A MULTI-MODES COUPLING RECEIVER FOR ACOUSTIC LOGGING WHILE DRILLING

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Acoustic logging while drilling (LWD) technology plays a more and more important role in highly deviated angle and horizontal well logging due to the advantages such as high efficiency, low cost and etc. However, there still exist bottleneck problems because of the acoustic LWD environment in the borehole including noise of mud and drilling bit and even tool mode waves. Flexural vibration transducers with a small volume and low resonant frequency is a good option in acoustic logging tools. We presented a Helmholtz resonator receiver with multi-modes coupling with wide frequency band, high sensitivity and flat sensitivity curves than receivers with pure bending mode. The finite element method was used to calculate the vibration, admittance characteristics and receiving sensitivities. Considering variables such as geometric sizes in the simulation progress, optimized receiving sensitivity curve was finally obtained, with a maximum value of -195dB, and a fluctuation within ±5dB in the range of 10 to 20 kHz. It is appropriate for receiving monopole waves on acoustic LWD tools.

Keywords: Logging while drilling; Multi-modes coupling; Receiving sensitivity response

1. INTRODUCTION

As the continuously demand of logging in highly deviated angle and horizontal wells, and also the exploration of non-conventional reservoir, acoustic logging while drilling technology is becoming one of the dominant methods owing to the real time, pollution free, high efficiency, etc[1,2]. However, a bottleneck problem that restricts the development of the LWD acoustic logging is the LWD environments in the borehole, including noise from mud and drilling bit vibration, and also collar waves in addition, and these result in the difficulty of full wave data extraction [3,4]. With the isolators optimized and the emission power increased, tool waves can be suppressed to a certain extent. It is also important to improve the receiving responses of the receivers.

Since the 1990s, three famous oil service companies, i.e., Halliburton, Schlumberger and Baker Hughes have started to focus on the research of acoustic LWD tools due to oil company requirements. Acoustic LWD transducers have experienced in the development trend of from monopole to multiple, from narrow to wide frequency bands, from compressional waves to shear waves measurements, etc [5,8]. The core technology in domestic has not been overcome own to intellectual properties. Although several published papers and patents are seen, they are mainly concentrated on monopole transmitters of acoustic LWD, but details of dipole and quadrupole transducers are not too much. In addition, performances of existing receivers of acoustic LWD need further research. Therefore, it is of great significance and application in doing research for this kind of transducers in the field of energy exploration.

In this paper, we proposed a kind of receiver with Helmholtz resonator structure, that high and broad band receiving performance will be implemented by means of multi-modes coupling in the resonance frequency ranges. Based on previous experiences on underwater acoustic transducer with resonator structure [9, 10], the receiver was designed and improved according to logging application. The vibration modes, admittance characteristics and receiving sensitivities of the receiver were numerically simulated using the finite element method (FEM) [11].

2. STRUCTURE OF RECEIVER

The receiver with a resonator is comprised of a polymer hollow cylindrical shell with a bi-laminated piezoelectric bender on the bottom. Its internal cavity is filled with silicon oil. The bi-laminated piezoelectric bender is configured of piezoelectric ceramic wafer and a polymer substrate bonded together. Schematic diagram of the receiver is shown in Fig. 1.

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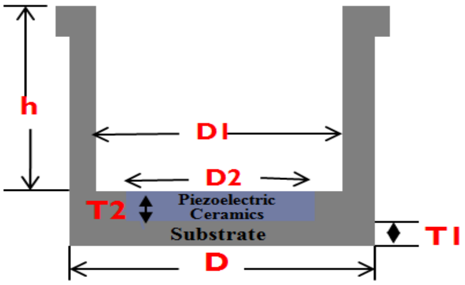

Figure 1. Schematic diagram of receiver with resonator structure

On the diagram above, the piezoelectric ceramics is PZT-5A wafer, while the substrate and cylindrical shell are made of Polyether-ether-ketone engineering plastics. High temperature resistant conductive adhesive was used to bond PZT-5A wafer and PEEK substrate together to be a bi-laminated vibrator. As shown in Fig. 1, the symbols represents geometric sizes of the receiver, where h is the highness of the cavity, D is the diameter, and T is the thickness of the bi-laminated bender. In more detail, D1 and D2 mean the diameters of substrate and the piezoelectric wafer, respectively. Similarly, the thickness of substrate and the piezoelectric wafer are represented by T1 and T2, separately.

3. NUMERICAL SIMULATION

The finite element method (FEM) was used to simulate the properties of the receiver, and the realization of calculation process was finished by the ANSYS analysis software. The frequency scope calculated is below 20 kHz referring to the frequency commonly used in the field of acoustic logging.

3.1. Modes of vibration

As considering the receiver in the air, the first and third order flexural vibration mode along the diameter direction was displayed in Fig. 2(a) and Fig. 2(b) . In this numerical example, the geometry sizes are as follows: D=20mm, T=1.5mm, and h=10mm. In the frequency range below 20 kHz mainly embodied in the first-order model diametrically.

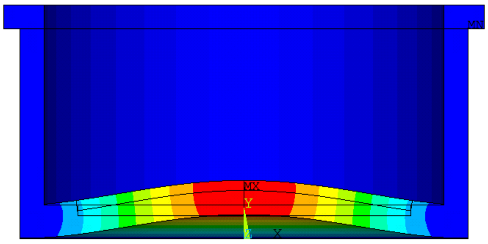

Figure 2(a). The first-order flexural vibration along the diameter direction

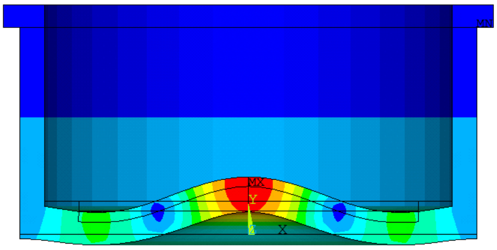

Figure 2(b). The third-order flexural vibration along the diameter direction

When the receiver was dipped in the fluid (water), changes in vibration performance caused by the load. Comparison of admittance curves of the receiver between air and water media were shown in Fig. 3. It could be concluded that water load resulted in lower resonance frequency, lower admittance and wider bandwidth.

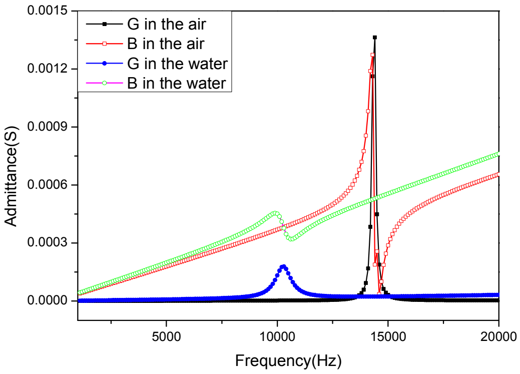

Figure 3. Admittance curves of the receiver in the air and water

3.2. Geometric influence on receiving performances

The receiving sensitivity characteristics with variable geometrical parameters were simulated in the media of water. Fig. 4(a), 4(b) and 4(c) represent the variable diameter of the bi-laminated bender, thickness of substrate and height of the cavity, respectively.

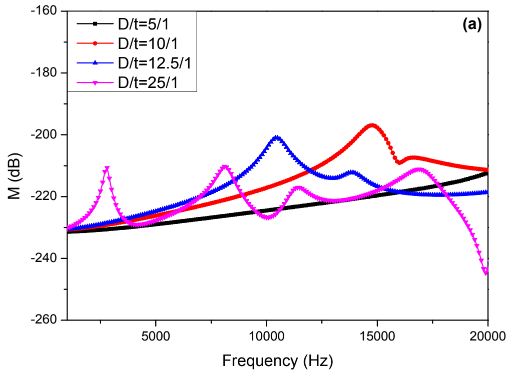

Figure 4(a). Receiving sensitivities of different diameters with fixed thickness and height

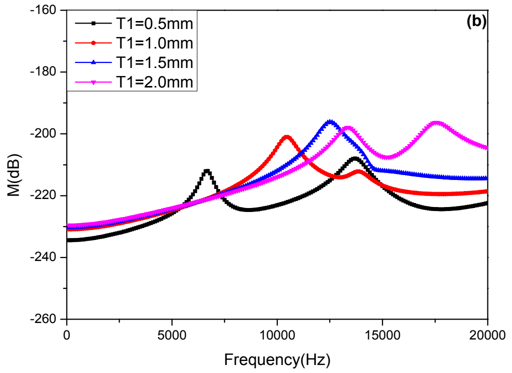

Figure 4(b). Receiving sensitivities of different thickness of substrate with fixed height, diameter and thickness of PZT

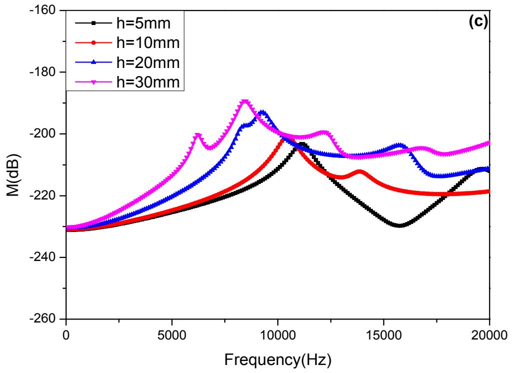

Figure 4(c). Receiving sensitivities of different heights with fixed thickness and diameters

In Fig. 4(a), the sensitivity curve behaves more ups and downs with increasing diameter, it can be attributed to more flexural vibration modes in the lower frequency range. It could be seen from Fig. 4(b) that resonate frequency and sensitivity increase with the increase of substrate thickness. When the thickness is 1.0mm, the flatness and bandwidth reached the best state in the range of 10-20kHz. The resonance vibration modes of the cavity were clearly displayed with the increasing height of cavity, which is shown in Fig. 4(c). Higher cavity generates lower resonate frequency and higher receiving sensitivity.

3.3Influences of closed cavity on receiving sensitivity

When working down in the borehole, the receiver cavity is designed to be closed with a metallic lid which plays the role of sealing oil and balancing the internal and external pressures. Then, the model of receiver with lid was established. Fig. 5 shows the 2-dimentional FEM model of closed cavity receiver. The lid was made of copper alloy in this example.

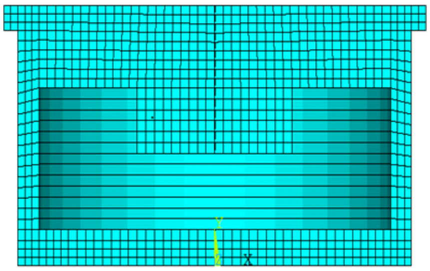

Figure 5. The 2-dimentional FEM model of closed cavity receiver

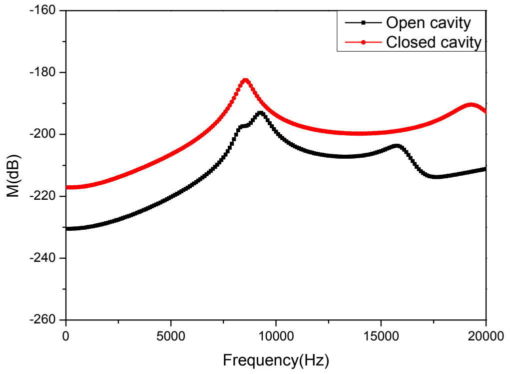

Figure 6. Comparison of receiving sensitivities between open and closed cavity receivers

Comparison of receiving sensitivities between open cavity and closed cavity models were given in Figure 6. The closed cavity could improve the attitude (up to -195 dB), and frequency band (10-20 kHz) of receiving sensitivity. Moreover, the ups and downs of the sensitivity curve becomes lower which is around ±5dB.

4. CONCLUSIONS

The resonator structured receiver filling with oil is suitable for acoustic LWD tools due to multiple vibration modes. Geometric parameters such as the diameter and thickness of the bi-laminated bender, and also the height of cavity that mainly impact performances of the receiver. A closed cavity is conductive to improve amplitude and frequency band of receiving sensitivity curves. And also, optimization design results in higher receiving sensitivity (up to -195 dB), wider frequency band (10-20 kHz) and higher flatness (±5dB) which is suitable to receive monopole sound waves in acoustic LWD.

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