

Honglian Cong,
Xiuli Li,
Aijun Zhang,
Zhe Gao

JiangNan University,
WuXi, 214122, P.R.China
E-mail: cong-wkrc@163.com

Design and Simulation of Jacquard Warp-knitted Towel Fabric

Abstract

This article proposes a method for designing and simulating jacquard warp-knitted towel fabric. Artistic conception drawing was used in realising the CAD design function of jacquard warp-knitted towel fabric based on the fabric structure and knitting principle. This study applied NURBS curves and the surface principle to build a three-dimensional solid model of the terry loop. Then using microscope type measurement instruments, the terry loop forms of the fabric surface were analysed and models of different forms of terry loop on the fabric surface built. With visual C++ for development tools combined with OpenGL graphics libraries, a CAD design and simulation function of jacquard warp-knitted towel fabric were finally realized within the CAD system.

Key words: warp-knitting, towel, jacquard, model, design, simulation.

Another method is to simulate the fabric appearance based on actual yarn photographs taken by a stationary camera [3]. Due to the lack of research on the surface simulation of warp-knitted towel fabric, the main work of this paper was using the first method to research the CAD design of jacquard warp-knitted towel fabric and simulate the surface sense of reality.



Figure 1. Photomicrograph of jacquard towel.

Introduction

Jacquard warp-knitted towel fabric is a new kind of warp-knitted product whose terry loops on the surface have the effect of jacquard. According to the design requirements, terry loops are knitted selectively so that various pattern effects can be formed on the surface of the fabric. This kind of fabric is produced by a towel warp-knitted machine, which is with jacquard. Figure 1 is a photomicrograph of jacquard towel.

At present, researches on the CAD design and surface simulation of fabric is universal in both China and abroad. The most commonly used methods in the field of fabric simulation is using a yarn image simulated from given or measured yarn parameters developed by some mathematical algorithms. For example, Moussa et al. applied the two-dimensional Fast Fourier Transform to plain and 2/1 twill weaves, which linked the typology of the spectrum obtained to fabric characteristics such as the pattern and yarn densities. This correlation represents the simulation of other fabrics with new structural parameters using the inverse FFT [1]. Renkens et al. consider the force equilibrium and several mechanical parameters of yarns when modeling warp-knitted structures using the key points to control the stitch shape [2].

Knitting principles of jacquard towel fabric

The features of jacquard warp-knitted towel fabric require special equipment in production facilities. In respect of the configuration of the guide bar, the bar knitting the looped piles at the front of the machine should be a half gauged jacquard bar. For the constitution of the knitting elements, full-head needles and common needles were arranged in an alternating fashion. And the space between the two sinkers on the sides of the full-head needles is larger than the common one. In addition, the machine must be equipped with a brush device at the front in order to emboss the loops on the surface of the fabrics.

During the production process, the jacquard bar is fully threaded, and other bars are threaded 1 in, 1 out. Generally the ground fabric is knitted by two bars with a pillar stitch and inlay, and its yarns are simply lapped on common compound needles. Jacquard looped piles are formed by the jacquard bar at the front of the machine. Yarns on some wales do not form terry loops and are just lapped on common compound needles, as shown in Figure 2.a, whereas yarns forming the terry loops are lapped on full-head compound needles, as shown in Figure 2.b.

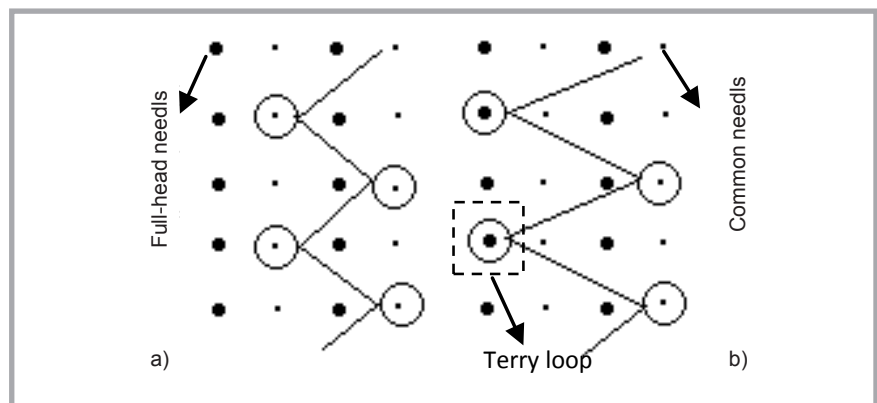


Figure 2. Lapping movements of jacquard towel fabric; a) basic structure, b) terry structure.

Design model of jacquard towel fabric

The effects of common warp-knitted fabric can be shown by the chain notations and threading repeat. As for the effects of warp-knitted jacquard fabric, they need to be shown by the jacquard pattern grid, except for the two methods mentioned above [4, 5].

Based on a detailed comprehension of jacquard warp-knitted towel fabric, a jacquard pattern grid was created, which was added to the design module of warp-knitted fabric in CAD. In the pattern grid, the height of a grid stands for two wales, the width of which represents two stitch lengths, and the different colors indicate the formation of the terry loops. The corresponding relationships between the different colours and the terry loop effect and between the lapping movement and skewing of the jacquard needles are shown in *Table 1*.

According to the contents above, matrix PMU was employed in this paper to describe the pattern grid, which is as formula (1) shows. Where: $j = 1, 2, 3, \dots, m$, m is the number of grids on the wales (equal to half of the pattern wales of the complete design), and $k = 1, 2, 3, \dots, u$, u is the number of vertical grids (equal to half the width of the pattern of the complete design). If $P_{j,k}$ equals 1, the grid is green; the data of jacquard stored in the system is H/H, and the relevant chain notations are 1-0/2-3//. If $P_{j,k}$ equals 2, the grid shows red; the data of jacquard stored in the system is H/T, and the relevant lapping figure is 1-0/3-4//.

$$P_{MU} = \begin{bmatrix} p_{1,1} & p_{1,2} & \dots & p_{1,u} \\ p_{2,1} & p_{2,2} & \dots & p_{2,u} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & p_{j,k} & \dots \\ \dots & \dots & \dots & \dots \\ p_{m,1} & p_{m,2} & \dots & p_{m,u} \end{bmatrix} \quad (1)$$

Programming according to the theory above and the mathematical model of jacquard terry loops, jacquard terry loops can be designed in CAD. Pattern grids of jacquard terry loops are showed in *Figure 3* and the relevant lapping movements in *Figure 4*.

Geometric modeling of jacquard towel fabric

Before the simulation, a relevant model should be built. To establish a model for

Table 1. The relationship between terry and structure.

R	Colour	Jacquard effect	Basic lapping	Skewing	Derivative lapping	Wale number
1	Green	No terry loop	1 - 0/ 2 - 3//	H	1 - 0/	Odd
					2 - 3//	Even
2	Red	Terry loop		T	1 - 0/	Odd
					3 - 4//	Even

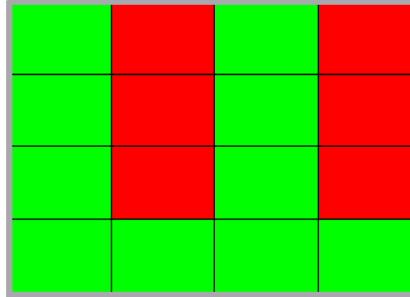


Figure 3. Jacquard terry design.

a kind of flexible material like fabric, a method which can control and describe the yarn route should be chosen. NURBS (Non-Uniform Rational B-Splines) can present the outline and shape inside the 3D model through a curve and curved surface, and this method can control the cambering amount of the surface better [6, 7]. The central axis trend of yarns in warp-knitted fabrics can be presented by NURBS curves, and a solid model of yarn can also be built through NURBS surfaces.

Geometric model of ground fabric

The ground tissue of jacquard warp-knitted towel fabric is formed by a pillar stitch and inlay. During the process of building the model, to make a section of the yarn circular, the 3D loop model presented in references [8 - 10] was employed. The loop is composed of a loop trunk and underlap, which can be identified by 18 control points, as shown in *Figure 5*. The inlay has no lapping in front of the needle, therefore the structure is constituted by the underlap at a certain gauge length and a small part of the arc formed by the movement between needles, which can be identified by 5 control points.

Three-dimensional solid model of terry loop

There are some researches on modelling the terry loop, however all of them focus on weaving and weft knitting. Han Chong from Donghua University studied the 3D simulation of the appearance of multi-pile tufting carpet. He used NURBS curves to establish a model of the terry loop in 3DS MAX and realised a 3D simulation of the

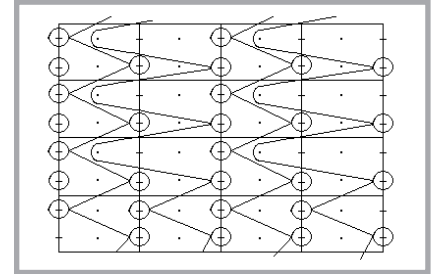


Figure 4. Jacquard terry lapping movement.

appearance of multi-pile tufting carpet in Direct3D [11].

There are no specialized researches on how to build a model of the warp-knitted terry loop of this new kind of jacquard warp-knitted fabric. How to establish an adaptive model of the terry loop will be discussed in this paper.

To build a vivid terry loop of great similarity, the real size of a terry loop is needed. A super depth field 3D microscopic system - VHX-600 was used to measure the structural parameters of the terry loop on the face of the jacquard effect, and data were compared and analysed with measurements repeated six times, as shown in *Table 2*. Where: H is the height of the terry loop, and W the width of the terry loop.

Usually in the technological data of the terry loop there will be some small differences in the data measured. The terry loop height in the technological deriva-

Table 2. The measured structure parameters of terry loop.

Times	H, mm	W, mm
1	1.53	0.55
2	1.63	0.53
3	1.51	0.51
4	1.50	0.49
5	1.48	0.56
6	1.36	0.53
7	1.52	0.51
8	1.49	0.52
9	1.43	0.56
10	1.42	0.52
Avg	1.487	0.528

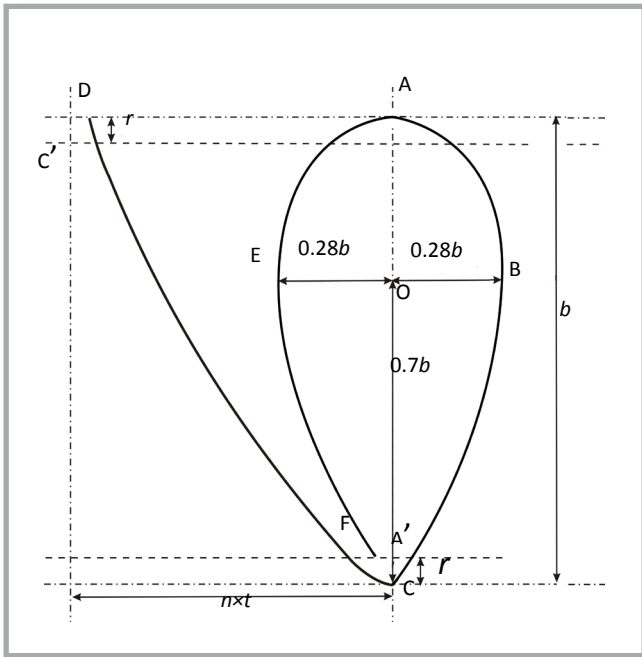


Figure 5. 3D loop model and dimensions.

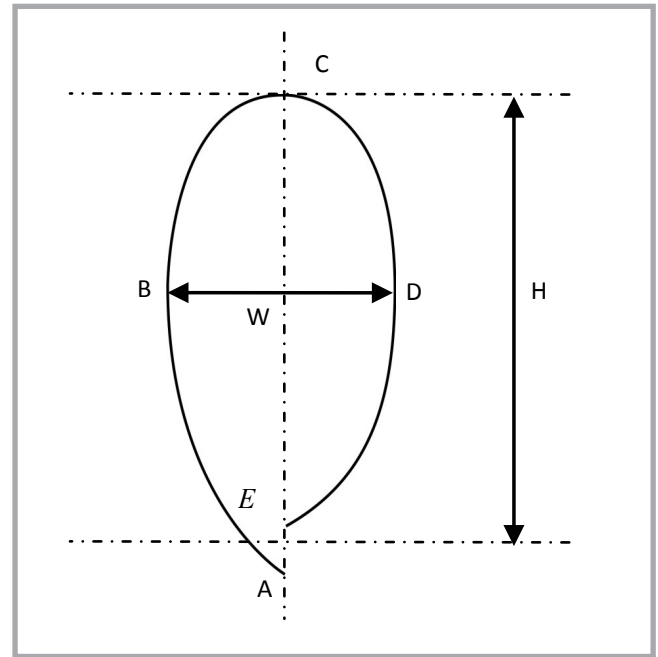


Figure 6. 3D terry model and its dimensions.

tion is about twice more than the real one. This would be caused by the deformation and striction of the terry loop after dyeing and finishing. According to the real sizes and combined with the results of technological derivation, a terry loop model (Figure 6) was established in this paper. We can suppose that the direction of the terry loop height is approximately vertical to the fabric plane, and the width of the terry loop is $W = 0.36 H$, which is obtained from the average data of Table 2.

Models of different forms of terry loop on the fabric surface

A single terry loop model is built through NURBS in ideal circumstances. However, real terry loops always have some complex deformation, since they are influenced by surrounding and neighbor terry loops.

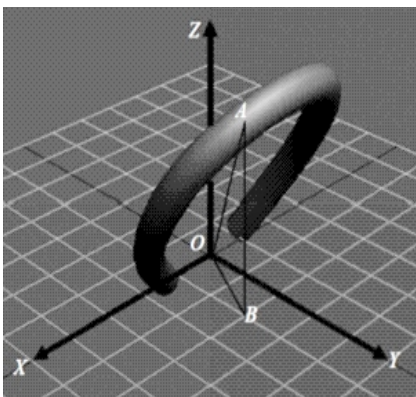


Figure 7. Schematic diagram of the terry loop space model and angle.

The morphology of a terry loop was analysed in this paper with respect to the density, space angle and shading proportion, etc. All of these elements have certain mathematical or logical connections with each other and they greatly influence the terry loop distribution morphology on the surface of fabric, thus expressing the connections exactly can improve the simulation effects of towel fabric surfaces.

The terry loop density refers to the number of terry loops per unit length, which is expressed by cpc (courses per cm) and wpc (wales per cm). Terry loop yarn is laid in every loop wale along the fabric wales, thus the wpc of the terry loop is equal to the wpc ground tissue; since terry loop yarn is only knocked over in even wales to form a terry loop, the relationship is as follows:

$$P_T = 0.5 P_B \quad (2)$$

where: P_T refers to the cpc of the terry loop, and P_B to the cpc of the ground tissue. The density of the terry loop is measured and calculated by computer and is saved in a data base as a known variable.

In this paper the “terry loop space angle” was identified in a 3D space to describe the different morphologies of the terry loop in space. The terry loop space angle is an inclined angle formed by the direction of the terry loop height and plane of the ground tissue, as shown in Figure 7, where: AO is the height of the terry loop,

XOY the plane of the ground tissue, and $\angle AOB$ is the terry loop space angle.

The projection of the terry loop height AO in plane XOY is BO, while the projection of AO in plane YOZ is CO. The included angle formed by BO and the axis Y is $\angle BOD$, and that formed by CO and the axis Y is $\angle COD$. The two included angles were identified as α and β separately. To deeply analyse the mathematic space connection between α , β and $\angle AOB$, the “terry loop space model” was simplified as a “space solid structure model”, as shown in Figure 8.

By using segment $AB = CD$ in the space geometric model, the corresponding relational expression is as follows:

$$\tan \angle AOB = AB/OB \quad (3)$$

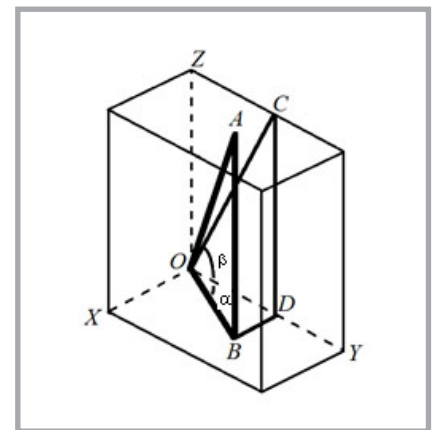


Figure 8. Simplified 3D structure model of terry loop.

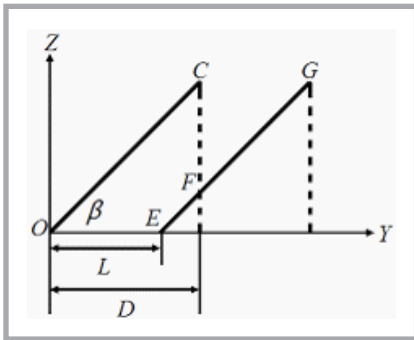


Figure 9. The shading condition schematic diagram of pile loop.

$$\tan\beta = CD/OD = CD/(OB \times \cos\alpha) \quad (4)$$

From simultaneous expressions (3) (4), the mathematic relational expression of the terry loop space angle, α and β , is as follows:

$$\tan\angle AOB = \cos\alpha \times \tan\beta \quad (5)$$

Where: the value of $\cos\alpha$ is in the range of $0 \sim 1$, which can be replaced by the deflection factor μ , then the formula can be obtained:

$$\tan\angle AOB = \mu \times \tan\beta \quad (6)$$

The value area should be confirmed in order to ensure the veracity of the mathematic relation. Decided by the features of the terry loop tissue, the biggest angle of inclination of the terry loop is related to the lapping movements. The theoretically biggest angle of inclination is:

$$\tan\alpha = B/(n \times w) \quad (7)$$

where: B refers to the height of one wale ($B = 10/P_B$), n to the gauge number of the shogging motion in the needle back made by the terry loop yarn, and w refers to the gauge.

The accurate value of the area of deflection factor μ , which can be obtained from formula (7), is $\{\cos[\arctan(10/(n \times w \times P_B))], 1\}$. Here the axes X and Y are in positive direction. If axis X or axis Y are in negative direction, the terry loop space angle relation is similar.

Shading each other inside the terry loop is another significant element to influence the simulation of terry loop morphology. The "terry loop shading proportion" was employed to solve this problem in this paper. The terry loop shading proportion M refers to the ratio of the visible part of the height in the next wale to the whole loop height. During simulation, the primitive graphics are filled in order from the top to bottom through computer

language based on the terry loop shading proportion in order to gain the simulation effects. The terry loop shading proportion M is related to the cpc of the terry-loop P_T , the height of the terry-loop H and the deviation angle of the terry-loop β . A sketch map of the shading situation of two adjacent terry loops in the same wale is as follows.

Figure 9 shows a simplified shading sketch map. Suppose $OC = EG = H$ (Height), then the definition of the terry loop shading proportion is:

$$M = FG/GE = FG/OB \quad (8)$$

The relation between M, L and D can be obtained through the proportional similarity of the right angle, where the definitions of L and D are as follows:

$$M = FG/H = L/D \quad (9)$$

$$L = 10/PT \quad (10)$$

$$D = H \times \cos\beta \quad (11)$$

The formula for calculating the terry loop shading proportion is achieved through simultaneous formulas (9) ~ (11):

$$M = 10/(H \times \cos\beta \times PT) \quad (12)$$

From above calculation procedure, it can be known that a certain value of β is related to the corresponding terry loop space angle and terry loop shading proportion. Measured through experiments, the results showed that the values of β assembled between 60° and 90° . Thus after settling the value of β at $60^\circ, 63^\circ, 66^\circ, \dots$, the relevant terry loop space angle and terry loop shading proportion were calculated. Furthermore the matching 3D geometrical models, which were numbered, were drawn and saved into the database in order to be easily recalled during simulation.

Simulation of jacquard towel fabrics

Illumination model and texture mapping

To enhance the sense of reality of the fabric surface effectively, an illumination model and texture mapping were employed during the simulation of jacquard warp-knitted towel fabrics.

The effects of colors and shade transition on the surface of fabric are identified by the environment reflection, diffuse reflection and specular reflection. Suppose $k_\alpha, k_\beta, k_\gamma$ represent the proportion values separately, $I_\alpha, I_\beta, I_\gamma$ - reflection compo-

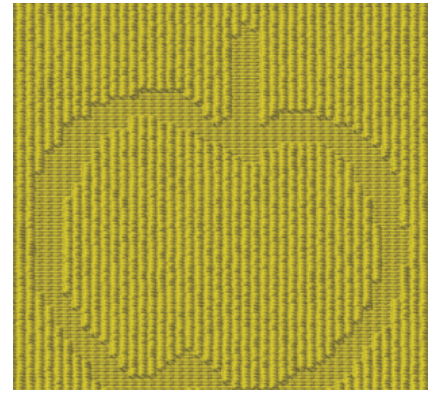


Figure 10. 3D simulation image of jacquard towel.

nents of the environment reflection, diffuse reflection and specular reflection separately, and n represents the number of illuminants, then the illumination model can be presented as follows [12]:

$$I = \sum_{i=0}^n [K_\beta I_\beta \cos\theta_i + K_\gamma I_\gamma \cos^n\theta_i] + K_\alpha I_\alpha \quad (13)$$

Terry loop yarns on the surface of fabrics are composed of fiber bundle. Different configurations of fibers will produce textures. Texture chartlet was used in this paper to create textures on the surface of the terry loop. The principle used was that after settling the visible points on the terry loop surface, textures could be inflected onto the surface through the product of the value of the texture space's corresponding point and the value of luminance[13]. In formula(15), where C refers to the intensity of colour at the pixel point, Suffix t refers to the colour strength of the texture image, f to the colour strength of the yarn before the creation of the texture, and v refers to the final intensity of colour.

$$C^v = C^t + C^f \quad (14)$$

Achievement of 3D simulation of fabrics

Combined with an OpenGL graphic base, visual C++ was employed as a development tool to achieve a simulation using warp-knitted CAD software. During 3D simulation, a part of the ground tissue could be obtained through a 3D solid model, built according to a coordinate system and settled controlling points. A part of terry loops on the surface could be obtained through recalling the built image base. The result revealed that the simulation method in this paper could have significant effects on simulating the real morphology on the fabric surface, as shown in Figure 10.

■ Conclusion

A mathematic model of the tissue of jacquard warp-knitted towel fabric was built in this paper through CAD. The space angle of a terry loop on the surface of fabric, the shading relationship analysed and a simulating model of the terry loop established. Finally combined with the application of illumination and texture, the simulation effect for terry loop was realised to a certain degree.

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■ Received 26.09.2012 Reviewed 12.03.2014



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Contact:

INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES
ul. M. Skłodowskiej-Curie 19/27, 90-570 Łódź, Poland
Elżbieta Baranek Dr eng. mech.,
tel. (+48 42) 638 03 31, e-mail: elabarunek@ibwch.lodz.pl