Predictive algorithm for run-in value of warp knitting based on weave matrix

Jisheng Zhang, Gaoming Jiang[a], Honglian Cong, Pibo Ma
& Zhiming Wu

Engineering Research Center for Knitting Technology,
Ministry of Education, Jiangnan University, Wuxi 214122, China

To predict the run-in values of single-needle-bar warp-knitted fabrics, three-dimensional weave matrixes have been established by considering main parameters of shogging movement, take-up density and total bar number. Length of a stitch has been deduced from the parameters in weave matrixes, and a new predictive algorithm model is developed. Moreover, to validate the accuracy of the proposed predictive algorithm, 30 samples with different parameters are knitted on HKS4-EL warp-knitting machine, and the predicted run-in values and measured run-in values of the samples are compared. It can be deduced from the comparison that the predictive algorithm model can provide high prediction accuracy with a relative error of < 4.26%.

Run-in is an essential parameter in positive warp knitting let-off system, which has considerable effect on fabric weight, fabric quality and continuity in production[1]. In the process of practical production, most of run-in values are confirmed in trial and error methods which are time-consuming[2]. Thus, it is significant to predict the run-in value of each guide bar before a warp knitted fabric is knitted on machine[3]. Several workers have suggested geometric model for predicting run-in values[2, 4]. Most of the models were proposed based on the four sections of a stitch, such as a semicircle and three straight lines[5]. Researchers suggested a model by taking into account that the geometrical deformation of a stitch is more likely to be determined by take-up density[6]. Moreover, most of the existing models were put forward based on a certain fabric weave and mainly focus on simple two-guide-bars warp knitting fabrics[7-9]. However, since electronic guide-bar shogging mechanism and EBC positive let-off mechanism were applied in high speed single-

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[a]Corresponding author.
E-mail: jgm@jiangnan.edu.cn

needle-bar warp knitting machine, a fraction of warp-knitted fabric weaves has became much more complex, e.g. more courses in a repeat and more complicated pattern, which have significantly increased the difficulty in predicting the run-in values[10,11]. In this situation, the run-in values can be hardly precisely stimulated by available methods and are always confirmed in trial and error methods.

In this study, attempts have been made to develop such an algorithm model that can be suitable for predicting run-in values of the single-needle-bar warp-knitting fabrics with weave matrixes. The complexity is more likely determined by multifarious shogging movement which deforms loop shape. In order to improving the accuracy of the prediction, the main influence factors of run-in such as shogging movement of each bar, take-up density and total bar number are taken into consideration during the development of algorithm model.

Theoretical Consideration

Weave Matrix for Warp-knitted Fabric

A weave matrix can be considered as mathematical model of a warp-knitted fabric, because before being knitted on the warp-knitting machine, a new warp-knitted fabric is designed in warp-knitting CAD system e.g. WKCAD or PROCAD, then a three-dimensional matrix is generated to store information of the fabric weave including shogging movement of each bars and take-up density. Moreover, shogging movement in one stitch consists of needle front shogging and needle back shogging, thus shogging movement in each stitch can be represented by two numbers of the needle front position (f) and needle back position (b).

Assuming that a warp-knitted fabric is made of J bars with a pattern length of n courses, a warp-knitted fabric can be reasonably manifested in a three-dimensional weave matrix in mathematics, as shown below:

$$D_{Jn2} = \begin{bmatrix} f_{(J,1)} & b_{(J,1)} & cpc_1 \\ f_{(J,2)} & b_{(J,2)} & cpc_2 \\ f_{(J,3)} & b_{(J,3)} & cpc_3 \\ \vdots & \vdots & \vdots \\ f_{(J,k)} & b_{(J,k)} & cpc_k \\ \vdots & \vdots & \vdots \\ f_{(J,n)} & b_{(J,n)} & cpc_n \end{bmatrix} \quad \dots (1)$$

where J represents total number of bars; n, the course number in a pattern cycle; $f_{(j,k)}$, the starting location of needle front shogging movement in the k-th course for the j-th bar $(1 \leq j \leq J, \ 1 \leq k \leq n)$; $b_{(j,k)}$, the starting location of needle back shogging movement in the k-th course for the j-th bar; and cpc_k, the take-up density of the k-th course in courses/cm.

Furthermore, the parameters of $y_{(j,k)}$ and $y'_{(j,k)}$ can be obtained from D_{Jn2}, and the relationship between the two parameters and D_{Jn2} can be represented by the following equations:

$$y_{(j,k)} = \left| f_{(j,k)} - b_{(j,k)} \right| \qquad \qquad \dots (2)$$

$$y'_{(j,k)} = \left| f_{(j,k+1)} - b_{(j,k)} \right| \qquad \dots (3)$$

where y is the number of needle pitch of needle front shogging movement, $y \in (0,1,2)$; and y', the number of needle pitch of needle back shogging movement, $y' \in (0,1,2 \dots 14)$.

Algorithm for Length of a Stitch

Length of a stitch, as a knitted cell, can be deduced from the parameters in weave matrix. As shown in the partial enlarged view (Fig. 1), a stitch can be divided into four parts, namely an overlap, two sidelimbs and a underlap. The geometrical shape of an overlap can be viewed as a semicircle, and both the sidelimbs and the an underlap can be abstracted as straight-line segments under take-up tension from draw-off mechanism. Moreover, the value of y is identical to the number of overlap and half of the number of sidelimbs, and there is always one l_u in a stitch.
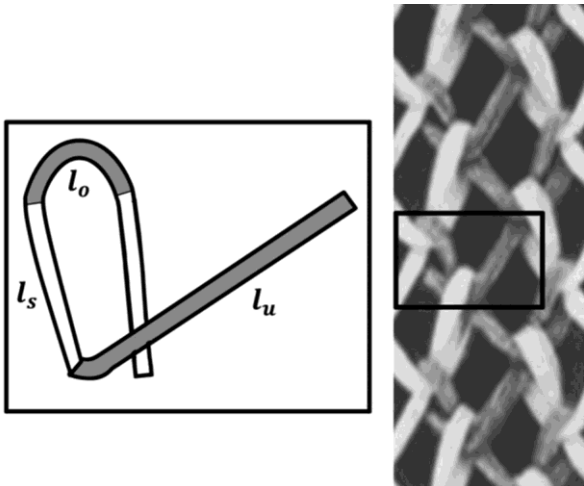
Hence, by considering the suggested geometry relationship in a stitch, the length of a knitted cell is given as:

$$l_{(j,k)} = y_{(j,k)} l_o(j,k) + 2 y_{(j,k)} l_s(j,k) + l_u(j,k) \quad \dots (4)$$

where l is the length of a loop in mm; l_o, the length of a overlap in mm; l_s, the length of a sidelimb in mm; and l_u, the length of a underlap in mm.

To predict length of a stitch, the relationship between the geometrical deformation of the four parts and the weave matrix of D_{Jn2} should be respectively considered, and more details of geometrical relationships are shown in Fig. 2. Firstly, the overlap can be considered as a semicircle with a diameter of width of needle hook. Moreover, a yarn in back bar is always threaded into the overlap formed by front bar, thus total bar number has a positive correlation with $l_o(j,k)$. Assuming that μ is the proportionality coefficient between the $l_o(j,k)$ with J bars and the one with J-1 bars, the $l_o(j,k)$ can be approximately considered as shown in following equation:

$$l_0(j,k) = \frac{y_{(j,k)} \mu^{J-1} \pi w}{2} \qquad \qquad \dots (5)$$

where w is the width of needle hook in mm.

Secondly, we can see that a sidelimb is slightly oblique under yarn tension from the underlap, and the distance of the deviation in course direction (m) increases with needle back shogging distance greater. Assuming that λ is the correlation coefficient between the distances of needle back shogging movement and

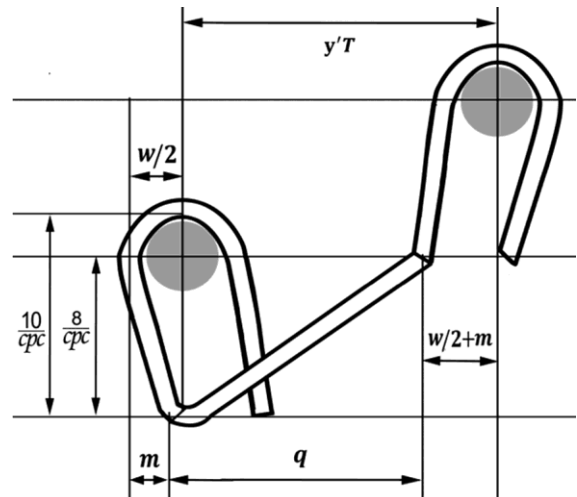Fig. 1–Enlarged schematic diagram of three parts of a stitch

Fig. 2–Geometrical relationship between four parts of a stitch

sidelimb deviation in course direction, $m_{(j,k)}$ can be represented by following equation:

$$m_{(j,k)} = \lambda T y'_{(j,k)} \qquad \ldots (6)$$

where T is the gauge distance in mm. Thirdly, a sidelimb can be considered as the hypotenuse of a right triangle in which the lengths of two right-tangle side are z_k and $m_{(j,k)}$. As shown in Fig. 2, there is a negative linear correlation between z_k and cpc, and z_k can be approximately considered as:.

$$z_k = \frac{8}{cpc_k} \qquad \ldots (7)$$

Thus, the length of a sidelimb can be deduced as following equation by the Pythagorean Theorem.

$$l_s(j,k) = \sqrt{z_k^2 + \left[\lambda T y'_{(j,k)}\right]^2} \qquad \ldots (8)$$

Finally, an underlap can also be abstracted as the hypotenuse of a right angled triangle. Length of the right-angle side in course direction (q) is mainly influenced by the y' as shown in Fig. 2 and can be represented as following equation:

$$q(j,k) = T y'_{(j,k)} - \frac{w}{2} \qquad \ldots (9)$$

Length of the other one in wale direction is approximately equal to z_k, thus $l_u(j,k)$ can be deduced from the following equation:

$$l_u(j,k) = \sqrt{z_k^2 + \left[T y'_{(j,k)} - \frac{w}{2}\right]^2} \qquad \ldots (10)$$

Combining the Eqs (4), (5), (7), (8), and (10), the length of a stitch in a warp-knitted fabric can be deduced from D_{Jn2}, as shown below:

$$l(j,k) = \frac{\mu^{J-1} \pi w y_{(j,k)}}{2} + 2 y_{(j,k)} \sqrt{\frac{64}{cpc_k^2} + \left[\lambda T y'_{(j,k)}\right]^2}$$

$$+ \sqrt{\frac{64}{cpc_k^2} + \left[T y'_{(j,k)} - \frac{w}{2}\right]^2} \qquad \ldots (11)$$

Predictive Algorithm for Run-in Values

Run-in is defined as the yarn consumption of each bar during 480 courses. Thus, based on length of stitch shown in Eq. (11), the run-in value of bar j can be indicated as in following Eq. (12). Therefore, combining Eqs (11) and (12), the algorithm model for predicting the run-in values of single-needle-bar warp knitted fabrics can be deduced, as shown below:

$$r_j = \frac{480}{n} \sum_{k=1}^{n} l_{(j,k)} \qquad \ldots (12)$$

$$r_j = \frac{480}{n} \sum_{k=1}^{n} \frac{\mu^{J-1} \pi w y_{(j,k)}}{2} + 2 y_{(j,k)} \sqrt{\frac{64}{cpc_k^2} + \left[\lambda T y'_{(j,k)}\right]^2}$$

$$+ \sqrt{\frac{64}{cpc_k^2} + \left[T y'_{(j,k)} - \frac{w}{2}\right]^2} \qquad \ldots (13)$$

where r_j represents the run-in value of the bar j in mm/rack.

On one hand, the parameters T and w are constants whose values depend on machine gauge. The values of T and w for different types of warp-knitting machines are shown in Table 1. On the other hand, in order to solve the parameters of μ and λ, and the parameters $y_{(j,k)}$, $y'_{(j,k)}$ and cpc_k for locknit, one of the most common warp-knitted structures were obtained from the weave matrix using the Eq (1), (2) and (7). Then, the parameters and actual run-in values for the locknit (Table 2) were substituted in Eqs (13). Finally, the solutions were obtained as μ=1.315 and λ=0.12. Thus, the predictive algorithm shown in Eq. (13) can be manifested by Eq. (14).

Experimental

Materials

Three single-bar warp knitting machines of HKS4_EL made by Karl·Mayer Co. Ltd with different

Table 1–Values of T and w for different gauges

Gauge needles/inch	E14	E20	E24	E28	E32	E36
Gauge distance (T), mm	1.81	1.27	1.06	0.91	0.79	0.71
Needles width (W), mm	0.7	0.7	0.55	0.5	0.41	0.41

$$\begin{cases} r_j = \frac{480}{n} \sum_{k=1}^{n} \frac{1.315^{J-1} \pi w y_{(j,k)}}{2} + 2 y_{(j,k)} \sqrt{\frac{64}{cpc_k^2} + \frac{\left[3 T y'_{(j,k)}\right]^2}{25}} + \sqrt{\frac{64}{cpc_k^2} + \left[T y'_{(j,k)} - \frac{w}{2}\right]^2} \\ y_{(j,k)} = \left| f_{(j,k)} - b_{(j,k)} \right| \\ y'_{(j,k)} = \left| f_{(j,k+1)} - b_{(j,k)} \right| \end{cases}$$

Equation (14)

Table 2–Parameters and actual run-in values of locknit

Bar number	Gauge needles/inch	Parameters in weave matrix			Actual run-in mm/rack
		cpc courses/cm	y	y'	
GB1	32	20	1	1	1170
GB2	32	20	1	2	1480

GB1–ground bar 1(j=1); GB2–ground bar 1(j=2).

gauge of 28, 32 and 36, polyester yarns of 6.1tex/24 filaments and statistical software of SPSS17.0 were used for this study.

The samples were divided into 5 groups with different parameters in the weave matrixes, i.e. shogging movement, total bar number and machine gauge. In addition, the values of *cpc* in each group were controlled within 10 to 36. Moreover, the details of the parameters of the samples are given in Table 3, from which the predicted run-in values are calculated with the proposed model as shown in Eq. (14).

Run-in Measurement

To measure the actual run-in values, all the 30 samples were knitted from the same 6.1 tex/24 filaments polyester yarns on single-needle-bar warp knitting machines of HKS4_EL made by Karl·Mayer Co. Ltd. These machines are equipped with EBC positive let-off system by which the run-in values of each bars can be measured in a precision of ±0.1%.

Analytical Method

The accuracy of the proposed predictive model can be evaluated by comparing the predicted run-in values with the measured ones. In his paper, the predicted run-in values were calculated with the proposed model shown in Eq. (14) based on the parameters of samples given in Table 3. Moreover, the predicted and measured run-in values of the 30 samples were compared using statistical software of SPSS17.0, and the estimated relative error can provide an evaluation criterion for model accuracy.

Results and Discussion

Validation of Predictive Accuracy

Figures 3 (a) and (b) show the comparison between the predictive run-in values and the experimental data, and the comparison demonstrates that the measured run-in values agree well with the predicted ones for all 5 samples groups. On one hand, results of the linear regression show that, for all 30 samples, the average relative error is 2.61% with a maximum relative error of 4.26% and a minimum relative error

Table 3–Parameters of 5 sample groups

Sample group	Parameters in weave matrixes				Gauge needles/inch
	cpc courses/cm	J	y	y'	
P_1	17	2	1	1	36
	21.5	2	1	1	36
	25	2	1	1	36
	28	2	1	1	36
	32	2	1	1	36
	36	2	1	1	36
P_2	14.9	2	1	1	32
	18	2	1	1	32
	20	2	1	1	32
	23	2	1	1	32
	28	2	1	1	32
	34.2	2	1	1	32
P_3	10	2	1	1	28
	13	2	1	1	28
	16	2	1	1	28
	19.8	2	1	1	28
	22	2	1	1	28
	25.7	2	1	1	28
P_4	17	2	1	2	36
	21.5	2	1	2	36
	25	2	1	2	36
	28	2	1	2	36
	32	2	1	2	36
	36	2	1	2	36
P_5	11	3	1	3	32
	14.9	3	1	3	32
	17.4	3	1	3	32
	22	3	1	3	32
	26	3	1	3	32
	30	3	1	3	32

of 0.40%. On the other hand, according to the practical experience in production, it is the basic prerequisite for the continuity, stability and reliability of production that errors of run-in values are below 10%. Therefore, it can be inferred from the comparison between the run-in values of model prediction and experimental measurements that the proposed algorithm model is capable to predict the run-in values of fabrics knitted on single-needle-bar warp knitting machines within acceptable error range. Moreover, as observed in Fig. 3, although both of the
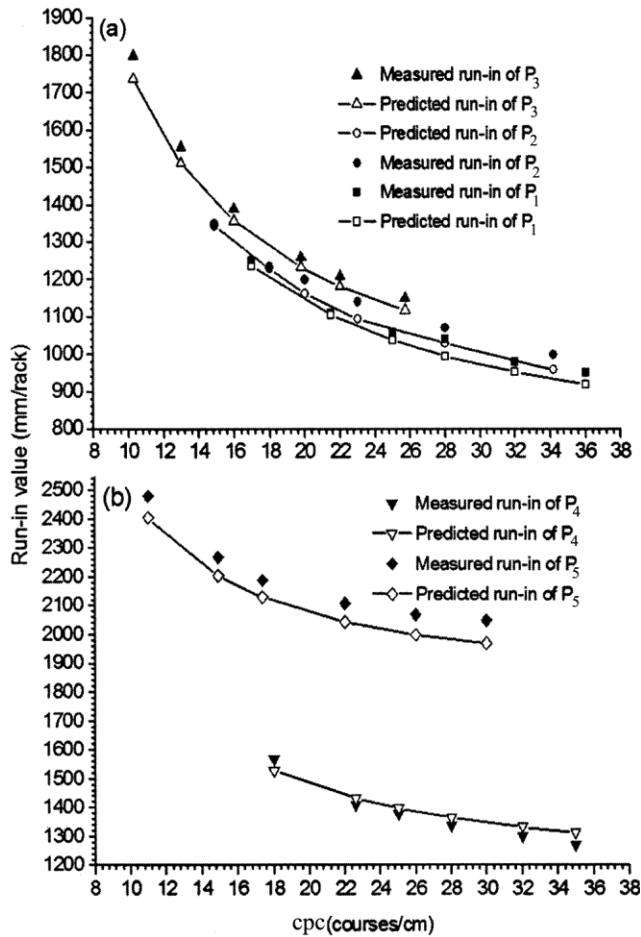
Fig. 3–Comparison between measured and predicted run-in values (a) P_1, P_2 and P_3; and (b) P_4 and P_5

two values keep a similar downtrend with increase of cpc, the forecasting error of the algorithm model slowly decreases to a minimum value and then slowly increases with the increase of cpc (courses/cm) from 10 to 36, indicating that precision of the predictive model is likely to be slightly superior when the cpc is in the range of 15-26.

Three-dimensional weave matrixes, as shown in Eq. (1), are established as mathematical model of single-needle-bar warp knitted fabrics, and a new algorithm model, as shown in Eq. (14), is developed based on the weave matrixes to predict run-in values of single-needle-bar warp-knitted fabrics. Prediction accuracy of the proposed algorithm is validated by comparing the predicted run-in values and environmental run-in values of 30 samples with different parameters. It can be concluded from the comparison that the proposed model can accurately predict the run-in values with a relative error of less than 4.26%, and when parameter cpc is within 15-26 courses/cm, the prediction results would be slightly more precise.

Acknowledgement

References

1 Jiang G, *Production Technlogy of Warp-kintted Fabric-warp Knitted theory and Typical Products* (China Textile & Apparel Press, Beijing), 2010, 134.
2 Dabiryan H & Jeddi A AA, *J Text Inst*, 102 (2011) 1065.
3 Das B, Das A, Kothari V K & Fangueiro R, *J Text Inst*, 10 (2011) 957.
4 Dabiryan H, Jeddi AAA & Rastgoo A, *J Text Inst*, 10 (2012) 1213.
5 Hallos R S & Sun F, *J Text Inst*, 88 (1997)282.
6 Nagham I, Nesreen G & Kamel G, *Text Res J*, 8 (2014) 2198.
7 H Cong & Ge M, *Fibres Text East Eur*, 17 (2009) 66.
8 Zhang Y, Jiang G, Yao J & Tong Y, *Text Res J*, 84 (2014) 28.
9 Badal M, Unmar R & Rosunee S, *Indian J Fibre Text Res*, 35 (2010) 172.
10 Jiang G, Gu L, Cong H, Miao X & Zhang A, *Fibres Text East Eur*, 22 (2014) 91.
11 Jiang G, Zhang D, Cong H & Gao Z, *Fibres Text East Eur*, 22 (2014) 53.