Research on New Intelligent Beating-up System of High-speed Rapier Loom

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Abstract. Aiming at the problems of mechanical beating mechanism, such as poor precision and poor performance, motion is not adjustable, a new design scheme of intelligent beating-up system is proposed. Through experimental tests, a mathematical model of the system was established using a neural network system identification method. Using fuzzy control method of dynamic evolutionary algorithm, intelligent controller is constructed. The controller and the servo system are used to drive the beating-up sley to achieve efficient and precise control of the beating-up motion, and improve the loom performance and fabric quality. The follow-up research results can provide theoretical and technical support for the design of high-speed rapier looms, and it has great significance for promoting the technical level of high-end weaving equipment and industrial transformation and upgrading.

Introduction

China’s textile industry has made incalculable contributions in upgrading national strength and promoting the overall coordinated development of the national economy in reference [1]. Rapier loom is more important model in textile equipment. However in rapier loom, more than 90% of high-end models are imported. The beating-up mechanism is a key part of the rapier loom. Its kinematics performance directly determines the quality of the fabric, the quality and efficiency of the loom. The conjugate cam beating-up mechanism is mostly used in modern loom in reference [2]. The conjugate cam mechanism is a closed-loop dimension chain. The main and auxiliary cams act together to drive the oscillating rod to oscillate back and forth. Due to the closed relationship between the dimensions, the follower’s rollers are kept in contact with the cam surface, enabling accurate movement and smooth operation. However, because of the existence of an error, when the main cam surface comes in contact with the roller, there is always a gap or interference between the sub cam surface and the roller. If the gap is too large, the shock, vibration, and noise will occur, and if the interference is too large, the movement of the mechanism is stuck and cannot even be installed in reference [3, 4]. The conjugate cam mechanism has high machining accuracy and performance requirements. The performance of the conjugated cam mechanism processed in China is poor, and it is difficult to meet the high-speed operation requirements of the rapier loom. At present, in high-grade rapier loom, almost all high-precision conjugate cam mechanism is imported from abroad. However, there are few substantive contents in relevant foreign literature. The key technologies are all in the hands of some professional cam manufacturers and scientific research institutions abroad.

Based on the experimental test, this paper the mathematical model of the beating-up system is established. Using control algorithms and formulating control strategies, intelligent controller is built and the design of intelligent beating-up system is completed. A method of replacing the mechanical beating-up mechanism with an intelligent controlled beating-up system is studied. The aim is to achieve precise control of the beating-up motion according to the dynamic changes of the yarn and the weaving mouth and to improve the performance of the loom and the quality of the fabric.
Establishing a Data Acquisition System through Experimental Tests

As shown in Figure 1, the conjugate cam beating-up mechanism of the rapier loom is mainly required to control the beating force at the end point of the beating base, and the inertia force of the beating base overcomes the beating resistance to tighten the weft yarn in reference [5, 6]. The beating force is determined by the swaying of the sley, and the beating resistance is related to the fabric structure parameters and the machine conditions, and is not related to the loom itself. The mechanical model of the beat-up process is shown in Figure 2, where \( F \) is the beating force, \( T_j \) is the warp tension, \( P \) is the beat resistance, \( T_z \) is the fabric tension, and \( \theta \) is the half angle of the shed. It can be seen that the beating resistance is determined by the warp tension, the shed angle and the fabric tension.

![Figure 1. The conjugate cam mechanism.](image1)

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\begin{align*}
T_j/2 &= \text{weft} \\
F &= \text{P} \\
T_z &= \theta
\end{align*}
\]

![Figure 2. The mechanical model of beating-up process.](image2)

The structure of the beat-up mechanism for rapier loom is shown in Figure 3. Based on the principle and process of beating-up motion, an experimental bench was set up. Force sensors were used to measure warp tension and fabric tension [7]. Angle sensors were used to measure the shed angle, and a data acquisition system was set up to provide data signals for the intelligent controller.

![Figure 3. Parameterized model of beating-up mechanism.](image3)

Building a Mathematical Model of the Control System

In warp weaving process, warp tension and weaving mouth movement is a complex dynamic process, it is difficult to derive the functional relationship between control variables and state variables and output variables. Using the method of BP neural network system identification, the neural network identification method was trained by Levenberg-Marquardt (LM) algorithm, and the mathematical model of the control system was constructed.
Research of Intelligent Controller

The main task of the controller is to detect warp tension, shed angle, and fabric tension in real time, and to select a suitable control strategy so that the beating force remains dynamic during loom weaving. In the weaving process of the loom, because warp yarn tension is affected by factors such as opening, beat-up and the like, there are many uncertain factors in the warp yarn tension change, so it is difficult to obtain an accurate warp yarn tension mathematical model. Fuzzy control has better control effect on the time-varying control object that cannot establish accurate mathematical model or parameters. Therefore, in this paper, a fuzzy control method based on dynamic evolutionary algorithm is adopted. The dynamical evolution algorithm is used to optimize the adjustment factors of the quantification factor, the proportional factor, and the control rule simultaneously. With the parallelism and intrinsic learning of the evolutionary algorithm, there can be no expert. Under the premise of experience, quickly find the optimal combination of parameters to design an efficient fuzzy control system. According to the changes of yarn tension, shed angle and fabric tension, the beating force can be controlled to realize intelligent and precise control of the beat-up motion [8-9].

Overall Plan Design of Intelligent Beating-up System

The principle of the intelligent beating-up system is: based on the sensor measurement, a data acquisition system is established, and the data is transmitted to an intelligent controller constructed
by a fuzzy control method of a dynamic evolution algorithm, the controller according to the set warp tension, shed angle and the fabric tension value controls the AC servo system to output the pulse signal, which in turn controls the swing of the beating seat, realizing dynamic stability of the warp tension, shed angle and fabric tension and precise control of the beating force[10].

In the mechanical structure, the rapier loom with the conjugate cam mechanism as the weft insertion and the weft insertion is selected, and the original cam box is structurally modified to remove the beating and wetting cams and swinging rods, simplifying the structure of the cam box and installing the intelligent controller and servo motor. The schematic diagram of the beating system is shown in Figure 6. The intelligent controller and AC servo system work together. In the weaving process, the control system is based on warp tension set on the man-machine interface. The shed angle and fabric tension control the servo motor rotation for accurate control. Slug encoders and spindle encoders are used to solve the problem of synchronization between beat-up motions and other loom motions.

![Figure 6. Scheme diagram of beating-up system.](image)

**Conclusions**

Due to the inherent factors in the mechanical beating-up mechanism, the performance of the beating-up mechanism can be improved to some extent through design and improvement, but it is difficult to fundamentally solve the problems of high speed and high precision. In addition, the motion law of the beating-up mechanism can not be adjusted intelligently following the changes of the yarn and the weaving mouth, and it is also an important factor that restricts the sports performance. Therefore, this paper proposes an intelligent beating-up system to replace the mechanical beating-up mechanism to achieve precise and intelligent control of high-speed loom beat motion. According to the change of the yarn during weaving, the beating system adjusts the servo system so that the beating force remains constant, and when the product is changed, it can also be arbitrarily adjusted according to the needs of the weaving product. This research is an innovative design for the beating-up mechanism of rapier loom. It is a new kind of research in beating-up system, which can provide a new pattern and ideas for the design of the beating-up mechanism. It has important practical significance in improving the performance of the loom and the quality of the woven fabric, reducing the mechanical noise of the loom, and improving the level of intelligence and automation of the loom.

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