

# Study on Detection of SRM Composite Structure Using Ultrasonic Fixed Distance Transmission Method

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**Abstract**—A new ultrasonic testing method used for the detection of solid rocket motor (SRM) composite shell is proposed, which does not require a coupling agent. The theoretical model of this method is established, and the effect of composite shell thickness, defect size and position on the detection result is studied respectively. The simulation results show that the detection sensitivity decreases with the increase of the shell thickness and the decreases of the defect size, and when the defect is located just in the middle of the transmitting probe and receiving probe, the detection effect is the best.

**Keywords**—SRM; ultrasonic, composite structure, detection

## I. INTRODUCTION

Rocket Motor Solid (SRM) has a series of advantages, such as its simple structure, reliable and easy maintenance, which is suitable for the modern war and the need of aerospace industry [1]. The composite shell is the weak link of SRM, which is easy to appear the defects such as delamination, aging, corrosion damage, weakening, and so on [2]. In order to ensure the normal operation of SRM, it is necessary to carry out nondestructive testing.

Ultrasonic detection is a common method for composite materials testing, which can be divided into the reflection method, transmission method and C scanning method. These methods generally need water as a coupling agent, but because the SRM shell to avoid water, oil and other contamination, therefore, conventional ultrasonic detection can not be used [3].

In this paper, a new ultrasonic testing method for the detection of SRM is studied. In this method the coupling agent such as water is not necessary, so it can be applied for the nondestructive testing of SRM composite materials. This new method uses two ultrasonic probes, respectively, for transmitting and receiving ultrasonic waves. In the detection process, the distance between the two probes remains constant, so this method is called the "fixed distance transmission" (FDT) method.

## II. THEORETICAL MODEL AND FINITE ELEMENT SIMULATION METHOD FOR FDT

### A. Theoretical Model of FDT

The detection principle of the FDT method is shown in Figure I. The testing object is a bonding structure made of a composite material shell and a rubber insulation layer. There

is a debonding defect existing between the shell and the insulation layer, and we aim to detect this defect.

The ultrasonic probe is composed of piezoelectric vibrator and the wave guide rod, the probe and the composite shell contact through the transmission rod. The distance between the transmitting probe and the receiving probe is  $L$ . In the detection process, the ultrasonic wave is generated by the piezoelectric vibrator of the transmitting probe, and enters the composite material shell through the guide rod. The wave propagates in the shell and is received by the piezoelectric vibrator of the receiving probe through the guide rod, and finally converted into a voltage signal. If there is a defect between the transmitting probe and the receiving probe, the signal voltage will change, so the deflection can be found through the changes of the signal voltage.

Because the friction between the shell and the guide rod is very small and the shear wave transmitted into the shell from the rod can be ignored, it can be considered that there is only longitudinal wave propagating in the rod and considered the rod as a fluid model. For the composite material shell, it can be regarded as a linear elastic material model.

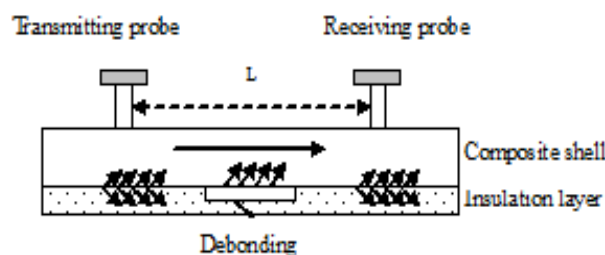


FIGURE I. THE CHEMATIC DIAGRAM OF FDT METHOD

### B. Finite Element Simulation of FDT

#### 1) Control equation of fluid

According to Newton's second law, the control equation of fluid is:

$$-\nabla p + \mathbf{f} = \rho \frac{\partial^2 \mathbf{u}}{\partial t^2} \quad (1)$$

where,  $p$  is the pressure,  $\nabla$  is the gradient operator,  $\mathbf{u}$  is the displacement vector,  $\mathbf{f}$  is the body stress,  $\rho$  is the

fluid density.

## 2) Control equations in solids

According to Newton's law, the control equation of continuous linear elastic solid is:

$$\frac{\partial}{\partial x_j} T_{ij} + f_i = \rho \frac{\partial^2 u_i}{\partial t^2} \quad (2)$$

Where  $T_{ij}$  is the two order stress vector,  $f_i$  is the body force,  $\rho$  is the density of materials,  $u_i$  is the displacement,  $x_j$  is the coordinate vector,  $i, j = 1, 2, 3$  is respectively coordinate directions of x, y and z.

## 3) Control equation of piezoelectric materials

In piezoelectric materials, the relationship between the stress and strain can be derived based on the Hooke's law and the inverse piezoelectric effect, which is:

$$\begin{cases} c_{ijkl}^E \frac{\partial^2 u_l}{\partial x_j \partial x_k} + e_{kij} \frac{\partial^2 \phi}{\partial x_j \partial x_k} = \rho \frac{\partial^2 u_i}{\partial t^2} \\ e_{jkl} \frac{\partial^2 u_l}{\partial x_j \partial x_k} - \varepsilon_{jk}^S \frac{\partial^2 \phi}{\partial x_j \partial x_k} = 0 \end{cases} \quad (3)$$

In these equations,  $c_{ijkl}^E$  is the elastic matrix where the superscript  $E$  indicates that it is the elastic properties under the condition of constant electric field, and  $\varepsilon_{jk}^S$  is elastic constant where the superscript  $S$  indicates that it is the electrical properties under the condition of constant stress, and  $e_{kij}$  is the piezoelectric constant matrix.

## III. SIMULATION RESULTS AND DISCUSSION

### C. Effect of the Composite Shell Thickness on Detection Results

Because the defects exist between the composite material shell and the insulating layer, the change of shell thickness will have an effect on the defect detection capability. In order to study this problem, we designed the shells with three thickness of 5mm, 8mm and 12mm, and the thickness of the insulating layers are all 1.2mm. The defect is located in the middle of the two ultrasonic probes, and its length and thickness are set to 10mm and 0.1mm respectively. The received signal is analyzed under two cases of deboning defect existing and no defect.

For the case of three different thicknesses, the curves of the receiving voltage changing with time are shown in Figure II. It can be found that the amplitude of the receiving voltage is decreased with the increase of the thickness of the composite shell, and for the same thickness, the voltage amplitude corresponding to a defect is higher than that of the corresponding defect free. This means that the FDT method

has a high sensitivity for testing a small thickness composite shell, and with the increase of the thickness, the detection sensitivity is decreased.

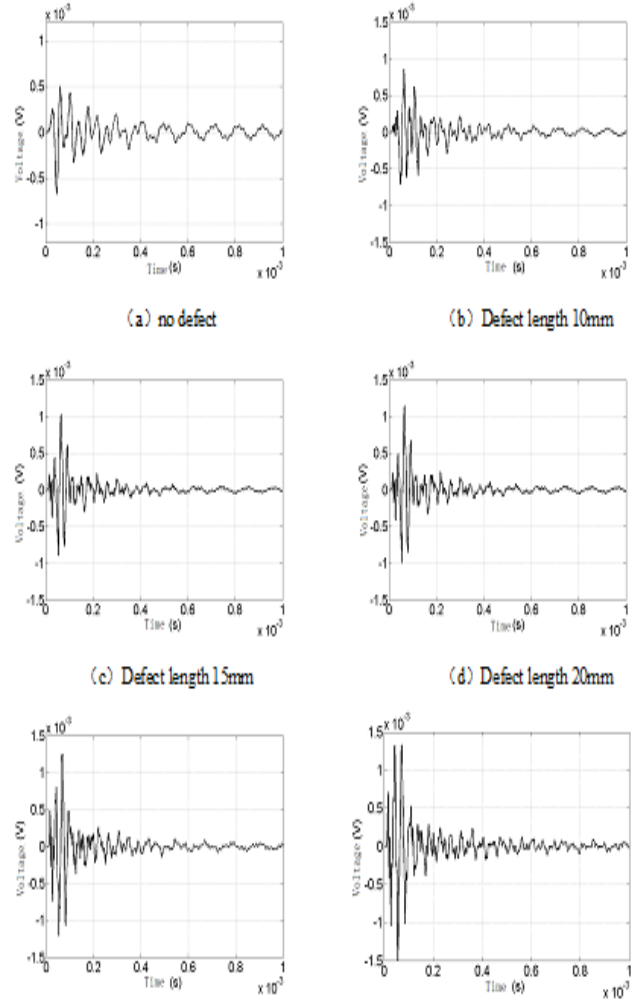


FIGURE II. THE RECEIVING SIGNAL OF THE DIFFERENT SHELL THICKNESSES

### D. Effect of the Defect Geometrical Dimensions on Detection Results

In order to study the influence of the geometrical dimensions of the defect, we set up the defects of different sizes in the model of Figure 1, and analysis the voltage signals corresponding to different defects. In these models, the thickness of the composite material is 8mm, the thickness of the insulation layer is 1.2mm, the thickness of the defect is 0.1mm, and the length of the defect is 10mm, 15mm, 20mm, 25mm and 30mm respectively.

For the defects of different length, the curves of the receiving voltage signal are shown in Figure III. It can be found that the amplitude of the receiving voltage increases with the increase of the defect length, and this means that the size of the defect can be evaluated by the change of the signal voltage. Obviously, the defect with more large size can be detected more easily.

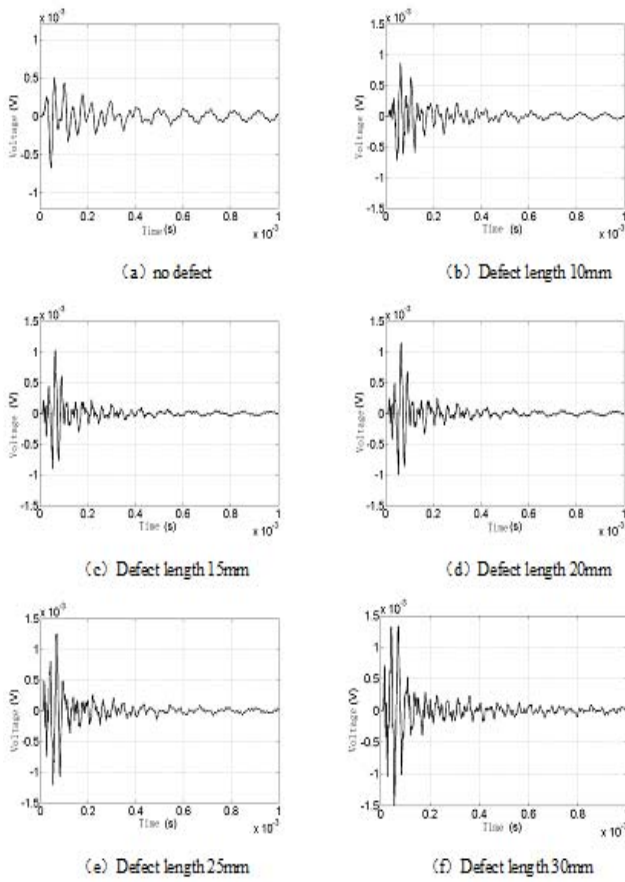


FIGURE III. THE RECEIVING SIGNAL OF THE DIFFERENT DEFECT SIZE

#### E. Effect of the Transducer Position on the Detection Results

Based on the simulation analysis in 3.2 section, we set five defects of different positions in the model respectively, as shown in Figure IV. The sizes and the interval of the five defects are the same. The defects lengths are 10mm and thickness are 0.1mm. The defect of No.1 is located just below the transmitting probe, the No.5 is located just below the receiving probe, and the No.2 to No.4 are located between the two probes.

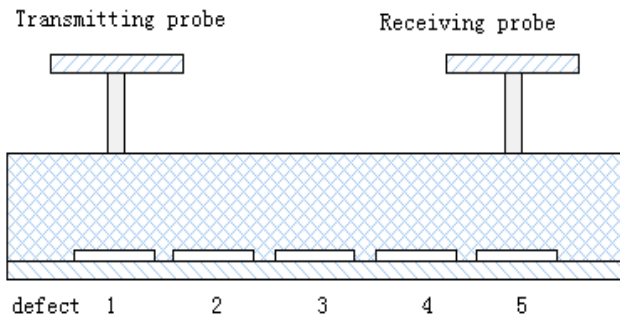


FIGURE IV. THE SCHEMATIC DIAGRAM OF DIFFERENT DEFECT POSITION

For the defects of different position, the curves of the receiving voltage signal are shown in Figure V. It can be found that the voltage is changed with the position of the defect, the defect is closer to the middle of the two probes, the signal received is stronger, the voltage is maxim when the defect is located just in the middle of the two probes. For example, the signal of defect No.2 is stronger than that of No.1, while signal of defect No.3 is stronger than that of No.2. This means that if the defect is located just at the middle of the two probes, the detection sensitivity will be the highest.

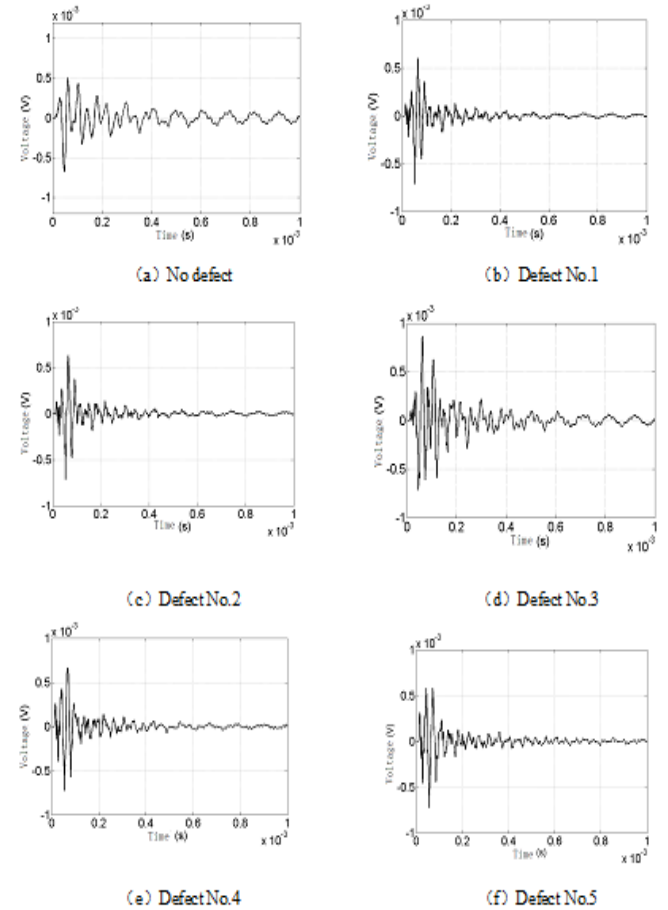


FIGURE V. THE RECEIVING SIGNAL OF THE DIFFERENT DEFECT POSITION

#### IV. CONCLUSIONS

In this paper, the theoretical model of FDT method is established, and the detection principle is analyzed. In the process of simulation, the shear wave in the wave guide rod is ignored, and the control equation of fluid is used to solve the acoustic wave equation in the rod. The effect of composite shell thickness, defect size and position on the detection result is studied respectively. The simulation results show that the detection sensitivity decreases with the increase of the shell thickness and the decreases of the defect size, and when the defect is located just in the middle of the transmitting probe and receiving probe, the detection effect is the best.

#### REFERENCES

- [1] Li Tao, Zhang Le, Defect analysis of solid rocket motor and the nondestructive testing technique, J. Nondestructive Testing, 28(2006)541-544.
- [2] Yuan Hongbin, Zheng Haiping, Research on the ultrasonic flaw detection of the position of the nozzle composite material, J. Solid rocket technology, 25(2002)73-76.
- [3] Geng Rongsheng, New method for the evaluation of bonding quality of aircraft composite materials, J. Nondestructive Testing, 11(2001)461-464.