A novel motion regulation of the heald frame on looms
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An 8-order polynomial motion has been proposed which optimizes the heald frame’s dynamical performances. Compared to the simple harmonic and 7-order polynomial motion regulations, this motion regulation is proved to be more advantageous. The motion regulation improves the dynamic performance of heald frame. It is found to be suitable for high speed looms.

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All woven fabrics are made of two sets of yarns, namely warp and weft. The warp yarns extend throughout the length of the fabric, whereas weft yarns go across the warp yarns. The weft yarns have to move between the warp yarns in weaving. A warp end is inserted in the eye of a heald and many healds are supported by the heald frame. Consequently, the heald frame makes the warps to move vertically up and down. Thus, the heald frame’s motion will greatly influence the shedding motion and warp tension. In spite of loom being equipped with more heald frames and moving at a higher speed, today’s trend of weaving is high speed, variable and high dense. Since the dynamical performance of the heald frame, such as acceleration, becomes very severe as the speed of a loom becomes faster, the motion regulation of the heald frame should be designed in a more reasonable way.

Simple harmonic and 7-order polynomial motion regulations are widely used in looms today. The simple harmonic motion regulation is unfit for high-speed looms because of its poor dynamical performance. The 7-order polynomial motion regulation is superior to the simple harmonic motion and used widely in high-speed looms. In this paper, a novel motion regulation is reported which is much superior to both simple harmonic and 7-order polynomial motion regulations.

8-Order Polynomial Motion Regulation of Heald Frame
The motion regulation of the heald frame should satisfy the following requirements in terms of weaving technology so as to reduce the poor influence imposed on the warp by the heald frame’s motion and to provide good conditions for the weft insertion.

(i) When the shed gets open, the warp tension increases gradually. The velocity of the heald frame should be the highest when the shed is smallest, afterwards the velocity decreases gradually and turns to be the lowest when the shed is largest. In this way, the warp breakage caused by a sudden increasing tension or acute friction between warp and heald may be avoided. Furthermore, it is of great help to make shed clear. On the contrary, when the shed gets close, the warp tension decreases gradually. Correspondingly, the velocity increases gradually and turns to be the highest when the shed closes completely.

(ii) When shed starts opening or closing, i.e. the heald frame begins to change from motion to motionlessness or from motionlessness to motion, the acceleration should be reduced to the least. For the rest, the change in acceleration should be mild so as to reduce the warp tension appended by the vibration of the heald frame and to improve the shed mechanism’s adaptability to high speed of looms.

Assume $\phi$, the angle of drive shaft of loom; $\varphi_1$, the corresponding angle of drive shaft when the heald frame begins to move; and $\varphi_2$, the corresponding angle of drive shaft when the heald frame’s motion ends. Therefore, the corresponding angle section of the drive shaft for the heald frame motion is $\alpha = \varphi_2 - \varphi_1$. Restricted conditions are given below:

$$0 \leq \varphi \leq \frac{\alpha}{2}$$

When $\varphi = 0$, $s = 0$, $\dot{s} = 0$, $\ddot{s} = 0$
Here, $\dot{s} = \frac{d s}{d \varphi}$, $\ddot{s} = \frac{d^2 s}{d \varphi^2}$, $\dddot{s} = \frac{d^3 s}{d \varphi^3}$

When $\varphi = \alpha/2$, $\dddot{s} = -c l / \alpha^2$, $\dddot{s} = 0$

Here $c$ is the pending coefficient; $s$, the displacement of the heald frame; and $l$, the scope of the heald frame.

When $\varphi = \alpha/2$, $s = l/2$, $\dddot{s} = 0$, $\dddot{s} = 0$

\[ \alpha/2 \leq \varphi \leq \alpha \]

When $\varphi = \alpha/2$, $s = l/2$, $\dddot{s} = 0$, $\dddot{s} = 0$

When $\varphi = 3\alpha/4$, $\dddot{s} = -c l / \alpha^2$, $\dddot{s} = 0$

When $\varphi = \alpha$, $s = l$, $\dddot{s} = 0$, $\dddot{s} = 0$

According to the restricted conditions given above, the motion regulation of the heald frame should be 8-order polynomial. Assume its format is:

\[ s = p_0 + p_1 \varphi + p_2 \varphi^2 + p_3 \varphi^3 + p_4 \varphi^4 + p_5 \varphi^5 + p_6 \varphi^6 + p_7 \varphi^7 + p_8 \varphi^8 \ldots (1) \]

From Eq. (1), we can get $\dot{s}$, $\ddot{s}$ and $\dddot{s}$ using the following relationships:

\[ \dot{s} = p_1 + 2p_2 \varphi + 3p_3 \varphi^2 + 4p_4 \varphi^3 + 5p_5 \varphi^4 + 6p_6 \varphi^5 + 7p_7 \varphi^6 + 8p_8 \varphi^7 \ldots (2) \]

\[ \ddot{s} = 2p_2 + 6p_3 \varphi + 12p_4 \varphi^2 + 20p_5 \varphi^3 + 30p_6 \varphi^4 + 42p_7 \varphi^5 + 56p_8 \varphi^6 \ldots (3) \]

\[ \dddot{s} = 6p_3 + 24p_4 \varphi + 60p_5 \varphi^2 + 120p_6 \varphi^3 + 210p_7 \varphi^4 + 336p_8 \varphi^5 \ldots (4) \]

Hence, two equation groups each of which contains 9 equations can be established when $0 \leq \varphi \leq \alpha/2$ and $\alpha/2 \leq \varphi \leq \alpha$ respectively. Each coefficient can be obtained as follows:

When $0 \leq \varphi \leq \alpha/2$

\[ p_0 = p_1 = p_2 = p_3 = 0 \]

\[ p_4 = \frac{280l}{\alpha^4} - \frac{32cl}{\alpha^3} \]

\[ p_5 = \frac{-2016l}{\alpha^3} + \frac{256cl}{\alpha^2} \]

\[ p_6 = \frac{5824l}{\alpha^4} - \frac{768cl}{\alpha^3} \]

\[ p_7 = \frac{-7680l}{\alpha^3} + \frac{1024cl}{\alpha^2} \]

\[ p_8 = \frac{3840l}{\alpha^4} - \frac{512cl}{\alpha^3} \]

When $\alpha/2 \leq \varphi \leq \alpha$

\[ p_0 = l - 248l + 32cl \]

\[ p_1 = 2944l/\alpha - 384cl/\alpha \]

\[ p_2 = -15120l/\alpha^3 + 1984cl/\alpha^2 \]

\[ p_3 = 43680l/\alpha^3 - 5760cl/\alpha^2 \]

\[ p_4 = -77560l/\alpha^4 + 10272cl/\alpha^3 \]

\[ p_5 = 86688l/\alpha^5 - 11520cl/\alpha^4 \]

\[ p_6 = -59584l/\alpha^6 + 7926cl/\alpha^5 \]

\[ p_7 = 23040l/\alpha^7 - 3072cl/\alpha^6 \]

\[ p_8 = -3840l/\alpha^8 + 512cl/\alpha^7 \]

By inputting the above values in Eq. (1) and tidying up, a group of the motion regulations can be obtained. Its displacement equation is:

\[ s = 8l[(35 - 4c)(\varphi/\alpha)^3 - (252 - 32c)(\varphi/\alpha)^5] + (728 - 96c)(\varphi/\alpha)^6 - (960 - 128c)(\varphi/\alpha)^7 + (480 - 64c)(\varphi/\alpha)^8 \ldots (5) \]

\[ 0 \leq \varphi \leq \alpha/2 \]

\[ s = l - 8l[(31 - 4c)(\varphi/\alpha)^3 - (368 - 48c)(\varphi/\alpha)^3] + (1890 - 248c)(\varphi/\alpha)^5 - (5460 - 720c)(\varphi/\alpha)^5 + (7448 - 992c)(\varphi/\alpha)^6 - (2880 - 384c)(\varphi/\alpha)^7 + (480 - 64c)(\varphi/\alpha)^8 \ldots (6) \]

When $c$ is equal to 6.88, the 8-order polynomial motion regulation shows a good performance. Its curve (curve 1) is shown in Fig. 1. Here, $l$ is equal to 200mm, and opening and shutting angle is 120°.
Table 1—Characteristics of 3 kinds of motion regulation

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Peak Velocity Position</th>
<th>Peak Acceleration Position</th>
<th>Peak Jerk Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.6667 120</td>
<td>0.0239 60/180</td>
<td>6.5351×10⁻⁴ 18.7663/101.2337/138.7663/221.2337</td>
</tr>
<tr>
<td>2</td>
<td>1.8229 120</td>
<td>0.0261 66.6344/172.6656</td>
<td>7.5955×10⁻⁴ 120</td>
</tr>
<tr>
<td>3</td>
<td>1.3090 120</td>
<td>0.0171 0/240</td>
<td>2.2429×10⁻⁴ 120</td>
</tr>
</tbody>
</table>

Fig. 1—Comparison of 3 kinds of motion regulation

Curve 2 is the 7-order polynomial motion regulation. Its displacement equation is:

\[ s = l \left[ 35 \left( \frac{\varphi}{\alpha} \right)^4 - 84 \left( \frac{\varphi}{\alpha} \right)^3 + 70 \left( \frac{\varphi}{\alpha} \right)^2 - 20 \left( \frac{\varphi}{\alpha} \right) \right] \]

Curve 3 is the simple harmonic motion regulation. Its displacement equation is:

\[ s = \frac{l}{2} \left[ 1 - \cos \left( \frac{\varphi \alpha}{l} \right) \right] \]

The characteristics of 3 kinds of motion regulation are shown in Table 1.

Under the condition of same heald frame’s scope and corresponding angle of the drive shaft, compared to curve 3, the curves 1 and 2 have higher velocity when the shed begins to open and have lower velocity when the shed begins to close. Therefore, it is beneficial to make the shed clear and to let the weft fly out of the shed successfully. The peak value of curve 1 is slightly less than that of curve 2. But around the position where the shed is completely open or begins to close, the curve 1 makes the heald frame move slower. This can reduce the possibility of the warp breakage and relatively prolong the static time of the heald frame, thus making the weft fly through the shed successfully.

The curve of acceleration shows that the peak value of the curve 3 occurs at the both ends of the heald frame’s motion. It makes the acceleration much bigger when the heald frame changes from motionlessness to motion or vise versa so as to produce larger inertia force to make the heald frame to vibrate to some extent. It is disadvantageous to increase the loom’s speed, so the simple harmonic motion is unfit for the high speed looms. The acceleration values of curves 1 and 2 are zero when the heald frame motion begins or ends, and hence specially are fit for the high speed looms. Furthermore, the change in acceleration of curve 1 is milder than that of curve 2, and the peak value is less. Therefore, the curve 1 is much fitter for the high speed looms.

The curve of jerk shows that the peak value of curve 1 is less than that of curve 2, which improves the heald frame’s dynamic performance.

A novel heald frame motion regulation, 8-order polynomial motion regulation, accords with technical requirements of the shedding completely and has more advantages as compared to the simple harmonic and 7-order polynomial motion regulations. The motion regulation improves the dynamic performance of the heald frame. It is suitable for the high speed looms.

References