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Simulation of the Processing of Fibrous Products in the OE-Rotor Spinning System

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Abstract
The OE rotor spinning system is interpreted as a probability system, and in this study the probability simulation was applied for optimisation of the combing zone and air transport channel. We created a probability model of the release of fibres from the feeding sliver resulting from the effect of the combing cylinder, as well as a probability model of fibre flow in the air transport channel of the OE- rotor spinning system. The description of the technological processes is based on the specific parts of probability theory (Markov chains - a probability theory which describes the covering of a specific length interval). The aim of the analysis is the determination of the probability of additional one dimensional separation of fibres in the air transport channel as well as the mean fibre dwell time in the comb-out zone of the OE-rotor spinning system.

Key words: *OE-spinning system, spinning process, probability model, combing zone, air transport channel.*

Symbols and notation

P_1 - basic stochastic matrix of fibre - transfer from state i to state j
p_{ij} - probability of fibre transfer from state i to state j (during one step)
Q - matrix of fibre movement at the feed roll speed (5 × 5)
R - matrix of fibre movement change from the roll speed to the opening roll speed (5 × 5)
O - null matrix (5 × 5)
I - unit matrix (5 × 5)
N - matrix with elements n_{ij}
n_{ij} - average number of passages through the states while the fibre stays at the feed roll speed
B - matrix with elements b_{ij}
b_{ij} - probability of the fibre passing from state i (feed roll speed) to state j (opening roll speed)
τ_1 - vector with elements τ_{1i}
τ_{1i} - average number of states up to fibre acceleration – input state 1
ξ - unit vector
τ_{10} - average number of states up to fibre acceleration-input state 0
τ_2 - vector with elements τ_{2i}
τ_{sq} - quadratic vector from vector τ_1
τ_{2i} - scatter of the number of states which the fibre passes through until transfer to the opening roll speed according to input state i
τ_{20} - scatter of the number of states which the fibre passes through until transfer to the opening roll speed-input state 0
P - probability of additional separation in the air transport channel
$S_n(l)$ - probability that all partial length intervals are lower than a
P_{max} - maximal probability P
n - number of tail ends of fibres of length l
λ - parameter of Poisson distribution
L'_v - mean effective fibre length, m
l - length of air transport channel, m
T_o - fineness of sliver, tex
T_v - fineness of fibre, tex
P_{02} - partial draft
η - coefficient of fibre strength
n_2 - mean number of fibres in the cross section of fibre flow
L_v - mean of the fibre length measured, m
v_o - sliver feed speed, m/s
v_2 - mean speed of fibres in air transport channel, m/s
$l(P_{max})$- length of air transport channel at maximal probability P, mm

Introduction

The optimisation of a textile technology process and the highest possible degree of utilisation of the technological reserves of a given spinning system under the conditions of the high-standard kinematic parameters of the process are conditions for the utilisation of up-to-date methods of theoretical and experimental research. This trend has become evident especially in relation to the successful development of OE-rotor spinning machines, which at the same time has brought many stimuli to the sector of research methods for the processes of textile technology.

In the following section a probability model of the sliver opening in OE-spinning units is presented, which describes the opening out of fibres in the drafter sliver and their transference to the clothing of the opening roll, which determines the conditions for achieving minimal additional unevenness and the technological prerequisites for optimum transfer of the fibres to the opening roll.

This study also evaluated a probability model of fibre flow in the air transport channel. In this case, we attempted to make a probability description of the fibre flow transport process in the air transport channel in the direction of the collecting surface of the rotor. The function of the air transport channel in the OE rotor spinning system is transporting fibre to the collecting surface of the rotor with a high level of fibre separation. The condition of this transport and the parameters of the air transport channel have an effect on other fibre separation as well on the final mass irregularity of yarn. In this study, we attempted to form a probability description of one dimen-

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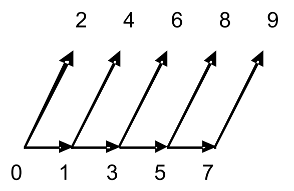

***Figure 1.** Diagram of fibre transfer from the peripheral speed of the feed roll to that of the opening roll; the 0, 1, 3, 5, and 7 states of fibre movement at the feed roll speed (the so-called transient state), the 2, 4, 6, 8 and 9, states of fibre transfer from the feed roll speed to the speed of the opening roll (the so-called absorbing state).*

sional fibre separation and the value of probability of this.

Probability model of the fibre opening and transport process in the opening roll/zone.

The fibres are transferred to the opening roll clothing when the nip on the fibre exerted by the feed roll and press plate (relative to fibre length) is no longer effective, allowing the fibres to be carried along in different areas of the opening zone by the opening roll. The probability of fibre transfer from the peripheral speed of the feed roll to that of the opening roll can be described with the aid of the *Markov* chain laws [5]. A diagram of fibre transfer from the feed roll to the opening roll speed can be seen in ***Figure 1***.

$$P_1 = \begin{bmatrix} 0 & p_{01} & p_{02} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & p_{13} & p_{14} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & p_{35} & p_{36} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & p_{57} & p_{58} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

$$P_1 = \begin{bmatrix} Q & R \\ O & I \end{bmatrix} = \begin{bmatrix} 0 & p_{01} & 0 & 0 & 0 & p_{02} & 0 & 0 & 0 & 0 \\ 0 & 0 & p_{13} & 0 & 0 & 0 & p_{14} & 0 & 0 & 0 \\ 0 & 0 & 1 & p_{35} & 0 & 0 & 0 & p_{36} & 0 & 0 \\ 0 & 0 & 0 & 0 & p_{57} & 0 & 0 & 0 & p_{58} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2)$$

Equations 1 and 2.

***Table 1.** Mean probability of the fibre transfer and mean fibre dwell time (fibre fringe-6 sections, the fibre transfer matrix P 14 × 14); T = OE rotor yarn count in tex, τ_{10} = average number of states up to fibre transfer from the feed roll speed to the opening roll speed, t = mean fibre dwell time in the comb-out zone.*

No.	T, tex	Mean probability of fibre transfer						τ_{10}	t, s
		p_{01}	p_{13}	p_{35}	p_{57}	P_{79}	$p_{9,11}$		t ± δt, s
1	40	0.7912	0.5994	0.4968	0.5873	0.3996	0.4616	2.7266	1.1035 1.0351 ÷ 1.1719
2	40	0.8345	0.6434	0.5442	0.5071	0.3210	0.5122	2.8868	1.1683 1.1239 ÷ 1.2127
1	18	0.7509	0.5934	0.4591	0.5368	0.4154	0.5558	2.5671	3.0276 2.8634 ÷ 3.1918
2	18	0.8529	0.7015	0.5993	0.4637	0.3859	0.3460	3.0709	3.6218 3.4101 ÷ 3.8335

A probability model of fibre transfer to the opening roll is derived from this diagram. The fibre transfer matrix forms the basis for determining the fibre dwell time in the feed roll and press plate nip zone before transfer to the opening roll (average time, time scatter). The transfer probabilities p_{ij} are therefore the probabilities of fibre transfer from condition i (movement at the peripheral speed of the feed roll) to condition j (movement at the peripheral speed of the feed or opening roll). Matrix P_1, denoting fibre transfer from condition i to condition j, can be seen in equation (1).

Matrix P_1 is converted into part matrices Q, R, O and I in accordance with equation (2).

Equation (2) is valid for matrix P_1:

In accordance with Markov chain theory [5], the following matrices can be deduced for fibre movement at the feed roll speed and fibre transfer to the opening roll:

1) Matrix: $N = (I - Q)^{-1}$ (3)

Matrix elements n_{ij} correspond to the average number of passages through the states while the fibre remains at the feed roll speed (equation 4).

As fibre movement always begins in state 0, only the first line of the matrix is taken into account in further calculations, and the same applies to matrices, B, τ_1 and τ_2.

2) Matrix B of the probability of fibre speed change from the feed to the opening roll speed.

$$B = N \cdot R \qquad (5)$$

Matrix B elements b_{ij} correspond to the probability of the fibre passing from state i (feed roll speed) to state j (opening roll speed) (equations 6, 7).

The mean fibre dwell time in the comb-out zone and its scatter can be deduced from this. The mean fibre dwell time in the comb-out zone is obtained from vector τ_1 (average number of states up to fibre acceleration).

$$N = \begin{bmatrix} 1 & p_{01} & p_{01}.p_{13} & p_{01}.p_{13}.p_{35} & p_{01}.p_{13}.p_{35}.p_{57} \\ 0 & 0 & p_{13} & p_{13}.p_{35} & p_{13}.p_{35}.p_{57} \\ 0 & 0 & 1 & p_{35} & p_{35}.p_{57} \\ 0 & 0 & 0 & 1 & p_{57} \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$B = \begin{bmatrix} p_{02} & 0 & 0 & 0 & 0 \\ 0 & p_{14} & 0 & 0 & 0 \\ 0 & 0 & p_{36} & 0 & 0 \\ 0 & 0 & 0 & p_{58} & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \cdot N \tag{6}$$

$$B = \begin{bmatrix} p_{02} & p_{01}.p_{14} & p_{01}.p_{13}.p_{36} & p_{01}.p_{13}.p_{35}.p_{58} & p_{01}.p_{13}.p_{35}.p_{57} \\ 0 & P_{14} & p_{13}.p_{36} & p_{13}.p_{35}.P_{58} & p_{13}.p_{35}.p_{57} \\ 0 & 0 & P_{36} & p_{35}.p_{58} & p_{35}.p_{57} \\ 0 & 0 & 0 & P_{58} & p_{57} \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

$$\tau_1 = \begin{bmatrix} 1 + p_{01} + p_{01}.p_{13} + p_{01}.p_{13}.p_{35} + p_{01}.p_{13}.p_{35}.p_{57} \\ 1 + p_{13} + p_{13}.p_{35} + p_{13}.p_{35}.p_{57} \\ 1 + p_{35} + p_{35}.p_{57} \\ 1 + p_{57} \\ 1 \end{bmatrix} \tag{9}$$

Equations 4, 6, 7, and 9.

$$\tau_1 = N \cdot \zeta \tag{8}$$

ζ unit vector

Elements τ_{1i} correspond to the average number of states passed through up to the transfer of the fibre from the feed roll speed to the opening roll speed (equation 9).

As the fibres enter the opening unit in state 0, the following is valid:

$$\tau_{10} = 1 + p_{01} + p_{01} \cdot p_{13} + \\ + p_{01} \cdot p_{13} \cdot p_{35} + \\ + p_{01} \cdot p_{13} \cdot p_{35} \cdot p_{57} \tag{10}$$

The fibre dwell time scatter in the comb-out zone can be represented by vector τ_2.

$$\tau_1 = (2N - I) \,.\, \tau_1 - \tau_{sq} \tag{11}$$

τ_{sq} quadratic vector from vector τ_1

$$\begin{gathered} \tau_{20} = 1 + p_{01} + p_{01} \cdot p_{13} + p_{01} \cdot p_{13} \cdot p_{35} + \\ + p_{01} \cdot p_{13} \cdot p_{35} \cdot p_{57} + \\ 2p_{01}(1 + p_{13} + p_{13} \cdot p_{35} + p_{13} \cdot p_{35} \cdot p_{57}) + \\ + 2p_{01} \cdot p_{13}(1 + p_{35} + p_{35} \cdot p_{57}) + \\ + 2p_{01} \cdot p_{13} \cdot p_{35}(1 + p_{57}) + \\ + 2p_{01} \cdot p_{13} \cdot p_{35} \cdot p_{57} - \\ - (1 + p_{01} + p_{01} \cdot p_{13} + p_{01} \cdot p_{13} \cdot p_{35} + \\ + p_{01} \cdot p_{13} \cdot p_{35} \cdot p_{57})^2 \end{gathered} \tag{12}$$

The elements τ_{2i} of matrix τ_2 correspond to the scatter of a number of states which the fibre passes through up to the transfer to the opening roll speed. In the OE rotor machine opening unit, the sliver feed-in is opened out to individual fibres, and the necessary high draft required is produced between the nip of the feed roll and press plate and the opening roll. Ideal conditions for this speed change exist when, for each fibre, transfer takes place to the opening roll speed immediately on release of the fibre end by the press plate. Under the premise of a constant fibre length, the minimum dwell time of the fibre in the comb-out zone for this fibre length and its scatter is a measure of the variation from ideal drafting conditions. The structural design of the comb-out zone must therefore ensure that a speed change always occurs when the fibre end passes the same, narrowest possible fibre feed zone. The experimental results confirm the theoretical considerations that with constant raw material the conditions in the opening roll zone, which lead to a minimum fibre dwell time in the comb-out zone, also provide the lowest yarn unevenness. If a minimum mean fibre dwell time is achieved in the comb-out zone, the fibre scatter and consequent possibility of additional sliver unevenness due to the draft are also reduced. In order to be able to study the fibre dwell time in the comb-out zone experimentally, the fibre fringe formed in the comb-out zone was broken down into 4 mm long sections in each case, and its weight was determined to an accuracy of ± 1 mg. This gives the probabilities of fibre transfer to the opening roll in the different sections of the fibre fringe. Opening roll speed: 7050 min^{-1}. There were two types of press plate for the OE spinning unit (BD-S), and the sliver count was 3240 tex. The mean probability of the fibre transfer and the mean fibre dwell time in the comb-out zone can be seen in ***Table 1***.

Probability model of additional separation in the air transport channel

The description of the process is based on specific parts of the probability theory which describe the covering of a specific length interval [3, 4].

If the interval (length l) is randomly divided into partial intervals, then the probability $S_n(l)$ that all partial intervals are lower than a is

$$S_n(l) = \sum_{\nu=0}^{n} (-1)^{\nu} \binom{n}{\nu} \left(1 - \nu \frac{a}{l}\right)_+^{n-1} \tag{13}$$

The sign + mean $[f(x)]_+ = 0$ when $f(x) \leq 0$.

If we use relation (13) for the length l of the air channel, then the development of the final relation for the probability of one-dimensional additional separation will be as follows: We suppose that in the interval $<0,l>$ there are n points and then n+1 subintervals. There are characteristics points (backward ends of fibres)

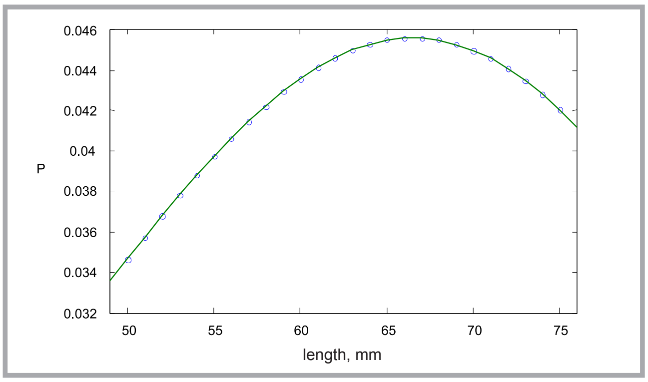

Figure 2. *Course of the probability of one-dimensional additional separation in the air transport channel P in dependence on the length of the air transport channel l in mm (P_{02} = 2500; T_o = 2200 tex; T_v = 0.17 tex; L_v = 25 mm; $l(P_{max})$ = 66.5 mm; P_{max} = 0.0456).*

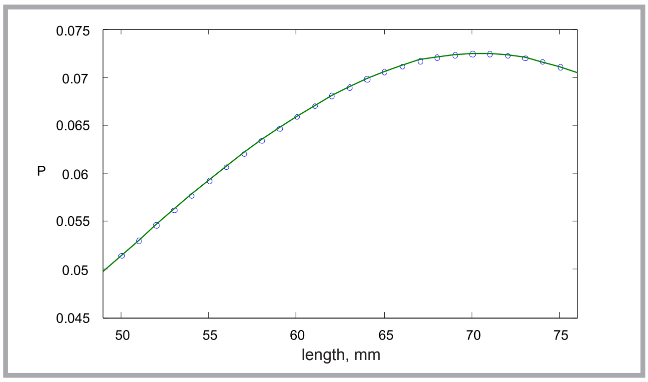

Figure 3. *Course of the probability of one-dimensional additional separation in the air transport channel P in dependence on the length of the air transport channel l in mm (P_{02} = 5000; T_o = 4000 tex; T_v = 0.17 tex; L_v = 25 mm; $l(P_{max})$ = 70 mm; P_{max} = 0.07254).*

which we can mark as $x_1, x_2, x_3, \dots x_n$, and intervals as $l_1, l_2, l_3, \dots l_{n+1}$. We studied the probability ($1 - S_{n+1}$) that at least one of the intervals is bigger than the average effective fibre length, which means that separation occurs:

$$1 - S_{n+1} = \sum_{v=1}^{n+1} (-1)^{v-1} \binom{n+1}{v} \left(1 - v\frac{L'_v}{l}\right)_+^n \quad (14)$$

For particular expression of the probability of one-dimensional separation P, we must also include the random discrete value *n* in the calculation, which is determined by the Poisson distribution with parameter λ (probability distribution of the number of fibre tail ends *n* for length *l*). The Poisson distribution includes discrete (integer) random values. The assumption regarding the Poisson distribution corresponds with results of analysis of fibre flow in the air transport section of the experimental OE-rotor spinning unit.

Term (15) must include the following: the probability distribution of incidence, and the number of tail end fibres *n* for a technologically realistic interval of value *n*.

$$\mathrm{P} = \sum_{n=0}^{\infty} \frac{\lambda^n e^{-\lambda}}{n!} \sum_{v=1}^{n+1} (-1)^{v-1} \binom{n+1}{v} \left(1 - v\frac{L'_v}{l}\right)_+^n \quad (15)$$

$$\lambda = \frac{l}{L'_v} \frac{T P_{02}}{T_v P_0} = \frac{l.n_2}{\eta L_v} \quad (16)$$

For the solution of equation 15, the process of the real solution of the probability of one-dimensional separation with the possibility of setting the ideal air feed channel length (the length for which the best conditions for longitudinal fibre separation exist) was developed.

The own numerical calculation are realized in our program. We can easily calculate several values of these parameters: the fineness of the sliver T_0, partial drafts P_{02}, the mean effective fibre length and mean values of the fibre fineness for several ranges of fibre fineness. The results are illustrated in ***Figures 2*** and ***3***.

From our results the influence of the sliver fineness and the value of the partial draft between fibre flow in the air feed channel and the input sliver is evident. From the courses of probability presented, we can set up the optimal air feed channel length in dependence on technological conditions related to the process of fibre flow transport in the OE-rotor spinning system.

Conclusion

A probability model of the fibre opening and transport process in the opening roll zone is a very important application for research of the OE rotor spinning system. The structural design of the feed roll/press plate system must ensure minimum scatter of the fibre dwell time in the comb-out zone.

The probability of one–dimensional additional separation expresses the rate of fibre separation forf the whole length of the air feed transport channel in dependence on technical and technological values. We can calculate the optimal transport channel length for a specific range of the partial draft in the spinning system in dependence on the fineness of the input sliver, the average fineness of the fibre and the average fibre length. The description of the process is based on specific parts of the probability theory which describe the covering of a specific length interval.

The delivery speed increases in the OE rotor spinning unit and the production of finer OE rotor yarns place stringent requirements on the scientific research control of all part technological processes in the OE rotor spinning system.

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References

1. *Ursíny P.: Spinning simulation – scientific means and view of applications. Simulation in industry, 14th European simulation symposium, October 23.-26. 2002, Dresden, Germany. Proceedings, 450 – 453, ISBN 3-936150-21-4.*
2. *Ursíny P. Janoušek J. Hedánek O. Drozdová I.: The Analysis of spinning process by means of probability modeling. Magic world of textiles, Book of proceedings, 3rd International textile clothing and design conference,2006,University of Zagreb, p. 222-226, ISBN 953-7105-12-1.*
3. *Minoru Uno, Akira Shiomi, Nobuishi Sakoda: A study on Open – End Spinning, Part I., Journal of the Textile Machinery Society of Japan, 15, 1969, č. 4, pp. 131-140.*
4. *Feller W.: Introduction in the probability theory, Part II. Mir, Moscow,1970.*
5. *Kemeny I., Snell I.: Finite Markov Chains,Van Nostrand,ISBN 59.15644, New York ,1960.*
6. *UrsÍny P., Šafář V., Mägel M.: Analysis of sliver opening on the OE rotor spinning system. Melliand Textilberichte,76(1995), 4, pp. 219-222, ISSN 0341.0781.*

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