Research on EMAT Excitation Based on RLC Oscillator

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Abstract: The paper mainly researches a new method of EMAT (Electromagnetic Acoustic Transducer) excitation-continuously pulse excited electro-magnetic ultrasonic. Its aim is improving magnetic-sound transform efficiency of EMAT. It solves some problems such as low sensitivity and blight of thermal affection. Based on the basis model of EMAT, it uses IGBT, a new kind of switch power supply, instead of AC contactor. It realizes auto-excitation of EMAT, and accomplishes charge and discharge capacitance automatically. It introduces fundamental of EMAT, and dynamic analyze how to choose the parameters of RLC pulse circuit plus IGBT. The whole circuit is researched through the way of experiment. Then it acquires ideal projects of arranging elements’ parameters. In the end, the paper acquires unite conclusion of theory analysis and experiment.

Keywords: EMAT; IGBT; RLC oscillation

1 Introduction

EMAT is short for Electro-Magnetic Acoustic Transducer. It’s a new device for acoustic emission and receiving. It has many advantages such as noncontact the material being tested directly in process of testing. It doesn’t need couple agent, has high speed testing and good repeatability, and performs well at high temperature, and is suitable to test material with special shape, and so on. So the EMAT has taken more and more attention of people in the field of Nondestructive-Testing. The traditional method for producing EMAT excitation is that signal source makes pulse signals, and power is amplified, and then is transmitted to coil as excitation. There are some problems in this method, such as power is consumed too much when current is amplified. And intensity of acoustic signals could be affected because of hot bearing capacity of coil. So the paper puts forward using the way of capacitance discharges in the RLC oscillating circuit to produce strong current pulse as coil excitation. This method has many advantages such as concentrating power, high instantaneous current peak and low heat. It is propitious to improve ultrasonic signals intensity.

2 Basic Principle of Electro-Magnetic Ultrasonic

Generally, EMAT includes 3 parts: ① coil; ② magnet; ③ work piece. The basic principle is: The eddy current will be induced in the surface of the work when there is a coil near it; the coil is accompanied with high frequency alternating current. At the same time, make it in a directional magnetic field. So the eddy current and the magnetic field can interact each other to generate Lorentz force. This force will act on crystal lattice; the folium of the material is under the reciprocating force. Finally, the ultrasound is generated. The inverse process of this is the principle of electromagnetic ultrasonic receiving. For different materials, the force source is not only Lorentz force, but also it includes magnet anstrictive effect.

3 Choosing Circuit Parameter Theoretically

Analyzing RLC circuit which is shown in figure 1, and acquiring ideal signals as excitation of pulse electro-magnetic ultrasonic, it should choose reasonable circuit parameter to make RLC discharge circuit work in under-damp. Frequency of signals is higher than 20kHz. The peak signal must be as high as possible. The attenuation should not be too fast. As follows, it discusses the relation among parameters in “under damped” producing alternating signals.
3.1 Total Resistance in the Circuit

The total resistance in the circuit should fulfill the formula \( R \leq 2 \sqrt{L/C} \); considering attenuation modulus \( \alpha \) : \( \alpha = R/2L \). Because the larger \( \alpha \) is, the more quickly \( U_c(t) \) attenuate, to ensure the excitation of pulse electro-magnetic ultrasonic has durative, the total resistance should be as small as possible. It can make attenuation of signals not too fast.

3.1.1 Considering the Signal Frequency \( f \)

The formula

\[
\frac{1}{f} = \frac{\omega_0}{2\pi} = \frac{1}{\sqrt{LC}} \left( 1 - \frac{R^2}{4L^2} \right)
\]

shows inverse ratio between frequency \( f \) and resistance \( R \). Because exciting ultrasonic signals in the end, the frequency of stimulating signals should be higher than 20kHz. \( R \) must be small enough to ensure \( f > 20 \text{kHz} \).

3.1.2 Considering current peak \( i_m \)

The formula

\[
i_m = -U_0 \sqrt{\frac{C}{L}} \exp \left( -\frac{2L}{\sqrt{LC}} \arctan \frac{1}{\sqrt{4L}} \right)
\]

shows decreasing \( R \) can increase \( i_m \). Considering conversation of energy, capacitance power storage is \( W_C \), inductance power storage is \( W_L \), from beginning of discharge to current peak, the Active Power Loss is \( W_R \). The relation of the three is

\[
\Delta W_C = W_L + W_R
\]

Namely

\[
\frac{1}{2} C U_m^2 - \frac{1}{2} C U_0^2 = \frac{1}{2} L i_m^2 + \int_0^t i^2 Rd\tau
\]

In the formula, \( U_m \) is the voltage of capacitance when \( i_m \) is peak. So it shows \( R \) must be decreased as much as possible so that the active power loss is decreased and \( i_m \) is increased.

3.2 Inductor value \( L \)

3.2.1 Considering attenuation modulus \( \alpha \)

The formula \( \alpha = \frac{R}{2L} \) shows increasing inductor value \( L \) properly can decrease \( \alpha \) , and delay the attenuation of the signals.

3.2.2 Considering current peak \( i_m \)

The formula

\[
i_m = -U_0 \sqrt{\frac{C}{L}} e^{-\frac{L}{R}}
\]

shows the change of \( L \) will affect \( i_m \) much. So decreasing \( L \) is helpful to increasing current peak.

Considering apparent wave-head time of discharge current (raising time of pulse current from zero to 90% peak). Accompany with the increase of \( L \), discharge current apparent wave-head time is delayed. Because when \( t=0 \), maximum rising rate of pulse current is \( \left( \frac{di}{dt} \right)_m = \frac{U_0}{L} \).

So the bigger \( L \) is, the smaller maximum rising rate is.

3.3 Capacitance value \( C \)

3.3.1 Considering signal frequency \( f \)

According to (2), it’s inverse ratio between capacitance value \( C \) and frequency \( f \). So reducing \( C \) can ensure signal frequency \( f > 20 \text{kHz} \).

3.3.2 Considering current peak \( i_m \)

According to (1), increasing \( C \) can increase \( i_m \).

3.4 Initial value of capacitance voltage \( U_0 \)

According to (1), it shows direct ratio between \( U_0 \) and \( i_m \), so it must increase \( U_0 \) as much as possible.

Considering apparent wave-head time of discharge current, Increasing \( U_0 \) can raise maximum rising rate of pulse current. So it decreases the time, and makes wave-head steeper.

Sum up the upper theories, to acquire ideal excitation signals, parameter should be chosen as follows:

1. \( R \) should be small
2. \( L \) should be moderate
3. \( C \) should be moderate
4. \( U_0 \) should be large.

4 Choosing Circuit Parameter Experimentally

4.1 Analyzing RLC Pulse Discharging Current

A kind of switch power-IGBT is used in the experiment as an electronic switch for conduction and shutdown. The paper uses multivibrator and monostable trigger to control IGBT. The figure of time series is showed in figure 2. Its working steps are as follows: figure 3 is a sketch map of the current. At \( t=0 \), IGBT\(_1\) conducts, and then high voltage DC power supply charge up the capacitance, and calculate the charge time \( t_1 \). The dropping edge of multivibrator makes monostable trigger 1 work, which is delaying the whole process, called \( t_2 \). The falling edge makes
monostable trigger 2 work. When the upper level comes, IGBT₂ conducts, and then RLC oscillates, and its time is t₃.

![Figure 2. Waveform chart of time series](image)

4.2 Experiment for Pulse Discharge of Capacitance Storage Type

In the experiment, two high voltage capacitance which are 1 μF and 5 μF respectively (rated voltage is 1000V) and two spiral coils (No.1 and No.2) are used to do discharge experiment. No.1 is 3.5 μH, No.2 is 0.95 μH.

Combining 1 μF capacitance with No.1 coil, Charge the capacitance to 500V, the waveform on the oscillograph is shown in figure 5.

Combining 1 μF capacitance with No.2 coil, the initial voltage is 500V, the waveform is shown in figure 6.

Comparing figure 5 with figure 4, the bigger the capacitance value, the slower the signal attenuates. Because the resistance changes with the inductance, the voltage amplitude of two figures can’t be compared.

Combining 5 μF capacitance with No.1 coil, The initial voltage is 500 V; the waveform is in figure 6. Comparing figure 6 with figure 4, only the capacitance value increases, the current peak of 5 μF capacitance becomes higher than 1 μF capacitance. Otherwise, the frequency is f=47.6 kHz when capacitance is C=5 μF, f=83.3 kHz when C=1 μF. It proves the frequency decreases when the capacitance increases.

Combining 5 μF capacitance with No.1 coil again, the initial voltage is 300 V, the waveform is shown in figure 7.

Comparing figure 7 with figure 6, amplitude of 500V is bigger than 300V under the same condition. So it proves the initial voltage $U₀$ is direct ratio to amplitude. Furthermore, the figure shows the change of $U₀$ has little affection to the signal gradient.

Sum up the upper experiment results, the current parameters should be chosen as follows:

1. $R$ should be small
2. $L$ should be moderate
3. $C$ should be moderate
4. $U₀$ should be big.
5 Choosing Circuit Parameter Experimentally

The paper analyzes working process of RLC pulse discharge current in theory and researches underdamped instance deeply, and acquires choosing parameters projects through experimentation. In the end, the conclusion of pulse discharge experiment is the same with theory.

References


