JUSTIFICATION OF THE CONSTRUCTIVE PARAMETERS OF THE ULTRASONIC GENERATOR AND ACOUSTIC RESONATOR FOR THE COCOON REELING PROCESS

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Abstract. The paper substantiates the constructive parameters of the ultrasonic generator and acoustic resonator intended for the ultrasonic cocoon reeling process. The resonant thickness of the PZT-4 piezoelectric element and the length and gain of the titanium (Ti-6Al-4V) acoustic resonator (booster) are calculated. The acoustic field of four generators in the water bath is modelled on the basis of the Helmholtz wave equation and the superposition principle. It is shown that a symmetric 2+2 arrangement of the generators produces constructive interference that increases the acoustic intensity at the bath centre by a factor of 16. The justified parameters (resonant frequency 40 kHz, piezoelement thickness 16 mm, resonator length 64 mm, gain factor K = 6.25, total acoustic power 600 W) ensure stable cavitation above the Blake threshold.

Keywords: cocoon reeling, ultrasound, piezoelectric transducer, PZT-4, acoustic resonator, booster, Helmholtz equation, constructive interference, cavitation.

Introduction.

The efficiency of ultrasonic cocoon reeling depends primarily on the design of the acoustic subsystem, namely the piezoelectric generator and the acoustic resonator. For cavitation to soften the sericin layer effectively, the acoustic pressure amplitude in the bath must exceed the Blake cavitation threshold, while the resonator must transfer acoustic energy into the liquid with minimal losses. Therefore, justifying the constructive parameters of the generator and resonator is a key task in the development of the mechatronic reeling system.

Resonant frequency of the piezoelectric element.

The resonant frequency of a PZT-4 piezoelectric disc operating in the thickness mode is determined by its elastic constant and density:

$$f_0 = (1/2t_p)\sqrt{(c_{33}^D/\rho_p)} \qquad (1)$$

where $c_{33}^D = 11.5\times10^{10}$ Pa is the elastic constant of PZT-4 and $\rho_p = 7500$ kg/m^3 is its density. For the target frequency of 40 kHz, the required thickness of the piezoelement is:

$$t_p = (1/(2\times40000))\sqrt{(11.5\times10^{10}/7500)} = 15.5 \text{ mm} \approx 16 \text{ mm} \qquad (2)$$

Thus, a piezoelement thickness of 16 mm provides operation at the required resonant frequency of 40 kHz, which is optimal for cocoon reeling: at this frequency the cavitation is intense enough to soften the sericin, while the rise height of the cocoons remains within the safe range.

Acoustic resonator (booster).

To amplify the vibration amplitude, a conical titanium (Ti-6Al-4V) resonator with input diameter D_1 = 50 mm and output diameter D_2 = 20 mm is used. The amplitude gain factor of a conical booster equals the ratio of the cross-sectional areas:

$$K = D_1^2/D_2^2 = 50^2/20^2 = 6.25 \qquad (3)$$

The half-wavelength resonant length of the resonator is determined by the speed of sound in titanium (c_m = 5100 m/s):

$$L_x = c_m/(2f) = 5100/(2\times40000) = 64 \text{ mm} \qquad (4)$$

Consequently, a Ti-6Al-4V resonator with a length of 64 mm and a gain factor K = 6.25 amplifies the displacement amplitude of the piezoelement 6.25 times, ensuring efficient transfer of acoustic energy into the water. Titanium alloy was selected for its high fatigue strength, low acoustic losses and corrosion resistance.

Acoustic field in the bath.

The acoustic field generated by the four transducers is described by the Helmholtz wave equation with the wave number $k = 2\pi f/c = 169.8\ \mathrm{m}^{-1}$ (at 40 kHz):

$$\nabla^2 p + k^2 p = 0 \qquad (5)$$

The resulting pressure field is obtained as the superposition of the four sources arranged symmetrically (2+2) at the bottom of the bath. At the centre, where the waves arrive in phase, constructive interference raises the acoustic intensity to $16P_0^2$, giving an acoustic intensity of about $I = 21.2\ \mathrm{kW/m}^2$. Each generator has an electrical power of 150 W, so the total power is 600 W (with an efficiency of about 85%, the acoustic power is ≈510 W). The corresponding pressure amplitude (≈2.47 atm) safely exceeds the Blake cavitation threshold (≈1.28 atm at 40 kHz), guaranteeing stable cavitation throughout the working volume.

Conclusion.

The constructive parameters of the acoustic subsystem of the ultrasonic cocoon reeling installation have been justified. A PZT-4 piezoelement thickness of 16 mm provides operation at the resonant frequency of 40 kHz; a conical Ti-6Al-4V resonator with a length of 64 mm and a gain factor K = 6.25 amplifies the vibration amplitude 6.25 times. Modelling of the acoustic field on the basis of the Helmholtz equation showed that a symmetric 2+2 arrangement of four 150 W generators produces constructive interference that increases the acoustic intensity at the bath centre by a factor of 16 (about $21.2\ \mathrm{kW/m}^2$). The resulting pressure amplitude reliably exceeds the Blake threshold, ensuring stable and uniform cavitation. The obtained relationships can be used in the design of similar ultrasonic technological systems.

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