Optimization of Circuit Parameters for the EMA Sensor Excitation

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Abstract. The paper presents the analysis of excitation pulses of the electromagnetic acoustic (EMA) transducer for rod stocks. The requirements to the key component of the node of excitation are stated. The transient processes in the system are simulated. The experimental results are given.

Keywords: generator for transducers, simulation of electronic assemblies

INTRODUCTION

The Pump Rods Acoustic Flaw Detector (PRAFD) is applicable for the wave guided acoustic nondestructive testing method to control bar solids with the diameter of 15–36 mm [1, 2]. The next step in evolution of this flaw detector could be utilization of a contactless acoustic signal receiver.

The use of contactless electromagnetic-acoustic (EMA) transducers possesses the following significant operational benefits:

- the control is possible via an air gap instead of liquids and also available in high temp conditions;
- EMA transducers are not subject to wear;
- testing results are not dependent upon either misalignment of the transducers relative to the surface of the object or possible rust, scale, paint or dirt on the product surface. The main disadvantages of EMA transducers are low conversion index [4] and a significant increase of the acoustic probe impulse in a shadow area. Therefore, it is necessary to increase the efficiency of acoustic pulses excitation and to diminish transient disturbances on the system device receiver along with utilizing complex systems of extracting information on noise background [5].

This would require a development of new sensors and some electronic circuit modification [3]. Optimization of the generator circuit elements would allow to adapt the radiator to the Russian standard GOST 13877-96 to the bar stock.

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1. DESCRIPTION OF THE GENERATOR BLOCK DIAGRAM

The node responsible for probe impulse and the oscillating system is formed by the following components of the electrical circuit (Fig. 1): Switch K, Condenser C, ballast resistor R2 and the sensor with inductance L. The System is configured for 50 kHz frequency. The optimization aim is to obtain the maximum field momentum in the emitter in the form of a coil L.

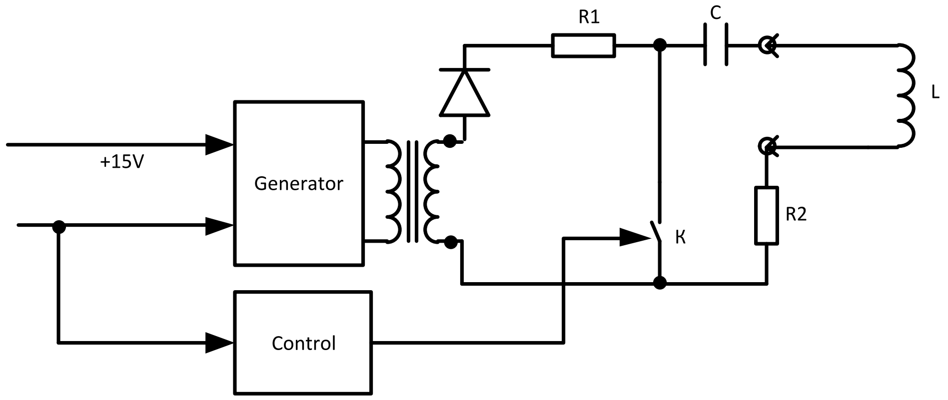

Figure 1. PRAFD Generator Block Diagram

The field momentum is proportional to the product of current in coil *I* by the number of turns of the coil *N* (*I*N*). The limiting element in the circuit is maximum current in the switch. Unfortunately, the market for the key elements to solve the problem is not very wide now.

The use of a common IGBT transistor as a high-voltage (over 200 V) switch is limited by current (less than 30 A). A typical solution is a thyristor with a reverse conductivity. The market for these devices is growing at a rate of 10–12 % per year [5]. In contrast to the IGBT transistor, the thyristor control does not require significant energy.

A typical high-frequency pulse thyristor provides the pulse current I = 100 A in the open state, a constant voltage U = 500 V in the closed state and the current slew rate dI/dt = 1300 A/μs in the open state.

The main circuitry feature of the sensor is a nonlinear decrease of the inductance *L* depending on the number of coil turns at different frequencies. The change in inductance along with the frequency decrease is due to electromagnetic properties of the core.

2. MATHEMATICAL ANALYSIS

The system analysis is done using MathCad software with the following parameters: the voltage on the coil at the moment of the key closing corresponds to the voltage in the capacitor that is E = 350 V, the resonance frequency is 50 kHz. The voltage on the coil *U* and current *I* in a transient oscillatory process is calculated by the classic formulas (1):

$$U = \frac{E}{\omega_0 \sqrt{LC}} \cdot e^{\delta t} \cdot \sin(\omega_0 t + a\tan\frac{\omega_0}{\delta}), I = \frac{E}{\omega_0 L} e^{\delta t} \sin(\omega_0 t + \pi), \qquad (1)$$

where *L* is the coil inductance, *C* is the capacity of the driving condenser, *R* is the total ohmic resistance of all circuits involved, including circuits connecting the coil, δ – damping factor of the system (2), ω_0 – cyclic frequency of the oscillatory process (2).

$$\delta = \frac{R}{2L},\ \omega_0 = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}. \qquad (2)$$

The voltage and current on the coil in a transient oscillatory process are damped sinusoids, angularly shifted relative to each other.

Damping of the oscillating system is influenced by the effective resistance R. During the analysis it is necessary for the damping to be significant, not to increase the shadow area (the area in which the control process is not yet possible due to the probe pulse, RNP is the Reverberation-Noise Performance). The size of the shadow area is defined at 600 μs that is about 1m for the speed of an ultrasonic wave $V = 5200$ m/s (the movement of the acoustic pulse from a transducer and back).

The recommended rejection level is set at the value 0.5 %. These parameters can be used to estimate the minimum resistance in the oscillatory system. Let us set RNP values to be $Trhx = 400$ μs and the level $Urhx = 0.1$ %.

The active resistance of the coil depends on the number of coils and is calculated according to the resistance of 1 meter of Ø 0.49 – 93 mω/m copper wires and the diameter of the mandrel. The resistance of the supply cable 1.5 m with a copper core size-due-section of 0.5 (0.32) mm^2 is about 107 (165) mOhm. The resistance of the open key is 35 mOhm. Thus, the minimum circuit value of active resistance is estimated in the system, $R_{min} = 143\ (200) + 7.9\ N$ mOhm, where N is the number of turns. Based on the required RNP duration for a transient oscillatory process, it is possible to calculate the minimum resistance R for a coil with N turns:

$$Rrhx = -\ln(Urhx)\frac{2LN}{Trhx}, \qquad (3)$$

where LN is the inductance of the coil with N turns.

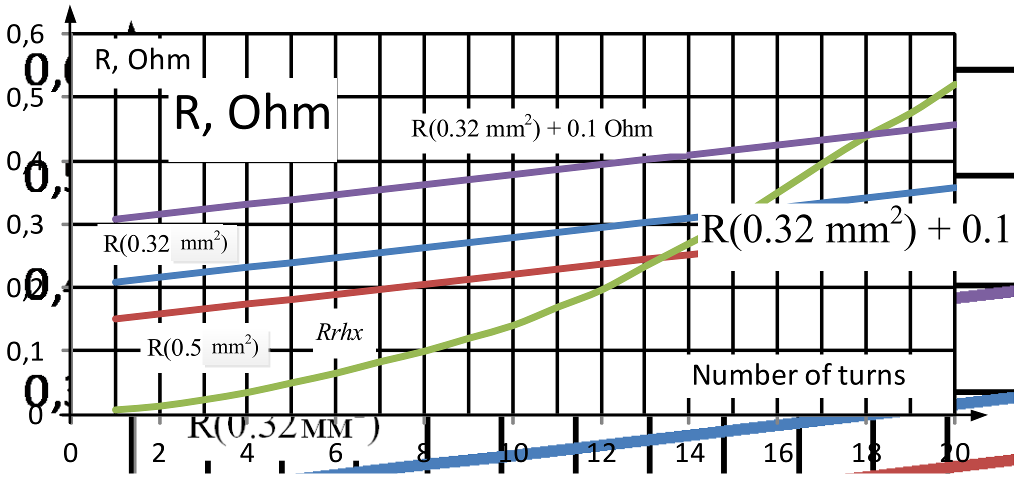

Figure 2. Minimum resistance values in the oscillatory system

Fig. 2 shows the values of active resistance minimum in the oscillatory system at the cross-sections of copper conductors of 0.5 (0.32) mm^2 with lead wire and minimum resistance calculated from the required duration RNP. Thus, the minimum resistance in the system should be increased only if there are 14 or more turns.

3. THE SIMULATION RESULTS

The simulation results are presented in the graph (Fig. 3). The value *IN* at different internal resistance values has maxima at different numbers of coil turns.

The decrease of the resistance leads to an increase of the maximum current in the system and greater value of *IN*. Unfortunately, the system is restricted by the maximum resultant current *I* passing through the switch.

Application of new editions of triodes by the IXYS company (for example, MCC 310-08 model has 9.2 kA at a 800 V voltage mode) could be a perspective one [6].

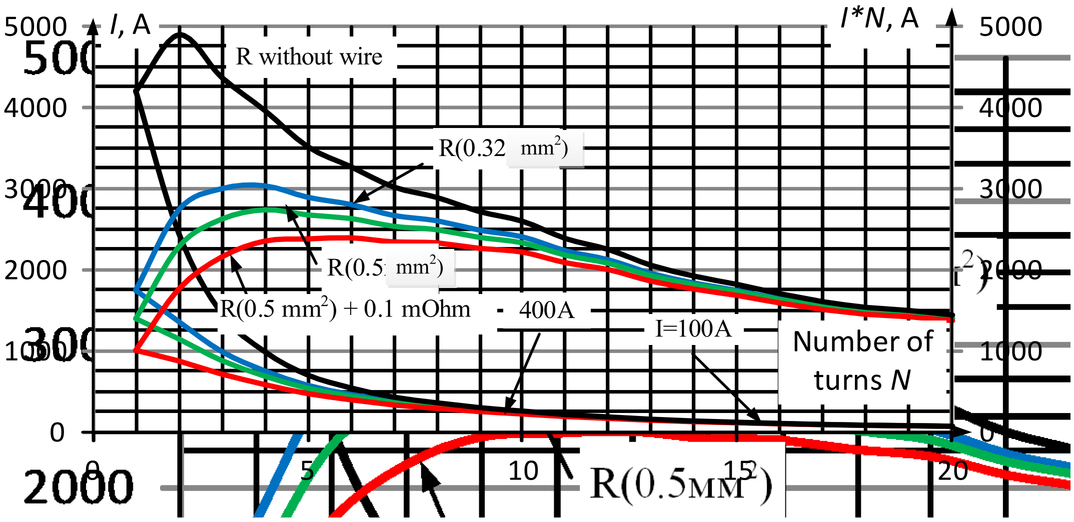

Figure 3. Maximum currents and the product of the current by the number of turns depending on the number of turns of the coil

The oscillator circuit assembled with the ballast resistor is 0.1 Ohm and the 7 turns’ coil showed the pulse current $I = 200$ A at pulse voltage $U = 150$ V (Fig. 4). The results obtained on the oscilloscope AKIP-4115/4A, probe HP9258-x100-1500V. The shadow area defined with RNP was about 250 µs at 0.5 %.

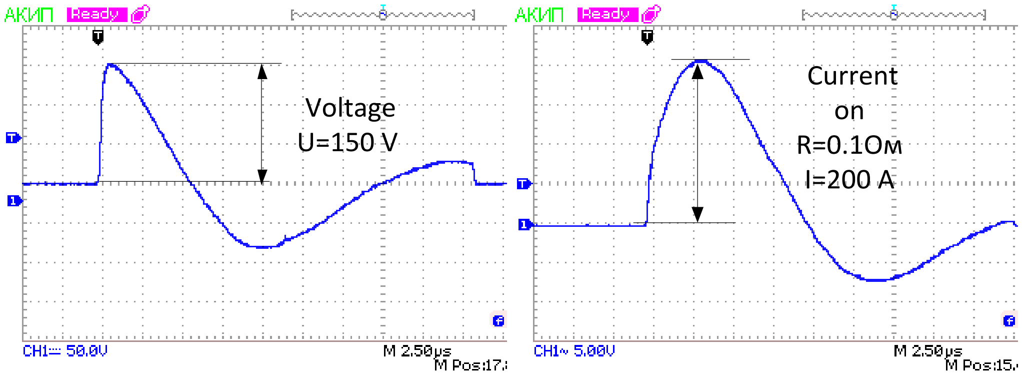

Figure 4. The maximum current and the product of the current by the number of turns depending on the number of turns of the coil

The disadvantage of this method of calculation is the lack of consideration of the capacitor internal resistance and the presence of the core (object of control) with non-linearity and saturation capability.

CONCLUSION

The analysis of EMA sensor excitation for the purpose of obtaining the maximum field momentum allows to design a laboratory bench in order to continue the research by a contactless EMA method with the use of Pump Rods Acoustic Flaw Detectors, implementing the wave guided acoustic method of nondestructive testing.

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