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Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 253-254
18-20 November, 2009

Second Harmonic Components Detection for Fastening Bolts Using Double-Layered Piezoelectric Transducer

二層型圧電振動子を用いたボルト締め付けにより発生する 2 次高調波の検出

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1. Introduction

Bolt fastening is frequently used for the assembly of machine structures. Since broken, slack or over-tightened bolts lead to serious accidents, the quality control and maintenance check of a bolt fastening is a very important issue. Inspection methods for measuring bolt axial force include the ultrasonic, strain gauge, and load cell methods [1)]. In these methods, complicated corrections for the measured values are required to obtain accurate bolt axial force [1)]. Thus, the novel measuring methods without complicated corrections for determining the fastened condition of a bolt.

In the conventional ultrasonic method for measuring bolt axial force, only the fundamental component of the ultrasonic waves is generally used. On the other hand, nonlinear ultrasonic waves and the second harmonic components have been studied for use in Nondestructive Evaluation (NDE) [2, 3)]. The second harmonic component is generated by nonlinear vibrations of closed cracks and dislocations when the bolt is subjected to the finite-amplitude ultrasonic waves. When the structure is bolted, the bolt stretches and axial force is applied with the nut. If the axial force exceeds the elastic yield point, a part of the bolt will be plastically deformed, and fractures may be generated. These plastic-deformations or fractures can cause the generation of second harmonic ultrasonic waves. In this study, the second harmonic component generated from the bolt was detected before and after the fastening of a bolt with a nut using a double-layered piezoelectric transducer (DLPT).

2. Method of experiment

The DLPT, which can transmit finite-amplitude ultrasonic waves and receive a second harmonic component, was used to construct a simple pulse-echo system [4, 5)]. The DLPT was composed of two $PbTiO_3$ (PT) thickness-mode piezoceramic plane disks that have the same characteristics (resonance frequency f_0 = 2 MHz). The DLPT was electrically connected in parallel or in series and its frequency-admittance characteristics when connected in parallel and in series are shown in Figs. 1(a) and 1(b). An effective fundamental transmission (1 MHz) was obtained when the DLPT was electrically connected in parallel while efficient second harmonic reception (2 MHz) was obtained when the DLPT was connected in series.

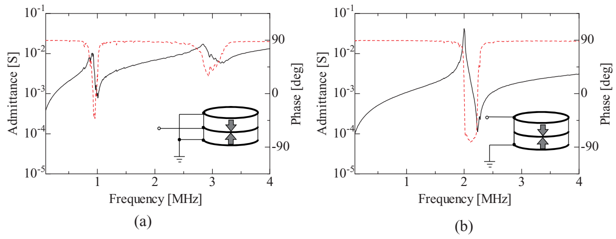

Fig. 1 Frequency-admittance characteristics of a DLPT connected electrically (a) in parallel and (b) in series.

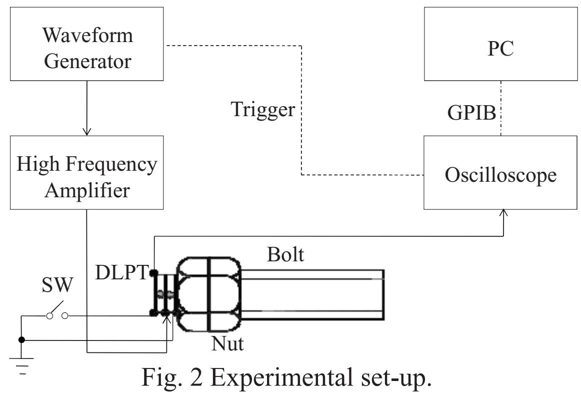

Fig. 2 Experimental set-up.

The system of employing DLPT is shown in Fig. 2. Exciting voltage signals were generated using an arbitrary waveform generator and their amplitudes were amplified up to 150 V with a high-frequency power amplifier. Ultrasonic pulses of 1 MHz were transmitted through the bolt. Before the reflected pulse waves reached the DLPT transducer, the switch was turned off to receive the

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second harmonic component (2 MHz). An oscilloscope captured the resultant pulses and their spectra and the second harmonic components were observed in real time using the FFT function of the oscilloscope. Finally, the received pulse waveforms were digitized and fed to a personal computer via a general purpose interface bus (GPIB).

Hexagon head iron bolts for general purpose use with a screw diameter of 12 mm and a length of 100 mm were used in the experiment. The bolts were fastened by nuts using a torque wrench and no object was included. The torque was 40 N-m (general torque of intensity classification 4.8 [1]).

3. Results and discussion

The received waveform and its spectrum before fastening the bolt are shown in Fig. 3(a) and 3(b), and the received waveform and its spectrum after fastening the bolt are shown in Fig. 3(c) and 3(d). These waveforms were processed by pulse inversion averaging (PIA) to cancel the fundamental components. The amplitudes of these spectra were normalized by the amplitudes of the fundamental component before PIA. The detected result of the second harmonic component after fastening was increased by approximately 10 dB.

The bolt axial force for the case of the bolt fastened by a torque of 40 N-m was approximately 30 kN, which was measured by the load washer. A previous study reported that detected second harmonic components using plastic-deformed metal rods also showed an increase in tensile strain [5]. The bolt axial force was increased as the bolt was fastened, and the bolt may have been plastic-deformed as the bolt axial force was increased. Thus, second harmonic component detection using our system will be applied to evaluate the condition of the several bolts, such as over-tightening.

However, the bolt axial forces fastened by a torque of 40 N-m are dispersed from 15 kN to 30 kN shown in Fig. 4. The bolt axial force might demand on the tribology effect of the nut. The relation between the friction and the generated second harmonic component should be considered.

4. Conclusions

The second harmonic component before and after fastening a bolt was detected by using double-layered piezoelectric transducer (DLPT). The detected second harmonic component after fastening the bolt was increased by approximately 10 dB compared with before it was fastened.

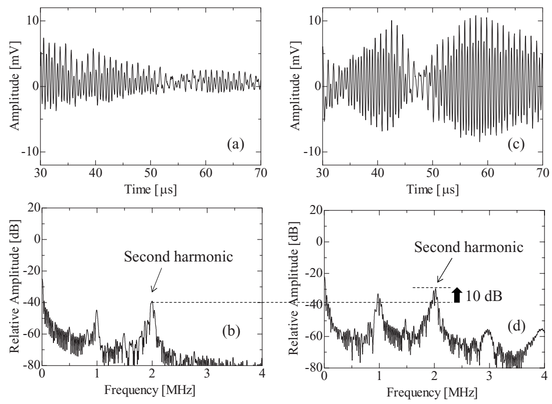

Fig. 3 (a) The received waveform and (b) its spectrum before fastening the bolt. (c) The waveform and (d) its spectrum after fastening the bolt. These results were carried out with pulse inversion averaging.

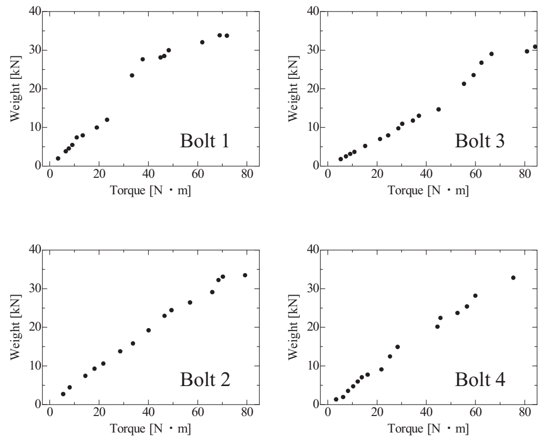

Fig. 4 The relation between the torque and the weight.

It is not certain whether we have reached the yield stress with the torque in the experiment, since the coefficient of friction of a bolt is not clear. In the future, a quantitative measurement of changing torque levels will be required.

Acknowledgment
This work was supported by a Grant-in-Aid for Young Scientists (Start-up) (No.20860020) from the Japan Society for the Promotion of Science.

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