PARAMETER OPTIMIZATION AND NUMERICAL CALCULATION
FOR GIANT MAGNETOSTRICTIVE TRANSDUCER

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ABSTRACT. In the study of piezoelectric ceramic transducers, a lot of high quality papers are published in journal NATUR. In this paper, a new type of transducers is developed with rare earth giant magnetostrictive materials (GMM). The transducers are good at solving the ultrasonic nondestructive testing of the large components in concrete. For the transducers, the impedance characteristics, the vibration velocity and the stress of the rare earth GMM transducers are calculated by a new method of Four-Terminal Network Method (FTNM) combined with the Fourier Transform (FT). Experimental results prove that the results numerically calculated by the new method are correct. In addition, the pre-stress, the electrical parameters and the geometric dimensions are optimized, and thereafter, the rare earth Giant Magnetostrictive Transducer (GMT) with longitudinal vibration is developed based on the optimal parameters. The studied transducer has the advantages of the larger power, higher frequency and minimum residual vibration in nondestructive testing. The testing results show that the ultrasonic nondestructive detection of bridge and the massive concrete (length: 6m~10m) with internal quality can be carried out.

Keywords: Giant magnetostrictive transducer, Nondestructive, Concrete, GMM transducer, Optimization

1. Introduction. Piezoelectric ceramic materials have been developed rapidly in the world currently [1], and the materials can be used to produce the ultrasonic transducers with good directivity, and it is suitable for the parametric measurement of speed and distance [2]. At present, many piezoelectric ceramic transducers are used for nondestructive testing [3] and diseases diagnosis [4], but the main usage of such transducers is in the low-power status, only for the electromechanical transformation with lower efficiency. The piezoelectric chip with the high Q value that causes narrow bandwidth, is difficult to meet the need of the large components for nondestructive testing [5], and the piezoelectric ceramics made of lead zirconate titanate (PZT) is currently still in dominant. And the content of PbO and PbO3 in the lead-based piezoelectric ceramics is about 70% of the raw material, which causes serious harm to human health and environments in the process by using and disposing the transducers [6]. For the KNN-based piezoelectric ceramics, Saito (2004) published two papers in the NATURE journal [7,8]. Although Saito (2004) successfully developed a kind of the KNN-based piezoelectric ceramics [7], in which the electromechanical properties are comparable with PZT, it is still difficult to apply into industrial applications [8] due to the shortage of the KNN ceramics manufacturing method,
which results in that the electromechanical properties are that the piezoelectric ceramic materials have been developed rapidly in the world currently [1], and the materials can be used to produce the ultrasonic transducers with good directivity, and it is very suitable for the parametric measurement of speed and distance [2]. At present, many piezoelectric ceramic transducers are used for nondestructive testing [3] and diseases diagnosis [4], but the main usage of such transducers is in the low-power status, only for the electromechanical transformation with lower efficiency.

The rare-earth GMM has been gradually used in transducers, sensors, ultrasonic and other fields, because they can exhibit giant magnetostrictive strain value, high mechanical energy-electrical energy conversion rate, fast response, and the high reliability at room temperature [8,9]. Many institutes have committed to study and apply the high-power magnetostrictive transducers in the world [10]. Nowadays, the rare-earth GMM is mainly applied in the high-power underwater ultrasonic transducers and micro-pump drivers, and its working frequency is low, generally at 0~10kHz. German Materials Institute developed a kind of micro-pump with rare earth giant magnetostrictive thin film materials [11], when the frequency is 2kHz; the maximum flow rate is 10μL/min and the outlet pressure can be up to 100Pa [11].

The development of high-frequency transducers is difficult, and the main reason is the lack of useful experiences and information [12]. When the nondestructive testing (NDT) experiment is made on the large bridges and large concrete components (6m-8m), in order to improve the location precision of the internal flaws, it is required that the transducers must have some special properties such as high power, high frequency and short residual vibration.

In the past, the high-frequency transducers used in NDT for bridges are mainly made of PZT materials. In this paper, the rare-earth GMM is used to develop the superior performance transducers [11]. Although the materials of magnetostrictive transducers and piezoelectric transducers are different, the basic designing methodology is the same. The FTNM is a classic and analytic method which can be used to calculate the longitudinal vibration piezoelectric transducers [12], and the other researchers [13] used the Finite Element Analysis Method (FEAM) to design the structure of piezoelectric transducers. The FTNM can be applied to calculate the rare-earth longitudinal vibration transducers, in which the compared results with the finite element method are in reference [12]. Kei used a professional software SPICE to make the simulation for the power converters [14].

Because the functions of the professional software are limited and cannot simulate the special cases. In this paper, an optimal design software based on the FTNM is developed for the parameter calculation of magnetostrictive transducers. When the material parameters and the constructional parameters of the transducers are entered into the software developed by the authors, the calculation results can be given in the forms of data and curves. By using this software, the pre-stress, the electrical parameters (such as the coil turns, the capacity of the storage capacitor) and the geometric dimensions (such as the length of GMM rod, the area, the thickness of the head transmitter and the thickness of the back clamp) are optimized, and thereafter, a rare earth Giant Magnetostrictive Transducer (GMT) with longitudinal vibration is developed based on the optimal parameters. The frequency response to the characteristics of the transducer with small-signal is tested, and the ultrasonic wave of a high-current excitation by the energy storage capacitor is measured. By comparing the experimental results with the calculated results, it proves that the calculation results are correct. Experimental results show that the transducer has the advantages of the larger power, higher frequency and minimum residual vibration in nondestructive testing. Its penetration distance in a large block of concrete component is 6m~10m.
2. GMT Calculation Principle.

2.1. GMT structure. The structure of GMT is designed and developed as shown in Figure 1. To simplify the calculation, the springs, the coils and the circuit boards are usually ignored. The transducer in Figure 1 can be divided into three parts, they are the active magnetostrictive rod, the passive transmitter (including the top, the cylinder and the flange of the transmitter) and the back (involving the back clamp, back baffle, shell, rear cover and the flange of shell). The three parts are established into three equivalent circuits respectively, and then they are connected in a series of circuits to do the analyses and calculations. There is less impact to the results in which the transmitter cylinder, the transmitter flange, the back baffle, the shell, the shell flange and the rear cover are ignored in the equivalent circuit. So, only the gray filled part in Figure 1 is considered, i.e., the longitudinal vibration of the magnetostrictive rod, the longitudinal vibration and the bending vibration of the transmitter, and the back clamp in the following calculations.

![Schematic diagram of the transducer](image1)

![Transducer](image2)

Figure 1. GMT structure: (a) internal structure and (b) outer form

2.2. Equivalent circuit of FTNM of GMT. Considering the case of the vibration in the longitudinal direction, the piezomagnetic equations of the rare earth rod are shown
as:

\[
\begin{aligned}
S_3 &= S_{33}^H T_3 + d_{33} H_3 \\
B_3 &= d_{33}^T T_3 + \mu_{33}^H H_3
\end{aligned}
\]  

(1)

where, \(S_3\) and \(B_3\) are the strain and the magnetic flux density respectively, \(d_{33}\) is the magnetostrictive strain derivative, \(\mu_{33}^T = \frac{\partial B_3}{\partial H_3}\)|\(_{H=\text{const}}\) is the magnetic permeability with a constant stress.

After solving the vibration equation of the rare earth rod, the following equation can be obtained

\[
S_3 = \frac{\partial \xi}{\partial z} = \frac{\dot{\xi}_2 - \dot{\xi}_1 \cos k_1 l_1}{j \omega \sin k_1 l_1} k_1 \cos k_1 z - \frac{\dot{\xi}_1}{j \omega} k_1 \sin k_1 z
\]  

(2)

Suppose the values of \(B_3\) and \(H_3\) are constants, and in this study, only the 0-order and 1-order vibration modes are discussed.

\[
\begin{aligned}
V &= \frac{d_{33}}{j \omega N^2 A_1 \mu_{33}} \frac{d_{33}^T}{S_{33}^H} \mu_{33} \cdot \frac{j \omega N}{S_{33}^H} \cdot (\dot{\xi}_2 - \dot{\xi}_1) + I \left( \frac{R_e}{R_e + R_{\text{out}}} \right)
\end{aligned}
\]  

(3)

where, \(\alpha = R_e/(R_e + R_{\text{out}})\), \(\alpha\) means shunt coefficient in Equation (3), \(R_e\) is a magnetic resistance of the rare earth rod, and \(R_{\text{out}}\) is a magnetic resistance of the outer loop.

Solving Equation (1) for \(T_3\), it has \(T_3 = S_3 / S_{33}^H - d_{33} / S_{33}^H \cdot H_3\), and then the both sides of Equation (3) are multiplied by the cross-sectional area \(A_1\), hence, it has

\[
F = T_3 A_1 = A_1 \cdot \frac{\partial \xi}{\partial z} / S_{33}^H - A_1 \cdot d_{33} / S_{33}^H \cdot H_3
\]  

(4)

In this way, substituting Equation (2) into Equation (4), the equation set of voltage is formed as follows:

\[
\begin{aligned}
\varphi V &= \left(- j \omega L |\varphi|^2 + \frac{\rho_1 c_1 A_1}{j \sin k_1 l_1} \right) (\dot{\xi}_2 - \dot{\xi}_1) - j \rho_1 c_1 A_1 \tan \frac{k_1 l_1}{2} \dot{\xi}_1 + F^A_1 \\
\varphi V &= \left(- j \omega L |\varphi|^2 + \frac{\rho_1 c_1 A_1}{j \sin k_1 l_1} \right) (\dot{\xi}_2 - \dot{\xi}_1) + j \rho_1 c_1 A_1 \tan \frac{k_1 l_1}{2} \dot{\xi}_1 + F^A_2 \\
\alpha I &= \frac{V}{j \omega L} - \varphi (\dot{\xi}_2 - \dot{\xi}_1)
\end{aligned}
\]  

(5)

where, \(L = \frac{\mu_{33}^S N^2 A_1}{l_1}\) represents static inductance, \(\varphi = \frac{d_{33}}{j \omega S_{33}^H \mu_{33}^S N}\) is a coefficient of electromechanical conversion, \(N\) is the number of coils, \(A_1\) is the cross sectional area of the rare earth rod, \(\xi_1, \xi_2\) are the vibration speeds of the both terminals of the rare earth rod respectively, \(\rho_1\) is the density and \(c_1\) is the equivalent sonic velocity of the rare earth rod, and \(k_1 = \omega / c_1\).

When \(Z^A_1 = j \rho_1 c_1 A_1 \tan \frac{k_1 l_1}{2}\), \(Z^A_2 = \frac{\rho_1 c_1 A_1}{j \sin k_1 l_1}\) and \(Z_E = j \omega L\), the equivalent circuit can be constructed and re-designed in Figure 2.

The initial current \(I_0\) and inductor \(L\) of the coils are used in an excitation source, the constant \(H\) equivalent circuit of the rare earth rod is shown in Figure 4. Where, \(L I_0 \delta(t)\) is the excitation voltage supplied, and \(R_X\) is the freewheeling resistance, \(S_{33}, d_{33}, \mu_{33}\) are complex numbers, so the wave number \(k_1\) of the equivalent circuit from the piezomagnetic equation as mentioned above is obtained. \(j \rho_1 c_1 A_1 \tan \frac{k_1 l_1}{2}\) and \(\frac{\rho_1 c_1 A_1}{j \sin k_1 l_1}\) [9] are also complex numbers, and in this study, only the 0-order and 1-order vibration modes are discussed.

Since the equivalent circuit of the transmitter, the back and the rare earth rod are used, the equivalent circuit of the transducer can be achieved when the current is supplied. The
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Figure 2. (a) Constant $H$ equivalent circuit of the rare earth rod when the constant power is supplied ($Z_{\text{out}} = j\omega N^2/R_{\text{out}}$ is the electrical impedance of the outer loop) and (b) Constant $H$ equivalent circuit of the rare earth rod driven by energy storage capacitor ($CU_0\delta(t)$ represents the impulse current supplied, and $R_1$ represents the loop resistance)

equivalent circuit is illustrated in Figure 3. In Figure 3, the head of the transmitter, the back of the longitudinal vibration and the bending are considered, which means that the use of the longitudinal vibration resistance and the bending resistance of the parallel equivalent circuit is valuable.

$$Z_{BY1}^F = j\rho_2 c_2 A_2 \tan \frac{k_2 l_2}{2}, \quad Z_{BY2}^F = \frac{\rho_2 c_2 A_2}{j\sin k_2 l_2}, \quad Z_W = \rho_w c_W A_2$$

$$Z_{BY1}^B = j\rho_3 c_3 A_3 \tan \frac{k_3 l_3}{2}, \quad Z_{BY2}^B = \frac{\rho_3 c_3 A_3}{j\sin k_3 l_3}$$

Figure 3. $H$ equivalent circuit of the whole transducer when current power is supplied

Among these equations, $\rho_2$ is the density of the top of the transmitter head, $A_2$, $l_2$, $c_2$ are the cross-sectional area and thickness, and the sound velocity respectively. On the top of the transmitter head, $k_2 = \omega/c_2$. $\rho_3$ is the density of the back clamp, $A_3$, $l_3$, $c_3$, are the cross-sectional area and thickness, and the equivalent sound speed of the post-plate, where $k_3 = \omega/c_3$. When the testing target is the concretes with a large volume, one can consider $z_w$ as a purely resistive load, $\rho_w$ as the load density, and $c_w$ as the load velocity of the sound. Considering the transmitter head as a thin plate, when $n = 1$, the bent
The vibration impedance [15] can be presented as:

\[ Z_{FW} = R_w + j \left( 2\pi f_1^FM_1^F - \frac{1}{2\pi f_1^FC_1^F} \right) \]

In the above equation, \( R_w \) shows the damping resistor of the bending vibration, estimated by 0.5\( Z_{W} \), and \( M_1^F \) represents the top equivalent quality. When the boundary is simply supported, the ratio between bending equivalent quality and actual quality is \( M_1^F = m^F = 0.1224 \) (kg), so, \( M_1^F = 0.2843 \times 0.01224 = 0.003478 \) (kg). The bending vibration frequency of the top of the transmitter head [16] is \( f_1^F = \frac{\mu_1^2 \cdot h \cdot c_{plate}}{2\sqrt{12\pi a^2}} = 48.812 \) (kHz).

And the smooth coefficient of the transmitter head is \( C_1^F = \frac{1}{(2\pi f_1^F)^2M_1^F} = 3056\) p (s^2/kg). In the similar way, one can calculate the equivalent quality of the post-plate \( M_1^B = m^B \times 0.2843 = 0.03401 \) (kg). The bending vibration frequency \( f_1^B = 29.830 \) (kHz), and the smooth coefficient \( C_1^B = 837\) p (s^2/kg).

According to Kirchhoff circuit laws, the equivalent circuit equations are shown in Figure 5, and then the complex matrix operations to solve the equations are applied, in this way, each vibration speed is obtained, and the bending vibration speed of the transmitter head is \( v_9 = v_1 + v_8 = v_1 + v_3 - v_2 \), where, \( v_1 \) is the longitudinal vibration speed of the transmitter head, \( v_8 \) is the bending vibration speed of the transmitter head, and \( v_3 \) is the longitudinal vibration speed for the top of the rare earth rod, so the stress on the top of the rare earth rod is \( T_3 = Z_Fv_3/A_1 \).

2.3. Exciting circuits of magnetostrictive transducer. The transducer exciting circuit is designed as shown in Figure 4. It contains the high voltage direct current power sources \( E \approx 450\) V, the limit resistor of charging current \( R_L \approx 10\) k\( \Omega \), the diode \( D_1 \) and the energy storage capacitor \( C \approx 11\) \( \mu \)F, the loop resistance \( R_l \approx 5\) \( \Omega \), the limit resistor of trigger \( R_2 \approx 500\) \( \Omega \), the freewheeling diode \( D_X \), the freewheeling resistance \( R_X \approx 5\) \( \Omega \), the switch \( V_T \) and the transducer \( T \) \( (L \approx 0.1\) mH).

\[ \text{Figure 4. Exciting circuit of transducer} \]

First of all, without the conduction of the switch transistor \( V_T \), the capacitor \( C \) is charged by the power sources \( E \) through \( R_L \) and \( D_1 \), and the final charged voltage is \( E \). When the rising edge of trigger pulse arrives, and the switch \( V_T \) conducts, the charge on the energy storage capacitor \( C \) is discharged rapidly to the transducer coil \( T \). During the discharging period, the current on the energy storage capacitor \( C \) and the transducer coil \( T \) is declined linearly. In order to produce ultrasound with a single pulse, when the voltage on the capacitor \( C \) is reduced to \( U_1 \) or the coil current is increased to \( I_0 \), the switch \( V_T \) can be turn-off rapidly by the trailing the edge of trigger pulse. Because the
transducer coil current cannot be mutated, \( I_0 \) will continuously decay to zero through the freewheeling diode \( D_X \) and freewheeling resistance \( R_X \), and the voltage \( (U_X \approx I_0 R_X) \) will be reversal at the both ends of the transducer coil. In Figure 5, the trigger pulse is produced by a computer-aid control system which can accurately control the pulse width \( (T_d) \) of the exciting current of the transducer.

2.4. Calculation of pulse excitation response of transducer. The transducer excitation circuit can be divided into three parts calculated as shown in Figure 5. The first part is that the pulse current \( CU_0 \delta(t) \) is made to be an exciting source. The vibration velocity \( v_0 \) of the transmitter head of the transducer between 0 and \( T_d \), the vibration velocity \( v_{1st} \) after the \( T_d \) period, the capacitor voltage \( U_1 \) and the coil current \( I_0 \) at \( T_d \) moment can be obtained by using the methods described above. The second part is that the pulse voltage \( CU_1 \delta(t-T_d) \) is taken as an exciting source, during \( 0 \sim T_d \) the vibration velocity is 0 because there is no incentive, but the vibration velocity \( v_{2nd} \) after \( T_d \) can be obtained. The third part is that the pulse voltage \( LI_0 \delta(t-T_d) \) is made to be an exciting source too. In this case, there is no incentive source during \( 0 \sim T_d \), and the vibration velocity is 0. However, he vibration velocity \( v_{3rd} \) of the transmitter head of the transducer after \( T_d \) can be got in this situation. The actual vibration velocity of the transmitter head of the transducer consists of these three parts, during \( 0 \sim T_d \) the velocity is \( v_0 + 0 + 0 \), after \( T_d \) the velocity is \( v_{1st} + v_{2nd} + v_{3rd} \).

![Figure 5. Equivalent circuit when the transducer is driven by a trigger pulse](image)

When computing the transducer parameters by using the optimal software developed by the authors, firstly, the excitation sources are transformed into an unit impulse function \( \delta(t) \) in an equivalent circuit, the unit impulse response signal \( h(j\omega) \) of the vibration velocity, the stress, the capacitance voltage and so on in the frequency domain can be measured, e.g., the velocity of vibration \( v(j\omega) \). Then, the FT is performed in real excitation sources \( e(t) \), e.g., \( e(j\omega) = F[e(t)] \). After that, the Inverse FT is carried out for the excitation source \( e(j\omega) * h(j\omega) \). The velocity of vibration, the stress, the capacitance, and voltage, etc. can be obtained. For example, the velocity of vibration can be presented as \( v(t) = Re\{F^{-1}[e(j\omega) * v(j\omega)]\} \), where, \( F \) represents FT, \( F^{-1} \) represents Inverse FT and \( Re \) represents the real part.

3. Optimal Design of Transducer.

3.1. Optimal design of axial pre-stress of transducer. The pre-stress structure is used in the magnetostrictive ultrasonic transducers in this study, the magnetostrictive curves under different pre-stress are shown in Figure 6.

The magnetostrictive materials are very brittle, which can withstand the compressive strength 700MPa, but the tensile strength is only 28MPa. It imposed a certain of pre-stress on the rare earth magnetostrictive material that can avoid the tensile effects. Figure
Figure 6 shows that after imposing pre-stress between 5 and 15 Mpa, $d_{33}$ became the larger, and the linear regions became the wider, so that pre-stress between 10 and 30 MPA can be selected in designing.

The rare earth rod can bear the compressive strength of $T_{\text{max}}$ 700 Mpa when the transducer vibrates. When the mechanical pre-stress is $T_{\text{pre}}$, the pulse pre-stress is between $-T_{d1}$ and $+T_{d2}$, the transducer (when it works normally) will meet the following conditions [8]:

$$T_{\text{pre}} - T_{d1} > 0, \quad T_{\text{pre}} + T_{d2} < T_{\text{max}}$$

Equation (6) represents that the rare earth rod must be always in a pressure status while the transducer is in vibrating, and the maximum stress of the rare earth rod cannot exceed $T_{\text{max}}$ while the transducer is in vibrating.

The values of $T_{d1} \approx 17$ MPA and $T_{d2} \approx 53$ MPA can be estimated as shown in Figure 6. From Equation (6), $T_{\text{pre}} = 17$ MPA and the diameter of the rare earth rod $d = 10$ mm can be selected, which is equivalent to the force on the earth rod as 1335 N. If the pre-pressure spring allow deformation not upto 10 mm, then the spring stiffness is $K = 133.5$ N/mm. The rare earth rod will be crashed if the condition does not meet Equation (6) because the end face of the rare earth rod will be subjected to tension, which is resulting in the gap and crashed earth rod. To avoid to damaging the rare earth rod, a steel protective pad can be bonded to the end face of the rare earth rod to protect it. It needs to make sure that the area of the pad and the end face of the rare earth rod are the same, which can reduce the stress concentration. As $T_{\text{pre}} + T_{d2} \approx 70$ MPA, when the stress concentration is less than 10 times of that on average, the conditions represented by Equation (6) will be met.

3.2. Optimization of electrical parameters of transducer. In the maximum operating magnetic field of the rare earth rod, $H = 2.5$, kOe = 200 kA/m, the switch $V_T$ instantaneously is set to work at 50 A/500 V, the current $I = 50$ A, the length of the rare earth rod $l_1 = 0.04$ m, so the coil number $N = Hl_1 / I \approx 160$ is selected. The capacity of the energy storage capacitor needs to be selected largely enough to meet that the voltage drop of the capacitor is not heavy when the trigger pulse width is $T_d$. The energy storage capacitor $C$ can be estimated by the formula: $C = IT_d / VU = 50 \times 25 \mu s (0.1 \times 440) = 22 \mu F$. 
3.3. **Optimization of transducer geometric structure.** The length of the rare earth rod determines the longitudinal resonance frequency of the transducer, the longer the length, the lower the longitudinal resonance frequency will be. The length of the rare earth rod $l_1$ is 40 mm in this study. The smaller is $A_1$, the higher $V$ and $T$ by using the optimal software. However, if the cross section $A_1$ of the rare earth rod is too small, it will lead to the higher stress $T$, and the stress will damage the rare earth rod. It is appropriate that $d_1$ is 10 mm, and the cross section $A_1$ of the rare earth rod is $25\pi \text{mm}^2$ in this study.

The thickness of the transmitter head $h_1$ is set as 4.5 mm and the thickness of the back clamp $h_2$ is taken as 13 mm in this experiment. Their bending frequencies are 49 kHz and 35 kHz respectively. The total resonance frequency of the transducer is 40 kHz, and it consists of the longitudinal vibration and the bending vibration.

4. **Experiments and Discussions.** The rare earth rod is developed on high-current unipolar pulses, its magnetic field operating point can be considered as the average of the high current pulse. In the testing of the transducer spectrum characteristics by the AC small-signals, the operating point of the magnetic field is near to zero, which does not match the actual usage. A 10 mm permanent pre-bias magnetic field can be adopted in the testing of the transducer spectrum characteristics by the AC small-signals, which can be considered as improving the operating point in the magnetic field. Then the frequency spectrum characteristics of the transducer coil is tested by a HP impedance analyzer instrument. The measured results of the resonance frequency of the transducer is between 30 and 50 kHz, and it is consistent with the calculation result.

The transducer is driven by a high power exciting signal source controlled by a computer, the trigger pulse width $T_d$ of the exciting signal source can be easily changed, which drives the transducer. With the 50 kHz piezoelectric transducer and the receiver sensor, the ultrasound emitted by the GMT head is measured, and the testing result of the energy storage capacitor voltage ($CH_2$) and the ultrasonic wave ($CH_1$) are obtained.

The testing shows that the vibration velocity pulse of the transmitter head is correspond to the stress pulse, and the vibration velocity is not constant even that some small resonance waves are emerged, and the $CH_1$ is a reflected ultrasonic wave received by the piezoelectric pressure sensor directly connected to the transmitter head. During the period of the high level of the trigger pulse signals, the energy storage capacitor voltage decreases linearly, and it shows that the measurement results are consistent with the calculations.

When the ultrasonic technology is used to test the large block of concrete components, it requires that the ultrasound wave emitted by the transducer has a good directivity. In this paper, a semicircle-type plexiglass specimen is designed to test the directivity of the GMT and the PZT transducer. The distribution of transducers is shown in Figure 7. The transducer is placed at the center of the specimen, and the receiver transducer is placed on the arc of the specimen, at every 15 degrees. The first-wave amplitude curves of the ultrasound waves emitted by the GMT and the PZT transducer on different angles are shown in Figure 8. From the figure, it can be found that the ultrasound energy emitted by the GMT is 10 times higher than that by using the PZT transducer, therefore, the ultrasound wave emitted by the GMT has the better directivity.

To test the developed GMT penetration distance in a large block of concrete component, the GMT is used to transmit a high power ultrasound, and then the PZT is applied for transducer to receive ultrasonic wave at different distances (from 6 m to 10 m) and finally the waveforms are recorded. The distribution of the transducers is shown in Figure 8. The experiment proves that the received waveforms are very clear even at 10 meter distance,
Figure 7. (a) Calculation of the head of transmitter bend and the velocity of the longitudinal bending while trigger pulse width $T_d = 200\mu s$ and (b) Measured waveform of the ultrasonic wave ($CH1$) and the energy storage capacitor voltage ($CH2$) while the trigger pulse width $T_d = 200\mu s$ which meets the needs of the real applications. However, if the PZT transducer is used as the transmitter transducer, the ultrasound wave emitted will be seriously degraded in the 6-meter-long of concrete components, and it is difficult to analyze the received waveforms.

5. Conclusions. In this paper, the main research work includes three parts. Firstly, a new method of the FT combined with the FTNM is presented in this paper. By using the new method, the impedance of the transducer, the vibration velocity in frequency domain and the time domain are calculated, the strain of the rare earth rod top, the pre-stress of the transducer, the structure parameters of the device, and the geometry structure are optimized, which provide the theoretical basis of the transducer design. Secondly, by means of the experiment, the characteristics of the transducer impedance, the trigger pulse widths, the voltage of the energy storage capacitor, and the wave of the emission of the ultrasonic transducer are measured. The experimental results are consistent with the computation results of the new method. Finally, the rare earth giant magnetostrictive
Figure 8. Calculation of the head of transmitter bend and the velocity of the longitudinal bending while trigger pulse width $T_d = 25\mu s$ and (b) Measured waveform of the ultrasonic wave ($CH1$) and the energy storage capacitor voltage ($CH2$) while the trigger pulse width $T_d = 25\mu s$.

A transducer is developed based on the optimal parameters, thus the ultrasonic nondestructive of bridge and the large block of concrete ($6m\sim10m$) with internal quality can be obtained.

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REFERENCES


