Unevenness of air-jet spun yarn in comparison with ring and rotor spun yarn made from micro modal fibers

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All unevenness parameters (overall unevenness, unevenness on different cut lengths of 1 m, 3 m and 10 m and hairiness) of the air-jet yarn produced from micro modal fibers spun on the J20 air jet machine using the unevenness parameters of the rotor spun and conventional ring spun yarn produced from the same fibers were compared. In order to reduce the number of input influencing parameters on the unevenness properties, the comparison was performed on yarns for the same end-use (knitting) and with an equal count of 20 tex (Nm 50). Assuming that the mass distribution in the yarns follows a normal (Gauss) curve a t-test of yarn unevenness was carried out. It was shown that the overall unevenness of the air-jet spun yarn is smaller than that of the rotor spun yarn and is greater than the unevenness of the conventional ring spun yarn, while over larger cut lengths (1 m, 3 m and 10 m) it is smaller than in both yarns, rotor and ring spun yarns. The number of thin places in air-jet spun yarns at a sensitivity level -30% is higher than the number of these faults in the ring spun yarn by 9.2 times and compared with the rotor spun yarn lower by 4.2%. The air-jet spun yarn at a sensitivity level +50 % has the smallest number of thick places. In terms of hairiness, the air-jet spun yarn has a relatively higher quality.

Key words: *air-jet yarn, unevenness, faults, hairiness, micro modal fibers*

1. Introduction

Around 46 million tons of spun yarns are produced from short staple fibers annually, of which 27 million tons are ring spun yarns, 15 million tons are rotor spun yarns, 3 million tons are compact yarns and 1 million ton are air-jet spun yarns [1]. With regard to the process of making yarns, i.e. spinning machine type, approximately 20% yarn is combed. Furthermore, more than 60% of all compact yarns and about 30% of all ring spun yarns are combed. Rotor spun yarns is practically uncombed, while about 25% of air-jet spun yarns are combed. In the long term, up to 2030 it is anticipated to stabilize the consumption of man-made staple fibers (including regenerated cellulose fibers) at about 25% and cotton at about 28% (Fig.1). In today's world the ring spinning is most predominant, followed by the rotor spinning, while the air-jet spinning is mainly used for blends with man-made and regenerated cellulose fibers (Fig.2).

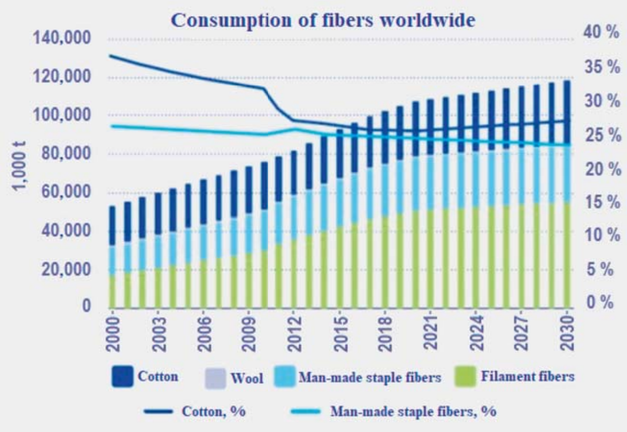

Fig.1 Consumption and consumption forecast of fibers worldwide by 2030 [1]

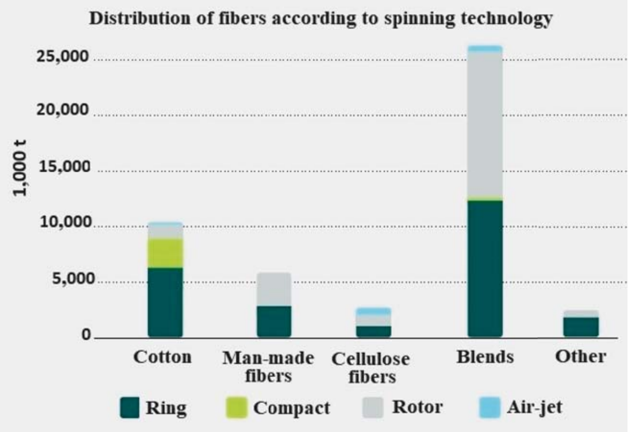

Fig.2 Consumption of different types of staple fibers according to spinning technologies [1]

The latest 2016 data reveal that of 47 million tons of yarns spun from short staple fibers 25 million tones are ring spun yarns (54%), 17 million tons of yarns are rotor spun yarns (36%), 4 million tons of yarns are compact yarns and about 1 million ton of yarns (2%) are air-jet spun yarns (Fig.3) [2].

Cellulose fibers, cotton and regenerated cellulose fibers are today predominant fibers for making garments. Due to their improved properties in relation to cotton regenerated cellulose fibers, and primarily due to higher hygroscopicity, comfortable wearing sensation, etc. play a significant role in the production of garments that are worn next to the skin. Natural cellulose fibers are cleaned in order to remove noncellulosic substances (such as waxes, pectins, proteins, etc.). To obtain viscous, modal and Lyocell fibers, different manufacturing processes are used to create a different fiber structure and properties, despite being chemically pure cellulose [3].

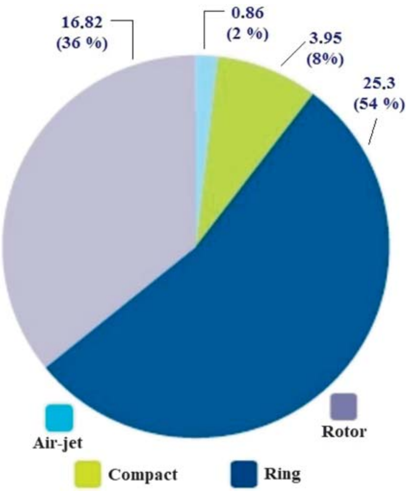

Fig.3 Consumption and share according to the type of yarn made from short staple fibers [2]

From a commercial point of view, the significant types of regenerated cellulose fibers are viscose fibers with CE marking (Viscose or Rayon), high wet modulus viscose fibers (HWM) with trade mark Modal and Lyocell fibers marked as CLY (e.g. Tencel). Modal fibers (CMD) are obtained by the viscose spinning method from a solution of high quality wood pulp (beech). Modal fibers have less micro pores which is the reason why the Interior of the fiber is better arranged in comparison with standard viscose fibers [4].

Modal fibers from the regenerated cellulose fiber group have a special place. The supermolecular structure of modal fibers is different in relation to other cellulose fibers. The degree of polymerization, in particular physical characteristics of microfibrils, defines the structure and properties of fibers and yarns as well as of fabrics. Tab.1 lists important data on the structure and properties of modal and cotton fibers [5, 6].

By definition of BISFA (Bureau International pour la Standardisation des Fibres Artificielles, International Bureau for the Standardization of Man-Made Fibers) cellulose fibers that meet 2 conditions, high breaking force in the conditioned state (BFc, cN) and high wet modulus – necessary elongation force of 5% (Fw, cN) are modal fibers [7].

$$BF_c \geq 1,3\sqrt{LD} + 2LD \qquad (1)$$

$$F_w \geq 0,5\sqrt{LD} \qquad (2)$$

where LD (linear density) is fineness, i.e. mass per unit length, in dtex

Tab.1 Key physical parameters of modal and cotton fibers [5, 6]

Parameter	Modal	Cotton
Tenacity cond, cN/tex	35	24-28
Elongation cond, %	13	7-9
Tenacity wet, cN/tex	20	25-35
Rel. wet tenacity, %	57	105
Loop tenacity, cN/tex	8	20-26
BISFA modul	6	10
Grade of fibrillation	1	2
Natural moisture content, % (65% rel. H.)	11	8
Polymerisation degree (DP)	640	3000
Volume swelling in water, %	63	35
Crystallinity	0.39	0.78
Crystallity width, nm	4.1	4.3
Crystallity length, nm	16	40-90

Lenzing AG, Austria, was the first to manufacture modal fibers. They absorb up to 50% more moisture than cotton. The main difference in relation to other cellulose fibers is higher strength in the wet state and high softness. They are often called fibers "as soft as feathers" and "the softest fibers in the world" [8].

Modal fibers produced by Lenzing Group are manufactured in a slightly modified viscose spinning method allowing to achieve special properties. Modal fibers are easy to wash due to higher strength. They are pleasantly soft despite high strength [9]. They are easily dyed, their luster is high, and they are particularly soft and feel pleasant to the skin. In blends with other fibers they will significantly enhance fabric softness, increasing the overall comfort [10].

For a particular yarn count, e.g. 20 tex (Nm 50), fiber fineness defines the number of fibers in the yarn cross-section. Fibers whose fineness ranges from 0.1 to 1.0 dtex are called microfibers [11]. Because of the high fineness of micro modal fibers, yarns can be finer and fabrics more lightweight. Products, especially knitwear made from micro fibers, are softer in contact with the skin, they are more air-permeable, have better drape and are durable enough. Modal and microfiber yarns are most commonly used to produce knitwear articles that feel comfortable on the skin.

Furthermore, the structure and properties of the products made from micro modal fibers are determined by the spinning technique, i.e. by the machine on which the yarn is formed from roving or sliver. With regard to spinning techniques, each of today's commercially available spinning techniques (ring, rotor and air-jet spun) is significantly different.

The number of published papers separately dealing with modal and micro modal yarns produced by various spinning techniques is small. The papers mainly deal with multiple yarn types, but not micro modal fibers.

Röder Th. et al. compared viscose, modal and Lyocell fibers and concluded that a variety of fibers and a wide range of properties can be determined by choice of solvents, variations of spinning conditions or variations of after-treatments [12].

Mechanical properties of yarns from micro modal fibers with a count of 1 dtex (0.9 den), a staple length of 38 mm and 40 mm respectively spun on the ring spinning machine with a compacting device and on the air-vortex spinning machine were investigated by Kim H.A and Kim S.J. [13]. Among other things, they concluded that the strength and elongation at break of air-jet spun yarn is lower than of compact and classical ring spun yarn.

Erdumlu N. et al. investigated the properties of air-jet spun (vortex), ring spun and rotor spun yarns of different counts spun from different fiber types (cotton, viscose, and cotton/modal blend 50/50). They concluded that air-jet spun yarn has better peeling resistance in relation to ring and rotor spun yarn, while viscose air-jet spun yarn has better strength results (especially coarser yarns) and hairiness [14].

Furthermore, a number of researchers deal with the migration of fibers in air-jet spun yarns [15], viscoelastic properties of air-jet spun and rotor spun yarns [16], the structure of air-jet spun yarn [16], the structure of air-jet spun yarn from a PET/cotton blend [17] and the assessment of tensile properties of air-jet spun yarn [18].

Yarn mass irregularity, which is the subject of this study, is directly related to fiber type and its physico-mechanical parameters. Today, it is determined by two methods, capacitive and optical. The capacitive method is more widely used. Typical parameters of yarn unevenness are overall unevenness, yarn faults, yarn hairiness. Furthermore, in addition to the above-mentioned tests, periodic faults are investigated using spectrograms. Using its testing instruments of the series Uster Tester, Uster Technologies determines the following basic characteristics:

- Overall unevenness expressed by coefficient (CVm) or linear unevenness U (%).
- The number of faults over a specific length of yarn (1000 m) defined as thin places, thick places and neps at different sensitivity levels of measurement: for thin places: -30%, -40%, -50% and -60%, for thick places: +35%, +50%, +70%, +100%, +140%, +200% and +280% and for neps: +140%, +200%, +280% and +400%.
- Yarn hairiness H
- Spectrogram to define periodical faults.

Unevenness of yarn expressed by CV (%) or by linear unevenness U (%) are defined by following equations:

$$CV = \frac{100}{\overline{x}} \sqrt{\frac{1}{T} \int_0^T (x_1 - \overline{x}) dt} \qquad (3)$$

$$U = \frac{100}{\overline{x}\; T} \int_0^T \left| x_i - \overline{x} \right| dT \qquad (4)$$

where x_i is current mass value, $\overline{x}$ is average mass value and T is testing time.

Several researchers studied the properties of spun yarn unevenness. In their paper Carvalho V. et al. [19] presented the automated yarn characterization system based on the capacitive sensor for measuring yarn unevenness as well as the optical sensor for analyzing yarn hairiness. A number of researchers such as Barela A. [20], Yilmaz D. and Usal M. R. [21] and Haleem N. and Wang X. [22] dealt with assessments of spun yarn properties.

Furthermore, a number of researchers dealt with evaluations of different properties of spun yarns. Üreyen M. E. and Gürkan P. [23,24] evaluated elongation properties, hairiness and unevenness of ring spun yarns by using artificial neural networks. Nurwaha D. and Wang X. H. [25] evaluated the strength of rotor spun yarn using ANFIS (Adaptive Neuro-Fuzzy Inference System) method.

In a broader sense yarn unevenness encompasses overall unevenness, yarn faults and periodic faults. identified by spectrograms. In terms of occurrence yarn faults may have a random character. Since the results of unevenness of various types of yarns spun from 100% micro modal fibers are not sufficiently known, this work will investigate overall unevenness, thin places, thick places, neps and hairiness of air-jet spun yarn and compared with ring-and rotor spun yarn.

2. Experimental part

From micro modal fibers of a length of 39 mm and a fineness of 1 dtex air-jet spun, rotor-spun and ring-spun yarns of a count of 20 tex (Nm 50) were made to be used for purposes in knitting.

The yarn spinning process consists of the following technological steps:

a) Ring-spun yarn: fiber preparation (opening, blending and carding), spinning preparation (drawing and roving) and ring spinning and winding (spinning machine Zinser 351, winding machine Schlafdorst X5).
b) Rotor-spun yarn: fiber preparation (opening, blending and carding), spinning preparation (drawing) and rotor spinning (rotor machine Schlafhorst A8).
c) Air-jet spun yarn: fiber preparation (opening, blending and carding), spinning preparation (drawing) and air-jet spinning (spinning machine Rieter J20).

The following yarn parameters were specified: fineness – according to HRN EN ISO 2060 2008 [26], twist in yarns – according to HRN EN ISO 2061 2015 [27], unevenness, number of faults and hairiness according to standard ASTM D1425/D1425M-14 [28] and tensile properties according to HRN EN ISO 2062 2010 [29]. Fineness and twist in yarns were specified from 10 cross wound packages, whereby twist in yarns was determined only for the ring spun yarn, while twist in yarns was not determined for rotor-spun and air-jet yarns according to the mentioned method because the method was unsuitable; thus, it was read from the machine and technical technological machine parameters.

Unevenness, number of yarn faults and hairiness were measured over 1,000 m of yarn from each of 10 cross-wound packages, while tensile properties were determined from 100 measurements, also from each package.

3. Results and discussion

Basic physico-mechanical parameters of air-jet spun, rotor spun and

Tab.2 Results of individual quality properties of air-jet spun, ring and rotor spun yarn made from micro modal fibers

Yarn quality parameter	Air-jet	Rotor	Ring
Yarn linear density (tex); s (tex); CV (%)	20.15; 0.23; 0.46	20.12; 0.169; 0.84	20.04; 0.204; 1.02
Number of yarn in cross section (Yarn linear density/Fiber linear density)	201.5	201.2	200.4
Number of twists (m^{-1}); s (m^{-1}); CV (%)	Air presure 0,6 MPa (6 bar)	750	734; 16.882; 2.3
Hairiness index H; s; CV (%)	3.56; 0.24; 6.8	4.08; 0.069; 1.7	5.28; 0.211; 4.0
Tenacity (cN/tex), s (cN/tex); CV (%)	20.55; 1.51; 7.37	15.86; 1.356; 8.55	24.09; 1.549; 6.43
Elongation (%); s (%); CV (%)	9.01; 0.63; 7.02	8.00; 0.634; 7.92	10.30; 0.543; 5.27
Work (N cm); s (N cm); CV (%)	10.78; 1.30; 12.10	7.70; 1.078; 14.0	14.26; 1.410; 9.89

Tab.3 Yarn unevenness in function of cut length

Cone No.	Air-jet				Rotor				Ring			
	CVm	CV, 1m	CV, 3m	CV, 10m	CVm	CV, 1m	CV, 3m	CV, 10m	CVm	CV, 1m	CV, 3m	CV, 10m
1	12.16	2.93	2.21	1.32	12.77	4.6	3.78	2.57	9.5	3.43	2.47	1.61
2	12.1	2.81	2.02	1.11	12.82	4.66	3.78	2.53	9.57	3.03	2.18	1.53
3	11.86	2.88	2.11	1.11	12.57	4.34	3.49	2.68	9.84	3.32	2.32	1.62
4	13.14	2.91	2.11	1.31	12.68	4.4	3.57	2.51	10.04	3.15	2.17	1.54
5	11.46	2.76	1.92	1.15	12.68	4.45	3.57	2.5	9.44	3.43	2.53	1.96
6	12.42	2.98	2.16	1.24	12.59	4.25	3.4	2.38	9.71	3.31	2.21	1.62
7	12.87	3.1	2.31	1.36	12.73	4.47	3.62	2.6	9.57	3.18	2.16	1.48
8	11.98	2.98	2.22	1.22	12.74	4.4	3.58	2.62	9.69	3.28	2.27	1.61
9	11.93	2.8	1.99	1.05	12.77	4.58	3.73	2.78	9.76	3.23	2.2	1.47
10	11.31	2.93	2.06	1.19	12.59	3.97	3.14	2.43	9.56	3.17	2.33	1.7
Average	12.12	2.91	2.11	1.21	12.69	4.41	3.57	2.56	9.67	3.25	2.28	1.61
STDEV.S	0.569	0.101	0.118	0.103	0.087	0.199	0.193	0.117	0.18	0.13	0.13	0.14
VAR.S	0.323	0.010	0.014	0.011	0.008	0.040	0.037	0.014	0.032	0.016	0.017	0.020
CV	4.69	3.47	5.59	8.52	0.686	4.51	5.41	4.59	1.96	3.89	5.66	8.72

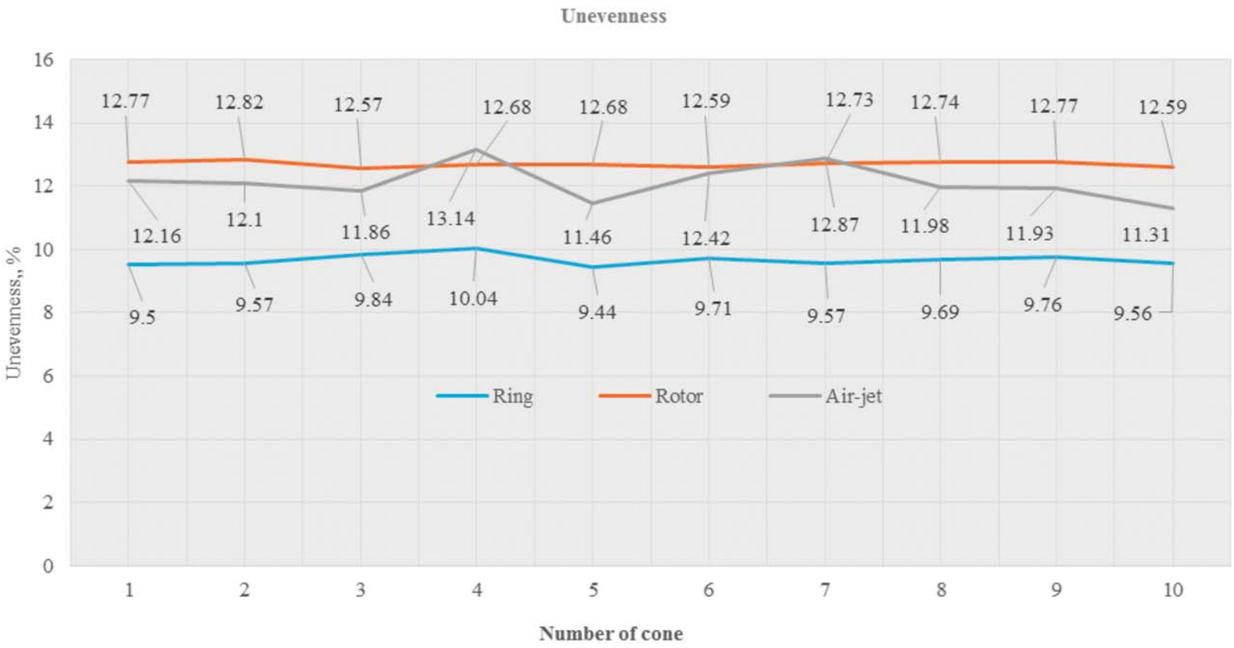

Fig.4 Unevenness of ring, rotor and air-jet-spun yarn made from micro modal fibers

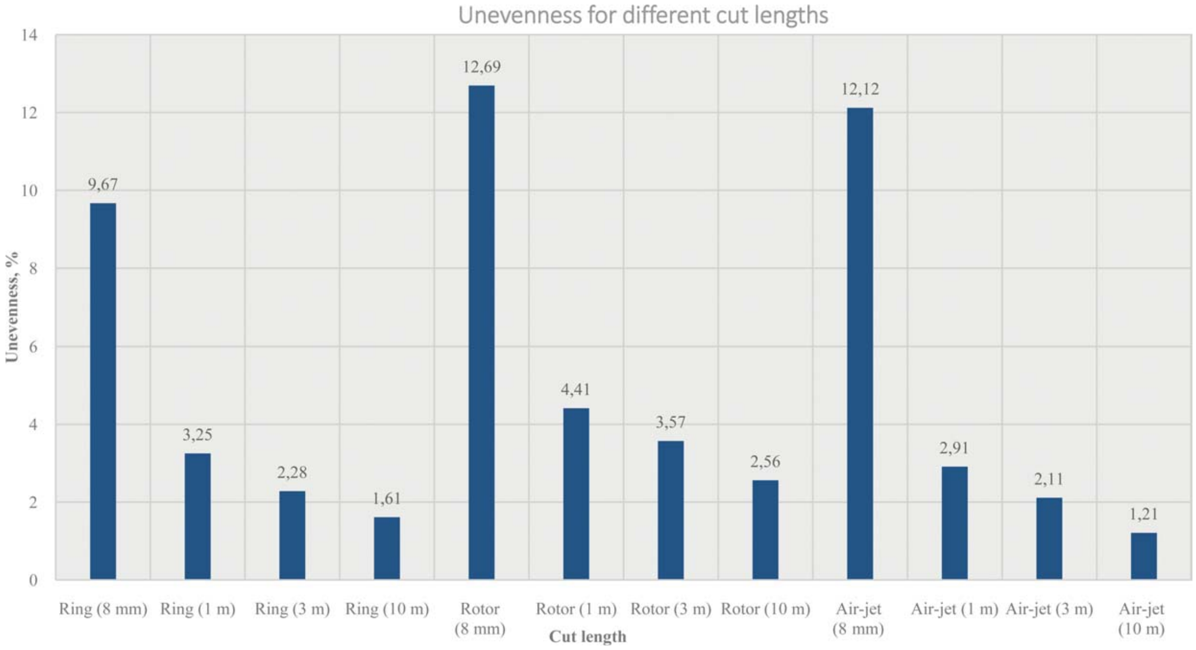

Fig.5 Unevenness of ring, rotor and air-jet spun yarn made from micro modal fibers from 10 cross-wound packages for different cut lengths

ring spun yarns made from micro modal fibers are given in Tab.2. In this paper the results of rotor and ring spun yarns [30] are elaborated i as well as graphically illustrated and compared in detail with air-jet spun yarn.

3.1. Yarn mass irregularity

The results of yarn mass irregularity for different cut lengths of 8 mm, 1 m, 3 m and 10 m of air-jet spun, rotor and ring spun yarns from micro modal fibers are given in Table 3 and shown in Figs. 4, 5, 6, 7 and 8. Since short-staple spinning mills usually use unevenness for cut lengths of 8 mm, so-called overall unevenness (CVm), these values are separately shown in Fig. 4. The overall unevenness CVm of air-jet spun yarn (12.12%) is generally smaller than the unevenness of rotor spun yarn (12.69%) and is greater than the unevenness of ring spun yarn (9.67%), while it is over larger cut lengths (1 m, 3 m and 10 m) smaller than for both yarns, rotor and ring spun yarns (Tab.3, Figs.4 and 5). The overall unevenness of air-jet spun yarn in relation to ring-spun yarn is greater by 25.3%, while compared with rotor spun yarn is smaller by 4.5%. The cause of the greater unevenness of air-jet spun and rotor spun yarn in relation to ring-spun yarn is their relatively greater disorder of unevenness of the yarn structure. The fibers of air-jet spun yarn have a bundle-like structure, i.e. the yarn core is composed of a bundle of parallel fibers, while the wrap is made up of wrapping fibers which fix the bundle of parallel core fibers. By increasing the cut length (CV (L) function), unevenness decreases in all yarn types (Fig.5). By increasing the cut length from 8 mm to 10 m, the decrease in average unevenness value CVm of ring spun yarn amounts from 9.67% to 1.61%, of rotor spun yarn from 12.69% to 2.56% and of air-jet spun yarn from 12.12% 1.21%. Comparing air-jet spun yarn with ring-spun yarn, air-jet spun yarn has smaller unevenness (2.91, 2.11 and 1.21%) for all three cut lengths of 1 m, 3 m and 10 m than the other yarn types, i.e. the best evenness. The aforementioned facts reveal a high quality consistency which is certainly the effect of the complete technology including only the air-jet spinning on the J20 spinning machine. More detailed analyses of unevenness and its causes can be sought in yarn spectrograms. By analyzing the variations of unevenness CVm among 10 cross-wound packages for each of the yarn types, a trend of increasing variation with increasing the cut length from 8 mm to 10 m (Fig.6, 7 and 8) was mostly observed.

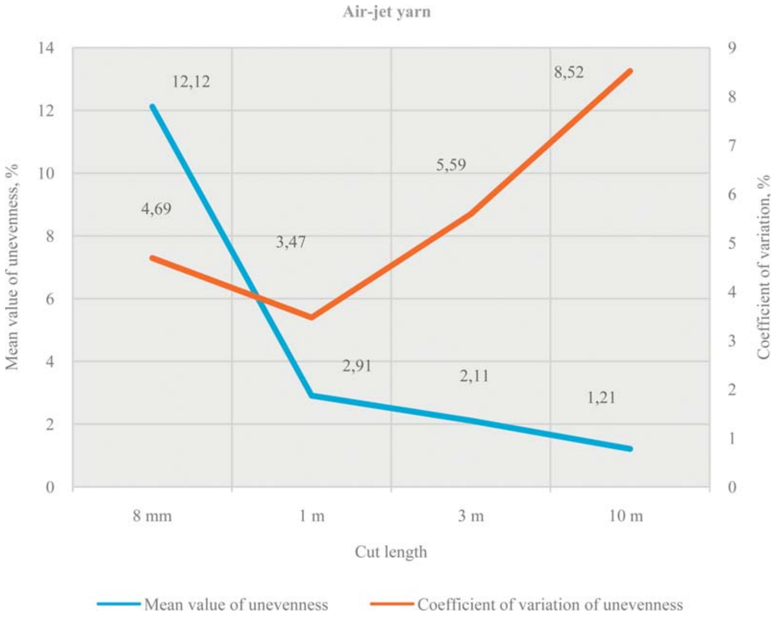

Fig.6 Mean values and coefficient of variation of unevenness of air-jet spun yarn made from micro modal fibers

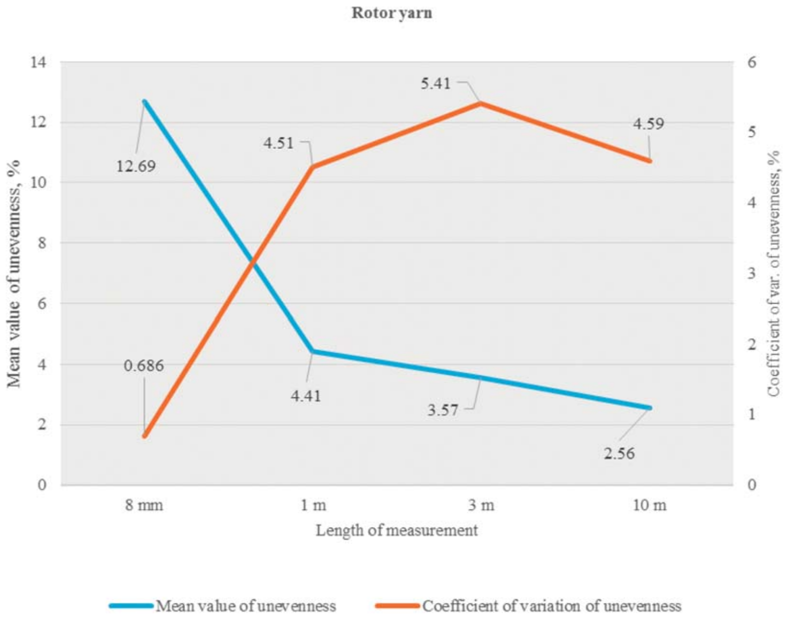

Fig.7 Mean values and coefficient of variation of unevenness of rotor spun yarn made from micro modal fibers

3.2. T-test of yarn mass irregularity

A more precise evaluation of air-jet spun yarn parameters in comparison with rotor and ring spun yarn is obtained by conducting statistical tests. Therefore, after comparing the absolute values of unevenness parameters, a statistical test (t-test) was conducted assuming that the variances are statistically equal and that the mass distribution of all yarns follows the normal (Gaussian) distribution. The results of the conducted t-test and the evaluation of air-jet spun yarn in comparison with rotor spun and ring spun yarn are presented in Tab.4 and 5 [31].

The results of examining differences between the mean values of air-jet spun yarn unevenness in comparison with rotor and ring spun yarn are shown in Table 6. Thus, for example, the air-jet spun yarn is significantly different in overall unevenness CVm, both from the rotor spun yarn and from the ring spun yarn with a high confidence level (higher than 99.9%). Therefore, it has smaller unevenness CVm than the rotor spun yarn and greater unevenness than the ring spun yarn.

3.3. Yarn faults

3.3.1. Thin places

The measurement results of the number of thin places in the yarn are given in Tab.6 and shown in Fig.9. The number of thin places in each yarn type varies essentially. Thus, the number of thin places whose cross-section was reduced by 30% and more over the yarn length greater than 4 mm in the ring spun yarn (130.2) was almost 10 times smaller than the number of faults in the rotor spun yarn (1250.4). The number of this fault type in the air-jet spun yarn lies between the ring and rotor spun yarn (1197.4). A greater number of faults in the air-jet spun and rotor spun yarn is the consequence of fiber disorder in the structure caused by the spinning technique. Furthermore, at this level of measurement sensitivity significantly greater scattering of the number of thin places in the air-jet spun yarn (32.6%) in comparison with the ring spun yarn (26.78%) and the rotor spun yarn (3.09%) was obtained. At a higher level of measurement sensitivity (-40%), the number of thin places in all yarns was significantly smaller as expected, ranging on average from 1.4 in the ring spun yarn, 61.1 in the rotor spun yarn to 79.7 in the air-jet spun yarn. It is therefore evident that at a level of sensitivity of -40% the number of thin places in the rotor and the air-jet spun yarn is several times greater than the number of thin places the ring spun yarn. In this case, too, a relatively greater structure disorder

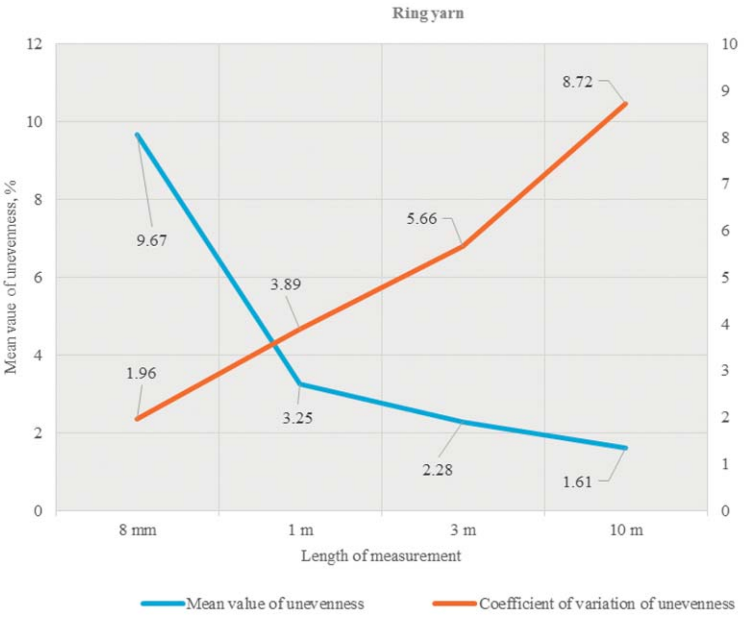

Fig.8 Mean values and coefficient of variation of unevenness of ring spun yarn made from micro modal fibers

Tab.4 Parameters of yarn mass unevenness and calculated parameters to conduct a t-test with a 95% confidence level assuming the normal mass distribution of yarn

No	Quality parameters	Air-jet yarn	Rotor yarn	Ring yarn	$S_{d,ar}^2$	$S_{d,ap}^2$	t_{ar}	t_{ap}	$t_{o,ar}$	$t_{o,ap}$
1	CV_m (%); s (%) CV (%)	12.12; 0.570 4.69	12.69; 0.099 0.7	9.67; 0.184 1.9	0.0333	0.0359	3.132	12.963	2.101	2.101
2	CV_{1m} (%); s (%) CV (%)	2.91; 0.101 3.5	4.41; 0.198 4.5	3.25; 0.127 3.9	0.0049	0.0026	21.428	6.637	2.101	2.101
3	CV_{3m} (%); s (%) CV (%)	2.11; 0.118 5.6	3.57; 0.193 5.4	2.28; 0.130 5.7	0.0051	0.0031	20.419	3.063	2.101	2.101
4	CV_{10m} (%); s (%) CV (%)	1.21; 0.103 8.5	2.56; 0.118 4.6	1.63; 0.155 9.5	0.0245	0.0035	27.273	7.143	2.101	2.101

Tab.5 Statistical analysis and comparisons of mass unevenness of air-jet-spun yarn with rotor and ring spun yarn (t-test)

No	Unevenness	Probability (t-test) Air-jet/Rotor	Probability (t-test) Air-jet/Ring
1	CV_m	$0{,}001 < P\{\lvert t\rvert > 2{,}101\} < 0{,}01$ Unevennesses are different. Air-jet yarn has lower unevenness than rotor	$P\{\lvert t\rvert > 2{,}101\} < 0{,}001$ Unevennesses are different. Air-jet yarn has higher unevenness than ring yarn.
2	CV_{1m}	$P\{\lvert t\rvert > 2{,}101\} < 0{,}001$ Unevennesses are different. Air-jet yarn has lower unevenness than rotor	$P\{\lvert t\rvert > 2{,}101\} < 0{,}001$ Unevennesses are different. Air-jet yarn has lower unevenness than ring yarn
3	CV_{3m}	$P\{\lvert t\rvert > 2{,}101\} < 0{,}001$ Unevennesses are different. Air-jet yarn has lower unevenness than rotor	$0{,}001 < P\{\lvert t\rvert > 2{,}101\} < 0{,}01$ Unevennesses are different. Air-jet yarn has lower unevenness than ring yarn
4	CV_{10m}	$P\{\lvert t\rvert > 2{,}101\} < 0{,}001$ Unevennesses are different. Air-jet yarn has lower unevenness than rotor	$P\{\lvert t\rvert > 2{,}101\} < 0{,}001$ Unevennesses are different. Air-jet yarn has lower unevenness than ring yarn

Tab.6 Number of thin places in the air-jet spun, rotor and ring spun yarn determined for different levels of measurement sensitivity

No.	Air-jet				Rotor				Ring			
	-30%	-40%	-50%	-60%	-30%	-40%	-50%	-60%	-30%	-40%	-50%	-60%
1	985	53	0	0	1294	58	2	0	92	2	0	0
2	1154	71	0	0	1298	63	3	0	119	0	0	0
3	981	52	0	0	1208	52	0	0	165	1	0	0
4	1980	171	6	0	1276	66	1	0	198	4	0	0
5	936	54	0	0	1225	72	1	0	102	1	0	0
6	1342	89	1	0	1242	62	0	0	155	2	0	0
7	1767	158	10	0	1298	64	0	0	114	2	0	0
8	1090	69	0	0	1249	61	0	0	125	2	0	0
9	996	57	0	0	1200	56	2	0	143	0	0	0
10	743	23	1	0	1214	57	0	0	89	0	0	0
Average	1197.4	79.7	1.8	0	1250.4	61.1	0.9	0	130.2	1.4	0	0
STDEV.S	391.37	47.86	3.43	0	38.68	5.68	1.10	0	34.87	1.26	0	0
VAR.S	153172	2290	11.73	0	1496.49	32.32	1.21	0	1217.1	1.6	0	0
CV	32.68	60.05	190.5	0	3.09	0.093	122.2	0	26.78	90.0	0	0

of the rotor spun and air-jet spun yarn is the cause of this occurrence. At the level of sensitivity -50% and -60%, the number of thin places on all the count is very small on average. The latter aspect suggests a high consistency of yarn quality during yarn manufacturing and especially the consistency of spinning machine operation.

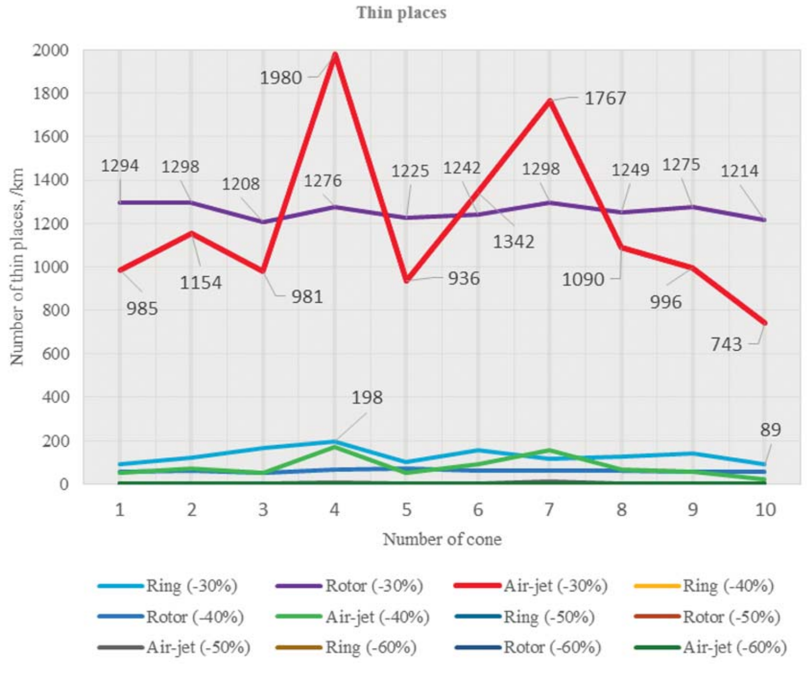

Fig.9 Number of thin places in the ring, rotor and air-jet spun yarn made from micro modal fibers

3.3.2. *Thick places*

The measurement results of thick places are listed in Tab.7 and shown in Fig.10. The number of thick places according to a measurement sensitivity of 35% is considerably greater than the number of thick places at higher levels of sensitivity for all types of yarn. At this level of measurement sensitivity the air-jet spun yarn has in relation to the ring spun yarn a significantly greater number of thick places (on average 132 and 30.4 respectively) over 1,000 m of yarn length, and a significantly smaller number of thick places than the rotor-spun yarn (245.8). It was observed that the scattering of thick places expressed by the coefficient of variation is greater in the air-jet spun yarn (46.25%) in relation to the ring spun yarn (26.38%) and the rotor spun yarn (7.19%). At higher sensitivity levels than + 50% the same trend was retained, i.e. the number of thick places is the greatest in the rotor spun yarn (12.9 on average) in comparison with the ring spun (5.8) and air-jet spun yarn (5.4). It is interesting that at this level the number of thick places in the air-jet spun yarn is the smallest on average. At higher sensitivity levels + 70% and + 100% respectively the number of thick places in all types of yarn is still negligibly small. A significant number of the mentioned faults in the air-jet spun and rotor spun yarn in the form of thick places is present at sensitivity levels + 35% and + 50%. Thus, the air-jet spun yarn is with regard to thick places more qualitative than the

Tab.7 Number of thick places in the air-jet, rotor and ring spun yarn determined for different levels of measurement sensitivity

No	Air-jet				Rotor				Ring			
	+35%	+50%	+70%	+100%	+35%	+50%	+70%	+100%	+35%	+50%	+70%	+100%
1	156	10	1	0	270	17	0	0	35	4	0	0
2	130	3	0	0	237	17	0	0	28	10	3	1
3	90	6	1	0	210	8	1	0	44	15	7	1
4	259	11	1	0	229	11	0	0	26	3	3	0
5	74	3	0	0	253	12	0	0	16	0	0	0
6	155	4	0	0	247	10	0	0	37	9	2	1
7	193	7	0	0	247	18	0	0	22	2	0	0
8	98	4	0	0	265	11	0	0	29	5	1	0
9	109	2	1	0	242	9	0	0	35	4	0	0
10	56	4	0	0	258	16	0	0	32	6	4	0
Average	132	5.4	0.4	0	245.8	12.9	0,1	0	30.4	5.8	2	0.3
STDEV.S	61.05	3.06	0.52	0	17.68	3.73	0.32	0	8.02	4.42	2.31	0.48
VAR.S	3727	9.38	0.27	0	312.6	13.88	0.1	0	64.3	19.5	5.33	0.23
CV	46.25	56.7	130.0	0	7.19	28.91	320	0	26.38	76.21	115.5	160.0

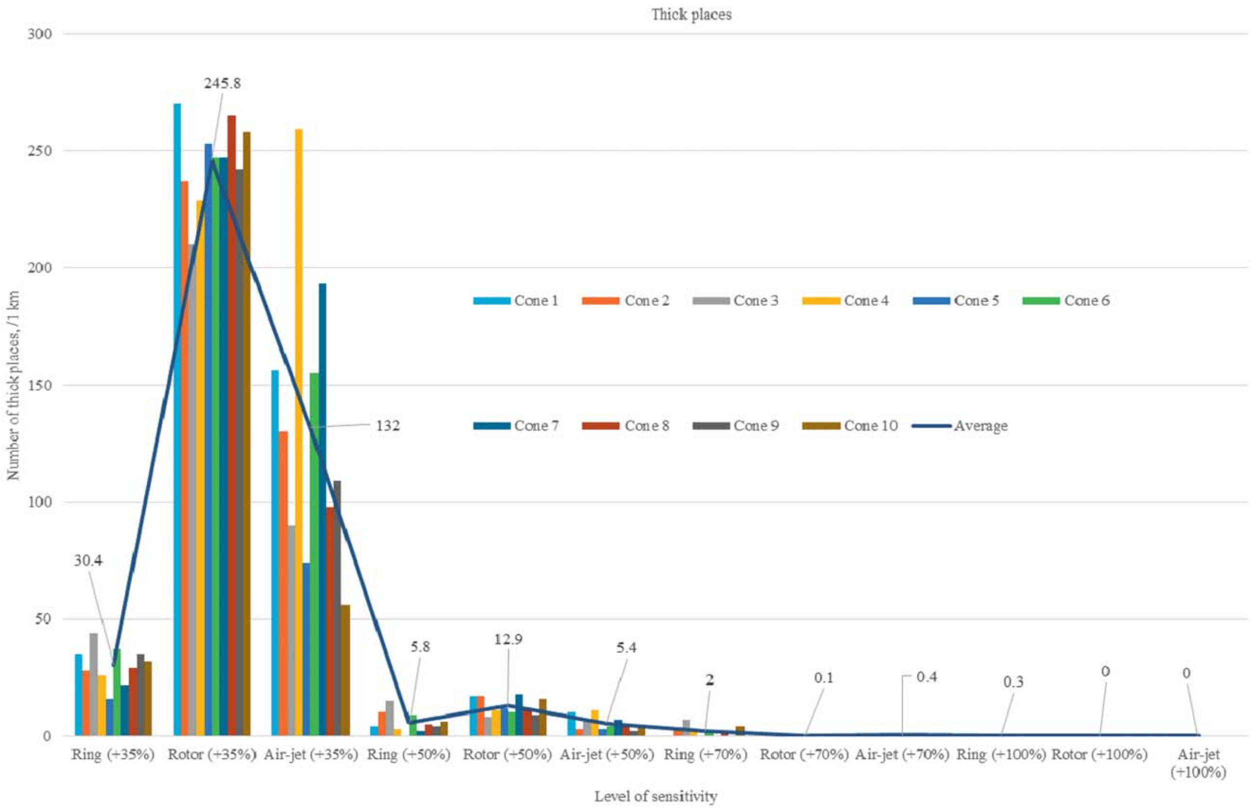

Fig.10 Number of thick places in the ring, rotor and air-jet spun yarn made from micro modal fibers

rotor spun yarn, but with a slightly higher coefficient of variation at a sensitivity level +35%.

3.3.3. Neps

The number of neps defined as thick places at the length less than 4 mm is given in Tab.8 and shown in Fig.11. The occurrence rate of the number of neps at levels of measurement sensitivity +140% and +200% follows the number of thick places for all types of yarns as expected because neps are also thick places but at a yarn length shorter than 4 mm. Thus, the number of neps at a level of measurement sensitivity +140% is the greatest in the rotor spun yarn (778.8) followed by the air-jet spun yarn (280.6) and the ring spun yarn (98.9). At this level of measurement sensitivity the air-

Tab.8 Number of neps in the air-jet, rotor and ring spun yarn determined at different levels of measurement sensitivity

No	Air-jet				Rotor				Ring			
	+140%	+200%	+280%	+400%	+140%	+200%	+280%	+400%	+140%	+200%	+280%	+400%
1	274	16	2	0	843	25	0	0	96	31	8	1
2	315	6	0	0	716	25	0	0	90	33	13	7
3	223	13	2	0	722	27	2	1	128	47	16	1
4	734	36	4	1	831	41	1	0	92	22	2	1
5	89	7	1	0	752	27	1	0	63	13	1	0
6	206	16	1	0	781	27	2	0	111	27	11	3
7	396	20	4	1	838	42	2	0	91	28	6	0
8	243	6	0	0	791	34	2	0	88	25	6	2
9	226	14	1	0	755	33	0	0	107	23	5	1
10	100	7	1	0	759	31	3	0	123	36	10	3
Average	280.6	14.1	1.6	0.2	778.8	31.2	1.3	0.1	98.9	28.5	7.8	1.9
STDEV.S	183.4	9.16	1.43	0.42	46.4	6.27	1.06	0.1	19.0	9.14	4.76	2.08
VAR.S	33635	83.9	2.04	0.18	2150.2	39.3	1.12	0.01	360.5	83.6	22.6	4.32
CV	63.4	65.0	89.4	210.0	5.96	20.1	81.5	100.0	19.2	32.1	61.0	109.5

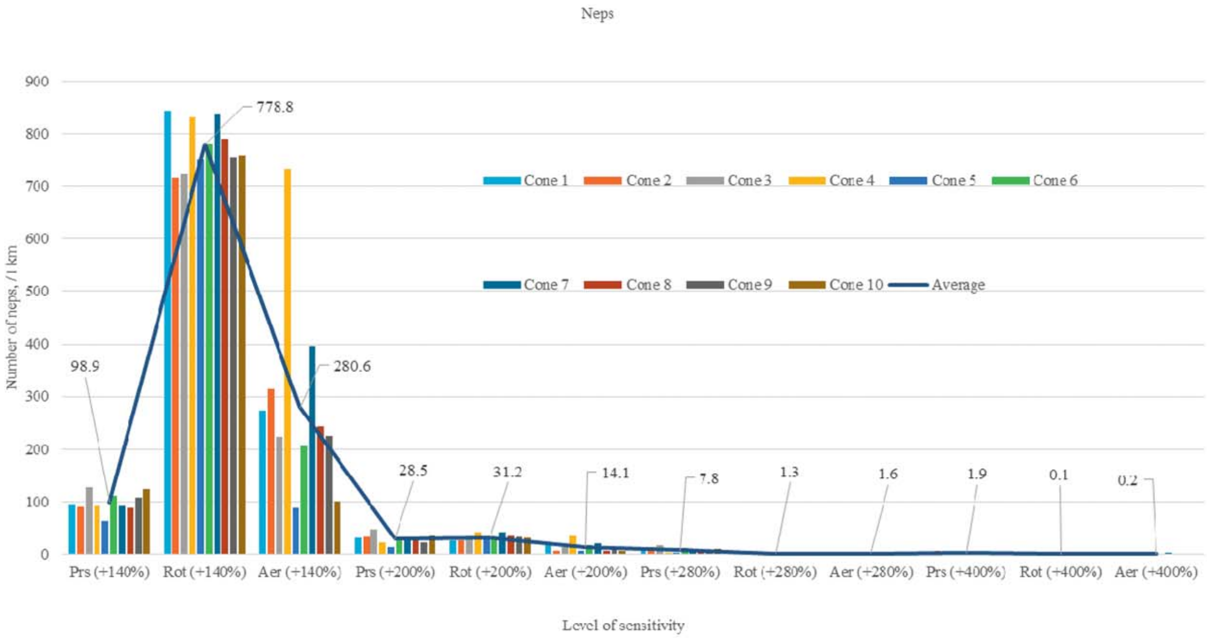

Fig.11 Number of neps in the ring, rotor and air-jet-spun yarn made from micro modal fibers

jet spun yarn has the greatest scattering of the number of neps expressed by the variation coefficient (63.4%) followed by the ring spun yarn (19.2%) and the rotor spun yarn (5.96%). At a level of measurement sensitivity +200%, the number of neps is the smallest in the air-jet spun yarn (14,1), while the ring and rotor spun yarns have a significantly greater number and mutually almost the same number of neps (28,5 or 31,2).

It can be concluded that the number of neps in the air-jet spun yarn is at both levels of measurement sensitivity +140% and +200% considerably smaller than the number of neps in the rotor spun yarn, while at a level of measurement sensitivity of +200% the number of neps is smaller than in the ring spun yarn.

Although the number of neps at levels of measurement sensitivity +280% and +400% in absolute amounts is small and ranges from 7.8 in the ring spun yarn at +280% to 0.1 in the rotor spun yarn at +400%, these rare events also show a structure image and possible yarn behavior in the subsequent processing phases. Thus, for example, the mass of a cylindrical package of 20 tex (Nm 50) air-jet spun yarn and weighing 4.5 kg contains 225,000 m of yarn. If the o occurrence rate of neps ranges from 2 to 1,000 m of the yarn, there will be a total of 50 faults

Tab.9 Hairiness of the air-jet, rotor and ring spun yarn

No	Hairiness (H)		
	Air-jet	Rotor	Ring
1	3.53	4.1	5.29
2	3.54	4.03	5.43
3	3.62	4.09	5.25
4	3.57	4.15	5.6
5	2.93	4.07	5.07
6	3.8	4.14	5.19
7	3.52	4.18	5.04
8	3.6	4.01	5.08
9	3.77	4.06	5.65
10	3.75	3.96	5.24
Average	3.56	4.08	5.28
STDEV.S	0.245	0.068	0.214
VAR.S	0.060	0.0046	0.046
CV	6.88	1.67	4.05

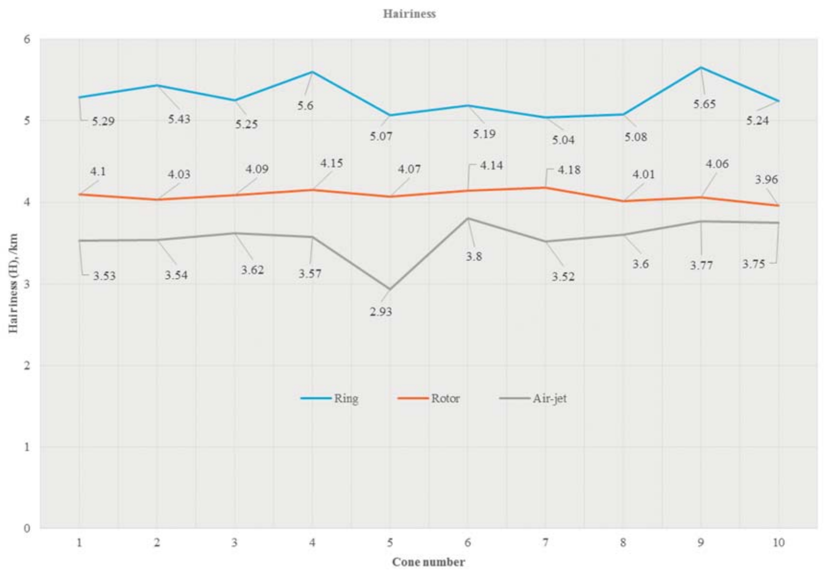

Fig.12 Hairiness of the ring, rotor and air-jet spun yarn made from micro modal fibers

of this kind on one package ((0.2/1,000) x 225,000), which is not insignificant and which to a certain extent affects the knitting machine downtime and/or knitted fabric appearance. In the case that the occurrence rate of the number of neps in the air-jet spun yarn is 0.1 over 1,000 m, then there will be a total of 25 neps or 50% less on one yarn package. In conclusion, a less frequent occurrence of faults is also important for subsequent yarn processing.

3.3.4. Hairiness

The values of hairiness index H are listed in Tab.9 and shown in Fig.12. Yarn hairiness defined as the index of hairiness H and determined on the Uster Tester 4S corresponds to the total length of the protruding fibers divided with the sensor length of 1 cm, and it is a dimensionless number. The air-jet spun yarn has the lowest hairiness (3.56) while the ring spun yarn has the highest hairiness (5.28). Although the hairiness of the rotor spun lies between the air-jet spun and ring spun yarn, it has the smallest scattering of hairiness values (on 10 cross-wound packages) defined by the variation coefficient (1.67%). Yarn hairiness has a significant impact on the appearance of the fabric as well as on the subsequent yarn processing. It depends on several factors such as fiber types, yarn fineness and number of twists, i.e. intended use of yarn.

Since it is only about one type of fiber (micro modal fibers), the same yarn count (20 tex) and the yarn end-use (knitting), the differences in the values of hair index H are caused by the difference in the yarn structure which is the result of different processing in the previous phases (fiber preparation) and the for the most part of method of yarn formation (on the spinning machine). It is evident that the cause of the lowest hairiness in the air-jet spun yarn is a smaller number of wrapping fibers around the core of the untwisted bundle and a good compact structure.

4. Conclusions

In order to reduce the number of input parameters, such as fiber type and twist, i.e. yarn end- use, for the purposes of this study the results of the unevenness parameters of the air-jet spun yarn made from micro modal fibers spun on the Rieter J20 air-jet-spinning machine were compared with the results of the unevenness parameters of the rotor and ring spun yarn made from the same fibers and for the same end-use (knitting). Therefore, the only parameters affecting the structure and unevenness parameters of these yarns are the fiber preparation phases and the spinning phase, i.e. spinning machine. Based on the results obtained, the following conclusions can be drawn:

- Overall unevenness CVm of the air-jet spun yarn is generally smaller than the overall unevenness of the rotor spun, but greater than the overall yarn unevenness of the ring spun yarn, while at greater cut lengths (1 m, 3 m and 10 m) it is smaller in both yarns, rotor and ring spun yarn.
- Overall unevenness of the air-jet spun yarn in comparison with the ring spun yarn is greater by 25.3%, while in comparison with the rotor spun yarn it is smaller by 4.5%.
- The cause of greater unevenness of the air-jet and rotor spun yarn in relation to the ring spun yarn is their relatively greater fiber disorder in the yarn structure; the fibers of the air-jet spun yarn have a bundle-like structure, i.e. the yarn core is composed of a bundle of parallel fibers, while the wrap is composed of wrapping fibers

which fix the bundle of the parallel fibers of the core.

- The number of thin places in the air-jet spun yarn at a level of measurement sensitivity of -30% is greater than the number of these faults in the ring spun yarn by 9.2 times, while in relation to the rotor spun yarn it is approximately equal or to be more accurate, it is smaller by 4.2%;
- The air-jet spun yarn at a level of measurement +35% has a significantly greater number of thick places (132) in relation to the ring spun yarn (30.4), i.e. greater by 4.3 times, while in relation to the rotor spun yarn it has a smaller number of thick places (245.8), i.e. smaller by 1.9 times.
- The air-jet spun yarn at a level of measurement sensitivity of +50% (usual level of measurements in spinning mils) has the smallest number of thick places.
- The occurrence rate of the number of neps at a level of measurement sensitivity +140% and +200% follows the number of thick places for all yarn types, as expected, because neps are also thick places, but at yarn length shorter than 4 mm.
- The number of neps in the air-jet spun yarn at both levels of measurement sensitivity +140% and +200% is considerably smaller than the number of neps in the rotor spun yarn, while at a level of measurement sensitivity +200% the number of neps is smaller even in the ring spun yarn.
- The lowest hairiness was recorded in the air-jet spun yarn (3.56), while the highest hairiness was recorded in the ring spun yarn (5.28); although the hairiness of the rotor spun yarn lies between the air-jet and the ring spun yarn, it has the greatest scattering of hairiness values.

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