Design and test of mine transducer and drive circuit

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Abstract. Based on the technical requirements of the mine acoustic wave communication technology for the controllable acoustic wave signal source, the effects of the transducer structure on the output impact performance are studied, including: pre-stressing, magnetostrictive material size and the number of coil turns, etc. Then we investigated the factors affecting the output impact performance of the drive power, including: peak voltage, boost time and peak current; After optimizing the design and test verification of the transducer structure and the driving power supply, a technical solution capable of meeting the mining communication needs is developed.

1. Background

The mining acoustic wave transmission technology is a new technology that uses the drill pipe as the transmission medium to transmit the measurement data of the bottom of the hole from the bottom of the hole to the orifice by using the propagation characteristics of the sound wave, as shown in Figure 1. The instrument in the hole encodes the measurement data and controls the transducer action according to the coding format to transmit the acoustic signal. The acoustic signal is coupled to the drill pipe wall and transmitted along the drill pipe wall to the orifice. The vibration sensor adsorbs the sound signal at the end of the drill pipe and converts the acoustic signal into an electrical signal, the receiving decoding module receives the electrical signal from the vibration sensor and decodes the signal. The data display module receives the decoded signal for display. The data transmission method relies on the drill pipe wall as the transmission medium, which is more versatile and is suitable for directional drilling construction of conventional holes and shallow holes.

![Figure 1. The Ideal Model of Drill Pipe Column.](image)

A transducer is a device that converts electrical energy and acoustic energy into each other. Depending on the physical characteristics and materials used, transducers can be divided into
two categories: magnetostrictive transducers and electrostrictive transducers. The former applies the magnetostrictive effect of ferromagnetic materials, often made of nickel or nickel-iron alloy; the latter uses electrostrictive and piezoelectric effects, often made of dielectric materials such as barium titanate ceramics and lead titanate ceramics. The transducer in this study uses rare earth giant magnetostrictive alloy as the driving material and is one of the core components of the whole acoustic wave transmission technology. It is responsible for converting electrical energy into mechanical energy and emitting it in the form of sound waves.

2. Transducer Structure

Because of the working conditions, the installation space of the mine transducer is limited, and the outer diameter is no more than 42 mm. The fundamental structure is shown in Figure 2. The locking bolt and the butterfly spring prestress the ultra-magnetic magnetostrictive alloy under pressure, which can generate more deformation due to its compressive stress; The excitation coil acts to apply the excitation current signal to generate a transient magnetic field; the rare earth giant magnetostrictive material acts as a transducer driving element, which is in a variable magnetic field environment, and can generate stretching vibration; The tapping block represents the stretching vibration of the rare earth giant magnetostrictive material to push the vibration of the knocking block, and radiates sound waves to the device casing, which is the final output component.

![](image)

Figure 2. Mine Acoustic Wave Signal Generator.

In order to ensure the maximum value of the transducer vibration output in a limited space, the parameters such as the bar size, the number of turns of the coil and the prestressing force are optimized according to the static output force formula (1) of the transducer.

$$F_{\text{max}} = \frac{A}{S} \left\{ \frac{\Delta l}{l} - \alpha \Delta T - d \left( N \int R \sum_{i=1}^{\lambda} \left( \mu A \frac{R}{T} + H \right) \right) \right\}$$  (1)

F indicates the static output force of the transducer; A: equivalent cross-sectional area; N: number of excitation coil turns; S: longitudinal flexibility coefficient when the magnetic field is constant; $\Delta l$: bar strain length; l: magnetic path length; I: excitation current intensity; $\mu$ Material permeability; R: magnetoresistance; T: temperature rise; d: axial dynamic magnetostriction coefficient; $\alpha$: thermal expansion coefficient.

After the transducer design uses rare earth giant magnetostrictive material, the material performance parameters in formula (1) become constant value. (such as $\mu$, R, d, $\alpha$). Then the maximum value is obtained in the local range, and the remaining structural parameters are determined by mathematical calculation and actual situation equalization. The results are shown in Table 1.
### Table 1. Design Value.

| Value | Equivalent area \((A)\) | Coil length \((I)\) | Coil turns \((N)\) |
|-------|--------------------------|---------------------|------------------|
| Value 314 mm\(^2\) | 130 mm | 1000 |

3. Transducer drive power

Transducer impact output performance is limited by structural parameters on the one hand, and is also affected by the drive power. The double-tube box forward converter is a commonly used circuit topology, which makes the home circuit simplified and reliable, and does not have a common conduction phenomenon like the bridge converter. Due to the presence of a filter inductor on the output side of the forward converter, an inductive load is present, causing significant switching losses when the switch is turned off. RCD or RC snubber circuit is usually used to solve the problem of switching tube loss, but the snubber circuit will still generate losses. In order to reduce and eliminate this loss, phase shift zero voltage switching control is usually adopted in the bridge converter, and the single-ended forward converter can adopt the circuit topology of the active box. Although the above circuit topology greatly reduces the switching loss, there is still a problem that the control is relatively complicated.

![Circuit Diagram of Driving Power Supply](image)

Figure 3. Circuit Diagram of Driving Power Supply.

The passive lossless buffer circuit of the double-tube hoop forward converter is shown in Fig. 3. In the figure, D1 and D2 are the buffer freewheeling circuits of Q1 and Q2, respectively. Capacitor C1 is a storage filter capacitor. D1 and D2 are the home diodes of the dual-tube forward converter. The working state of the circuit can be divided into: the switching tube is turned from on to off, and the switching tube is off. During the conduction of the switch, the voltage of the C1 capacitor is V1, and the current flows through the inductor L1 through the conduction of Q1/Q2. The switch is turned from on to off, and the original current path is cut off. Since the inductor current cannot jump, an induced potential voltage is generated and a new current path is built, that is, through the high voltage diode D1/D2 flowing through the inductor L1. The formula for the rise of the inductor current is as follows:

\[
I_{\text{MAX}} = \frac{U \cdot dt}{L}
\]

Among them: \(I_{\text{MAX}}\): current maximum (peak); \(U\): voltage applied across the inductor; \(dt\): inductor power-on time; \(L\): the inductance of the inductance itself.

4. Test platform

According to the structural characteristics and parameter range of the mine transducer, the impact performance test device is built. As shown in Fig. 4, the transducer is fixed on the impact force sensor, the spring applies pressure from the upper direction to the transducer, and the pressure is adjustable; The plastic righting sleeve stabilizes the transducer position to ensure the radial output of the transducer; the impact force sensor detects the transducer output force.
in real time and uploads the data to the data acquisition card; The computer receives the data signal uploaded by the data acquisition card and draws a waveform display. The impact performance test device can specifically adjust a parameter, pre-pressure or drive power parameter in the transducer to verify its effect on the output impact force.

5. Performance test
The drive power is used as the energy input unit of the transducer, and its output performance is directly related to the output performance of the transducer. In order to balance the relationship between the output performance and the power consumption of the driving power supply, it is necessary to test the output of the transducer by continuously adjusting the output parameters of the driving power in the transducer impact test device, and provide a reference for determining the optimal output performance of the driving power source.

When the drive power test is performed, the pre-stress of the test device spring is constant at 202N, the structural parameters of the transducer are constant, and the power supply voltage is changed to 50V, 100V, 150V and 200V respectively. Then we change the load current peak (rising edge triangle wave) by changing the power-on time of the driving power supply, and test the output impact force of the transducer. The impact force curve is shown in Figure 5.
By observing the impact waveform, it can be seen that after the driving voltage is determined, as the peak value of the driving current increases, the output impact force will increase linearly at the initial stage, and the linear growth rate between different voltages is basically the same; After linear growth, it will enter a period of saturation. The output impact is basically stable and no longer increases with the increase of current. The larger the driving voltage, the greater the impact strength of the saturation interval, and the impact strength of the saturation interval is linearly related to the driving voltage value.

6. Conclusion
The mine transducer is affected by the working conditions, the installation space is limited, and the optimization effect has the upper limit. Under the condition that the structural optimization parameters are determined by mathematical calculation, it is necessary to tap the potential of the driving power supply to the transducer output as much as possible.

By adjusting the driving power supply parameters, the change of the output force of the transducer is observed on the impact test platform. It can be seen that the output impact force of the transducer is positively correlated with the driving voltage parameter in the driving power source. When determining the driving voltage parameter, it is necessary to consider the system’s instability and high power consumption caused by the high voltage; when determining the current peak parameter, the value of the inflection point in the impact waveform is the optimal value.

Acknowledgment
[1] Technology Innovation Program of CCTEG XI’AN Research Institute (2017XAYMS01).
[2] Major National Science and Technology Special Tasks in the 13th Five-Year Plan (2016ZX05045-003-001).
[3] Special Fund for Scientific and Technological Innovation and Entrepreneurship of CCTEG(2018MS007).

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