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Process and Design of Jacquard Warp Knitted Spacer Fabric

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Abstract
Due to the rapid production of warp knitted jacquard spacer fabric in recent years, as well as physical properties of light, heat conduction, buffering effect, compression resistance, moisture permeability and air permeability, warp knitted spacer fabric has been used more and more widely in clothing, shoes and hats, as well as in fields such as medical care, construction engineering, safety protection and others. The design demand for different patterns and functions is also increasing gradually. Jacquard designers established a complete design model which plays a certain guiding role in the design of warp knitted spacer fabric. It brings innovative design to the surface pattern and structure of the fabric, making it more functional. The adoption of computer aided design also has a certain guiding role in the design process. Taking the CAD pattern design of warp knitted spacer fabric as an example, which combines the functional characteristics of the fabric and the jacquard pattern. Thus, we design fabric products that meet the market demand and initiate fashion trends.

Key words: *warp knitting, jacquard, pattern design, spacer fabric, computer aided design.*

Introduction

Raschel jacquard warp-knitted spacer fabric is knitted on a double-needle bed raschel warp knitting machine using a warp-knitting computer-aided system. It is a three-dimensional woven fabric with a vertically connected layered ring structure. Due to its unique structure, the fabric has the functions of lightness, compression resistance, air permeability, heat conduction, and sound insulation [1-2]. Because of its fast production speed, this fabric is used more and more in various fields, for example, in daily life in bras, car seat materials, shoe uppers, and especially in the field of clothing. Not only does it have good style plastic effects but also a rich appearance in the jacquard designs [3-5]. As a new type of intelligent product in the textile industry, a computer-aided design program is needed to guide the jacquard pattern design and knitting process of double-needle raschel jacquard spacer fabric, and provide a more high-quality and convenient design method for the innovation and development of textile products.

Knitting principle of jacquard spacer fabric

Principle of knitting

Warp-knitted spacer fabric is a three-dimensional fabric composed of upper and lower layers: side A, side B and spacer layer C. The spacer wire of the spacer layer serves as a connection. There is a certain separation distance. The two single-sided fabrics on side A and side B are separately woven on a single comb section of the front needle bed and rear needle bed. The two single-sided fabrics on side A and side B are separately knitted on a single comb section of the front needle bed and rear needle bed, forming dense thick tissue or loose mesh tissue [6-7]. The spacer layer C is usually an orderly loop, which is repeated one after another, and has a supporting effect as shown in ***Figure 1***.

As the knitting process of double-needle bed raschel jacquard warp-knitted spacer fabric is different from that of traditional double-needle bed raschel warp-knitted spacer fabric, the comb setting on the knitting machine can be changed. For warp knitting machines currently on the market, the most common number of combs is 7-8. The structure of spacer fabric, types of raw materials, and specifications are generally selected with respect to the fabric's tensile strength, compression resistance and thickness. The most common are single hole filament and long fiber yarn or staple fiber yarn. The direction of the yarn is shaped into an I-shape and V-shape. The organisational structure and technology of spacer fabric make the distance of the looper needle board adjustable, and the distance of the looper board can control that between the yarns of the spacer layer.

Principle of jacquard

There are mainly two types of machines for producing warp-knitted spacer fabrics: RDPJ7/1 and RDPJ5/1. RDPJ7/1 is a special machine commonly used by enterprises to produce raschel jacquard warp-knitted spacer fabrics [8] equipped with piezoelectric ceramic elements. The jacquard is formed into loops on the back needle bed, the jacquard section generally being set at the 4th and 5th comb as JB4 and JB5. The front of the fabric is generally the plane of the back needle bed. Because of its rich pattern and organisational structure, it has a strong decorative effect. The reverse

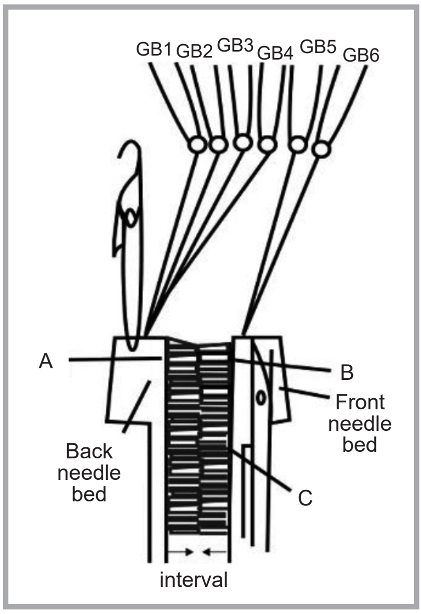
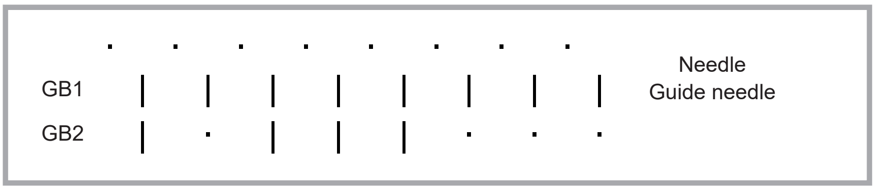


Figure 1. *Three production processes of spacer fabric.*



Threading design diagram.

side of the fabric is the plane knitted by the front needle bed. The jacquard comb configuration system of the RDPJ model is conducive to detecting defects in the knitting of warp knitted fabrics, thereby ensuring the high quality of the fabric. As shown in ***Table 1***, when the jacquard knit is: 1-1-1-2/1-1-1-0//, the fabric is thin.

It can be seen from the RDPJ model that the thickness of the fabric is affected by the length and extension of the loop yarn. The thickness of the fabric is formed by the lateral deviation of the inlay yarn. The jacquard needle is used for the backing fabric, a thin knit appears, and then a knitted mesh is formed when the odd course is offset. Thick structures are formed when even-numbered courses are shifted. The horizontal density and vertical density of the fabric are the key factors that affect the size of the fabric, hence in the process of designing the size, the shrinkage of the finished product's density and machine density must be considered [9]. In addition, because the double needle bed raschel machine is composed of two loops, formed on the front and back latch needle bed respectively, there is no ground organization to participate in and knitting. To ensure that each course has a loop backing on each needle, some colours of two adjacent vertical rows in the same row cannot meet. That is, during the yarn laying movement, it is necessary to ensure that each needle has at least one comb section on each course to lay the yarn, otherwise the string sleeve between the wales will be lost, resulting in holes [10].

Computer aided model of raschel warp-knitted spacer fabric

The CAD design of raschel jacquard warp-knitted spacer fabric is generally composed of an inlay digital design, drawing-in digital design, and jacquard ingenuity computer design, forming a complete systematic computer model design.

Mathematical model of lapping design drawing

The lapping design model of common warp knitted fabrics is different from that of jacquard spacer fabrics. The notes on each comb section of the raschel jacquard warp knitting machine are arranged in the order of 0, 1, 2, 3... from the right. The 4 numbers represents the number of inlay yarns in the same row, and then "—" is used to connect the middle part. A three-dimensional matrix $FLM_4(i, j, 4)$ is adopted as the mathematical model of the lapping design. The number of comb section is L; the number of courses is represented by M as the pattern height, i is the comb section number, and j is the course number. The complete digital yarn chart is shown in ***Figure 2***, FL(i, j) indicates the overlapping movement when the i-th comb section of the front needle bed is at the j-th course position BL(i,j) represents the overlapping movement when the i-th comb section of the rear needle bed is at the j-th course position. BL'(i,j) represents the underlapping movement when the i-th comb section of the rear needle bed is at the j-th course position. Therefore, FL(i, j) = f(i, j, 2) – f(i, j, 1), BL(i, j) = f(i, j, 4) – f(i, j, 3), FL'(i, j) = f(i, j, 3) – f(i, j, 2), BL'(i, j) = f(i, j + 1, 1) – f(i, j, 4) [6].

Mathematical model of drawing-in design

The drawing-in design model is called a two-dimensional matrix. The colourful patterns woven by the warp-knitted spacer fabric are produced by weaving the yarns at different positions on the guide comb. In the two-dimensional matrix mathematical formula, the number of comb nodes is represented by L and the complete series of vertical row numbers by C, which is the pattern width. The number of comb section is $i \in \{1, 2, 3, 4, 5, ..., L\}$, and the vertical row number is $c \in \{1, 2, 3, 4, 5, ..., C\}$. The mathematical model formula of the drawing-in design is shown in ***Figure 3***. For the yarns arranged longitudinally at position c, letters A, B, C, D, and E represent the yarn types on the i-th bar.

Mathematics model designed by jacquard

The mathematic model of the jacquard graphic design is generally called a two-dimensional matrix. Different thickness effects on the fabric are rep-

$$\begin{bmatrix} f_{i11} & \cdots & f_{i14} \\ \vdots & \vdots & \vdots \\ f_{ij4} & \cdots & f_{ij4} \\ \vdots & \vdots & \vdots \\ f_{iM4} & \cdots & f_{iM4} \end{bmatrix}$$

Figure 2. *Digital yarn chart.*

$$\begin{bmatrix} t_{11} & \cdots & t_{1C} \\ \vdots & \vdots & \vdots \\ t_{i1} & \cdots & t_{iC} \\ \vdots & \vdots & \vdots \\ t_{L1} & \cdots & t_{LC} \end{bmatrix}$$

Figure 3. *Drawing-in matrix for drawing-in design cycle diagram [A * * A].*

$$J_{cn} = \begin{bmatrix} j_{11} & \cdots & j_{C1} \\ \vdots & \vdots & \vdots \\ j_{1n} & \cdots & j_{cn} \\ \vdots & \vdots & \vdots \\ j_{1n} & \cdots & j_{cn} \end{bmatrix}$$

Figure 4. *The mathematical model of the jacquard graphic design.*

Table 1. *Basic organisation and jacquard yarn number.*

Comb section	Thin tissue	Thick organization	Mesh organization	Connect organisation	Suture tissue
JB3.1Front piece	1-0-1-1/1-2-1-1//	1-0-1-1/2-3-1-1//	2-1-1-1/1-2-1-1//	1-0-1-1/2-2-2-1//	1-0-1-2/2-3-2-1//
JB3.2After piece	1-2-1-1/1-0-1-1//	2-3-1-1/1-0-1-1//	1-2-1-1/2-1-1-1//	1-2-0-0/0-0-1//	2-3-1-1/2-2-1-1//
JB4.1Front piece	1-1-1-0/1-1-1-2//	1-1-1-0/1-1-2-3//	1-1-1-0/1-1-0-1//	1-1-1-0/2-1-2-2//	2-1-1-0/1-2-2-3//
JB4.2After piece	1-1-1-2/1-1-1-0//	1-1-2-3/1-1-1-0//	1-1-0-1/1-1-1-0//	1-1-1-2/0-1-0-0//	1-1-0-1/1-1-1-0//

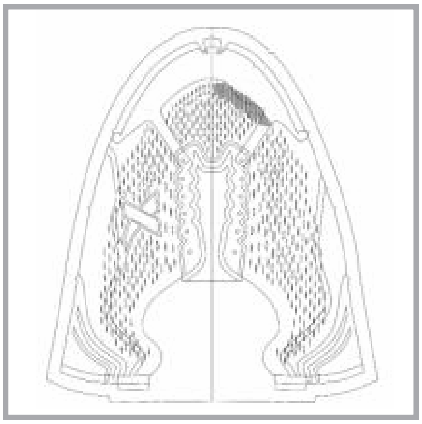


Figure 5. Flat style drawing.

Figure 6. Swatch pattern.

Figure 7. Final pattern.

resented by different pattern colours of jacquard pattern diagram. The two-dimensional matrix is represented by the mathematical formula as JCN = j(c, n). The pattern width is denoted by C and the pattern height by N. The horizontally arranged jacquard is denoted by the creative grid number $c \in \{1, 2, 3, 4, 5, ..., C\}$. When the jacquard information of the 2n -1 and 2nth rows at the longitudinal row c is on the jacquard section, the jacquard design is represented by a mathematical formula, shown in ***Figure 4***. In $jcn \in \{1, 4, 8, 12\}$, 1 represents the red thick effect, 4 and 8 the green and blue thin effects, respectively, and 12 the white mesh effect.

CAD design of warp-knitted jacquard spacer fabric

With the continuous development of warp knitting technology, at present, the traditional artisan paper design of warp knitting spacer fabrics has been replaced by a new modern computer screen, namely the warp knitting CAD design system. In addition to design operations, you can also modify the process on the computer screen, and finally display a high-definition simulated image of the fabric. For the design of lapping and threading, jacquard design has brought a fast and convenient design mode to the entire process, which has improved production efficiency for enterprises. The design process of spacer fabrics is generally as follows: 1. determine the model, number of bars, pattern height, pattern width, density, etc.); 2. draw pattern, perform inlay design and draw-in design, determine raw materials and creative drawings; 3. generate a high-definition simulation fabric map, confirm the machine, and knit the pattern.

Process data setting

Machine type – RDPJ7 /1, machine width – 350 cm, machine number – E24, machine speed – 300 r/min, finished product horizontal density – 10. longitudinal travel/cm -7, vertical density of the finished product – 16.3 courses/cm, output – 11 m/h, and the areal density – 293 g/m.

Bar arrangement

Once the CAD software is opened, a movement diagram of the yarn laying will be automatically generated in the system after inputting the yarn laying number in the design model. As shown in ***Table 2***, there is a switch between successive needle beds, which greatly improves the production efficiency of the enterprise.

Jacquard design preparation

Yarn material

The design of sports shoe materials usually has special requirements, such as good wear resistance, stretch elasticity, deformation limitation, comfort and ease-of-walking. Moreover, it must protect the soles of the feet from damage. Therefore. appropriate original materials must be selected. Nowadays, the commonly used shoe upper materials on the market are polyester and nylon, being two kinds of raw material. When producing single-sided sneakers jacquard raw materials are generally 100% polyester; and the nylon and polyester are employed for two-colour warp-knitted jacquard sports shoes, because of the different dyeing properties of polyester and nylon yarns at the same dyeing temperature.

Because filament is relatively soft and has a strong tensile force, it is generally used to produce the single-layer or double-layer structure of warp-knitted jacquard uppers. If warp-knitted jacquard spacer fabric is used as the upper material of sports shoes, it must be stab and wear resistant, as well as protect your foot from damage from external forces. Therefore, during production, the stiffness of spacer yarn is very high. The yarn of the spacer layer is usually nylon. Polyester monofilament and filament are usually used as raw materials for surface fabrics.

Sample size

The finished horizontal density of jacquard spacer upper fabric is usually

Table 2. *Movement diagram of yarn laying.*

	Yarn laying organisation	Drawing in and tying in
GB1	1-0-2-2/3-4-3-3/1-0-2-2/3-4-3-3/1-0-2-2/3-4-3-3/ 1-0-2-2/3-4-5-5/6-7-6-6//4-3-4-4//6-7-6-6//4-3-4-4/ 6-7-6-6/4-3-4-4/6-7-6-6/4-3-2-2//	(3A, 3*) × 3, 2A
GB2	6-7-6-6/4-3-4-4/6-7-6-6/4-3-4-4//6-7-6-6/4-3-4-4/ 6-7-6-6/4-3-2-2/1-0-2-2/3-4-3-3/1-0-2-2/3-4-3-3/ 1-0-2-2/3-4-3-3/1-0-2-2/3-4-5-5//	(3B, 3*) × 3, 2B
GB3	1-0-2-1/2-3-1-2//	(1C, 1*) × 10
GB4	1-0-2-1/2-3-1-2//	(1*, 1C) × 10
GB5	1-1-1-0/1-1-1-2/1-1-1-0/1-1-1-2/1-1-1-0/1-1-1-2/ 1-1-1-0/3-3-3-4/4-4-4-5/4-4-4-3//4-4-4-5/4-4-4-3/	4E, 1A, (1*, 5E) × 2, 1*, 2E
GB6	4-4-4-5/4-4-4-3/4-4-4-5/2-2-2-1// 4-4-4-5/4-4-4-3/4-4-4-5/4-4-4-3/4-4-4-5/4-4-4-3/ 1-1-1-0/1-1-1-2/1-1-1-0/3-3-3-4///	(5F, 1*) × 3,2F

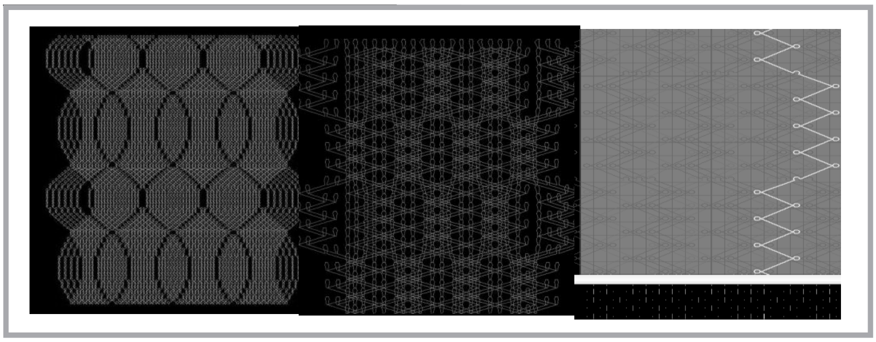


Figure 8. *Pattern organisation chart.*

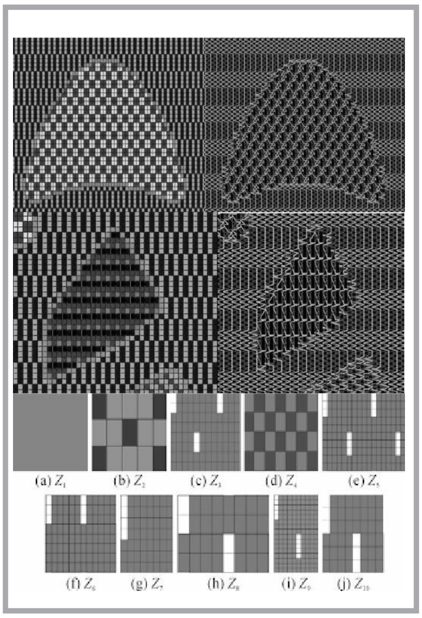


Figure 9. *Tissue filling.*

maintained at around 8.7-10.3 longitudinal travel/cm). The machine density is set between 12-19 (line/cm). The separation distance of the double-layer fabric is generally 2-2.5 mm.The spacing of the loop-off plate of the three-layer fabric is generally 4-4.5 mm.The let-off amount is adjusted according to the organisational structure, machine density, and raw material specifications, as shown in ***Figure 6*** and ***Figure 7***.

For example, in the design of shoe material fabrics, customers usually provide pattern information first. The plane style design is shown in ***Figure 5*** and the physical sample layout in ***Figure 6***. The length and width of the shoe are electronically scanned, namely the pattern height and pattern width, which are adjusted accordingly. The plan style drawing required by the customer is imported into the CAD system. The sample cloth picture also given by the customer is then imported into ACDSee software. Next the pattern is interposed on the software page, excess sample cloth deleted, and the pattern on the sample cloth saved. The storage pattern is in bmp format, whose size is adjusted according to the software interface.

Pattern design

The pattern organisation structure is analysed according to the customer sample cloth. A creative drawing is then designed and a pattern drawing generated. First the desktop HZCAD software system is opened, documents are established and appropriate process parameters are determined. Then, proper colours are selected and jacquard pattern is drawn that represents the target fabric organization.

Then the jacquard design bar in the HZCAD software system is opened and the color determined from the list. If the picture colour is not in the system, the system will automatically recognise a similar colour instead. In the end, the jacquard master plan is formed and saved. Next, the outer contour line of the shoe is drawn, the outer contour map determined, and the colour block area filled with coloured blocks. Finally, the organizational area is filled and modified, as shown in ***Figures 8*** and ***9***.

Conclusions

Warp-knitted spacer fabric is a new type of textile material with both fashion and function and with a lot of room for design and development. This study presents a complete series of mathematical design models and a CAD computer-aided design system created based on the special organisational structure of warp-knitted spacer fabrics. The digital movement, drawing-in design and jacquard design of yarn inlay are carried out in an orderly and efficient operation. According to the case analysis of the jacquard design of a shoe upper, the correctness of this series of models is explained. Warp-knitted spacer fabrics have good breathability, firmness, pressure resistance, and lightness, and are very popular in the shoe material market. Its unique three-dimensional structure makes it an emerging textile in the warp-knitted market. In the future, the development of innovative warp knitted fabrics will be more and more popular, bringing fashion and convenience to everyday life. Above all, there is a lot of room for development.

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