The Research of Rare Earth-Iron Giant Magnetostrictive Seismic Source of Shallow Seismic Exploration

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Abstract. Due to the lack of resolution and precision of shallow seismic reflection exploration, the seismic source made of rare earth-iron giant magnetostrictive material (GMM) is used in the shallow reflection seismic exploration, and the resolution and precision is improved. GMM seismic source has more merit than the conventional seismic source. The characteristic of GMM seismic source is that the bandwidth of the seismic wave transmitted by the source is large. It is able to sweep through a range of frequency from tens Hz to thousands Hz. The parameters of the seismic source are easy to change, such as seismic energy, waveform and time length. Portable structure makes it convenient to transport and setup. The only thing should be considered before use is coupling. Its cost is not as big as other seismic source. The seismic source mentioned above can cover the shortage of shallow seismic exploration. It is an effective method to improve the exploration. A shallow seismic reflection exploration specimen machine with GMM seismic source is designed, including seismic source, driving circuit, waveform generator, data acquisition instrument and experiment system. The speed of propagation of seismic wave and the attenuation factor of soil was tested. Echo detecting experiment has also been finished. Basal experiment result is positive and further experiment is on progress at present.

1. Present status of seismic source in shallow seismic reflection exploration
The main factor which determines the resolution, depth and complexity of seismic exploration is the seismic source. Exploration personnel tried to design a controllable seismic source which is easy to operate and has high performance. There are hydraumatic controllable seismic source, electromagnetic controllable seismic source and piezoelectric controllable seismic source which have been developed presently [7]. Hydraumatic controllable seismic source has the efficiency that low frequency and powerful energy, but its repeatability, timing and detect efficiency is not perfect. The technological development of hydraulic controllable seismic source is slow in China. In the middle of 1990's, electromagnetic controllable seismic source has been developed. It is a portable, controllable high frequency seismic source. In 2000, electromagnetic controllable seismic source was designed and acquire the national patent in China [8]. Because of the limit of its structure, the frequency of seismic wave transmitted by it is less than one thousand Hz. This is disadvantageous for increasing the resolution of exploration. The piezoelectric transducer is controllable and has a well high frequency performance, fast detecting time, exact timing, and good repeatability, but its low energy and bad stability limit its development. Considering the merit and shortcoming mentioned above and the rapidly developing character of GMM in recent year, GMM seismic source was designed with the...
character of small volume, large bandwidth, powerful energy, excellent repeatability and exact timing. It is a valid method to raise the resolution, reduce the cost and increase the efficiency of shallow seismic reflection exploration [5].

2. The principle and merit of GMM seismic source
Magnetostriction occurs in most of ferromagnetic materials. It leads to the magnetostrictive effect which makes the materials expanse (post magnetostriction) and contract (negative) in magnetic field. In 1970’s, GMM was discovered by US navy weapon lab. It has the largest magnetostriction in all the known materials. From then on, a new time of magnetostrictive material began [6].

GMM have advantages as follow: Firstly, high energy conversion efficiency. The magnetostriction of GMM is 30 times larger than nickel and 3 to 5 times larger than piezoelectric materials in static magnetic field. And the dynamic strain is higher than static strain in resonance frequency. Secondly, fast response. The response time of GMM is less than 1 microsecond, so the response time is determined by the excitation time of solenoid coil. It is about 10 microseconds. Thirdly, excellent stabilization. Because of its high Curie temperature, it will not polarize when it works in high temperature. It also can work in low voltage such as tens volts, so the high voltage breakdown will not occur on it. Fourthly, large frequency response bandwidth. It is able to sweep through a range of frequencies from about tens Hz to thousands Hz [7].

GMM can be used as the seismic source because of its characters. The principle of GMM transducer (seismic source) is that: putting the GMM rod in solenoid coil which works in alternating current, its length will change with the alternating current in the same frequency. So the amplitude frequency response of the rod can be changed by controlling the amplitude and frequency of the driving signal of the solenoid coil. If the transducer is well coupled to the earth’s surface, the seismic wave will be transmitted to the soil.

GMM transducer developed rapidly in geological exploration field in recent years abroad. Lots of products and patent appear, such as well-logging transducer and subaqueous transducer. There are also some companies which dedicate to the design and manufacture of GMM transducer in China.

3. GMM seismic source and the technology of driving
In order to get a high resolution of shallow seismic reflection exploration, the GMM transducer is selected as the seismic source. The GMM transducer is manufactured by a company. The factors of the transducer, such as power, structure and amplitude frequency response characters, are calculated and designed by us. The structure schematic plan is showed in figure 1. The mark number in figure 1 is that: 1, tail mass connector; 2, shell; 3, initial stress bolt; 4, electric plug; 5, GMM rod; 6, core clamper; 7, solenoid coil; 8, head mass connecter.

![Figure 1. the structure schematic plan of the transducer.](image)

The depth of the seismic exploration has a direct relationship with the power of the seismic source. The power of the seismic source is determined by the machine structure and the driving circuit. If the driving circuit is designed with power operational amplifier, the capacity factor will be less than several kilowatts and it is hard to increase. In this article, the driving circuit is designed with power inverter. The capacity factor of this type circuit could be larger than 10 megawatt. The driving circuit
structure is showed in figure 2. The transducer is controlled by the computer. A PCI waveform generating card is designed to generate the PWM signal to control the IGBT driver. Plus signal, serial signal and sweep signal can be generated by this transmitting card and be converted to PWM drive signal. The PWM signal is calculated by the FPGA in the card. The IGBT driver is made of EXB series IGBT drive chip and the IGBT bridge converter is made of Fuji series IGBT. The DC power supply provides the energy to the converter. At last, the signal is sent to the transducer and it will generate the seismic wave which has the same amplitude frequency character as the driving signal. Then the seismic wave can be used to process the seismic exploration.

Figure 2. the structure of driving circuit.

4. Experiment

4.1. Introduction of the experiment system
In order to check and improve the performance of the transducer, the experiment system is developed after the design of the transducer and the driving circuit. The experiment system includes that: GMM transducer, PCI waveform generating card, transducer driving circuit, PZT geophones, power supply, Agilent data acquisition instrument, VEE data acquisition procedure, experiment box and computer.

Figure 3 shows the schematic diagram of the experiment box. Figure 4 shows the picture of the experiment box. The frame of the experiment box is made of iron. It is composed to 1.2 m in each side and 1 m in depth. Four flanks are covered by wood. The bottom is made of steel and 11 detection positions are made in the bottom. The box is filled with soil on the top 85 cm. In the figure 3, the above black area performances as the transducer, the green areas performance as the detection position. The P1 to P4 detection positions are used to detect the propagation character of the seismic wave in the surface. The C0 to C6 detection positions are used to detect the longitudinal wave propagating in the soil. In figure 4, the dark blue column is the transducer, and the light blue disk is the transmitting head. On the top of the transducer is the mass head which is used to make more energy transmitted to the soil. The soil is wrapped with plastic after experiment in order to keep the dampness. PZT geophones are showed in figure 5.

4.2. The frequency response of the transducer
The prime method to improve the resolution of seismic exploration is increasing the frequency of the seismic wave. The frequency of seismic wave in traditional seismic exploration is from tens Hz to hundreds Hz. This is helpful to the deep exploration. The resolution is proportional to the frequency when the wavelength is invariable, so we can increase the frequency in order to get a high resolution. The transducer works in varied frequency by the driving signal generated in the driving circuit in this experiment. Then the geophone is used to acquire the seismic acceleration and analyze the acceleration signal in the computer. The result is that the frequency response of the transducer is ideal. The spectrum is showed in figure 6. The frequency of the driving signal is 500 Hz, 1000Hz, 1500 Hz and 2000 Hz.
4.3. The speed of propagation of the longitudinal wave detecting

An important parameter for ranging the object is the speed of the propagation of the seismic wave in the medium. The position of the object could be calculated with the arrival time of the seismic wave and the speed. The measurement scheme is that: the transducer is placed on the top center of soil. The geophones are set in various bottom detection positions. Driving the transducer to generate the seismic wave and transmit it to the soil, the acceleration signal is acquired by the geophones. Then the spread time of the seismic wave in single trip can be calculated. The distance between the transducer and the geophone is known, so the speed of propagation of the seismic wave is equal to the quotient of the distance and the time. In figure 3, the length of OtCi (i=0, 1, 2, 3, 4, 5, 6) is known, the spread time could be calculated by the signal acquired by the geophone. Then the speed of propagation of the seismic wave can be calculated and the result is showed in figure 7.

The experiment result is showed in figure 7. The speed is different in each detection position. It can be concluded that: the speed of propagation of the axial direction in different driving frequency is basically uniform, but it is different in other directions. There are two factors that can lead to this result. The first factor is the nonhomogeneity of the soil filled in the box. The density, the dampness and the component of the medium may be different in each direction. The second factor is the nonhomogeneity of the sound field [10]. The basic relationship of the frequency and the speed showed in figure 7 is that the lower of the frequency, the higher of the speed. All the result is basically the same as the conclusion given in the reference [1].
4.4. The test of the attenuation coefficient of the medium
The depth of the exploration is another parameter that we care about. Two factors determine the depth of the exploration. One factor is the energy of the seismic source, the other is the attenuation of the medium. The energy of the seismic source could be changed by the driving circuit and adjusting the structure of the transducer. The attenuation coefficient is the character of the medium. The attenuation coefficient is proportional to the frequency [1]. A low frequency leads to a large depth, but the resolution will be lower because of the low frequency. A high frequency leads to a high resolution, but the depth will be small because of the big attenuation. So it is a tradeoff between the depth and the resolution. The speed of propagation of the seismic wave is about 250 m/s (Figure 7), if the frequency of the seismic wave is 1000 Hz, the resolution is about 12.5 cm. If the frequency is 2000 Hz, the resolution is about 6.25 cm. If the frequency is 500 Hz, the resolution is about 25 cm.

\[ A = 20 \log \frac{E_a}{E_b} / D \]

A is the attenuation. \( E_a \) is the energy transmitted by the transducer. \( E_b \) is the energy acquired by the geophone. \( D \) is the distance between the transducer and the geophone. Figure 8 shows the result of the attenuation. It can be concluded that: Firstly, the more of the frequency, the bigger of the attenuation. The relationship between the frequency and the attenuation is the same as the result showed in [1]. Secondly, the attenuation of different directions is different. The basic trend is that a far distance of the...
axes of the transducer gets a big attenuation. It is because that more energy is in the main lobe of the sound field than the side lobe. The result showed in figure 8 is beneficial to a high resolution exploration. Because of the less attenuation in axial direction of the transducer, the echo signal could reflect more information of the geologic conformation in the axial direction than other direction. In real exploration, change the position of the exploration continuously within an area, then the geologic conformation can be reconstructed by analyzing all echo signals in the area. It only needs one seismic source and tens of geophones. This method is more flexible and cheaper than the traditional method which needs one seismic source and hundreds of geophones. The analyses of the echo signal are easier and will be real-time and high efficiency.

5. Conclusions and future work

The GMM transducer is used in this project and proved that it is better than other seismic sources in shallow seismic reflection exploration. It has an ideal frequency response and enough energy for the exploration. The exploration instrument is flexible and portable. So the GMM transducer is appropriate for the high resolution shallow seismic exploration.

Specimen machine for the exploration is designed and basic experiments such as speed of propagation detecting and attenuation detecting are finished. The result is helpful to the improvement of the specimen machine and the real exploration. In the future, a receive array will be used to get the echo in order to get a high resolution. The experiment will be carried out outdoor in further work.

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