The spatial distribution the thickness of polymer powder coatings for ultrasonic sensors

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Abstract. Objects of research are coatings and technology of their applying to the piezoelectric elements for ultrasound. Results of studies the distribution coating thickness according to different modes of coating process are presented. Experimentally confirmed the simulation results of the movement gas suspension on the electrostatic field in the electrode system "needle - plane".

1. Introduction
Ultrasound remains one of the most popular tools non-destructive testing and diagnostics in various areas including medicine. Our research group conducts researches in the field of ultrasound and the development of new methods and equipment for non-destructive testing of multiphase and biological objects [1-5].

The source of ultrasonic vibrations are electromechanical transducers based on piezoelectric materials. Despite the appearance of new piezoelectric composite materials and various polymer piezoelectric films the most common materials remains barium titanate (BaTiO₃) and lead zirconate titanate (PZT). The main problem of these materials is the brittleness.

Close contact ultrasonic sensor with the test object is necessary in the process of diagnosis liquid and solid objects. This requires to use different protective coatings and prisms which prevent the damage transducer and protect it from aggressive environments. For example, in the medicine copolymers of vinyl chloride and ethyl acrylate are applied. Plates of which are glued to the piezoelement. However, the protective coatings are abraded and are damaged, resulting in a failure of the sensors. To solve this problem a corona discharge plasma for drawing polymer powder coating has been proposed [6]. Advantages of the method of plasma spraying in an electrostatic field are ease the adjustment process, the possibility of automation, high productivity, lack of pre-heating products, uniform coating thickness, the ability to produce coatings on thin-walled products, as well as products made from different materials [7].

2. The protective layer thickness calculation
The important function of the coating applied to the piezoelectric element is the matching of the acoustic impedances of the piezoelectric element and the test environment. It is necessary to reduce the loss upon reflection at the interface. This matching is carried out by introducing "quarter wave" layer. Waves which reflected from both boundaries matching layer are in antiphase and will have the same amplitude. This will lead to their mutual compensation. The phase shift by 180 degrees is
provided the path difference of the waves between the boundaries in half of wavelength, and the equality of the amplitudes - rational choice acoustic impedance transforming layer [8].

For most tasks of ultrasound diagnostics and probing the frequency range 0.5-15 MHz is used. Ultrasonic vibrations in this frequency range provide sufficient resolution in the low level vibration damping.

The average propagation velocity of ultrasonic vibrations in human tissues is 1540 m/s, in water (at t = 20° C) 1480 m/s, in transformer oil is about 1390 m/s. The transformer oil is used for the simulation experiments, as the location of the piezoelectric elements in the water leads to disruption of their acoustic properties. The expression for calculating the acoustic impedance matching layer:

$$Z_{\text{tr}} = \sqrt{Z_1 Z_2}$$

where $Z_1$ – the acoustic impedance of the first medium, $Z_2$ – the acoustic impedance of the second medium.

For water, the acoustic impedance $Z = 1.483 \times 10^6 \text{ kg/m}^2 \text{s}$, for piezoelectric ceramics PZT-19 $Z = 22.42 \times 10^6 \text{ kg/m}^2 \text{s}$, respectively, the acoustic impedance the polymer powder coating should be about $Z_{\text{tr}} = 5.77 \times 10^6 \text{ kg/m}^2 \text{s}$.

3. Preparation of the samples and selection of spraying system parameters

In this paper we investigated the polyether paint coating PD810119G («BECKER»). This paint corresponds safety requirements due to the absence of organic solvents and heavy metals.

Powder paint - is the solid dispersed multicomponent system, which includes a special film-forming resins, hardeners, pigments, fillers and special purpose additives. For medical products polyether, epoxy-polyester coatings is used. They have the following characteristics: resistance to abrasion, impact resistance, smoothness and convenience the surface, non-toxicity, protection from the bactericidal activity, suitability for sterilization, ease for cleaning, chemical resistance.

Getting coatings requires careful surface preparation. The process of preparing the surface discussed in [10]. Surface must be clean, dry and free of contaminants.

Spraying the coating is carried out using a spray gun. The spray gun - the unit for applying the polymer powder paint that provides to obtain a powder mixture with air, the formation of the torch and giving the powder particles an electric charge.

Many properties of polymer powder coatings are largely dependent from the dispersion of the powder paint. As a method of determining dispersion microscopic analysis is widely used. The main advantage is that it allows to determine not only the geometrical dimensions of the studied objects, but also to see the features of their shape, surface structure.

Research and microscopic analysis of the particulate composition of the powder paint for electrostatic spraying showed that the most suitable powder coating for the application on piezo element ultrasonic sensors is such that the particulate composition which is in the range of 12-35 microns [11]. Was found that the powder paint particles the size of 1-12 microns during the spraying carried away on the air filter unit of the spray chamber due to the small weight. And the powder paint particles larger than 35 microns are showered from sprayed surface under gravity.

The studies [7] of physical and mechanical properties the samples of the coatings of polyether paint PD510226 («BECKER»), epoxy-polyether paint EP110022G («BECKER») showed the suitability of using this type of coating to the surface of the ultrasonic transducers. Such parameters as impact strength, flexibility, adhesion, gloss, hardness and wear resistance were evaluated.

Spraying is carried out in the chamber of coating polymer powder materials at the samples. Spraying occurs due to sticking of the electrified polymer particles with the sample. The subsequent formation of the coating is carried out by heating.

The polymerization process occurs in the drying chamber, where the product is heated, fusion the polymer particles and the final formation of the coating occurs.
The measurement of the potential electrostatic field during application polymer powder coatings on metallic substrates using different speeds of micro-particles and the distance to the substrate have been carried out [12]. The current-voltage characteristics for different flow speeds in the discharge, as well as without spraying at various distances from the substrate are obtained. The current-voltage characteristic of corona discharge during application of polymer powder coatings shows that the corona discharge ignition occurs at a voltage of 5 kV (the value of the discharge current is not higher than 0.5 mA) at a voltage of 5 - 10 kV, the discharge current has a value not exceeding 5 mA at various flow rates; in the range of 10V - 30 kV is visible smooth increase of the discharge current at a flow rate of 8 - 22 m/s; maximum discharge current of 25 mA is achieved at a voltage of 30 kV and a flow rate of 22 m/s.

The concentration of solid particles close to processed surface depends on its shape, the distance and potential difference between surface and electrode and the spray gun, the concentration of the carrier and the dispersed phase in the flow, dimensions, density and charge aerosol particles.

Modelling of movement the gas suspension on the electrostatic field in the electrode system "needle - plane" is produced [13]. As a model that takes into account the above factors was chosen system of equations collisionless dynamics of monodisperse two-temperature two-speed medium without phase transitions.

It is shown that the influence of electrostatic forces on the flow of gas suspension is observed only in close proximity to the electrodes where the potential gradients are greatest. In the interelectrode space in these charge density of the particles dominate the aerodynamic forces. The presence of the Coulomb force near the surface can reasonably set on the surface adhesion conditions for the velocity of the particles.

Except the above parameters protective matching layer of ultrasonic sensors, the coating thickness is also important. It must correspond to a quarter of the wavelength emitted and received by the sensor. The performance characteristics coating system were established and the conditions of their formation are proposed [8].

4. Experimental results and discussion

The experiments to measure the spatial distribution of coating thickness produced in the different modes are performed (Figure 1a, 1b and Figure 2). For this the prepared metal substrate (size 7x10 mm) was coated by PD810119G polyether paint. Polymerization was carried out in the drying chamber at 200 °C within 10 min.

The measurement of thickness the obtained coatings was carried out symmetrically relative to the centre of the substrate to the left and to the right in increments of 5 mm using an ultrasonic thickness gauge PosiTector 200 B/Adv. This device allows to measure the thickness of the coatings in the range from 13 to 1000 microns with an accuracy ± (2 microns + 3% from the measurement value). Figure 1 shows that the coating is heterogeneous with a maximum thickness at the centre, followed by a decrease and an increase closer to the substrate edge.

Conducted calculations [13] showed that during application the aerosol to a flat surface oriented normal to the axis spraying in an electrostatic field, the solid phase is applied nonuniformly and its density increases towards the free edge. At free edge the solid phase reaches the highest value. This is defined bigger intensity of the electrostatic field in this area. The experimental results confirm these calculations.
In the absence of a field, the greatest density of the dispersed phase is reached in the internal surface spraying area that is connected to the configuration of the vortex flow formed in front plate [13]. This is most likely explained by the fact that at the centre of the substrate exhibits a maximum thickness, i.e. the particles deposited screen the electric field, and the particles are the next depositing according to the configuration the vortex flow.

In both modes, the maximum coating thickness is obtained at a distance from the needle the spray gun to the applied surface equal to 10 cm. With further increase distance the thickness of the coating sharply decreases, and measure it used devices failed. With decreasing distance to 5 cm thickness of the coating is also strongly decreases and becomes highly inhomogeneous. This is because the aerodynamic forces the flow of the gas suspension impede of paint particles sticking to the surface blowing them.

With increasing deposition time (Figure 2) it becomes possible to increase the distance from the needle the spray gun to the applied surface.

![Figure 1a. The distribution of the coating thickness at different distances spray gun to the substrate: spraying time t=2 sec, pressure on the gun P=0.2 MPa](image1a)

![Figure 1b. The distribution of the coating thickness at different distances spray gun to the substrate: spraying time t=4 sec, pressure on the gun P=0.2 MPa](image1b)

![Figure 2. The distribution of the coating thickness at different distances spray gun to the substrate: spraying time t=6 sec, pressure on the gun P=0.2 MPa](image2)
Figure 2 shows that increasing the spraying time to 6 seconds leads to an increase in the thickness of the coating and increase its homogeneity. This is because during prolonged spraying occurs shielding the electric field on the surface of the substrate settled by particles of paint.

Simulation results [13], and the experimental data shows that the coating is heterogeneous by thickness, which is rather critical for solving our problem. However, it is possible to select and use the various modes of spraying, depending from the geometry of the ultrasonic sensor.

4. Conclusions
Results of studies the distribution coating thickness according to different modes of coating process are presented. Experimentally confirmed the simulation results of the movement gas suspension on the electrostatic field in the electrode system "needle - plane". The modes to obtain polymer powder coating of ultrasonic sensors for different geometric dimensions is proposed.

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