CONTRIBUTION IN CALCULATION OF ULTRASONIC TRANSDUCERS USED IN METAL REWORKING PROCESS BY WELDING IN ULTRASONIC FIELD

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ABSTRACT: The paper presents the calculation and construction elements for the ultrasonic transducer system used in reworking by welding in ultrasonic field.The transducer is modeled by the finite element method analysis to determine the diagram of particle velocity amplitude variation along the ultrasonic transducer.
All items ultrasonic system are made to work under the resonant frequency of 24kHz, respectively, at 25 kHz resulting in the optimal finite element analysis.
KEYWORDS: reworking, ultrasonic, metal, deposition, welding

1. INTRODUCTION

The ultrasonic transducer is that part of the system which carries out the transfer of ultrasonic energy from the ultrasonic generator to rewoking place by welding.

In a largely yield and performance of a system for reconditioning [1,2,3,4], by loading by welding [7] in ultrasonic field depends on how construction of fairness sizing, the nature of the materials from which it is made, how to adapt to the high frequency generator and how to adapt the scheme cinematic ultrasonic transducer concrete design.

The ultrasonic system design and implementation requirements had to considered acoustic, mechanical and technology requirements that must satisfy the acoustic system used in active applications [5]. Mechanical requirements and technological depends largely on introduction scheme of ultrasonic energy in the loading zone and concerns: execution precision of ultrasonic system, surface quality, nature of the material from which it is made, heat treatment, wear resistance and fatigue stiffness, heat stability, etc.

Acoustic requirements are conditioned [6] by the necessity of creating in the ultrasonic system an operating system in the resonance or standing waves. These requirements can be formulated as follows:

- maximum transfer of acoustic energy from the concentrator to reworking area, only achieved when working under the regime of resonance or standing waves;
- minimum energy loss in ultrasonic elements of the system itself and in passive elements of the ultrasonic system for the realization of the proposed operation;
- Maximum concentration of acoustic energy directly into the loading zone requirement that is realized only by selection, calculation, construction and proper execution of waveguides, ultrasonic energy concentrators and ultrasonic activation part.
- Ultrasonic energy radiation uniformity over the area of the working area. The quality of the material depositon obtained after the reworking process depends on this uniformity.
- Ultrasonic system stability over time in long-term operation.
- Technological simplicity and constructive ultrasonic elements and the whole system as a whole. This is the most important indicator of any device.

An important step in achieving a reconditioning facility by reworking through the welding in ultrasonic field is that of achieving a corresponding ultrasonic system by this new method.
The main issues of ultrasonic system design studied and settled in this paper are:

- components sizing of ultrasonic transducer to work under resonance and / or working under standing wave or traveling wave;
- the choice of scheme installation and fixing housing, the cooling mode transducer and how ultrasonic sound insulation of the entire system;
- adoption decision about transducer type: magnetostrictive, electrostrictive, piezoceramic
technology implementation and installation of ultrasonic system elements and necessary adjustments for operation at stable resonance under conditions of temperature variation;
- correct determination of excitation schemes in load and without load;
- Establishing criteria of efficiency of ultrasonic systems and measures to be taken to improve them

2. ULTRASONIC TRANSDUCER ELEMENTS CALCULATION

Any application of ultrasound which uses an ultrasonic system requires a very rigorous calculation for the entire system that must work at resonance.

Calculus and building elements are quite complicated and the results for certain operating conditions are essential to the efficient functioning of the entire system ultrasonic.

To calculate the ultrasonic system design first, the initial data with corresponding values are considered:

$$\varepsilon_0 = 8.854 \cdot 10^{-12} \ \frac{\mathrm{F}}{\mathrm{m}} \quad (1)$$

$$j = \sqrt{-1} \quad (2)$$

- resonance frequency:

$f_0 = 25000$ Hz ; $f_0 = 2{,}5 \times 10^4$ Hz (3)

- pulsation at resonance:

$\omega_0 = 2 \cdot \pi \cdot f_0$ (4)

- minimal aplitude at the active part peak:

$$A_{\max} = 85 \cdot 10^{-6} m \quad (5)$$

- input electrical power:

$P_{in} = 3500$ W (6)

- minimal acoustic intensity:

$I_a = 150 \frac{W}{cm^2}$ (7)

- acoustic and mechanical yield:

$\eta_{am} = 0.78$ (8)

- electromechanical coupling factor:

$k_{em} = 0.65$ (9)

- electroacoustic yield:

$\eta_{eap} = 0.96$ (10)

- density:

$\rho_p = 7.6 \cdot 10^3 \frac{kg}{m^3}$ (11)

- Young modulus:

$Y_p = 7.4 \cdot 10^{10} \frac{N}{m^2}$ (12)

- relative permitivity at 1 kHz:

$\varepsilon_{rp} = 2600$ (13)

- loss angle:

$\delta_p = 0.687472$ deg (14)

$\tan(\delta_p) = 0.012$ (15)

- piezoelectric constant:

$k_p = 665 \cdot 10^{-12} \frac{m}{V}$ (16)

- Curie temperature:

$\theta_p = 558.15$ K (17)

The reflector is built from titanium alloy:

- Young modulus:

$Y_{Ti} = 80.3 \cdot 10^9 \frac{N}{mm^2}$ (18)

- density:

$\rho_{Ti} = 4.43 \cdot 10^3 \frac{kg}{m^3}$ (19)

Calculations of the compound transducer dimensions with a different active and passive elements granted in two quarter-wave was done for ultrasonic system used in experiments (model SU-25 ASE 01)presented in Figure 1.

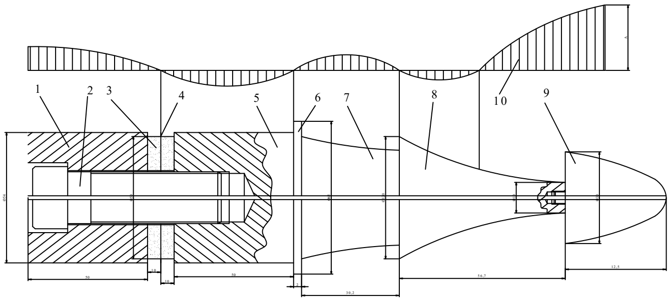

Figure 1. ULtraacoustic system model SU25-ASE 01, used in reworking by welding in ultrasonic field by electrode-wire activation:
1. – reflector element, 2. – mechanical polarization screw, 3. – piezoceramic disc; 4. – electrode for electrical polarization, 5. – radiant element; 6. – nodal flange, 7. – acoustic amplifier; 8. – ultrasonic energy concentrator, 9.- active part, 10. – diagram of particle speed variation, A-maximal amplitude of the longitudinal ultrasonic wave

3. CONTRIBUTIONS REGARDING FINITE ELEMENT MODELING OF THE ULTRASONIC TRANSDUCER

The active element of the ultrasonic system [8,9] is the piezoceramic ultrasonic transducer that converts electrical oscillations applied by the electric generator to elastic vibration of acoustic reflector (fig.3). The compound transducer consists in a package of the piezoelectric elements fixed between two enrolling blocks of materials of different density and modulus of elasticity (the reflector and radiant), assembled by amechanical polarization screw. In the piezoceramic assembly (Figure 4), two piezoceramic discs are prestressed assembled between a reflector element 3 and a radiant element 1. Finite element modeling of the piezoceramic assembly provides a prediction of his behavior both displacement (amplitude) and the state of stress.

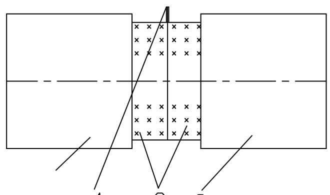

Figure 2. Constructive element of a ultrasonic transducer

Figures 3 presents the steps of the construction of ultrasonic transducer model.

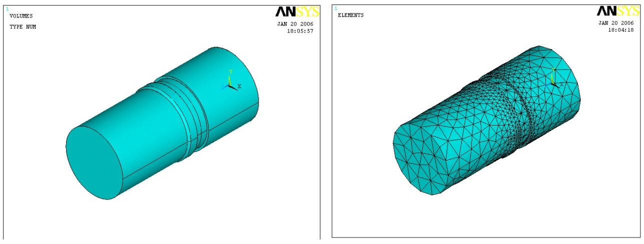

Figure. 3 Finite element model of the ultrasonic transducer

In modeling the ultrasonic transducer an harmonic analyse was developed that provides capabilities in predicting the dynamic behavior of structures maintained, to check whether the model reach resonance, fatigue and other effects introduced by harmonic vibrational forces.

Harmonic analysis is a technique used to determine the structure stationary linear response when the load varies sinusoidal (harmonic). For applications, it is important to calculate the structure for several frequency response and make plotting the frequency response of several sizes (usually displacements). By this analysis is calculated only stationary vibration forces of the structure.

Transient vibrations that occur at the beginning of excitation are not taken into account by harmonic analysis. Harmonic response analysis is a linear analysis. Any non-linearity such as plasticity and contact gap between the elements are ignored even if they were defined. The harmonic analysis can be performed for a prestressed structure, as in the present case.

The analysis was carried out for the frequency of 25 kHz corresponding to the resonant frequency of the ultrasonic transducer and for the ultrasonic system as system.Figure 4 presents displacement isometric view of the piezoceramic assembly at resonance frequency of 25 KHz.

The results of the analysis in the condition of deformation of the piezoceramic assembly are presented in Figure 5.

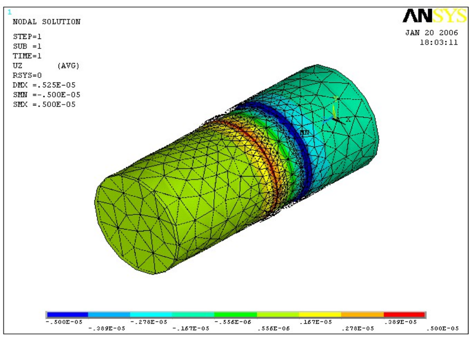

Figure 4. Displacement isometric view of the piezoceramic assembly

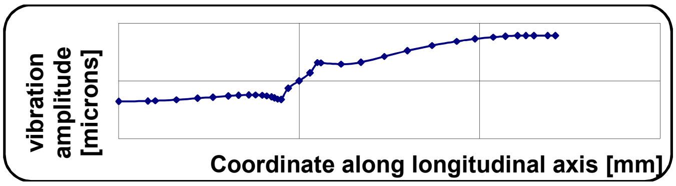

Figure 5. Particle velocity amplitude variation along the piezoceramic transducer

Table 1 contains pairs of values of the nodes coordinated of the reflector and radiant block and vibration amplitude. The origin of the coordinate system being on exit plane of the reflector. The table 1 is marked corresponding values of pair of nodal plane located between piezoceramic elements.

Table 1. Values for amplitude vibration along the ultrasonic transducer

Coordinate z [mm]	Amplitude. [µm]	Coordinate z [mm]	Amplitude. [µm]
0	-17.68	50	0
8.08	-17.52	53	6.88
10.17	-17.08	56	16
16.01	-16.24	56	15.68
21.86	-15.04	61.64	14.6
26.11	-14.08	67.09	16.04
30.36	-13.08	73.54	21.24
33.19	-12.52	79.98	26.08
36.02	-12.12	86.8	30.68
37.91	-12.04	93.62	34.32
39.8	-12.32	98.68	36.44
41.06	-12.92	103.75	37.96
42.32	-13.84	107.12	38.64
43.16	-14.68	110.5	39.08
44	-15.68	112.75	39.12
44	-16	115.02	39.12
47	-9.44	118.8	39.16
49	-6,15	121	39.16

The second analysis, the modal analyze, determines the frequencies and vibration modes of the transducer system that is actually the starting point în first harmonic analysis presented in the first part.

Based on the modal analysis, optimal vibration frequencies that serve the intended purpose are searched. Modal analysis performed for the ultrasonic transducer designed in order to reconditioning by welding refers to the transducer assembly which consists of two ceramic discs glued together, the acoustic radiant element located on top of them and acoustic radiant element positioner at inferior part of the piezoceramic plates. This system allows the converting electrical oscillations into mechanical oscillations and their amplification in order to transfer the movement with greater amplitude at assembly intermediate element - concentrator.

Modal analysis allows determining the vibration modes of the radiant system when no action constant force acts from exterior. Figure 6 shows the geometric ultrasonic transducer assembly made up of the elements described above.

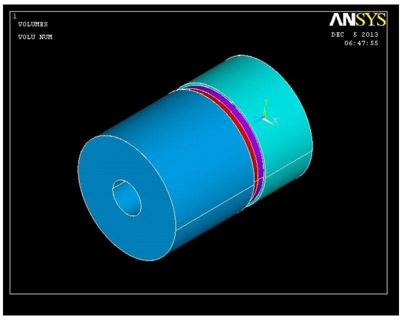

Figure6. Presentation of ultrasonic transducer system

Starting from this model, in the following, possible vibration modes will be studied. Figure 7 shows the first mode of vibration that was running at the frequency f = 22050 Hz. In this case, the maximum amplitude vibratory movement is accomplished by, as is the manner of the amplifier system. It is alternatively deformed axially on the two diameters located on 90^0. Along one diameter the radiant extends and in the same time at 90^{0} it is compressed. In the next phase, the movement changes on the opposite side.

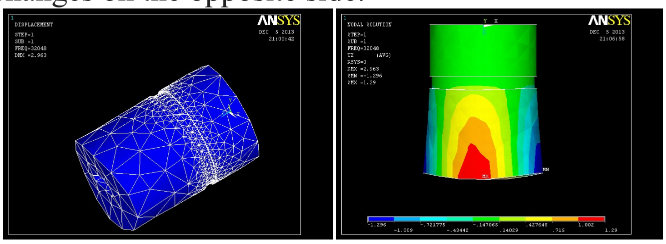

Figure7. System vibration at frequency f = 22050 Hz

Since the frequency of vibration is coming very close to the previous one and it is natural vibration mode to be very similar. As can be seen in Figure 8, alternating movements of compression and stretching to acoustic radiation are performed while not vibration are observed on reflector.

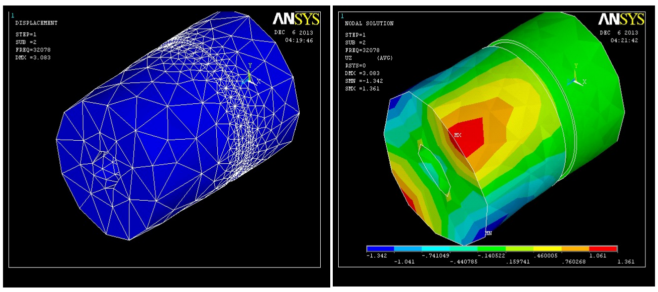

Figure 8. System vibration at frequency f = 22850 Hz

Vibration mode that was running when the frequency f = 23880 Hz is a totally unnecessary because the oscillations are made of reflector and no acoustic radiation, radiant vibrating and can not send the motion to the concentrator (Figure 9).

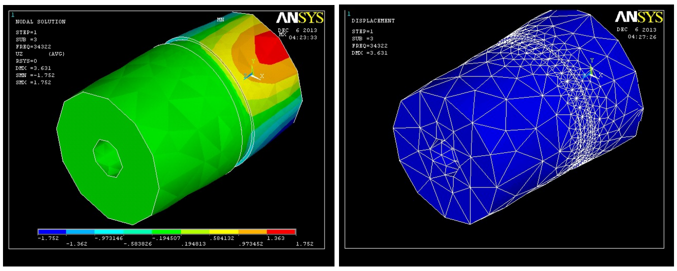

Figure 9. System vibration at frequency f = 23880 Hz

For the next vibration mode is found that vibration of the reflector, is done, this time, at frequency f = 24540 Hz. Oscillation occurs along the axis OZ and can not be used in ultrasonic activation of the concentrator. Figure 10 shows the corresponding vibration frequency of 24 870 Hz, which also can not be used.

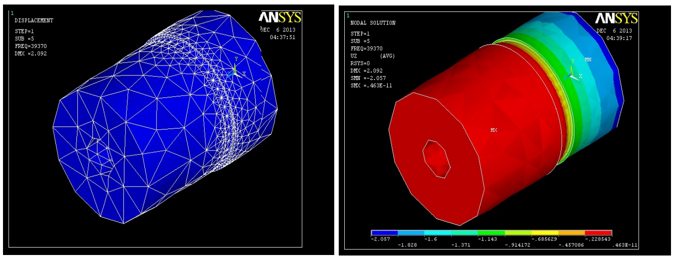

Figure 10. System vibration at frequency f = 24540 Hz

At frequency f = 24900 Hz vibration mode is produced on acoustic radiant longitudinal axis that presents compression and tension located alternately on extreme side of the amplifier. Figure 11 shows the vibration mode at this frequency.

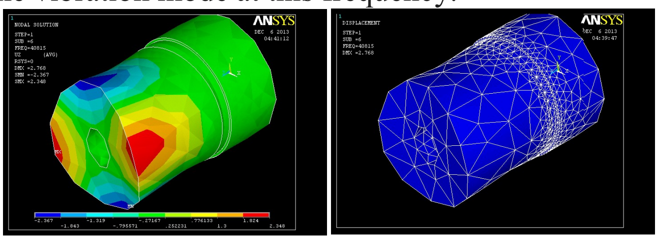

Figure 11. System vibration at frequency f = 24900 Hz.

The next mode of oscillation is appropriate to resonance frequency (f = 25000 Hz), when radiation has maximum amplitude output and reflector has zero amplitude (Figure 12).

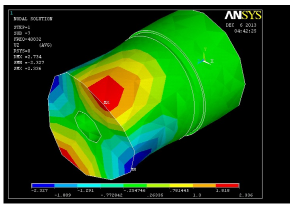

Figure 12. System vibration at frequency f = 24900 Hz.

Another vibration mode that is useful in ultrasonic vibration activation of welding bath occurs at frequency f = 25 450 Hz. This vibration mode is shown in figure 13 that is a combination of movement along the OZ axis OZ with a rotating along OY axis, proper to welding bath.

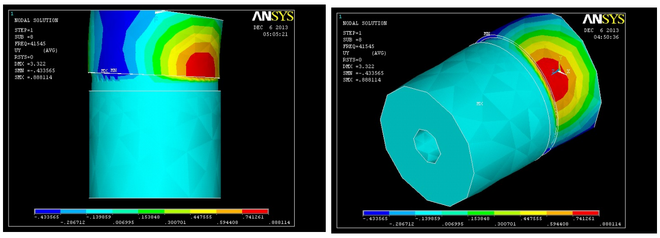

Figure 13. System vibration at frequency f = 24900 Hz.

A particularly interesting movement is shown in Figure 13, where the oscillation mode has a movement component in welding bath surface. Consequently, the frequency f = 26500 Hz can be used in drive active part of the ultrasonic system.

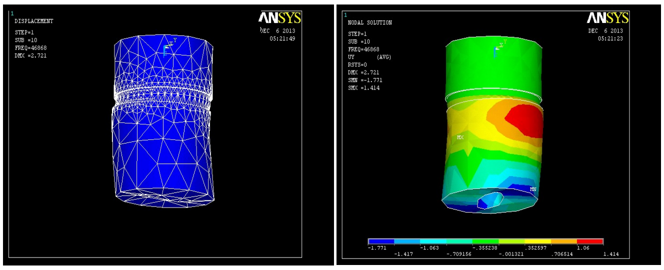

Fig.14 System vibration at frequency f = 26500 Hz.

4. CONCLUSIONS

1. Ultrasonic transducer is part of ultrasonic system that transfers the ultrasonic energy from the generator to working process zone (in the deposition layer).

In a largely yield and performance of ultrasonic systems depends on design and construction, nature of materials that are made, how to adapt to the high frequency generator and how to adapt the ultrasonic transducer scheme to cinematic reconditioning system by ultrasonic welding.

2. computing elements for a composed piezoceramic transducer designed and made in an enterprise are: provided mechanical resonance; electromechanical resonance condition; acoustic power emitted at resonance; acoustic power at low frequencies; characteristic frequency near the resonance of acoustic power; electrical impedance transducer; electroacoustic transducer yield of; sensitivity electromechanical transducer under resonance; low frequency receiver sensitivity; the frequency characteristic of reception sensitivity and specific electric currents at resonance;

3. experimental finding that although ceramic reflector subassembly transmits only longitudinal oscillations to radiating element, it occurs in both longitudinal and transversal oscillations due to the coupling existing in a solid medium. These oscillations, according to the Hooke law propagates independent and characteristic impedance of the radiating element is a sum of the characteristic impedance for each type of radiation excited;

4.knowing how each section vibrates the ultrasonic system design is required and possible by a finite element analysis after which the plot diagram of variation in particle velocity amplitude along the section and the type of vibration excited in the system.These diagrams are necessary not only for the design and determination of the resistance elements but also to achieve an ultrasonic system which have a yield acustomecanic imposed a priori.

5. ACKNOWLEDGEMENTS

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