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A Simulation Model of Lace Made on a Multibar Raschel Machine

Abstract
An exact and applicable mathematical model is the basis of computer simulated Multibar lace fabric. In this study, a spline curve is used to simulate the loop structure of Multibarlace fabric. The number and position of control points are determined for stitch, inlay and fall-plate lapping. Thus, theoretical models are built for each type of lapping, and deformation of stitch brought about by yarn tension is also taken into account. Moreover, the displacement theory and calculation formula are given. VC++.net is used to develop the simulation program. The real Multibar lace effect of the simulation proved that the model is rational and applicable.

Key words: *warp-knitted fabric, multibar, lace, mathematical model, CAD, simulation.*

Features of multibar knitted structure

Fabric made on a multibar Raschel machine is a kind of fabric with various patterns on the net ground, with different size and shape of holes on the surface. The fabric has a ground and pattern structure, so it's clear to identify whether the pattern and ground have a different construction and texture. The ground structure of fabric consists of relatively small repeats with rather simple lapping and normally knitted from thinner yarn, with or without elastic yarn, using two to four guide bars, such as a "knit-marquisetter", power net, technical net and "honeycomb". The Pattern structure is knitted by the complex lapping of pattern bars. Normally, pattern bars use inlay to produce the pattern, and inlay yarns are held into/onto the ground structure. The stitch pattern bars use a yarn float (named foot) to produce a pattern, and the fabric is featured with a three-dimensional pattern effect. Fall-plate patterns are also three-dimensional and produced by pattern bars at the front of the fall-plate. Jacquard bars are used to produce a fancy ground structure. Figure 1 shows lace with a fall-plate pattern and Jacquard ground.

Different multibar machine configurations will create a different pattern effect. The Jacquard pattern effect will be more stabile if Jacquard bars are put at the back of the pattern bars.

Modelling the loop structure of multibar fabric

Many studies of the loop structure of warp-knitted fabric have been carried out in the last 60 years, and mathematic models for it were brought forward one after another. In general, there are two ways to build these models: the warp-knitted loop structure is represented as a certain geometrical model which defines the relationships between structure parameters, then the model and the experimental data is corrected. However, another way is to estimate the influential factors for the structure by conducting experiments and then find the experiential relationship between the parameters based on the experiments. The intention of both ways is to estimate the yarn run-in, output and so on. Most studies have focussed on warp-knitted fabric with fewer guide bars and seldom involved the multibar knitted structure.

With experimental verification using a lot of computer programs, the spline curve has proved to be a good mathematic model to simulate the yarn shape in a loop structure. Therefore, we will use a spline curve to describe the backbone of the stitches. The number and position of control points are determined for the features of different structures, including inlay, stitch and fall-plate pattern. The operation speed of computer simulation is also taken into account. The feet of stitches in the fabric are generally represented by straight line, which will be adequate for our model.

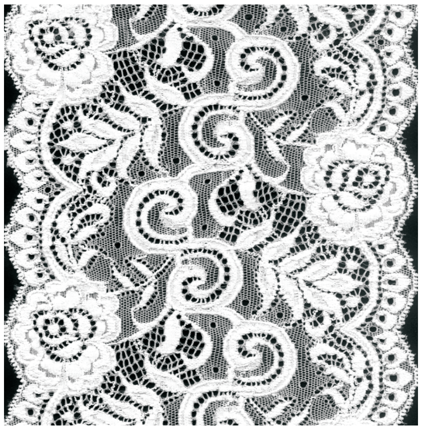

Figure 1. *The structure of multibar lace fabric.*

In order to simulate multibar lace fabric visually and quickly, we gave the following assumptions when we built the model and constructed the displacement theory:

- The three-dimensional loop structure is simplified as a two-dimensional one;
- The backbone of the stitches are described by a spline curve, and a straight

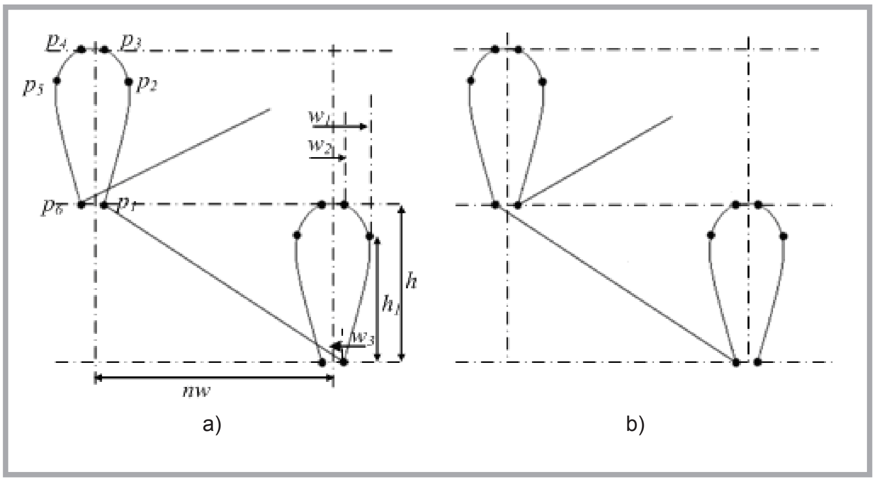

Figure 2. *Simulation model of stitches.*

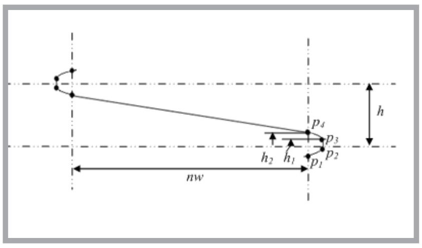

Figure 3. Simulation model of inlay.

line is used to describe the feet of the stitches.

- The displacement of the loops only occurs in the x-direction and at the root of the stitches.
- The displacement of some of the guide bars can be accumulated.

A model of stitch

The ground structure of multibar lace fabric consists of stitches. Most of the stitches are of the pillar, varied pillar, or tricot type. Sometimes, the patten bar also knit stitches. We use six points (*P1 ~ P6*) to describe the backbone of the stitch based on its characteristics (Figure 2). The value of w_1, w_1, $w_{3,}$ h_1 can be determined by experiment using subsequently a computer program. Point P_6 of the current course connects P_1 of the next course, where h is the lengthwise distance between neighbouring courses; w is the transverse distance between neighbouring wales; n is the length of inlay which is counted by the number of gauges that the underlap goes through. Figure 2.a shows a closed loop, and Figure 2.b shows an open loop, respectively.

A model of inlay

Inlay is mostly used in multibar lace fabrics. It is a bit simpler and without overlap. We use four points P_1, P_2, P_3 and P_4 to control its shape, based on its characteristic. The positions of these four points can be determined by parameters h_1, h_2 as shown in Figure 3, where h is the lengthwise distance between neighbouring courses; w is the transverse distance between neighbouring wales; n is the length of inlay, which is counted by the number of gauges that the underlap goes through. A straight line is used to connect point P_6 of the current course to point P_1 of the next course.

A model of fall-plate lapping

The structure of a fall-plate pattern is relatively complex. The stitches have four different shapes, which are determined by the lapping direction of the fall-plate pattern bar, ground bar and the way the stitches are formed. The shape of the fall-plate stitch is abstracted into a computer simulation model, based on the shape of the virtual stitches in the fabric. Figure 4 shows fall-plate stitch shapes of equal overlapping of closed loops (Figure 4.a), counter overlapping of closed loops (Figure 4.b), equal overlapping of open loops (Figure 4.c) and counter overlapping of open loops (Figure 4.d), respectively. It is clear that if the overlaps of the fall-plate pattern bar and ground bar are different, the fall-plate lapping is also different. Hence, we determine the number and position of control points with respect to different conditions. Four control points are used in Figure 4.c, whereas six are used in Figure 4.a and 4.b. Moreover, seven control points are used in Figure 4.d. For example, seven points determine the shape of stitch in the condition of counter lapping of open loops in Figure 4.d. Control points can be adjusted to the optimal position by modifying the value of $w_{2,}$ w_3 to make the simulation more true. Figures 4.b and 4.d, in which the overlap of the fall-plate pattern bar acts as a counter to the ground bar, show the conventional lapping in most multibar knitted structures with fall plate.

These three simulation models have been proved to be simple, rational, and easier to realise with less calculation. The speed of simulation on a computer is faster, so it tends to be accepted by pattern designers.

The principle of loop structure deformation

The loop structure is deformed as a function of yarn tension so that all the

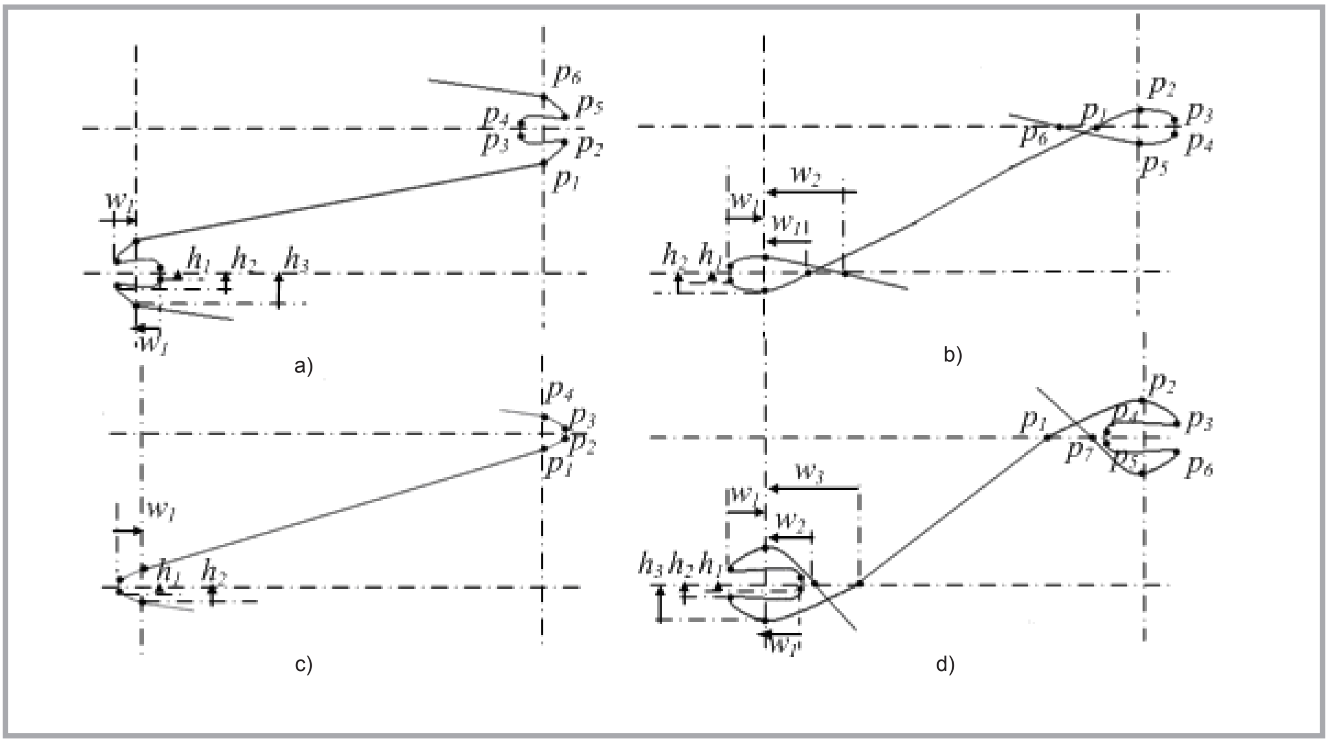

Figure 4. Simulation model of fall-plate lapping.

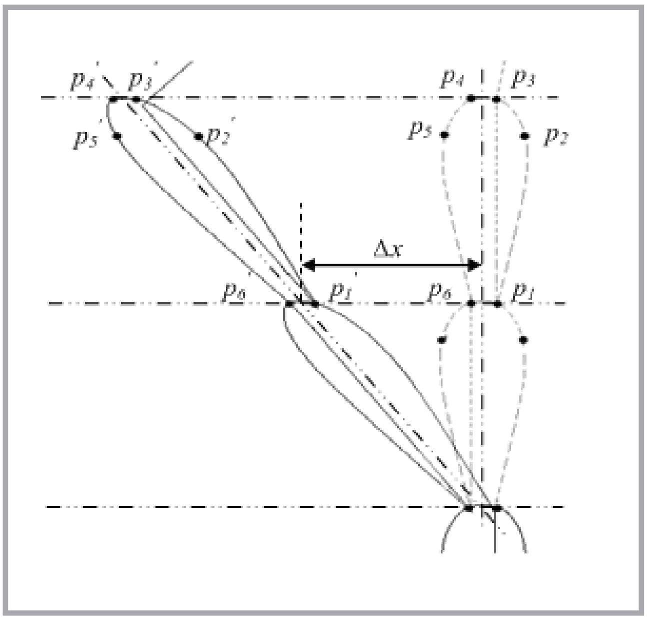

Figure 5. Displacement of stitches.

models discussed above are ideal without taking the deformation into account. Neighbouring wales may lose connection in some courses and result in the fabric having holes. The holes will be stretched and displaced by the tension on the yarns. Furthermore, The size of the holes will be larger. The main deformation of the structure is the displacement of the stitches around. For example, like the ground structure, pillar stitches will be displaced with tension on the pattern yarns and Jacquard yarns. The principle of the displacement is shown in Figure 5.

The broken and real lines in Figure 5 present pillar stitches before and after deformation. Due to the fact that two yarns act on the root of the loop of the inlay loop, stitch and fall-plate lapping, we think that the displacement mainly occurs at the root of the loops, and most are transverse displacement. In order to simplify the simulation on a computer, lengthwise displacement and loop size change are not taken into account here.
Based on the above assumptions, the displacement of a single loop can be calculated by the following formula 1.

$$\Delta x(j,k)=\begin{cases} K_1\times(UL(j)-UL(j-1)) & f(i,t,j)=k \\ 0 & f(i,t,j)\neq k \end{cases} \quad (1)$$

Where: K_1 is the yarn tension factor, which is determined by the ground lapping, jacquard lapping, liners, gimps and shade effects; $f(i, t, j)$ is the wale on which No. i guide bar No. t yarn on j course acts; $UL(j)$ is the length vector of the underlap of the current course; $UL(j-1)$ is the length vector of the underlap of the previous course.

The lapping of every guide bar at j course and k wale causes the total displacement of final stitches, and the displacements can be accumulated as formula 2.

$$dx(j,k) = \sum_{i=1}^{n} \Delta x(j,k) \quad (2)$$

The displacement principle of stitches is concluded by analysing and studying a lot of multibar knitted structures, and it is perfectly suitable for simulation on a computer.

Figure 6. Simulation of multibar lace fabric.

Realisation of simulating multibar fabric

The theory discussed above is the basis of our simulation software developed using VC++.NET. The lapping and threading of each guide bar can be achieved in the design procedure. The fabric can be assumed to be composed of such yarn layers as fall-plate lapping, feet of pillar stitch, inlay, Jacquard yarns, backbone of pillar stitches, and we use the yarn layer concept to display the fabric. The operation speed of the program is faster as a result of the connection of a simple spline curve to the straight line. So our purpose of simulating multibar fabric faster on a computer to view the effect of a fabric before production is validated.

Different yarn count and colour can be selected as the material parameters to display more real multibar fabric. The simulation of lace with a rich Jacquard pattern ground is shown in Figure 6. The texture displayed is more like real fabric. Designers can certainly modify or slightly adjust various technical parameters until they are satisfied with the simulation effect.

Summary

1. In this study of a wide range of multibar fabrics and analysis of various loop structures with patterns, a simulation model of multibar fabric was established by multiple correction and optimisation.
2. We built mathematic models for inlay, stitches and fall-plate lapping. A computer simulation system based on these models was developed and the simulation of multibar lace fabric is intuitionistic, fast and exact.
3. We give a detailed mathematic description of the deformation principle of multibar knitted structure, and it covers all structures of multibar fabric.

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Received 06.11.2006 Reviewed 10.04.2007