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Research Article

Fiber Transfer and Compensation for Carding Unit of Sliver Knitting Machine

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Abstract

Carding unit of sliver knitting machine draws and transfersfibers to needles. Sliver loses massin this process.This results in that the quality of sliver knitting fabric is below standard.In this paper, a transfer factor was proposed to define the percentage of fiber mass transferred.Based on the transfer factor, a mathematical model that revealed the fiber transfer processes ofcarding unit was built.Then,the mass of a tuft offibers drawn by each needlewas calculated according to the model.Thus, once a fabric was designed, the forecast result is got.Besides, a compensation method was also proposed to eliminate the error between forecast and design result. These results were used in the CAD system of sliver knitting. Itprovided aquantitative method to sliver knitting to replacethe method relied on artificial experience.

Keywords: Carding Unit; Compensation Method; Mathematical Model; Sliver Knitting Machine

Introduction

Sliver Knitting, circular knitting coupled with the drawing-in of a sliver by the needles to produce a pile like fabric[1].Itis used in the field of cloth, toy, decoration and healthcare industry[2,3] et al.Its production quality is troubled by poor fiber distribution. Uneven fiber distribution exists in the fabric. Especially in sliver jacquard knitting, it looks like the pattern has shadows. The phenomenon constantly occurs while fabrics are produced.A simple and effective solution is modifying fabric design in the CAD system. Although this method is used widely, it isnot reliable because it depends on artificial experience completely. Rework is required to eliminate the error between fabric and design in practice. This paper aims at proposing a quantitative assessment and compensation method for accurate and efficient product.

Sliver knitting fabric production includes carding, knitting and finishing.In sliver knitting machine, eachknitting systemhas a carding unit.Theunit is mounted at theup side of the carrier rim. It has a pair of feed rollers, a card roller, a clear roller and a worker roller (Figure 1). All the rollers take part in sliver carding. Except conventional card function, feed rollers also guide sliver into the unit, worker roller feeds the carded sliver to the knitting needles and clear roller transfer residue fiber after sliver fed.While needles are raised to draw fiber tufts, the fibers insert into the hooks of knitting needles.Air-jet nozzle over the knitting point ensure that the tufts are retained in the needle hooks and the free fiber ends are orientated through to the inside of the fabric tube (the technical back), which is the pile side[4].After knitting,fabrics go througha series of technical finishing processes including back-coating,heat setting and shearing[2].In such a way, the sliver knitting fabric are knitted.

The way carding unit works islike carding machine. There are a lot of literatures studied carding from many perspectives[5]. Setting, machinery condition[6], card wire[7] and aerodynamic flow field[8,9] parameters have been studied for better sliver quality.Some models have been built to study fiber transfer[10,11] in carding machine. Simulation[12] and image analysis[13]have also been used.Althoughcarding principle is similar, the difference of research emphasisis also apparent. These studies of carding machine have paid more attention to the carding quality rather than the effectiveness and veracity ofoutput. Sometimes doffer efficiency was reduced to improve fiber mixing[14], and this increased recycling[15,16]. However, the study of sliver knitting focus on the validity and timeliness of fiber mass transferred.

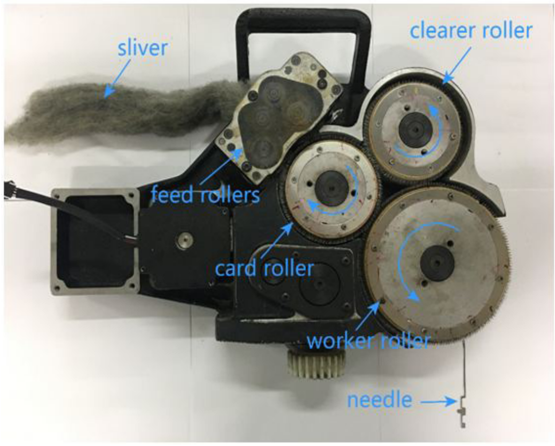


Figure 1: A photograph of card unit of sliver knitting machine.

In this paper, mathematical model is built according to the process of fiber transfer in sliver knitting.Based on this model, a prediction and compensation method is put forward.

Methods

Mathematical Model

Fiber Transfer Mathematical Model

As rollers work, fiber transfer from one roller to the other. The difference in speeds of rollers pulls the fiber clumps apart. Some of the fibers are pulled down into the teeth and some are distributed above the tips of the teeth.The clearance between the pin sets of wires is small, meaning that fiber tufts become caught in both sets of pins. Fibers generally distributealongteeth both rollers. This means that fiber transferis uncompleted immediately.

Fiber transfer depends on parameters such as the geometry of the clothing,the clearance between two rollers, relative speeds of the rollers, fiber parameters such as fiber length, diameter, and crimp, wire parameters such as tooth density, height, and angle, and card parameters such as the number and settings of rollers[10, 12].

In the actual production, some parameters of carding almost impossible to change since the carding unit has been set once the sliver knitting machine produced. Some parameters change with the machine aging.The uncertainty, poor operability of parametersand the complexity of the method make analytic models with parameters of fiber transfer too difficult for practice.In this paper, transfer factor is proposed to present the fiber transfer efficiency between two rollers. The relationships of transfer factor and various parameters are denoted by a functionas follows

$$k=F(v) \quad (1)$$

Where k is transfer factor, v is any parameter, F is the function mapping v to k.This function is built according to experimental data.

Sliver Carding Mathematical Model

Since the fiber transfer between two rollers is not completely efficient, some fibers recycle around the roller where them mixes with incoming newer-fed fibers. It is a complicated and opening process.

min(t) is the fiber mass per unit time.Input X(t) is information of needle drawing fiber. Value 1 means drawing fiber, value 0 means not drawingfiber.i and j are feed rollers, b is carding roller, w is worker roller, c is clearer roller.A, B, C, D, F are separation points of working areas between carding roller and worker roller, worker roller and clearer roller, clearer roller and carding roller, feed rollers and carding roller, two feed rollers respectively.E is the point where needle draw fibers. It is considered that fiber has been transferred while the fiber arrived separation point of working area.(Figure 2)

k_{bw}, k_{wc}, k_{cb}, k_{ib} are transfer factors of corresponding rollers with subscripts text.$m_{iF}(t)$,$m_{iD}(t)$, $m_{bD}(t)$, $m_{bC}(t)$, $m_{bA}(t)$, $m_{wA}(t)$, $m_{wE}(t)$, $m_{wB}(t)$, $m_{cB}(t)$, $m_{cC}(t)$ are fiber mass of corresponding rollers(first subscript) in separation points(second subscript).

Ti1 is the time that fiber moves from D to F,Ti2is the time that fiber moves from F to D. T_{b1}, T_{b2}, T_{b3}, T_{w1}, T_{w2}, T_{w3}, $T_{c1}$and Tc2 are the time that fiber on rollers revolves corresponding degrees according θ_{b1}, θ_{b2}, θ_{b3}, θ_{w1}, θ_{w2}, θ_{w3}, θ_{c1} and θ_{c2} in (Figure 2).

For input rollers, fiber mass of point F comes from two parts, one is fiber fed in, the other is point D. Fiber mass of point D is left fiber after transferred to carding roller.

$$m_{iF}(t)=m_{in}(t)+m_{iD}(t-T_{i1}) \quad (2)$$

$$m_{iD}(t)=(1-k\_ib)m_{in}(t-T_{i2}) \quad (3)$$

For carding roller, fiber mass of point D comes from two parts, one is transferred from feed rollers, the other is point A. The fiber mass of point C comes from point D and clear roller.The mass of point A is the left mass of point C after transferred to worker roller.

$$m_{bD}(t)=m_{iD}(t)\,k_{ib}+m_{bA}(t-T_{b3}) \quad (4)$$

$$m_{bC}(t)=m_{bD}(t-T_{b1})+m\_cB(t-T_{c1})\,k_{cb} \quad (5)$$

$$m_{bA}(t)=m_{bC}(t-T_{b2})(1-k_{bw}) \quad (6)$$

For worker roller, the mass of point A comes from carding roller and mass of point B of worker roller. The mass of point E is left mass after fiber draw by needle hook. The mass of point B is left mass after fiber transferred to clear roller.

$$m_{wA}(t)=m_{bC}(t-T_{b2})\,k_{bw}+m_{wB}(t-T_{w3}) \quad (7)$$

$$m_{wE}(t)=m_{wA}(t-T_{w1})(1-k_{out}X(t)) \quad (8)$$

$$m_{wB}(t)=m_{wE}(t-T_{w2})(1-k_{wc}) \quad (9)$$

For clearer roller, fiber mass of point B comes from worker roller and point C. The mass of point C is left mass after transferred to carding roller.

$$m_{cB}(t)=m_{wE}(t-T_{w2})k_{wc}+m_{cC}(t-T_{c2}) \quad (10)$$

$$m_{cC}(t)=m_{cB}(t-T_{c1})(1-k_{cb}) \quad (11)$$

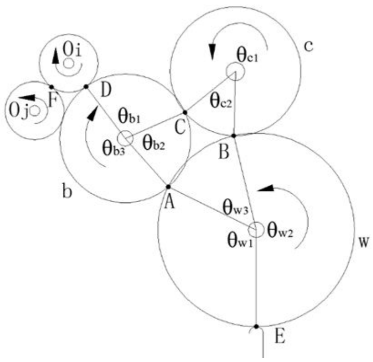


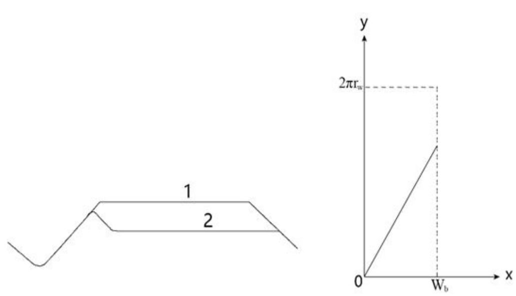
Figure 2: Schematic view of carding unit working principle.

Fiber Drawing Mathematical Model

At each sliver feed, the needles are lifted to an extra high level(Figure 3(a)) wherethey rise through the wires of the worker roller to collect a tuft of staple fibers intheir hooks.There is a relative motion between needle and worker roller in this procedure. A coordinate is built(Figure 3 (b))by using needle horizontal motion direction as coordinate axis Xand worker rollerrotational direction as coordinate axis Y on the flatted wire fillet.

$$\begin{cases} x = r_{cy}\omega_{ct}t \\ y = r_w\omega_w t \end{cases} \quad (12)$$

Where r_cy is radius of cylinder, ω_ct is rotate speed of cylinder, r_w is radius of worker roller and ω_w is rotate speed of worker roller.w_bis the width of worker roller.



(a) (b)

Figure 3(a-b): (a) Track of needle movement (Track 1 for needles drawing fiber; Track 2 for needles not drawing fiber)(b) Track of needle catching fiber on worker roller.

Needles draw fibers at separation point E of worker roller and the transfer factor is kout. m_out (t)is system output and it means the fiber mass transferred from worker roller to needle.

$$m_{out}(t)=m_{wA}(t-T)\,k_{out}\,X(t) \quad (13)$$

Mass of fiberdrawn by one needle is

$$\int_{t-T}^{t} m_{out}(t)dt = \rho S \quad (16)$$

Where ρ isthe fiber density of area from A to E on worker roller, S and T areestimated contact area and time of needle hookrespectively.

Fiber density of area from A to E on worker roller is

$$\rho = \frac{\int_{t-T_{W1}}^{t} m_{wA}(t-T_{W1})dt}{r_w\theta_{w1}w_b} \quad (14)$$

Needles draw the fiber along the needle track in the set coordinate on fillet wire of worker roller. This area is estimated according the needle hook movement in (Figure 3(b)).

$$S = l * \sqrt{(r_{cy}\omega_{ct}T)^2 + (r_w\omega_w T)^2} \quad (15)$$

Where l is fiber length.

Thus k_{out} can becalculated as follows

$$k_{out} = \frac{\rho S}{\int_{t-T}^{t} m_{out}(t)dt} \quad (16)$$

Fabric prediction method

The fabric can be predicted according above mathematical model of carding unit. One of the inputs of the mathematical model can be calculated by combing sliver feeding information with sliver parameters

$$m_{in}(t)=\omega_{in}r_{in}\rho_t \quad (17)$$

Where ω_in is rotate speed of feed rollers, r_in is the radius of feed roller, ρ_tis the density of sliver.

Needle draw fiber information is the source of another input *X(t)* of the model. As mentioned before, the information is a 0-1 sequence, meaning drawing fiber or not with time.

According to the mathematical model, the forecast mass m_{out}(t)as the outputdata of the model.

Compensation method

Based on the state feedback, one input control strategy is presented to improve fabric appearanceaccording to the design requirements.This strategy is a kind of error-compensation method based on the errorand error changes between forecast outputand designed fiber mass.

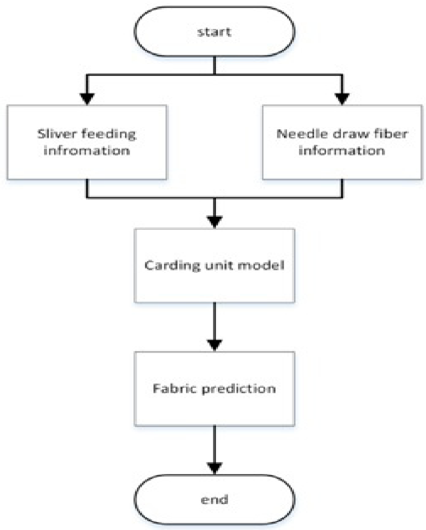


Figure 4: Flow chart of predicting sliver knitting fabric.

Flow chart of compensating sliver knitting fabric is shown in (Figure 5). As mentioned before, m_in (t) and X(t) are inputs of the mathematical model, according to the sliver feeding information and needle draw fiber information,respectively. The compensation process provides compensation to the knitting system according to the error and error changes between forecast output fiber mass and designed fiber mass. The compensation method to solve system problem by two ways, time delay compensation and output mass compensation.

Through this compensation, a uniform distribution and clearsliver knitting fabric could be knitted.

Materials and Methods

Fabrics were knitting on a sliver knitting machine(M18) in the experiment.Maximum rotate speedof the machine is 30 rpm in jacquard.Polyester DTYwas used as ground, and two kinds of sliver were used in experiment. Details are shownas follow (Table 1).

Machine	Ground yarn	sliver 1	sliver2
Modle:M18	Type:polyester DTY	Type: acrylic fiber	Type: acrylic fiber
Diameter: 27inch	Denier:100D	Length: 102mm	Length: 38mm
Needles:1184		Denier:3D	Denier:1.5D
Number of feeds:18		Density: 18.32g/m	Density: 17g/m
Colors:1-6			

Table 1: Experiment Materials Details.

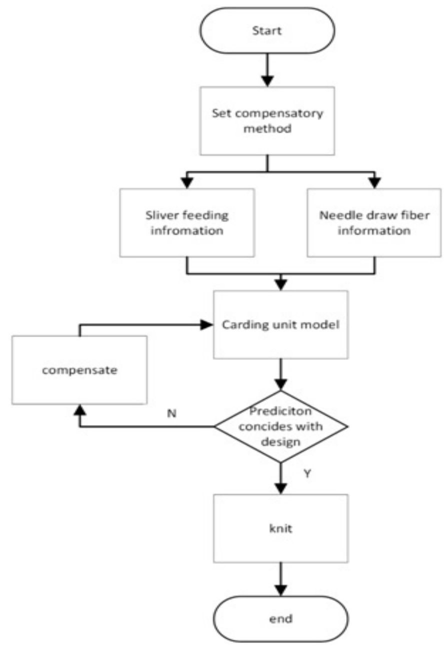


Figure 5: Flow chart of compensating sliver knitting fabric.

Experimental measurement

Fiber mass on roller can be measured after machine run for a period of time.Transfer factors can be calculated according follow equations.

$$m_i(t) = \int_{t-T_{i1}}^{t} m_{iF}(t-T_{i1})dt + \int_{t-T_{i2}}^{t} m_{iD}(t-T_{i2})dt \quad (15)$$

$$m_b(t) = \int_{t-T_{b3}}^{t} m_{bA}(t-T_{b3})dt + \int_{t-T_{b2}}^{t} m_{bC}(t-T_{b2})dt + \int_{t-T_{b1}}^{t} m_{bD}(t-T_{b1})dt \quad (16)$$

$$m_w(t) = \int_{t-T_{w1}}^{t} m_{wA}(t-T_{w1})dt + \int_{t-T_{w2}}^{t} m_{wE}(t-T_{w2})dt + \int_{t-T_{w3}}^{t} m_{wB}(t-T_{w3})dt \quad (17)$$

$$m_c(t) = \int_{t-T_{c1}}^{t} m_{cB}(t-T_{c1})dt + \int_{t-T_{c2}}^{t} m_{cC}(t-T_{c2})dt \quad (18)$$

According to fiber transfer, there are

$$m_i(t) + m_b(t) = \int_0^t m_{in}(t)dt,\ T_{i1} < t < T_{i1} + T_{i2} + \min[T_{i2}, T_{b1}] \quad (19)$$

$$m_i(t) + m_b(t) + m_w(t) = \int_0^t m_{in}(t)dt,$$
$$T_{i1} + T_{b1} + T_{b2} < t < T_{i1} + T_{b1} + T_{b2} + \min[T_{b3}, T_{w1}] \quad (20)$$

$$m_i(t) + m_b(t) + m_w(t) + m_c(t) = \int_0^t m_{in}(t)dt,$$
$$T_{i1} + T_{b1} + T_{b2} + T_{w1} + T_{w2} < t < T_{i1} + T_{b1} + T_{b2} + T_{w1} + T_{w2} + \min[T_{w3}, T_{c1}] \quad (21)$$

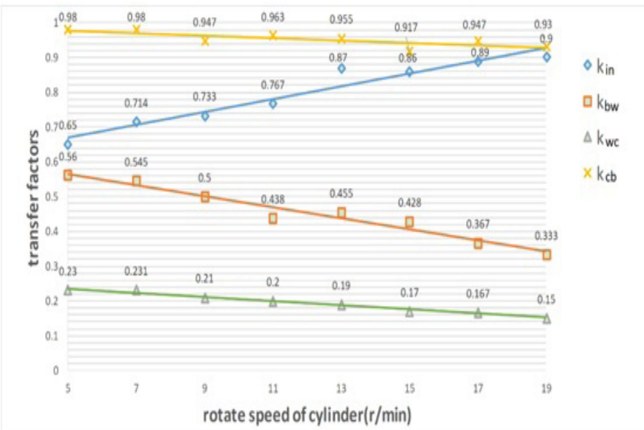
$$\int_{t-T_{b2}}^{t} m_{bA}(t-T_{b2})dt = k_{cb}\int_{t-T_{b2}}^{t} m_{cB}(t-T_{b2})dt + \int_{t-T_{b2}}^{t} m_{bD}(t-T_{b2})dt,$$
$$t > T_{i1} + T_{b1} + T_{b2} + T_{w1} + T_{w2} + T_{c1} \quad (22)$$

Where $m_i(t)$, $m_b(t)$, $m_w(t)$, $m_c(t)$ are total fiber mass on input rollers, carding roller, worker roller and clearer roller respectively.

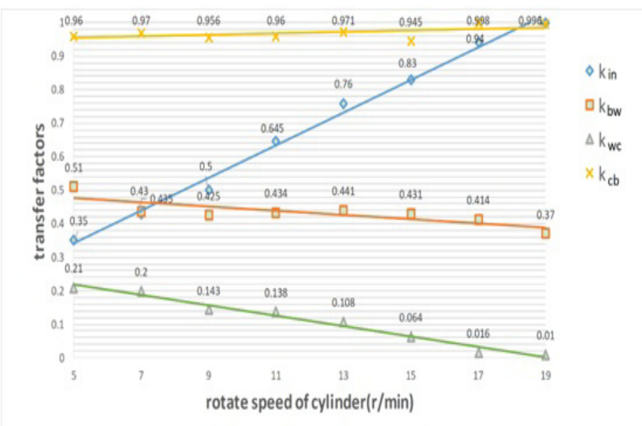
Result and Discussion

Fiber transfer factor

Each transfer factor varies with the cylinder rotational speed increasing.Under the experimental conditions mentioned above, how the transfer factors changed while feedingsliver 1 and sliver 2 are shown in (Figure 6).



(a)



(b)

Figure 6 (a-b): Transfer factors of fibers (a) fiber 1 (b) fiber 2.

The regression equations of transfer factors to rotate speed of cylinder in (Figure 5(a)) are written as follows:

$$k_{in} = F_{in}(n_1) = 0.0179n_1 + 0.5777 \quad (23)$$

$$k_{bw} = F_{bw}(n_1) = -0.0159n_1 + 0.6445 \quad (24)$$

$$k_{wc} = F_{wc}(n_1) = -0.006n_1 + 0.2656 \quad (25)$$

$$k_{cb} = F_{cb}(n_1) = -0.0036n_1 + 0.9962 \quad (26)$$

Where n_1 is the rotate speed of cylinder, $F_{in}(n_1)$, $F_{bw}(n_1)$, $F_{wc}(n_1)$, $F_{cb}(n_1)$ are the function relationship of k_{in}, k_{bw}, k_{wc}, k_{cb} and n_1 respectively.

The regression equations of transfer factors to rotate speed of cylinder in (Figure 5(b)) are written as follows:

$$k_{in} = G_{in}(n_1) = 0.0486n_1 + 0.0989 \quad (27)$$

$$k_{bw} = G_{bw}(n_1) = -0.0051n_1 + 0.493 \quad (28)$$

$$k_{wc} = G_{wc}(n_1) = -0.0154\,n_1 + 0.2959 \quad (29)$$

$$k_{cb} = G_{cb}(n_1) = 0.0018\,n_1 + 0.9468 \quad (30)$$

Where n_1 is the rotate speed of cylinder, $G_{in}(n_1)$, $G_{bw}(n_1)$, $G_{wc}(n_1)$, $G_{cb}(n_1)$ are the function relationship of k_{in}, k_{bw}, k_{wc}, k_{cb} and n_1 respectively.

The experimental method to get the relationship between parameters and transfer factor is practical in industry. But the method has an inevitable problem that the relationship should vary along parts of machine deterioration. Once the situation occurs, the parameter-transfer curve should be measured again. Appropriate analysis method to build the parameter-transfer relationship for carding unit of sliver knitting machine is worth further study.

Fabric prediction

Fabric prediction and compensation methods were implemented by C# language in visual studio 2010.Calculated results were displayed after visualization processing.

Amplitude of $m_{out}(t)$is presented by gray of color. The ratio of output to the standard input range between 0% and 100% correspond to the gray level range between 0 and 255. Then the data can be converted into color image according fed sliver color. Combined the amplitude of $m_{out}(t)$ and the relevant needle position of fabric, the prediction fabric image isgotaccording mathematical model.

A typical triangle pattern in three colors wastested in the experiment. Pattern width was 1184 needles, height was400 needles. Then,prediction image1184 pixels wide and 400 pixels high is shown in (Figure 7).

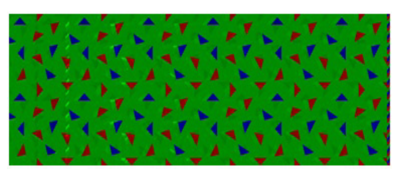


Figure 7: Prediction result of one designed fabric.

Compared with the design pattern, it is clear that the prediction image has many disturbing dark or bright spots.These spots mean uneven and wrong fiber distribution. The ratios of output to standard input of all needles are shown in (Figure 8(a)).

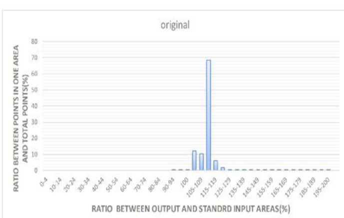
There are only 0.23% outputs are equal standard input.Outputs in range between 110% and 114% take up 68.47%. Outputs in range between 101% and 104%, 105% and 109%, 115% and 119% take up 12.08%,10.34%, 5.92% respectively.Except these centralized areas, there are 3.19% outputs scattered in other areas.In ideal sliver knitting fabric, the data should be centralized on 100%. The more centralized distribution, the fabric is more uniformity.

This prediction image is a visual form of forecast output mass. It is intuitive for designer to know knit result. But it only works asa reference, a sliver knitting simulation according to the knit parameters should be studied in further study, which will provide vivid fabric prediction.

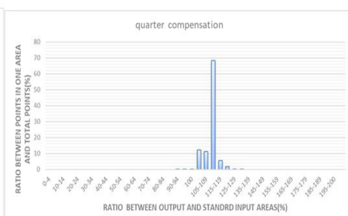
Fiber Transfer Compensation

In consideration of fiber feeding controlled by stepper motor, the precision of compensation method should fit the precision of stepper motor.Thus, there are three kinds of precision provided to choosein this experiment, quarter, one-eighth and one-sixteenth. After sliver knitting fabric designed, precisionshould be chosen firstly according to stepper motor performance.

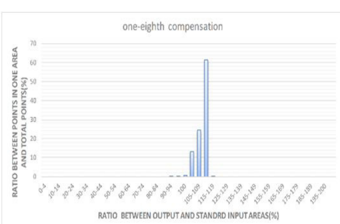
Output data using three compensation precision are shown in histograms as follows.



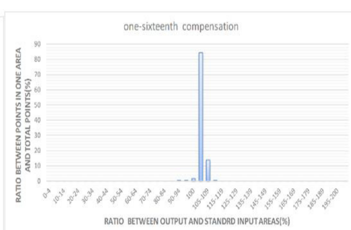
(a) Original.



(b) Quarter compensation.



(c) One Eighth Compensation.



(d) One-Sixteenth Compensation.

Figure 8: Statistics data of fiber weight of each needle used three compensation methods.

In quarter compensation, fiber mass distribution concentrated in 101%-104%, 105%-109%, 110%-114% and 115%-119% four ranges. In one-eighth compensation, fiber weights distribution concentrated in 101%-104%, 105%-109% and 110%-114% three ranges. In one-sixteenth compensation, fiber mass distribution concentrated in 101%-104% and 105%-109% two ranges.It is evident that the output distribution is more concentrated and compensation result is promoted along the precision improved.

A prediction image used one-sixteen compensation is shown in (Figure 9).Compared with the original prediction image, the image color is more uniform.

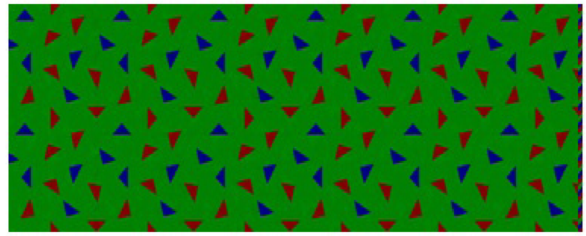


Figure 9: Compensatory results used one-sixteenth compensatory method.

This compensation method can compensate the pattern knitting error completely in theory. But it is limited by the control precision of stepper motor in practice. For the better compensation effect, the control precision need to be improved.

Conclusions

The carding unit is key technology structure for sliver knitting. This paper studiedfiber transfer in the whole sliver knitting processes, which included sliver carding and drawing. Fiber transfer percentage was defined as transfer factor, which was a function related with fiber parameters, wire parameters et al. It was obtained by experimental measurement. The experimental data showed transfer factor was linear to rotate speed of cylinder in a certain machine. A mathematical model was built for fiber transfer in carding procedure.This model was the basis of quantitative analysis of sliver knitting. Fabric appearance can be predicted based on this model.Compensation method was also proposed according to this model, which eliminate the error between the forecast mass of sliver tufts in each needle loop to the design. Analysis data has proved that the prediction and compensation method is useful for sliver knitting fabric quality improving. Although this compensation effect isrestricted to the precision of the stepper motor in practice, it is easy to improve the compensation precisionwith stepper motor precision improvement.The model and compensation method have been applied in a CAD system. The results of fabric prediction and compensation have been visualized in the system. It is convenient, efficient and accurate for sliver knitting product.

However, the measuredparameter-transfer curve used to get the relationship between parameters and transfer factor may change while a machine deteriorates. A better analysis model of fiber transfer should be built for sliver carding unit in the further research.

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