Protective matching polymer powder coating of piezoelectric element

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Abstract. Objects of research are coatings and technology of their applying to the piezoelectric elements for ultrasound. Acoustic impedance and thicknesses of matching layers for medical ultrasound transducers have been defined. In this paper performance characteristics of coating systems with predetermined properties have been selected. The conditions for selection of polymer powder paint for quarter wave matching layer have been determined. Conditions of forming polymer powder coatings have been proposed.

1. Introduction

Is known to in liquids and gases can only be distributed longitudinal elastic (acoustic) oscillations. This is due to lack of liquids and gases forms, and hence elastic form. Therefore, liquids and gases expand or contract only in the direction of wave propagation. Space filled with a substance in which the sound wave are spreading is called the sound field. The most important quantities characterizing the acoustic field are sound pressure \( p \) and the particle velocity \( v \) [1].

2. Calculation the thickness and the acoustic impedance of matching layer

The oscillatory particle velocity in the propagation of longitudinal acoustic waves is described by equation d'Alembert:

\[
\nabla^2 v - \frac{1}{V^2} \frac{\partial^2 v}{\partial t^2} = 0.
\]

Similarly, describes changing the acoustic pressure:

\[
\nabla^2 p - \frac{1}{V^2} \frac{\partial^2 p}{\partial t^2} = 0.
\]

Coefficient in front of second derivative in both equations is the inverse of the square of the velocity of propagation of longitudinal waves.

The joint solution of the equations defines the relationship between the amplitudes of the acoustic pressure \( p_a \) and particle velocity \( v_a \) of the longitudinal wave in the form of:
where, $\rho_0$ - the equilibrium density of the medium, $V$ - velocity of longitudinal waves.

The proportionality coefficient in brackets is called the acoustical impedance of the medium:

$$Z = \rho_0 V.$$  

This quantity characterizes the environment in which the wave propagates, namely the scattering of wave energy in the sound field.

Ultrasound diagnosis, including medical, based on the phenomenon of reflection of elastic waves at the boundary between media with different acoustic impedances. However, the same phenomenon is one of the major challenges in the study since the acoustic impedance the source of ultrasonic waves and the object of the study may be different quite significantly, which causes strong reflection of ultrasonic waves while entering into the object. Presence of air between the source and the object under investigation is also fatal because of acoustic impedance values for metal and air are different an average of five orders of magnitude.

For successful research is needed to minimize losses when entering ultrasonic waves into the test object.

To eliminate of air are used couplant such as glycerin.

Reduction of losses upon reflection at the interface is the introduction of the quarter wavelength matching layer. This additional layer of material should have such acoustical impedance to provide equal acoustic impedance of the first medium and the second input acoustic impedance of the medium. Reflected from the both boundary of the matching layer waves will be equal in amplitude and antiphase that will lead to their mutual compensation. The phase shift of 180 degrees is provided the half wavelength path difference of the waves between the boundaries. Equality of the amplitudes - a rational choice acoustic impedance transforming layer [2].

The expression for calculating the acoustic impedance matching layer:

$$Z_p = \sqrt{Z_1 Z_2}.$$  

Based on the impedance value (5) material for the manufacture of the matching layer is chosen. Since the thickness of the matching layer is equal to a quarter wavelength in the material, the frequency band for which there will be a low reflection coefficient is small. To increase this frequency band is applied multiple matching layers.

Matching layers can be glued or can be electroplated. For the manufacture of the protective layer are selected materials characterized by high wear resistance, low attenuation of ultrasonic oscillations and high speed of sound, usually a sheet of a copolymer of vinyl chloride and ethyl acrylate [3]. Also, is used of industrial layers of a mixture epoxy resin filled with titanium dioxide. In the completed device case transition layer are made of the same material with the body. Transition layer is the integral part of the body.

The most common medical diagnostic ultrasound transducers are operating frequencies of 2, 2.5, 3.5, 5 and 10 MHz. Average propagation velocity of ultrasonic waves in human tissues is 1540 m/s, in water (at $t = 20^\circ$ C) 1480 m/s, in transformer oil 1390 m/s. Transformer oil is used to conduct simulation experiments, as the premises of piezoelectric elements in the water is not recommended by the manufacturer. The following table shows the thickness of the quarter wavelength matching layers for various piezoelectric elements.
Table 1. Thickness of matching layers piezoelectric elements for different media.

| The operating frequency of the piezoelement, MHz | The thickness of the matching layer for piezoelement for humans, um | The thickness of the matching layer for piezoelement for water, um | The thickness of the matching layer for piezoelement for transformer oil, um |
|-----------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 2                                            | 192.5                                                        | 185                                                          | 174                                                          |
| 2.5                                          | 154                                                          | 148                                                          | 139                                                          |
| 3.5                                          | 110                                                          | 106                                                          | 99                                                           |
| 5                                            | 77                                                           | 74                                                           | 69.5                                                         |
| 10                                           | 38.5                                                         | 37                                                           | 35                                                           |

Selection of the coating is carried out on the basis of condition (5). For water, the acoustic impedance \( Z = 1.483 \times 10^6 \, \text{kg/m}^2 \cdot \text{s} \), for piezoelectric ceramics PZT-19 \( Z = 22.42 \times 10^6 \, \text{kg/m}^2 \cdot \text{s} \), respectively, the acoustic impedance the polymer powder coating should be about \( Z_p = 5.77 \times 10^6 \, \text{kg/m}^2 \cdot \text{s} \).

Acoustic impedance is defined by the expression (4). The velocity of propagation of elastic waves in the polymer powder coating is determined empirically.

3. The method of recovery the protective layer piezoelectric element

In operation, face of the transducer progressively wears away. In defectoscopy this problem is solved by replacing the prism normally set to the transducer. In medical diagnosis as a result of the properties of living tissues that are similar in properties to the water, prisms do not apply. In this case, the average transducer lifetime period is 2 years [4].

In [4] proposes the extension of lifetime the ultrasound transducer by applying a polymer powder coating on the surface of the piezoelectric transducer in the corona discharge.

The application of polymer powder coatings include coating and subsequent polymerization.

The spraying process is carried out by means of a spray gun – the unit for the application of polymer powder coating. To the electrodes spray is applied a high voltage. And between the spray gun and the grounded detail is created a strong electric field. Powder particles entering the region of corona discharge, acquire a charge [5].

The spraying process takes place in the spray chamber, designed to prevent scattering and centralized collection powder coating particles are not deposited on the painted product.

Experiments have been conducted and optimum operating parameters is determined of the system of homogeneous coating polymer powder coatings (PPC) (Table 2).

Table 2. Optimal operating parameters of the PPC application.

| Thickness of the matching layer, um | The voltage on the discharge electrode, kV. | Supply air pressure, atm. | The distance from the needle spray gun, cm | Time of the coating process, s |
|-------------------------------------|---------------------------------------------|---------------------------|------------------------------------------|-------------------------------|
| 192.5                               | 25                                          | 0.8                       | 15                                       | 8                             |
| 154                                 | 25                                          | 0.8                       | 30                                       | 6                             |
| 110                                 | 10                                          | 0.8                       | 30                                       | 6                             |
| 77                                  | 10                                          | 0.4                       | 25                                       | 2                             |
| 38.5                                | 20                                          | 0.4                       | 15                                       | 2                             |

The polymerization process occurs in the drying chamber, where due to the high temperatures, is the heating of products, fusion of the polymer particles and the final formation of the coating. [6]
Particularly important adherence solidification thermosetting paints, because any deviation from adversely affecting the properties of the resulting coatings.

For medical products is used polyether, epoxy- polyether coating. Their main characteristics are: abrasion resistance, impact resistance, surface smoothness and comfort, the lack of toxicity, obstruction of bactericidal activity, suitability for sterilization, easy to clean, resistant to chemical attack [7].

Table 3 shows the conditions of forming polymer powder coatings.

| Type of PPC        | Temperature of curing, ° C | Time of curing, min |
|--------------------|----------------------------|---------------------|
| Polyether          | 180                        | 15                  |
| Epoxy-polyether    | 180                        | 15                  |
| Polyether          | 200                        | 10                  |
| Epoxy-polyether    | 200                        | 8                   |

In Figure 1a. is presented transducer with the removed protective cover. The outside of the piezoceramic plates electroplated nickel-plated. The result of applying a protective coating is shown in Figure 1b.

4. Conclusions

Performance characteristics of the coating system with predetermined properties have been selected. The conditions for selection of polymer powder coating have been determined. The conditions for the formation of polymer powder coatings of various types have been proposed.

References

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