DEVELOPMENT OF A MECHANISM FOR UNIFORM MOVEMENT AND STABLE HOLDING OF COCOONS IN THE ULTRASONIC WATER BATH

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Abstract: The paper presents the development of a mechanism for the uniform movement and stable holding of cocoons in the ultrasonic water bath of the cocoon reeling system. The mechanism consists of a stainless-steel (AISI 304) mesh holder, a vertical guiding frame, a NEMA 17 stepper motor and a screw-nut transmission. A dynamic model of the mechanism is constructed in the form of second-order differential equations. It is shown that the maximum driving force of the motor (2010 N) exceeds the maximum load (6.08 N) by a factor of 330, which guarantees reliable operation. The positioning accuracy reaches 6.25 µm per full step and 0.39 µm in 1/16 micro-stepping mode, ensuring precise depth control of the cocoons.

Keywords: cocoon reeling, holding mechanism, stepper motor, NEMA 17, screw-nut transmission, dynamic model, positioning accuracy, mechatronic system.

Introduction

During ultrasonic cocoon reeling, the cocoons must be kept submerged at a stable depth in the water bath: if they are held too shallow, the acoustic radiation force may lift them to the surface, whereas excessive depth reduces cavitation efficiency. Manual holding cannot ensure a stable and reproducible position. Therefore, a dedicated mechanism is required to move the cocoons uniformly and hold them stably at the prescribed depth under the control of the mechatronic system.

Design of the mechanism.

The proposed mechanism comprises a mesh holder made of AISI 304 stainless steel (mesh cell 5×5 mm, dimensions 500×350×150 mm, capacity 100–150 cocoons), a vertical guiding frame, a NEMA 17 stepper motor (step angle 1.8°, holding torque 0.4 N·m) and a screw-nut transmission with a pitch p = 1.25 mm/revolution. The mesh holder retains the cocoons while allowing free circulation of water and unimpeded propagation of ultrasonic waves. The stepper motor, through the screw-nut transmission, converts rotary motion into precise vertical displacement of the holder, thereby setting the immersion depth of the cocoons.

Dynamic model.

The dynamics of the mechanism are described by two coupled second-order differential equations – for the rotation of the motor shaft and for the translational motion of the holder:

$$J(d^2\theta/dt^2) + b(d\theta/dt) = M(t) - M_l(t) \qquad (1)$$

$$m_eff(d^2h/dt^2) + c(dh/dt) = F_m(t) - F_l(t) \qquad (2)$$

where J is the moment of inertia of the rotating parts, b is the viscous friction coefficient, M(t) is the motor torque, m_eff is the effective mass of the moving parts, c is the damping coefficient, F_m is the driving force and F_l is the load force. The maximum load force, created by the weight of the cocoons and the holder, is:

$$F_l max = (m_p n + m_t)g = (0.0008\times150 + 0.5)\times9.81 = 6.08\ N \qquad (3)$$

The maximum driving force developed by the stepper motor through the screw-nut transmission is:

$$F_m max = 2\pi M/p = 2\times3.14\times0.4/0.00125 = 2010\ N \qquad (4)$$

Hence the safety factor of the mechanism is K = $F_m max/F_l max$ = 2010/6.08 ≈ 330, which provides a very large reserve and guarantees reliable operation under all loading conditions.

Positioning accuracy.

Since one full revolution of the screw (200 steps at 1.8°) displaces the holder by the pitch p = 1.25 mm, the displacement per full step is 1.25/200 = 6.25 µm. In the 1/16 micro-stepping mode the resolution improves to 6.25/16 ≈ 0.39 µm. Such accuracy is far higher than required for depth control of the cocoons (the rise height is regulated within ±0.5 mm), which means that the mechanism does not limit the overall accuracy of the system. The combination of the high safety factor and the fine positioning resolution makes the mechanism suitable for precise, repeatable and reliable holding of the cocoons during ultrasonic treatment.

Conclusion.

A mechanism for the uniform movement and stable holding of cocoons in the ultrasonic water bath has been developed, consisting of an AISI 304 mesh holder, a vertical guiding frame, a NEMA 17 stepper motor and a screw-nut transmission. The dynamic model, constructed in the form of second-order differential equations, showed that the maximum driving force of the motor (2010 N) exceeds the maximum load (6.08 N) by a factor of 330, ensuring reliable operation with a large reserve. The positioning accuracy reaches 6.25 µm per full step and 0.39 µm in micro-stepping mode, which is more than sufficient for precise depth control of the cocoons. The developed mechanism enables stable and reproducible positioning of the cocoons under the control of the mechatronic system, thereby reducing thread breakage and improving the quality of the reeled raw silk.

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