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Optimum Selection of the Opening Roller and Navel for Rotor Spun Silk/Cashmere Blended Yarn

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Abstract
Machine part selection in rotor spinning from possible alternatives with different properties and performance levels in terms of yarn quality is a difficult task. Classical statistical methods have been used to solve the problem, but the priorities and preferences to obtain the end product characteristics desired have not been taken into consideration. The best type of opening roller and navel depends on the type of fibre and yarn. This paper studies rotor spinning blended yarn produced from spun silk and cashmere. Nine samples were spun from three different opening rollers and navels. According to the Uster test results of yarn quality properties, optimum selection was achieved using the multi-objective fuzzy optimal model. A pin type roller and spiral grooved ceramic were the best choice for spinning stability and yarn quality properties.

Key words: *opening roller, navel, spun silk/cashmere blended yarn, optimum selection.*

Introduction

As far as economics is concerned, open-end spinning does not need a roving and winding machine. Nowadays, according to the end uses desired, rotor yarn can be spun from different types of fibre like spun silk and cashmere. The yarn produced is more uniform, fuller, aerated and regular in strength [1].The profit margin is higher compared to the ring spinning system, with other bonus advantages of less space and fewer labour requirements. As a rule, the raw material should be selected in such a way as to build a balance between the raw material cost and yarn characteristics desired.

To obtain good spinning stability, the yarn must have sufficient twist at the peeling point, where it leaves the rotor groove. The necessary twist is created with the help of the navel. The rotation of the yarn around the inner wall of the navel creates an additional false twist on the yarn between the rotor groove and the yarn draw-off tube [2]. In addition to causing tension breaks, higher rotor speeds increase the false twist effect, and when smooth navels are used in this condition, over-twisting and yarn ruptures can occur. There is an optimum depth of roughness for a particular fibre and yarn type.

Navels differ in their materials, forms, number of grooves, existence of fluted inserts, lengths of ceramic parts and grooves [3]. Smooth navels often give better yarn characteristics: the yarn is more resistant to rubbing and has good heat conductivity and generally less false twist. A higher ends-down rate must be expected. Grooved navels can operate at lower twist levels. The running performance is better because of the greater false-twist effect; but the hairiness does increase. Ceramic navels with 4-6 grooves have proved advantageous in the spinning of blended yarns and fibres that are not strongly sensitive to heat [4].

The main purpose of the opening roller is to open the fibre sliver to individually aligned single fibres. The efficiency of the opening fibre on the roller surface depends on the total opening force affecting the fibres, caused by the opening roller tooth. Well straightened, aligned and parallelised fibres of the opened sliver are expected to build twisted rotor yarn bodies [5] efficiently. There are two kinds of opening rollers: the pin roller and saw-toothed roller. The saw-toothed roller can be made of garnet wire mounted or of a multiple leaf saw-toothed assembly. The specification and speed of the opening roller are important factors which influence combing effects [6]. It can be seen that along with an increase in opening roller speed, the degree of fibre separation improves. A pin roller is better than a saw-toothed roller, especially in low speed conditions. The contents of short fibre will increase when the speed of the saw-toothed roller increases; however, there is no change when the pin speed increases. Nevertheless, it needs an advanced manufacturing technique and is hard to make [7]. The parameters of the saw-toothed roller are the wire work angle, wire wedge angle, wire rear angle, the height of the tooth, the tooth depth and the tooth density. The main factors influencing combing effects are the wire work angle and tooth density. For spinning different materials, various types of saw-toothed roller must be used. Several choices exist for the opening roller wire. The wire most used in the industry is saw-tooth shaped and hardened with diamond and nickel. Depending on the fibre being used, the angle of the wire is selected to allow for the most effective combing and fibre removal. Several studies have been published on the effect of opening roller clothing in rotor spinning. The main findings relate to the angle of the tooth and point density required to obtain effective fibre separation with minimal fibre breakage. It was reported that there is a marked increase in twist efficiency with an increase in opening roller speed. The increase in twist efficiency is the result of a decrease in the percentage of sheath fibres. Greater fibre separation at higher opening roller speeds reduces the possibility of some fibres becoming wrapper simply because they happen to entangle with the fibres undergoing belt formation. The slightly increased number of twists at high opening roller speeds can be attributed to the high degree of fibre separation at high speeds. The teeth shape and number of teeth on the surface coating material are important features affecting the opening force and opening efficiency of a sliver on a rotor spinning unit. Increasing the opening roller speed raises fibre separation efficiency and maintains a better twist insertion rate [8].

Spun silk and cashmere are natural fibres that have a lot in common with other types, such as cotton, wool, linen and mohair. Silk is a luxury fibre known for its beautiful drape, handle and luster [9]. Cashmere is a very soft and luxurious fibre giving luster as well as visual charm to garments and carpeting [10]. The processing of this kind of fibre presents some difficulties when using the common practice of spinning. Rotor spinning is the one in which a short fibre length can be used because the coefficient of variation of fibres in cashmere raw material is quite good. The blending of these fibres is carried out to reduce the cost of the end product.

Multi-objective fuzzy optimal model

Making a decision implies that there are alternative choices to be considered, and in such a case we would like not only to identify as many of these alternatives as possible but to choose the one that best fits our goals, objectives, desires, values and so on. The alternatives offer different approaches to change the initial condition into the one desired. There are several tools for solving a decision problem. The selection of an appropriate tool is not an easy task and depends on the type of decision problem. Sometimes the simpler the method, the better, but complex decision problems may also require complex methods. After evaluations of the decision making tool selected, it can be applied to rank the alternatives or to choose a subset of the most promising ones. Those selected by the decision making tools applied must always be validated against the requirements and goals of the decision problem. Supposing that the properties of yarn quality were the set of objectives for evaluation, samples would then be created as a set of alternatives for the evaluation process, in which different methods such as borda count, pairwise and fuzzy are used [11].

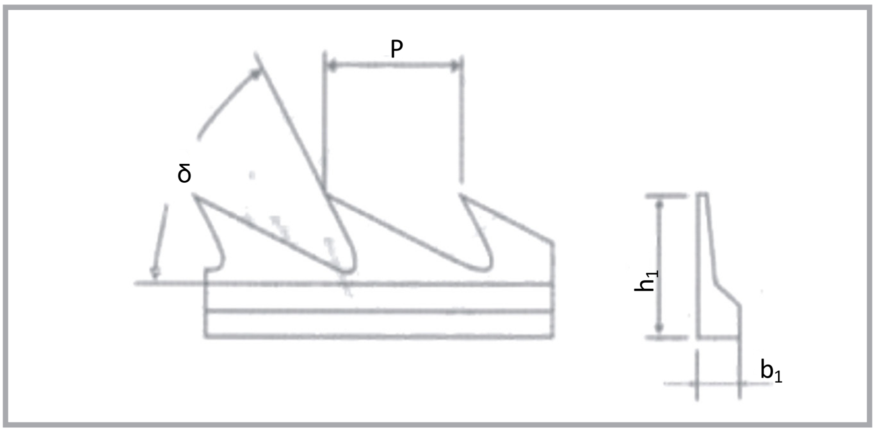

Figure 1. *Schematic of an opening roller.*

Table 1. *Parameters of different types and specification parameters for an opening roller.*

Types	Models	Specification parameters			
		h_1, mm	δ, deg	P, mm	b_1, mm
Saw-tooth Roll	OK40	3.60	65	2.62	0.90
	OK61	3.60	75	3.93	0.90
Pin roller	10°	8 head and 72 other straights			

Table 2. *Navel type and specification parameters.*

Types \ specifications	diameter, mm	curvature, mm	aperture, mm
4-grooved ceramic	15	10	2
Ray chrome-plated steel 45	22	10	2
Spiral grooved ceramic	15	10	2.4

Table 3. *Sample designs.*

Samples	Opening roller	Navel
1#	OK40 Saw tooth Roll	Spiral grooved ceramic
2#		Ray chrome-plated steel 45type
3#		4-grooved ceramic
4#	OK61 Saw-tooth Roll	spiral grooved ceramic
5#		Ray chrome-plated steel 45type
6#		4-grooved ceramic
7#	Pin roller	Spiral grooved ceramic
8#		Ray chrome-plated steel 45type
9#		4-grooved ceramic

Experimental research

Raw materials and machine processing parameters

Different samples were produced from spun silk/cashmere (blend ratio is 85/15) using three different opening rollers and navels. The sliver size was 3.6 ktex, the fibre length 15 - 20 mm, and the humidity of the sliver was 10%. The yarn count of the design was 36.4tex.

- Machine setting: rotor spinning machine type FA601A
- Yarn count: 36.4 tex (design)
- Blend ratio: 85/15 (Spun silk/Cashmere)
- Sliver size: 3.6 ktex
- Rotor diameter: φ 66 mm
- Rotor speed: 35,000 revolutions per meter (r.p.m) (design)
- Opening roller diameter: φ 65 mm
- Opening roller speed: 6,500 r.p.m (design)
- Twist factor: 450 (design)
- Draft ratio: 98.90
- Temperature in the laboratory: 20 °C.

Types and specifications of opening roller and navel

In this work, we produced nine different samples from a combination of three different types and specifications of opening roller and navel. ***Table 1*** shows different types and specifications of opening roller, and ***Figure 1*** presents a schematic an opening roller. Different types and specification of navel are presented in ***Table 2***. The sample designs of opening rollers and navels are shown in ***Table 3***.

Experimental design

All the samples were tested for the following: the Coefficient of Variation (CV) of the yarn count, the thinness, thickness, neps, hairiness, breaking tenacity, the CV of the tenacity, the breaking elongation, and CV of the elongation. The irregularity of the yarn count and yarn imperfections (thick, thin, neps) were measured using an Uster YG135G with a yarn speed of 400 m/min, the testing time of which was 1 minute. The degree of sensitivity of the thinness, thickness and neps were -50%, +50% and +280%, respectively. A YG172 hair tester was used to determine the hairiness with a testing speed of 30 m/min and test length of 100 m; only

Table 4. Test results for yarn quality properties.

Samples	CV of count, %	Thin (-50%) per km	Thick (+50%) per km	Neps (+200%) per km	Hairiness	Tenacity, cN	CV of tenacity, %	Elongation, %	CV of elongation, %
1#	15.34	2	92	268	119.60	359.0	13.42	8.4	9.30
2#	15.72	0	78	260	121.20	363.0	11.52	8.4	8.63
3#	15.66	12	132	512	252.30	319.2	11.61	6.7	14.22
4#	15.38	0	75	262	122.00	366.4	10.76	8.1	9.34
5#	14.79	8	90	308	103.00	343.1	15.25	8.5	10.30
6#	16.12	5	150	485	237.70	326.6	12.19	7.0	12.28
7#	14.42	8	60	272	111.40	367.4	11.27	8.0	8.06
8#	15.72	8	70	328	129.10	340.6	11.92	8.4	7.05
9#	16.36	5	140	485	206.40	319.2	11.53	7.1	10.28

hairs above 3mm per meter were measured. The breaking tenacity and elongation with their coefficient of variation were determined using the YG061 tensile tester with a test length of 500 mm and extension rate of 500 mm/min. ***Table 4*** shows test results for the properties of yarn quality .

Results and discussions

Table 4 shows test results for the properties of yarn quality for nine samples from a combination of different types of opening roller and navel. Choosing the best sample is a problem because, for example, the one which is the best for yarn breaking tenacity may be the worst for the CV of the yarn count. To solve the problem, different methods are used, such as the borda count method, and pairwise and fuzzy pattern classification analysis. The gradation of the nine yarn samples according to the Borda count method is as follows: 7#, 4#, 2#, 5#, 1#, 8#, 3#, 6#, 9#. Each sample gets a score from the yarn quality properties, and the one which has the highest score is the best choice. In this case sample 7# is the best choice. Meanwhile, according to the pairwise method, the gradation of all the yarn samples is as follows: 4#, 2#, 7#, 1#, 8#, 5#, 6#, 9#, 3#. The yarn quality properties rank all the samples in order of preference, and the samples are paired and compared with each of the other samples in turn. The one which obtains a majority of scores against any other sample as a pair is the best choice. According to this method, sample 4# is the best choice. The two gradations above are different, therefore the next step is to use fuzzy pattern classification analysis, which is shown in ***Table 5***. Yarn quality properties give a score of 1 for the best sample, otherwise the score is 0 according to the relative degree of membership (λ) for all the fuzzy system. The final score is achieved by summing the score of the sample over all the yarn quality properties. The one with the higher score is the best choice. In this work, a relative membership degree of $\lambda = 0.7275$ was selected, the result of which shows the gradation of four samples at the same level: 1#, 2#, 4#, 7#. Therefore, in order to test the performance of the four samples, the lowest twist index was calculated. Sample 7# showed the lowest twist index: $\alpha_{t\ min.} = 296.0$, i.e. 7# has the best spinning stability. Hence the combination of a pin type roller and spiral grooved ceramic navel (7#) is the best choice.

The short-fibre length of raw materials, low strength of fibres and high degree of parallel extension can explain why the combination of a pin roller and spiral grooved ceramic is better. Most of the wire used in the industry is 'saw-tooth' shaped, but, depending on the fibre being used, the angle of wire is selected to allow for the most effective opening and fibre removal. The type of pin roller for these fibres brought about some improvement in yarn strength. To provide different levels of friction on the yarn and maximum resistance to wear, most navels are made out of ceramic.

Table 5. Fuzzy pattern classification results.

	Samples								
λ=0.4875	1#,	2#,	3#,	4#,	5#,	6#,	7#,	8#,	9#
λ=0.7071	1#,	2#,	4#,	5#,	7#,	8#	3#,	6#,	9#
λ=0.7089	1#,	2#,	4#,	7#,	8#	3#,	6#,	9#	5#
λ=0.7275	1#,	2#,	4#,	7#	3#,	6#,	9#	5#	8#
λ=0.7422	1#,	2#,	4#	3#,	6#,	9#	5#	7#	8#
λ=0.8217	1#,	2#,	4#	3#	5#	6#,	9#	7#	8#
λ=0.8931	1#	2#,	4#	3#	5#	6#,	9#	7#	8#
λ=1.0000	1#	2#	3#	4#	5#	6#	7#	8#	9#

Conclusion

According to the study reported in this paper concerning the optimum selection of an opening roller and navel, sample (7#) is the best choice. The yarn quality properties from this sample present the best evenness and imperfection (thin, thick and neps) values, as well as the highest value for breaking tenacity. There are several methods and tool for solving a decision problem, the multi-objective fuzzy optimal model is the one of them. Several studies have reported that a pin roller is better than a saw-toothed roller, especially in low speed conditions; but it does need an advanced manufacturing technique and is hard to make it. Therefore, the results showed that the best choice for the opening roller and navel is a pin roller and spiral grooved ceramic (7#); however, the difference between this and the second choice, which was the 0k40 saw-toothed with Ray chrome-plated steel 45 type (2#), was not too big. The results put forward in this study are valid only for this particular case, and may be completely different for another type of yarn production process.

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Received 17.01.2009 Reviewed 26.01.2010