SIMULATION OF THE MULTI-MORPH BENDER TRANSDUCER

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The finite element method (FEM) is used to simulate a multi-morph bender bar, which comprises an inert substrate having two pairs of piezoelectric elements attached to its two sides. The simulation shows that the multi-morph bender bar has a lower fundamental frequency than the trilaminar bender bar. The effects of geometry on its fundamental frequency and conductance are investigated, demonstrating that the two pairs of piezoelectric elements affect differently. Simultaneously, a gap is proposed to carve in this multi-morph bar structure. By choosing adequate structure sizes, the proper working frequency and highly efficient radiation performance can be obtained. Numerical simulation results provide a good guidance on the optimization design for the multi-morph bender transducers.

Keywords: Multi-morph bender bar; Fundamental frequency; Conductance; FEM

1. INTRODUCTION

In the oil and gas well logging industry, it is desirable to measure formation shear velocity because it provides information important for the exploration and production of oil and gas. In conventional wire-line logging, various acoustic methods have been developed to measure the formation shear velocity. Using a monopole acoustic tool, the shear velocity can be measured from the shear wave refracted along the borehole wall, if the formation shear wave velocity is greater than the borehole fluid acoustic velocity. However, in a slow formation where the shear velocity is less than borehole fluid velocity, the shear velocity cannot be directly measured by monopole logging [1,2]. Because of the need to measure shear velocity in slow formation, especially in the soft sediments of deep-water reservoirs, all kinds of dipole acoustic logging tools were developed. At low frequency, the flexural wave travels at the formation shear velocity.

The trilaminar bender bar has been widely used as a dipole source for its low frequency with limited size. Effects of the trilaminar bender bar' geometry sizes and other performance parameters on its frequency character and radiation property were detailedly discussed in Refs. [3,4]. However, current bender bars have difficulties with low frequency response, resulting in difficulties in producing high quality logs for large holes and soft formation applications [5]. Therefore, there is a need to develop better performing bender bars. In this paper, the multi-morph bar, a new type of flexural transducer, is analyzed.

2. THE MULTI-MORPH BAR

2.1. Model description

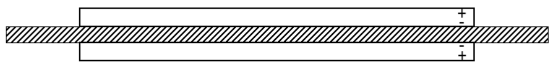

Figure 1. Schematic diagram of the trilaminar bender bar

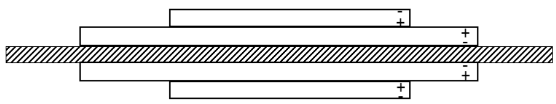

Figure 2. Schematic diagram of the multi-morph bender bar

The trilaminar bender bar, which comprises an inert substrate having a pair of piezoelectric elements polarized in thickness attached to its two sides, as shown in Fig. 1, is usually used as a dipole source in sonic well logging tools. Usually, piezoelectric elements are less than the inert substrate and the transducer is mounted on a skeleton, so the two ends could be thought as weld boundary condition. When applied with voltage, one of the piezoelectric elements stretches while the other one contracts, thus leading to the flexural vibration of transducer [6]. Specially, inert substrate is an aluminum plate of thickness T, length L, and width W. And piezoelectric elements are PZT-4, each of which having a

978-1-4799-6425-3/14/$31.00 ©2014 IEEE

thickness T1, length L1, and width W1. Figure 2 depicts the multi-morph bender bar, a new type of flexural transducer, another pair of piezoelectric elements attached to the trilaminar bender bar. Each of the piezoelectric elements has a thickness T2, length L2, width W2. For definite description, the piezoelectric elements bonded to the inert substrate and the other one are referred as the first and the second pair of piezoelectric elements, respectively. Only the first order flexural vibration mode of bender bars is discussed in this article.

A finite element model of the multi-morph bender bar is constructed, of which dimension can be referred in the Table 1. What's more, the analysis about a trilaminar bender bar with identical size is also provided for comparison. The properties of the inert substrate are presented in table.2. Material parameters of PZT-4 used in this paper, including permittivity matrix, elastic constants and piezoelectric matrix can be referred in reference [7]. In these models, components such as epoxy and electrodes are neglected for they are much thinner than the elements of bars.

Table 1. Dimensions of the reference model

Geometry size	
L (mm)	154
L1 (mm)	102
L2 (mm)	30
T (mm)	3.2
T1 (mm)	3.5
T2 (mm)	3.5
W (mm)	38
W1 (mm)	38
W2 (mm)	38

Table 2. Properties of the inert substrate

Inert substrate	*(Aluminum)*
Density(kg/m^3)	2700
E (10^{10} N/m^2)	7
Poisson's ratio	0.33

2.2. Modal analysis

In ANSYS modal analysis, we can get the fundamental frequency of the bars and the corresponding eigen modes of them. The flexural vibration modes of the two bars are presented Fig. 3.

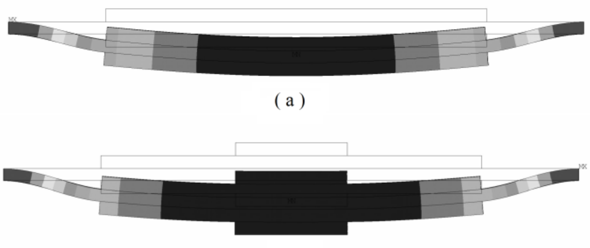

Figure 3. The vibration mode of the trilaminar bender bar (a) and the vibration mode of the multi-morph bender bar (b)

2.3. Harmonic analysis

By harmonic analysis, the admittance can be obtained in post26 of ANSYS. The current flow of reaction forces is extracted from coupling electrode nodes, which is denoted as Q. The excitation electric field V is assumed to be unit voltage. The conductance G is the real part of admittance Y, which is defined as the ratio of input current to voltage, is used to reflect the vibration characteristic of measured transducer.

$$Y = \frac{I}{V} = \frac{1}{V}\frac{\partial Q}{\partial t} = j\omega\frac{Q}{V} \quad (1)$$

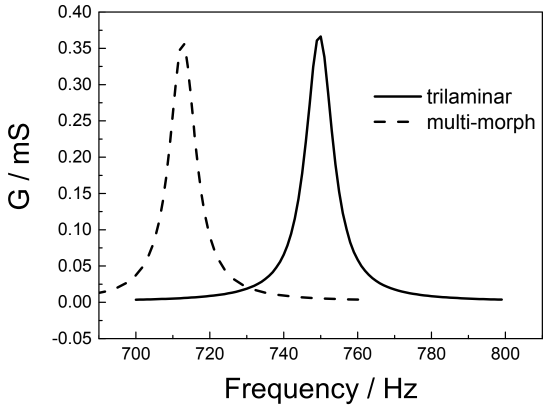

Figure 4. The input electrical admittance of bender bars (in air)

The input electrical admittance of these two bender bars in air is illustrated in Fig. 4, in which peaks are existed in the curve of the input electrical conductance at resonance frequencies, which means that the electrical power could be transformed to mechanical power more efficiently at these frequencies. It can be revealed from the simulation results that the multi-morph bender bar has a lower fundamental frequency than the trilaminar bender bar while the radiation efficiency remains high.

3. EFFECTS OF THE GEOMETRY SIZES

The borehole has limited the size of the transducer. On the basis of size satisfaction, the lower frequency response and more efficient radiation performance are what the transducer heads for. According to the numerical simulations with different size of the transducer, it is capable of analyzing the dynamic performance of a structure quantitatively, thereby, condensing the design cycle and economizing the cost of design.

3.1. Effects of the first pair of piezoelectric elements

To find out how the multi-morph bender bar behaviors when the length of the first pair of piezoelectric elements changes, models with L1 ranging from 50mm to 150mm with the increment 10mm are computed, while other parameters keep constant (L=154mm, L2=30mm). The results demonstrate that with the first pair of piezoelectric elements increasing, the resonance frequency will increase while the conductance will decrease after reaching the peak when the first pair of piezoelectric elements reaches 90 percentages length of the inert substrate. For simplicity, only several representative results are given in Fig. 5.

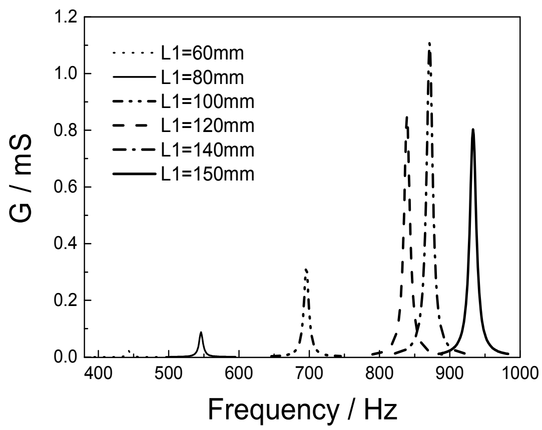

Figure 5. The input electrical admittance with different L1 (in air)

3.2. Effects of the second pair of piezoelectric elements

Similarly, models with L=154mm, L1=102mm are constructed to find out how the second pair of piezoelectric elements affects. Keeping the other parameters constant, L2 ranges from 20mm to 100mm with the increment 10mm. Only a few results are presented in the Fig. 6 for simplicity.

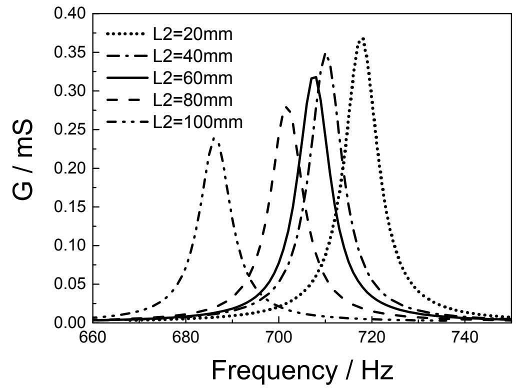

Figure 6. The input electrical admittance with different L2 (in air)

As shown in the Fig. 6, when the second pair of piezoelectric elements increases, both the resonance frequency and conductance will decrease.

3.3. Effects of the gap

Furthermore, multi-morph bender bar with a gap splitting the two pairs of piezoelectric elements is analyzed. Figure 7 shows that the resonance frequency and conductance will decrease rapidly once a gap is carved, and continue decreasing as the gap increases.

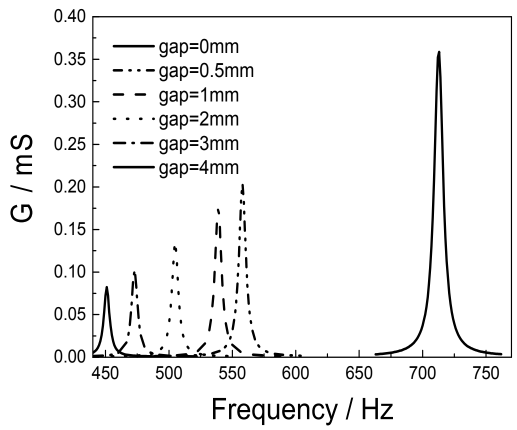

Figure 7. The input electrical admittance with different gap (in air)

4. CONCLUSIONS

In this paper, the multi-morph bender bar is proposed to serve as a dipole source in sonic well logging tool, which proves to have a lower fundamental frequency than the trilaminar bender bar. Numerical results show that the decreasing of the fundamental frequency can result from the decreasing of the first pair of piezoelectric elements, but may also occur from the increasing of the second pair of piezoelectric elements or the gap. The conductance G, related to the radiation performance, will be enhanced as the second pair of piezoelectric elements decreases, or as the gap decreases, and especially, it will reaches its highest as the first pair of piezoelectric elements being 90 percentages of the inert substrate. However, these two is interacted with each other. On the basis of size satisfaction, the working frequency and conductance should be comprehensively considered when designing the transducer.

ACKNOWLEDGEMENTS

The work was supported by the National Natural Science Foundation of China (Grant No. 11134011).

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