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Nonlinear ultrasound behavior dependence on crack closure using FEM method
有限要素法を用いたき裂の開閉口と非線形超音波伝搬挙動

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1. Introduction

When large amplitude ultrasound is incident to the crack with the frequency of f, nonlinear harmonic frequency ultrasound of 2f and f/2 and so on sometimes generate at crack. The subharmonic wave is especially considered to be practical because only subharmoninc wave is independent on the contact condition of couplant. Until now, many experiments have been reported about subharmonic wave using fatigue crack or stress corrosion crack, and it becomes clear that the generation of subharmonics are quite restrictive comparing with the one of superharmonics. About the mechanism of a subharmonic wave generation, the simple numerical-analysis models were proposed based on the experiment. Thus unsteady clapping of crack surfaces considered to arise subharmonics at some crack contact conditions between the crack opening and the amplitude of incident ultrasound[1-3].

However, since the convensional analisis using simple numerical model is quantitatively, experimental material parameter, geometric shape of crack and incident ultrasonic waveform, etc. cannot relate to the analysis quantitatively. This research is the first step of the the basic research to establish the subharmonic wave simulator at crack using improved finite element method code..

2. Previous Studies of Subharmonic Wave

The experimental sample of the subharmonic ultrasound which authors reported previously are shown [1] in Fig.1. Fig.1 shows the transmitted waveform of angled longitudinal wave of 6.4MHz in frequency through the closed fatigue crack. According to the applied stress by three points bending, amplitude of the transmitted wave decreased due to the increase of crack opening. In parallel to this, special alternate amplitude change can be observed in the transmitted waveform. These waveforms relate to the half of an input ultrasound frequency which called as subharmonic.

To investigate the mechanism of subharmonic

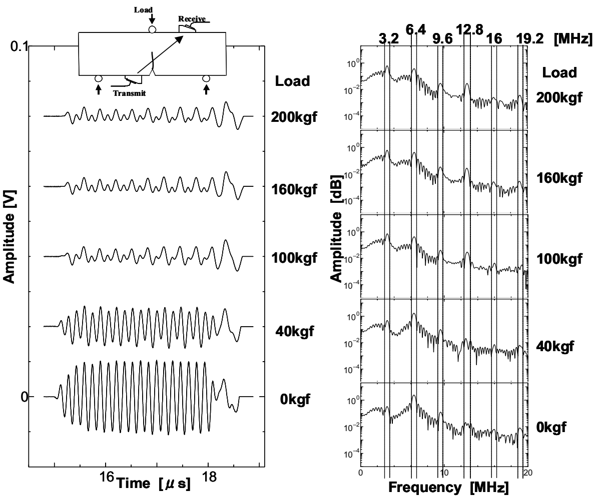

Fig.1 Previous transmitting experiment at fatigue crack of subharmonics generation

generation, K.Yamanaka proposed the contact model of a crack surfaces based on the tapping model of the needle in an atomic force microscope and the similar subharmonic behavior can be obtained [2]. The similar models have also proposed by others and subharmonic ultrasound is considered as an elastic contact problem of crack surfaces which strongly relate to the amplitude of the incident ultrasound and to the crack opening. However, these models proposed until now is a simple analytical model supposing the mass and the spring constant of a crack to solve a dynamic equation. Then, physical parameters of materials, gap of crack and incident wave displacement and so on were difficult to relate to the previous analysis for the quantitative estimation of subharmonic wave. To investigate the quantitative mechanism of generation of the subharmonic wave, accurate analysis method of subharmonic wave has been expected.

3. FEM Analysis for Nonlinear Ultrasound

As to the nonlinear ultrasound analysis, boundary element method and finite element method have been applied up to now and have confirmed the generation of superharmonics which agreed well to the experiment [4]. However as to the subharmonics, previous analyses have not found the

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generation of subharmonics until now. We have developed the new FEM analysis code for ultrasonic transmission using voxel element which realized an accurate analysis with more rapid calculation time. However ultrasonic travelling model around a crack of nm order in gap will takes long calculating time even using this code because a huge number of elements must be considered using uniform mesh analysis. Then in this study, double node model for closed crack was introduced. In this virtual crack model, though defined node distance of crack was zero, crack opening distance can be defined independently. When ultrasonic wave oscillate a crack surface lager than defined crack opening, partial contact will transmit the oscillation to an opposite crack surface as an elastic contact problem.

4. Analytical Result

Fig.2 shows the model for FEM analysis of the transmit measurement of angled longitudinal wave of 45 degree through the closed fatigue crack which correspond to the previous experimental setup as shown in Fig.1. A crack opening distances were changed from 0.2 to 1.0 in 0.2 pitch which was normalized with the maximum constant displacement of input wave. Transmitted received waveform through crack was observed with the angle probe on the back surface. Sample of the ultrasonic travelling behavior in case of normalized crack opening of 0.4 was shown in Fig.3. The amplitude of transmitted wave and reflected wave at a crack were observed due to the crack opening. Obtained transmitted waveforms trough crack were analyzed with FFT and the power spectrum were shown in Fig.4. According to a crack opening, the amplitude of transmitted waves of the fundamental frequency peak decreased. At the subharmonic frequency of half of the fundamental frequency, the amplitude of the spectrum show the peak at 0.2 and 0.4 in normalized crack opening and after that the peak disappear at larger crack opening. Although the amplitude of the peak was small as compared with an experiment as shown in Fig.1, a clear generation of subharmonics might be obtained due to the crack opening distance change.

5. Conclusion

1) We developed a voxel type FEM code improved for closed crack model using double node technique and applied to the angle beam transmission measurement through crack in steel.
2) Amplitude change of subharmonic ultrasound can be observed using the new FEM model, though the generated subharmonic ultrasound was weak comparing with the previous experiment.
3) This FEM model might be the first step to establish the accurate simulation of subharmonc ultrasound, because other important factors of residual stress due to crack extension and more details of crack shape will easily to be taken in account for this model.

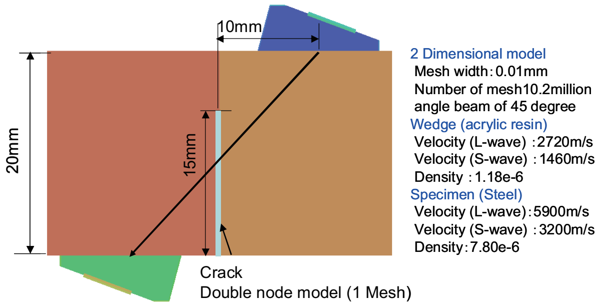

Fig.2 New FEM analysis model for closed crack

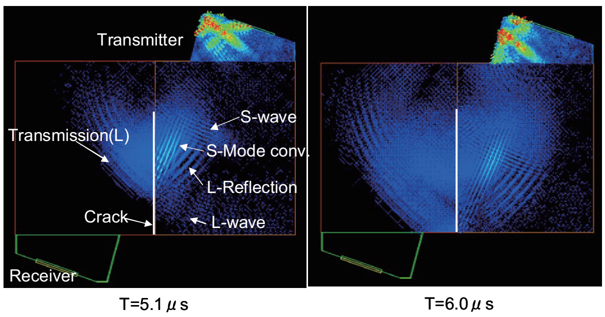

Fig.3 Traveling wave behavior at crack in steel

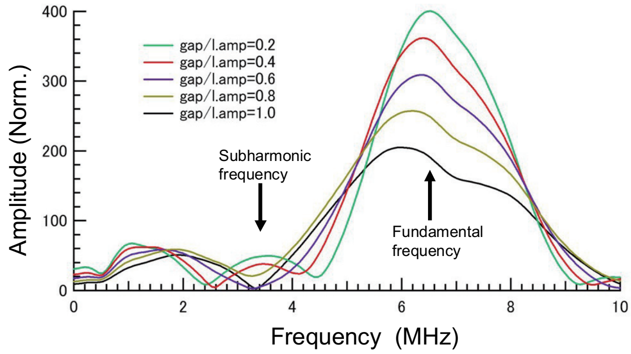

Fig.4 Spectrum of transmitted wave trough a crack due to the crack opening displacement

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