ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 12, No. 1. 2006

The Optimization of Complex Hand Rate Determination

Diana GRINEVIČIŪTĖ[1*], Laima PAPRECKIENĖ[2], Matas GUTAUSKAS[1]

[1]*Faculty of Design and Technologies, Kaunas University of Technology, Studentų 56, LT-51424 Kaunas, Lithuania*
[2]*Faculty of Fundamental Science, Kaunas University of Technology, Studentų 50, LT-51368 Kaunas, Lithuania*

Received 31 May 2005; accepted 01 July 2005

The article presents an objective evaluation of textile hand during the extraction of a disc shaped specimen through a central hole. The influence of separate extraction curve *H–P* parameters on the numerical hand value is analyzed. Two types of the extraction curve parameters that determine force and deformational fabric properties characterize fabric behavior during the extraction process. The optimal set of parameters for different fabric types is defined. The complex hand rate is expressed as the polygon area of a circular chart. The significance of parameters set arrangement in a circular chart is established. Also two equations for textile hand determination are presented.
Keywords: textile, hand, mechanical properties, complex rate, instrumental measurement.

INTRODUCTION

Textile hand evaluation method based on the extraction process of a disc shaped specimen through a central hole is considered to be a simple and perspective method for fabric stiffness, drape, anisotropy and other mechanical properties determination. During the test the specimen is slipping, folding, bending and is affected by complex tension and compressive deformations that are similar to the garment wear conditions.

Recently such kind of research was reported in [5 – 9]. Since 1998 investigations based on an unstrained sample extraction process and possible sample loading and restriction variations were fulfilled. Also typical extraction curves and fabric mechanical characteristics under different load conditions were analyzed. A special attention was paid to the evaluation of specimen's geometry changes and to the prediction of specimen's behavior. It's stated that fabric behavior during the extraction process could be estimated from the shape of the extraction curve, it's typical peaks and deflection position, also from the stepped shape and the sharpness of the beginning and the end of the extraction curve [10 – 12]. Thereby during a single test multiple fabric properties such as: softness, stiffness, elasticity, friction, drape and others can be determined. The method of the restricted pulling can also be applied to the evaluation of fabric anisotropy.

The search of fabric hand objective valuation is of great significance. Textile hand is defined as the subjective assessment of fabric, obtained from the sense of touch. Subjective hand characterization by touching, bending, creasing the investigated fabric is not trustworthy because of disagreement in a judges' panel (the same fabric property could be characterized by separate judges in different ways) [13 – 15].

Objective evaluation is based on parameters (number values) which are assessed instrumentaly. Textile hand is used to be evaluated by the same method as well known complex rate of fabric quality – from the polygon area in an appropriate circular chart. Several parameters are obtained from the fabric extraction curve (deflection height – extraction force). Values of parameters then are recalculated into the scale and marked down the axes of a circular chart, and the obtained points are joined by the straight lines which form the polygon. According to this, the better fabric quality is characterized by the less area [16]. It was noticed that the area of the polygon depends on the order of axes arrangement. Consequently the software was applied to pick out the sets of parameters arrangement which determine the less polygon area of all possible variants. In comparison the software also scores the maximal area value. Then comparing the minimal polygon areas, it is possible to clasify various fabrics according to the magnitude of their hand values, and to characterize them as fabrics of gentle, medium and poor hand. Thereby the unified method for textile hand measurement for different fabric types was created.

The earlier publications concerning the assessment of fabric hand introduced several variants of complex hand evaluation, such as: fabric hand modulus application [17, 18], mathematical expression of total hand value (THV) [19], the comparison of evaluated fabric and the sample fabric [17, 18] and the circular chart of the complex hand rate [16]. Developing the unified complex hand rate evaluation method and optimizing the set of parameters and their arrangement order in a circular chart would allow to compare different fabrics among themselves.

The aim of this work is to optimize textile hand evaluation method: to form an optimal set of parameters, to predict the influence of the arrangement of parameters' set on the precision of complex hand rate, to compare different mathematical equations of the complex hand rate.

EXPERIMENTAL

The test was performed with KTU-Griff-Tester attached to the standard tensile testing machine [5, 6, 14].

The objects of investigation were 37 clothing fabrics (woven and knitted) of different thickness, composition and structure (Table 1). More detailed information about investigated fabrics was presented in our earlier work [15].

*Corresponding author. Tel.: + 370-37-706941; fax.: +370-37-353989.
E-mail address: *diana.grineviciute@stud.ktu.lt* (D. Grinevičiūtė)

Table 1. The objects of investigation

Fabric group (number)	Areal density, g/m^2	Thickness δ, mm
Suiting woven fabric (19)	59 – 365	0.10 – 1.04
Outwear woven fabric (5)	244 – 505	0.81 – 2.35
Knitted fabric (13)	84 - 437	0.32 – 2.10

The circular specimen with the radius $R = 56.5$ mm (100 cm^2) was extracted by the spherical punch of radius 5 mm through the central hole. Extraction speed $v = 100$ mm/min. The distance between limitting plates h and the radius of a circular hole of the lower plate r were chosen in respect to the thickness of tested fabric δ and taking into account the conditions of specimen jamming between limitting plates and in the hole [5, 6]:

$$\begin{cases} \pi r^2 > 2\pi R\delta \\ 2\pi rh < 2\pi R\delta \end{cases}.$$

Optimal test regimes [6]:

when $0 < \delta < 0.9$; $r = 10$; $h = 5.6\delta$;

when $1.0 < \delta < 1.4$; $r = 12.5$; $h = 4.5\delta$;

when $1.5 < \delta < 2.0$; $r = 15$; $h = 3.8\delta$.

During the test extraction curve H–P (deflection height – force) was registered (Fig. 1) and on its basis primary hand parameters were determined:

P_{max} – maximal force,

tgα – initial slope angle,

A – pulling work,

H_{max} – maximal deflection height,

H – deflection height, which corresponds to P_{max},

$\Delta H = H_{max} - H^*$ – difference between maximal deflection value and its theoretical value H^* ($H^* = 52$ mm, when $r = 10$ mm) [6].

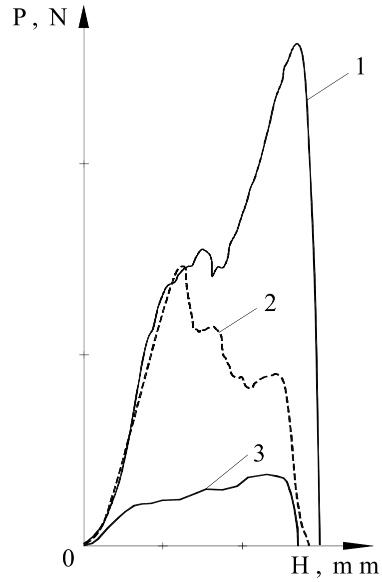

Fig. 1. Typical extraction curves H–P: 1 – woven fabric, 2, 3 – knitted fabrics

Other parameters: the distance between limitting plates h and the weight of specimen m were determined separately. The variation of fabric thickness $\Delta\delta$ due to the changes of measurement loading (ratio 1 : 5) was measured with special device [14].

Some changes were made in the process of the test. Parameters H and ΔH were derivative; also a big number of parameters accomplished the processing of results. According to this it was decided to refuse the evaluation of parameters H, ΔH, h and m.

Fabric softness is supposed to be the primary hand property that is characterized by initial parameters $\Delta\delta$ and H_{max}. Compression is a characteristic property of woven fabrics but elongation during the extraction process was insignificant, that is why the parameter H_{max} varied between (52.0 – 57.0) mm [6, 14, 15]. It is possible to eliminate the parameter H_{max} from woven fabrics evaluation and narrow the set of parameters to the four, mentioned above. However deformational properties are inherent for knitted fabrics. The parameters $\Delta\delta$ and H_{max} defining fabric softness and compression varied in a wide range, therefore knitted fabrics hand was evaluated by the five parameters.

All the measured and recalculated values of parameters $p_1, p_2, \ldots, p_n$ (n = 3, 4 or 5) of a separate fabric were marked down the axes $0x_1$, $0x_2$,…, $0x_n$ of a circular chart (Fig. 2), which were drawn from the centre 0 at the angles of $\frac{2\pi}{n}$. But if the values were of a great difference they were relocated to the 10 units scale (100 %) where the minimal value of several parameter corresponded to the point marked 1, and maximal – to the point 11. If p_k was the value of parameter, when $k = 1,\ldots, n$; and $M_k = \max p_k$, $m_k = \min p_k$, then a new value (1) marked out the axis $0x_k$ was:

$$x_k = 1 + \frac{p_k - m_k}{M_k - m_k} 10 . \quad (1)$$

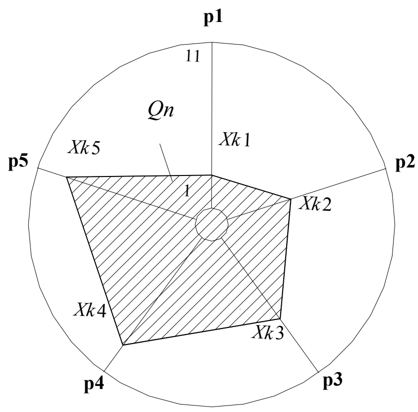

Fig. 2. The principal scheme of the circular chart

The obtained area of n – polygon (Fig. 2) was expressed as the complex hand rate Q_n:

$$Q_n = \frac{1}{2}\sin\frac{2\pi}{n}(x_1x_2 + x_2x_3 + x_3x_4 + \ldots + x_{n-1}x_n + x_nx_1) \cdot \quad (2)$$

In this research complex hand rate was calculated as the ratio of the area of n – polygon (2) with the area of a circular chart $Q = \pi \cdot 11^2 \approx 379.94 \approx 379.9$, i. e. Q_n/Q.

The better fabric hand is characterized by the lower values of parameters. If fabric hand became better because of an increase of any parameter's p value, this value then was relocated on the axis in reverse direction, i. e. instead of p in Equation (1) the value was $(11 - p)$.

The unified hand evaluation of different fabric types was performed using five, four and three initial parameters that characterize fabric mechanical properties.

Five parameters were registered during the extraction process of knitted fabrics:

$$p_1 = P_{max}\,;\; p_2 = \mathrm{tg}\alpha\,;\; p_3 = A\,;\; p_4 = \Delta\delta;\; p_5 = H_{max}\,. \qquad (3)$$

The calculations for all fabric types were performed twice. Complex hand rate Q_5 (2) was obtained when the order of parameters arrangement was according to Equation (3). After that the software was used to select $2 \cdot 5 = 10$ variants with minimal value of Q_5 of all possible $1 \cdot 2 \cdot 3 \cdot 4 \cdot 5 = 120$ variants of the arrangement of parameters. In both cases investigated fabrics were grouped in accordance to minimal Q_5 value. In comparison the maximal value of Q_5 was calculated.

Also the rate Q_4 that expresses woven fabrics properties was calculated for all evaluated fabrics according to Equation (2) when $n = 4$ (excluding H_{max}). Then the software from $1 \cdot 2 \cdot 3 \cdot 4 = 24$ possible variants picked up those $2 \cdot 4 = 8$ with minimal Q_4 value.

To analyze all possible variants of fabric hand expression, besides the techniques mentioned above, only three force parameters p_1, p_2 and p_3 in Equation (3) were used. Such set of parameters was chosen for stiff and hard woven fabrics hand evaluation. In this case the arrangement of parameters had no influence on the precision of complex rate Q_3.

Besides the first method (the calculation of polygon area in a circular chart) more simple method for fabric hand evaluation might be recommended. That is the sum G of recalculated values of parameters:

$$G = p_1 + p_2 + \ldots + p_n\,. \qquad (4)$$

RESULTS AND DISCUSION

Investigations have revealed that when the number of parameters $n > 3$, the precision of complex hand rate Q_n depended on their arrangement order in a circular chart. Complex hand rates were evaluated by two methods: *I* – using fixed order of parameters arrangement and *II* – according to the minimal value of Q_n. Then evaluated fabrics comparing Q_n/Q values were classified into three groups: fabrics of gentle, medium and poor hand. The standard fabrics E1 (gentle hand) and E2 (poor hand) were selected [20]. The average values of rates Q_n/Q were calculated for each group of fabrics thus they were compared in between (Fig. 3).

Minimal Q_5/Q values (method *II*) in several fabric groups noticeably differed from those achieved in method *I* (Fig. 3, a). Using fixed order of five parameters arrangement the values of Q_5/Q were close to maximal ones. In the case of four parameters the dependence of parameters arrangement and the precision of the rate Q_4/Q was tenuous, for the rates determined in both methods were almost similar (Fig. 3, b).

Evaluating fabrics only by three parameters, complex hand rate remained of the same value in all cases and it didn't depend on the arrangement of parameters.

According to the obtained results there were displayed general intervals of complex rates Q_n/Q variation: Q_5/Q – [0.037 – 0.336]; Q_4/Q – [0.018 – 0.252], Q_3/Q – [0.003 – 0.150]. Appropriate intervals of Q_n/Q change in separate fabric groups are presented in Figure 3.

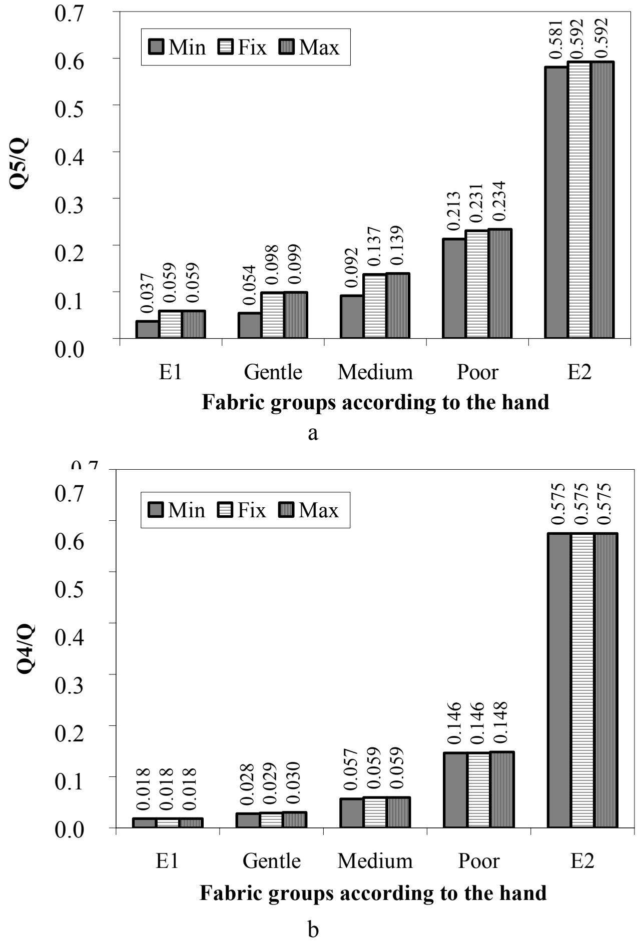

Fig. 3. The comparison of complex hand rate Q_n/Q using distinct order of parameters arrangement: a – Q_5/Q; b – Q_4/Q (Min – minimal values of Q_n/Q, Fix – fixed order of parameters arrangement, Max – maximal values of Q_n/Q, E1 – standard fabric of the best hand, E2 – standard fabric of the worst hand)

In order to unify the test conditions it was recommended to use the software for minimal complex hand rate Q_n achievement. The aim of this investigation was to simplify the determination of complex hand rate, thereby it was stated that there is no point to evaluate different fabric types together using 5 parameters – only 4 was enough. As the order of 3 parameters' arrangement didn't influence the precision of complex rate, it is recommended to use only three force parameters $P_{max} - \mathrm{tg}\alpha - A$ for unified complex hand rate evaluation and comparison of results.

It was noted that the variation of complex hand rate depended on the separate fabric group (Table 2): the ratio of parameters in the fabric group with gentle hand (soft ones) was maximal, and in the fabric group with poor hand (stiff ones) – minimal. This could be explained according to the proportion of polygon area in a circular chart for fabrics with poor hand: in all cases of parameters arrangements the large areas of polygons influenced their inconsiderable ratios.

Table 2. The comparison of complex hand rate

Q_n ratio, %	Fabric group				
	E2	Poor hand	Medium hand	Gentle hand	E1
Q_5/Q_4	1.03	31.5	38	48.1	57.1
Q_4/Q_3	28	45.9	71.9	71.4	83.3
Q_5/Q_3	28.7	62.9	82.6	85.2	92.9

Table 3. The variation limits of hand parameters

Parameter p	Parameter value		Ratio p_{max}/p_{min}
	p_{min}	p_{max}	
P_{max}, N	1.36	87.3	64.2
tgα	0.76	71.4	93.9
A, N·cm	3.79	300.2	79.2
$\Delta\delta$, %	6.19	25.0	4.04
H_{max}, mm	52.0	67.8	1.30
Q_5/Q	0.037	0.581	15.7
Q_4/Q	0.018	0.575	31.9
Q_3/Q	0.003	0.414	138

Note: initial hand parameters expressed in their actual values, and rates Q_n – in recalculated values.

The change of complex rate in fabric group with gentle hand was more significant because of insufficient precision of parameters $\Delta\delta$ and H_{max}. These parameters were not reliable to the behavior of very soft and flexible fabrics. According to this reason the areas of Q_5 polygons in circular charts were disproportionaly large.

In order to ascertain the influence of deformational parameters to dispersion of Q_5 data, the variation limits of initial hand parameters were defined. The obtained data is presented in Table 3. The results show that the most precise were initial force parameters P_{max}, tgα and A. This could be proved by a significant ratio of maximal and minimal value of appropriate parameter. Whereas the change limits of fabric deformational parameters were very narrow: the ratio of $\Delta\delta$ values was 4.04 and the ratio of H_{max} – only 1.3.

The change limits of complex hand rates Q_n/Q were also set in this investigation. According to the data it was stated that the most precise results of fabric hand were obtained by the rate Q_3, and the less – by Q_5 (the ratio of maximal and minimal Q_5/Q values was 15.7, and the ratio of Q_3/Q values – 138).

In our earlier works underwear knitted fabric E1 was certified as a standard fabric characterized by a gentle hand, i. e. thin, soft, flexible and smooth [20]. Consequently the values of its force parameters were the lowest (Table 4). A standard fabric with poor hand (E2), that was stiff and hard denim, was characterized by force parameters of maximal values (Table 4).

Obtained results revealed overall regularities between force and deformational parameters and rates Q_n in cases of 5, 4 and 3 initial parameters. Data in Table 5 show that relations between Q_n and initial force parameters P_{max}, tgα and A were significant in all cases. As mentioned above,

Table 4. Standard fabrics characteristics and hand parameters

Fabric	Composition	Thickness δ, mm	Area density, g/m^2	Parameter			
				P_{max}, N	tgα	A, N·cm	Q_3/Q
Underwear knitted fabric E1	100% rayon	0.42	135	1.36	0.76	3.79	0.003
Denim woven fabric E2	100% cotton	0.88	429	87.3	71.4	300.2	0.414

Table 5. Dependencies between complex hand rate Q_n/Q and initial parameters of H–P curve

Parameter		Q_{min}/Q		Q_{fix}/Q	
x	y	R^2	Function	R^2	Function
P_{max}	Q_5/Q	0.9216	$y = a + bx$	0.8114	$y = a + bx^2$
tgα		0.9629	$y = a + bx$	0.8552	$y = a + bx^2$
A		0.9107	$y = a + bx$	0.7941	$y = a + bx^2$
$\Delta\delta$		0.0529	$y = a + b(\ln x)^2$	0.1440	$y = a + b(\ln x)^2$
H_{max}		0.0126	$y = a + b\ln x/x$	0.0334	$y = a + b\exp(-x/c)$
P_{max}	Q_4/Q	0.9591	$y = a + bx^2$	0.9577	$y = a + bx^2$
tgα		0.9688	$y = a + bx^2$	0.9659	$y = a + bx^2$
A		0.9489	$y = a + bx^2$	0.9473	$y = a + bx^2$
$\Delta\delta$		0.0642	$y = a + b(\ln x)^2$	0.0674	$y = a + b(\ln x)^2$
P_{max}	Q_3/Q	0.9952		$y = a + bx^2$	
tgα		0.9853			
A		0.9892			

the rate Q_3 determined the most precise hand values – so that is the motivation for the selection of three initial parameters for unified hand evaluation. Low determinations between initial deformational parameters and rates Q_5 and Q_4 show the loss of precision. It should be noted that after the software application (accepting minimal Q_n value) higher determinations were perceived only in the case of 5 parameters set. So, it's recommended to use software when the number of initial parameters is more than 4, in other case the arrangement of parameters has no influence to the final result.

Drafting of a circular chart for complex hand rate requires precision, though its not complicated. Another hand value G – the sum of initial parameters of extraction curve $H–P$ according to Equation (4) is presented in this work. Comparative analysis between complex hand rates Q_5/Q, Q_4/Q, Q_3/Q and parameters G_5, G_4, G_3 showed nonlinear dependancies $y = a + bx^2$ (when $x = G$, $y = Q_n/Q$). Determination coefficients between Q_5/Q and G_5 were 0.9712; between Q_4/Q and G_4 – 0.9918; between Q_3/Q and G_3 – 0.9999. According to this it can be stated that it is purposive to use unsophisticated Equation (4) for complex hand rate determination when the number of parameters is more than 4.

CONCLUSIONS

KTU-Griff-Tester is a simple, reliable instrumental device suitable to obtain the quantitative information about fabric mechanical properties that characterize textile hand.

In this investigation primary hand parameters that characterize fabric hand were determined: force parameters (P_{max}, tgα and A) and deformational ones ($\Delta\delta$ and H_{max}).

It was stated that complex hand rate of soft and flexible fabrics should be evaluated by 5 initial mechanical parameters. The number of parameters of stiff fabrics (i. e. woven ones) is possible to decrease to 4 (excluding H_{max}).

In order to compare different fabric types three initial force parameters are enough.

The most precise results of fabric behavior are determined by force parameters of extraction curve $H–P$: P_{max}, tgα and A, and by the complex rate Q_3.

There were defined standard fabrics that determine variation limits of hand parameters.

REFERENCES

1. **Bereck, A., Dillbohner, S., Mitze, H., Weber, B., Riegel, D., Riegel, M., Pieper, J. M., Brakelmann, A.** Eine neue, einfache Methode zur Messung der Weichnen textiler Flächengebilde. Teil 2. Einfluss der Ausrüstung auf die Gewebeweichheit *Textilveredlung* 32 (9/10) 1997: s. 216 – 222.
2. **Ganssauge, D., Lehmann, K. H., Angenadel, A.** Wie beeinflussen typische Gewebemerkmale den Griff einer Ware *Melliand Textilberichte* 6 1998: s. 427 – 435.
3. **Henrich, L., Seidel, A., Rieder, O.** Griffprüfung an Maschenwaren *Maschen-Industrie* 7 1999: s. 46 – 47.
4. **Seidel, A.** Griffbewertung von Strumpfwaren mit dem JTV–Griff–Tester *Melliand Textilberichte ISSN 0341-0781* 6 2001: s. 491 – 494.
5. **Martišiūtė, G., Gutauskas, M.** A New Approach to Evaluation of Textile Fabric Handle *Materials Science (Medžiagotyra) ISSN 1392-1320* 7 (3) 2001: pp. 186 – 190.
6. **Strazdienė, E., Papreckienė, L., Gutauskas, M.** New Method for the Objective Evaluation of Technical Textile Behavior *6th Dresden Textile Conference, 2002* CD ROM Page 1 – 8 of 8, (http://www.fiz-technik.de).
7. **Daukantienė, V., Gutauskas, M.** Textile Hand: An Analysis of Knitted Fabric Behavior *Materials Science (Medžiagotyra) ISSN 1392-1320* 8 (3) 2002: pp. 299 – 303.
8. **Strazdienė, E., Daukantienė, V., Gutauskas, M.** Bagging of Thin Polymer Materials: Geometry, Resistance and Application *Materials Science (Medžiagotyra) ISSN 1392-1320* 9 (3) 2003: pp. 262 – 265.
9. **Daukantienė, V., Papreckienė, L., Gutauskas, M.** Simulation and Application of Pulling Textile Fabric through a Central Hole *Fibres and Textiles in Eastern Europe ISSN 1230-3666* 11 (2) 2003: pp. 38 – 42.
10. **Grover, G., Sultan, M. A., Spivak, S. M.** A Screening Technique for Fabric Handle *Journal of the Textile Institute ISSN 0040-5167* 3 (23) 1993: pp. 486 – 494.
11. **Kim, O. J., Slaten, B. L.** Objective Evaluation of Fabric Hand. Part I: Relationships of Fabric Hand by the Extraction Method and Related Physical and Surface Properties *Textile Research Journal* 69 (1) 1999: pp. 59 – 67.
12. **Pan, N., Yen, K. C.** Physical Interpretations of Curves Obtained Through the Fabric Extraction Process for Handle Measurement *Textile Research Journal* 62 (5) 1992: pp. 279 – 290.
13. **Bishop, D. P.** Fabrics: Sensory and Mechanical Properties *Journal of the Textile Institute ISSN 0040-5167* 26 (3) 1996: pp. 1 – 63.
14. **Grinevičiūtė, D., Gutauskas, M.** The Comparison of Methods for The Evaluation of Woven Fabric Hand *Materials Science (Medžiagotyra) ISSN 1392-1320* 10 (1) 2004: pp. 97 – 100.
15. **Grinevičiūtė, D., Daukantienė, V., Gutauskas, M.** Textile Hand: Comparison of Two Evaluation Methods *Materials Science (Medžiagotyra) ISSN 1392-1320* 11 (1) 2005: pp. 57 – 63.
16. **Pan, N., Zeronian, S. H., Ryu, H. S.** An Alternative Approach to the Objective Measurement of Fabrics *Textile Research Journal* 63 (1) 1993: pp. 33 – 43.
17. **Alley, V. L.** Nozzle Extraction Process and Handlemeter for Measuring Handle *US pat. 4,103,550* 1978.
18. **Yoon, H. N., Sawyer, L. C., Buckley, A.** Improved Comfort Polyester. Part II: Mechanical and Surface Properties *Textile Research Journal* 54 1984: pp. 357 – 365.
19. **Pan, N., Yen, K. C., Zhao, S. J., Yang, S. R.** A New Approach to the Objective Evaluation of Fabric Handle from Mechanical Properties. Part I: Objective Measure for Total Handle *Textile Research Journal* 58 1988: pp.438 – 444.
20. **Grinevičiūtė, D., Gutauskas, M.** The Search of Standard Fabric for The Textile Hand Evaluation *Clothing Design and Technology (Gaminių technologijos ir dizainas)* Kaunas: Technologija, 2004: pp. 53 – 61 (in Lithuanian).