

Research on a Pattern of Pulse Electromagnetic Ultrasonic Generation

LI Zhiyu, CHEN Peng, WANG Shuai, XU Aihua

Ordance Engineering College, Shi Jiazhuang, China

e-mail: bryantzhi@126.com

Abstract: Base on the basic principal and existed generation method, the system sets up a pattern of electromagnetic ultrasonic generation. By the experiment, revise original amplitude formula. The aim is making further efforts on finding the law of electromagnetic ultrasonic generation. Using power device to improve the system can reduce noise and eliminate electric arc, which always effective the experiment when using AC contactor as circuit changer. By comparing experiment data between before and after revising the system, explaining the advantages after improving it. In the end, revise original amplitude formula, and gain more ideal electromagnetic ultrasonic-testing results.

Key words: EMAT; nondestructive testing; RLC

1. Introduction

Electromagnetic ultrasonic is a new technology of non-destructive testing. It uses a way of electromagnetic coupling generation and receipt ultrasonic-wave. Comparing common ultrasonic, electromagnetic ultrasonic does not need couplant, and it can test both any ultrasonic-testing and ultrasonic-testing unable to do, such as high-temperature environment elements with keeping warm and shielding layer, and so on. At present, in this field in China, there are some distinct shortcomings of big noise, high heating, and low transforming efficiency. However, the main problem is at the generation part. The system sets up a pattern of electromagnetic ultrasonic generation base on the basic principal and existed generation method. The aim is making further efforts on finding the law of electromagnetic ultrasonic generation. Through the experiment, revise original amplitude formula. By comparing experiment data between before and after revising the system, explaining the advantages after improving it. In the end, revise original amplitude formula, and gain more ideal electromagnetic ultrasonic-testing results. Using power device to improve the system can reduce noise and eliminate electric arc, which always effective the experiment when using AC contactor as circuit changer.

2. Optimize Experiment System

The experiment improves the EMAT (electromagnetic acoustic transducer) in generation system, circuit charger and tested device, and establishes generation pattern, to gain a more ideal and credible EMAT system.

2.1 Generation System

The main parts of the system are shown in Figure 1.

2.2 Ferromagnetic Metallic Sample

The experiment selects sample of steel (225.5×34.5×25) which has three holes ($\phi=3\text{mm}$). The holes are used as defect inside. And make sure that there is enough distance between holes.

The general outline and parameters are shown in Figure 2.

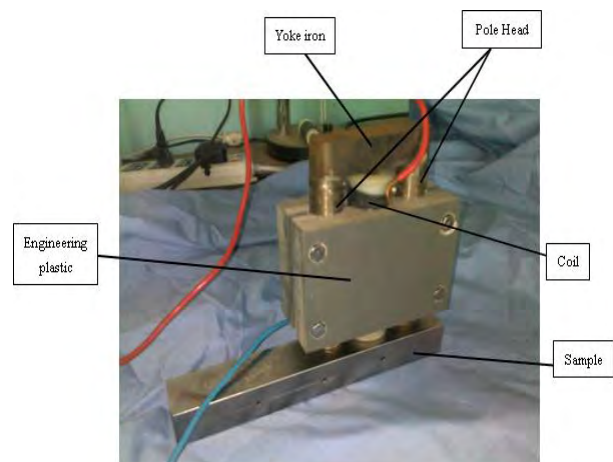


Figure 1. Improved EMAT generation system is making real-time test

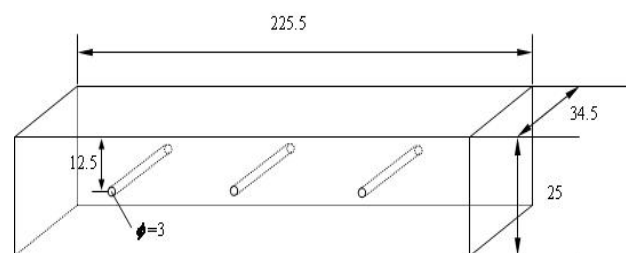


Figure 2. Structure of sample.

2.3 The Whole Experiment System

The experiment improves original system; the diagram of

improved pulse electromagnetic ultrasonic generation is shown in Figure 3.

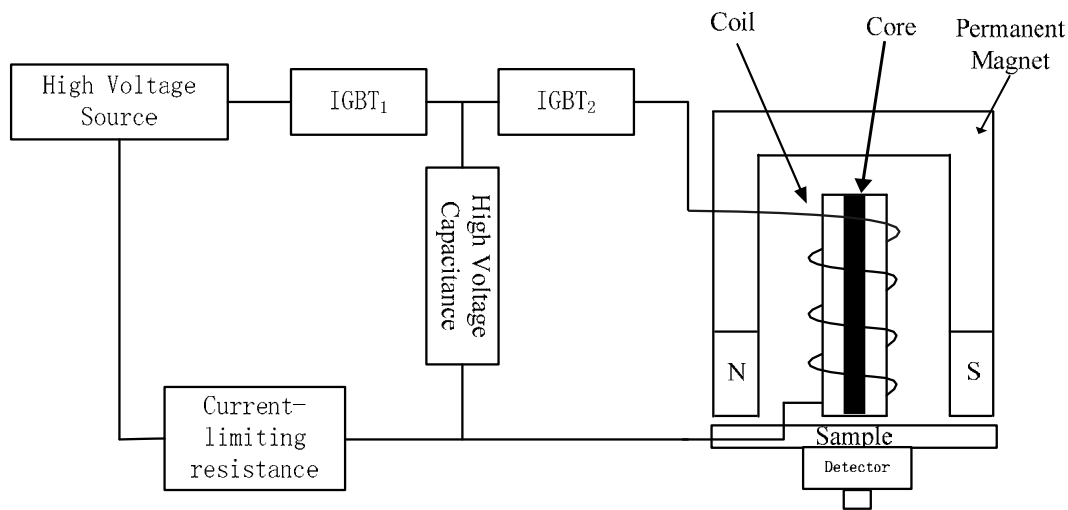


Figure 3. Improved EMAT system

Using a new charger, IGBT, improved the original system deeply. It can not only eliminate noise, but also reduce the energy consumption. So, the amplitude of ultrasonic is more obvious, and it is easy to observe and summarize.

2.4 The Process and Conclusion of the Experiment

2.4.1 The Process of the Experiment

To meet the demands of IGBT, the experiment chooses devices as follows:

(1) $L=3.51\mu\text{H}$, $R=0.094\Omega$ with core;

(2) Capacitance ($10\mu\text{F}$, 1000V);

(3) U shape magnetic-iron made by (NdFeB);

(4) Sample of steel;

(5) Two IGBTs parameter is 600V and 1200A ;

(6) Wooden trough;

(7) Piezo-electric detector, oscilloscope and high voltage source.

(8) Some pure copper lines.

The experiment uses detector to receive ultrasonic signals, oscilloscope to display and preserve them, and then the computer collect and analysis data. The flow chart is shown as follows:

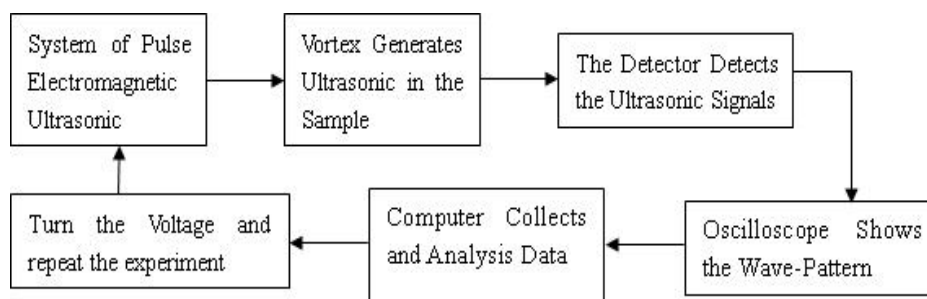


Figure 4. Flow chart of EMAT

The detailed process is: switch on the IGBT₁ firstly to make the source charge up the capacitance. Then turn off the IGBT₁, and turn on the IGBT₂, to make the right parts of the circuit a whole RLC circuit and oscillate. Vortex is created and generates ultrasonic in the sample, and tests the sample.

Through lots of experiments, improve nondestructive

testing (NDT), hence the amplitude and strengthen power transforming efficiency and penetrate ability. So, the experiment starts at 100V , straight to 1000V . The common difference is 50V . Gain lots of data and figures.

Give fore typical figures (they are the same except amplitude) and all data.

Table 1. Data comparing

Voltage (V)	Before improve system			After improve system			Ultrasonic amplitude raise (%)
	Ultrasonic amplitude (V)	Ultrasonic frequency (kHz)	Ultrasonic amplitude (V)	Ultrasonic frequency (kHz)	The second ultrasonic amplitude (V)	Interval time (s)	
100	0.34	41	0.41	43.8	0.117	0.24	20.6
150	0.38	42.5	0.47	42.9	0.134	0.21	23.7
200	0.66	42.6	0.81	45.6	0.231	0.26	22.7
250	0.81	44.1	1.02	43.7	0.291	0.28	25.9
300	0.96	43.2	1.23	43.1	0.351	0.25	28.1
350	1.1	41.3	1.43	41.7	0.409	0.26	30
400	1.26	44.8	1.64	42.6	0.469	0.23	30.2
450	1.42	42.8	1.84	44.1	0.526	0.23	29.6
500	1.59	41.7	2.1	43.7	0.604	0.22	32
550	1.73	43.5	2.25	44.6	0.643	0.22	30.1
600	1.88	42.8	2.46	42.5	0.703	0.22	30.9
650	2.05	41.9	2.66	44.8	0.761	0.27	29.8
700	2.2	43.7	2.86	43.8	0.817	0.26	30
750	2.39	43.8	3.07	43.2	0.877	0.23	28.4
800	2.55	42.5	3.27	41.4	0.934	0.26	28.2
850	2.7	42.9	3.48	42.5	0.991	0.27	28.9
900	2.89	42.7	3.68	42.8	1.05	0.23	27.3
950	3.01	41.1	3.89	43.5	1.111	0.22	29.2
1000	3.1	41.7	4.1	43.8	1.173	0.25	32.3

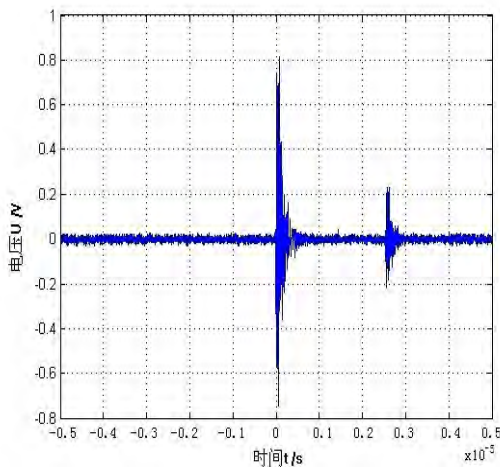


Figure 5. $U_0=200V$

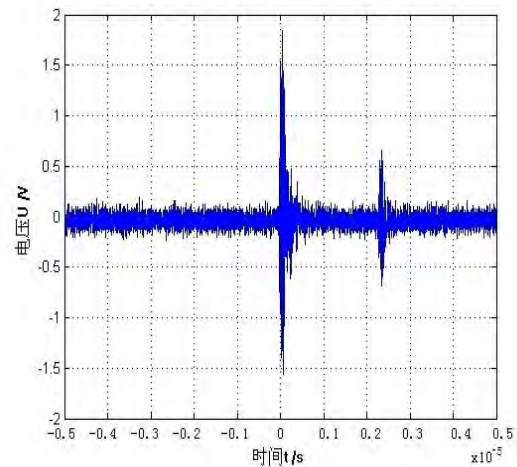


Figure 6. $U_0=450V$

The chart and figures show that the second wave amplitudes are low because of defect. The second is lower 1/3 than the first. The interval time is about 0.25×10^{-5} second. The factors of affecting receiving ultrasonic are many and very complicated, so it describes the appearance qualitatively. However, that the reduction and the interval time are similar. That explains that we can find a law and make base for the future research.

If there are no defects inside, the physical formula during the whole process is:

$$t = \frac{s}{v}$$

s means ultrasonic effective distance and $s=25\text{mm}$; v means ultrasonic propagation velocity in the sample, and $v \approx 5900\text{m/s}$; t means ultrasonic propagation time.

After calculation, the ultrasonic propagation time is

about $0.42 \times 10^{-5}\text{s}$ when there are no defects. However, after the reduction given by defects, the second wave is $0.17 \times 10^{-5}\text{s}$ later than the first. That explains the main reason of the reduction is defects. So it can be supposed that we can gain the location, size and even shape, by calculating and anglicizing ultrasonic reduction.

2.4.2 Revising the Experience Formula

The common method of Pulse electromagnetic ultrasonic generation is: the source creates the pulse signals, and then amplifies the power, and generates the coil. A big disadvantage of this method is wasting power and the heat-resisting of the coil will limit generation of the ultrasonic signals.

Using RLC in-line electric discharge loop can achieve generation. Because it's an advanced technology, it is

used in many pulse-power systems. Its basic principle is

shown in Figure 9.

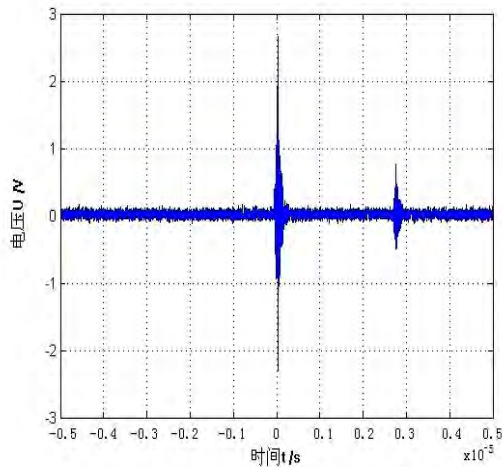


Figure 7. $U_0=650V$

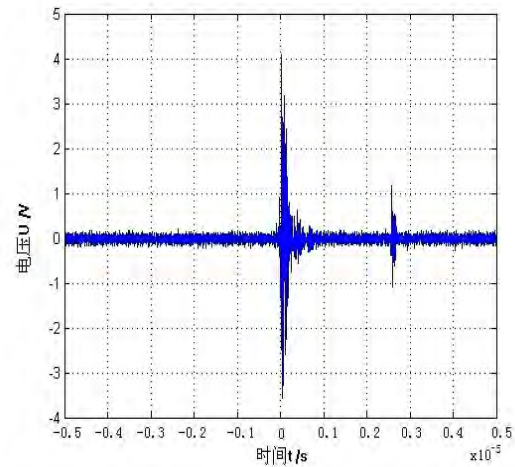


Figure 8. $U_0=1000V$

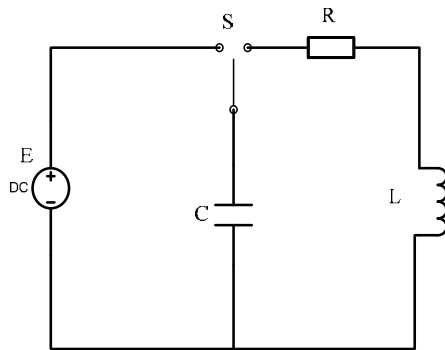


Figure 9. RLC discharge circuit

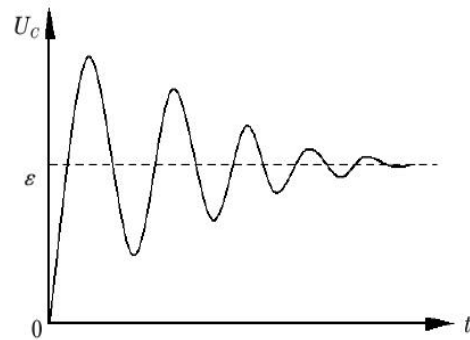


Figure 10. Typical damping oscillation chart

E is high-voltage source;

C is high-voltage capacitance;

L is a coil;

R is the sum of coil-resistance, line-resistance, touching-resistance, and internal resistance.;

S is controlling charger.

Its working process is: the source charges the capacitance firstly, cutting down the charging loop when the capacitance is full. Then connect the discharging loop (RLC). The discharging process is a second order zero input. The formula is

$$LC \frac{d^2 U_c}{dt^2} + RC \frac{dU_c}{dt} + U_c = 0$$

Wanting to gain alternating signals, the demand is

$$R < 2\sqrt{\frac{L}{C}}. \text{ Now}$$

$$I = \frac{U_0}{\omega L} e^{-\sigma t} \sin \omega t$$

Form the formula knowing that to gain heavy current, C should be large. The typical discharging wave is:

So when $t_m = \frac{\psi}{\omega}$, the peak value of impulse current is.

$$I_m = \frac{U_0}{\omega_0 L} e^{-\sigma \frac{\psi}{\omega}}$$

In the formula

$$\sigma = \frac{R}{2L},$$

$$\omega_0 = \frac{1}{\sqrt{LC}},$$

$$\omega = \sqrt{\omega_0^2 - \sigma^2},$$

$$\psi = \sin^{-1} \frac{\omega}{\omega_0}.$$

The coil will create alternating magnetic field when it gets alternating generation signals. Keep the coil above

the sample, it will be induced vortex, the degree and nature of it obey Faraday electromagnetic induction law. The degree of vortex density depends on variety speed of alternating magnetic field in the coil. And its rate equals to current in the coil. Current will be affected by Lorentz strength in any magnetic field. Alternating current and magnetic interact on each other. Particle of the sample will be bear by alternating power and vibrate. Ultrasonic wave is generated in the sample. By the Lorentz strength, amplitude of molecule vibration is:

$$A = \frac{\mu_r I}{2\pi a \rho S \omega_l (1 + \frac{q^2 \delta^2}{2})^{1/2}} B_L$$

μ_r s relative permeability of material,

I s the maximum current of the coil;

a s the distance between coin and material;

ρ s density of material;

S s current angular frequency of the coin;

ω_l s number of sonic wave;

q s the deep of skin effect;

δ s magnetic induction intensity of horizontal direction;

According to the experiment, given constant parameters, the data gained are about 22%-28% more than calculation. The formula above is base on the common method. So after improving the system and considering the factors of capacitance and inductance, the formula should be revised as follows:

$$A \propto \frac{\mu_r U_0 B_L e^{-\sigma \frac{U}{\omega}}}{2\pi a \rho S L \omega_0 \omega_l (1 + \frac{q^2 \delta^2}{2})^{1/2}} (1 + K)$$

Here, K is revised parameter; its valuation is about between 0.22 and 0.28. From this way, the electromagnetic ultrasonic formula is exacter, and it will make fine

basement for further research.

3. Conclusion

The main introduction is an improving EMAT system, and the process of the experiment. By comparing data before and after improving, it gains more ideal conclusion. In the end, revise the experience formula, and gain exacter amplitude formula. The next step of the experiment wants to use single chip or "555" timer to control IGBT, which wants to make a continuous pulse generation and electromagnetic ultrasonic testing.

References

- [1] D. Driscoll, J. Aron. Development of an EMAT ILI System for SCC in Pipelines. Natural gas infrastructure reliability industry forum. 2002, 9.
- [2] Dr. J. Damaschke, T. Beuker. First Survey Run with Electromagnetic Acoustic Transducers [J]. Pipeline & Gas Journal. 2006, 10: 55-57.
- [3] H. OGI, M. HIRAO, T. OHTANI. Flaw Detection by Line-focusing Electromagnetic Acoustic Transducers [J]. IEEE Ultrasonics Symposium. 1997: 653-656.
- [4] K. Sawaragi, H. J. Salzburger and G. Hubschen, *et al.* Improvement of SH-wave EMAT Phased Array Inspection by New Eight Segment Probes. Nuclear Engineering and Design. 2000: 153-163.
- [5] D. MACLAUCHLAN, S. CLACK, B. COX, *et al.* Recent Advancements in the Application of EMAT to NDE [J]. 16th World Conference on NDT. 2004.
- [6] T. YAMASAKI, S. TAMAI and M. HIRAO. Arrayed-coil EMAT for Longitudinal Wave in Steel Wires [J]. IEEE Ultrasonics Symposium. 1998: 789-792.
- [7] M. Pereira da Cunha, J. W. Jordn. Improved Longitudinal EMAT Transducer for Elastic Constant Extration [J]. IEEE. 2005.
- [8] A. M. HUSSEIN. Current Distribution and Input Impedance of a Finite Electromagnetic Acoustic Transducer [J]. IEEE Trans, on Magnetics. 1991, 27(5): 4258-4261.
- [9] K. J. COAKLEY, A. V. CLARK, C. S. HEHMAN. Empirical Modelling of Electromagnetic Acoustic Transducer Data [J]. Meas, Sci, Technol. 2000: 193-200.
- [10] R. LERCH. Simulation of Piezoelectric Devices by Two and Three Dimensional Finite Elements [J]. IEEE Trans, on Ultrasonics, Ferroelectrics, and Frequency Control. 1990, 37(2): 233-247.