ULTRASONIC SIGNALS EMITTER BASED ON PIEZOELECTRIC TRANSDUCERS

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Abstract: *The device constitutes a specific application of piezoelectric transducers, which allow the generation of impulses series with constant or pseudo-aleatory frequency, and constant or variable pause. The device work is based on the process of achieving inverse piezoelectric effect, meaning the deformation of the crystalline network of the piezoelectric device caused by an external electrical field. The equipment was physically realized and it constituted the object of a research contract of the Optical-Electronic Institute of Bucharest. In this paper is also presented a PSpice simulation of the projected equipment.*

Keywords: *piezoelectric transducer, generator, acoustic power, electrical field, ultrasonic signals, pseudo-aleatory frequency.*

1. INTRODUCTION

Ultrasonic signals generating equipment, based on piezoelectric crystals, is used to obtain ultrasonic signals with fixing frequency between 20 and 120 kHz. The device could also generate packets of ultrasonic signals with constant or pseudo-aleatory frequency, and constant and variable pause. It is a specific application of the piezoelectric crystals, which allow the obtaining ultrasonic signals, based on unconventional method. Its work is based on the inverse piezoelectric effect, obtained by the deformation of the crystalline network of the piezoelectric device under the action of an external electric field.

The piezoelectric transducers present the advantages: high positioning accuracy with a resolution of 0,005 μm/V, high stiffness, fast response, and high efficiency. Possible applications: optical systems and measurement technology, laser tuning, fiber positioning, microelectronics, micro-lithography, acoustic propagation system, precision mechanics and mechanical engineering.

The equipment consists in a piezoelectric generator and a command and supply system. Under the action of the oscillating electrical field produced by the excitation source, the piezoelectric generator will pulse with the frequency of the command impulses (will expand and respectively contract).

The power module is achieved using VMOS transistors, which are connected in derivation. The high-voltage transformer ensures the necessary voltage for the supply of the piezoelectric device and also the adaptation to the load. A specific computer program is used to generate the series of datum impulses.

The generator is a piezoelectric transducer, which belong to the series of piezoelectric devices with elastic wave of volume.

The configuration of the electro-elastic piezoelectric transducer is presented in figure 1.

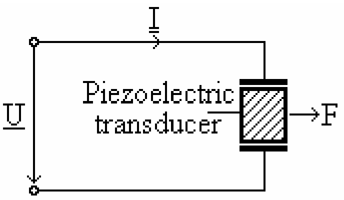

Fig. 1 Configuration of the electro-elastic piezoelectric transducer

2. EQUIPMENT BLOCK DIAGRAM. PRINCIPLE OF OPERATION

The ultrasonic signals generating equipment using piezoelectric crystals was the object of a research contract.

Technical conditions for input and output were the following: the equipment supply was realized from the supply network – 220±15% V a.c., f = 50Hz; operating regime – a) generation of pulses trains with pseudo-aleatory frequency (20 ÷ 120kHz), and constant and variable pause, b) generation of pulses trains with constant frequency (established by the user between 20 and 120 kHz), and constant and variable pause; maximal voltage on piezoelectric device, U_{amax} = 3,5kV; efficiency of excitation electronic source, η = 80%; the supply and command of the piezoelectric device were realized at maximum depth of 300m; electrical resistance of supply cable, R_C = 80Ω/km; imposed acoustic power, P_a = 250W; the programmable time of pulses train between 0 ÷ 35ms, and pause between pulses trains, 0 ÷ 75ms; variation of excitation voltage value will determine the variation of acoustic output power value; protection against overload, supra-voltage, electrocution, radio-electronic interferences in/from network; the electronic source and piezoelectric device were introduced into a stainless steel cylinder with inside diameter – 105mm, outside diameter – 110mm and maximal height – 1m.

The block diagram of ultrasonic signals generating set, which is presented in figure 2, has two components: surface equipment (A) and equipment inside a stainless steel cylinder (b), which functions at 300m depth.

Considering the input and imposed output conditions were established functional units, which compose the generating equipment.

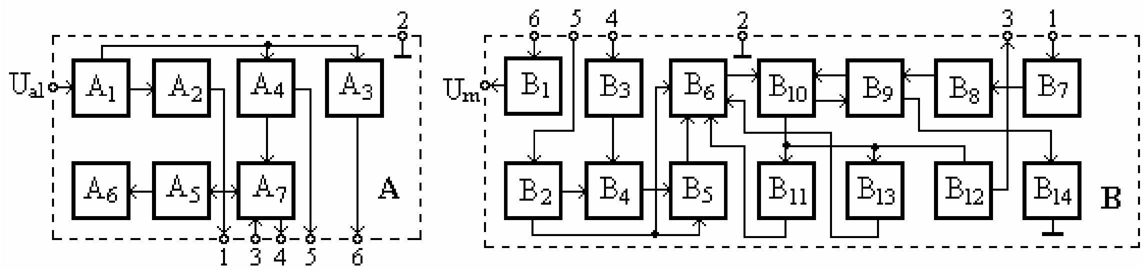

Fig. 2 The block diagram of ultrasonic signals generating set

The functional units of the surface equipment (A) are the following: protective unit against radio-electronic interferences in/from network (A_1); rectify and filtering unit for supply voltage (A_2); auxiliary power supply for lifting motor (A_3); auxiliary power supply of ±18 V (A_4); computer with keyboard (A_5); display (A_6); interface and command unit (A_7).

The equipment (B) has the following functional unit: steady voltage of ±29V for lifting motor supply (B_1); steady voltage of ±15V (B_2); low-pass filter (B_3); circuit for amplitude discrimination of command pulses (B_4); circuit for width discrimination of command pulses (B_5); command circuit of power module (B_6); filter for radio-electronic interferences (B_7); condensers battery (B_8); high-voltage transformer (B_9); power module (B_{10}); protection overload unit (B_{11}); reaction circuit (B_{12}); supra-voltage protection unit (B_{13}); piezoelectric generator (B_{14}).

The switching element of power module is realized by four power transistors MOSFET, connected in derivation, that allow to obtain an electrical power of 600W [2,6]. Input and output parameters are presented on display, and working conditions are established with keyboard computer.

The interface and command unit realizes the interface between PC and functional unit (B), processes input and output data, and establishes working conditions. The command circuit (B_6) realizes charge and discharge the gate-drain capacitance of VMOS transistors, determining saturation or blocking them.

Because the command pulses are conducted through a 300m long cable, it was necessary to utilize some receiving circuits for command pulses, like: low-pass filter, pulse height discriminator realized with a Smith trigger, circuit for time discrimination, circuit for reject the spikes and unlike interferences.

High-voltage transformer delivers necessary voltage to supply piezoelectric generator; also, it realized the load matching. The transfer of energy is made sin-phase. Piezoelectric device consists in one or two piezoelectric radial polarized transducers, which pulse with frequency of the command pulses. The acoustic power of piezoelectric transducer is approximately 250W.

3. DESIGNING ELEMENTS. OBTAINED RESULTS

The piezoelectric transducers are made of ceramic materials as PZT (titanium, zirconium, lead) and the research was realized using a material as $Pb(Zr_{0,53}Ti_{0,47})O_3$ doped with Nb_2O_5, BiO_3 and MnO [5].

The dimensions and the composition of the piezoelectric transducers were determined considering the frequency band (20 ÷ 120kHz) of the ultrasonic signals and the imposed acoustic power.

After the performed experiments at Optical-Electronic Institute of Bucharest, it resulted that the piezoelectric generator represents a preponderant capacitive load with a capacitance around 8nF. For an electrical power of 400W and a frequency of 100kHz, the electrical stored energy in piezoelectric crystal capacitance is around 4mJ. It results the relation for excitation voltage of piezoelectric crystal:

$$U_a = \sqrt{\frac{2E}{C}} \quad \Rightarrow \quad U_a \cong 1\text{kV} \qquad (1)$$

For a conduction time of5μs and a required power of 400W, the electrical voltage on piezoelectric crystal increases to maximum 1000V.

An important parameter that we must consider for piezoelectric crystal designing is maximum pulsing frequency. Considering relaxation time of crystal around 5μs, it results the maximum working frequency around 100kHz.

Another requirement for piezoelectric crystal is its output impedance to be better matching to radiation impedance of environment. So, the oscillatory circuit represented by piezoelectric crystal must have its own damping, and its impedance must varies linear in frequency band (doesn't have poles).

The piezoelectric generator is formed by a cylindrical piezoelectric piece, radial polarized, with dimensions: ϕ_{ext} = 50mm, ϕ_{int} = 38mm, h = 6mm. Piezoelectric generator assembly is show in figure 3, and it is composed by the following elements: cylindrical stainless steel tube (1), terminal for high-voltage supply (2), metallic reflector (3), non-conductive metallic axle (4), insulated piece (5), piezoelectric crystal (6), silicone oil (7), mixture of resin and wolfram powder (8), sealing piece (9).

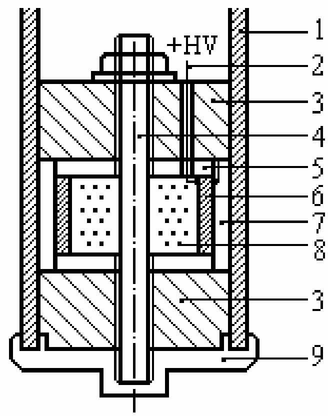

Fig. 3 Piezoelectric generator assembly

On both extremities of piezoelectric crystal are two metallic reflectors, fixed by a metallic axle with thread. The piece is filled inside with a composition made by resin and wolfram powder, which involves as a reflector and sustains metallic axle. The piezoelectric generator works into a silicone oil medium, which allows acoustic propagation. The oscillatory circuit realized by the secondary inductance of high-voltage transformer and by the piezoelectric generator capacitance is strongly damped because the medium radiation impedance, where the generator is situated.

By PSpice simulation [1,3] was tested in time and frequency domains the excitation source of piezoelectric device. In order to simplify the analysis and to reduce simulation time, from projected source was considered only the power module. The excitation source is in essence a closed loop regulating system (fig. 4), and it must be analyzed its stability.

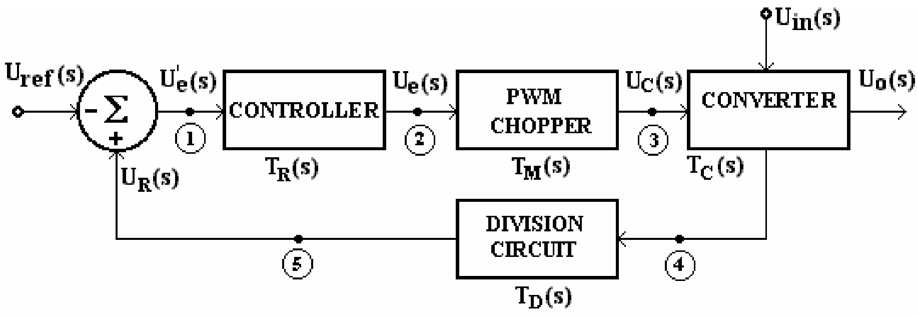

Fig. 4 Excitation source as a closed loop regulating system

The waveforms for: grid current, drain current, drain-source voltage, and excitation voltage of piezoelectric device are presented in figure 5.

The frequency attenuation characteristic and envelope-delay characteristic (phase response), for excitation source, are presented in figure 6.

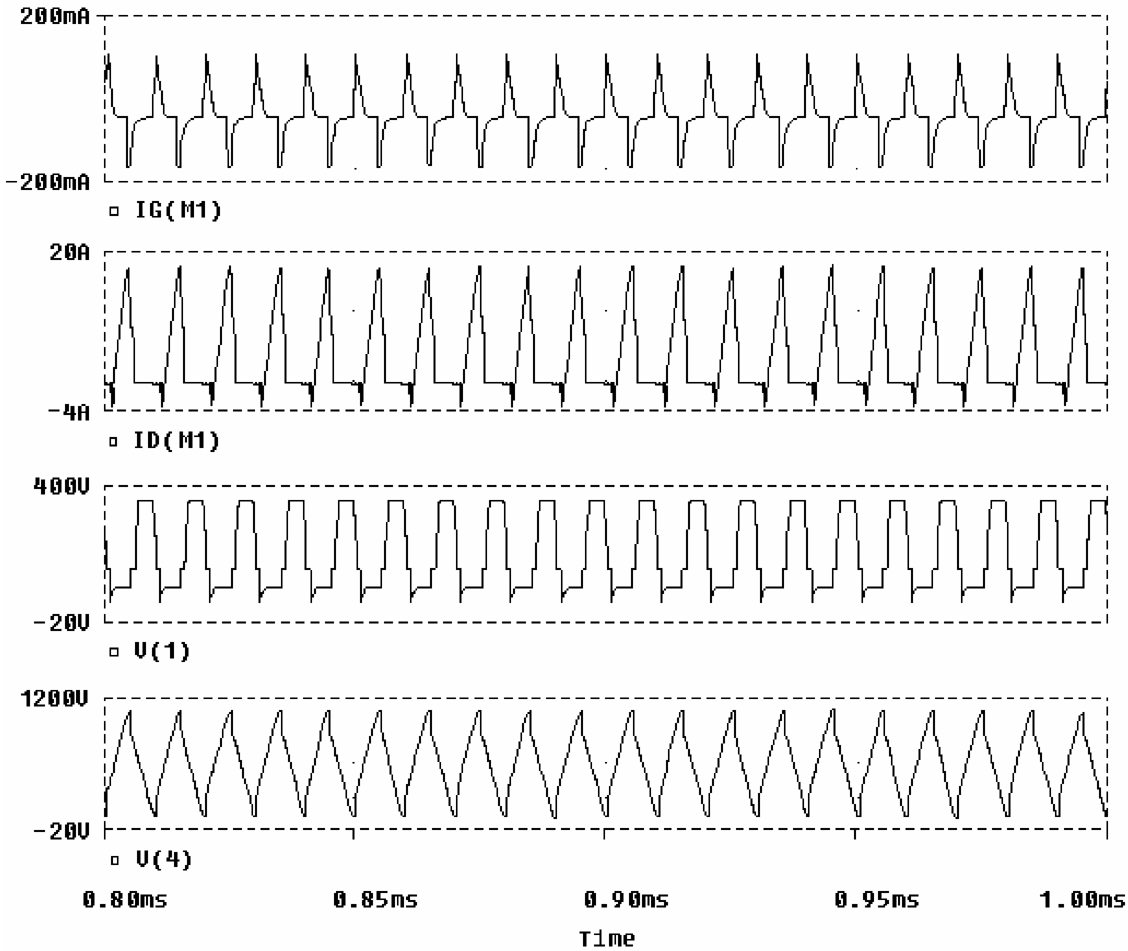

Fig. 5 Electrical quantities waveforms for analyzed circuit

The open loop transfer function of the system has a pole in fixed point, which is introduced by the controller, a double pole introduced by the converter, and two zero, one introduced by the controller and the other one introduced by the converter. The presence of pole in fixed point ensures a high gain at low frequencies.

The zero introduced by the controller is placed near the double pole introduced by the converter, so that the passing through f_{cross} is realized with 20dB/dec. It results f_{cross} = 4,2kHz. The phase edge is positive and has the value equal to 49,3°.

Considering the results of performed analyze it is allowed to affirm that the open loop transfer function of the system ensures its stability.

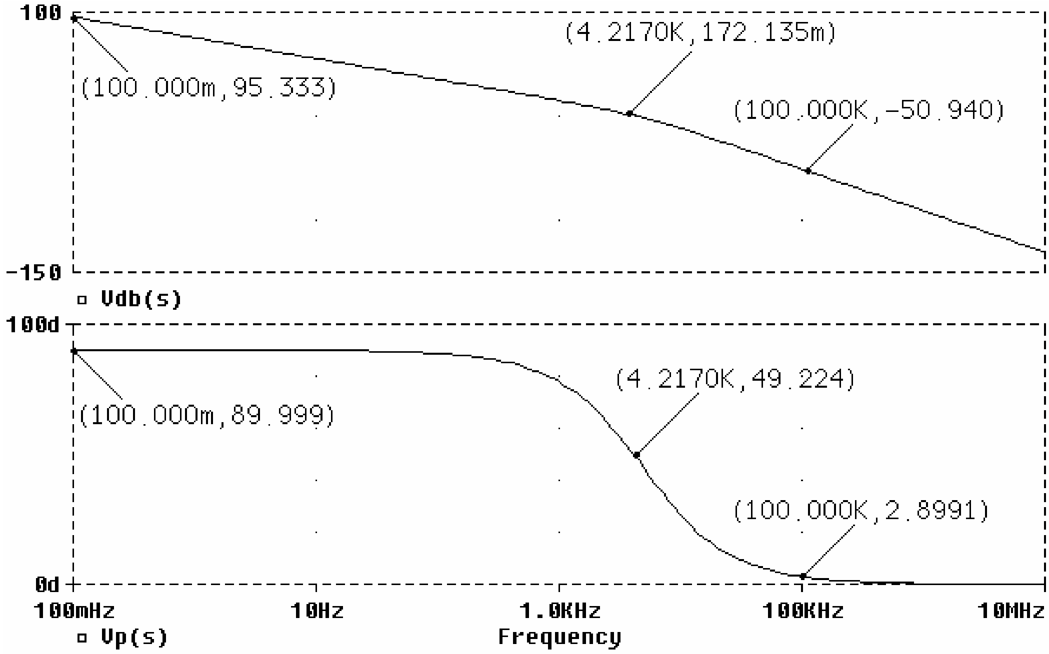

Fig. 6 Waveforms in frequency domain

4. CONCLUSIONS

The presented equipment is a complex system, purposed to generate ultrasonic signals by an unconventional method, using piezoelectric transducers.

The piezoelectric generator is composed of a piezoelectric crystal supplied by impulses and it pulses with the command impulses frequency.

The geometric conformation and the structure of the piezoelectric piece were established considering first maximal work frequency and the imposed acoustic power. The excitation source works in switching and allows obtaining an electrical power of 600 W. The piezoelectric generator works also as a storage condenser and the transfer of energy is made sin-phase.

As a consequence of the performed PSpice analysis, it results that the evolution in time of the electrical quantities and also the obtained signal levels have a good concordance with calculated values.

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