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Detection of Second Harmonic Ultrasonic Waves Generated from Fastened Bolts
締結状態下におけるボルトからの２次高調波超音波の検出

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1. Introduction

Bolts and nuts are frequently used as a standard fastener used in the assembly of mechanical structuers. Since broken, slack, or over-tightened bolts can lead to serious accidents, quality control becomes the important issue. Current inspection methods for measureing bolt axial force include ultrasonic, strain gauge, and load cell techniques. However, complex corrections for the measured values are required to obtain accurate measurements of bolt axial force using these methods.[1)] Therefore, simple quality control techniques has been demanded.

Recently, the measurement of nonlinear ultrasonics, including second harmonic components, has been applied in nondestructive evaluation (NDE).[2, 3)] The second harmonic components are generated by the nonlinear responses of closed cracks or contact acoustic nonlinearity (CAN) when objects are subjected to finite-amplitude ultrasonic waves. When a structure is fastened by a bolt, an axial stretch force is applied to the bolt. When the axial force exceeds the bolt's elastic yield point, the bolt is plastically deformed and may develop and grow the fractures. These plastic deformations and fractures can increase the second harmonic response of the bolt.

In our previous paper, the detection of second harmonic components generated from the fastened bolts, which ultrasonic waves were transmitted and received in the bolt heads or the bolt edges.[4)] To evaluate the fastened bolt, ultrasonic waves should be transmitted through the part fastened by nuts.

In this study, the second harmonic components generated from the part fastened by nuts in the fastened bolt are detected by the ultrasonic transmission method before and after fastening.

2. Experimental Method

A schematic diagram of our system for detecting second harmonic components using the ultrasonic transmission method is shown in **Fig. 1**. To drive the system, 20 cycles a 1 MHz burst sinusoidal waveform generated using an arbitrary waveform generator were amplified to 100 V with a high-frequency power amplifier. The amplified signal was applied to a 1-MHz-resonant transmitting transducer, which transmitted the ultrasonic pulses through the bolt. The 2 MHz second harmonic component generated from the fastened bolts was received by a 2-MHz-resonance receiver transducer. An oscilloscope captured the resulting pulses and displayed their spectra in real time using the FFT function. Finally, the received pulse waveforms were digitized and sent to a computer via a general purpose interface bus. In our system, the pulse inversion averaging (PIA) method[5)] was applied to enhance the second harmonic component. This method involves time averaging of received waves to cancel out their fundamental and odd-harmonic components.

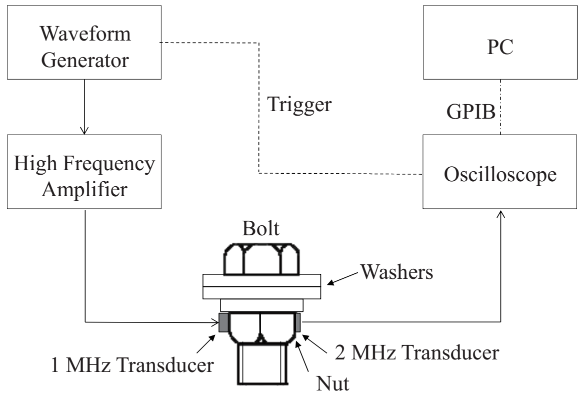

Fig. 1 Experimental set-up.

General-purpose hexagon-head iron bolts with a screw diameter of 14 mm, a length of 25 mm and an optimal torque of 40 N-m (general torque of intensity classification 4.8[1)]) were used in the experiment. The bolts were fastened by nuts using a torque wrench and washers were included.

3. Results and discussion

The spectrum of received waveform before fastening the bolt are shown in **Fig. 2(a)**, and the spectrum of received waveform after fastening the bolt are shown in **Fig. 2(b)**. These results were

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processed by PIA to cancel the fundamental components. The amplitudes of these spectra were normalized by the amplitudes of the fundamental component before PIA. The detected results of the second harmonic component after fastening was increased by approximately 3 - 20 dB. It is conceivable that second harmonic components before fastening were generated by CAN between bolts and nuts or between nuts and transducers. Since the condition of the surfaces between respective bolts and nuts after fastening was different, the second harmonic components were changed.

In Fig. 2(b), sub harmonic components (500 kHz) were detected. Sub harmonic components were known to be also generated by CAN.[3] Therefore, the 500 kHz subharmonic component generated from the fastened bolts was replaced a 2-MHz-resonance receiver transducer with 500-kHz-resonance receiver transducer. The spectra of received waveforms before and after fastening the bolt are shown in **Fig. 3(a)** and **3(b)**. The detected result of the subharmonic component after fastening was increased by approximately 10 dB. Since subharmonic components don't generate from the coupler, the evaluations for the bolt fastening using both second harmonic components and subharmonic components shuold be carried out in the future.

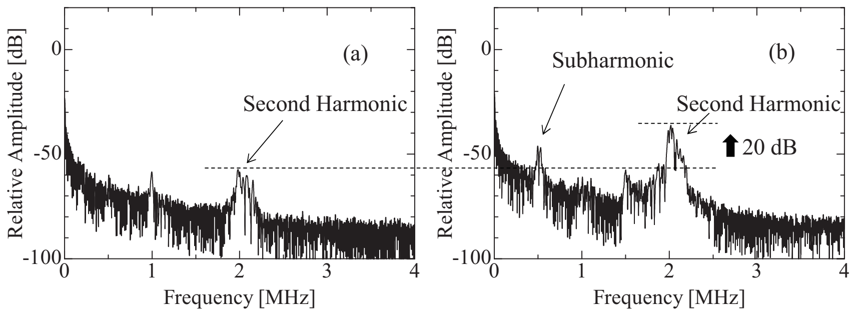

Fig. 2 The spectra of received waveform
(a) before and (b) after fastening for Bolt B.
Transmission 1MHz- reception 2MHz.

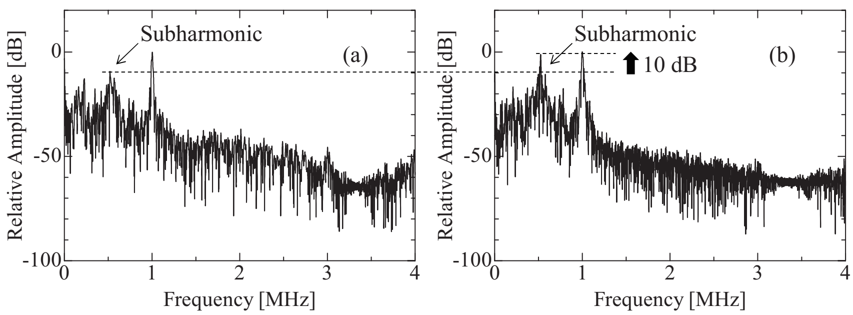

Fig. 3 The spectra of received waveform
(a) before and (b) after fastening for Bolt B.
Transmission 1MHz- reception 500 kHz.

4. Conclusions

The second harmonic component before and after fastening a bolt was detected. The detected second harmonic component after fastening the bolt was increased by a maximum of 20 dB, compared with before it was fastened. Furthermore, the subharmonic component before and after fastening a bolt was detected. The detected subharmonic component after fastening the bolt was increased by approximately 10 dB.

To establish a second harmonic component and a subharmonic component bolt fastening evaluation methods, the evaluations for the several bolts second harmonic components and subharmonic components will be required.

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