# Matching Speciality of Electronic Ultrasonic Generators with Piezoelectric Oscillatory Systems

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***Abstract* — Article is devoted to problems of matching ultrasonic electronic generators with piezoelectric oscillatory systems by means LC circuits with adjusting reactive elements.**

***Index Terms*— Ultrasonic generators, matching networks.**

## I. Introduction

Along with a choice of rational circuits of generators, designs of oscillatory systems, application of new economic materials for converters and wave guides, important value has the optimal matching of ultrasonic generator with oscillatory system which radiates ultrasonic energy in the certain technological environment. Optimal matching provide transmitting maximal power energy to load. Matching problems have more importance at creation of high-energy ultrasonic devices.

Existing matching schemes do not provide the optimal matching of electronic generators with piezoelectric oscillatory systems. This is caused by changes, at working mode, properties of treatment mediums (temperature, acoustic resistance, pressure e.t.c.) and electric parameters elements of the electronic generator (electric capacity of piezoelements including in oscillatory system, values elements of matching circuits).

Further one ways of matching electronic ultrasonic generators with piezoelectric oscillatory systems is considered.

## II. Theory

Ultrasonic oscillatory systems with the piezoelectric converter we can represent as serial oscillatory circuit [1], as show at figure 1, a. The element $C_0$ is defined by capacity of piezoelements included in ultrasonic oscillatory system. The value of $C_0$ depends to quantity of piezoelements, their geometrical sizes, dielectric permeability of a material of which they are made, and mode of their electric connection (parallel, serial, parallel-serial). Elements $R_M L_M C_M$ form a

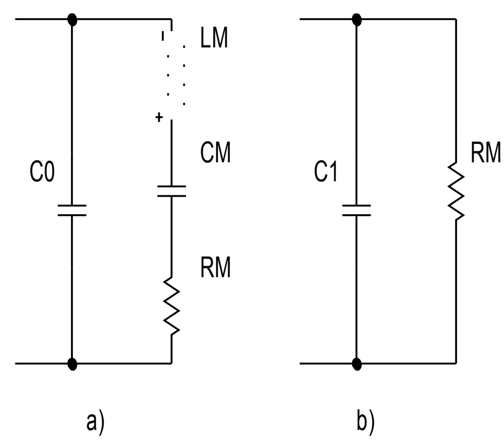


Fig. 1. Electric equivalent circuits of oscillatory systems with the piezoelectric converter.

mechanical branch and on resonant frequency (only the resonant operating mode of oscillatory system further is considered) its resistance have active character (see figure 1,b).

As show on figure 1, input impedance of oscillatory system working in a resonant mode has active - capacitor character and defined by the following expression:

$$Z = \frac{R_M X_{C_0}}{R_M + X_{C_0}}, \tag{1}$$

where $X_{C_0}$ - capacitor impedance of branch, consist of element $C_0$.

In common case input impedance of oscillatory system defined as:

$$Z = R + X_C, \tag{2}$$

where $X_C$ - capacitor impedance component, $R$ - active impedance component.

Because oscillatory system connecting to electronic generator, which have own output impedance, it is necessary to solve problems of their matching. In this case it is

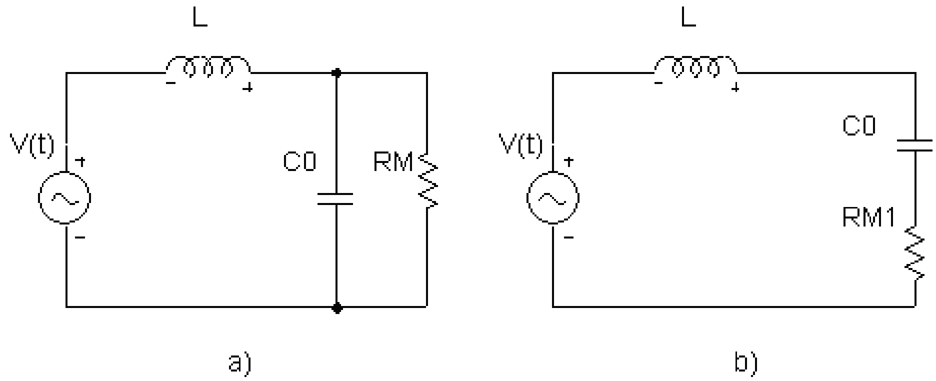


Fig. 2. One way of matching ultrasonic generators to ultrasonic oscillation system with piezoceramic converter.

necessary to execute next condition:

$$R + X_C = R_G - X_L \,, \tag{3}$$

where $R_G$ - active component of output generator impedance, $X_L$ - inductive component of output generator impedance.

Because output impedance of electronic generator have active character, it is necessary connect additional inductive element [2] as show on figure 2.

Inductor $L$ together with capacitor $C_0$ formed a electric oscillatory circuit with resonance frequency, defined as:

$$\omega_0 = \frac{1}{\sqrt{LC_0}} \,. \tag{4}$$

When $\omega_0$ equal to frequency of ultrasonic oscillatory systems, this is optimal case. At this condition impedance of ultrasonic oscillatory systems with addition inductive element have active character.

For analysis circuit (fig. 1.a) transform this as show on figure 2.b. In this case reactive components is not changes, element $R_M$ transform to element $R_{M1}$, which define as:

$$R_{M1} = \frac{\rho^2}{R_M} \,, \tag{5}$$

where $\rho$ - characterristic impedance of electric oscillatory circuit which formed by $L$ and $C_0$ elements, and defined as:

$$\rho = \sqrt{\frac{L}{C_0}} \,. \tag{6}$$

Thus, for circuit shows on fig.2.b which worked at forced oscillation mode on resonance frequency we can write next equation [3]:

$$L\frac{di}{dt} + R_{M1}i + \frac{1}{C_0}q = U_m \cos(\omega_0 t) \,, \tag{7}$$

where $i$ - current in circuit, $q$ - electric charge, $U_m$ - output amplitude of generator $V(t)$.

Based on equation (7) we can write equation for amplitude of current:

$$I_m = \frac{U_m}{\sqrt{R_{M1}^2 + (\omega_0 L - \frac{1}{\omega_0 C_0})^2}} \,. \tag{8}$$

Amplitude $I_m$ have maximal value at next condition: $\omega_0 = \omega_r$, where $\omega_r$ - resonance frequency of ultrasonic oscillatory systems. In this case, phase shift between voltage and current on generator output tend to zero. At another conditions amplitude $I_m$ is decrease, due to breakdown matching conditions.

$LC_0$ circuit have a amplifier property. Transfer function (on voltage) for circuit showed on fig.2.a. defined as:

$$K = \frac{\dot{U}_{C_0}}{\dot{U}_G} = -jQ \,, \tag{9}$$

where $Q$ - qood quality factor of electronic oscillatory circuit, which depend to active loses (effective and parasitic) in ultrasonic oscillatory system.

Because mechanical branch $R_M L_M C_M$ have activity in resonance mode, $Q$ factor be frequency-depending parameter.

Thus, $LC_0$ oscillatory circuit worked on own frequency $\omega_0$ amplify input voltage from generator with gain factor equal $Q$.

## III. Discussion

Using matching circuit showed on figure 2.a. have some problems. Parameters and the conditions influencing on initial option of matching network and also parameters and the conditions causing a mismatch of matching network

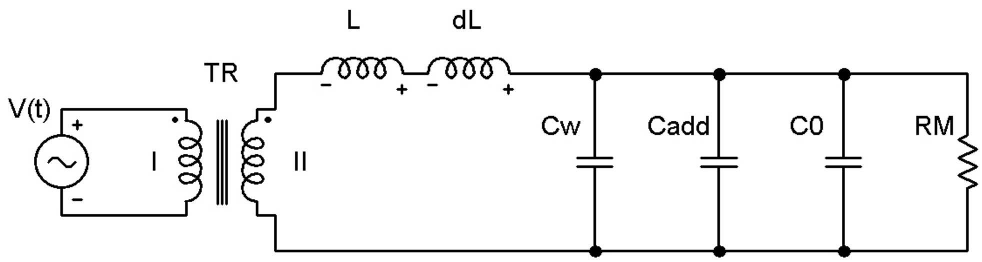


Fig. 3. Full scheme of matching network.

during work ultrasonic device, that, finally, reduces efficiency of ultrasonic influence on technological object are below submitted.

On initial option of matching network influencing next factors:

1. Quantity of piezoelements.
2. Geometrical parameters of piezoelements.
3. Ways of electric connection of piezoelements.
4. Initial temperature of an environment.
5. Dielectric properties material of piezoelements.
6. Total electric capacity of the conductors uniting oscillatory system with the electronic generator $C_W$.
7. Presence of the additional electric capacity connected in parallel to piezoelements $C_{ADD}$.
8. Initial (under normal initial thermal conditions) resonant frequency of oscillatory system which influences the certain technological environment in a mode of small amplitudes (up to 3 microns).
9. Inductive and capacitor components output resistance of the electronic generator.

Precomputation inductance $L$ is carried out by means of expression (4) in which the element $C_0$ unites itself total entrance electric capacity of oscillatory system in view of capacity of connecting wires $C_W$ and in addition connected capacities $C_{ADD}$.

During ultrasonic influence on technological object efficiency of ultrasonic influence on object is reduced. It is connected to below-mentioned factors and conditions, namely:

1. There is a change of resonant frequency of oscillatory system which depends to her temperature, properties of processable environments (acoustic properties of the processable environment as can change in process ultrasonic influences), an operating mode of oscillatory system (modes of small, average, big amplitudes of mechanical fluctuations).

2. There is a change of dielectric permeability (hence, and electric capacity) a material of piezoceramic elements.

3. There is a change of frequency of the electronic generator, caused by work of automatic-frequency system which continuously traces change of resonant oscillatory system.

All this causes necessity of updating, during work of the ultrasonic device, matching inductance $L$.

For practical calculations values of elements of matching network we shall consider more full circuit of the coordination submitted in figure 3.

The source of sine wave or rectangular voltage V (t) by means of transformer TR is connected to matching LC to the circuit. Transformer TR, except for a galvanic outcome of circuits of the electronic generator and oscillatory system, carries out as a role of an matching element, coordinating active output and input resistance of the electronic generator

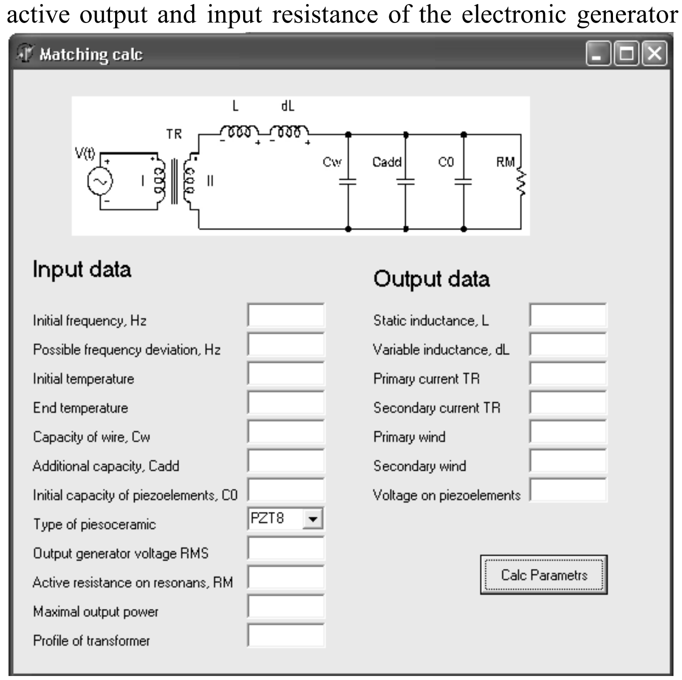


Fig. 4. Dialog windows of calculation program.

and oscillatory system accordingly.

For automation of process of calculation of parameters of matching network, the program which dialogue window is submitted in figure 4 has been developed.

As initial parameters accept resonant frequency of oscillatory system, a range of its possible deviation, a range of working temperatures, capacity of connecting conductors, size of additional capacity (is underlined at presence those), initial electric capacity of piezoelements, type used piezoceramics, root-mean-square value of a output voltage of the electronic generator, active input resistance of oscillatory system on her resonant frequency in a mode of the nominal load, required output power, profile of transformer TR.

As target parameters stand out size of static inductance $L$, a range of change of inductance of a variable inductive element $dL$, quantity of coils of transformer TR, a current in a primary and secondary circuit of transformer TR, a voltage on piezoelements.

## IV. Conclusion

The developed technique has been tested at calculation of elements of an matching network of the ultrasonic device for processing on liquid environments «Bulava» [4] by capacity 3000 Watt.

As for the optimum coordination of the electronic generator and piezoelectric oscillatory system during work ultrasonic device it is necessary to correct inductance in some range, the mechanism representing the controlled inductive element which appearance is submitted in figure 5 has been developed.

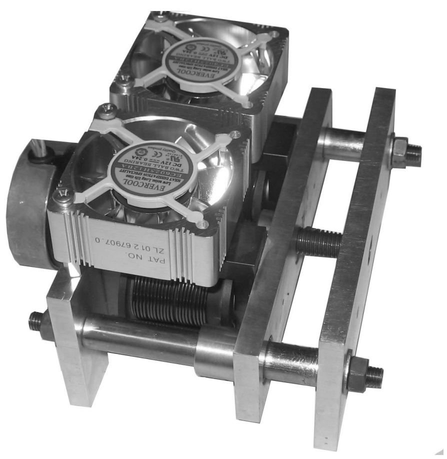

Fig. 5. Adjustable inductance with a changeable clearance in the magnetic core.

The special controller which is built in the ultrasonic technological device has been developed, allowing to supervise conditions of the coordination of the electronic generator with oscillatory system, and to arrange in appropriate way inductance $dL$.

Criterion of adjustment a matching network is equality to zero of shift of phases between a current and a voltage on an output of the generator.

The control system, during work of the ultrasonic generator, irrespective of work of other electronic systems (automatic-frequency system, a control system of power) continuously carries out measurement of phase shift, develops managing signals for the driver of the engine, operating that clearance in magnetic core of inductive element of matching network.

Process of updating of elements of a matching network proceeds until there will come the established thermal operating mode of oscillatory system and a stationary mode ultrasonic influences. In case of the non-stationary processes occuring in the processable environment in immediate proximity from the radiating surface, process of updating of parameters of an agreeing link does not stop.

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