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Determination of handle of knitted fabrics using an objective measuring technique

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An objective approach to assess the handle of various knitted fabrics has been made by analyzing the force-displacement curves. In comparison to the conventional pulling-through method, a rounded sample is pulled through a hole and from the space between two horizontal plates and the required pulling force is measured with respect to the displacement of specimen, recorded as a force-displacement curve. The results of the correlation test show that the features of the pulling-through curves associate with all mechanical and surface properties, except fabric thickness and compression energy. For this reason, a combination of the features selected from pulling-through curve and the parameters, which reflect the compression properties and thickness of all kinds of fabrics, is recommended.

Keywords: Fabric handle, Knitted fabric, Mechanical properties, Pulling-through method, Surface properties

1 Introduction

The ease of pulling a fabric through a ring varies according to material type and fabric properties. This provides a measure of handle of fabric, as reported by Gunter[1]. He made a simple device to pull a piece of cloth through a porcelain pot eye and recorded the amount of required force. Sultan *et al.*[2, 3] developed a test method to measure fabric handle based on similar principles. They measured the force generated while a fabric specimen was pulled through a ring. The test apparatus consisted of an attachment fitted to a tensile-testing machine. The fabric was folded, compressed and rubbed against the interior wall of the ring during withdrawal.

The pulling force could be recorded on the tensile testing machine. The forces involved in the initial deformation are related to the bending modulus and shear stiffness of the fabric. Fabric friction with the inner surface of the ring and the extensibility of the fabric also affect the withdrawal force. Grover *et al.*[3] applied the maximum withdrawal force as a measure of fabric handle and reported that the pulling force correlates with fabric weight, bending properties, coefficient of friction and work of compression.

Pan and Yen[4] analysed the general shape of the pulling-through curve to identify the specific characteristics of the curve corresponding to the fabric properties as measured by KES-F system. They investigated correlation of the mechanical and physical properties of 48 different fabrics with features of the pulling-through curves obtained from conventional pulling-through method. They concluded that the pulling-through curve was strongly influenced by bending stiffness, compressional properties, surface roughness, tensile energy, thickness, weight and shear hysteresis of the fabrics.

Kim and Lewis[5] observed a strong positive relationship between hand values measured by pulling-through method and selected physical properties, such as fabric weight, flexural rigidity and drape coefficient. But no relationship was found between hand values and surface properties of the fabrics.

The variation in pulling force measured by conventional pulling-through method is high, as a result of variation in the folding configuration formed by the fabric passing through the ring. This variation may necessitate the need of increasing the number of tests. In order to reduce the variation in results as well as the control of the folding configuration during the withdrawing, a novel technique has been developed in this study, which is basically similar to the conventional pulling-through method. The correlations between features of the pulling-through curves with mechanical and surface properties, recommended by Kawabata[6], have been investigated.

2 Materials and Methods

Thirty-six (36) fabric specimens were knitted on the circular knitting machine using different fibres,

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yarns, fabrics and finishing specifications. The specifications of the knitted fabrics are shown in Table 1. The specimens were selected considering their use as summer T-shirt. The mechanical properties of the knits were measured using the KES instruments. Sixteen properties were measured under a standard condition, including tensile, bending, shear, compression and surface properties as well as thickness and weight of the knitted fabrics. Because anisotropy is a consideration in knitted fabrics, eleven of the tests (tensile, bending, shear and surface properties) were measured in both wale and course directions and mean values were used in data analysis. Furthermore, the fabrics were tested by the PDP

Table 1— Specifications of knitted fabrics

Fabric code	Yarn specifications	Spinning system	Fabric structure	Knit density loop/cm^2	Finishing stage
C001	Cotton / Nm 68/Carded	Ring	1x1 Rib	112	Dyed
C002	Cotton / Nm 68/Carded	Vortex	1x1 Rib	45	Dyed
V001	Viscose/ Nm 68/Carded	Ring	1x1 Rib	84	Dyed
V002	Viscose/ Nm 68/Carded	Vortex	1x1 Rib	60	Dyed
C01	Cotton/ Nm 50/ 750 TPM/Combed	Vortex	Plain single jersey	349	IB
C02	Cotton/ Nm 50/ 750 TPM/Combed	Open-end	Plain single jersey	357	IB
C03	Cotton/ Nm 50/ 750 TPM/Combed	Compact	Plain single jersey	352	IB
C05	Cotton/ Nm 50/ 750 TPM/Carded	Compact	Plain single jersey	352	IB
C10	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	333	IB
C04	Cotton/ Nm 50/ 750 TPM/Carded	Ring	Plain single jersey	344	IB
C06	Cotton/ Nm 50/ 850 TPM/Combed	Ring	Double cross tuck	192	IB
C07	Cotton/ Nm 50/ 850 TPM/Combed	Ring	Plain single jersey	341	IB
C08	Cotton/ Nm 50/ 850 TPM/Combed	Ring	Double cross miss	168	IB
C09	Cotton/ Nm 50/ 650 TPM/Combed	Ring	Double cross tuck	186	IB
C10	Cotton/ Nm 50/ 650 TPM/Combed	Ring	Plain single jersey	338	IB
C11	Cotton/ Nm 50/ 650 TPM/Combed	Ring	Double cross miss	161	IB
C12	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Double cross tuck	208	IB
C13	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	195	IB
C14	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Double cross miss	145	IB
C15	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	285	IB
C16	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	352	IB
A01	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	247	-
A02	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	300	IB
A03	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	320	I B+ S_1 (2%)
A04	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	320	I B+ S_2 (2%)
A05	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	320	I B+ S_2 (4%)
A06	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	320	I B+ S_3 (2%)
A07	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	300	NB
A08	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	310	N B+ S_1 (2%)
A09	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	310	N B+ S_2 (2%)
A10	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	310	N B+ S_2 (4%)
A11	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	310	N B+ S_3 (2%)
A12	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	315	Dyed
A13	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	315	N B+Dyed
A14	Cotton/ Nm 50/ 750 TPM/Combed	Ring	Plain single jersey	315	N B+Dyed+S_1

I B — Intensive bleaching at 80°C for 30 min with 1.5% H_2O_2.
S_1 — First softener (Tubingal 220), S_2— Second softener (Tubingal MSQ), and S_3— Third softener (Tubingal KRE).
N B — Normal bleaching at 98°C for 60 min with 15% H_2O_2.

Table 2—Range of mechanical and surface properties of the tested specimens

Properties	Maximum value	Minimum value	Average value
G (Shear stiffness), g/cm.deg	0.76	0.29	0.53
2HG (Hysteresis of shear force at 0,7 grad), g/cm	3.88	1.00	2.43
2HG5 (Hysteresis of shear force at 8,7 grad), g/cm	4.28	1.43	2.86
B (Bending rigidity), g.cm²/cm	20.76	0.88	10.82
2HB (Hysteresis of bending moment), g.cm/cm	36.51	1.60	19.05
WT (Energy in compressing fabric under 5 kPa), g.cm/cm²	162.02	73.03	117.51
RT (Tensile resiliency), %	30.70	17.00	23.80
LT (Tensile linearity)	0.74	0.59	0.67
WC (Compression work) g.cm/cm²	5.44	3.52	4.48
RC (Compressional resilience), %	48.09	28.05	38.07
LC (Linearity of compression)	0.33	0.42	0.38
MIU (Coefficient of steel/fabric friction)	0.30	0.21	0.25
MMD (Mean deviation of *MIU*)	0.020	0.012	0.016
SMD (Geometric roughness), µm	18.50	4.90	11.701
T (Thickness), mm	1.23	0.89	1.06
W (Weight), g/m²	197.40	118.03	157.70

method and the pulling-through curves were analyzed. The range of mechanical properties of the tested specimens is shown in Table 2.

2.1 Experimental Procedure

In this technique, the test is performed by a special pulling device, mountable on a tensile testing machine, which consists of two transparent horizontal plates, namely a replaceable base plate with a hole in the center and a distance plate made of plexiglass which is fixed at a specified distance from the specimen and base plate. In this technique (PDP method), a circular fabric sample (100 cm²) held by a pulling needle is placed on a base plate and pulled downwards through the hole and from the space between the two plates[7]. The principles of this technique are shown in Fig. 1. The rounded sample is pulled through the hole and the required pulling force is measured with respect to the displacement of specimen and recorded as a force-displacement curve. A typical pulling-through curve (force-displacement curve) obtained by PDP method is shown in Fig. 2. Applying a distance plate increases the number of creases and also the contact of the specimen with hole's wall. Therefore, it is expected that the features of the pulling-through curve associate better with mechanical and surface properties.

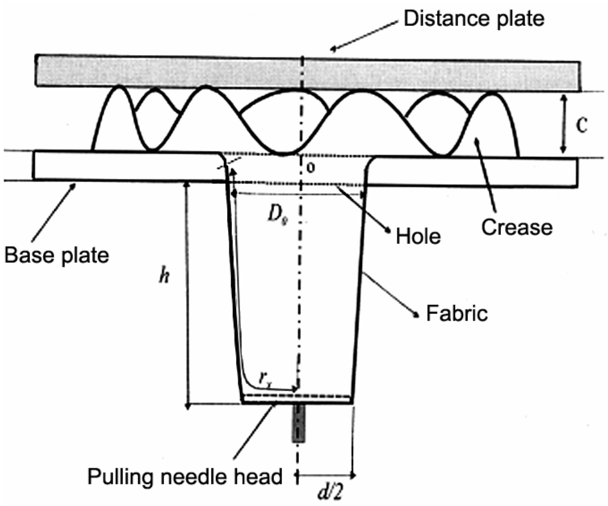

Fig. 1—Principle of PDP method

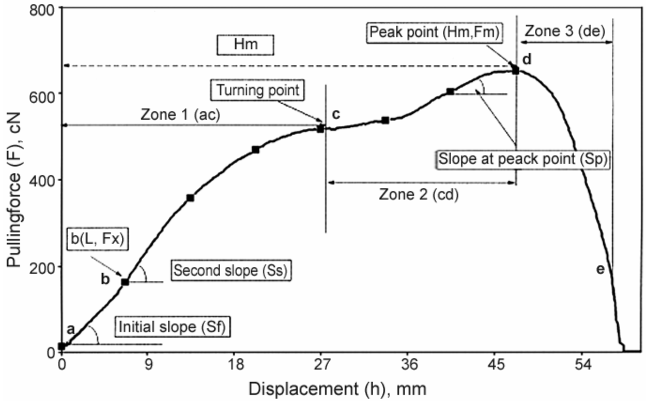

Fig. 2—Force - displacement curve obtained from PDP method

2.2 Correlation between Fabric Mechanical Properties and Pulling-through Curve

Although it has been theoretically proven by many researchers that the information related to fabric mechanical properties is contained in the pulling-through curve, yet there is no direct method available to derive information translating into well-defined physical and mechanical parameters or to identify the specific characteristics on the curve corresponding to known fabric properties. The statistical correlation analysis was the only tool which could be found to relate the results of different methods.

In the first approach, each of the knitted fabric was tested using the PDP method, and the pulling-through curve obtained was fed into a computer by data acquisition system in the form of a discrete data set *X*, as shown below:

$$X = (X_1, X_2, X_3, ..., X_n), \qquad n = 24. \qquad ...(1)$$

This data set was obtained from the distance between the start point and the peak point of each pulling-through curve. The result of a numeric differentiation of data set *X* is given below:

$$Z_k = \frac{X_n - X_{n-1}}{Q}, \qquad k = 1, 2, ..., 12. \qquad ...(2)$$

where Q is the interval between X_n and X_{n-1} which is assumed to be constant for all pulling-through curves. In fact, Z_k represents the slopes of various locations on the pulling-through curve. Hence, for each fabric sample, there are now two data sets, one set from sixteen mechanical parameters and another Z_k set from numerical differentiation of the X set. The statistical correlation analysis is used to correlate these data sets. Table 3 shows the correlation coefficients of this analysis.

2.3 Selection of Pulling-through Curve Features

In order to understand how pulling-through curve features correlate with mechanical properties of the fabrics, an easier and simpler approach was used to examine the shape of the curve. Following six characteristics of the pulling-through curve (Fig. 2) were chosen:

(i) Initial slope of the pulling-through curve (S_f). This slope is taken out at the start point of the curves.

(ii) Second slope of the pulling-through curve (S_s). It must be calculated when the sample is completely in contact with the hole's wall. The complete contact occurs after the sample is pulled more than 5 mm (the height of the hole) downwards.

(iii) Slope of the pulling-through curve before peak point (S_p). This slope is taken out at the peak point of the curves.

(iv) Maximum pulling force (F_m).

(v) Area under the pulling-through curve (A).

(vi) Peak location (H_m).

These features can be easily extracted from the pulling-through curves.

3 Results and Discussion

Correlation between pulling-through curve features and mechanical properties has been analysed. The results reveal that except compression energy (*WC*) and thickness (*T*), the Z_k set obtained from pulling-through curves highly correlates with all mechanical and surface properties as recommended by Kawabata. Moreover, the fabric bending and shear properties

Table 3— Correlation between mechanical and surface properties and slopes of various locations on the pulling-through curve

Parameter	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}	Z_{12}
WT	-0.090	-0.180	-0.150	-0.290	-0.360*	-0.220	-0.140	-0.060	0.038	0.142	0.082	-0.020
RT	-0.380*	-0.47**	-0.44**	-0.420*	-0.44**	-0.48**	-0.300	-0.250	-0.220	-0.220	-0.180	-0.310
LT	0.741**	0.335*	0.114	0.319*	0.396*	0.264	0.100	0.453**	0.451**	0.248	0.019	0.242
2HG	0.768	0.663**	0.477**	0.64**	0.74**	0.651**	0.376*	0.46**	0.548**	0.427**	0.289	0.434**
2HG5	0.781**	0.651**	0.451**	0.621**	0.732**	0.65**	0.401**	0.455**	0.562**	0.432**	0.282	0.416**
G	0.784**	0.586**	0.382**	0.611**	0.71**	0.482**	0.241	0.479**	0.547**	0.425**	0.211	0.391*
B	0.648**	0.813**	0.711**	0.767**	0.759**	0.68**	0.260	0.336*	0.52**	0.569**	0.508**	0.534**
2HB	0.588**	0.890**	0.806**	0.831**	0.841**	0.813**	0.372*	0.332*	0.536**	0.572**	0.586**	0.573**
W	0.384*	0.420**	0.324*	0.323*	0.309*	0.315*	0.159	0.289	0.565**	0.56**	0.584**	0.437**
T	-0.050	0.204	0.263	0.178	0.129	0.177	-0.00	-0.1700	-0.1300	0.062	0.135	0.136
WC	-0.230	-0.210	-0.120	-0.230	-0.240	-0.210	-0.07	-0.1200	-0.2600	-0.200	-0.030	-0.150
RC	-0.59**	-0.350*	-0.230	-0.280	-0.31*	-0.34*	-0.290	-0.37*	-0.39*	-0.290	-0.180	-0.33*
LC	-0.37*	-0.210	-0.120	-0.240	-0.220	-0.200	0.0220	-0.000	-0.010	-0.030	0.177	-0.080
MIU	-0.02	0.368*	0.49**	0.413**	0.408**	0.547**	0.267	0.060	0.084	0.197	0.313*	0.274
MMD	0.056	0.355*	0.307*	0.357*	0.364**	0.199	0.08	-0.070	-0.09	-0.04	-0.010	0.054
SMD	0.059	0.762**	0.871**	0.749**	0.672**	0.652**	0.202	-0.120	0.100	0.273	0.407**	0.368*

* Significant at the 0.05 level, ** Significant at the 0.01 level.

Z_1-Z_{12} — Slopes of various locations on the pulling-through curve.

have the highest correlation coefficients with the Z_k set obtained from pulling-through curves. The correlation between selected pulling-through curve features and the mechanical properties of the fabrics is also investigated. Table 4 shows the correlation coefficients between mechanical and surface properties of fabrics and five selected curve features.

The results show that the bending properties (*B* and *2HB*) have the highest correlation coefficient with features selected from the pulling-through curves (Fig. 2). This indicates that the bending properties are the most important parameters which influence the resistance of a fabric passing through a hole. Naturally higher values of the bending rigidity and hysteresis lead to a higher pulling force. The area under the curve (*A*) and the maximum pulling force (F_m) have the highest correlations with the *B* and *2HB* values. Figure 3(a) shows the relationship between area under the curve (*A*) and bending rigidity (*B*) of fabrics.

Shear properties are also important parameters which influence the pulling-through curve features. The influence of shear stiffness (*G*) on the initial slope (S_f) is more than other pulling-through curve features, because initial slope has the highest correlation with shear stiffness. When a fabric specimen is pulled through a hole, creases are generated and consequently shear forces develop on the fabric. When a distance plate is used, fabric shearing becomes more intensive, since the distance plate multiplies the number of creases. Figure 3(b) shows the relationship between initial slope (S_f) and the shear stiffness (*G*).

Pulling-through curve features also correlate significantly with the fabric weight. Since fabric weight is related to loop density as well as bending properties of the knitted fabric, the slope at peak point (S_p) and peak location (H_m) have the highest correlations with the fabric weight.

There is a high correlation between the surface properties and the second slope (S_s) and the area under pulling-through curve (*A*), owing to the fact that the fabric has a great contact to the base plate and distance plate. Moreover, the direction of fabric movement in PDP method changes at 90°. This provides a high contact between hole's wall and the specimen during withdrawing. Figure 3(d) shows the relationship between second slope (S_s) of the pulling-through curve and fabric roughness.

The scientists[3,5], who used the conventional pulling-through method to investigate the fabric handle, have reported that the correlation between curve features and surface properties is not significant. In comparison to conventional pulling-through method, a high correlation between some pulling-through curve features of the PDP method and surface properties can be observed. On the other hand, this case can be one of the advantages of the PDP

Table 4— Correlation between mechanical and surface properties of fabrics and five selected curve features

Parameter	F_m	H_m	A	S_f	S_s	S_p
WT	-0.140	0.347*	-0.150	-0.150	-0.150	0.059
RT	-0.480**	-0.380**	-0.490**	-0.390**	-0.480**	-0.28
LT	0.397*	-0.02	0.370*	0.789**	0.176	0.303*
2HG	0.727**	0.324*	0.713**	0.782**	0.544**	0.532**
2HG5	0.715**	0.284	0.699**	0.792**	0.521**	0.530**
G	0.660**	0.224	0.644**	0.820**	0.457**	0.504**
B	0.811**	0.497**	0.815**	0.650**	0.756**	0.653**
2HB	0.887**	0.575**	0.902**	0.610**	0.847**	0.678**
W	0.496**	0.527**	0.462**	0.341*	0.366*	0.637**
T	0.156	0.315	0.188	0.090	0.284	0.034
WC	-0.200	0.104	-0.200	-0.130	-0.1200	-0.220
RC	-0.440**	-0.360**	-0.400**	-0.690**	-0.2700	-0.330*
LC	-0.1900	-0.0600	-0.200	-0.520**	-0.1600	0.011
MIU	0.414**	0.572**	0.427**	-0.040	0.506**	0.261
MMD	0.1800	-0.2500	0.230	0.1800	0.292	-0.06
SMD	0.632**	0.457**	0.694**	0.046	0.863**	0.363*

* Significant at 0.05 level, ** Significant at 0.01 level.

F_m— Maximum pulling force, H_m—Maximum displacement, *A*—Area under pulling curve,
S_f— Initial curve slope, S_s—Second slope, and S_p—Slope at peak point.

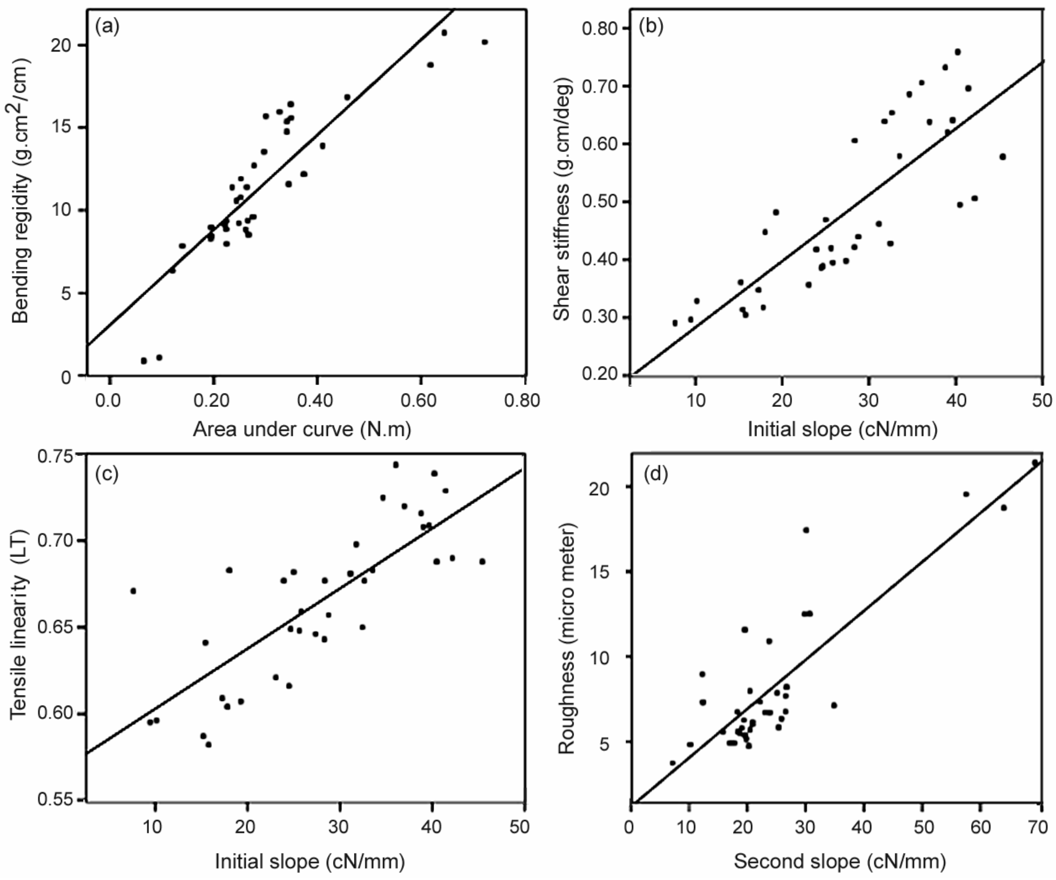

Fig. 3—Relationship between various fabric mechanical properties and pulling-through curve features

method as compared to conventional pulling-through method.

During withdrawing, the change of the fabric direction in the hole acts as a brake. The fabric resists the withdrawing and the specimen is elongated. It is therefore expected that the tensile properties of the fabric affect the features of pulling-through curve. The area under pulling-through curve (*A*), the initial slope (S_f) and the peak location (H_m) correlate highly with fabric tensile properties. Figure 3(c) shows the relationship between first slope of the pulling-through curve and tensile linearity.

Except compression recovery (*RC*), there is no correlation between pulling-through curve features and compression properties. In addition, fabric thickness is also not correlated with curve features.

In the previous studies[3,5,6,8], only one pulling-through curve feature was used, like the maximum pulling force as a measure of fabric handle and discarded the rest of the curve information. Because the fabric handle is a complex phenomenon, a single index is not complete enough to represent it. However, the shortcoming of the method was pointed out. In a novel approach, it was focused on those features of the pulling-through curves which have the highest correlation with mechanical and surface properties measured by KES-FB instruments. Various variables extracted from pulling-through curve can serve as powerful parameters to distinguish differences in overall fabric handle. These features are as follows:

(i) Initial slope of the pulling-through curve (S_f) — It correlates signifantly with shear properties (0.875) and tensile linearity (0.675). Therefore, it can be considered as an indicator for these fabric properties.

(ii) Second slope of the pulling-through curve (S_s) — This feature, which is the result of the fabric contact at two parallel plates and the hole's wall, correlates signifantly with the fabric roughness (0.863), bending hysterisis (0.847) and bending rigidity (0.756) . Therefore, it can be considered as an indicator of fabric roughness and bending properties.

(iii) Area under the pulling-through curve (A) — This feature can be considered as an indicator of bending properties and tensile resilience.

(iv) Maximum displacement of the pulling-through curve (H_m) — The comparison of the samples based on this feature can be an indicator to compare the extensibility and the surface friction of the fabric.

(v) Slope of the pulling-through curve before peak point (S_p) — This feature can be considered as an indicator of fabric weight.

It is necessary to note that the features chosen from pulling-through curve cannot describe completely the handle of a fabric because they are not correlated in some cases, with thickness and compression properties. For this reason, a combination of the features selected from the pulling-through curve and the parameters, which reflect thickness and compression properties of the knitted fabrics, is recommended. Therefore, the following features must be added:

- Hardness (H)— This is determined by the following formula [9]:

$$H = \frac{P_m - P_0}{T_0 - T_m} \qquad \ldots(3)$$

where P_0 is the 10 cN/cm²; T_m, the thickness in cm under pressure 10 cN/cm²; P_m , the 100 cN/cm²; and T_0, the thickness in cm under pressure 100 cN/cm². This parameter reflects the compression properties of the fabrics.

- Fabric thickness (T) — For comparison between individual fabrics, the mean and standard deviations of the above parameters and the features of the pulling-through curve were standardized. The standardized values were charted on the polar diagrams, which show the relative position of one fabric to another. Figure 4 shows a typical polar diagram which describes the handle of three single jersey knitted fabrics with different structures. The polar diagram includes nearly all fabric characteristics, which are needed to evaluate handle of a knitted fabric. In order to compare the handle of different fabrics based on polar diagrams, the area under each curve(Φ) can be applied. According to the polar diagram (Fig. 4), it can be concluded that the handle of fabric A3 is worse than fabrics A2 and A1.

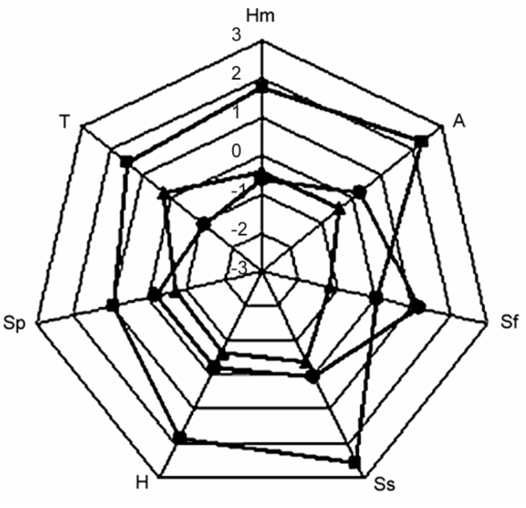

Fig. 4—Typical polar diagram of three single jersey knitted fabrics with different structures [–●–A1 plain single jersey, –▲–A2 double cross miss, and –■–A3 double cross tuck]

4 Conclusions

The results of correlation analysis reveal that other than compression energy and thickness, the curve features obtained from PDP method highly correlate with all mechanical and surface properties as recommended by Kawabata. Therefore, the features chosen from pulling-through curve cannot describe entirely the handle of summer knitted T-shirts since in some cases, they do not correlate with thickness and compression properties. For this reason, a combination of the features selected from pulling-through curve and the parameters, which reflect the compression properties and thickness of all kinds of fabrics, is recommended. These parameters and the features from the pulling-through curve can be plotted by a polar diagram.

The PDP method demonstrated effectiveness in detecting changes in fabric handle affected by different parameters. Theoretical investigations of the knitted fabric behavior reveal that the pulling-through method reported could be considered not only as an instrumental basis for the measurement and prediction of the textile handle, but also as a suitable method for the evaluation of anisotropy, drapeability, and other specific properties of textile materials.

Industrial Importance: The PDP technique is advantageous due to its complicity and easy adaptability to the textile testing laboratories. It is not time consuming and interpretation of the results is not complicated. This measuring method is inexpensive and gives a good prediction of fabric performance as a garment. The textiles produced in different systems can be tested by this technique. It could be a useful quantitative method to determine the fabric handle during product development, quality control and consumer preference studies. These advantages make the PDP method suitable for industrial applications, especially in the case of small-scale apparel and textile manufactures.

References

1 Gunter D, *Am Dyest Rep*, 46 (1952) 89.
2 Sultan M and Grover G , *Text Horizons*, 10(13) (1992) 17.
3 Grover G, Sultan M & Spivak S M, *J Text Inst*, 84 (3) (1993) 486.
4 Pan N and Yen K C, *Text Res J*, 62 (1992) 279.
5 Kim J O & Lewis B, *Text Res J*, 67 (1999) 59.
6 Kawabata S & Niwa M, *J Text Inst*, 80 (1989) 19.
7 Seidel A, *Melliand Textilber*, 6 (2001) 491.
8 Ze Li, *Proceeding, 7 th International Wool Textile Research Conference*, (Taylor & Francis Inc., Tokyo, Japan), 1985, 71.
9 Hallos R S, Burnip M S & Weir A, *J Text Inst*, 81 (1) (1990) 15.