

Halina Dopierala,
Czesław Radom,
Paweł Swaczyna,
*Leszek Zawadzki

Textile Research Institute
ul. Brzezińska 5/15 92-103 Łódź, Poland
E-mail: swaczyna@iw.lodz.pl

*Lodz University of Technology
Faculty of Material Technologies
and Design of Textiles
Department of Textile Machine Mechanics
ul. Żeromskiego 116, 90-924 Łódź, Poland

Modelling the Indicators of Air-Flow Intensity in Different Construction Designs of Nozzles for the Pneumatic Linking of Yarns

Abstract

This article is a continuation of the publication entitled: Modelling the parameters of air-flow in pneumatic nozzles for linking staple and filament yarns. Part I. Determining of the volume flow and local speeds of air-flow, and Part II. Results of the average speeds and asymmetry of the air stream flowing out of a nozzle, published in Fibres & Textiles in Eastern Europe No. 3 (86) 2011 and 4 (87) 2011. The study, whose results are presented in this publication, includes the development of methodology for determining the parameters of an air stream such as the force of air flow acting longitudinally, a stream of air impulses and an analysis of the results of the indicators mentioned above. These indicators are parameters describing the intensity of the air stream in pneumatic linking of yarns manufactured from staple and filament fibres, determined on the basis of values of the speed of air flowing out from the nozzle, on the pressure of the air supplied to the interlacing nozzle, on selected constructional features of the nozzles (dimensions of the interlacing duct), and on structural features of the yarns linked. The results presented below relate to an innovative group of nozzles for the pneumatic linking of yarns, developed at the Textile Research Institute (IW), and designated for exploring the extent to which it is possible to shape the parameters of the air stream acting on the yarns linked - mainly through the selection of particular structure and constructional features of the nozzle design, and changes in the pressure of the air supplied.

Key words: pneumatic nozzle, air-flow parameters, air stream, air speed, stream asymmetry.

■ Introduction

Articles [1, 2] present an analysis of constructions of solutions for interlacing nozzles designed for linking filament yarns and an analysis of new constructions developed at the Textile Research Institute designed for linking staple fibre filament yarns. The research material consisted of 14 variants of nozzles for which:

- features of the internal structure were described;
- results of measurements of the volume of the air stream (Q) flowing out from the nozzle were presented;
- results of measurements of the speed (V_1 and V_2) of air flowing out from both sides of a nozzle (in the outlet planes of their interlacing duct – A_1 and A_2), the methodology of measuring such parameters and the measuring sets were described;
- analysis of the parameters mentioned above was performed.

The very small dimensions of the interlacing and air ducts in the interlacing nozzle did not allow to determine the three dimensional structure of the air flow. The speeds of the air stream (V_1 and V_2) flowing out from both sides of the interlacing nozzle (in their outlet planes A_1 and A_2)

of different constructions showed great differences in the distribution of this parameter between the nozzles of different shapes and dimensions of the interlacing duct and the dimensions and arrangement of the air duct. The nozzles also vary with the parameters of the air volume stream (also called air consumption). The level of these parameters increases with an increase in the air pressure.

Analysing what we already know about the internal geometry of nozzles, the speeds of air flowing out and the air volume stream, the authors aimed to determine the indicators which could show the intensity of the air flow on the yarns linked in different solutions of interlacing nozzles. The result of linking the component yarns in the yarn pneumatically linked depends on the intensity of the compressed air flow. Such investigations on forming component yarns pneumatically linked with the use of new solutions of nozzles [3] were performed at IW, mainly using cotton yarns and polyester yarn. Cotton yarn has a very specific structure of fibre configuration [4 - 10], which is re-structured by the stream of compressed air, the intensity of which, by modelling changes in the yarn structure, informs about the quality of the component yarns obtained and their physical parameters.

For the analysis of modelling the intensity of air flow acting on yarns subjected to pneumatic linking, the authors proposed the following two parameters:

- thrust of the air flowing out from the both sides of the interlacing duct,
- stream of impulses of the air flowing out from the both sides of the interlacing duct.

It was proved that it is possible to model the intensity of air flow in the process of the pneumatic linking of yarns. The factors determining the value of the indicators of the air flow are the air pressure and constructional features of the nozzles.

A description of changes in the intensity of the air flow on the physical and qualitative properties of yarns formed with the use of different kinds of new constructions of nozzles designed at IW will be the subject of our future publications.

■ Aim of the research studies

The aim of this research was to determine the indicators of the intensity of air flow in the process of pneumatic linking yarns and to analyse the possibilities of modelling the indicators of the intensity of air flow depending on the constructional features of the interlacing nozzles, with the pressure of air supplied to the nozzle changing gradually.

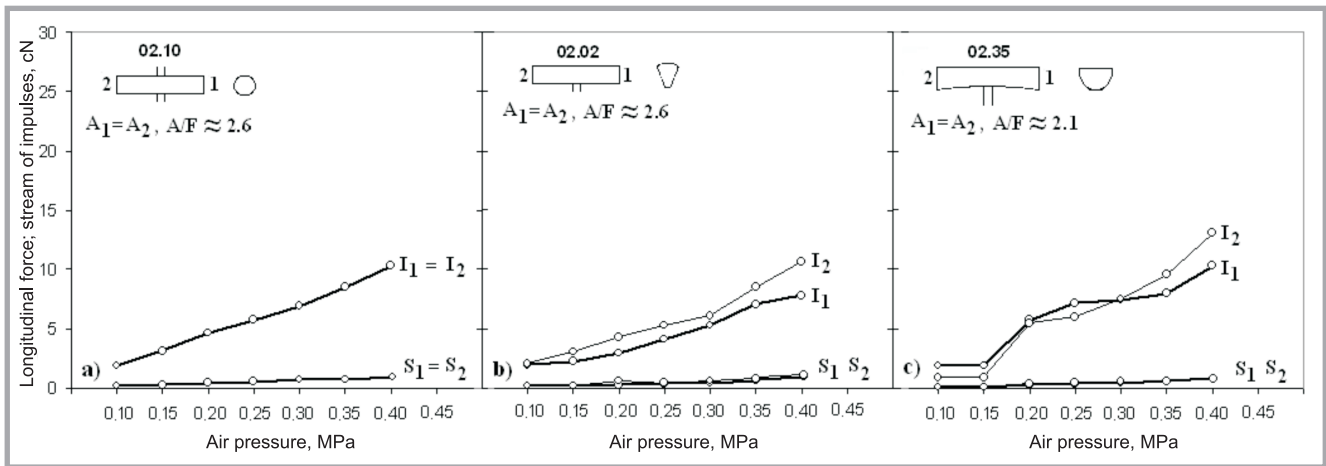


Figure 1. Modelling the indicators of air flow intensity for nozzles with a symmetrical interlacing duct and perpendicular air duct.

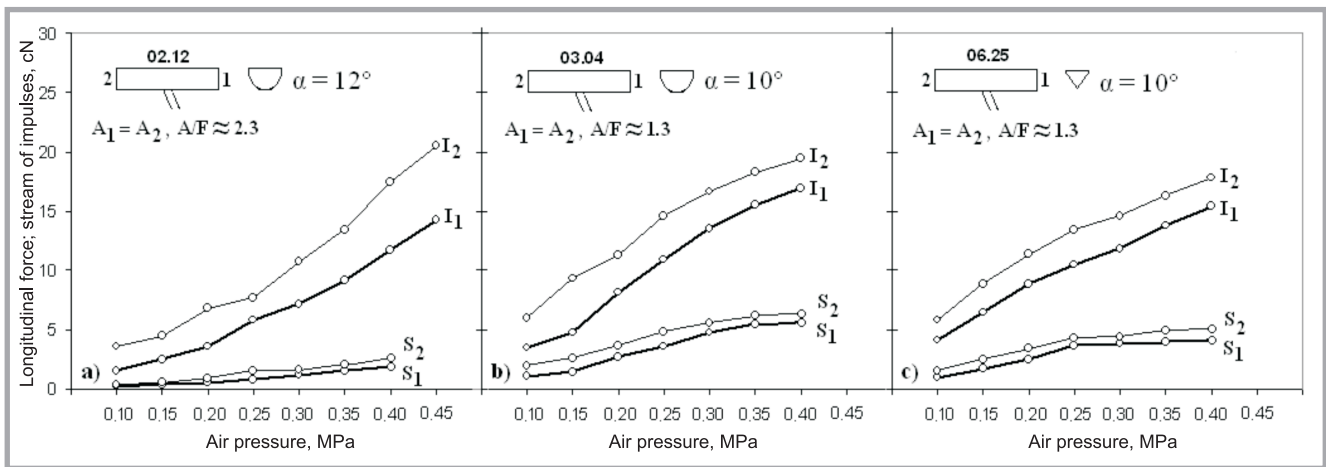


Figure 2. Modelling the indicators of air flow intensity for nozzles with a symmetrical interlacing duct and air duct at an angle.

Research materials and range of study

Research material included 14 variants of nozzles for pneumatic linking yarns, 10 of which were developed at the Textile Research Institute (IW), while the other nozzles were developed by world-

famous companies producing such elements (Heberlein, Temco, Fibreguide). The nozzles investigated were divided in the following two groups, depending on their constructional features:

- nozzles with a symmetrical interlacing duct,

- nozzles with an asymmetrical interlacing duct.

A precise description of nozzles for pneumatic linking yarns, including the nozzles developed at IW designated for linking staple fibre component yarns, is presented in [1, 2].

Table 1. Results of the indicators of the asymmetry of air flow impulses calculated (a).

Nozzle Symbol	Air pressure, MPa							
	0.10	0.15	0.20	0.25	0.30	0.35	0.40	
Figure 1	02.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	02.02	1.07	1.35	1.47	1.28	1.16	1.21	1.36
	02.35	2.12	2.12	1.05	1.19	1.01	1.20	1.27
Figure 2	02.12	2.28	1.80	1.89	1.33	1.50	1.47	1.49
	03.04	1.70	1.98	1.39	1.34	1.23	1.18	1.15
	06.25	1.40	1.39	1.28	1.28	1.23	1.18	1.15
Figure 3	04.08.a	15.09	11.65	11.79	5.70	4.82	4.25	4.30
	04.08.a'	1.29	1.02	1.20	1.20	1.16	1.35	1.47
	05.03	1.70	1.42	1.26	1.41	1.27	1.32	1.25
	05.02	3.70	2.18	2.06	1.62	1.82	1.62	1.58
Figure 4	02.02.a	5.45	5.99	4.98	3.37	3.88	4.02	4.28
	02.08.a	3.44	3.84	3.38	3.12	2.60	2.41	2.81
	06.01	3.90	2.92	2.33	1.84	1.87	1.93	1.96
	06.02	3.33	2.63	3.26	2.34	2.12	2.11	2.12

Schemes of the nozzles investigated, the shapes of the interlacing ducts and arrangement of the air duct to the interlacing duct, as well as a description of selected structural features of these nozzles are presented in Figures 1, 2, 3 and 4, including the results of the parameters selected.

The range of studies, whose results are the subject of this article, is as follows:

- developing a methodology for determining indicators of the intensity of air flow in the process of pneumatic linking yarns;
- determining indicators of the intensity of the air flow – the force of longitu-

dinal air flow (S) and the stream of air impulses (I);

- analysing the results obtained – for different variants of interlacing nozzles of different structures and constructional features depending on the air pressure supplied to the nozzle.

Methodology of determining the indicators of air flow intensity

The indicators of the intensity of air flow on the yarns linked in the stream of compressed air were determined on the basis of the results presented in the previous publications [1, 2].

The basis for determining parameters that evaluate the air flow intensity in the process of pneumatic linking were the values of the average speed (V_1 and V_2) of the air stream flowing out from both sides of the nozzle, the air pressure supplied to the nozzle, selected constructional features of the nozzles, and structural parameters of the yarns linked.

The methods for calculating the indicators of longitudinal air flow and stream of air impulses, which are the measure of interactions of air flow in the process of pneumatic linking, are presented below.

Calculating the force of longitudinal air flow (S_1 and S_2)

The forces of air flow acting longitudinally (S_1 and S_2 – at the inlet and outlet of yarn in the interlacing nozzle) were calculated according to the equations [11] given below:

$$S_1 = K \cdot p_{d1} \cdot \pi \cdot d \cdot l \quad (1)$$

$$S_2 = K \cdot p_{d2} \cdot \pi \cdot d \cdot l \quad (2)$$

where K – coefficient of yarn resistance (for cotton yarn $K = 0.05$), d – diameter of linked yarn in m (for yarns analysed $d = 0.001$ m), l – half-length of the interlacing nozzle in m ($l = 0.007$ m), p_{d1} and p_{d2} – dynamic pressure at the inlet and outlet of yarn from the interlacing nozzle in N/m^2 , $\pi = 3.14$.

It is a simplified equation, assuming that the yarn is motionless and fixed in the interlacing duct. According to the preliminary calculations, the movement of yarn changes the thrust along the thread flow by the air stream by about 3 to 10%.

The dynamic pressure (p_d in mm Hg), measured using a Pitot tube, was con-

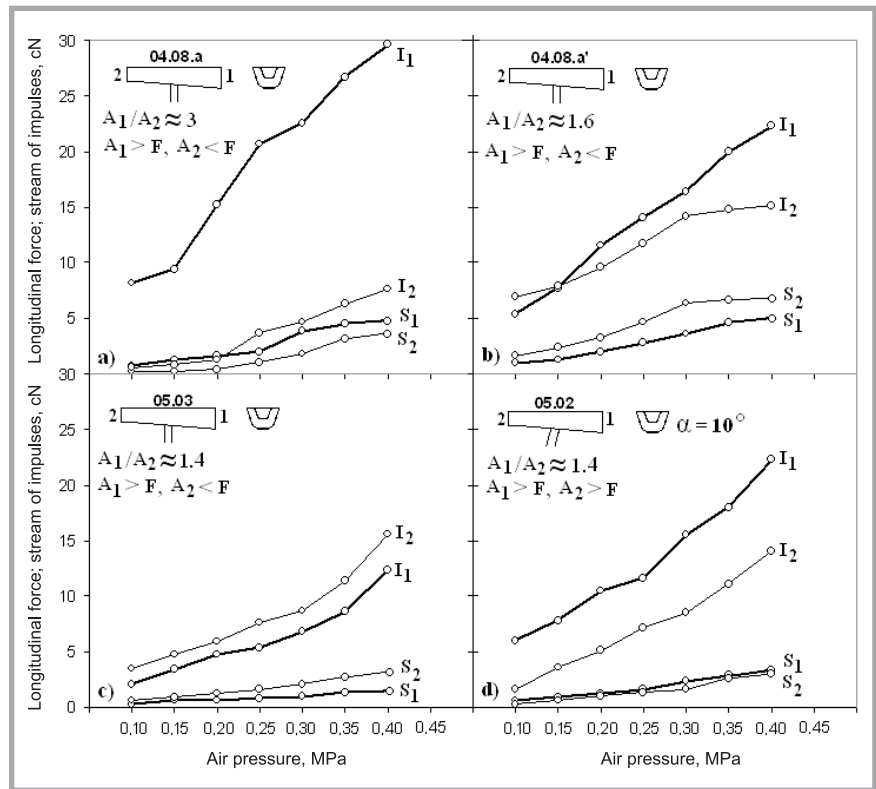


Figure 3. Modelling the indicators of air flow intensity for nozzles with an asymmetrical convergent interlacing duct.

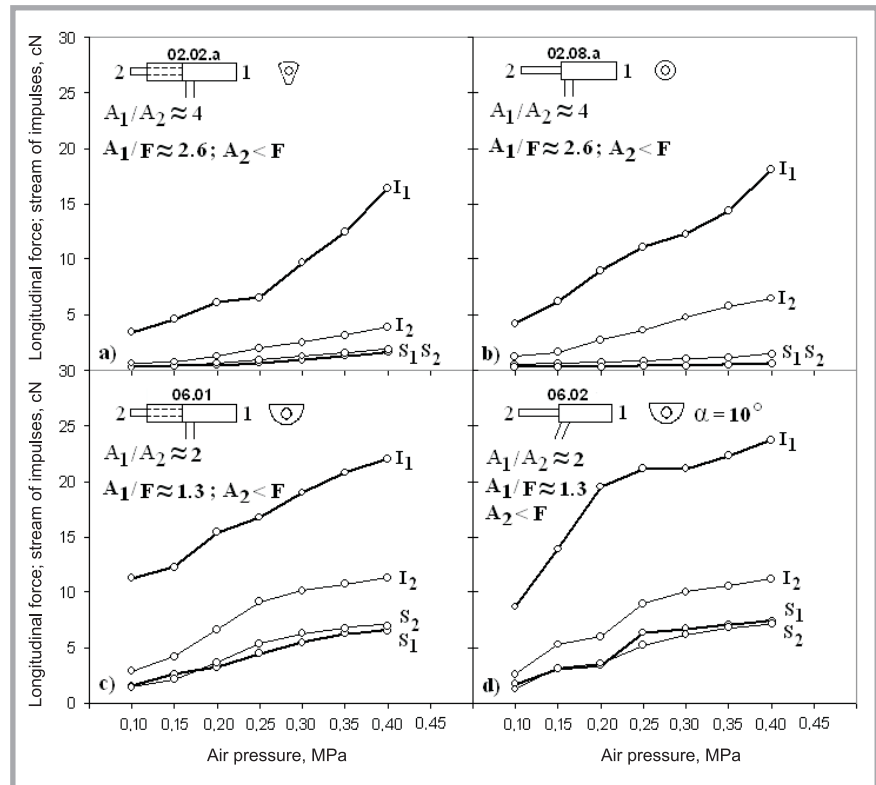


Figure 4. Modelling the indicators of air flow intensity for nozzles with an asymmetrical segmental interlacing duct.

verted to a pressure given in N/m^2 . Two values of the longitudinal force were measured: S_1 – at the inlet of yarn to the interlacing duct and S_2 – at the

outlet of yarn from the interlacing duct. The area in which air is supplied to the interlacing duct is placed in its half length.

This way the aerodynamic forces for the manometric pressures were calculated in the range from 0.1 to 0.4 MPa.

Calculating the values of air stream impulses (I_1 and I_2)

Using the already determined values of the speed V in m/s of air flowing out from the nozzle (V_1 – at the inlet, V_2 – at the outlet of the interlacing duct) and the surface of cross-sections of the interlacing duct A in mm: A_1 – at the inlet, A_2 – at the outlet of the interlacing duct, the stream of air impulses I in N, which is the mass flow of air acting in a unit of time on the yarns linked, was calculated according to the formula:

$$I = \dot{m} \cdot V \quad (3)$$

where \dot{m} - mass flow of air flowing out in kg/s; V - average speed of air flowing out in m/s;

$$\dot{m} = \rho \cdot Q \quad (4)$$

where ρ - density of air flowing out from the nozzle in kg/m³; Q - air volume stream in m³/s;

$$Q = A \cdot V \quad (5)$$

where A - cross-sectional area of the interlacing duct in mm²;

After rearranging **Equation 3** we obtain:

$$I = \rho \cdot A \cdot V^2 \quad (6)$$

The air stream is divided, which can be written as:

$$I_1 = \rho_1 \cdot A_1 \cdot V_1^2 \quad (7)$$

$$I_2 = \rho_2 \cdot A_2 \cdot V_2^2 \quad (8)$$

In this way I_1 and I_2 were calculated for the nozzles investigated and range of air pressure from 0.1 – 0.4 MPa, giving their values in cN.

Results and discussion

Figures 1, 2, 3 and 4 (see pages 54 & 55) present the results of the indicators of air flow intensity determined for the nozzles of different features of the internal structure analysed, where F is the area of the cross-section of the interlacing duct.

On the basis of the values of I_1 and I_2 calculated, indicator aI – known as the indicator of the asymmetry of air stream impulses, was determined, and its value was calculated as a quotient of I_1 and I_2

values, where the higher value was related to the lower value, thus its value is equal or higher than one ($aI \geq 1$).

$$aI = \frac{I_1}{I_2} \quad (9)$$

$$\text{or } aI = \frac{I_2}{I_1} \quad (10)$$

The values of the indicator of impulse asymmetry (aI) inform about the scale of differences between the intensity of air flow in both the inlet and outlet planes of the nozzle (A_1 and A_2). These values, determined for air pressure within the range of 0.1 – 0.4 MPa, are presented in **Table 1** (see page 52).

Analysis of the parameters determining the intensity of air flow in the process of pneumatic linking yarns, for interlacing nozzles with different internal constructions showed the following dependencies:

1. For all constructions of nozzles analysed, the dependencies of the value of air stream impulses (I) and force of longitudinal air flow (S) on the air pressure supplied to the nozzle were noted. An increase in the air pressure increases the values of both indicators.
2. For nozzles with a symmetrical interlacing duct, in which the inlet and outlet planes are identical (**Figures 1 and 2**), the following relations of the indicators of air flow intensity between the outlet planes were obtained:
 - for the air duct placed perpendicularly to the interlacing nozzle (**Figures 1.a, 1.b & 1.c**), the distribution of air stream impulses and force of longitudinal air flow was symmetrical or near-symmetrical;
 - for the air duct placed at an angle to the interlacing duct (**Figures 2.a, 2.b & 2.c**), the distribution of parameters I and S was near-symmetrical;
 - for nozzles with an air duct at an angle, the asymmetry of indicators I and S is higher (higher differences in values between the outlets) than for those with a perpendicular air duct.
3. For nozzles with an asymmetrical interlacing duct, in which the inlet and outlet planes differ in the shape and/or dimensions of the cross-section area, it is possible to model the values of air stream impulses and the force of longitudinal air flow between the surfaces of the inlet and outlet of the interlacing duct:

- For nozzles with a convergent interlacing duct, the distribution of air stream impulses (I) was asymmetrical in most cases, and the distribution of the forces of air flow acting longitudinally (S) was near-symmetrical;
- Similar dependencies were obtained for the nozzles with a segmental interlacing duct – asymmetrical distribution of air stream impulses (I) and near-symmetrical distribution of the forces of air flow acting longitudinally (S).

Summary

An air stream was introduced to the interlacing duct, flowing out from both its sides. The intensity of its action on the yarn in the process of pneumatic linking is determined by the stream of impulses (I) and force of air flow acting longitudinally (S), simultaneously it is modelled with different factors such as:

- longitudinal structure of the interlacing duct (symmetrical, asymmetrical, segmental);
- dimensions of cross-sections of the interlacing duct (A);
- arrangement of the air duct in relation to the interlacing duct (perpendicular or at an angle) and dimensions of its cross-section area (F);
- pressure of air supplied to the nozzle.

The investigations performed proved that modelling the intensity of air flow in the process of pneumatic linking is possible by selecting a suitable construction of the nozzle and value of air pressure.

The results showed how diverse an influence the internal construction of the nozzle (structure of the interlacing and air duct, and their mutual relations) has on modelling the air flow parameters – the connecting medium in the technique of pneumatic linking yarns.

In light of the research results presented in this article and also in [1, 2], the process of modelling the parameters of yarns pneumatically linked, formed using new (developed at IW) constructions of nozzles and those manufactured by world producers, will be the subject of our future publications.



References

1. Dopierała H, Radom Cz, Swaczyna P, Zawadzki L. Modelling of the parameters of air-flow in pneumatic nozzles for linking staple and filament yarns. Part I. Determining of the volume flow and local speeds of air-flow. *Fibres & Textiles in Eastern Europe* 2011; 3(86).
2. Dopierała H, Radom Cz, Swaczyna P, Zawadzki L. Modelling of the parameters of air-flow in pneumatic nozzles for linking staple and filament yarns. Part II. Results of the average speeds and asymmetry of air stream flowing out of the nozzle. *Fibres & Textiles in Eastern Europe* 2011; 4(87).
3. Research project No 3T08E03630 "Development and optimisation of new generation pneumatic nozzles for linking staple and staple-filament yarns" (in Polish), July 2006 – June 2008, Textile Research Institute.
4. Swaczyna P, Dopierała H, Cyniak D. Highly efficient air interlacing as the way of forming connected yarns, staple yarns and composite yarns (staple – filament). In: *10th Scientific Conference – Faculty of Textile Engineering and Marketing*, Technical University of Lodz (PŁ), 2007.
5. Ankudowicz W, Dopierała H, Radom C, Swaczyna P. Linking Yarns From Staple and Filament Fibres by High-Efficiency Pneumatic Interlacing. Part I: Factors Influencing the Linking Effect and the Properties of Interlaced Yarns. Analysis of Tensile Strength Parameters. *Fibres & Textiles in Eastern Europe* 2008; 1.
6. Ankudowicz W, Dopierała H, Radom C, Swaczyna P. Linking Yarns from Staple and Filament Fibres by High-Efficiency Pneumatic Interlacing. Part II: Analysis of Hairiness, Number of Faults and Estimation of the Linking Effects. *Fibres & Textiles in Eastern Europe* 2008; 2.
7. Frydrych I, Matusiak M, Świąch T. Cotton Maturity and Its Influence on Nep Formation. *Textile Research Journal* 2001; 7.
8. Frydrych I, Matusiak M. Predicting the Nep Number in Cotton Yarn—Determining the Critical Nep Size. *Textile Research Journal* 2002; 10.
9. Jabłoński W, Jackowski T. *Nowoczesne systemy przędzenia bazą innowacyjności w procesach wytwarzania przędz*. Ed. Beskidy Textile Institute, Bielsko-Biała 2001.
10. Jackowski T, Chylewska B. *Przędalnictwo. Budowa i technologia przędz*. Ed. Technical University Lodz, Łódź 1999.
11. Zawadzki L. *Intensification of the effect of an air jet on the thread*. Scientific Letters of Technical University Lodz, Łódź 2004.

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For more information please contact:

Department of Material and Commodity Sciences and Textile Metrology
Technical University of Lodz
ul. Żeromskiego 116, 90-924 Łódź, Poland
tel.: (48) 42-631-33-17 e-mail: nonwovens@p.lodz.pl web site: <http://www.k48.p.lodz.pl/>

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