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The Analyzing of Ultrasound Propagation Wawes through a Piezoelectric Transducer in Function of Acoustic Charge

The nature of acoustic charge, which works with an electronic generator to generate high intensity ultra-acoustic field is very various in function of application used [2]. The values of elements from equivalent scheme may be to vary in time in function of technologic process [3]. This fact determines the variation of accord frequencies and value of acoustic charge. In this manner the efficiency can be modified in time if it no take measures to minimize these influences of complex impedance that works with electronic generator [4]. In this paper it is presented a method to analysis the influence of variation of acoustic charge and to minimize this influences for to assure an optimum operation of electronic generator, it is presented a program to calculate the power variation in function of acoustic charge and to chart the diagram of this variation. It is presented the experimental results obtained with the theory presented.

Keywords*: acoustic charge, ultrasound vibration, piezoelectric transducer*

1. Introduction

To increase the efficiency [6] of ensemble system generator-acoustic charge and to maintain this efficiency constant in function time of technologic process we will use the components at the limit resistance of materials but without to destroy them for a long functionary time. We can use [1] the schemes to reduce the influences of acoustic charge variation on general assembly function of whole chain: electronic generator-acoustic charge. For, to prevent the destruction of ultra-acoustic system, we must control the power in the worst situations, caused by the variations of acoustic charge. The control of the power losses will grow up the functionary efficiency of ultra-acoustic system.

2. The principle of operation.

The power losses, in case of a piezoelectric transducer, will be – figure 1:

- electrical losses (R_0) ;
- mechanical losses (R_m) which are generate from: mechanic hysteretic of materials from what it is built the piezoelectric transducer and flatness defects of surface.

In order to control the power losses [5] we must control the current that pass through mechanic arm – I_m –. If I_m = ct. and the charge (r) varies then the losses on R_m will remain at the same level, for small and medium levels of vibrations because at high levels R_m varies from two causes which are exposed above. The generator, which works in commutation for to have a high efficiency, will assure a constant tension for small charges (r) and the current I_m will grow with diminution of acoustic charge. This will determines the increase of mechanic losses (R_m).

Will need from a circuit, which cancel the reactance of equivalent scheme and has a resonance frequency equal with series resonance frequency of mechanic arm – L_m, C_m. This condition is accomplished by relation:

$$f_s = \frac{1}{2 \cdot \pi \cdot \sqrt{L_m \cdot C_m}} \quad , \tag{1}$$

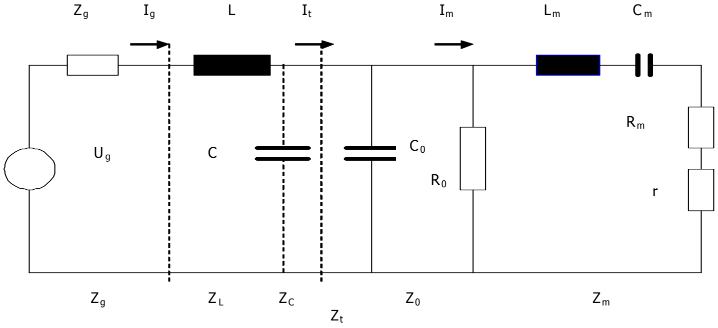

Figure 1. The equivalent scheme of piezoelectric transducer series compensates.

The equation is valid for a single value $r = r_0$ – the optimum value for maximum efficiency –, which is given from the relation:

$$r_0 = \sqrt{R_0 \cdot R_m} \quad , \tag{2}$$

The total capacity of transducer, according with equivalent scheme given in Fig. 1, will be:

$$C_P = C + C_0 \tag{3}$$

The equivalent parallel resistance of transducer, at work frequency f_S, is given from relation:

$$R_P = (r + R_m)\cdot R_0 \;/\; (r + R_m + R_0)\ , \qquad (4)$$

The equivalent series impedance, given by C_P and R_P parallel connected, help us to determine the equivalent series capacity C_S and equivalent series resistance R_S, conform to figure 2.

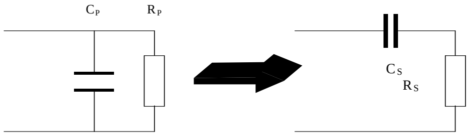

Figure 2. The parallel to series transformation of equivalent scheme in case of piezoelectric transducer.

We have a parallel to series transformation in which a parallel circuit it is transformed into series circuit which it is easier to calculate the component values. The equivalent input impedance for this transformation:

$$Z = \frac{Z_1 \cdot Z_2}{Z_1 + Z_2} = \frac{R_P - j\cdot\omega\cdot C_P \cdot R_P^2}{1 + \omega^2 \cdot C_P^2 \cdot R_P^2}\ , \qquad (5)$$

So: $R_S = \dfrac{R_P}{1+\omega^2 C_P^2 R_P^2}$ and

$$C_S = \frac{1+\omega^2 C_P^2 R_P^2}{\omega^2 C_P R_P^2} = C_P + \frac{1}{\omega^2 C_P R_P^2}\ , \qquad (6)$$

We have:

$$C_S = C_P + \frac{1}{\omega^2 \cdot C_P \cdot R_{P0}^2}\ , \qquad (7)$$

where $R_{P0} = \dfrac{(r + R_m)\cdot R_0}{r + R_m + R_0}$

For a maximum power transfer at f_S the reactance of impedance L connected at generator must be in accord with C_S and result:

$$L = \frac{1}{4\cdot\pi^2\cdot f_S^2 \cdot C_S}\ , \qquad (8)$$

The transducer input impedance, for fundamental frequency ($f_n=nf_o$,n=1), will be:

$$Z_t(r, f_o) = \frac{R}{\sqrt{1+\omega_0^2 \cdot R^2 \cdot C_0^2}} \cdot e^{j\,arctg(-\omega_0 C_o R)} \qquad (9)$$

Where: ω_0 - is the pulsation at resonance frequency, $\omega_o = 2\pi f_o$;

R - is the transducer resistance at resonance (f_o), R= $\frac{(R_m + r)R_0}{R_m + r + R_0}$

According as the frequency increases ($n \geq 3$) the transducer will become such as a capacity. For a suitable efficiency, the transducer impedance Z_t (r,n) will be compensated with a compensation circuit so at the fundamental frequency, the charge resistance of generator will become active ($\cos\varphi = 1$) and for higher harmonics this impedance will increase as much as possible. The circuit of classical matching dipole is showed in the fig.3.

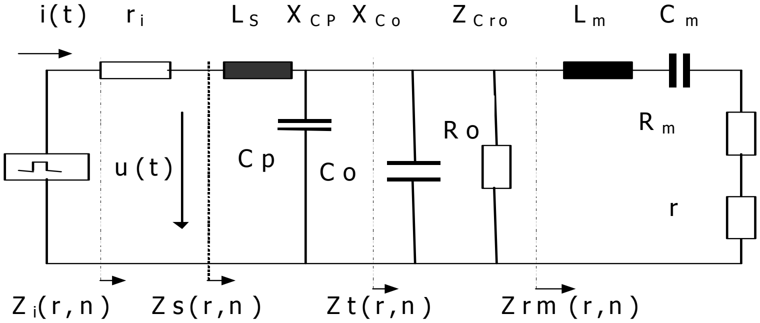

Figure 3. Electrical circuit with classical series compensation circuit

Let's note: $\omega_0 = 2\pi f_0$ - fundamental pulsation of piezoelectric transducer;

The transducer impedance for fundamental frequency [n=1, $Z_m = (\omega_0 L_m - \frac{1}{\omega_0 C_m}) \approx 0$ and $R_0 >> R_m + r$] will be :

$$Z_{1t}(r) = \frac{R_m + r}{\sqrt{1 + \omega_0^2 \cdot (R_m + r)^2 \cdot C_0^2}} \cdot e^{j \cdot arctg(-\omega_0 R_0 C_0)} \quad (10)$$

The impedance for C_P and L_S will be , for fundamental frequency (n=1):

$$\begin{cases} X1Cp(1) = \frac{1}{\omega_0 Cp} \cdot e^{j \cdot arctg \frac{3\pi}{2}} \\ X1Ls(1) = \omega_0 \cdot Ls \cdot e^{j \cdot arctg \frac{\pi}{2}} \end{cases} \quad (11)$$

The charge impedance of piezoelectric transducer and adaptation circuit, for fundamental frequency, will be:

$$Z1s(r) = X1Ls + \frac{Z1t(r) \cdot X1Cp}{Z1t(r) + X1Cp} \quad (12)$$

The efficiency, in function of acoustic charge r, for clasical compensation circuit, will be:

$$\eta 1(r) = \frac{\Pr}{P0} = \frac{Z1s(r)}{ri + Z1s(r)} \tag{13}$$

The electric circuit of the new adaptation scheme it is presented in fig.4.The piezoelectric transducer impedance for fundamental frequency [n=1, Zm=($\omega_0 L_m$–$\frac{1}{\omega_0 C_m}$) ≈ 0 and $R_0 >> R_m + r$] will be:

$$Z_{a1t}(r) = \frac{R_m + r}{\sqrt{1 + \omega_0^2 \cdot (R_m + r)^2 \cdot C_0^2}} \cdot e^{j \cdot arctg(-\omega_0 R_0 C_0)} \tag{14}$$

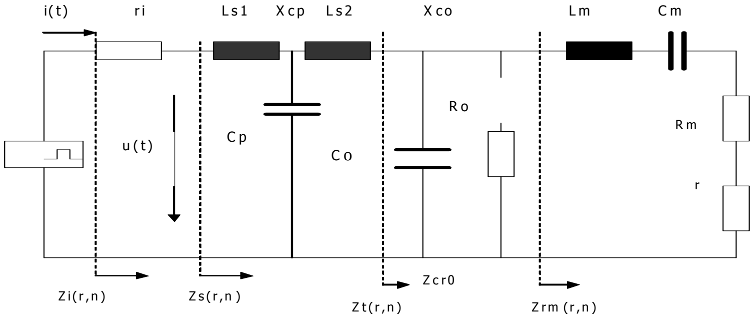

Figure 4. Electrical circuit generator–new series compensation scheme–piezoelectric transducer.

The impedance for C_P, L_{S1} and L_{S2} will be:

$$\begin{cases} X1Cp(1) = \dfrac{1}{\omega_0 Cp} \cdot e^{j \cdot arctg \frac{3\pi}{2}} \\ X1Ls1(1) = \omega_0 \cdot Ls1 \cdot e^{j \cdot arctg \frac{\pi}{2}} \\ X1Ls2(1) = \omega_0 \cdot Ls2 \cdot e^{j \cdot arct \frac{\pi}{2}} \end{cases} \tag{15}$$

The charge impedance of piezoelectric transducer and adaptation circuit will be:

$$Z1sa(r) = X1Ls1 + \frac{X1Cp \cdot [Za1t(r) + X1Ls2]}{Za1t(r) + X1Ls2 + X1Cp} \tag{16}$$

The efficiency, in function of acoustic charge r, for new compensation circuit, will be:

$$\eta 1a(r)=\frac{\Pr}{P0}=\frac{Z1sa(r)}{ri+Z1sa(r)} \tag{17}$$

Based on relation (13) and (17) we can trace the efficiency in function of acoustic charge r for fundamental frequency , with classical adaptation scheme η1(r) and with new one η1a(r) – fig 5 .

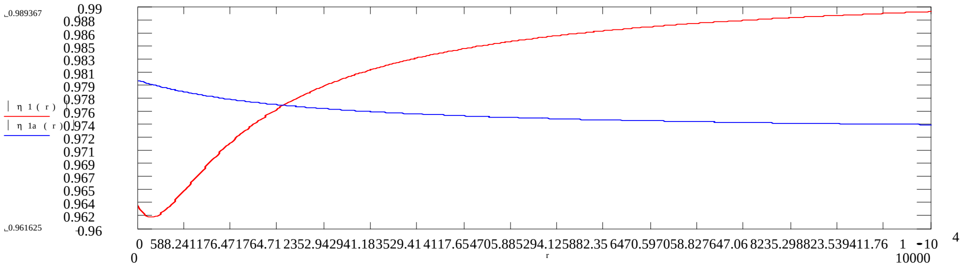

Figure 5. The efficiency as a function of acoustic charge r for fundamental frequency, with classical adaptation scheme η1(r) – red- and with new one η1a(r) – blue- .

As piezoelectric transducer was tacked the TGUS-150-40-2 type, built at the Institute of Solid Mechanics.

Referring to the fig. 6 it can observe that the efficiency η1(r) as function of acoustic charge r for fundamental frequency rise with r . This rise is more pronounced at new adaptation scheme, expecialy for used values.

This is the most important advantage of the new adaptation scheme described in this paper. Other advantage of this new adaptation scheme is that the inductance used has a little value therefore it is more easy to built.

3. The experimental results.

We can find out [7] the elements of equivalent circuit in function of charge resistance – *r* – and we can find out the value of *C* for adaptation circuit, conforms to relations:

$$Z_0 = R_0\cdot\frac{1-j\omega\cdot C_0\cdot R_0}{1+\omega^2\cdot C_0^2\cdot R_0^2},$$

$$Z_m = R_m + r + j\cdot\left(\omega\cdot L_m-\frac{1}{\omega\cdot C_m}\right), \tag{18}$$

$$Z_t = \frac{Z_m\cdot Z_0}{Z_m+Z_0},$$

$$Z_C = \frac{1}{j \cdot \omega \cdot C},$$

$$Z_L = j \cdot \omega \cdot L\ ,$$

The correspondences between [8] the value of generator current I_g, of the current through transducer I_t and motion current I_m will be:

$$I_g = U \cdot \frac{Z_C + Z_t}{\left(Z_g + Z_L\right) \cdot \left(Z_C + Z_t\right) + Z_C \cdot Z_t},$$

$$I_t = I_g \cdot \frac{Z_C}{Z_C + Z_t}, \qquad (19)$$

$$I_m = I_t \cdot \frac{Z_0}{Z_0 + Z_m}.$$

The mechanic power losses P_m, the electric power P_0 and charge power P_r will be:

$$P_m = R_m \cdot I_m^2 / 2,$$

$$P_0 = \frac{1}{2} \cdot \frac{\left|I_t \cdot Z_t\right|^2}{R_0}, \qquad (20)$$

$$P_r = r \cdot I_m^2 / 2$$

It may trace the diagrams for I_m and P_r in function of charge resistance r with capacity C taken as a parameter.

For a practically case [9], we took the type transducer TGUS-040-150-2 having the follower parameters: U = 200V; f_S = 40kHz; f_P = 42kHz; $C_0 = 4 \cdot 10^{-9}$F; R_0 = 100kΩ; R_m = 40Ω; Z_g = 50Ω.

From these curves it seen that we can found an adaptation circuit so that the current I_m not varies very much in function of charge variation r.

From power curve [10], it observes that we can obtain a maximum power when r varies in large limits – figure 6.

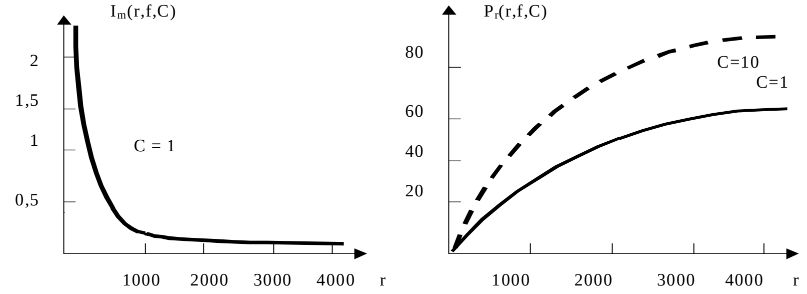

Figure 6. The diagrams I_m , P_r in function of acoustic resistance charge r.

We have the following cases:

a) The small values of charge r (air). In this case the impedance given from (C_0, R_0) may be neglected by report with the impedance of motion arm. In equivalent scheme will rest only resistances R_m, r.

b) The high values of charge r (the most frequently situation in practice). We will have $r << R_0$ and $R_0 >> r + R_m$. In this case, the motion current may be determined, at resonance frequency, by measuring of total current and of shift between the current and the tension at terminal transducer.

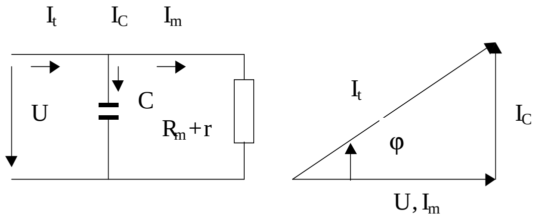

Figure 7. The phase diagram for currents through equivalent scheme of transducer.

We have the relation (figure 7):

$$I_m = I_t \cdot \cos\varphi \tag{21}$$

An indirect determination it take place by observation that I_m is direct proportional with vibration amplitude A at radiation surface of transducer for a given frequency $f = \omega/2\pi$ or with velocity amplitude $v = \omega \cdot A$ for any frequency.

If we take in calculation the charge power P_r, given above, and which represents, in the same time, the acoustic power P_a given to charge, we will obtained:

$$P_r = r \cdot I_m^2 / 2 \text{ and } P_a = (A \cdot \omega)^2 \cdot Z_0 \cdot S. \tag{22}$$

Where: Z_0 is the specific acoustic impedance and S is the radiation area.

By equalization, we obtain:

$$I_m = k \cdot \omega \cdot A\,, \tag{23}$$

where:

- the term $\omega \cdot A$ it is determines by accelerometer;
- the constant of proportionality k is given by the relation: $k = \sqrt{\frac{Z_0 \cdot S}{R_0}}$

and it may be determined, by measurement, at small charge, of current through transducer and of velocity amplitude $\omega \cdot A$.

From practice [11] it may take conclusion that the maximum value allowed for stress amplitude in nodal plan of acoustic chain will determine velocity amplitude ($\omega \cdot A$) at end of acoustic chain, at radiation surface.

If we know k for every transducer, we can obtain the maximum permissible value for I_m and by utilization of diagrams $I_{m(r,f,C)}$ function of r and $P_{r(r,f,C)}$ function of r we can find out the values of circuit for constant amplitude function.

The debited power [12] from generator to piezoelectric transducer, in the case of a small acoustic charge (by example, when transducer works in air, without acoustic charge coupling – *r* are a small value-), will be large and transducer will vibrate with too much amplitude, which may destroy the transducer. So the debited power and supported by transducer depends from acoustic charge and for small acoustic charge values the power can be dangerous.

For to estimate this variation, which is not be necessary linear, it starts from equivalent scheme given in figure 1. The electronic generator, which excites piezoelectric transducer, debits a constant tension U_g. The current, which pass through branch that contents the charge resistance *r*, will be:

$$I_r = \frac{U_g}{R_m + r} \quad , \tag{24}$$

The power debited on acoustic charge resistance *r*, the useful power which self transforms into ultra-acoustic vibrations, will be given by relation:

$$P_r = r \cdot I_r^2 = \frac{r}{(R_m + r)^2} \cdot U_g^2 \quad , \tag{25}$$

In figure 8 it is presented the variation of useful power P_r with acoustic charge *r* by to chart the diagram of this equation.

It is observed that [13], for small values of acoustic charge, the power debited is very large and than it subtract approximate exponential with the growth of resistance. In calculations effectuated, it is considered that the value of resistance R_m, the mechanic losses, may be 40 Ω – continue line – and 100 Ω – dot line –. It can be seen that if the transducer are a better quality (R_m is a small value) and the absorbed power, at small charge is too large, so the possibility to destroy it are too higher because of large amplitude vibrations.

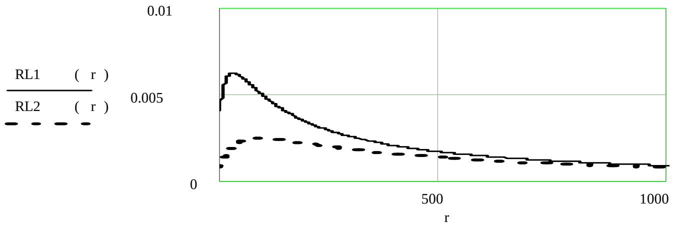

Figure 8.The variation of debited power on compensate piezoelectric transducer which has the mechanic losses resistance R_m of 40 Ω – the continue line – and of 100 Ω – the dot line –.

For acoustic charge measurement of transducer one uses a K7103 Velleman digital oscilloscope coupled with PC computer. With a K8016 Velleman digital generator, one generates a sinusoidal signal with variable frequencies from 100 Hz per step. It was followed the answer of transducer which was charged with different acoustic chargers. It was traced the frequencies answer curves – figure. 9.

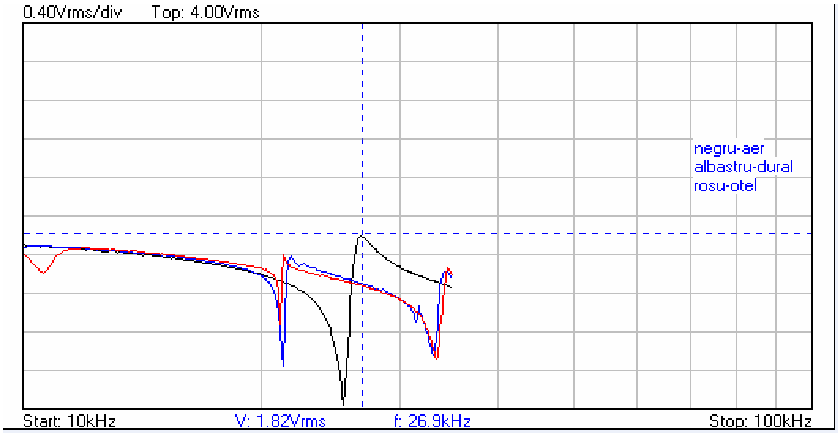

Figure 9. The answer curves of transducer charged with different acoustic charges: air – black; aluminium – blue; steel – red.

On digital generator output it was connected a resistance equal with 1,8kΩ in series with transducer and output amplitude of digital generator was $5V_{vv}$. The acoustic charge – air or an aluminium/steel cylinder – was laid on surface of the transducer. It can seen that when the acoustic charge is air the minimum of frequency characteristic transfer is for 25,5 kHz – r = 31 Ω –, for aluminium 21,4kHz – r = 396 Ω – and for steel 21,2 kHz – r = 960 Ω.

In Figure 10 it is presented the measurement scheme for absorbed power from system transducer – acoustic charge. It takes a Versatester type generator that supplied a linear power amplifier which, has like charge, the transducer with different acoustic charges.

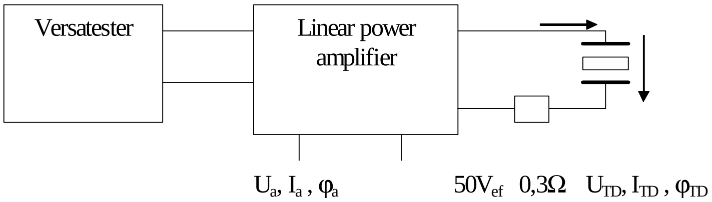

Figure 10 – The measurement scheme for absorbed power from transducer.

The experimental measurements are pasted in table 1.

It was observed that the absorbed power is smaller in the case that acoustic charge is air (r = 31Ω) – Figure 7. For plastic (r = 514 Ω), aluminium (r = 396 Ω), steel (r = 960 Ω) the absorbed power is reduced like in Figure 8.

Table 1

	U_{TD} [V_{ef}]	I_{TD} [A_{ef}]	φ_{TD} [^{0}]	P_{TD} [W]
Air - 31Ω	50	1,09	77	12
Aluminium- 396Ω	“	0,72	62	17
Steel - 960Ω	“	0,49	58	13
Plastic - 514Ω	“	0,75	61	18

4. Conclusion

In this paper were finding the mathematical expressions of power debited from a piezoelectric transducer in function of acoustic charge – relation (25).

It was traced the curves corresponding of these relations – Figure 8.

The curves were experimental verified with help of precision digital oscilloscope and generator coupled with PC computer.

The presented paper it makes easily to design in the case of ultrasonic system by putting at disposition the necessary formulas and the graphs.

References

[1] G.L. Odobescu, I. Rugina and C. Lala, “*Metode de creştere a eficienţei sistemelor acustice de mare putere”,* Sesiunea de comunicări ştiinţifice – Comisia de Acustica – Academia Română Bucureşti, 12-13 octombrie 2000, pp.31-36.

[2] N.O. Eddy, I.J. Ukpong, “*Possible relationship between the soap and the lye*", Applied Science-APPS, 8/2006, 1, (60-64).

[3] Moulay Rchid Sidi Ammi, Delfim F.M. Torres, “*Existence and regularity of optimal solution for a dead oil isotherm problem*", Applied Sciences-APPS, 9/2007, (2-12).

[4] Nnabuk O. Eddy, “*Applied statistics in designing special organic mixtures*", Applied Sciences –APPS, 9/2007, (78-85).

[5] G.L. Odobescu, C. Lala *"The variation of ultra-acoustic system efficiency in function of acoustic charge*" , *The Annual Symposium of the Institute of Solid Mechanics, SISOM 2003,* (15-16) May, Bucharest 2003, (239-242).

[6] G.L. Odobescu, *"The propagation study of ultrasound high intensity waves through resonance bodies transformation with a new adaptation scheme with acoustic charge", First Conference of the Romanian Acoustical Society,* (15-17) October 2001, Bucharest,

Romania, pp. 175-182.

[7] G.L. Odobescu, *"The propagation study of ultrasound high intensity waves through resonance bodies transformation / adaptation with acoustic charge", The 17th International Congress on Acoustic, (2-7) September 2001, Rome, Italy,* abstract ID 1522, Oral session on 7A.02.07 " Nonlinear acoustics", 7.09.2001, hour 10.00, pag. 351- Book of Abstracts; pag. 89 – Scientific programme, pp. 71 abstract.

[8] B.L. Oodbescu, "*A method which may be utilizes in case of acoustic resonators used for ultrasonic welding technique",* Annals of the Academy of Romanian Scientists, Series on Science and Technology of Information, Volume 2, Number 1/2009, pag. (21-26), ISSN: 2066-2742.

[9] G.L.Odobescu, "*Vibration theory which may be applied in case of mechanical tension determination for acoustic transformers utilized in ultrasonic vibration technique",* The Fifteenth International Congress on Sound and Vibration, ICSV 15, Daejeon, Korea 6-10 July 2008, paper no SS0106, Congress Topics T01-Acoustic and Vibration Theory, Structured Session: SS33-3 Wave Propagation in Solid, Soils and Structures, ISBN: 3-9501554-5-7.

[10] G.L.Odobescu, "*The optimization of electric parameters for rises the power transfer in case of uses piezoelectric transducers excited by electronic generators",* The Annual Symposium of the Institute of Solid Mechanics, SISOM 2008,(29-30) May, Bucharest 2008, pag.(303÷310), ISBN: 978-973-713-212-3 .

[11] G. L. Odobescu, R. A. Odobescu, "*The use of the propagation equation for the case of plane longitudinal waves through bars with variable section, to study the impedance transformers utilized for ultrasonic welding",* The Fourteenth International Congress on Sound and Vibration, ICSV 14, (9–12) July 2007, Cairns, Australia, p 17 Program and abstracts, Structured Session: Advanced signal processing on sound and vibration, Congress topics: R- Acoustics and vibration theory, no.82, ISBN: 3-9501554-5-7.

[12] G.L. Oodbescu, R.A. Odobescu, "*The influence of charge variation on efficiencies power transfer in case of piezoelectric transducers used for generated a high intensity field",* Homagial session of the commission of acoustics, Politechnica University of Bucharest, 29-31 May, Bucharest 2007, pag.228÷233, ISBN 978-973-713-179-9.

[13] G.L. Odobescu, R.A. Odobescu, "*The rise of energy transfer, function of acoustic charge, in case of piezoelectric transducers*", U.P.B. sci. bull. Series A, vol. 67, nr.4/2005, pag. (209-216), ISSN: 1223-7027.