Open Structure and Tension Analysis of Three-dimensional Spacer Woven Fabrics

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Abstract

The process of weaving three-dimensional spacer fabrics on double-shed rapier looms is analyzed. In order to solve the tension control problem of the longitudinal warp non-closed shed, a brief opening model of heald frame is constructed in this paper, and the opening tension is analyzed. The results show that the longitudinal warp tension has a compound function relationship with the length of the rear shed of the loom. When the distance of the front shed and the height of the ground warp in the weaving process are known, the guide bar position of the warp drop frame can be effectively measured by the ratio of the ground warp opening elongation and the ground warp length. In this way, the tension during weaving of multiple sets of warp yarns is uniform.

Key Words: Three-dimensional spacer fabric, Tension measurement, Rapier loom, Open model

1. Introduction

The rapier loom is a shuttle-less loom invented earlier. After more than 100 years of development, its application technology has been quite mature, and it plays an important role in the weaving of commonly used textiles [1]. Rapier looms are mostly used in the design and development of two-dimensional fabrics, and some semi-stereoscopic fabrics can also be developed through special raw materials and craftsmanship. The design and development of 3D fabrics has been a hotspot in composite material technology research in recent years. Compared with two-dimensional fabrics, it has the advantages of stable overall performance, superior impact resistance and good mechanical properties, and its application fields are gradually increasing [2, 3]. The three-dimensional spacer fabric has become a research hotspot in recent years because of its relatively complete three-dimensional structure and hollow structure characteristics. When using it to prepare composite materials, it can meet the needs of one-time molding in many cases and meet the needs of different properties [4, 5]. Through the process of compounding three-dimensional spacer fabric and resin, the sandwich composite structure has the advantages of good integrity and light weight. It can be used in thermal insulation, armor and other fields [6, 7]. Huang Jinbo et al proposed a scheme to realize three-dimensional fabric design through a two-shed loom [8]. Through the equipment transformation of the traditional rapier loom, a set of ground warps and a set of longitudinal warp yarns are added on the basis of the original warp yarns. The longitudinal warp yarns are interlaced at the upper and lower openings respectively, and the weft yarns are pushed through the steel reed to join the upper and lower ground warps. Longitudinal warp are vertically staggered between the two warps. In order to make the three-dimensional fabric have a better three-dimensional presentation, it is necessary to design a reasonable process and the opening structure of multiple groups of warp threads. However, it is easy to cause friction between warp yarns and healds during the weaving process when weaving multiple sets of warp yarns. Therefore, in order to ensure the smooth progress of weaving, it is necessary to effectively control the warp tension of the loom [9-10].

In recent years, with the advancement of science and technology, the electronic let-off tension control technology has become relatively mature. However, there is no change in the general motor let-off and take-up speed. Further research is needed on the longitudinal warp tension control technology of the non-closed shed for three-dimensional spacer fabrics [11]. Therefore, this paper analyzes the realization form of the shed of the three-dimensional spacer loom and the tension of the yarn in the structure of the longitudinal warp opening of the loom. This approach facilitates the rational design of the on-machine process in actual production.

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2. The structure of the three-dimensional spacer loom

The basic structure of the three-dimensional spacer loom is consistent with the traditional rapier loom. It consists of six major components: take-up mechanism, opening mechanism, weft insertion mechanism, selvage mechanism, beating-up mechanism, and let-off mechanism [12, 13]. Compared with the traditional loom, the difference is that the opening structure is adjusted to a double opening mode. When assembling the equipment, two sets of ground warps are used to open respectively, and the longitudinal direction is interspersed back and forth between the two sheds. Therefore, in the installation design, the longitudinal warps should be arranged between the two sets of grounds to reduce the entanglement between the warps. The spacing between the two openings can be designed according to product characteristics and application requirements [8]. The structure diagram of the 3D loom opening based on this idea is shown in Fig. 1. 

In Fig. 1, 1 denotes a longitudinal warp, and 2 and 3 denote two sets of warps. Three sets of warp lines correspond to 1-4, 5-8, 9-12 heald frames respectively. Longitudinal warp 1 corresponds to heald frames 1-4, due to the large opening at the front end of the shed, upper warp line No. 2 corresponds to heald frames 4-8, and bottom warp 3 corresponds to heald frames 8-12. The longitudinal warp heald frames 1, 3 and 2, 4 move in the same direction. The warp heald frames 5 and 7, 6 and 8, 9 and 11, and 10 and 12 also move in the same direction, so the structure diagram is simplified to 6 pages of heald frames for the convenience of the reader to understand the running structure. When the loom is open, the yarn in the upper half of the longitudinal warp 1 is flush with the yarn in the upper half of the upper warp 2 opening, and the yarn in the lower half of the lower warp 3 opening in the lower half of the opening is flush. In the weaving process, the longitudinal warp of 1 intersects with the weft of the upper and lower sheds respectively. In the alternate running of the heald frames, the longitudinal warp 1 is perpendicular between the two weaving planes.

3. Process structure design

3.1 The design of wearing heald

In the weaving design process of the three-dimensional loom, the three groups of warp threads need to be opened separately. If it is ordinary drapery, it will easily lead to unclear opening and confusion of drapery. In order to make each opening independent and clear, we use the method of heald frame partition to realize each opening. According to the existing rapier looms, mostly 12-sheet heald frames are used. Since the longitudinal warp threads need to intersect with the upper and lower warp threads respectively when the longitudinal warp threads are opened, the opening angle is relatively large. Therefore, the first 4 pieces are used as longitudinal warp heald frames, and the last 8 pieces are upper warps and lower warps. Due to the use of many heald frames during installation, the opening angle of the front and rear angles of the heald frames are slightly different. In order to meet the requirements of shed opening, three sets of heald frame heights can be set during equipment debugging.

The most suitable drawing method should be selected according to the weave and density of the fabric. By adopting the zoned heddle method, each zone can be heddled in sequence, which is beneficial to the uniform distribution of equal warp yarns to each heald frame. This can reduce problems such as uneven force between the heald frames.
As shown in Fig. 2, it is a drawing of the partitioned heddle structure of the three-dimensional spacer fabric. The number of warp loops is 12, that is, the abscissa is expressed as the number of warps. The ordinate 12 represents the 12-page heald, the 1-4 position is the longitudinal warp heald frame, the 5-8 position is the upper warp wire heald frame, and the 9-12 position is the lower warp heald frame. There are four upper warp, lower warp and longitudinal warp in the picture. Assuming that the number of warp threads in each group is the same, the number of warp threads in each heald frame is the same. If there are more longitudinal warp threads, the number of warps of the heald frame in the zone can be increased accordingly.

3.2 Consolidation method of longitudinal warp

The longitudinal warp can be consolidated in various ways during the interweaving process with the upper and lower warps. This paper presents two common consolidation methods as shown in Fig. 3. The longitudinal warp is divided into two parts in Fig. 3(a), which intersect the upper and lower openings at the same time. At this time, the fabric surface of the three-dimensional spacer fabric is relatively flat because the longitudinal warps are evenly spread on both sides of the fabric. In Fig. 3(b), longitudinal[A2] warps intersect at the same time as above or below at the same time. In the weaving process, the warp of one side opening will be much more than the other opening, and the flatness of the fabric surface will be poor.

4. Analysis of longitudinal warp opening tension

4.1 Construction of the shed tension model

Because the three-dimensional loom contains multiple sets of warp interlacing, and there are different tension control systems for longitudinal warp and warp. In order to make the opening clear and easy for weft insertion, it is necessary to reasonably configure the longitudinal warp and warp tension. Assuming that the longitudinal warp is located in the middle of the ground, when the longitudinal warp opens, the closure system is quite different from that of the warp, so it is necessary to reasonably configure the longitudinal warp tension [14]. A brief schematic diagram of its opening is shown in Fig. 4, and the opening height of the longitudinal warp has a direct impact on the warp tension. As shown in Fig. 4, A and D are the upper and lower weaving sheds, and C is the position of the warp drop frame. AD is the distance a between the upper shed and the lower shed, assuming that the warp is inserted at the opening of the two heald frames B and E. The height of the opening BE is h.

The warp rises and its length is:

\[ L = AB + BC \]  \hspace{1cm} (1)

From the right triangles AOB and BFC it follows:

\[ AB = \sqrt{l_1^2 + \left(\frac{h-a}{2}\right)^2} \quad BC = \sqrt{l_2^2 + \left(\frac{h}{2}\right)^2} \] \hspace{1cm} (2)

In formula (2), h is the gap between the rising warp and the falling warp. \( l_1 \) refers to the front opening length. \( l_2 \) is the rear opening length. Bringing the AB value into the previous formula can get formula (3):

\[ L = \sqrt{l_1^2 + \left(\frac{h-a}{2}\right)^2} + \sqrt{l_2^2 + \left(\frac{h}{2}\right)^2} \] \hspace{1cm} (3)

The longitudinal warp obtains the length L due to the elongation of the warp by the lifting of the heald frame. Its elongation \( \Delta l \) is equal to:

\[ \Delta l = L - l_0 \]
Then \[ \Delta = \sqrt{l_1^2 + \left(\frac{h-a}{2}\right)^2} + \sqrt{l_2^2 + \left(\frac{h}{2}\right)^2} - l_i - l_j \] (4)

Using the simplified relation \[ \sqrt{1+x} = 1 + \frac{x}{2} \] (when the absolute value of \[ x = \left(\frac{h-a}{2d}\right)^2 \] is very small), it can be obtained from the above formula:

\[ \Delta = \frac{(h-a)^2}{8l_1} + \frac{h^2}{8l_2} = \lambda_1 + \lambda_2 \] (5)

where \[ \lambda_1 = \frac{(h-a)^2}{8l_1}, \quad \lambda_2 = \frac{h^2}{8l_2} \] represent the front and rear warp elongation, respectively.

Similarly, the elongation formula of warp can be obtained

\[ \Delta l = \frac{k^2 + h^2}{8l_1} \] (6)

It can be seen from formula (5) that during the opening process of the longitudinal warp, the opening tension of the longitudinal warp is proportional to the square of the height of the shrinkage.

When weaving on a double-shed loom, generally the opening height \( h \) of the heald frame and the length \( l_i \) of the front of the shed remain unchanged. The \( l_j \) at the rear of the shed can be adjusted by the guide bar of the drop frame, that is, it changes with the position of the drop frame. Therefore, in practical production, the composite function relationship between the length of the warp yarn and the length of the heald frame \( l_j \) at the rear of the loom can be obtained.

Simplifying the company can get the longitudinal warp elongation formula on the machine:

\[ y = a + \frac{b}{x} \] (6)

In the formula (6), \( y \) is the elongation of the warp, \( a \) and \( b \) are constants, and \( x \) is the length of the back of the heald frame.

4.2 Tension analysis of longitudinal warp opening

In order to make the opening tension of the three-dimensional spacer fabric consistent, the composite function relationship of the longitudinal warp elongation can be introduced to analyze the reasonable position of the guide bar of the longitudinal warp. As shown in Fig. 5.

The healds commonly used in rapier looms are 380 mm, and the upper warp height \( DE = h/2 \) is about 160 mm. The rear length \( l_i \) of the heald frame is 730 mm. The minimum distance from the first heald frame to the shed of loom is 70 mm[A4] [15], and the distance between the two sheds is \( a = 50 \) mm. Through the shed warp elongation formula (4), the warp opening elongation \( \Delta l \) can be obtained as

\[ \Delta l = \frac{320^2}{8 \times 70} + \frac{320^2}{8 \times 730} = 201 \text{ mm} \]

When the warp is opened, since the adjacent spacing between 1 to 12 heald frames is not large, it can be approximated that the longitudinal diameter and the height of the respective heald frames of the warp are the same under the condition of complete opening. It can be approximately regarded as the same height, that is, \( l_x = l_i \), according to the known heald frame lifting height of 160 mm. Then the height of the longitudinal warp is \( h' = h/2 - a/2 = 135 \) mm.

According to the formula (4), the warp elongation formula can be obtained

\[ \Delta l = \frac{(320 - 50)^2}{8 \times 70} + \frac{320^2}{8l_1} \]

Assuming that the same yarn is used for warp and warp, it is considered that the elongation tension is the same in equal proportion, then

\[ \Delta l = \frac{l_x + l_y}{l_j + l_y} \]

When the warp elongation is 201 mm, then the longitudinal warp can get \( l_y = 539 \) mm.

When the warp tension is set in the weaving process, it is necessary to properly measure the warp tension. The position of the stopper at the rear of the longitudinal warp heald frame can be effectively measured by the above derivation formula.

5. Conclusion

Based on the traditional rapier loom, this paper builds the open structure model of the double shed structure design, and analyzes the weaving process and the way of yarn collision in the weaving process. Through the brief model of the loom opening, the effective
analysis of the loom opening tension is carried out. In the process of weaving three-dimensional spacer fabrics, the warp opening coincides with the opening of the rapier loom, and the longitudinal warp openings intersect the weft yarns of the upper and lower sheds, respectively. Since the longitudinal warp threads are intertwined with the warp, the tension design of the longitudinal warp threads should be as consistent as possible with the warp tension. By substituting data into the model, it can be concluded that the warp elongation has a compound function relationship with the rear of the heald frame. Therefore, in actual production, the reasonable position of the guide bar of the longitudinal warp drop frame can be effectively calculated through the functional relationship, so as to ensure the smooth weaving.

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