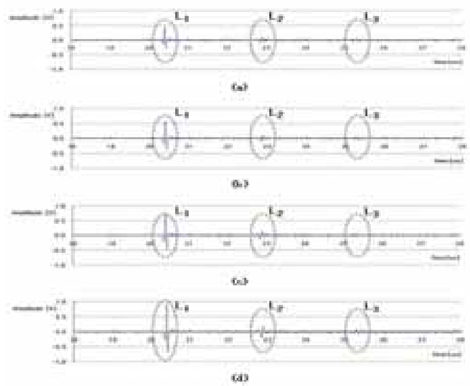

Fig. 3. Laser ultrasonic signals acquired from the intact specimen according to pulse laser power.

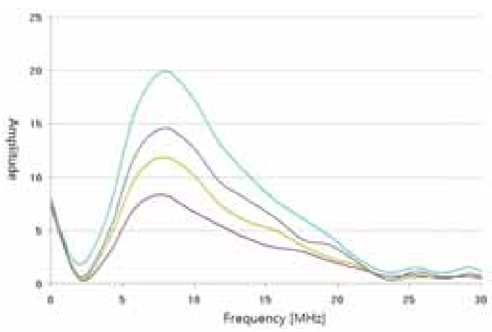

Fig. 4. Frequency spectrums for the L2 signals according to power level of the pulse laser.

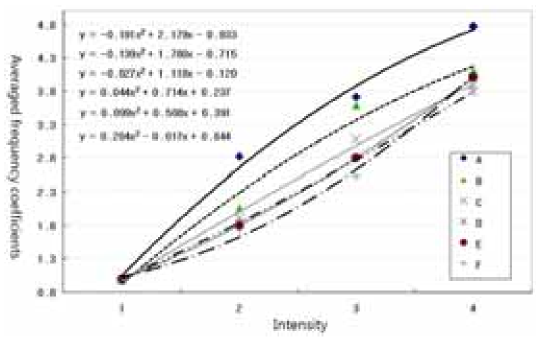

Fig. 5. Graph of the averaged frequency coefficients according to intensities.

Averaged frequency coefficient values from 10 MHz to 24 MHz according to laser power are shown in Fig. 5 and also their 2nd order fitting graphs including nonlinear components are shown in Fig. 5. A normalized graph between the 2nd order coefficient values and fatigue damage rate is shown in Fig. 6. As we can see, the fatigue damage rate was efficiently extracted from the nonlinear laser ultrasounds.

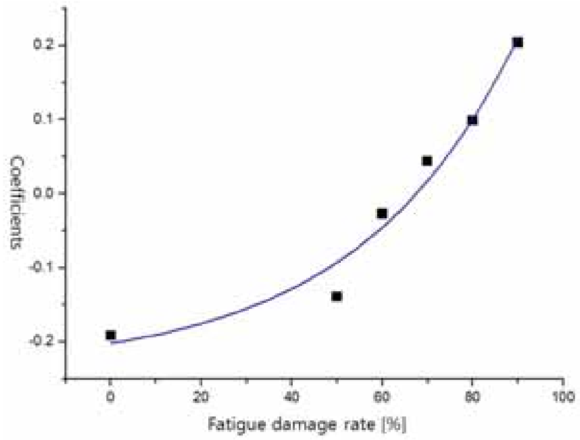

Fig. 6. Measured fatigue rate by using nonlinear coefficient value of the laser ultrasound.

3. Conclusions

A new detection technique for the fatigue damage by using nonlinear laser ultrasound was developed in this paper. The value of the 2nd order fitting coefficient was used as a nonlinear value. An averaged frequency component value from the wide band frequency area was used because the laser ultrasonic signal including all frequency components is generated by one pulse laser. As the experimental results, the fatigue rate was efficiently extracted by this technique.

For further research, it is necessary to improve the generation technique of high frequency laser ultrasound and signal processing technique in the frequency domain.

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