SIR Publishers
CENTER FOR INTERNATIONAL SCIENTIFIC PUBLICATIONS
JOURNAL OF MULTIDISCIPLINARY BULLETIN
ISSN(Online): 2984-6722 |
Volume-9, Issue-04, Published |18-11-2026|

Spinning plan and ring frame parameters for an antistatic combined yarn: draft chain consistency, productivity and traveller dynamics

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Abstract. In an antistatic combined yarn, a cotton fibre strand and an electrically conductive multifilament are twisted together on a ring frame, so only the cotton component passes through the preparatory stages, whereas the multifilament enters the process at spinning. This study develops and verifies a spinning plan for a 24 tex combined yarn made of cotton (18.4 tex) and the conductive multifilament Nega-Stat® P210 (5.6 tex) on a carded line of Rieter C60, RSB-D40, Zinser 668 and G35 machines. A systematic calculation procedure links the mass balance of the draft chain, the production norms, the ring frame kinematics and the traveller dynamics. The resulting draft from the card feed batt to the cotton component is 35,100 and agrees with the product of the stage drafts within 0.1 %. The production norms are 91.1 (card), 204.0 (draw frame), 93.1 (roving frame) and 31.3 kg/h (ring frame). For the G35 frame, Koritsky's formula gives a twist contraction of 3.14 %, the delivery roller speed is 21.0 m/min and the traveller speed is 33.4–33.7 m/s. The centrifugal force of an ISO 52 traveller is 2.6 N; for a traveller–ring friction coefficient of 0.10–0.15 the winding tension is estimated at about 10–15 % of the yarn breaking force. Because spindle productivity is inversely proportional to twist, increasing the twist from 700 to 800 t/m lowers it by 12.5 %. A scheme for equipping the frame to feed the multifilament is proposed, and the consequences of traveller friction for surface-located conductive components are discussed.

Keywords: combined yarn; spinning plan; draft chain; ring spinning; productivity; traveller dynamics; conductive multifilament

1. Introduction

Protective clothing for explosion- and fire-hazardous workplaces must not accumulate static charge, and the electrostatic requirements for its materials are laid down in EN 1149-5 [1]. A widely used way of imparting conductivity to textiles is to integrate electrically conductive yarns into the textile structure [2]. For cotton-rich workwear, a convenient carrier of the conductive phase is a combined (core-spun) yarn in which an electrically conductive multifilament is twisted together with a cotton fibre strand on a ring spinning frame in a single process, so that the fibrous sheath and the conductive component are formed simultaneously [3–5]. Similar core-spinning principles have been applied on modified ring spinning machines to combine cotton with copper or stainless-steel wires for electromagnetic shielding and

conductivity applications [6], and, more generally, core coverage and resistance to stripping are regarded as the key quality indicators of filament-core spun yarns [7].

Industrial production of such a yarn requires a spinning plan that covers every stage of the preparation of the cotton component, together with a substantiated set of machine parameters. The combined yarn has a technological feature that distinguishes it from a conventional cotton yarn: the conductive component is introduced only at the spinning stage. The productivity of all preceding stages must therefore be calculated for the cotton component alone, whereas the ring frame must be equipped with additional devices for feeding the multifilament. In ring spinning, yarn formation, spinning tension and the end-breakage rate are governed by the spindle speed, the twist and the parameters of the ring–traveller pair [8–11]. The distribution of fibre tension in the spinning triangle also depends on spinning tension and twist, as shown analytically [12] and by finite element modelling [13]. In a combined yarn, part of the conductive component lies on the yarn surface; the yarn–traveller friction and the winding tension may therefore also affect the wear of this component and the retention of its conductivity.

Previous studies of combined conductive yarns have dealt mainly with the method of combining the components and with the adaptation of spinning or twisting equipment [3, 4, 14], while metal–cotton core yarns have been characterised mainly in terms of their bending rigidity, tensile properties and hairiness [6]. The consistency of the drafts along the complete process line, the trade-off between productivity and twist, and the traveller dynamics have not been analysed jointly for the production of a combined antistatic yarn. This gap has practical consequences: a twist chosen for electrical reasons cannot be justified without knowing its cost in output, and traveller conditions acceptable for a cotton yarn are not necessarily acceptable for a yarn whose surface carries a conductive component.

The aim of this study was to develop the spinning plan for a 24 tex antistatic combined yarn consisting of cotton and an electrically conductive multifilament, to verify the consistency of its draft chain, and to substantiate the production norms of the equipment and the kinematic and dynamic parameters of the ring spinning frame. The novelty of the work lies in a systematic calculation procedure that links the spinning plan with the mass balance of the draft chain, the productivity–twist trade-off and the traveller dynamics. The specific contributions are: (i) a closed mass-balance check of the draft chain from the batt fed to the card to the cotton component of the yarn; (ii) production norms of all machines with explicitly stated efficiency coefficients; (iii) a kinematic and dynamic calculation of the Rieter G35 ring frame, including the traveller centrifugal force and an order-of-magnitude estimate of the winding tension; (iv) a quantitative productivity–twist relationship over the recommended twist range; and (v) a practical scheme for equipping the ring frame to feed the multifilament.

2. Materials and methods

2.1. Materials

Cotton fibre of industrial type 4, grade I, with a mean length of 26.09 mm and a linear density of 165 mtex was used for the fibrous component. The electrically conductive component was the Nega-Stat® P210 multifilament with a linear density of 5.6 tex, in which the carbon-containing conductive core is protected by a polyester sheath [15]. The nominal linear density of the combined yarn was 24 tex, of which the cotton component accounted for 18.4 tex (77 %) and the multifilament for 5.6 tex (23 %).

2.2. Process line and design of the spinning plan

The process line was designed according to the carded spinning system. It comprised a Rieter blowroom line (UNIfloc A11, UNIclean B11, UNImix B70 and UNIflex B60), a C60 card, two passages of RSB-D40 draw frames, a Zinser 668 roving frame with 144 spindles and a Rieter G35 ring spinning frame with 1200 spindles [8]. The spinning plan was developed in reverse order, starting from the spinning stage, so that the linear densities of all intermediate products follow from the required linear density of the cotton component. The twist K (t/m) was determined from the twist multiplier α_T (tex system):

$$K = \frac{100\,\alpha_T}{\sqrt{T}}, \qquad (1)$$

where T is the linear density of the yarn or roving, tex. At each stage, the linear densities of the input and output products are related through the draft E and the number of doublings d by $T_{out} = T_{in} \cdot d/E$. For the whole chain, the mass-balance condition reads

$$\frac{T_0}{T_c} = \frac{\prod E_i}{\prod d_i}, \qquad (2)$$

where T_0 is the linear density of the batt fed to the card, tex; T_c is the linear density of the cotton component of the yarn, tex; and the products are taken over all stages i of the chain. Equation (2) is a necessary condition of internal consistency: if the stage drafts and doublings do not reproduce the ratio of the end linear densities, at least one of the planned values is wrong.

2.3. Productivity and production norms

The theoretical productivity of one delivery of the ring spinning frame and of the roving frame (kg/h) was calculated as

$$P = \frac{n \cdot 60 \cdot T}{K \cdot 10^6}, \qquad (3)$$

where n is the rotational speed of the spindle (flyer), rpm. For the card and the draw frames $P = V \cdot 60 \cdot T/10^6$, where V is the delivery speed, m/min. The production norm was obtained as the product of the theoretical productivity and the machine efficiency (time-utilisation) coefficient $\eta = K_a \cdot K_b$, where K_a accounts for the time losses associated with maintaining the technological process and K_b for the time losses associated with servicing the workplace and operator rest.

2.4. Ring frame kinematics and traveller dynamics

The contraction of the yarn during twisting was determined by Koritsky's formula [16]:

$$U_k = 0.0009\,\alpha_T^2 \sqrt[3]{T}, \qquad (4)$$

where U_k is the twist contraction of the yarn, %. The corresponding contraction coefficient is $K_u = 1 - U_k/100$, and the surface speed of the delivery roller is $V_d = n/(K \cdot K_u)$, m/min. The linear speed of the traveller was calculated as $v = \pi D_r n_t/60$, where D_r is the ring diameter and n_t is the rotational speed of the traveller, and its centrifugal force as

$$F = \frac{m_t\, v^2}{r_r}, \qquad T_w \approx \mu F, \qquad (5)$$

where m_t is the traveller mass, kg (the ISO traveller number equals the mass of one traveller in milligrams); r_r is the ring radius, m; T_w is the winding tension; and μ is the traveller–ring friction coefficient. The second part of Eq. (5) is a simplified estimate that neglects the balloon and the angles of the yarn path [9]; it was used only to determine the order of magnitude of the winding tension, which was then compared with the breaking force of the yarn.

3. Results

3.1. Spinning plan and production norms

With $\alpha_T = 34.8$, Eq. (1) gives $K = 100 \cdot 34.8/\sqrt{24} = 710$ t/m for the combined yarn. The total draft on the ring frame, given by the ratio of the linear densities of the roving (526 tex) and the cotton component (18.4 tex), is E = 28.6. The draft is therefore referred to the cotton component, whereas the twist and the productivity of the ring frame are referred to the combined yarn (24 tex), because the multifilament joins the drafted strand only at the front roller nip. The complete spinning plan is given in Table 1.

Table 1. Spinning plan for the antistatic combined yarn (24 tex)

Machine	T, tex	d	E	K, t/m	V, m/min (n, rpm)	P_{th}, kg/h*	η	Norm, kg/h*
C60 card	5400	–	11 9.6	–	300	97.2 / 97.2	0.9 37	91.1 / 91.1
RSB-D40, 1st passage	5400	6	6.0	–	800	259.2 / 259.2	0.7 87	204.0 / 204.0
RSB-D40, 2nd passage	5400	6	6.0	–	800	259.2 / 259.2	0.7 87	204.0 / 204.0
Zinser 668 roving frame (144 spindles)	526	1	10. 27	52	1500	0.910 / 131.1	0.7 1	0.646 / 93.1

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Volume-9, Issue-04, Published |18-11-2026|

Machine	T, tex	d	E	K, t/m	V, m/min (n, rpm)	P_{th}, kg/h*	η	Norm, kg/h*
G35 ring frame (1200 spindles)	24 (18.4 + 5.6)	1	28.6	710	14,460	0.0293 / 35.2	0.89	0.0261 / 31.3

* Before the slash – per delivery (spindle); after the slash – per machine.

For the C60 card, the machine time for filling a can is 29.6 min, $K_a = 0.976$ and $K_b = 0.96$, so that $\eta = K_a \cdot K_b = 0.937$. The value of 0.931 given in the underlying technological report does not agree with this product and was corrected; accordingly, the production norm of the card is 91.1 instead of 90.5 kg/h. The operator service norms were taken as 8 machines for the card, 2 machines for the draw frames and 1200 spindles for the ring frame. The per-spindle norm of the ring frame is 0.0261 kg/h, i.e. 26.1 g/h.

3.2. Consistency of the draft chain

Table 2 checks the linear densities and drafts of the individual stages against the mass-balance condition (2). The linear density of the batt fed to the card is $T_0 = 5400 \cdot 119.6 = 645{,}840$ tex (≈ 646 g/m). Because the number of doublings equals the draft at both drawing passages (d = E = 6), their resulting draft is unity, and the resulting draft of the chain reduces to the product of the drafts at the carding, roving and spinning stages: $119.6 \cdot 10.27 \cdot 28.6 = 35{,}129$. The mass balance gives $T_0/T_c = 645{,}840/18.4 = 35{,}100$. The difference of 0.08 % results from rounding of the drafts at the roving and spinning stages. In production, this consistency is maintained by controlling the yarn linear density according to ISO 2060 [17].

Table 2. Mass-balance check of the draft chain

Stage	T_{in}, tex	d	E	$T_{out} = T_{in} \cdot d/E$, tex	Resulting draft E/d
Carding	645,840	1	119.6	5400	119.6
Drawing, 1st passage	5400	6	6.0	5400	1.0
Drawing, 2nd passage	5400	6	6.0	5400	1.0
Roving	5400	1	10.27	526	10.27
Ring spinning	526	1	28.6	18.4	28.6
Whole chain	645,840	36	–	18.4	35,100

The sixfold doubling at each of the two drawing passages (36 doublings in total) theoretically reduces the linear irregularity of the sliver by a factor of $\sqrt{36} = 6$, which makes the drawing stage the main factor in the evenness of the cotton component of the combined yarn [8, 9].

3.3. Kinematic and dynamic parameters of the G35 ring frame

The technological and kinematic schemes of the G35 ring spinning frame are shown in Figs. 1 and 2. The roving bobbins 2 are mounted on the creel 1; the roving is drawn into the drafting system 3 and attenuated to the required linear density. The drafted strand is twisted by the rotating spindle 9 carrying a tightly fitted tube, passing through the eyelet of the yarn guide 5, which centres it above the spindle axis, and under the traveller. After an end break, the drafted strand is sucked away by the pneumatic strand catcher 4. Balloon control rings 7 and separators 6 at each delivery reduce the yarn tension during winding and prevent neighbouring yarns from interfering. The spindles are driven by tapes passing around the tin drum 11, and the full packages are removed and replaced by empty tubes with the ROBOdoff automatic doffer 10. The spindles, the delivery roller and the feed roller are driven by separate motors D1, D2 and D3, respectively (Fig. 2).

The initial data for the calculation were: T = 24 tex, K = 710 t/m, roving linear density 526 tex, ring diameter 45 mm, mean tube diameter 23 mm, tube height 220 mm, n = 14,460 rpm and η = 0.89. According to Eq. (4), $U_k = 0.0009 \cdot 34.8^2 \cdot 24^{1/3} = 3.14$ %, so that the contraction coefficient is $K_u = 0.969$. The surface speed of the delivery roller is $V_d = n/(K \cdot K_u) = 14{,}460/(710 \cdot 0.969) = 21.0$ m/min. The results of the kinematic and dynamic calculation are summarised in Table 3.

Table 3. Results of the kinematic and dynamic calculation of the G35 ring spinning frame

Parameter	Value
Speed of the spindle drive motor n_{D1}, rpm	3126
Twist contraction U_k, % / contraction coefficient K_u	3.14 / 0.969
Delivery roller: surface speed, m/min / rotational speed, rpm	21.0 / 247.9
Speed of the delivery roller drive motor n_{D2}, rpm	3926
Total / break / main draft	28.6 / 1.145 / 24.97
Feed roller: surface speed, m/min / rotational speed, rpm	0.735 / 8.67
Speed of the feed roller drive motor n_{D3}, rpm	2666
Traveller number (ISO)	52
Traveller rotational speed (full package / empty tube), rpm	14,306 / 14,165
Traveller linear speed (full package / empty tube), m/s	33.7 / 33.4
Traveller centrifugal force F, Eq. (5), N	2.6

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Parameter	Value
Winding tension T_w (μ = 0.10–0.15), cN	26–39
Ring rail speed (lower / upper position), m/min	0.12 / 0.23
Yarn mass on the package, g / package volume, cm^3 / package density, g/cm^3	98 / 176 / 0.56
Machine productivity: theoretical / norm, kg/h	35.2 / 31.3
Running time per doff (with efficiency coefficient / pure machine time), min	225 / 200

For $m_t = 52 \cdot 10^{-6}$ kg, v = 33.7 m/s and $r_r = 0.0225$ m, Eq. (5) gives F = 2.6 N. The resulting winding tension $T_w \approx 26–39$ cN corresponds to 10–15 % of the breaking force of the yarn (11.3 cN/tex·24 tex ≈ 271 cN). The traveller lags behind the spindle by the winding speed, so its rotational and linear speeds are slightly higher on the full package than on the empty tube (Table 3). A full package carries 98 g of yarn, which corresponds to 200 min of pure machine time or 225 min per doff when the efficiency coefficient is taken into account.

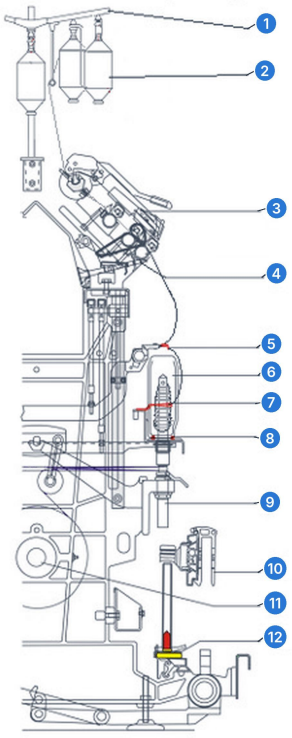


Figure 1. Technological scheme of the Rieter G35 ring spinning frame

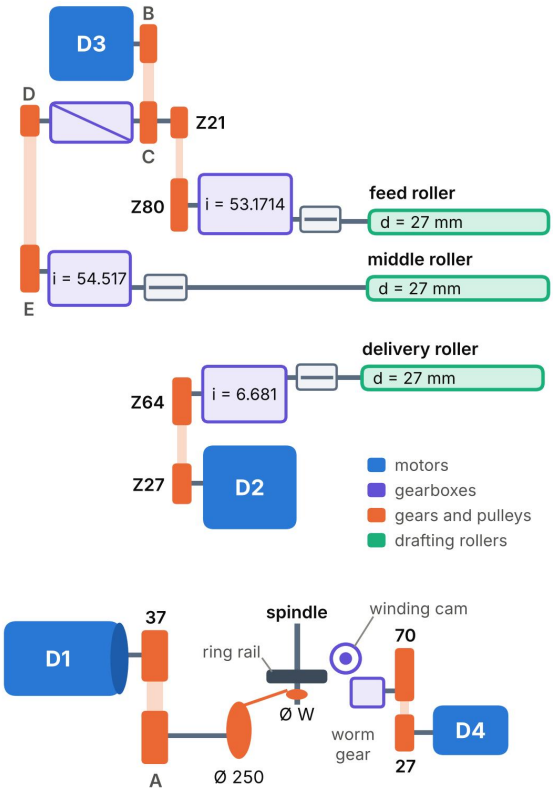


Figure 2. Kinematic scheme of the Rieter G35 ring spinning frame

3.4. Productivity–twist trade-off

According to Eq. (3), spindle productivity is inversely proportional to twist. Fig. 3 shows this dependence for three spindle speeds. Over the twist range of 700–800 t/m, which is recommended on the basis of the surface exposure of the conductive component and the yarn properties, the spindle productivity at n = 14,460 rpm decreases from 29.7 to 26.0 g/h, i.e. by 12.5 %.

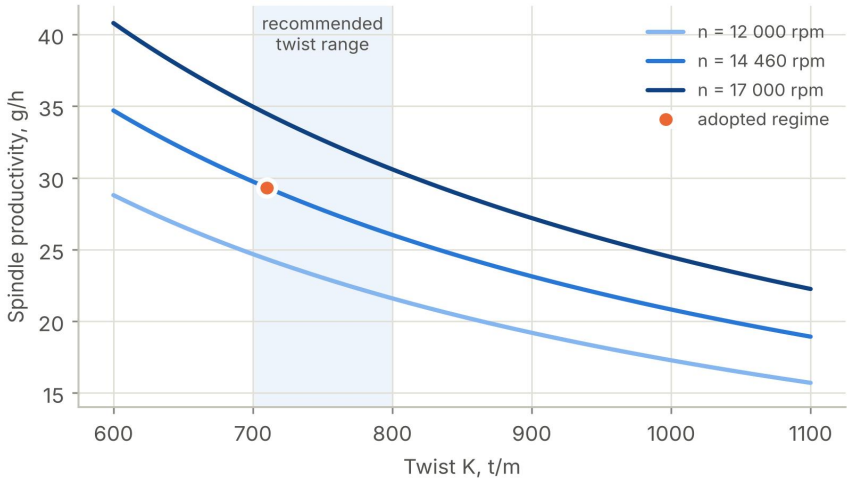


Figure 3. Theoretical spindle productivity of the ring spinning frame versus twist (T = 24 tex; ● – adopted regime)

3.5. Equipping the ring frame for feeding the multifilament

The G35 frame is equipped with an additional creel for the multifilament bobbins, a tensioning device for each spindle and yarn guides [3, 4]. The multifilament is unwound from the bobbin, passes over the guide rods, through the tensioning device and the thread guide, and is fed to the delivery (front) roller pair of the drafting system, where it joins the cotton drafted strand. The feed speed of the multifilament equals the surface speed of the delivery roller (21.0 m/min), so that the multifilament enters the twisting zone without being drafted. From the production norm of the frame and the mass fraction of the multifilament (5.6/24 = 0.233), the multifilament consumption is 31.3·0.233 ≈ 7.3 kg/h per frame.

4. Discussion

4.1. Internal consistency of the spinning plan

The mass-balance check of the draft chain confirms the internal consistency of the spinning plan: the linear densities and drafts of the individual stages agree within 0.1 %. This check is particularly important for a combined yarn. Its nominal linear density is the sum of two components, and an error in the linear density of the cotton component changes the mass fraction of the multifilament and, consequently, the electrical and mechanical properties of the yarn. The same kind of arithmetic cross-check revealed the inconsistency of the efficiency coefficient of the card (0.931 in the report versus $K_a \cdot K_b = 0.937$), which illustrates the value of closing every product relation in a spinning plan instead of adopting coefficients without verification.

The theoretical sixfold reduction of irregularity at drawing assumes that the irregularities of the doubled slivers are random and independent; the drafting process itself adds irregularity, so the actual improvement is smaller [8, 9]. Two drawing passages are nevertheless justified for the combined yarn: because the linear density of the multifilament is constant, any irregularity of the cotton component translates directly into local variations of the multifilament mass fraction along the yarn.

4.2. Productivity–twist trade-off and twist contraction

The ring spinning frame is the limiting stage of the process line. Since its productivity is inversely proportional to twist, the choice of twist is a compromise between the surface exposure of the conductive component, the yarn strength and the productivity. As Fig. 3 shows, increasing the twist from the adopted 710 to 800 t/m reduces productivity by 11 %. This loss could be compensated by raising the spindle speed from 14,460 to 16,300 rpm, but the traveller speed would then reach about 38 m/s. An increase in twist is therefore limited by the permissible speed of the ring–traveller pair [8, 9]. Because the twist multiplier α_T characterises the helix angle of the surface fibres independently of the yarn linear density [9, 10], the same reasoning applies to other counts of the combined yarn.

Twist influences not only output but also the mechanics of yarn formation. In the spinning triangle, a higher twist increases the tension of the outer fibres and the compression of the central fibres [12], and the stress state of the triangle can be resolved numerically [13]. For a combined yarn, this means that the twist selected from Fig. 3 also governs how firmly the cotton sheath grips the multifilament, that is,

the core coverage and the resistance to stripping that are considered the key quality indicators of filament-core yarns [7].

Koritsky's formula (4) retains the quadratic dependence on the twist multiplier that follows, at small helix angles, from idealised helical yarn geometry, in which contraction is governed by the helix angle of the fibres [11]; the additional weak dependence on $T^{1/3}$ is empirical [16]. The calculated contraction of 3.14 % raises the required delivery roller speed by approximately the same proportion; it must therefore be included in the setting of the drafting system so that the twist in the finished yarn equals the planned value.

4.3. Traveller dynamics and the conductive component

The calculated traveller speed (33.4–33.7 m/s) lies within the usual operating range of ring spinning [8]. The estimated winding tension (10–15 % of the yarn breaking force) corresponds to the tension level recommended for ring spinning [9]. In the combined yarn, however, part of the conductive component lies on the surface and is in direct contact with the traveller. In Nega-Stat® P210 the conductive core is protected by a polyester sheath [15], whereas in metallised polyamide yarns the metal layer is located on the surface. Since, according to Eq. (5), the friction force is proportional to the traveller mass and to the square of its speed, the wear of a surface metal layer can be reduced when changing to metal-organic components by selecting a lighter traveller and a lower spindle speed. This conclusion follows from the force balance only and requires experimental verification.

In ring-frame core spinning of metal wires with cotton, the conductive core is likewise fed to a modified ring spinning machine [6], and comparisons of filament-core spinning methods use core coverage and stripping resistance as the main quality criteria [7]. The feeding scheme proposed in Section 3.5 is designed with these criteria in mind: the multifilament is delivered under controlled tension at the delivery roller speed, so that the conductive component is not drafted and its position relative to the drafted strand is set by the thread guide. Because the multifilament is drawn off by the delivery rollers, its feed speed automatically follows any change in delivery speed caused by a change of twist.

4.4. Utilisation of the preparatory equipment

The productivity of the blowroom line and of the draw frames considerably exceeds the volume needed for the combined yarn (their loading is 12 and 48 %, respectively), whereas the card and the roving frame are fully loaded. This imbalance results from introducing the conductive component only at the spinning stage, so that the preparatory machines process only the cotton component. It is therefore advisable to use the spare capacity of these machines for another product range.

4.5. Limitations

The study is based on calculation from machine data and established formulas; the end-breakage rate, the actual spinning tension and the wear of the conductive component were not measured. Koritsky's formula is empirical and was established for conventional yarns [16]; its applicability to a combined yarn in which 23 % of the mass is a multifilament should be confirmed by measuring the actual contraction. The

winding-tension estimate neglects the balloon and the yarn-path angles and assumes a friction coefficient of 0.10–0.15, so it indicates only the order of magnitude [9]. Finally, the effect of traveller friction on surface-located metal layers was inferred from Eq. (5) and should be quantified in spinning trials with metal-organic components.

5. Conclusions

1. A spinning plan for a 24 tex antistatic combined yarn consisting of cotton and an electrically conductive multifilament was developed for a carded process line of Rieter C60, RSB-D40, Zinser 668 and G35 machines; the draft is referred to the cotton component (18.4 tex), and the twist and productivity of the ring frame to the combined yarn.
2. The mass balance of the draft chain was verified: the resulting draft is 35,100 and agrees with the product of the stage drafts within 0.08 %.
3. The production norms of the equipment were determined: card 91.1, draw frame 204.0, roving frame 93.1 and ring frame 31.3 kg/h (26.1 g/h per spindle); the efficiency coefficient of the card was corrected to 0.937.
4. The kinematic calculation of the G35 frame gave a twist contraction of 3.14 %, a delivery roller speed of 21.0 m/min, a total draft of 28.6, a traveller speed of 33.4–33.7 m/s and a running time per doff of 225 min (200 min of pure machine time); the traveller centrifugal force was estimated at 2.6 N and the winding tension at 26–39 cN.
5. Increasing the twist from 700 to 800 t/m reduces productivity by 12.5 %; the twist should be selected as a compromise between the surface exposure of the conductive component, the yarn strength and productivity, within the limit set by the permissible traveller speed.

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