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Subharmonic generation at interfaces of a thin layer between metal blocks

金属ブロック間の薄膜界面における分調波の発生

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1. Introduction

Nonlinear ultrasonic tesing, a new nondestructive evaluaton technique for materials, has been studied recently in many groups, being expected to detect tiny inclusions and adhered closed cracks which is supposed to be undetectable by conventinonal ultrasonic techniques. Especially after Solodov[1] showed nonliear ultrasonic phenomena appear strongly by interface contacts and introduced a wide variety of measurements for non-destructive evaluation, many studies on high accurate crack evaluation have been presented.

Nonlinear phenomena at contact interfaces were theoretically studied by Richardson[2], Baik and Thompson[3], Pecorari[4], and Biwa et.al.[5]. Especially, higher harmonic generation were investigated in detail, because it can be easily modelled by dashpod –mass[3], spring-mass[4], or nonliear spring[5]. On the contrary, studies on the mechnism of subharmonic generation are still limited[6-9].

Therefore, this study first shows subharmonic waves can be generated largely at a thin layer between metal blocks, and discusses the mechanism of subharmonic generation.

2. Significant subharmonic generation at a thin layer between metal blocks

In most studies on subharmonic generation, experimental specimens include structures with very large vibrations. For example, Korshak et. al.[6] dealed with cracks on SAW, and Delrue and Abeele[7] used a plate with delamination, that is, a plate with a thin membrane. Considering these results , this paper deals with ultrasonic transmission through thin foil between metal blocks.

Fig.1 shows a schematic figure of experi-mental set-up. Ultrasonic wave transmits through interefaces of aluminum foil of 20μm thickness and two aluminum alloy blocks (A5052, 40x40x50mm) and received by an ultrasonic transducer. Aluminum blocks with three different roughness were prepared with polishing papers of #180, #320, and #1000. Compression load was applied to the specimens including two aluminum blocks and the load was measured by a load cell.

Fig.2 is typical frequency spectra shwoing the differece of detected signals between with and without the aluminum foil. Although higher harmonic waves were detected in both cases, a subharmonic peak at half of fundamental frequency were obtaind only in the aluminum blocks with foil.

The absolute value of displacement in the aluminum blocks was estimated about 2nm from the results in the through-transmission measuremnet by laser doppler vibrometer using the same transmitter setting and one aluminum alloy block of 80mm length with no interfaces This represents that subharmonic wave can be detected with much smaller incident wave than Yamanaka and Ohara's studies[9, 10].

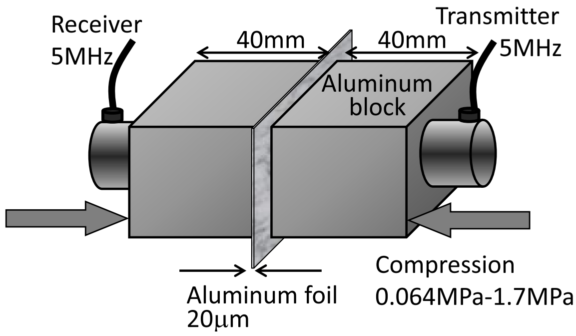

Fig. 1 Schematic figure of experiments

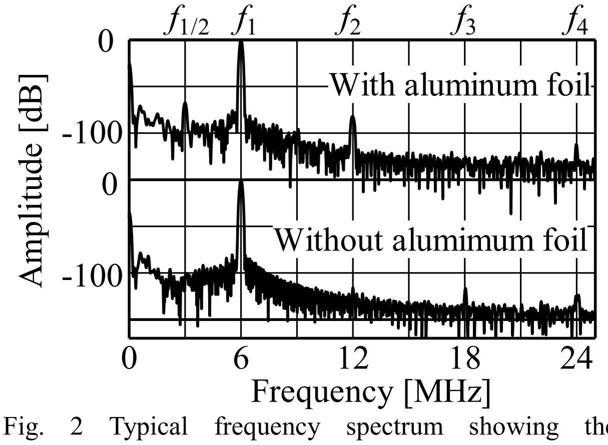

Fig. 2 Typical frequency spectrum showing the difference of detected signals with and without an aluminum foil. (Incident wave is 6MHz, 72cycle sinusoidal wave with about 370 Vp-p, compressional pressure is about 0.064MPa, and contact surfaces of aluminum block are polished with a #1000 paper.)

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3. Relationship of subharmonic generation with input voltage, contact pressure, and surface roughness

To investigate the mechanism of subharmonic generation, subharmonic amplitude denoted as $A_{1/2}$ is evaluated for various input voltage, contact pressure, and surface roughness.

Fig.3 is frequency spectra in dB representation for four different input voltages applied to the transmitter. In (b), (c), and (d), a distinct subharmonic peak can be seen at 3 MHz for 6 MHz incident wave, while in (a) for the smallest input voltage, it cannot be obtained.

Here we introduce the value of relative subharmonic amplitude described by the difference between subharmonic $A_{1/2}$ and fundamental amplitudes A_1 in dB representation as,

$$A_{1/2}[dB]-A_1[dB]=20\log(A_{1/2}/A_1). \quad (1)$$

Fig.4 shows variations of the relative subharmonic amplitude as a function of input voltage for four different contact pressures. The hatched area in the figure means that subharmonic peaks cannot be measured as seen in Fig.3 (a).

In the case for low contact pressures (0.064MPa, 0.26MPa) where significant relative subharmonic amplitude was obtained, the subharmonic amplitude changes abruptly at certain input voltages. For example, in 0.064MPa, the curve of the subharmonic amplitude jumps up at about 100Vp-p first and increases linearly until about 160Vp-p. Then it abruptly increases at about 230Vp-p again. The sudden changes of subharmonic generation like this, characterizing nonlinear effect at the interface, were also observed experimentally by Korshak's and Ohara's studies[7,10].

Next, variations of relative subharmonic amplitude for three different surface roughnesses as a function of input voltage are shown in Fig.5. These results manifest that subharmonic wave generates easier in flatter surfaces. Flat surfaces facing at smaller average distance repeat contact and separation in large incident ultrasonic wave, which leads to large nonlinear characteristics.

4. Conclusions

This study described significant subharmonics generate at interfaces of aluminum foil between two aluminum alloy blocks. Moreover, relative subharmonic amplitude was measured for various input voltage, contact pressure, and surface roughness, and the results showed characteristics of nonlinear effect at the contact interfaces.

References

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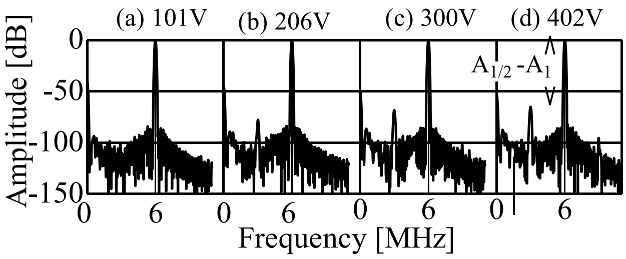

Fig.3 Frequency spectra for various input voltage (#1000 specimen, contact pressure 0.26MPa)

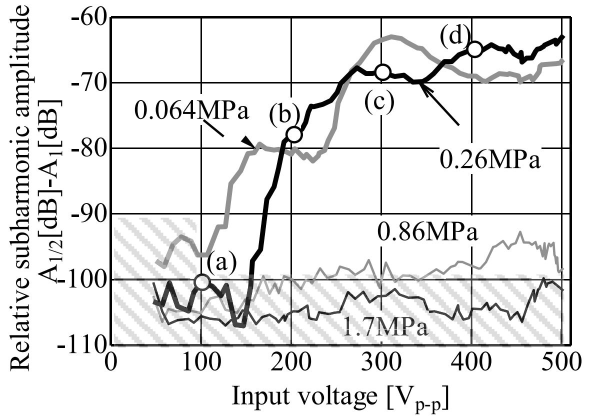

Fig.4 Input voltage versus relative subharmonic amplitude for various contact pressure (#1000 specimen)

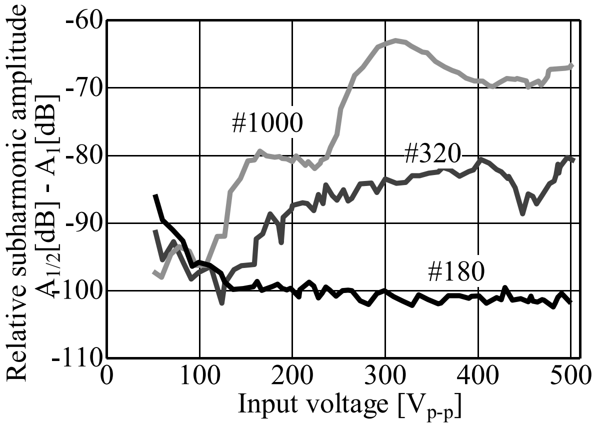

Fig.5 Input voltage versus relative subharmonic amplitude for various surface roughness (contact pressure 0.064MPa)