NUMERICAL SIMULATION AND OPTIMIZATION DESIGN OF ACOUSTIC IMPEDANCE PROBE

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In this article, a set of complete numerical simulation model for the bimorph acoustic impedance probe is developed using finite element method. The resonant characteristics and transmitting-receiving characteristics for the probe are numerically analyzed by ANSYS software. The two sides cover the key steps of the probe research and development. Additionally, the numerical simulation can solve the engineering problems for probe optimization design. An optimized acoustic impedance probe is developed and the measurement is well done. The sample bonding state is distinguished by means of amplitude based method. It has some common reference for probe design and optimization in engineering applications of bonding detection.

Keywords: Acoustic impedance probe; Harmonic analysis; Transient analysis; FEM; ANSYS

1. INTRODUCTION

Acoustic impedance technology has been often used in bonding quality detection of aerospace structure and composite material structure[1-2]. It was put forward by the former Soviet union scientist Io BπaHre in 1959[3]. In domestic, the earliest and the most comprehensive acoustic impedance research was done by Mingxuan Li et al[4-5]. As one of the key parts, bimorph acoustic impedance probe plays a crucial role in the acoustic impedance detection. The electromechanical analogy method has been traditionally used to establish equivalent circuit of acoustic impedance probe. But it often has such disadvantages as complex computation and weak effectiveness, which shortages are not suitable for engineering applications.

In this article, numerical modeling for the bimorph acoustic impedance probe is developed using finite element method. The resonant characteristics and transmitting-receiving characteristics for the probe are numerically analyzed. The two sides cover the key steps of probe research and development. A good agreement with the measured results are also verified the correctness and validity of the numerical method used in this article. Additionally, the numerical simulation can solve the engineering problems for probe optimization design.

2. NUMERICAL MODEL OF PROBE

2.1. Operating principle

The structure of the bimorph acoustic impedance probe is shown in Fig. 1. It often has four parts, including damping block (1), transmitting piezoelectric ceramic (2), amplitude amplifier pole (3) and receiving piezoelectric ceramic (4). Sometimes, a protective film is added on the surface of receiving piezoelectric ceramic (4) to modify the detection effect. Actually, it can be used as a complex of two sandwich type probe.

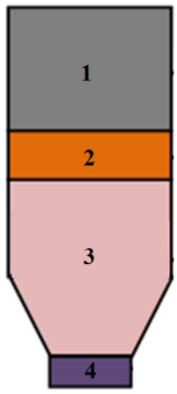

Figure 1. Structure of acoustic impedance probe

The operating principle is as follows. The transmitting piezoelectric ceramic is excited by applied voltage (often burst pulse) in order to make bending vibration of the test sample. The sample mechanical impedance information feedback is made to the receiving piezoelectric ceramic. Different bonding quality reflects the different mechanical impedance. Thus amplitude and phase change of the receiving piezoelectric ceramic produce different voltage output to achieve the effect of defects detection.

2.2. Numerical model

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The FEM simulation for the acoustic impedance probe is carried out with the commercial software ANSYS. The basic steps are: Simplifying the problem into a physical model; Establishing finite element model; Meshing; Applying load and boundary conditions; Solving and processing[5].

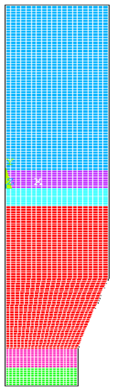

Figure 2. Finite element model of acoustic impedance probe

Figure 2 shows the finite element model of the acoustic impedance probe. The 2D axial symmetrical model is established to simplify the actual problem. It is needs to be stressed that the transmitting piezoelectric ceramic is connected in series and the receiving piezoelectric ceramic is connected in parallel. Thus the polarization direction should be set correctly.

The structure of bimorph acoustic impedance probe is listed here. The damping block is made of Steel No. 304 with 20 mm diameter and 23 mm height. The amplitude amplifier pole is Aluminum with 14 mm diameter and 20 mm height. Transmitting ceramic is PZT4 with 20 mm diameter and 2.0 mm height, and receiving ceramic is PZT5 with 14 mm diameter and 2.0 mm height.

3. HARMORNIC ANALYSIS

Harmonic analyses are used to determine the steady-state response of a linear structure to loads that vary sinusoidally (harmonically) with time, thus enabling you to verify whether or not your designs will successfully overcome resonance, fatigue, and other harmful effects of forced vibrations. We can get impedance characteristic and resonant frequency from the harmonic analysis. These are key parameters for the probe design and manufacture process.

The frequencies sweep is from 10 kHz to 60 kHz with a sub-step of 1 kHz. The constant damp ratios are set to be 0.6% for air. The transmitting and receiving ports are numerically calculated separately and results are compared with experimental measurement. The comparision is shown in Fig. 3 and Fig 4 respectively as follows.

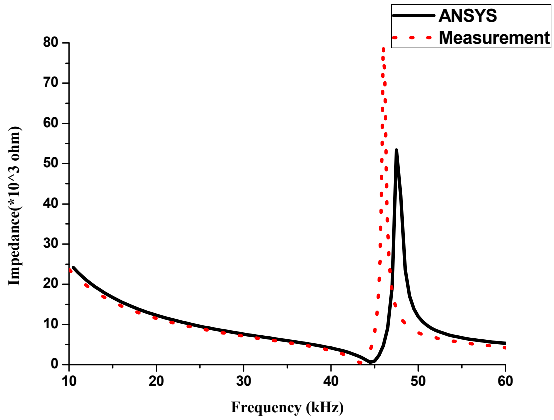

Figure 3. Impedance characteristic of transmitting port

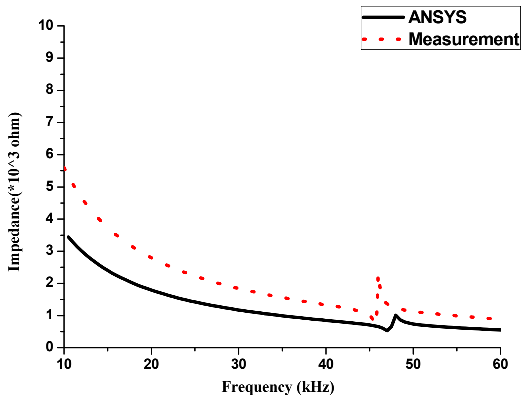

Figure 4. Impedance characteristic of receiving port

Figure 3 and Fig. 4 show the good agreement between numerical calculation and experimental measurement. From the impedance characteristic of transmitting and receiving ports of probe, the resonant frequency is 45 kHz. This is the desired frequency because it is much more sensitive for target sample bonding detection. Through the determination of impedance characteristic, the designed material and structure parameters are adjusted and optimized. It is obvious that the numerical model for harmonic analysis of acoustic impedance probe is verified to be correct.

4. TRANSIENT ANALYSIS

A transient analysis, by definition, involves loads that are an arbitrarily function of time. It can be used to simulate the actual detection process. The transmitting port is excited by a continuous sweep-frequency burst pulse. The voltage signal from receiving port is extracted and peak to peak value is calculated and kept in the data table.

Thus the curve of amplitude change with frequency can be shown in forms of contrast between debonding and bonding.

For the actual detection simulation, the test sample is established in the numerical model. It has two statuses of bonding and debonding. The sample model is 1 mm steel and 2 mm rubber and 40 mm rubber. The target detection layer is the layer between rubbers.

The numerical calculation result of bonding detection is listed in Fig. 5. For the bonding sample, the voltage amplitude is lower than the debonding, especially on the resonant status. This is because the bonding sample can be treated as 'heavy' load for receiving piezoelectric ceramic. The amplitude must be lower than the debonding case. The difference value of the two curves on resonant status can decide the detection sensitivity directly. From the calculated results, the operation frequency should be 44 kHz, which is the series resonant frequency of the designed acoustic impedance probe. At this frequency, the difference value for bonding status has maximum. That is the basis of amplitude method.

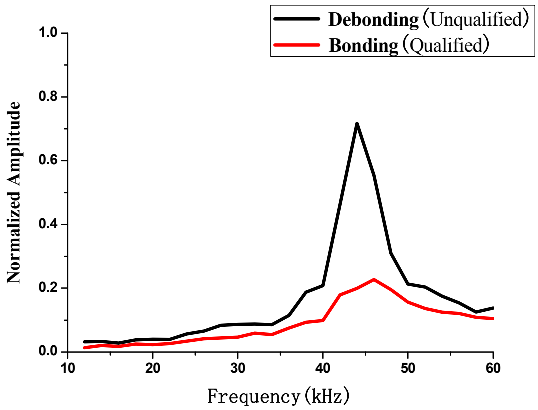

Figure 5. Transient calculation for bonding detection

In the transient model, the cycle loading, peak-to-peak value extracting and saving can be carried out by APDL command stream. It is more effective and reliable. The verification is carried out by experimental measurement. The Digital Intelligent Acoustic Impedance Test System is developed independently in our group. The specific bonding sample is tested by acoustic impedance probes which are optimized and manufactured.

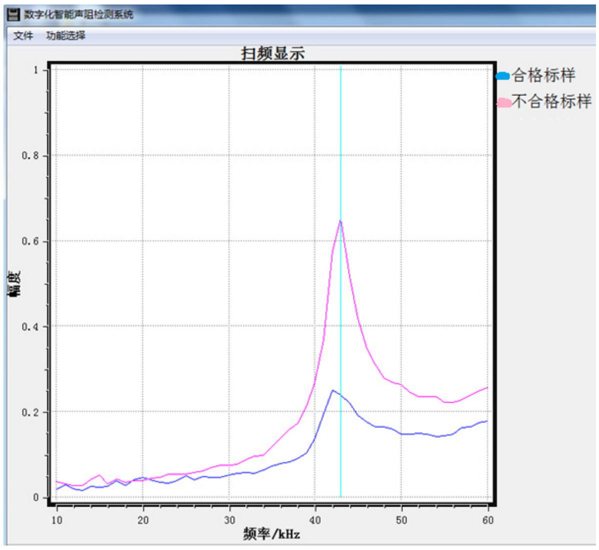

Figure 6. Screen capture of Digital Intelligent Acoustic Impedance Test System for bonding detection

Figure 6 shows the actual detection curve for bonding and debonding samples. The data on Digital Intelligent Acoustic Impedance Test System cannot be saved. Thus, the screen capture is displayed here. Compared with Fig. 5, the different bonding status corresponds to different amplitude. They have the same variation trend for bonding status. It is can be proved that the numerical transient model could simulate the actual behavior of acoustic impedance probe on bonding detection.

5. CONCLUSION

In this article, a set of complete numerical simulation model for bimorph acoustic impedance probe is established on the platform ANSYS. It includes impedance characteristics by harmonic analysis and transmitting-receiving response by transient analysis. The numerical model is verified by experimental measurement, respectively. Using this model, we developed a bimorph acoustic impedance probe, which is designed with the optimal material and structure parameters. As it turns out that the probe has good bonding detection effect.

The research work above has certain reference significance for engineering practice and application of acoustic impedance method.

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