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A Laser-based Ultrasonic Inspection System to Detect Micro Fatigue Cracks

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1. Introduction

Laser-based ultrasonic techniques have been established as a viable non-contact alternative to piezoelectric transducers for generating and receiving ultrasound[1]. Laser-based ultrasonic inspection system provides a number of advantages over the conventional generation by piezoelectric transducers, especially a non-contact generation and detection of ultrasonic waves, high spatial scanning resolution, controllable narrow-band and wide-band spectrum, absolute measurements of the moving distance, use of fiber optics, and an ability to operate on curved and rough surfaces and at hard-to-access locations like a nuclear power plant.

Ochiai[2] and Miura[3] used the laser-based ultrasound to detect micro fatigue cracks for the inspection of a material degradation in nuclear power plants. This widely applicable laser-based ultrasonic inspection system is comparatively expensive and provides low signal-to-noise ratio to measure ultrasound by using the laser interferometer. Many studies have been carried out to improve the measuring efficiency of the laser interferometer[4]. One of the widely used laser interferometer types to measure the ultrasound is the Confocal Fabry-Perot Interferometer(CFPI). The measurement gain of the CFPI is slightly and continually varied according to the small change of the cavity length and the fluctuations of the measuring laser beam frequency with time. If we continually adjust the voltage of a PZT which is fixed to one of the interferometer mirrors, the optimum working point of the CFPI can be fixed[1, 5]. Though a static stabilizer[5] can fix the gain of the CFPI where the CW laser beam is targeted at one position, it can not be used when the CW laser beam is scanned like a scanning laser source(SLS) technique[6]. A dynamic stabilizer can be used for the scanning ultrasonic inspection system[2]. A robust dynamic stabilizer is needed for an application to the industrial inspection fields. Kromine[6] showed that the SLS technique is effective to detect small fatigue cracks on the surface. We can detect small fatigue cracks by finding the abrupt changing of the amplitude of the ultrasound and its center frequency in the SLS technique[6]. It means that the scanning laser beam is located in the vicinity of the cracks.

In this paper, we developed a stable laser-based ultrasonic inspection system using a pulse laser, a CFPI with a dynamic stabilizer and a computer. The computer is equipped with a GHz high speed A/D converter, three A/D converters, one D/A converter and one digital output port. The configured dynamic stabilizer generates the laser-based ultrasound by triggering a pulse laser at the maximum gain time by continually observing the gain of the CFPI. The computer acquires the laser-based ultrasound by using the GHz high-speed A/D converter and processes the ultrasonic signal in real time. We experimentally confirmed that the developed laser-based ultrasonic inspection system is stable and can detect cracks using the SLS technique.

2. The configured laser-based ultrasonic inspection system

The hardware configuration of a developed laser-based ultrasonic inspection system is shown in Fig. 1. We configured a laser-based ultrasonic inspection system using a personal computer with a high-speed data acquisition board(AL81G, ALI) and a multifunction board (PCI9112, ADLink), a pulse laser (Quantel-Brilliant), a stabilized CW green laser (142H, LightWave Elec. Inc.) and a CFPI(CFT-500, Buleigh, FSR 150MHz). The computer controls a 1-D translator(OEM57-83, Parker) and a 2-D translator(ATS212-M, Aerotech Inc) through the Ethernet communications by using a LAN port. We configured two high-speed and high-gain APD sensors(C3090E, PerkingElmer) to acquire an ultrasonic signal and we used two commercial photo sensors(DET210, DET100, ThorLabs) as a trigger sensor and a measuring sensor for a pulse laser beam. The optimum period of the pulse laser is 10 Hz and the FWHM of a pulse laser beam is 10 ns. So, the period of an applied saw-tooth wave is 10 Hz.

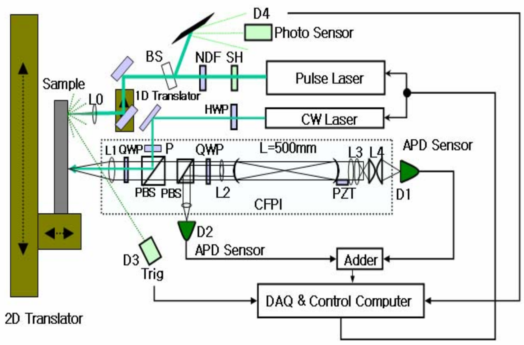

Fig. 1. Configuration of a developed laser-based laser ultrasonic inspection system

Ultrasound is generated when a pulse laser beam is targeting the surface of an object. Then, the CFPI measures the surface displacement caused by the ultrasound at the target position of a CW laser beam.

The adder circuit as shown in Fig. 1 makes a conjugate fringe signal by adding the reflected fringe signal of the APD sensor of D2 to the transmitted fringe signal of the APD sensor of D1. The intensity value of the conjugate fringe is a doubling when compared with the intensity of the transmitted or the reflected signal. So, we can acquire almost doubling amplitude of the ultrasound by using the conjugate fringe.

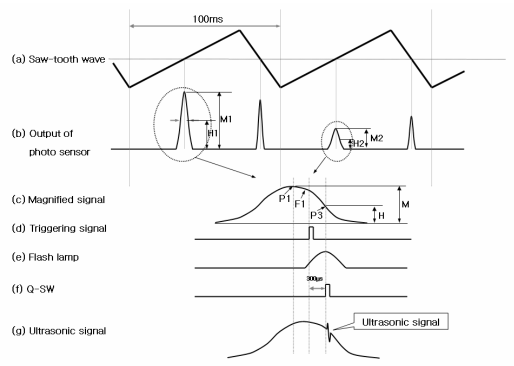

Fig. 2. Control procedures of a designed dynamic stabilizer

The control procedures of the designed dynamic stabilizer are shown in Fig. 2. The conjugate fringe signal is only out at the one voltage level of the saw-tooth wave as shown in Fig. 2(b). The dynamic stabilizer memorizes the voltage value on the rising edge of the saw-tooth wave at the peak time of the conjugate fringe signal. The dynamic stabilizer recognizes the start part of the effective area in one cycle after finding the start point of the rising edge by continually observing the saw-tooth wave. And then the dynamic stabilizer tries to find the peak position of the conjugate fringe by continually observing it. In Fig. 2 (c), the amplitude of the conjugate fringe signal at the peak position of P1 is M. If this position is found, then the dynamic stabilizer triggers the pulse laser at the position of F1 which is prior time of the Q-switching delay from the maximum slope position of P3 as shown in Fig. 2(c).

The computer controls the bias value of the PZT which positions the optimum working point of the CFPI to the center of the rising edge of the saw-tooth wave. This is processed just after a signal processing for the acquired ultrasonic signal. This bias control enables the laser-based ultrasonic inspection system to stably measure the ultrasound for a long time.

An experimental result using the SLS technique for a surface breaking crack is shown in Fig. 3. Here the width and the depth of the crack are 0.3mm and 0.4 mm respectively. The abrupt rising of the peak-to-peak signal of the ultrasound is caused by the constructive interference between the generated ultrasound by a pulse laser beam and the reflected ultrasound from the crack. So, we can detect the crack by finding the abrupt rising of the peak-to-peak value for the acquired ultrasound.

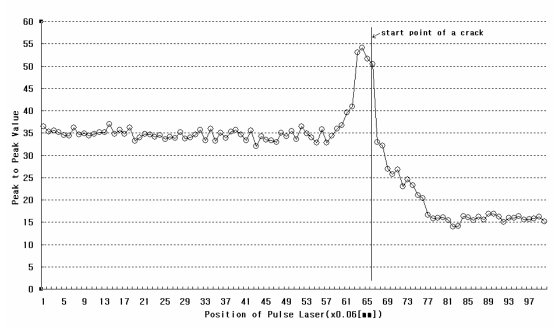

Fig. 3. Measured peak-to-peak value of ultrasound to detect a crack according to SLS position

3. Conclusion

We developed a laser-based ultrasonic inspection system using a pulse laser and a CFPI with a dynamic stabilizer in this paper. The developed system detects cracks without any contact by using a scan. This system generates the ultrasound at the maximum gain time of the CFPI by adaptively finding the maximum slope position of the conjugate fringe signal at each time.

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