BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI

Tomul LIX (LXIII)

Fasc. 1-2

TEXTILE. PIELĂRIE

2013 **Editura POLITEHNIUM**

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
PUBLISHED BY
"GHEORGHE ASACHI" TECHNICAL UNIVERSITY OF IAŞI
Editorial Office: Bd. D. Mangeron 63, 700050, Iaşi, ROMÂNIA
Tel. 40-232-278683; Fax: 40-232-237666; e-mail: polytech@mail.tuiasi.ro

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S U M A R

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ASPECTS CONCERNING THE CLEANING OF SIMPLE AND TWIST COTTON-TYPE YARNS

BY

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Received: February 27, 2013
Accepted for publication: April 5, 2013

Abstract. The work presents experimental results concerning the removal of rare flaws from cotton-type yarns by means of Leophe FR-30 electronic clearer installed on the Mettler spooler. The flaw frequency and shape allow identifying the cause-effect relationship at the level of the technological process which permits partial corrective actions; the elimination of damaging flaws whose appearance cannot be avoided, is performed by yarn cleaning in the spooling technological process. The presence of flaws (aggravated by the amplification of their frequency and shape) diminishes the processability of yarns and finally, the aspect of the woven and knitted fabrics produced from these yarns. The severity of yarns flaws is established based on the typo-dimensional criterion of classification, which permits establishing the values of the objective control limits. In order to appreciate the qualitative yarn level and the efficiency of cleaning operation, short section irregularities (U%), irregularities frequency within a 1000 m of yarn and the frequency of rare flaw/100 km of yarn before and after the cleaning operation have been analyzed for the following yarn assortment: yarn Nm 50/l (67% PES + 33% cotton); yarn Nm 70/l (67% cotton + 33% PES); yarn Nm 85/2 (67% PES + 33% cotton); yarn Nm 100/2 (67% PES + 33% cotton).

Key words: rare flaws, Classimat classification, cleaning, linear irregularity.

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1. Introduction

Structural and aspect characteristics of the yarns, reflected in the number of rare damaging, short, intermediate and mainly long and thick flaws, influence to a great extent the quality and aspect of the woven or knitted fabrics.

The yarn flaws originate in the manufacturing process, their appearance being determined by the quality of the raw material and the technological process (equipment, technological parameters, technical condition of equipment and accessories, organization of the manufacturing process). The rare yarn flaws are local manifestations of the structural irregularities characterized by exceeding the rated values of the yarn diameter/length density within the limits of (−30/−100%); (+100/+400) manifested on sections whose length can be situated between 0.1/32cm (Neculaiasa *et al.*, 2004).

Even if the spinning mills produce a relatively uniform yarn, the irregularity of the yarn diameter cannot be entirely avoided. That is why it is necessary to make a difference between the accepted yarn irregularity and its flaws.

2. Materials and Methods

2.1. Materials

In order to appreciate the efficiency of the cleaning operation, short segment irregularities (U%), irregularities frequency within 1000 m of yarn and the rare flaw frequency/100 km of yarn before and after the cleaning operation have been analyzed for the following yarn assortment:

− yarn Nm 50/l (67% PES + 33% cotton);
− yarn Nm 70/l (67% cotton + 33% PES);
− yarn Nm 85/2 (67% PES + 33% cotton);
− yarn Nm 100/2 (67% PES + 33% cotton).

Each yarn was cleaned in three variants of clearer adjustment:

R_1 – representing L= 3; D= 2, N= 7;
R_2 – representing L= 2; D= 2; N= 7;
R_3 – representing L= 2, D=2; N= 5.

where: the selector L performs the adjustment for establishing the removed flaws length; selector D − adjustment for establishing the removed flaws thickness, and selector N − adjustment for establishing the thickness of short flaws.

The flaws eliminated by means of the electronic clearer were classified in 16 classes of flaws, that are grouped as follows:

A − flaws with the length between 0.01 and 1 cm;
B − flaws with the length between 1.00 and 2.00 cm;
C − flaws with the length between 2.00 and 4.00 cm;
D − flaws with the length over 4 cm.

Thickness classes are symbolised by:

1 − thicknesses of 100%-150% from rated average yarn thickness;
2 − thicknesses of 150%-250%;
3 − thickness of 250-400%;
4 − thicknesses over 400%.

2.2. Methods

The flaws distribution follows the law of rare events, therefore the flaw detection, measurement and frequency determination implies the analysis of a long yarn length (100 km), to provide statistical results which motivates the "on-line" control applied within the spooling technological process.

The detection, frequency determination, classification and cleaning of rare flaws from cotton-type yarns were carried out by means of the Leophe FR-30 electronic cleaners installed on the Mettler spoolers.

The cleaning is the operation which permits detection and removal of yarn flaws, performed during the spooling process. The removal of a flaw implies stopping the spooler, which affects the machine yield.

As a compromise between quality and production, the choice of an optimum adjustment on the yarn clearer means in fact the avoidance of a large number of flaws with minimum production diminution, which can only be done by accurately establishing the cleaning limits.

The principle of cleaners' adjustment is based on flaws classification into the following categories:

− long flaws (length ranging between 1÷24 cm, while their thickness is tolerable, *i.e.* 1.2÷1.8 times the rated diameter);

− short flaws (whose tolerable length ranges between 0.5÷10 cm, but their thickness 1.8÷3.0 times the rated diameter, cannot be neglected);

− twist yarn (flaw with a very big length, arisen from two rovings spun together or, occasionally, two joined yarns).

3. Results and Discussions

In order to control the reproducibility of determinations and to eliminate the influence of non-uniform distribution of rare flaws along the yarns, the analyses were performed on the same yarn section.

In parallel with these determinations, the number of breakages reported per 1 kg of processed yarn was recorded for every yarn and adjustment variant.

The results of the analyses performed on the four articles proposed for study are synthetically presented in terms of the following aspects:

• frequency of rare flaws per 100 km yarn before and after the cleaning operation, according to the Cassimat system. In order to make the result processing and interpretation easier, the following symbols were used:

V_1 – version of yarn destined to cleaning, with R_1;

V_1^* – the same cleaned yarn with R_1;
V_2 – version of yarn destined to cleaning, with R_2;
V_2^* – the same cleaned yarn with R_2;
V_3 – version of yarn destined to cleaning, with R_3;
V_3^* – the same cleaned yarn with R_3.

• The qualitative aspect of the studied yarns was considered by including them in Uster - Classimat quality levels, for each class apart, as well as for categories of flaws conventionally defined by I.N.C.D.T.P. Bucharest;

• For a more efficient comparison of the qualitative level of various yarn types, taking into consideration their content of rare flaws, these flaws were grouped as follows:

T – total number of flaws, including the flaws from all the classes;
D – thick and long flaws, respectively severe and damaging flaws;
DL – a wider range of thick and long flaws, respectively severe and damaging flaws;
C – short flaws;
CL – a wider range of relatively short flaws of limited thickness;
I – intermediate flaws.

• The efficiency of the cleaning stage has been exemplified for the yarn Nm 50/l by a graphical representation (Fig. 1), which illustrates the relative decrease in frequency of the rare flaws (reported to the same yarn length of 100 km).

The relative frequencies of the flaws grouped as presented above have been summarized in Table 1.

From the performed analysis, one can notice that for the single yarns, the frequencies of the flaws from the classes A, B and C, before and after cleaning, are situated on the steps of world level 25% ÷ 75% from the Uster statistics, while the flaws from D category exceed the 95% world level step.

After cleaning, the flaws corresponding to the thickness classes 3 and 4 are considerably eliminated in the case of all the performed adjustments. The number of flaws from the length classes D_1, D_2, D_3 and D_4 is smaller in the case of a tighter adjustment, while those corresponding to the class D_l (flaw length exceeds 4 cm, flaw thickness up to 150% of the rated value) remain at a high level (around 95%) even after cleaning.

The percentage diminution of the flaws from category T is severe in the case of single yarns, while at the twist yarns no significant differences between the values corresponding to the three utilized adjustment versions are recorded.

The flaws from categories D and DL are considerably diminished for all the adjustment versions, more spectacular diminutions being recorded for single yarns in the case of using the R_3 adjustment for the yarn Nm 50/l, so that the number of flaws recorded and classified close to the world level step of 75% is reduced, being under the 25% world level step.

In the case when the R_1 and R_2 adjustment variants are used, the differences are insignificant for the twist yarn.

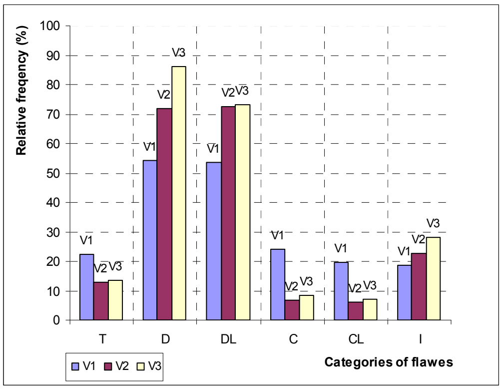

Fig. 1 − Graphic of the variation of flaws after cleaning, for the yarn Nm 50/l.

Table 1

The Relative Frequencies of the Flaw Number Grouped within Categories

Categories of flaws	Yarn fineness	Cleaning stage efficiency, [%]		
		$\frac{V_1 - V_1^*}{V_1}100$	$\frac{V_2 - V_2^*}{V_2}100$	$\frac{V_3 - V_3^*}{V_3}100$
T	Nm 50/1	22.37	13.02	13.5
D		54.16	71.73	86
DL		53.44	72.58	73.33
C		24.11	6.7	8.6
CL		19.78	6.2	7.1
I		18.75	22.85	28.2
T	Nm 70/1	38.17	20.88	13.78
D		66.45	67.94	69.87
DL		64.51	66.49	70.09
C		36.88	14.83	10.5
CL		36.73	17.51	11.9
I		53.28	45.62	4.5
T	Nm 85/2	10.16	12.88	9.81
D		63.15	79.31	81.38
DL		69.23	72.72	74.35
C		3.01	0.74	1.42
CL		3.8	4.9	0.6
I		17.64	21.05	2.72
T	Nm 100/2	5.71	7.04	9.9
D		39.39	72.41	72.97
DL		35.89	65.78	71.42
C		2.98	0.31	1.2
CL		2.49	0.55	2.01
I		9.09	12.5	39.39

The influence of adjusting the electronic cleaners for each class of flaws (Classmat classification) and their classification according to the world quality levels is presented in Fig. 2; one can notice that, irrespective of adjustment, they are considerably reduced after cleaning, especially what concerns the flaws corresponding to the thickness classes 3 and 4, those of length classes C and D, being situated close to the world level steps of 5% and 23%.

4. Conclusions

1. Irrespective of the utilized adjustment version, the number of rare flaws/100 km decreases for both each flaw class (Classimat classification) and each flaw category (according to the I.C.T. – Bucharest classification).

2. Irrespective of the utilized adjustment version, the cleaning significantly diminishes the flaws corresponding to the length classes C and D, therefore of the flaws with the length exceeding 2 cm, and of the thick flaws from classes A_4 and B_4.

3. Irrespective of the quality level to which they belonged prior to cleaning, the flaw corresponding to the length class A (0.1-1 cm) do not suffer essential modifications for none of the three adjustments.

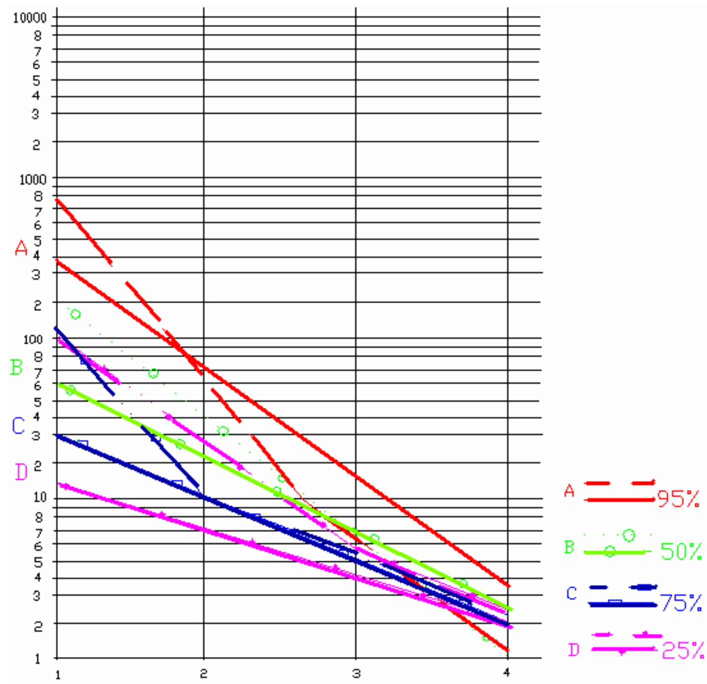

Fig. 2 − Variation of the rare flaws/100 km of yarn, as compared to the Uster Classimat world levels.

4. Important decrease of the flaw number is recorded starting with the length class B and thickness classes 3 and 4, and continuing especially at the other length classes (C and D).

5. By investigating the cleaning induced modification of the flaw number in terms of categories (the I.C.T. classification), an important diminution of the flaws from categories D and DL can be noticed for all the single yarns. Bigger values of the percentage diminution of the flaw number are obtained for R_2 (L-2; D-2; N-7) and R_3 (L-2, D-2; N-5) adjustments, yet the total flaw number (T category) decreases when using the R_1 (L-3; D-2; N-7) adjustment, as one can notice in Table 1.

6. In the case of twist yarns cleaning (Nm 85/2 and Nm 100/2), for all the adjustments, percentage decreases of the number of flaws from category T remain approximately the same, the differences in term of the utilized adjustment version being obtained at flaw from category D. The number of these flaws decreases when a tighter adjustment is used.

7. In favour of the first adjustment pleads only the number of breakages/kg, which is much smaller than that obtained for variant R_2; yet, it is worth mentioning that this parameter does not exceed the rated value for the both adjustments.

8. The tendency of yarn manufacturers to use too tight adjustments, as the result of too high quality requirements, does not solve the problem of yarns quality. The tight adjustment does not modify the total flaw number.

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ASPECTE PRIVIND CURĂȚAREA FIRELOR SIMPLE ŞI RĂSUCITE TIP BUMBAC

(Rezumat)

În lucrare sunt prezentate rezultatele experimentale privind eliminarea defectelor rare din fire tip bumbac cu ajutorul curățitoarelor electronice Leophe FR-30 montate pe maşinile de bobinat Mettler. Frecvența şi forma defectelor permite identificarea unor relații cauză-efect la nivelul fazelor procesului tehnologic de obținere a firelor, ceea ce permite acțiuni corective, parțiale, eliminarea defectelor dăunătoare a

căror apariție nu poate fi evitată, se realizează prin curățirea firelor în faza tehnologică de bobinare.

Prezența defectelor (agravată prin creşterea frecvenței şi a dimensiunilor) diminuează prelucrabilitatea firelor şi în final aspectul țesăturilor şi tricoturilor produse din acestea. Gravitatea defectelor firelor se stabileşte pe baza criteriului tipodimensional de clasificare, care permite stabilirea unor limite de control obiective. Pentru aprecierea nivelului calitativ al firelor şi eficiența operației de epurare au fost analizate neregularitățile pe porțiuni scurte (U %), frecvența imperfecțiunilor pe 1000 m fir şi frecvența defectelor rare/100 km fir înainte şi după operația de epurare pentru următoarea gamă de fire: fir Nm 50/1 (67% pes + 33% bumbac); fir Nm 70/1 (67% bumbac + 33% pes); fir Nm 85/2 (67% pes + 33% bumbac); fir Nm 100/2 (67% pes + 33% bumbac).

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THE PROPERTIES OF COTTONISED FLAX/COTTON BLENDED ROTOR SPUN YARNS

BY

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Received: April 12, 2013
Accepted for publication: April 26, 2013

Abstract. Over the last two decades the interest in processing blends of flax fibers and cotton on the cotton processing line has been increased continuous. In comparison to cotton spinning system, the flax spinning system is more labour-consuming and costly. One possibility to process blends of cotton and flax on the cotton processing line is to modify the technical flax fibres by cottonisation, which yields cotton-like fibres in terms of length and fineness.

This paper presents the characteristics of Nm 10, Nm 17 and Nm 34 rotor spun yarns from 30% cottonised flax and 70% cotton blend. All-cotton yarns of similar finesses were spun for comparison purposes. In comparison to all-cotton yarns, the cottonised flax/cotton blended yarns have lower tenacity, higher strength irregularity, lower breaking elongation, higher Uster irregularity and higher number of imperfections per 1000 m. In order to maintain the number of yarn breakages to an acceptable level, higher twist has been inserted to the cottonised flax/cotton blended yarns. The use of a higher twist in the case of the flax/cotton yarns decreases the productivity of the rotor spinning machine.

The yarns spun from cottonised flax/cotton blends create visual effects in the resulting fabric due to their so popular “Linen Look”.

Key words: cottonisation, flax/cotton blend, rotor yarn.

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1. Introduction

Over the last two decades the interest in processing blends of flax fibres and cotton on the cotton processing line has been increased continuous. Both flax and cotton are natural cellulosic fibres of vegetable origin with a cellulose content of about 95% in cotton and about 71% in flax (Foulk *et al.*, 2007). Although the constituent polymer is the same, the properties and the processing lines of the two categories of fibres are very different. Cotton fibres are single-celled extensions of the seed epidermis, while flax fibres, separated from the non-fibre tissues in the plant stem by retting, are multi-cells technical fibres (Sava & Ichim, 2005; Mustață, 2007). The longitudinal view of a cotton fibre is a twisted ribbon-like and the appearance of the fibre cross-section is referred as being kidney-shaped. Flax fibres are made of bundles of elementary fibres having a spindle-like shape and a polygonal (mostly pentagonal) cross-section. The elementary fibres are joined together with middle lamellae containing hemicelluloses, pectic substances, and lignin (Mustață, 2004; Cierpucha *et al.*, 2004, Cierpucha *et al.*, 2006).

The length of cotton fibres varies from a few millimetres to 55 mm, while the length of the flax technical fibres ranges between 40 cm and 125 cm. Furthermore, the difference in the fibre finesses is noticeable. Metrical number lies from Nm 3000 to Nm 9000 for cotton, and from Nm 400 to Nm 800 for technical flax fibres (Sava & Ichim, 2005; Gribincea, 2008). As a result, the cotton and the technical flax fibres are processed on different spinning systems. In comparison to cotton spinning system, the flax spinning system is more labour-consuming and costly. One possibility to process blends of cotton and flax on the cotton processing line is to modify the technical flax fibres by cottonisation, which yields cotton-like fibres in terms of length and fineness.

Cottonisation is the process of removing the lignified pectins from the middle lamella, thereby allowing the dis-aggregation of the elementary fibres contained in the long technical fibre. The elementary fibres are similar in length and fineness to cotton fibres and thus their blend can be processed on cotton spinning system with lower costs and higher productivity (http://www.jos-vanneste.com).

This paper presents the results of rotor spinning of Nm 10, Nm 17 and Nm 34 yarns from 30% cottonised flax and 70% cotton blend. All-cotton yarns of similar finesses were spun for comparison purposes.

2. Materials and Methods

The characteristics of the cottonised flax and cotton fibres are presented in Table 1. In respect of fineness, the cottonised flax fibres are about two times coarser than the cotton fibres. While the lengths of cottonised flax and cotton fibres are close, the short fibre content of cottonised flax is more than two times higher than cotton short fibre content. The breaking length of cottonised flax fibres is lower by about 15% than the breaking length of cotton fibres.

Table 1
Characteristics of the Raw Materials

Characteristics	Unit	Cotton	Cottonised flax
Fineness	[Nm]	5400	2615
Fibre strength	[cN/fibre]	3.52	6.12
Fibre breaking length	[km]	19	16
Fibre length	[mm]	28	27
Short fibre content	[%]	17	37
Fibre impurities	[%]	1.2	1.96

The blend of cottonised flax and cotton has been processed on a modified cotton processing line, as follows:

1. Cottonised flax emulsifying and 24 h of repose at room temperature.
2. Manual blending employing ‘sandwich’ (horizontal) layers.
3. Opening, cleaning and blending on an Ingolstadt blowroom and lap formation.
4. Carding on an Unirea 4C flat card.
5. Sliver lap formation; 24 card slivers are creeled, drafted and compressed on a Textima sliver lap machine and the sliver lap is wound into a cylindrical roll.
6. Second carding for a better division of multi-cells flax fibres; three sliver laps are fed simultaneously at the card in order to continue the fibre individualization and the cleaning process.
7. Doubling and drafting of card slivers on an Ingolstadt draw frame.
8. Evening-up of drafted slivers on an Unirea LB draw frame.
9. Spinning on BD-200 RN rotor spinning machine.

Linear density of yarns was determined according to SR EN ISO 2060:1997 test method. The tensile properties have been measured according to SR EN ISO 2062:2010 standard on a TINIUS OLSEN H5 K-T tensile yarn tester. The length of the test specimen was 500 mm. The yarn twist was tested according to SR EN ISO 2061:2011 test method, using a clamping distance of 250 mm. Uster Tester-II was used to determine short-term irregularity of yarns, total imperfections (thin places, thick places and neps) at a speed of 25 m/min.

3. Results and Discussions

Yarns of Nm 10, Nm 17 and Nm 34 fineness were obtained from both 30 % cottonised flax/70 % cotton and all-cotton blends. The twist of yarns was adjusted at a level for which the number of yarn breakages was acceptable.

Fig. 1 presents the tenacity of yarns and Fig. 2 presents the irregularity of strength of all tested yarns. The tenacity of cottonised flax/cotton blended yarns is lower than the tenacity of cotton yarns, but the requirements of quality standard are met.

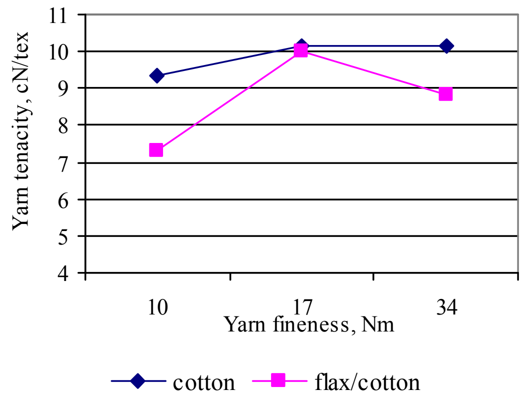

Fig. 1 − Tenacity of yarns.

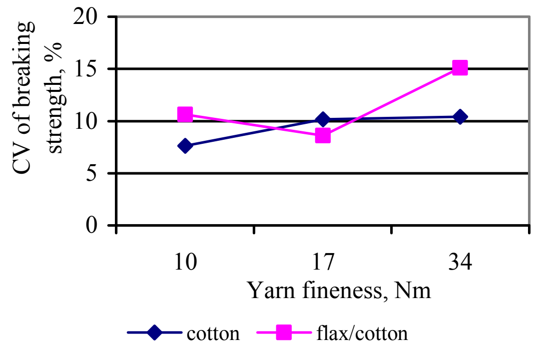

Fig. 2 − Breaking strength irregularity of yarns.

The differences in yarn tenacity of all-cotton and cottonised flax/cotton blended yarns lie between 2% and 28%. This behaviour can be explained by the fact that the cottonised flax fibres are coarser than the cotton fibres and thus the number of fibres in the cross-section of blended yarns is lower than in the case of all-cotton yarns.

With the exception of Nm 17 cottonised flax/cotton blended yarn, the CV of breaking strength of the other two blended yarn assortments are higher than the breaking strength irregularity of correspondent cotton yarns.

When compared to cotton yarns, the breaking elongation of cottonised flax/cotton blended yarns is lower with 11% to 22 % (Fig. 3), especially for the finer yarn assortments (Nm 17, Nm 34).

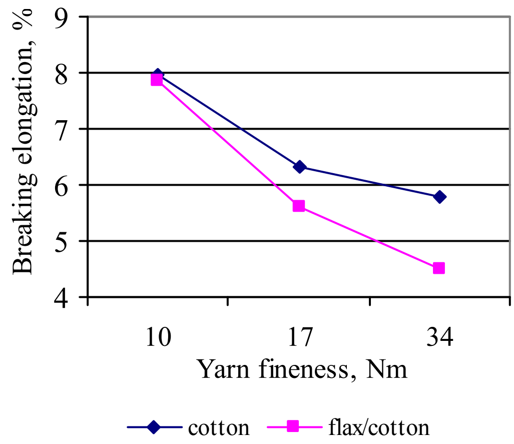

Fig. 3 − Breaking elongation of yarns.

In order to maintain the number of yarn breakages to an acceptable level, higher twist has been inserted to the cottonised flax/cotton blended yarns (Fig. 4). The differences between the twist of all-cotton and cottonised flax/cotton blended yarns ranged between 20% and 30%. The use of a higher twist in the case of the flax/cotton yarns decreases the productivity of the rotor spinning machine.

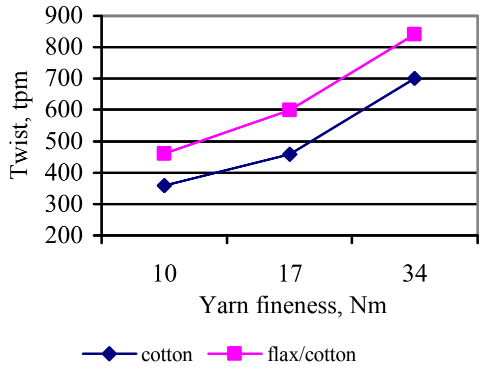

Fig. 4 − Twist values of yarns.

Mass irregularity of the yarns measured by CV Uster and the number of imperfections per 1000 m (with the exception of thin places) show better values for the cotton yarns (Figs. 5,…,8). Because the cotton fibres are two times finer than the cottonised flax fibres, the number of fibres in the cross-section of a cotton yarn is higher than in the cross-section of flax/cotton yarn. Also, the short fibre content is two times higher in the case of cottonised flax.

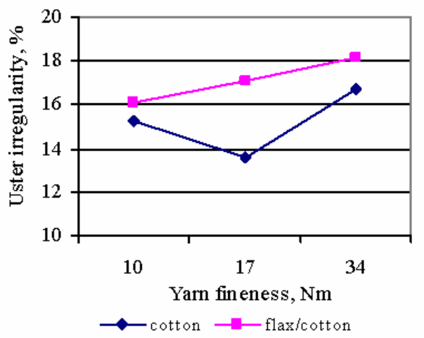

Fig. 5 – Uster irregularity of yarns.

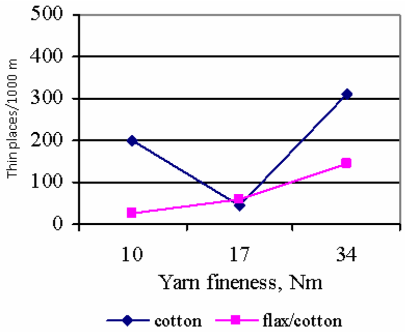

Fig. 6 – Thin places/1000 m of yarns.

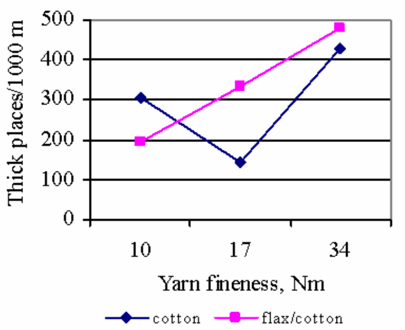

Fig. 7 – Thick places/1000 m of yarns.

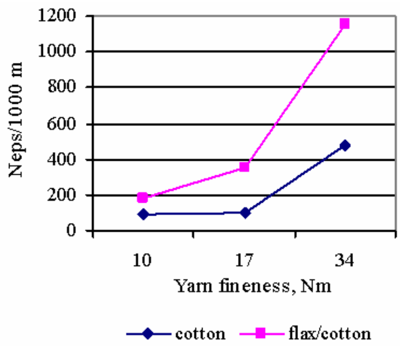

Fig. 8 – Neps/1000 m of yarns.

4. Conclusions

The technology developed for processing of 30% cottonised flax/70% cotton blends on the cotton spinning system allows the production of rotor spun yarns ranging from Nm 10 to Nm 34.

1. In comparison to all-cotton yarns, the cottonised flax/cotton blended yarns have lower tenacity (but above the value specified in the quality standard for all-cotton yarns), higher strength irregularity, lower breaking elongation, higher Uster irregularity and higher number of imperfections per 1000 m. This behaviour can be explained by the differences between the two categories of fibres in respect of fibre fineness, short fibre content and fibre structure.

2. In order to maintain the number of yarn breakages to an acceptable level, higher twist has been used for the cottonised flax/cotton blended yarns. Therefore, the productivity of the rotor spinning machine has been reduced.

3. In cottonised flax/cotton blends rotor spinning, the breakage rate is the lowest in the case of Nm 17 yarn assortment.

4. The yarns spun from cottonised flax/cotton blends create visual effects in the resulting fabric due to their so popular “Linen Look”.

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PROPRIETĂŢILE FIRELOR FILATE CU ROTOR DIN AMESTEC DE IN COTONIZAT ŞI BUMBAC

(Rezumat)

În ultimele două decenii, interesul pentru prelucrarea amestecurilor de in şi bumbac pe sistemul de filare tip bumbac a crescut continuu. În comparaţie cu sistemul de filare tip bumbac, sistemul de filare a fibrelor de in este mai costisitor şi necesită mai multă forţă de muncă. Una dintre posibilităţile de prelucrare a amestecurilor de bumbac şi in pe sistemul de filare tip bumbac constă în modificarea fibrelor tehnice de in prin cotonizare, obţinându-se astfel fibre tip bumbac din punct de vedere al lungimii şi fineţii.

Această lucrare prezintă caracteristicile firelor cu fineţea Nm 10, Nm 17 şi Nm 34 filate cu rotor din amestec de 30% in cotonizat şi 70% bumbac. Pentru comparaţie, au fost filate fire din bumbac 100% cu fineţe similară.

În comparaţie cu firele din bumbac 100%, firele din amestec de in cotonizat şi bumbac au tenacitate mai mică, neuniformitate la rezistenţă mai mare, alungire la rupere mai mică, neuniformitate Uster mai mare şi număr mai mare de imperfecţiuni pe 1000 m de fir. Pentru a menţine numărul de ruperi de fir la un nivel acceptabil, firelor din amestec de in cotonizat şi bumbac li s-a conferit o torsiune mai mare. Utilizarea unei torsiuni mai mari a condus la reducerea productivităţii maşinii de filat cu rotor.

Firele filate din amestecuri de in cotonizat şi bumbac crează efecte vizuale în ţesături datorită popularului “aspect de in”.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 1-2, 2013
Secţia
TEXTILE. PIELĂRIE

REDUCED MARKOV CHAIN FOR A WEAVING MACHINES INTERFERENCE PROBLEM

BY

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Received: April 11, 2013
Accepted for publication: April 27, 2013

Abstract. A weaving machines interference problem is treated in this paper. For a group of weaving machines allocated to the weaver, two indicators must be evaluated: the efficiency of the weaving machines and the work loading for the weaver. Two different approaches are available: analytical approach, based on Markov chains, and simulation. A reduced Markov model able to evaluate with accuracy the two indicators previously defined is proposed in this paper. A case study for five weaving machines, in which exact and approximate results are presented, demonstrates the effectiveness of this simplified analytical approach.

Key words: weaving process, interference time, Markov model.

1. Introduction

The weaving process is a discrete event one because the warp yarns and the filling yarn break off at random instants. In case a weaving machine (loom) is down because a yarn has broken, a weaver (loom operator) must remedy the broken yarn and then start up the loom again. In other words, a weaving machine is a system with repair. The problem of allocation of looms to the loom

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operators is a very important one in a large weaving mill. The prediction of the loom efficiency and the weaver work loading according to the number of looms allocated to the weaver is a machines interference problem. The problem of allocation of looms in weaving is widely dealt with in textile literature, both from a theoretical and a practical point of view (see for example, Bona, 1993; Caşcaval, 1999a; Caşcaval & Ciocoiu, 2000b).

The analytical approach for the machines interference problem is based on the theory of queues (see for example, Delaney &Vaccari, 1999; Trivedi, 2002). The standard model is a Markov chain for which the steady–state probabilities are required. For a Markov chain with s states, a system with s linear equations must be solved. This method is simple in essence but, unfortunately, the state space of the Markov chain increases rapidly (Bona, 1993; Caşcaval, 1999b). For any sizable practical problem s becomes very large and the solution time becomes very long, so that, the classical approach is difficult to apply. When the number of states of Markov chain is very large, the two approaches available to deal with this problem are to either tolerate the largeness or avoid it. In this work, a largeness avoidance technique for an approximate evaluating of the loom efficiency is discussed.

The simulation is a complementary approach for machine interference problem (Caşcaval, 1999a; Caşcaval & Ciocoiu, 2000a). A simulation program based on a stochastic coloured Petri net has been used to validate the all analytical results presented in this paper.

The remainder of this paper is organized as follows. In Section 2 the interference problem concerning the weaving process is defined. To illustrate the analytical method based on Markov chains, able to solve this interference problem, a simple case with three weaving machines served by one weaver is also presented in this section. A simplified analytical approach based on state-space largeness avoidance is proposed in Section 3. This method avoids the constructing of whole space of states and allows a good accuracy in evaluating the efficiency of the weaving machines and the work loading for the weaver. Finally, some conclusions regarding this work are drawing in Section 4.

2. Problem Formulation and Classical Analytical Approach

Consider a weaving process completely known from a statistical point of view. The stochastically model of the weaving process includes four primary random variables, namely:

• Time to break off a warp yarn – let λ_W be the breakage rate of the warp yarns;

• Time to break off the filling yarn – let λ_F the breakage rate of the filling yarn;

• Time to remedy a warp breakage – let μ_W be the remedying rate of warp breakages;

• Time to remedy a filling breakage – let μ_F the remedying rate of filling breakages.

In the case where all the parameters λ_W, λ_F, μ_W and μ_F are known, we have to estimate the efficiency of the looms (*EF*) and the work loading for the weaver (*WL*) according to the number *m* of looms allocated to the loom operator.

This prediction problem is treated under the following assumptions:

– all primary random variables are exponentially distributed;

– the weaving process is in a steady–state condition;

– any loom is either up or down, with no intermediate states;

– all break events are stochastically independent.

Let us consider three identical weaving machines allocated to the weaver (*m* = 3). For any loom, three distinct states must be taken into account: the machine is up (↑), the machine is down because a warp yarn has broken (↓-w), and the machine is down because the filling yarn has broken (↓-F). Because all the looms are identical, a Markov chain with thirteen states as presented in Table 1 is appropriate to describe this weaving process. Symbol * denotes the weaving machine under remedying. The graph of states is presented in Fig. 1. Based on this graph with *n* states (*n* = 13), the square matrix $M = [a_{i,j}]_{n \times n}$ of transition rates between states is then carried out. The location (i, j) in matrix *M*, $i \neq j$, represents the transition rate from state *j* to state *i,* whereas the value of a location (i, i), $i \in \{1, 2, ..., n\}$, is equal to the sum of the transition rates in column i, taken with minus.

Let p_i be the steady-state probability of S_i, $i \in \{1, 2, ..., n\}$, and the vectors $P_{n \times 1} = [p_1, p_2, ..., p_n]^T$ and $Z_{n \times 1} = [0, 0, ..., 0]^T$. To determine the steady-state probabilities $p_1, p_2, ..., p_n$, the set of linear eq. (1) must be solved.

$$\begin{cases} M \cdot P = Z \\ p_1 + p_2 + \cdots + p_n = 1 \end{cases} \tag{1}$$

After that, the loom efficiency can be obtained by using eq. (2).

$$EF = \left(p_1 + \frac{2(p_2 + p_3)}{3} + \frac{p_4 + p_5 + p_6 + p_7}{3} \right) \cdot 100\ \% \tag{2}$$

Table1

The States of Markov Chain for three Looms Allocated to a Weaver

S_i	State of Markov chain	Comments
S_1	3(↑)	All the three weaving machines are up
S_2	2(↑), 1(↓-w)*	Two weaving machines are up and the other one is down
S_3	2(↑), 1(↓-F)*	
S_4	1(↑), 1(↓-w), 1(↓-w)*	One weaving machine is up and the two other are down
S_5	1(↑), 1(↓-w)*, 1(↓-F)	
S_6	1(↑), 1(↓-w), 1(↓-F)*	
S_7	1(↑), 1(↓-F), 1(↓-F)*	
S_8	2(↓-w), 1(↓-w)*	All the three weaving machines are down
S_9	1(↓-w), 1(↓-w)*, 1(↓-F)	
S_{10}	1(↓-w)*, 2(↓-F)	
S_{11}	2(↓-w), 1(↓-F)*	
S_{12}	1(↓-w), 1(↓-F), 1(↓-F)*	
S_{13}	2(↓-F), 1(↓-F)*	

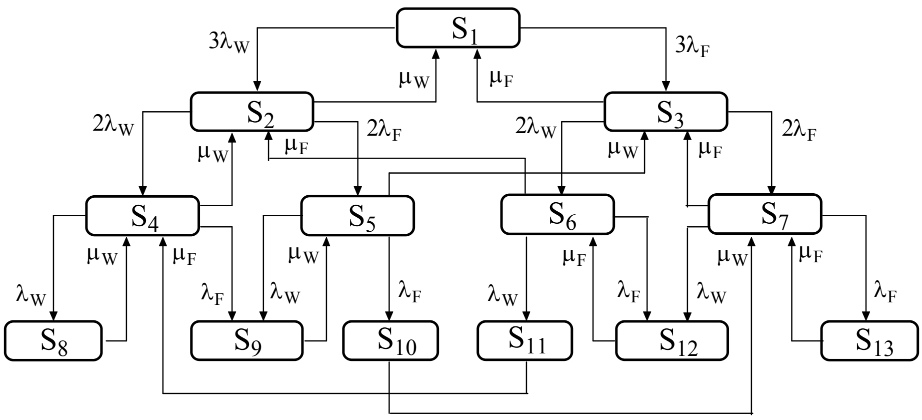

Fig. 1 − The Markov chain for three weaving machines served by one weaver.

The work loading for the loom operator is given by eq. (3).

$$WL = (1 - p_1) \cdot 100\,\% \tag{3}$$

With thirteen states, the Markov chain is quite complicated even for this simple case. For the case where four looms are allocated to the weaver, the

Markov chain includes twenty one states (Caşcaval & Ciocoiu, 2000b). Usually, a weaver serves up to ten looms when the graph grows up to one hundred eleven states. For this reason, a simplified approach is necessary to overcome the complexity of Markov models. A classical approach for reducing the Markov chain is based on a simplified stochastically model with only two primary random variables (Bona, 1993). Another method reduces the Markov model by applying of so called series or parallel transformation rules (Caşcaval & Caşcaval, 2005a; Caşcaval & Caşcaval, 2005b). In this paper a new approximate method based on a reduced Markov chain is discussed. The point is to reduce the state space of Markov chain by neglecting the states with a very low steady-state probability, like the states of the lower level where all the looms are down. As follows, this method is illustrated for the case in which five looms are allocated to the weaver.

3. A Simplified Analytical Approach

Consider five weaving machines allocated to the weaver. The Markov chain that allows an exact evaluation of the loom efficiency is composed of $n = 31$ states as presented in Table 2. The transition rates between states are also presented in this table. The steady-state probabilities can be obtained by solving the set of linear eq. (1). Based on these steady-state probabilities, the loom efficiency is given by eq. (4). For the weaver work loading, the same eq. (3) can be used.

$$EF = p_1 + \frac{4}{5}(p_2 + p_3) + \frac{3}{5}(p_4 + p_5 + p_6 + p_7) + \frac{2}{5}(p_8 + p_9 + p_{10} + p_{11} + p_{12} + p_{13})$$
$$+ \frac{1}{5}(p_{14} + p_{15} + p_{16} + p_{17} + p_{18} + p_{19} + p_{21} + p_{22}). \quad (4)$$

Observe that, in the states $S_{22} \div S_{31}$ all the five looms are down. A reduced Markov chain can be obtained by neglecting these ten states with much lower steady-state probability values. For the reduced model, with only $n = 21$ states, the steady-state probabilities can also be obtained by solving the set of linear eq. (1), and then, the loom efficiency can be calculated by using eq. (4). The weaver work loading is given by the same eq. (3). To evaluate the estimation accuracy by using this approximate approach, some numerical results are presented as follows. Take the following parameters of primary random variables: $\lambda_W =$ 2.613 and $\lambda_F =$ 1.812 breaks/h; $\mu_W =$ 51.87 and $\mu_F =$ 40.65 remedies/h, and consider the cases with two, three, four, and five looms allocated to the user. For the extended Markov chains, the steady-state probabilities are presented in Table 3.

Table 2

The States and the Transition Rates Between States for Five Weaving Machines

S_i	State description	Transition rates from current state
S_1	5(↑)	$a_{1,2} = \mu_W$, $a_{1,3} = \mu_F$
S_2	4(↑), 1(↓-w)*	$a_{2,1} = 5\lambda_W$, $a_{2,4} = \mu_W$, $a_{2,6} = \mu_F$
S_3	4(↑), 1(↓-F)*	$a_{3,1} = 5\lambda_F$, $a_{3,5} = \mu_W$, $a_{3,7} = \mu_F$
S_4	3(↑), 1(↓-w), 1(↓-w)*	$a_{4,2} = 4\lambda_W$, $a_{4,8} = \mu_W$, $a_{4,11} = \mu_F$
S_5	3(↑), 1(↓-w)*, 1(↓-F)	$a_{5,2} = 4\lambda_F$, $a_{5,9} = \mu_W$, $a_{5,12} = \mu_F$
S_6	3(↑), 1(↓-w), 1(↓-F)*	$a_{6,3} = 4\lambda_W$
S_7	3(↑), 1(↓-F), 1(↓-F)*	$a_{7,3} = 4\lambda_F$, $a_{7,10} = \mu_W$, $a_{7,13} = \mu_F$
S_8	2(↑), 2(↓-w), 1(↓-w)*	$a_{8,4} = 3\lambda_W$, $a_{8,14} = \mu_W$, $a_{8,18} = \mu_F$
S_9	2(↑), 1(↓-w), 1(↓-w)*, 1(↓-F)	$a_{9,4} = 3\lambda_F$, $a_{9,5} = 3\lambda_W$, $a_{9,15} = \mu_W$, $a_{9,19} = \mu_F$
S_{10}	2(↑), 1(↓-w)*, 2(↓-F)	$a_{10,5} = 3\lambda_F$, $a_{10,16} = \mu_W$, $a_{10,20} = \mu_F$
S_{11}	2(↑), 2(↓-w), 1(↓-F)*	$a_{11,6} = 3\lambda_W$
S_{12}	2(↑), 1(↓-w), 1(↓-F), 1(↓-F)*	$a_{12,6} = 3\lambda_F$, $a_{12,7} = 3\lambda_W$
S_{13}	2(↑), 2(↓-F), 1(↓-F)*	$a_{13,7} = 3\lambda_F$, $a_{13,17} = \mu_W$, $a_{13,21} = \mu_F$
S_{14}	1(↑), 3(↓-w), 1(↓-w)*	$a_{14,8} = 2\lambda_W$, $a_{14,22} = \mu_W$, $a_{14,27} = \mu_F$
S_{15}	1(↑), 2(↓-w), 1(↓-w)*, 1(↓-F)	$a_{15,8}= 2\lambda_F$, $a_{15,9}= 2\lambda_W$, $a_{15,23} = \mu_W$, $a_{15,28}= \mu_F$
S_{16}	1(↑), 1(↓-w), 1(↓-w)*, 2(↓-F)	$a_{16,9} = 2\lambda_F$, $a_{16,10}= 2\lambda_W$, $a_{16,24} =\mu_W$, $a_{16,29}=\mu_F$
S_{17}	1(↑), 1(↓-w)*, 3(↓-F)	$a_{17,10} = 2\lambda_F$, $a_{17,25} = \mu_W$, $a_{17,30} = \mu_F$
S_{18}	1(↑), 3(↓-w), 1(↓-F)*	$a_{18,11} = 2\lambda_W$
S_{19}	1(↑), 2(↓-w), 1(↓-F), 1(↓-F)*	$a_{19,11} = 2\lambda_F$, $\mathrm{a}_{19,12} = 2\lambda_W$
S_{20}	1(↑), 1(↓-w), 2(↓-F), 1(↓-F)*	$a_{20,12} = 2\lambda_F$, $a_{20,13} = 2\lambda_W$
S_{21}	1(↑), 3(↓-F), 1(↓-F)*	$a_{21,13} = 2\lambda_F$, $a_{21,26} = \mu_W$, $a_{21,31} = \mu_F$
S_{22}	4(↓-w), 1(↓-w)*	$a_{22,14} = \lambda_W$
S_{23}	3(↓-w), 1(↓-w)*, 1(↓-F)	$a_{23,14} = \lambda_F$, $a_{23,15} = \lambda_W$
S_{24}	2(↓-w), 1(↓-w)*, 2(↓-F)	$a_{24,15} = \lambda_F$, $a_{24,16} = \lambda_W$
S_{25}	1(↓-w), 1(↓-w)*, 3(↓-F)	$a_{25,16} = \lambda_F$, $a_{25,17} = \lambda_W$
S_{26}	1(↓-w)*, 4(↓-F)	$a_{26,17} = \lambda_F$
S_{27}	4(↓-w), 1(↓-F)*	$a_{26,18} = \lambda_W$
S_{28}	3(↓-w), 1(↓-F), 1(↓-F)*	$a_{28,18} = \lambda_F$, $a_{28,19} = \lambda_W$
S_{29}	2(↓-w), 2(↓-F), 1(↓-F)*	$a_{29,19} = \lambda_F$, $a_{29,20} = \lambda_W$
S_{30}	1(↓-w), 3(↓-F), 1(↓-F)*	$a_{30,20} = \lambda_F$, $a_{30,21} = \lambda_W$
S_{31}	4(↓-F), 1(↓-F)*	$a_{31,21} = \lambda_F$

Table 3

Steady-State Probability Values for the Cases: m = 2, m = 3, m = 4 and m = 5

	2 looms		3 looms		4 looms		5 looms	
	S_i	p_i	S_i	p_i	S_i	p_i	S_i	p_i
Level 1	S_1	0.82789	S_1	0.74405	S_1	0.66168	S_1	0.58204
Level 2	S_2	0.08414	S_2	0.11358	S_2	0.13405	S_2	0.14538
	S_3	0.07287	S_3	0.09804	S_3	0.11704	S_3	0.13126
Level 3	S_4	0.00424	S_4	0.01161	S_4	0.01898	S_4	0.02846
	S_5	0.00294	S_5	0.00886	S_5	0.01709	S_5	0.02452
	S_6	0.00468	S_6	0.00858	S_6	0.02048	S_6	0.02544
	S_7	0.00325	S_7	0.01137	S_7	0.01548	S_7	0.02740
Level 4			S_8	0.00058	S_8	0.00196	S_8	0.00426
			S_9	0.00085	S_9	0.00326	S_9	0.00709
			S_{10}	0.00031	S_{10}	0.00145	S_{10}	0.00710
			S_{11}	0.00073	S_{11}	0.00237	S_{11}	0.00279
			S_{12}	0.00106	S_{12}	0.00344	S_{12}	0.00434
			S_{13}	0.00038	S_{13}	0.00136	S_{13}	0.00389
Level 5					S_{14}	0.00010	S_{14}	0.00043
					S_{15}	0.00023	S_{15}	0.00104
					S_{16}	0.00019	S_{16}	0.00127
					S_{17}	0.00005	S_{17}	0.00057
					S_{18}	0.00015	S_{18}	0.00032
					S_{19}	0.00033	S_{19}	0.00073
					S_{20}	0.00024	S_{20}	0.00080
					S_{21}	0.00006	S_{21}	0.00035
Level 6							S_{22}	0.00002
							S_{23}	0.00007
							S_{24}	0.00010
							S_{25}	0.00007
							S_{26}	0.00002
							S_{27}	0.00002
							S_{28}	0.00006
							S_{29}	0.00008
							S_{30}	0.00006
							S_{31}	0.00002

Observe that, for the states where all the looms are down, the exact steady-state probability values are much lower on compared with all other states (values highlighted in Table 3). For this reason, these states can be neglected in an approximate approach.

Table 4 presents numerical results with respect to the loom efficiency (*EF*) and the weaver work loading (*WL*) for all these four case studies. To illustrate the accuracy of this simplified method, both exact and approximate values are presented in this table.

Table 4

Machine Efficiency (EF) and Weaver Work Loading (WL) for Some Case Studies

	EF, [%]			*WL*, [%]	
	Exact value	Approximate value	Estimation error, [%]	Exact values	Approximate values
2 looms	90.64	92.62	2.18	28.89	25.72
3 looms	89.86	90.39	0.59	42.00	41.00
4 looms	88.95	89.04	0.10	54.63	54.19
5 looms	87.97	88.01	0.05	65.72	65.50

It can be observed that the estimation error is greater for a small number of looms but it decreases rapidly once the number of looms allocated to the weaver increases. For a number of looms greater or equal to four, this approximate method ensures a very good accuracy. Of course, the accuracy also depends on the values of parameters of the primary random variables $(\lambda_W, \lambda_F, \mu_W, \mu_F)$.

4. Final Remarks

The simplified analytical method based on reduced Markov chains ensures good estimation when the number of looms is greater or equal to three-four. Usually, the number of looms allocated to the weaver grows up to ten or even more. In those cases, the Markov model can be reduced even more by neglecting and other states from lower levels. This approximate method is important from both theoretical and practical points of view.

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MODEL MARKOV REDUS PENTRU O PROBLEMĂ DE INTERFERENŢĂ A MAŞINILOR DE ŢESUT

(Rezumat)

Lucrarea tratează o problemă de interferență a maşinilor de țesut. Pentru un grup de maşini deservite de un muncitor trebuie evaluat randamentul maşinilor şi gradul de încărcare a muncitorului, în funcție de numărul de mașini alocate. Pentru rezolvarea acestei probleme de predicție pot fi aplicate metode analitice bazate pe modele Markov sau tehnici de simulare numerică. În lucrare se prezintă o metodă aproximativă, bazată pe un model Markov redus, pentru evaluarea cu o bună acuratețe a celor doi indicatori. Eficiența acestei metode de predicție, în care numărul stărilor lanțului Markov este considerabil redus, este ilustrată printr-un studiu de caz în care un muncitor deserveşte cinci maşini de țesut.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 1-2, 2013
Secţia
TEXTILE. PIELĂRIE

ASPECTS CONCERNING THE WARP STATIC TENSION ON WEAVING MACHINE

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Received: April 12, 2013
Accepted for publication: April 29, 2013

Abstract. The warp static tension represents a basic technological parameter for weaving. The value of the static tension should be adopted in accordance with the characteristics of processed yarns and the specifics of the fabric. The paper presents some technological aspects concerning the ways of obtaining warp static tension on the weaving machine. The influences of the technological parameters (advance at shed formation, the position of the back beam in relation to the position of front beam) on the value of the warp static tension are analysed.

Key words: weaving, static tension, warp yarns, technological parameters.

1. Introduction

In the weaving process the warp threads are subjected to the following strains: stretching, friction and bending. These strains are determined by the mechanisms which impose displacements in both directions, as well as guiding devices placed along the yarn path. The analysis of phenomena on the weaving machine shows applications carrying out separately or associated in various parts of the path (Cioară, 2008; Cioară, 2011; * * *, 2004). In the roll of warp -

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back crossbeam area, the main tension is created by the warp feeding (let-off) mechanism and take-up mechanism. The friction is produced by the contact of the warp threads with the back crossbeam.

In the warp controlling area, the yarns are subjected to friction and tensile stresses. The friction develops between blades and yarns and between neighbouring yarns during shed formation. Due to the yarn separating movement during shed formation, in the area between the warp controller and the shedding harnesses there is a cyclic strain and friction between the warp threads. In the harnesses area the yarns are subjected to tensile strain, several types of friction (yarn – yarn friction, yarn – heald friction, friction between yarns in neighbouring healds) and bending due to the repeated lifting and lowering of the shedding harnesses. The stress in the reed area is caused by tensile stress and friction.

Predominantly on the weaving machine, the warp threads will be put to tensile stresses. The total tension of the warp yarns is obtained by summing the values of the dynamic and static tensions. The dynamic tension develops only during weaving and represents about 10 to 15% of the breaking force of the yarns. The static or mounting tension of the warp yarns represents about 5 to 10% of the breaking force. Therefore the total tension of the warp can reach a level of about 15 to 25% of the breaking force of the yarns. To maintain the tensional characteristics of the warp yarns it is important to maintain the stress within the elastic range.

The static tension is the component of the warp total tension that is preset on the weaving machine (Cioară, 2008; Cioară, 2011; Marchiş & Cioară, 1986; Taloi *et al*., 1983). The necessary static tension is set with the help of let-off and take-up mechanisms. The static tension is required during weaving, as follows:

− For the controlled displacement of the warp yarns from the warp beam to the weaving area;

− For separating warp yarns for proper forming of shed layers; maintaining the preset tension of the warp yarns facilitates the beating of the weft yarn by the reed.

The level of static tension will be present according to the tensile properties of the yarns and the degree of compactness of the woven fabric. It is important for the weaving process to maintain the static tension as close as possible to the original value. This allows producing a uniform fabric regardless of the diameter of the warp beam.

In reality, the warp static tension is influenced by a number of factors that determine specific variations. Are highlights in this regard the factors that determine changing conditions from the conduct of warp yarns and the values for main technological parameters. The parameters for the let-off of the warp yarns are dependent on the type of system used. When using manually adjustable warp beam brake the level of static tension varies widely. These variations are created by the lack of accuracy of the worker when adjusting the braking force of the beam. The decrease of beam radius leads to an increase of the static tension in the warp yarns; this requires the worker to manually adjust the braking force in order to decrease the yarn tension to its pre-set value. The variation interval is dependent on the experience of the staff. In the case of automated brake mechanisms, the level of static tension is maintained between predefined limits depending on the accuracy level of the brake, without the intervention of worker. This implies the continuous reduction of the braking force in relation to the radius of the warp beam. When using negative regulators the warp static tension is adjusted continuously depending on the variation of the let-off angle of the warp yarns on back roll. This angle is minimum the beam is full and increases as the beam radius decreases.

On the other side it can be mentioned that during weaving cycle the static tension is at its minimum level when the warp yarns are in the same plan (at levelling). At this moment the warp yarns have no dynamic tension and are stretched only by their static tension. The minimum level of static tension obtained at levelling (closed shed position) is also recommended when the weaving looms are stopped for longer periods of time because this position protects the tensile behaviour of the warp yarns.

This paper presents the influence of the adjustments of technological parameters on the warp static tension. The technological parameters analysed are: advance of the shed formation and the position of the back roll in relation to the front roll. This analysis provides some quantitative criteria for assessing the influences of two parameters on the variation of the static tension.

2. Materials and Methods. Experimental

A rotatable central composite design with two independent variables was used to study the influence of two technological parameters on the warp static tension (Taloi *et al.*, 1983): advance of the shed formation and the position of the back roll in relation to the front roll .The encoded and real values of the independent variables are presented in Table 1. The static tension at levelling was chosen as the dependent variable. The static tension was measured using an electronic tensiometer.

Table 1
Encoded and Real Values of the Independent Variables

No.	Independent variables	Symbol	Units of measure	Coded values / real values				
				−1.414	−1	0	+1	+1.414
1	Advance of the shed formation	X_1	[grad]	0	10	30	50	60
2	Position of the back rest in relation to the front rest	X_2	[mm]	−40	−30	0	+30	+40

The complete experimental matrix is shown in Table 2. The experiments were carried out on a conventional weaving machine at a speed of 160 rev/min. The warp yarns were 100% cotton, count Nm 10/2 and breaking strength 620 cN/yarn.

Table 2
The Experimental Matrix

No.	X_0	X_1	X_2	X_1^2	X_2^2	X_1X_2	Y, [cN/yarn]	
							measured	calculated
1	1	−1	−1	+1	1	+1	67.8	66.03
2	1	+1	−1	+1	1	−1	59.9	56.63
3	1	−1	+1	+1	1	−1	40.4	41.27
4	1	+1	+1	+1	1	+1	46	45.35
5	1	−1.414	0	2	0	0	54.6	54.72
6	1	+1.414	0	2	0	0	48.7	50.95
7	1	0	−1.414	0	2	0	61.5	64.54
8	1	0	+1.414	0	2	0	39.7	39.05
9	1	0	0	0	0	0	48.7	49.16
10	1	0	0	0	0	0	48.1	49.16
11	1	0	0	0	0	0	50	49.16
12	1	0	0	0	0	0	48.7	49.16
13	1	0	0	0	0	0	50.3	49.16

For each experimental run, the static tension was measured ten times at levelling position. Table 2 presents the average values of the static tension.

The randomness of the output values from each run was verified using the mean square successive difference test. The aberrant values were tested using the Dixon test. Following these tests it was concluded that the experimental values presented no outliers.

The experimental data was modelled with the following equation:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_{11}X_1^2 + B_{22}X_2^2 + B_{12}X_1X_2 \quad (1)$$

where: B_1, B_2, B_9, B_{11}, B_{22}, B_{12} represent the equation coefficients; X_1 – independent variable (advance of the shed formation); X_2 – independent variable (the position of back roll in relation to the position of the front roll); Y − the output variable (the static tension at levelling).

According to the methodology presented in the literature (Taloi *et al.*, 1983), the equation coefficients are estimated with relations:

$$B_0 = 0.2(OY) - 0.1\sum(iiY) \quad (2)$$

$$B_i = 0.125(iY) \quad (3)$$

$$B_{ij} = 0.25(ijY) \tag{4}$$

$$\sum(iiY) = 11Y+22Y \tag{5}$$

$$B_{ii} = 0.125(iiY)+0.01875\sum(iiY) - 0.1(OY) \tag{6}$$

where: (OY) is the product of X_0 column and Y column; (iY) − the product of X_i column and Y column; (iiY) − the product of x_i^2 column and column Y; (ijY) − the product of X_iX_j column and column Y.

The values of the equation coefficients (1) were calculated based on the experimental data from Table 2. The significance of these coefficients was verified using the Student test and all coefficients were found to be significant.

The adequacy of the mathematical model was tested with the Fisher test. The confidence interval was determined to be 5%.

In these conditions the equation modelling the warp static tension is:

$$Y = 49.16 - 1.33X_1 - 9.01X_2 + 1.84X_1^2 + 1.32X_2^2 + 3.37X_1X_2 \tag{7}$$

3. Results and Discussions

The overall analysis of the relationship (7) shows different influences of the technological parameters X_1 and X_2 on the value of the warp static tension.

The linear terms determine the reverse influence of the static tension, for positive values of the coded parameters X_1 and X_2. For negative values of the coded parameters X_1 and X_2 the influences are direct.

The terms linear coefficient values show greater influence of X_1 parameter compared to X_2 parameter.

The quadratic terms determine the direct influence on the value of static tension throughout the experimental area.

The mixed term has a significant direct influence on static tension in the case when the independent variables (the technological parameters) have encoded values by the same sign.

Detailed interpretation of the effects of the technological parameters is performed based on the analysis of the static tension contours shown in Fig. 1. For the minimum value of advance of the shed formation ($X_1 = -1.414$) and back rest position changing from −1.414 to +1.414, the static tension registers a decrease of 55.6% (from the value 76.86 cN/yarn to 34.11 cN/yarn). The significant differences between the values of the static tension at the two extreme values of the position of the back rest are attributed to the asymmetric horizontal shed.

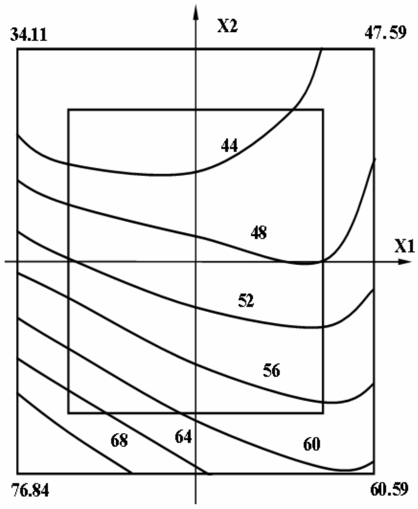

Fig. 1 – Contour plot of the static tension.

The minimum static tension at levelling is obtained for to the maximum positive back rest position (X_2 = +1.414). For the average value of shed formation advance (coded value $X_1 = 0$, real value $X_1 = 30^o$) the static tension variation is between 64 cN/thread and 40 cN/thread. The variation interval of static tension is restricted between 60.59 cN/thread and 47.59 cN/thread for the maximum value of parameter X_1 (value coded +1414, real value 60º).

For the minimum back rest position ($X_2 = -1.414$) the static tension decreases with 21.14% (from 76.84 cN/thread to 60.59 cN/thread), while the parameter X_1 varies between 0º and 60º. For the back rest position $X_2 = 0$, the variation of the static tension is placed in a smaller interval - between 48 cN/thread and 52 cN/thread. For the maximum positive back rest position (X_2 = +1.414) and the parameter X_1 (the shed formation advance) varying between 1.414 and +1.414, the static tension is placed in the 34.11 cN/thread to 47.59 cN/thread interval.

The analysis of the simultaneous influence of the independent parameters shows a 38.06% reduction in static tension (from 76.84 cN/thread at 47.59 cN/thread) while X_1 and X_2 pass from the negative maximum values to positive maximum values. In the case of the other diagonal, the static tension shall be reduced with 43.7% (from 60.59 cN/yarn at 34.11 cN/yarn) while parameter varies X_1 from +1.414 to −1.414 and parameter X_2 goes from −1.414 to +1.414.

From the technological point of view, all settings of the X_1 and X_2 parameters that determine the placement of static tension in the upper half of the experimental field (real values between 35 cN/yarn and 50 cN/yarn) can appreciated as favourable.

Conservation of tensional properties of warp yarns is obtained for the minimum static tension. Therefore the optimum interval can be considered to be - for X_1 between 0 and −1.414 and for X_2 between +1 and +1.414. In the field considered optimal, the static tension has values between 34 cN/thread and 40 cN/thread. For the warp yarns (breaking force of 620 cN), these values for the static tension values represent 5-6% of their breaking strength.

4. Conclusions

1. The static tension of the warp represents an important technological parameter for the adjustment of the weaving machine.

2. The level of the warp static tension on the weaving machine is significantly influenced by the values of the parameters: shed formation advances and the position of back rest in relation to the position of the front rest.

3. The experimental program presented in this paper is a way of finding the settings that provide the minimum values for the static tension.

4. For the conservation of the tensional properties of the warp yarns it is recommended the stationing of the weaving machine in the closed shed position.

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ASPECTE PRIVIND TENSIUNEA STATICĂ A URZELII PE MAŞINA DE ȚESUT

(Rezumat)

Tensiunea statică a urzelii reprezintă un parametru tehnologic de bază pentru maşina de țesut. Valoarea tensiunii statice se adoptă în concordanță cu particularitățile firelor prelucrate şi particularitățile țesăturilor realizate. În lucrare se prezintă aspecte tehnologice privind modalitățile de realizare a tensiunii statice a urzelii pe maşina de țesut. Sunt analizate influențele parametrilor tehnologici (avansul la formarea rostului, denivelarea traversei de spate în raport cu traversa de față) asupra valorii tensiunii statice a urzelii.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 1-2, 2013
Secţia
TEXTILE. PIELĂRIE

COMPRESSION AND BENDING STIFFNESS OF FUNCTIONAL WEFT KNITTED FABRICS

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Received: April 15, 2013
Accepted for publication: May 10, 2013

Abstract. This paper presents an investigation on the compression properties and bending stiffness of weft knitted spacer fabrics. The spacer fabrics were manufactured on Stoll CMS 530 E 6.2 computer controlled flat knitting machine. Sixteen kinds of spacer fabrics have been resulted from the combination between different raw materials and four types of the knitted structures. In order to accomplish the physical and psychological comfort requirement of the users, for the face layer, worn next to the skin, was used a soy protein yarn Nm. 56/3 and as spacer yarns and second layer were used synthetic fibres: polyester Nm 30/3, polyamide Nm 50/3 and polypropylene Nm 16. This yarn configuration was used to maintain the body’s microclimate during physical effort or unfavorable climatic conditions.

The KES FB3-AUTO-A compression tester was used for testing the compression property of the spacer fabrics. The testing method was used according to the instruction manual from Kato Tech Co., Ltd and to determine the bending stiffness was used he textile Flexometer.

The results show that fabric structure, thickness, raw material rigidity and the degree of yarn torsion are some parameters with a high influence on the compression and bending stiffness.

The tested mechanical properties were analyzed in accordance to the fabrics parameters: structure, weight, porosity and fabric thickness. Statistical software

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ANOVA and Statistical Regression were used to evaluate the significance of the structural parameters on the compression and bending stiffness properties.

Key words: compression, resilience, spacer weft knitted fabrics, bending stiffness.

1. Introduction

Weft knitted spacer fabrics found a fast development into a large range of products with applications in all areas of industry.

A great attention has been given to weft-knitted spacer fabrics due to their good transversal compressibility and excellent air permeability. Pereira *et al.* (2007) analyzed the physical-mechanical properties of some warp knitted fabrics designed for knee braces. The study indicates that in terms of dimensional properties, the knitted spacer fabrics have higher volume and lower bulk density than commercial structures. The researchers discovered that spacer fabrics are more suitable for knee braces than the commercial materials due to the fact that they are thinner and have lower weight. They also find out that the warp knitted spacer fabrics have similar breaking load values on course and wale direction, fact that makes the adequate for fabrics that require a uniform compression level.

Bakhtiari *et al.* (2006) analyzed the compression properties of the weft knitted fabrics made from shrinkable and non-shrinkable acrylic fibres. The knitted fabrics were produced with different structures and loop lengths. They find out that the fabrics with knit-tuck structure have higher compression rigidity than the knits with missed structures. Also the 20% shrinkable fibres are highly compressible.

Due to the fact that spacer fabrics are able to absorb kinetic mechanical energy under compression actions, Liu *et al.* (2011), used warp knitted spacer fabrics as a substituent for the polyurethane foams used for cushioning. These fabrics are more suitable for cushioning because of the better moisture transmission, very good compression behavior and similar energy absorption properties with the polyurethane foams.

The good comfort properties of these fabrics recommend them for apparels and medical care (Liu & Hu, 2011). Compression and bending stiffness of the weft knitted spacer fabrics are relevant mechanical properties, especially for functional clothing and cushioning.

Qun Du *et al.* (2011) studied the bending stiffness of textile fabrics, claiming that aesthetics and handle of textile products mainly depend on bending behavior. They also developed a handle evaluation system based on measuring and characterizing weight, bending, friction and tensile properties of the fabrics.

Ertekin & Marmarali (2012) discovered that the compression resistance of the spacer fabrics produced on circular knitting machines is significantly affected from the spacer yarn type, dial height and surface material.

To summarize, the compression and bending stiffness properties of the spacer fabrics are very important and they are designed according to the processing operations and the end-uses of the knitted fabrics.

2. Materials and Methods

The spacer fabrics have endless options regarding the potential yarns combinations and fabrics structures. Due to the fact that the knitted spacer fabrics are designed for functional clothing, for the face layer worn to the skin, was used a soy protein yarn Nm. 56/3 because of its good comfort properties and skin affinity, and as spacer yarns and second layer were used synthetic fibres: polyester Nm 30/3, polyamide Nm 50/3 and polypropylene Nm 16. This yarn configuration was used to maintain the body's microclimate during physical effort or unfavorable climatic conditions. The spacer fabrics were manufactured using Stoll CMS 530 E 6.2 computer controlled flat knitting machine. Sixteen kinds of spacer fabrics have been resulted from the combination between different raw materials and four types of the knitted structures. Fig. 1 displays the knitting sections of the four spacer structures denoted as S1, S2, S3 and S4.

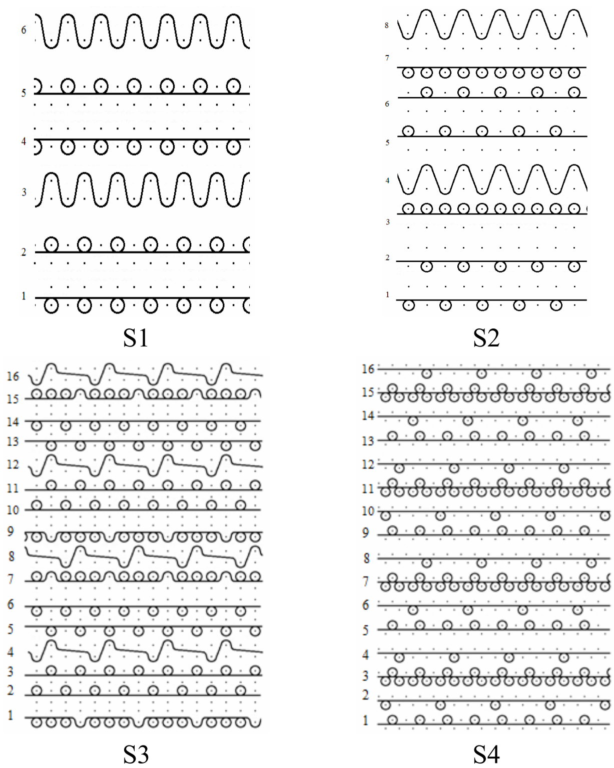

Fig. 1 − Knitting sections of the spacer structures.

The coding of the samples, the arrangement of yarns in the spacer structure and the fabrics characteristics are shown in Table 1.

Course and wale density per centimeter were measured at five different places on every sample using a magnifying glass and the average values were calculated. Mass per square meter (g/m^2) was determined using an electronic balance, KERN ABT 320-4M and the average of ten measured values for each variance was calculated. Thickness of the spacer fabrics was determined using Alambeta instrument. All measurements were repeated five times and Table 1 shows the mean values of the characteristics of the knitted fabrics.

The fabrics porosity was calculated with the eq. 1:

$$P = (1-m/\rho h)*100, \ [\%] \tag{1}$$

where: P represents the fabric porosity, [%]; m – fabric weight, [g/cm^2]; ρ – density of the fiber, [g/cm^3]; h – fabric thickness, [cm].

Fabric engineering was carried out in order to create an experimental plan, able to performing some comparative analysis. Therefore, the structures S1 and S2 have the same connecting point's ratio but the structure of the outer layers is different. For structure S3 it can be observed in Table 1 that the number of connection points of the spacer yarn is lower, and the outer layers have knit and tucks in their structure. The structure S4 is formed mostly of missed stitches and the link between the two layers is made using a rib structure.

Table 1

Spacer Fabrics Characteristics

Fabric code	Structure of the spacer fabrics			Fabric density		Weight [g/m^2]	Thickness [mm]	Porosity [%]
	F	B	S	Wales /5cm	Courses /5cm			
S1	Soy	Soy	Soy	33	39	685	3.32	86.41
S1-1	Soy	PES	PES	33	38	542	2.54	85.17
S1-2	Soy	PA	PA	33	37	482	2.41	84.49
S1-3	Soy	PP	PP	33	40	763	4.05	83.61
S2	Soy	Soy	Soy	33	39	546	3.01	88.06
S2-1	Soy	PES	PES	30	38	443	2.27	86.42
S2-2	Soy	PA	PA	32	40	379	2.25	86.91
S2-3	Soy	PP	PP	33	41	685	3.63	83.57
S3	Soy	Soy	Soy	34	52	623	3.42	88.01
S3-1	Soy	PES	PES	34	50	507	2.97	88.13
S3-2	Soy	PA	PA	36	48	459	2.84	87.46
S3-3	Soy	PP	PP	34	54	725	3.87	83.70
S4	Soy	Soy	Soy	42	44	412	2.82	90.38
S4-1	Soy	PES	PES	42	44	376	2.91	91.13
S4-2	Soy	PA	PA	44	46	354	2.75	90.60
S4-3	Soy	PP	PP	42	46	487	3.28	88.39

F – Front layer; B – Back layer; S – Spacer yarn

Statistical software was used to evaluate the experimental data and the analysis of variance (ANOVA) was used to evaluate the significance of fabric structural parameters on the comfort properties of the fabrics. To conclude whether the parameters are significant or not, *p* values were examined. Ergun (1995) has established that if '*p*" value of one parameter is greater than 0.05, this parameter will not present any influence and it will be ignored.

3. Results and Discussions

3.1. Compression Properties of the Spacer Fabrics

The KES FB3-AUTO-A compression tester was used for testing the compression property of the spacer fabrics. The testing method was used according to the instruction manual from Kato Tech Co., Ltd (Kawabata & Niwa, 1996). Five measurements of each 20 cmx20cm size sample were taken under a maximum load of compression of 50 [gf/cm^2] and the average values were reported.

The parameters obtained from the compression hysteresis curves are defined in Table 2.

Table 2
The Compresion Properties of Spacer Fabrics

Fabric code	Linearity of compression	Work of compression [gf*cm/cm^2]	Resilience of compression [%]	Thickness at the maximum load [mm]
S1	0.389	0.955	35.87	2.38
S1-1	0.521	1.040	35.39	1.75
S1-2	0.558	1.765	33.87	1.42
S1-3	0.772	1.057	29.74	3.47
S2	0.362	0.920	38.20	2.11
S2-1	0.544	1.210	36.10	1.13
S2-2	0.585	1.620	35.40	1.27
S2-3	0.725	1.112	31.22	3.02
S3	0.605	1.830	41.30	2.56
S3-1	0.387	1.210	35.74	2.01
S3-2	0.441	1.720	34.40	2.12
S3-3	0.762	1.206	30.70	3.26
S4	0.473	1.622	45.20	1.62
S4-1	0.524	1.674	42.50	1.70
S4-2	0.595	1.923	41.34	1.48
S4-3	0.622	1.470	33.20	2.61

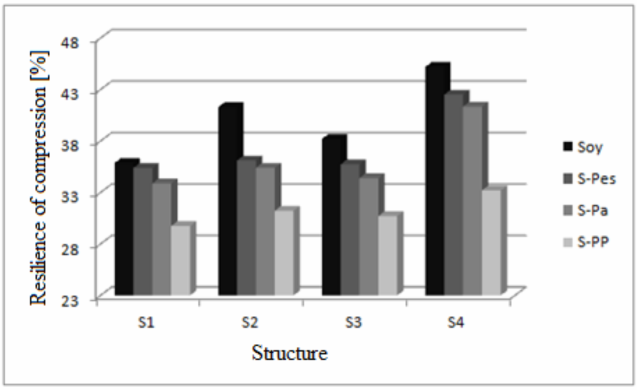

Fig. 2 − Weft knitted spacer fabrics resilience of compression.

Analysing the dates from Table 3, one can observe that, the linearity of compression is increasing with the fabric thickness. The resilience of compression is the percentage energy recovery from the compression deformation in the thickness direction. A higher resilience percentage indicates that the fabric has better recovery property.

From Fig. 2 it can be concluded that the raw material, fabric thickness, density, the arrangement and the connecting distance of the spacer yarn are factors that have a significant influence on the resilience of the spacer fabrics. Thus, structure S4 has the highest resilience and the structure S1 posses the lowest values of the compression resilience. More, the fabrics having both layers made of soy protein yarns have good resilience. By using a synthetic yarn for the reverse layer the resilience will decrease, the lowest values of the recovery it is shown by the fabrics that have the reverse layer made from polypropylene.

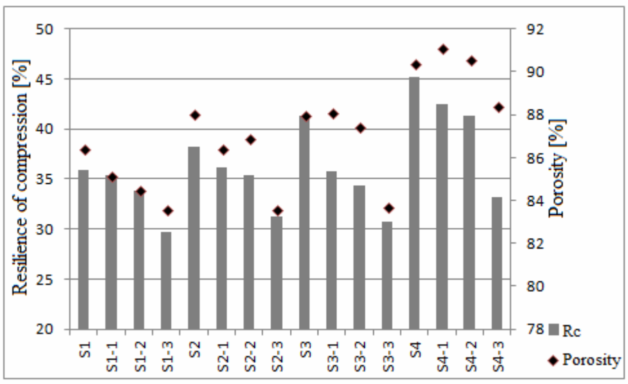

Fig. 3 − The relation of resilience of compression and porosity.

The relation between the resilience of compression and the porosity of spacer fabrics it is listed in Fig. 3. It can be noticed that the resilience is increasing with the porosity, so the higher is the porosity; the better is the fabric recovery from compression. The statistical analysis shows that the porosity has a significant effect on the fabrics resilience (p = 0.00035). Also the ANOVA analysis indicates a significant interaction between the raw material and the fabric resilience (p = 0.014) and between the linearity of compression and raw material (p = 0.0032).

3.2. Bending Stiffness of the Spacer Fabrics

Stiffness is the ability of material to resist at deformation. The bending length was determined with the Textile Flexometer as being the length under which the material will bend under an angle of 41º30' (Niculăiasa 2000; Harpa 2003). Samples of 150 x 20 mm dimensions have been weighted, and a number of five measurements of the bending length were determined the average being listed in Table 3.

The bending stiffness was calculated using the formula:

$$R = m\left(\frac{L_c}{2}\right)^3, \text{ [cm]} \tag{2}$$

where: R – bending stiffness, [cm]; m – weight, [g]; L_c – bending length, [cm]

Table 3

Bending Stiffness of Spacer Fabrics

Fabric code	Wale direction			Course direction			Fabric bending stiffness [cm]
	Weight [g]	Bending length [cm]	Bending stiffness [cm]	Weight [g]	Bending length [cm]	Bending stiffness [cm]	
S1	2.45	3.75	129.20	2.6	3.53	113.88	121.30
S1-1	1.85	4.20	137.06	2.0	4.01	128.96	132.95
S1-2	1.80	4.26	138.67	1.9	4.10	130.95	134.75
S1-3	2.95	4.36	244.50	2.8	4.14	201.50	221.96
S2	1.75	3.59	80.97	1.8	2.55	29.85	49.16
S2-1	1.65	3.43	66.29	1.7	2.28	20.74	37.08
S2-2	1.35	3.8	74.08	1.6	3.15	50.01	60.87
S2-3	2.50	4.03	163.02	2.4	3.30	84.45	117.33
S3	2.05	3.64	98.87	2.1	3.01	57.27	75.25
S3-1	1.80	3.92	108.01	1.9	3.42	75.67	90.41
S3-2	1.70	4.13	119.32	1.8	3.87	103.93	111.36
S3-3	2.70	4.37	224.55	2.7	3.98	166.44	193.32
S4	1.65	3.33	60.65	1.9	2.47	27.88	41.12
S4-1	1.30	3.47	54.08	1.4	2.70	26.57	37.91
S4-2	1.45	3.62	68.50	1.5	2.45	21.19	38.10
S4-3	2.15	4.08	145.49	2.2	3.44	91.59	115.44

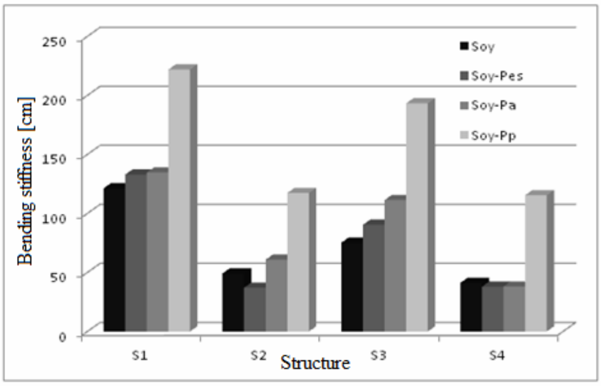

Fig. 4 − The bending stiffness of the weft knitted spacer fabrics.

Fig. 4 outlines the influence of the structure on the bending stiffness of the spacer fabrics. The structure S4 which is formed mostly of miss stitches has the lowest bending stifness, while the structure S1 due to the higher density of the conecting points of the spacer yarn and the density of the outer layers exhibits the highest bending stiffness. The fabrics that have the reverse layer made of polypropilene have the highest values of the bending stiffness due to the yarn rigidity and fabrick thickness.

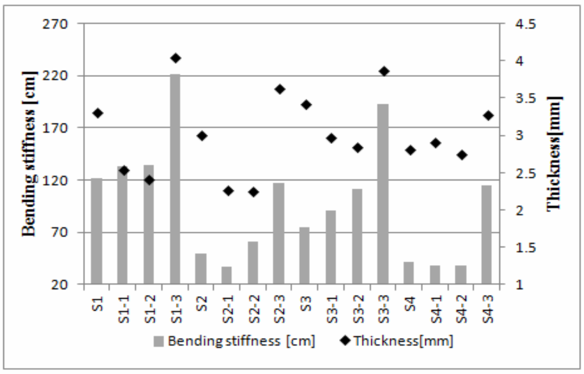

Fig. 5 − The relationship between bending stiffness and fabric thickness.

Fig. 5 outlines the relationship between bending stiffness and fabric thickness, clearly being that with the increasing of thickness the bending stiffness is higher. The statistical analysis confirm the relationship between the banding stiffness and fabric thickness since the p values is lower than 0.05 ($p = 0.007$).

However the fabric thickness is not a defining factor for the bending stiffness, the raw material rigidity and the degree of yarn torsion are also very important factors that have a strong influence on this property.

4. Conclusions

In this study, the compression and bending stiffness of weft knitted spacer fabrics designed for functional clothing were investigated, in relationship with yarn type distribution on the layers and fabrics parameters.

The fabric structure, fabric thickness, raw material rigidity and the degree of yarn torsion are some parameters having a high influence on the bending stiffness. The regression statistics demonstrates the influence of thickness on the analysed mechanical properties.

In case of compression properties of the spacer fabrics, from this study it can be concluded that the raw material, fabric thickness, stitch density and the cross section of the fabrics are significant factors. The fabrics having both layers from soy protein yarns show very good resilience. The resilience properties are decreased by using a synthetic yarn for the reverse layer of the spacer fabrics, the lowest values of the recovery it is shown by the fabrics that have the reverse layer made from polypropylene.

Statistical analysis was performed to determine the influence of porosity on the fabrics resilience of compression. ANOVA analysis indicates a significant interaction between the raw material and the fabric resilience and between the linearity of compression and raw material.

Structural design demonstrated a clear influence on the bending stiffness of the spacer fabrics.

Acknowledgments. This paper was financially supported by POSDRU CUANTUMDOC "DOCTORAL STUDIES FOR EUROPEAN PERFORMANCES IN RESEARCH AND INNOVATION" ID79407 project funded by the European Social Fund and Romanian Government.

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COMPRESIA ŞI RIGIDITATEA LA ÎNCOVOIERE A TRICOTURILOR DIN BĂTĂTURĂ STRATIFICATE

(Rezumat)

Această lucrare prezintă o cercetare asupra proprietăților de compresie şi rigiditate la încovoiere a tricoturilor din bătătură stratificate. Tricoturile stratificate au fost realizate pe maşina rectilinie electronică de tricotat din bătătură Stoll CMS 530, de finețe E 6.2. Şaisprezece variante de tricoturi stratificate au fost obținute prin combinarea diferitelor tipuri de materii prime şi a patru variantei de structuri. În vederea îndeplinirii cerințelor fizice şi psihologice de confort, pentru stratul față, care vine în contact cu pielea s-a utilizat un fir cu proteine din soia de finețe Nm. 56/3, iar ca fire de legatură şi pentru stratul spate s-au folosit fibre sintetice: poliester Nm 30/3, poliamidă Nm 50/3 şi polipropilenă Nm 16. Această aranjare a firelor a fost stabilită pentru a menține microclimatul subvestimentar in timpul efortului fizic sau în condiții climatice nefavorabile.

Pentru a testa proprietățile de compresie ale tricoturilor stratificate s-a folosit aparatul KES FB3-AUTO, în conformitate cu manualul de instrucțiuni al Kato Tech Co, Ltd, iar pentru a determina rigiditatea la încovoiere s-a utilizat Flexometrul textil.

Rezultatele arată că structura tricotului, grosimea, rigiditatea firului şi torsiunea sunt parametrii care au o influență semnificativă asupra proprietăților de compresie şi rigiditate la încovoiere. Proprietățile mecanice testate au fost analizate în corelație cu parametrii de structură, respectiv: structura, masa, porozitatea şi grosimea materialului.

Pentru validarea influenței parametrilor de structură asupra proprietăților de compresie şi rigiditatea la încovoiere a tricoturilor stratificate, s-a efectuat analiza statistică şi regresia statistică ANOVA.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 1-2, 2013
Secţia
TEXTILE. PIELĂRIE

3D VIRTUAL MODELING - INNOVATIVE TECHNOLOGY TO SIMULATE THE CORRESPONDENCE BETWEEN BODY AND GARMENT

BY

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Received: April 17, 2013
Accepted for publication: May 20, 2013

Abstract. In classic clothing design technology, both the manual and CAD systems, finalizing the design of basic patterns and model requires the production of the prototype, most of times repeating this step until the optimization of the basic and model patterns. This is a laborious task, time consuming and costly.

Research conducted by the authors of this paper focused on improving the design process of customized clothing, through the 3D simulation of the correspondence between the human body and the designed product. Extending the production of clothing according to the real body size of the users is based on the new profile defined for each customer, their desire to purchase a customised product and also the anthropometric survey results that have shown a large variability of the morphological types especially for women.

In the context of globalization of markets and creative industries there is a whole new approach to clothing design process whose ultimate goal it is a new garment engineering that is customer centred. This paper proposes an innovative approach to the clothing design process according to the body size of potential buyers.

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Mathematical processing of the raw data allowed the authors to develop an algorithm for the automated design patterns, using the MTM module of the Gemini Pattern Editor software. Patterns made with the actual dimensions of a user have been validated by 3D simulations, using facilities provided by Optitex system.

The paper makes the following contributions to the field of individualized clothing design: morphological characterization of the female body shape by specific indicators necessary for the classification of body types and provided by 3D scanning; development of an algorithm for 2D patterns by using MTM module of the Gemini Pattern Editor software (with application for the dress); 3D virtual simulation of the correspondence between product design and virtual mannequin that correspond to the body dimensions and shape of the tested subject, in order to validate the developed patterns; final reshaping of patterns by re-simulation in the virtual space.

Key words: virtual simulation, garment, human body.

1. Introduction

The widespread use of CAD systems in the apparel industry for models design, together with the database resulting by 3D scanning technology of the human body are the premises for extending virtual modelling of the body - garment correspondence during the stage of 2D patterns development, based on the specific dimensions of the clients (Da Silveira *et al*., 2001; Zulch *et al*., 2011).

In the classic technology of constructive clothing design, basic and model patterns are being completed following the practical execution of the product, a laborious process that involves high costs of labour and raw materials (Simmons & Istook, 2003).

The qualitative leap in the field of industrial design, according to the real dimensions of the customers, the so-called “customized clothing” is currently feasible due the performances of the CAD systems, integration of both modules for MTM and simulation in the virtual environment of the correspondence between body and the product designed in 2D (Jiao & Helander, 2006).

3D simulation of the correspondence between product design and the human body is an innovative technique that improves the whole process of constructive design of clothing products (Jagstam & Klingstam, 2002). This technique has many advantages among which the rapid renewal of models and reducing costs associated with the implementation of prototypes.

In this context, it explains the permanent concern of specialists in the field of constructive designing of clothing to improve the entire process, from defining the initial database to its operation so that the outcome of this process will ensure the users with garments that are correlated with their morphological features.

For this purpose, a methodology is proposed which allow the designer of clothing patterns to use all the facilities offered by the existing CAD systems.

For the implementation of the proposed methodology, the research started from the idea that there are clients with body sizes different from the standard, within limits that can be adapted by the designer to the real shape of the client's body. For this purpose, the role of the pattern designer is very important from two perspectives:

• Complex characterization for the morphological specifics of the subject's body, in order to assess the deviations from the standard body;

• Adopting the optimal solution for patterns remodelling during the 3D simulation, interactive technical stage between specialists and CAD system.

In this context, the research objectives were the following:

• Elaboration and implementation of the methodology for morphological characterization of women, an essential step in setting up a scientific database required in the use of innovative simulation techniques of the body-clothing correspondence in cyberspace;

• Application of the methodology to validate the developed patterns for a random body using "virtual fitting".

In order to fulfil the research objectives, an initial database was created from the anthropometric survey base on 3D scanning of a lot of Romanian adult women. The measurements were performed in 2009.

The initial data of the selection was processed mathematically (one-dimensional statistical method) and compared with the corresponding values given in the literature (SR 13545:2010, SR 13544:2010).

2. Development of Methods for Subjects' Morphological Analysis

2.1. Mathematical Model for Body Shape Assessing

The production of clothing according to the individual system is very important for the pattern designer to quickly and correctly evaluate the morphological features of the customer in order to design accurate patterns. In order to fulfil this overall objective, a specific algorithm was developed based on a relatively small number of anthropometric dimensions considered for a certain subject. It allows the pattern designer to quickly and objectively evaluate: body type (standard dimensions) and morphological features - stature, size and conformation for anyone (Filipescu *et al*., 2009).

The development of the mathematical model required a database for the automated evaluation of morphological features of the tested subjects.

The specifics of a certain body type (size, height group, conformation), and basic morphological indicators (posture, proportions, vertical balance and shoulder position) required the selection of the following anthropometric measurements (Filipescu, 2007):

1. Body height, Ic
2. Bust circumference, Pb
3. Hips circumference, Pş
4. Shoulders length, Lu
5. Thorax length from neck to waist, L’tf
6. Vertical arch of the back, Avs
7. Shoulders inclination angle, α
8. Distance from cervical point to a reference plane, placed behind the subject, D1
9. Distance from scapula projection to a reference plane, placed behind the subject, D2
10. Distance from back waist point to a reference plane, placed behind the subject, D3
11. Distance from buttock point to a reference plane, placed behind the subject, D4
12. Distance from clavicle point to a reference plane, placed behind the subject, D5
13. Distance from breast point to a reference plane, placed behind the subject, D6
14. Distance from the front waist point to a reference plane, placed behind the subject, D7
15. Distance from the maximum abdomen point to a reference plane, placed behind the subject, D8.

One more step is the acquisition of formation from standard anthropometric (SR 13545:2010) required to fit the subject to a standardized body type, relating to size groups, heights groups and conformation groups (Table 1).

Table 1
Conformation Groups

Confor-mation groups	Pş-Pb	Clothing sizes										
		40	42	44	46	48	50	52	54	56	58	60
		Bust circumference Pb										
		80	84	88	92	96	100	104	110	116	122	128
		Hips circumference Pş										
A	−4	–	–	–	–	–	–	100	106	112	118	124
B	0	80	84	88	92	96	100	104	110	116	122	128
C	4	84	88	92	96	100	104	108	114	120	126	132
D	8	88	92	96	100	104	108	112	118	124	130	136
E	12	92	96	100	104	108	112	116	122	128	134	140
F	16	96	100	104	108	112	116	–	–	–	–	–
Inter-dimensional range		4 cm							6 cm			

The morphological characterization of the subjects involves the calculation of averages and inter-dimensional intervals to assess the following morphological indicators: body stature (Pc), back waist depth (Ats), prominence of buttocks (Pfes), shoulder height (îu), vertical equilibrium (Ev1) and thoracic perimeter (Ipt).

The body stature or body position (Pc, cm) is calculated as the difference between D1 and D2; the back waist depth (first waist depth) Ats, cm is calculated as the difference between D2 and D3 and the buttocks prominence (second waist depth) Pfes, cm is calculated as the difference between D3 and D4. All these three indicators have the following interpretation (Filipescu, 1998):

− Tense stature: $Pc < 4.69$; $Ats < 2.9$; $Pfes < 3.49$
− Normal stature: $Pc = 6.2 \pm 1.5$; $Ats = 4.5 \pm 1.5$; $Pfes = 5 \pm 1.5$
− Crooked stature: $Pc > 7.71$; $Ats > 6.1$; $Pfes > 6.51$.

The next morphological indicator, the shoulders height ($î_u$, cm) is calculated with the following equation:

$$î_u = Lu * \sin \alpha \tag{1}$$

Its interpretation is:

− Shoulders lifted, $î_u < 5.19$
− Shoulders in normal position, $î_u = 5.9 \pm 0.75$
− Shoulders descended $î_u > 6.7$.

Vertical balance (Ev, cm) is calculated as the difference between the thorax length from neck to waist (L'tf) and the vertical arch of the back (Avs), offering information about the thorax position:

− Leaned forward, $Ev < -0.21$
− Normal vertical balance, $Ev = 1.8 \pm 2$
− Leaned back, $Ev > 3.81$.

The thoracic perimeter index (Ipt, %) offers information about the thorax type and it is calculated by the ratio of bust circumference (Pb) and body height (Ic):

− Narrow thorax, $Ipt < 56.9$
− Average thorax, $Ipt = 60 \pm 3$
− Large thorax, $Ipt = 66 \pm 3$
− Round thorax, $Ipt > 69$.

The selected anthropometric sizes and morphological indicators were then used in the two methods of assessing body shape. The mathematical model was developed to assess the overall exterior body shape, but a complex evaluation requires a comparative analysis between the morphological indicators of a subject and the standardized values of the body type that fits the subject in her principal dimensions (body height, bust circumference and hips circumference).

2.2. Complex Evaluation by Comparative Method

Apart from the above mentioned indicators (Pc, Ats and Pfes), the method required the use of several indexes characterizing the body prominence in the frontal plane, on its anterior part. The first additional indicator is the bust prominence (P_{bust}, cm) which is calculated by the difference between D6 and D5, characterizing the bust type:

− Less prominent bust, $P_{bust} < 9$
− Bust with normal prominence, $P_{bust} = 10.5 \pm 1.5$
− Bust prominent, $P_{bust} > 12.1$.

The waist depth compared to bust prominence (Atf, cm) is calculated by the difference between D6 and D7, offering information about the prominence type:

− Waist is more prominent than bust, Atf < 0
− Waist is as prominent as bust, Atf = 0
− Bust is more prominent than waist, Atf > 0.

Abdomen prominence compared to bust prominence (Pabd) in cm is calculated by the difference between D6 and D8, giving information about the prominence type:

− Abdomen is more prominent than bust, Pabd < 0
− Abdomen is as prominent as bust, Pabd = 0
− Bust is more prominent than abdomen, Pabd > 0.

The last indicator is the abdomen prominence compared to waist prominence (Pabd-t) in cm is calculated by the difference between D8 and D7, characterizing the prominence type:

− Abdomen is more prominent than waist, Pabd-t < 0
− Abdomen is as prominent as waist, Pabd-t = 0
− Waist is more prominent than abdomen, Pabd-t > 0.

2.3. Method for Drawing the Body in Sagittal Plane

For a more precise simulation of body-garment correspondence and a general characterization of the body shape using the two methods described above, the pattern designer needs to visualise shape of the body of the subject.

This visualisation can be obtained by drawing the thorax in the sagittal plane, using a relatively small number of anthropometric sizes, taken from the database from the body scan. If the pattern designer does not have access to the scanned body image and only knows the values of anthropometric measurements resulting from scanning, this visualization is very important.

Drawing the body in a sagittal plane requires the anthropometric sizes specified in Fig. 1.

No.	Anthropometric measure	Symbol
1	Cervical point height	Ipct.cerv
2	Scapula prominence height	Ipr.om.
3	Breast point height	Ipct.mam.
4	Waistline height	Ilt
5	Abdomen prominence height	Ipr.abd.
6	Butlock point height	Ipct.fes.
7	Body stature	Pc
8	Back waist depth	Ats
9	Buttocks prominence	Pfes.
10	Anterior-posterior bust diameter	Da-pb
11	Bust prominence	Pbust
12	Waist depth compared to bust prominence	Atf
13	Abdomen prominence compared to bust prominence	Pabd.
14	Abdomen prominence compared to waist prominence	Pabd-t

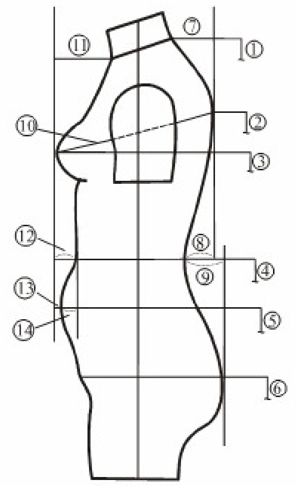


Fig. 1 – Visualization of the anthropometric body sizes identification.

Knowing the anthropometric measures, the thorax in sagittal plane is drawn in the following sequence:

• In the graphical space a vertical line was drawn, marking all the heights values (anthropometric dimensions no. 1 to 6 in Fig. 1);

• from the waist line height (Ilt), a vertical line was placed (tangent to scapula prominence) that intersects the horizontal line from the cervical point, the resulting segments defining the body posture (Pc) and back waist depth (Ats);

• from the waist line height (Ilt) a vertical line was drawn, parallel to the buttocks the resulting segment being the buttocks prominence (anthropometric dimension no. 9 in Fig. 1);

• an arc is drawn with the scapula prominence point as centre and radius r = D6 − D2 (anterior-posterior bust diameter); the arc will intersect the horizontal line at bust height resulting the anthropometric dimension no. 10 (in Fig. 1);

• a vertical line from the breast point is drawn, and the anthropometric dimensions no. 11 to 14 are defined;

• the contours of the front and back of the torso are drawn.

3. 3D Simulation of Body-Garment Correspondence

The following case study presents the simulation of the body-garment correspondence, by using the experimental data from morphological researches referring to the feminine body.

For exemplification, a random body was selected from the database (resulting from 3D body scanning), the selection criterion being that conformity of the subject's main dimensions to the body type B from the national anthropometric standard - body height of 160 cm, bust circumference of 100 cm and hips circumference of 100 cm (SR 13545:2010). The anthropometric dimensions of the subject were selected from values resulting from scanning.

The case study was conducted according to the methodology developed by using information stored in the database, created for this purpose.

3.1. Morphological Characterization of the Subject

The studied subject exemplifies the fitting for a certain type of stature, according to the methodology described in paragraph 2.1. In Fig. 2 are presented the values of anthropometric measures necessary for evaluating and classifying the subject according to the body type and to specific morphological indicators, using the developed mathematical model. It is noted according to the posture indicator (Pc) and back waist depth (Ats) the subject has normal posture values.

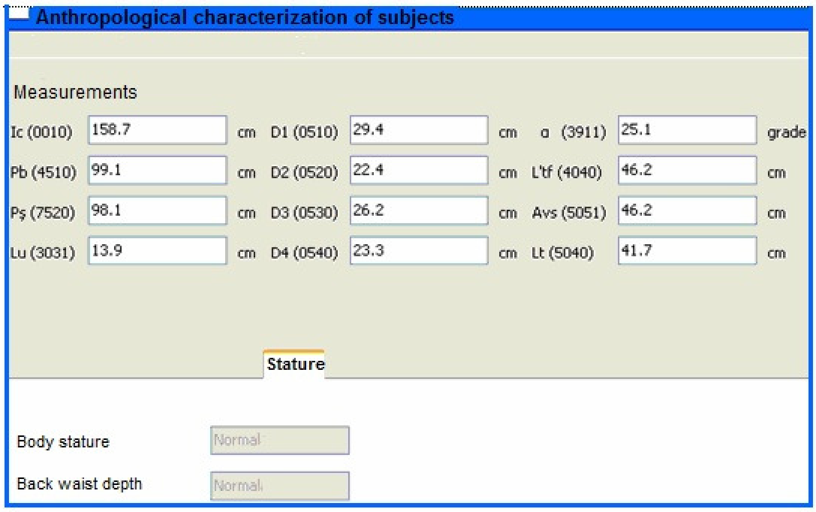


Fig. 2 – Anthropometric sizes of the subject and her type of stature.

After processing the initial data all information about the subject, as specified in paragraph 2.1 can be obtained. The values show that the subject has a normal posture, flat buttocks, shoulders descend, normal vertical balance and average thorax.

For a more comprehensive characterization of the tested subject, to store information necessary to base pattern design and to ensure the best possible fitting between body and garment, it was used the complex method of assessing the subject's body shape as specified in paragraph 2.2. Values of the prominence and depths evaluation indicators were compared, on the front and the rear of the subject with the body type that it fits through the main dimensions taken from standard anthropometric (Standard - SR 13545:2010) results are presented in Table 2.

Table 2
Indicators for Prominence and Depths Assessing Projections for Studied Subject

Evaluation indicator	Value according to the anthropometric standard, [cm]	Experimental value [cm]	Difference [cm]
Body stature (Pc)	6.8	7	−0.2
Back waist depth (Ats)	3.9	3.8	+0.1
Buttocks prominence (Pfes)	5.2	2.9	+2.3
Vertical balance (Ev)	2.5	0.0	+2.5
Bust prominence (Pbust)	10.7	11.4	−0.7
Waist depth compared to bust prominence (Atf)	1.3	−1.4	+2.7
Abdomen prominence compared to bust prominence (Pabd)	0.9	−2.4	+3.3
Abdomen prominence compared to waist prominence (Pabd-t)	0.4	0.5	0.1

Analysing the data from the table above, the following observations can be made:

• the subject has a normal stature (Pc = 7 cm);

• bust prominence is comparable to that of the body type;

• the subject has flattened buttocks, so a lower buttock prominence (Pfes) compared with the body type proves that the basin is front-bellied, a specific position for people with prominent abdomen;

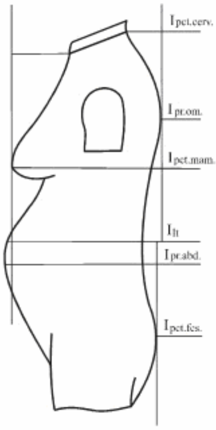
• abdomen prominence is more developed than the one of the body type;

• waist prominence is also higher than the bust.

Morphological analysis of the tested subject by the two proposed variants provides practical information needed for the pattern designer to remodel the patterns as stage of the 3D simulation process.

Based on the information specified in paragraph 2.3., it is presented in Fig. 3 the concrete values of anthropometric sizes and morphological indicators needed to draw the outline of the thorax in sagittal plan. Also, Fig. 3 presents the obtained drawing of the thorax form and the same body as the 3D scanning result. The results show that the method is useful because it gives the designer additional information on body shape.

Symbol	Subject
Ipct.cerv	136.9
Ipr.om.	121.7
Ipct.mam.	110.5
Ilt	96.4
Ipr.abd.	91.5
Ipct.fes.	78.3
Pcorp	7.0
Ats	3.8
Pfes.	2.9
Da-pb	11.4
Pbust	-1.4
Atf	-2.4
Pabd.	0.5
Pabd-t	29.1



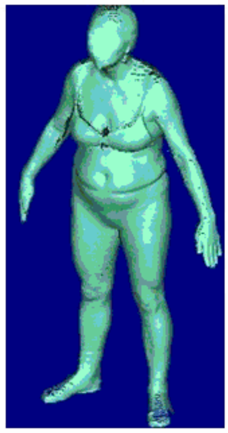


Fig. 3 – Visualization of the body by drawing and scanning.

3.2. Simulation in Virtual 3D Cyberspace

Transposing flat forms of clothing patterns using different CAD systems (Lectra, Gemini, Investronica, Gerber, Optitex) in 3D garments is a laborious activity that requires an understanding of the following aspects:

• data regarding the fabrics used for the garment (fibre content, draping, shrinkage, weight etc.);

• the geometry of the body area on which the element/product is positioned;

• the product manufacturing technology;

• the possibilities for pattern modification depending on the body shape and the characteristics of the fabrics.

The following information was used in order to solve the simulation of the body - garment correspondence in static position:

• results of the morphological analysis for the subject;

• basic pattern design for the dress design using Gemini CAD - design module Gemini Pattern Editor, for the body type that fits the subject according to the main dimensions (group B of conformation) (Filipescu, 2011);

The transformation of the 2D patterns designed with CAD (eg Gemini CAD – design module Gemini Pattern Editor) to a 3D garment takes place in the following sequence:

• three-dimensional modelling of the mannequin according to the dimensions defined in the dimensional table or the customer's size;

• import the flat forms (2D) of the patterns from a CAD system;

• modelling the patterns surface to obtain the product 3D shape;

• check and modify the pattern to ensure the body-garment correspondence.

The virtual modelling was obtained using the OPTITEX PDS CAD system. The stages of simulation are presented below, exemplifying the results of the first and last stages:

Step 1: Import basic patterns made with MTM Gemini CAD Systems module (for the body type 160-100-100) in the specialized software for the simulation of body-garment correspondence, OPTITEX PDS (Fig. 4).

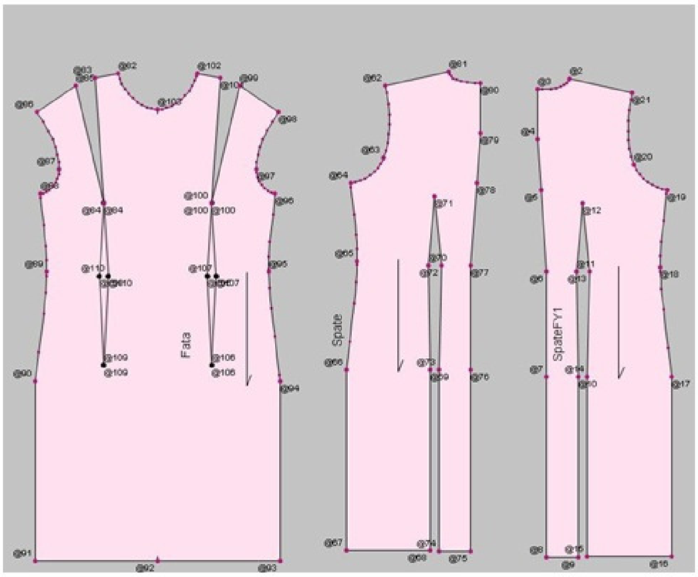


Fig. 4 – Basic patterns for body type: 160-100-100, group B.

Step 2: Definition of the sewing lines, between the construction of lines of the two elements, front and back.

Step 3: Preparation of the mannequin.

Step 4: Positioning of the patterns on the parametric mannequin (Fig. 5). To obtain the sewing simulation for the garment “dress with semi adjusted silhouette”, patterns should be placed in the PDS work area. The pattern designer has the role to accurately place the patterns to the virtual mannequin from the 3D virtual space. If the placement is not correct, the simulation will not be generated, an error message being displayed. To correctly position the patterns on the virtual mannequin, they must be initially synchronized with the position of the mannequin and then they can be simulated.

Step 5: First simulation stage (Fig. 6). Once the pattern is correctly positioned on the virtual mannequin and the correctness of assembly parts is verified, the simulation stage can begin. The duration of the simulation varies depending on the number of items placed in the window of 3D simulation, the simulation model complexity and the sewing lines.

Fig. 5 – Placing the patterns on parametric mannequin.

Fig. 6 – First simulation stage.

Step 6: Verification of body-garment correspondence (Fig. 7). OPTITEX PDS offers various possibilities to determine the precision of the correspondence between the body and the simulated product, one of them using the stress map. The visualization of stress map offers the pattern designer important information regarding the areas of pattern where he/she must intervene. The fact that the selected subject has a prominent abdomen and a larger thorax length both on front and back sides is shown by the product tension, highlighted in red, as seen in Fig. 7.

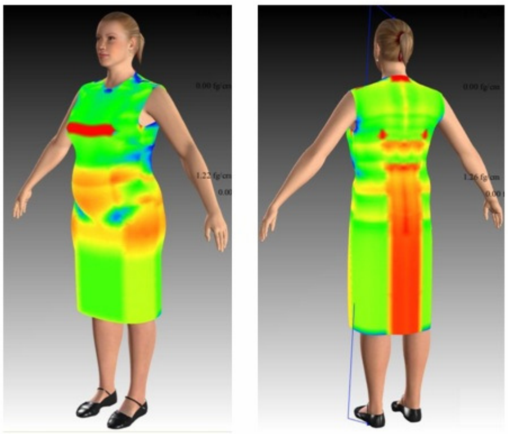


Fig. 7 – Virtual correspondence analysis.

Step 7: Modelling the initial pattern according to the subject's body shape focused on:

• resizing the pattern of the front and back elements on the waistline, with removal of dart on the front element due to abdomen prominence;

• changing the position of upper contour lines on front pattern, because the subject has a front length from the base of neck to the waist larger than the standard value;

• adapting the contour of the front symmetry line to the body particularities (prominent abdomen).

Adapting the basic pattern, developed for the average size of group B conformation to the concrete body form of the tested subject was conducted in successive stages specific for the patterns design activity.

The front pattern requires further processing steps which will define the line termination dart, temporarily built on the side seam contour line (Fig. 8).

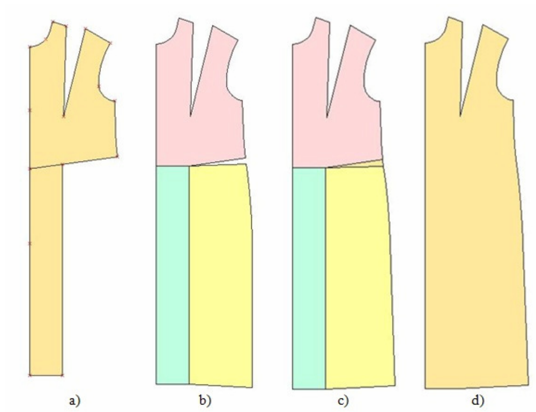


Fig. 8 – Successive stages in the modelling of the front element.

Step 8: Final evaluation is processed after correcting the basic patterns according to the initial simulation. The new simulation is obtained after placing the corrected patterns on the virtual mannequin. Fig. 9 shows the correspondence between the mannequin and the dress, based on the modified patterns.

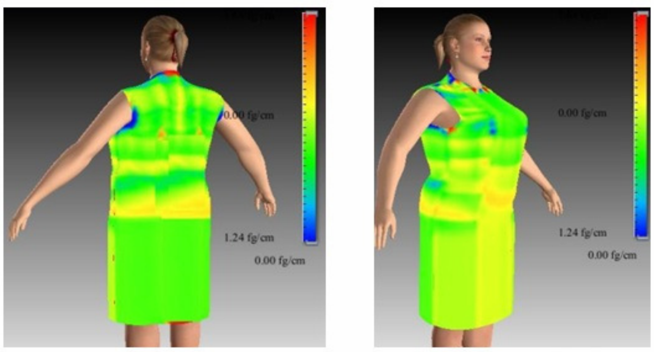


Fig. 9 – New simulation – visualization.

It appears that patterns correction according to the subject's body particularities ensure a better dimensional fitting between the body shape and the garment.

4. Conclusions

The paper brings a contribution to the development of theoretical and applied research aimed to improve the construction design process of clothing for concrete subjects, by proving to the experts in this field the performance and innovative techniques of simulation in virtual space of the correspondence between the body and the garment.

The research presented in this paper provides an important contribution to the following topics:

• The morphological analysis of the subjects was carried out using the mathematical model for body characterization, complex comparative analysis, body shape in sagittal view;

• The inventory of dimensional deviations of dimensional indicators between the tested subject and the body type that they fit through the main dimensions;

• The virtual simulation of correspondence between the selected body and garment designed for the body type, with concrete evaluation of unconformities that resulted;

• The development and implementation of solutions in order to adapt the initial base patterns to the concrete form the tested subject, remodelling basic patterns;

• Definition of the final patterns using successive simulation stages so that all stress areas are eliminated.

The research is opportune due to the methodology presented both theoretical and case study form, especially to specialists who carry out their activity in the technical domain of clothing design, both for industry but also for concrete dimensions of potential customers.

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MODELAREA VIRTUALĂ 3D – TEHNOLOGIE INOVATIVĂ ÎN SIMULAREA VIRTUALĂ A CORESPONDENŢEI DINTRE CORP ŞI PRODUSUL DE ÎMBRĂCĂMINTE

(Rezumat)

În tehnologia clasică de proiectare a îmbrăcămintei, atât în sistem manual cât şi prin folosirea sistemelor CAD, definitivarea procesului de proiectare a tiparelor de bază şi de model necesită execuţia materială a prototipului, de cele mai multe ori repetarea acestei etape până la definitivarea şi optimizarea tiparelor de bază, respectiv a tiparelor de model. Aceasta este o activitate laborioasă şi se realizează cu un consum mare de timp şi cheltuieli materiale, determinate de execuţia practică a prototipului.

Cercetările desfăşurate de autorii prezentei lucrări au vizat perfecţionarea procesului proiectării îmbrăcămintei individualizate, prin simularea în spaţiul virtual 3D a corespondenţei dintre corp şi produsul proiectat. Extinderea realizării îmbrăcămintei după dimensiunile corporale concrete ale utilizatorilor are la bază noul profil al acestuia, dorinţa accentuată de individualizare prin produsul vestimentar pe care îl achiziţionează dar şi rezultatele anchetelor antropometrice care au demonstrat marea variabilitate a tipurilor morfologice mai ales în cazul femeilor.

În contextul general de globalizare a pieţelor de desfacere se constată o nouă abordare a întregului proces de proiectare constructivă a îmbrăcămintei al cărei obiectiv final îl reprezintă o nouă inginerie a afacerilor şi anume vânzările centrate pe client. În lucrare se propune o abordare inovativă a procesului proiectării îmbrăcămintei după dimensiunile corporale ale potenţialilor cumpărători.

Prelucrarea matematică a datelor primare a permis autorilor elaborarea unui algoritm de proiectare a tiparelor în sistem automatizat, prin folosirea modulului MTM din cadrul programului Gemini Pattern Editor. Tiparele realizate, cu dimensiunile concrete ale unui purtător, au fost validate prin simularea 3D, prin utilizarea facilităților oferite de sistemul Optitex.

Lucrarea aduce următoarele contribuții la dezvoltarea domeniului de proiectare a îmbrăcămintei individualizate: caracterizarea morfologică a formei corpului la femei prin indicatori specifici oferiti de scanarea 3D, necesari în clasificarea tipurilor de corpuri; elaborarea algoritmului de proiectare 2D a tiparelor, prin folosirea modulului MTM din cadrul programului Gemini Pattern Editor (cu aplicație pentru produsul rochie); simularea în spațiul virtual 3D a corespondenţei dintre produsul proiectat şi corpul virtual care corespunde dimensional şi ca formă cu subiectul testat, în vederea validării tiparelor elaborate; modelarea finală a tiparelor prin resimularea în spațiul virtual.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 1-2, 2013
Secţia
TEXTILE. PIELĂRIE

TEXTILE HEATING FABRICS WITH POLYPYRROLE LAYER

BY

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Received: April 19, 2013
Accepted for publication: May 23, 2013

Abstract. This paper examines the possibility of obtaining conductive textile materials with applications in the field of thermal protection. Conductive textiles were made by coating samples of rayon and polyester fabrics with the conductive polymer polypyrrole. Conductive yarns with rubber core wrapped with copper filaments or covered with a layer of silver were inserted into the woven rayon structure. Polyester fabrics coated with polypyrrole have a conductive pattern printed with ink-based fine particles of silver. The samples obtained were analyzed using a thermographic camera, which allows recording the electrical resistance of the sample as well as the temperature emitted by the sample when it is put under electrical voltage. The coating of a thin film of polypyrrole on a cloth in order to obtain heating surfaces present the advantage that is a simple and effective process and at the same time requires a small amount of time; in the process of obtaining the coated fabric, polypyrrole was chosen for its electrical and thermal properties, while the fabric provides elasticity and flexibility of the conductive product.

Key words: heating fabric, polypyrrole, conductive polymer, coated textile.

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1. Introduction

By coating textiles with conductive polymers, conductive and functional textiles can be obtained. These textiles can be used as sensors, actuators, electromagnetic shields, in the field of radar absorption, applications in the heating fabrics field (Bhat *et al*., 2006). Investigations have been made in the field of heating fabrics made by methods of coating with polymers such as conductive polymers like polypyrrole or with carbon black conductive powders (Smith, 2010; Varesano *et al*., 2005; Gasana *et al*., 2006; Dall Aqua *et al*., 2004; Hakansson *et al*., 2004).

Methods for obtaining conductive textiles are diverse, some deriving from the textile processes, some being innovative: dyeing-printing of carbon nanotubes in aqueous solution, coating with conductive polymers - polypyrrole, polyaniline, polithiophene, metal fibre yarn, etc.

Requirements for obtaining conductive textiles are: the possibility to integrate electronic components into a textile structure and constant electrical properties, even after repeated washing and wearing.

Electric conductive polymers, described as a new class of “synthetic metals”, have aroused a great interest in recent years. Recent research undertaken in the world shows that conductive polymers are a viable alternative because these can be used in a multitude of applications: electronic devices, luminescent diodes, magnetic screens, actuators. These new materials present a great interest because of the relatively cheap synthesis methods, low consumption of raw materials and electric properties (Kuhn *et al*., 1995).

The most studied classes of conductive polymers are: polyacetylene, polythiophene, polypyrrole, polyaniline and its derivatives. Numerous methods for transferring the electrical conductivity of these polymers on the flexible textile substrate are based on coating the surface with layers of polymer. Coating is commonly used to provide conductivity for non conductive textile materials, including both natural and synthetic materials. Coated textiles with conductive polymers can be characterized by: measuring their resistivity, electron microscope scanning, properties reflecting thermal behaviour, transmission of electric current over a period of time and power dissipated in the form of thermal energy (heat).

By coating textile substrates with conductive polymers, electrical properties of the polymer can be combined with the strength and flexibility of the substrate fabric. The fragility of the conductive polymer layer does not affect significantly the flexibility and manoeuvrability of coated fabric.

Coated textiles obtained by the oxidative polymerization of the pyrrole monomer on a textile support is a method often used, the factors of influence, in accordance with the literature, being: the thickness of polypyrrole layer, which depends on the quantity of polypyrrole in solution, the oxidant/dopant ratio, the structure of textile materials. Physical and mechanical properties of conductive textiles can be affected by the doping agents of the monomer, as well as the synthesis parameters, such as time, temperature, pH, and the speed of stirring the solution.

In the present paper the possibility of use electro-conductive textiles for heating purposes is explored, focusing on temperature reached when electrical voltage is applied. The coating of a thin film of polypyrrole on a fabric in order to create heating surfaces presents the advantage of being a simple and effective process and it is not time consuming; for the coated fabric, the polypyrrole was chosen for its electrical and thermal properties, while the fabric provides elasticity and flexibility of the conductive product.

2. Materials and Methods

Among other conductive polymers, polypyrrole was considered a suitable material for coating in textile industry as it presents a good affinity with both natural and chemicals fibres, and the textile substrates can be easily covered by immersion in a solution containing pyrrole, an oxidant and a doping agent. The conductive polymer polypyrrole is often used to produce conductive textiles by chemical polymerization of the pyrrole directly on the textile surface. The polymerization of polypyrrole can be carried out on different substrates, such as textile fibres, yarns, fabrics (Shang *et al*., 2010; Najar *et al*., 2007; Lin *et al*., 2005; Collins & Buckley, 1996).

The following substances were used in the study presented in the paper:

− Conductive polymer polypyrrole has been used to coat textile fabrics in order to obtain homogenous heating surfaces.

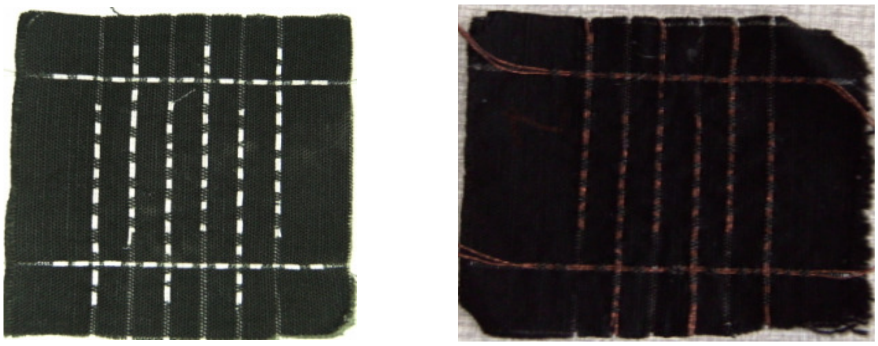
− Conductive wires are produced by ELEKTRISOLA Feindraht AG, with rubber core and covered with copper wires (type K306B) and rubber core covered with copper wires coated with a layer of silver (K105 type).

− Pyrrole is purchased from Sigma Aldrich, purity of 98% and the density of 0.967 g/cm^3.

− The conductive ink used to print the specific pattern onto the fabric has the trade name Electrodag PF-410 and contains very fine silver particles in a thermoplastic resin.

The method used for the polymerization of the polypyrrole was the oxidative polymerization of the polymer in aqueous solution in the presence of the dopants. Doping is the creation of defects in the structure of the polymer without destroying the polymeric chain. These defects in the polymer may be radicals, anions, cations, or combinations. As mentioned previously, the polypyrrole presents affinity for both natural and chemical fibres; two types of raw materials were selected to produce the fabrics: rayon and polyester. The type of woven fabric used in this research is canvas. The electrical current was distributed in the coated fabric according to a pattern developed by printing with conductive ink or by sewing conductive yarns. Two types of conductive threads were used: yarns with rubber core wrapped with a copper filament, yarn with rubber core wrapped with a copper filament coated with a layer of silver.

Fig. 1 presents the aspect of the rayon fabrics coated with polypyrrole with a conductive pattern with sewn conductive threads. Since the conductive threads are quite thick and stiff, the smoothness of the fabric surface was obtained by removing some yarns from the warp and weft and in their place were introduced the conductive threads. The electric circuit of the polyester fabrics coated with polypyrrole was produced through ink printing using a special pattern (Fig. 2).



a *b*

Fig. 1 − Samples of rayon fabrics with conductive threads inserted after polypyrrole coating: with rubber core yarns, wrapped with copper filament coated with silver (*a*) and with rubber core yarns wrapped with copper filament (*b*).

The use of an ink path has the following advantages: it can be applied manually, as well as with printing equipment, the layer thickness varying between 20 and 40 mm. The coated fabric has a good stability, surface resistance being less than 0.025 kΩ/square at a thickness of 25 μm. Additionally, the resistivity is very low, which implies a good conductivity, good flexibility, abrasion resistance and high glass transition temperature.

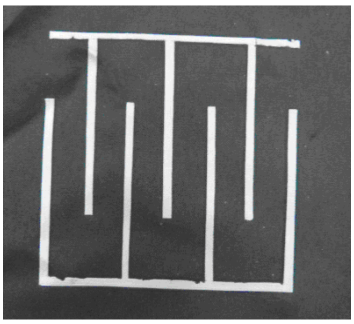


Fig. 2 − Polypyrrole coated polyester fabric with electrical circuit printed with conductive ink.

The dimensions of the samples with conductive threads inserted after coating with polypyrrole are 50x50 mm. The patterns used for the conductive threads are intended to reduce electrical resistance through an electrical equivalent of resistors connected in parallel (Banaszczyk *et al*., 2009).

3. Results and Discussions

To investigate the effectiveness of heating, the samples were connected to a source of direct current, and the temperature was measured using a camera IR Termovision AGEMA ® System 900. The experiment was performed at the Department of Textiles at the Ghent University, Belgium. This device is provided with dedicated software to record the hot spots on the surfaces of the samples; the device automatically records the maximum temperature and the temperatures of different points on the samples. Also, it can record electric voltage and amperage. Samples of rayon fabrics coated with polypyrrole were tested in terms to determine their electrical resistance and temperature when an electric voltage is applied. The intensity of the electric current was also recorded. The values obtained for these parameters are presented in Table 1.

Table 1
Electrical Resistance and Maximum Temperature Obtained for Samples of Fabrics of Rayon Coated with Polypyrrole

Sample	Electrical resistance [kΩ]	I [mA]	Voltage [V]	Temperature [ºC]
Rayon 1(Cu)	33.3	1	30	28.7
Rayon 2(Cu)	8.5	4	34	27
Rayon 3(Cu)	17.5	2	35	29.4
Rayon 4(Cu)	1.76	17	30	44.9
Rayon 5(Cu)	2.13	12	25.5	37
Rayon 6(Ag)	5.2	5	26	31.5
Rayon 7(Ag)	8.5	4	34	38
Rayon 8(Ag)	3.18	11	35	27

For samples of fabrics of rayon coated with polypyrrole with copper wires in the structure, the maximum temperature reached is 44.9°C for a current intensity of 17 mA at a voltage of 30 V; for samples of polypyrrole coated rayon fabrics with copper wires covered with silver, the maximum temperature reached is 38°C, at a current of 4 mA and a voltage of 36 V. Dissipated temperature was measured in standard conditions of temperature and relative humidity of the environment (22 ± 2°C and 65 ± 2%).

For the samples of polyester coated with polypyrrole and printed electrical circuit, the values of electrical resistance and temperature are presented in Table 2.

The minimum amount of electrical resistance is 0.23 kΩ, at a voltage of 10 V and the temperature measured on the sample is 44°C. The intensity value recorded is 44 mA. The maximum temperature value obtained for the samples of polyester coated with polypyrrole is 51.6°C under an applied voltage of 30 V.

Table 2
Maximum Temperatures for Different Types of Polyester Fabrics Coated with Polypyrrole

Sample	Electrical resistance, [kΩ]	Intensity [mA]	Voltage [V]	Temperature [ºC]
PES 1	2	5	10	45.8
PES 2	0.23	44	10	44
PES 3	0.48	21	10	34.3
PES 4	1.3	15	20	37.4
PES 5	2	15	30	51.6

Those values indicate that the samples of polyester coated with polypyrrole are more advantageous in terms of the energy released as heat. However, the 30 V value applied is quite high, and from this point of view sample PES1 is recommended. Polyester samples coated with polypyrrole have been obtained under the same conditions; the large intervals of the results are influenced by the polymerization process which is a factor that cannot be easily controlled.

Rayon fabrics coated with polypyrrole requires 30 V to heat up to a temperature of 28.7°C, while the maximum temperature reached for polyester fabrics at 30 V is 51.6°C.

4. Conclusions

Heating elements obtained using the presented method can be incorporated into articles of clothing, such as jackets, pants, gloves, shoes; they can be also used in the heating sound-absorbent systems and blankets, sports equipment, uniforms, helmets, skates and boots, upholstery, etc.

Heating elements that are based on a textile substrate were produced in order to activate different parts of the clothing, thus ensuring the heat needed in the different regions of the body. These items of clothing are supposed to have no additional cables, with the exception of small power units, which can include a battery and optionally a control unit with different temperature levels.

Getting conductive textiles remains an issue opens to specialists and researchers, representing an area of interest in textile research in view of the many applications of these in areas so diverse.

Acknowledgements. The authors want to thank the research staff from the Department of Textiles at the University of Ghent, where conductive textiles were made and tests have been carried out.

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MATERIALE TEXTILE DE ÎNCĂLZIRE PELICULIZATE CU POLIPIROL

(Rezumat)

Acestă lucrare analizează posibilitatea obținerii de materiale textile conductive cu aplicații în domeniul de încălzire. Materialele textile conductive au fost realizate prin peliculizarea unor mostre de țesături de viscoză şi poliester cu polimerul conductiv polipirol. În structura țesăturior de viscoză au fost inserate fire conductive cu miez de cauciuc pe care sunt infăşurate filamente de cupru simple sau acoperite cu un strat de argint. Pe țesăturile din poliester peliculizate cu polipirol a fost printat un model conductiv cu cerneală pe bază de particule fine de argint. Mostrele obținute au fost analizate cu ajutorul unei camere termografice, care permite determinatrea rezistenței electrice a mostrei, precum şi înregistrarea temperaturii degajate de aceasta când este pusă sub tensiune electrică.