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Studies on Reduction of Yarn Hairiness by Nozzles in Ring Spinning and Winding by Airflow Simulation

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Abstract: Reduction of yarn hairiness by nozzles in ring spinning and winding is a new approach. Simulation of the airflow pattern inside the nozzles provides useful information about actual mechanism of hairiness reduction. The swirling air current inside the nozzles is capable of wrapping the protruding hairs around the yarn body, thereby reducing yarn hairiness. Since production rate of winding is very high and the process itself increases yarn hairiness any method to reduce the hairiness of yarns at this stage is a novel approach. A CFD (computational fluid dynamics) model has been developed to simulate the airflow pattern inside the nozzles using Fluent 6.1 software. In this study, both S- and Z-type nozzles having an axial angle of 50 ° and diameter of 2.2 mm were used for simulation studies. To create a swirling effect, four air holes of 0.4 mm diameter are made tangential to the inner walls of the nozzles. S- and Z-twisted yarns of 30 tex were spun with and without nozzles and were tested for hairiness, tensile and evenness properties. The total number of hairs equal to or exceeding 3 mm (i.e. the S3 values) for yarn spun with nozzle is nearly 49-51 % less than that of ring yarns in case of nozzle-ring spinning, and 15 % less in case of nozzle-winding, while both the yarn types show little difference in evenness and tensile properties. Upward airflow gives best results in terms of hairiness reduction for nozzle-ring and nozzle wound yarns compared to ring yarns. Yarn passing through the centre of the nozzle shows maximum reduction in S3 values.

Keywords: Hairiness, Nozzle-ring, Nozzle-winding, S3 values, Simulation

Introduction

Traditionally prior to weaving, either sizing in the short staple sector or two-folding in the long staple sector has been used to reduce yarn hairiness. Some new technologies, which have been developed to reduce hairiness of ring spun yarns, are Compact Spinning [1], using nozzle in ring spinning (nozzle-ring) [2,3] and nozzle in winding (nozzle-winding) [4,5]. Nozzle-ring spinning combines features of ring and air-jet spinning technology. The single nozzle placed below the yarn formation zone, acts in a way similar to the first nozzle in air-jet spinning. The swirling air current inside the nozzle is capable of wrapping the protruding hairs around the yarn body, thereby reducing yarn hairiness [2]. Airflow is the major factor in reducing yarn hairiness by nozzles and simulation of airflow is needed to understand the mechanism of hairiness reduction. However, there is a lack of published information on this aspect.

Since commercial winding machine operates at high speed, any method to reduce yarn hairiness at the winding stage will not only reduce the processing cost in the downstream processing of yarns but also helpful in producing fabrics of good appearance. Some works have been published to reduce the yarn hairiness in winding [4,5]. In these published works, spun yarn is first wound onto pirn, and then the yarn from it is subjected to the action of nozzle in a yarn winding machine. This extra winding process is not cost effective. Reducing of yarn hairiness at first winding stage i.e. spun yarn is directly subjected to the action of nozzle has not yet been reported. Linear direction of airflow (upward and downward) and nozzle positioning (eccentricity) also play a major role in reducing yarn hairiness.

Simulation of airflow pattern inside the nozzles provides an insight into the actual mechanism of hairiness reduction. A CFD (computational fluid dynamics) model has been developed to simulate the airflow pattern inside the nozzles using Fluent 6.1 software, to solve the three-dimensional flow field [6,7]. Literature on effect of yarn positioning inside the nozzle, especially eccentricity between the yarn and nozzle axes on the efficiency of hairiness reduction is not available. How accurately the yarn should be positioned inside the nozzle so as to obtain maximum hairiness reduction is of practical importance to industry. So it is necessary to investigate the effect of nozzle positioning while performing nozzle-ring and nozzle-winding operations. The main objectives of the work are as follows: simulation of airflow pattern inside the nozzles, influence of linear direction (upward and downward) of airflow, rotational direction (S- and Z-type) of air and eccentricity of yarn placement inside the nozzles.

Experimental

In this study, both S- and Z-type nozzles having air inlets with an axial angle of 50 ° and yarn channel diameter of 2.2 mm were placed between the front roller nip and lappet at distance of 10 cm from the front roller nip, on the ring frame Lakshmi LG-5/1. To create a swirling effect, four air holes of 0.4 mm diameter were made tangential to the inner walls

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of the nozzles. Both S- and Z-twisted 30 tex carded cotton yarns were produced with and without nozzles. The spinning process parameters are as follows: spindle speed 16000 rpm, traveller type and number EM1 UDR 2/0, tpi 19.6.

A frame to mount the nozzle housing was fabricated after studying the geometry of the ring frame for exact positioning of the nozzle without altering the yarn path. A small ceramic guide was fixed at the bottom of the frame to keep the yarn at the centre of the nozzle. Nozzle was placed in a way that front roller nip and axes of nozzle, yarn, lappet and ceramic guide lay in a straight line.

In winding, nozzle was placed at a distance of 10 cm above the balloon bracket of winding machine. A frame was fabricated to mount the nozzle housing and a small ceramic guide was fixed at the bottom of the frame to keep the yarn at the centre of nozzle and to control yarn ballooning during unwinding of yarn from the package. The yarns were wound on the Savio Orion-M automatic winder at a speed of 1000 m/min. Angular view of the nozzle is shown in Figure 1.

For nozzle-ring and nozzle-winding, air pressure in the nozzles was kept at 0.5 bar (gauge). Compressed air was supplied to the nozzle through pipes with a pressure-regulator and an air-filter. Two directions of airflow were studied: along and against the direction of yarn movement.

Various yarn positioning inside the nozzle viz. at centre and at other eccentric positions, LE, RE, BE and FE were studied and are indicated in Figure 2.

The hairiness of yarns was tested on a Zweigle G 566 hairiness tester. For each sample, 800 m length of yarn was tested for hairiness at a speed of 50 m/min. Statimat ME tensile tester was used to test the tensile properties of yarns using a gauge length of 500 mm and cross head speed of 200 mm/min. Thirty reading were taken for each sample. Evenness characteristics of yarns were tested on the Uster Evenness tester UT-1. A 1000 m length of yarn was tested at a speed of 200 m/min. The sensitivity settings used for thick, thin and neps were +50 %, −50 % and +200 % respectively. Yarn samples were kept in standard testing condition, for 24 hours prior to testing.

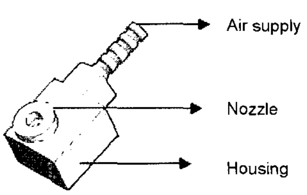

Figure 1. Angular view of the nozzle along with housing.

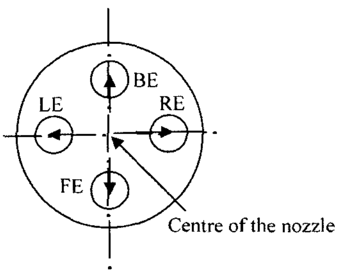

Figure 2. Eccentric positions of yarn inside the nozzle.

Simulation Method

In this study, the airflow inside the nozzles is simulated by using CFD (computational fluid dynamics) model. Fluid flow and related phenomena can be described by partial differentiation equations, which can't be solved analytically except in special cases. To obtain an approximate solution numerically, we have to use discretization method which approximates the differential equations by a system of algebraic equations, which can then be solved on a computer. The approximations are applied to small domains in space and/or time, so the numerical solution provides results at discrete locations in space and time. Much of the accuracy depends on the quality of the tools used, for which CFD is a powerful tool to predict the flow behavior of fluid inside any object. It gives various parameters like velocity profile, air particle path lines trajectory which are important information for further analysis. As the nozzle is the heart of process in reducing yarn hairiness, it is imperative to know about the behavior of air inside the nozzle in order to have insight on hairiness reduction. This is the main reason of using CFD package, Fluent 6.1, which uses finite volume method for airflow simulation than any other tool in order to have much accurate prediction of various airflow profiles. The airflow in the nozzles is turbulent and hence the standard k-ε model of turbulence along with standard wall functions is used. The simplest complete models of turbulence are two-equation models in which the solution of two separate transport equations allows the turbulent velocity and length scales to be independently determined. The standard k-ε model in Fluent falls within this class of turbulence model and has become the workhorse of practical engineering flow calculations. It is widely used for a range of turbulent flows in industrial flow and heat transfer simulations. It is a semi-empirical model, and the derivation of the model equations relies on phenomenological considerations and empiricism.

It has been assumed that the flow inside the nozzle chamber affects the yarn but the presence of yarn has no effect on the flow patterns and hence yarn is not modeled. High pressure and velocities of the air coupled with the considerably low volume of the yarn compared to that of the nozzles chamber justifies this assumption. In this present configuration, air inlet boundaries are assumed to be "Pressure Inlet" type while outflow boundaries are assumed "Pressure Outlet" type. Although the high velocity of air stream is a heat source that will increase the temperature in the nozzles, the nozzles are very short and the process occurs in a very short time. For simplification, we assume that the process is adiabatic i.e. with no heat transfer through walls. The flow model used was viscous, compressible airflow.

The following series of equations [6,7] were used to solve a compressible turbulent flow for airflow simulation;

Mass conversion equation:

$$\frac{\partial\rho}{\partial t} + \frac{\partial\rho u_i}{\partial x_i} = 0$$

Momentum conversion equation:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_l}{\partial x_l}\right)\right] + \frac{\partial}{\partial x_j}(-\rho\overline{u_i' u_j'})$$

Turbulent kinetic equation:

$$\frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G - \rho\varepsilon$$

Rate of dissipation of the turbulent kinetic energy:

$$\frac{\partial(\rho\varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right] + c_1\frac{\varepsilon}{k}G - c_2\rho\frac{\varepsilon^2}{k}$$

The nomenclature used is given below:
ρ: density of air, t: time, u: velocity of air, p: static pressure, u_i: fluctuation in u in x-direction, G: rate of generation of turbulent kinetic energy, k: turbulent kinetic energy, μ_t: turbulent viscosity, ε: rate of dissipation of turbulent kinetic energy, c_1, c_2, σ_k, σ_ε, c_μ: constants of the k-ε model

The structure of flow inside the chamber depends on the following factors: angle at which air enters in the chamber and pressure of the air at entry to the yarn chamber. The configurations studied in Fluent 6.1 are as follows: the diameter of air entry orifices is 0.4 mm, the diameter of yarn channel is 2.2 mm. Air enters at an angle of 50 ° to the yarn channel.

Results and Discussion

Influence of Airflow Direction in Nozzle-ring and Nozzle-winding

Table 1 shows the hairiness values of ring (C) and nozzle-ring (NRZ and NRS) yarns processed with upward (U) and downward (D) airflow directions. The hairiness of nozzle-ring yarns processed with upward airflow is the lowest. There is significant reduction in the S3 values in the order of 49-51 % for upward airflow compared to the ring spun yarns.

Mechanism of Hairiness Reduction

Figure 3 shows the path lines of air, released from air inlet holes of Z-nozzle rotating in anti-clockwise direction when viewed from top. Air path lines for S-nozzle are observed to be in clockwise direction. Resultant air velocity is resolved into three components viz. axial, tangential and radial. This swirling action of air is created by the tangential and axial velocity component of air velocity. There are four air holes of 0.4 mm diameter, which lie on the same horizontal plane. Absence of staggering in the location of air entry holes helps to generate swirling flow.

Divergent portion in the upper section of the nozzle also assists in swirling. We cut the nozzle into four sections in the upper half i.e. where swirling of air takes place (Figure 4). In the Z-nozzle, main body of the yarn passes through the center of the nozzle; where as protruding fibres on yarn surface are near the inner-wall of the nozzle. Average resultant air velocity found in the Z-nozzle is 9000 m/min (Figure 4), which is much higher than yarn speed, 20 m/min, incase of ring spinning and 1000 m/min in winding. From Figure 3, it

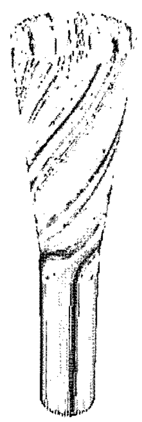

Figure 3. Typical path lines of air in Z-nozzle.

Table 1. Hairiness values of ring and nozzle-ring spun yarns

			Number of hairs/800 m length of yarn							
Sample code*	Twist direction	Airflow direction**	N1	N2	N3	N4	N6	N8	N10	S3
C	Z		23043	2265	668	316	68	7	1	1060
NRZ	Z	U	18186	1496	353	125	36	1	0	515
NRZ	Z	D	27460	3171	1222	753	235	10	0	2220
C	S		23410	2163	690	309	69	9	0	1077
NRS	S	U	18342	1531	365	136	39	0	0	540
NRS	S	D	27312	3056	1324	641	185	0	0	2150

*C: as spun yarn, NRZ: nozzle-ring yarns spun with Z-nozzle, NRS: nozzle-ring yarns spun with Z-nozzle, **U: upward, D: downward.

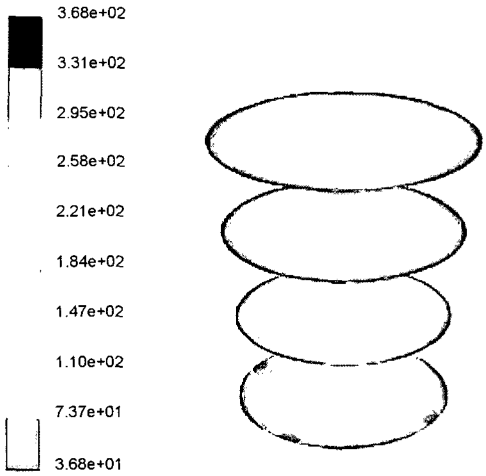

Figure 4. Contours of resultant velocity (m/s).

is observed that the airflow inside the Z-nozzle is swirling in the Z-direction. Due to the action of this vortex, yarn body with Z-twist when it enters the nozzle is untwisted in the case of nozzle-ring spinning and twisted in the case of nozzle winding. Because of the false twisting action, original twist in the yarn is restored. This process leads to the wrapping of protruding hairs, around the yarn body, thereby reducing yarn hairiness.

There is reduction in hairs in all hair-length groups with the upward airflow. This magnitude of reduction in hairiness is most likely due to the wrapping of the surface fibres by the swirling air current in the air nozzle. Reduction in N1 and N2 hairs is lower compared to S3 hairs. It can be ascribed to the fact the wrapping of longer hairs may readily cover up the short ones and reduce the number of short hairs [2].

Nozzle-ring spinning with downward airflow is ineffective in reducing yarn hairiness (Table 1) and this may be due to the fact that, the majority of the protruding fibres on yarn surface are trailing ends [8,9], it is logical to believe that the reduction in yarn hairiness may be more efficient when the air vortex induces an axial airflow in a direction opposite that of yarn traverse, and meets a majority of trailing fibre ends that are pushed against the yarn body more easily than the leading ends [3]. The downward airflow can cause these majority trailing fibre-ends to protrude more. Therefore, airflow issued from the nozzle placed at ring frame in the direction of yarn movement may promote, rather than suppress, protruding fibre ends [2]. This can be seen from Table 1, that the number of hairs in all length groups for nozzle-ring spun yarn processed with downward airflow is appreciably more than the number of corresponding hairs in ring spun yarns.

In winding of yarns with nozzles (NWZ and NWS), when the direction of airflow is upward (U-along the yarn movement), the number of hairs of all length groups are lower compared to as spun ring yarns (C) as shown in Table 2. This trend is observed for wound yarns processed with both Z- and S-nozzles. This can be attributed due to the fact that, during unwinding from the ring-cop, the directions of hairs are reversed i.e. majority of hairs are in leading direction and some hairs are in the trailing direction. It is difficult to fold the majority leading hairs, when air current issued from the nozzle is opposite to the direction of air drag due to the moverment of yarn at 1000 m/min, as the later tends to raise up these hairs. As a consequence of this the efficiency of pushing down and wrapping the majority hairs is lost considerably when the airflow is opposite (D-downward) to direction of yarn movement. Hence, downward airflow increases yarn hairiness.

A significant hairiness reduction of 15 % is observed in S3 values for yarns wound with nozzle using upward airflow from the values of as spun yarns. This reduction is less than the hairiness reduction observed for nozzle-ring yarns, 49-51 % from the values for ring yarns. Higher reduction in S3 values for nozzle-ring yarns compared to nozzle wound yarns is due to the fact that majority of hairs face in the trailing direction in the former case.

Eccentricity of Nozzles in Nozzle-ring and Nozzle-winding

The effect of yarn positions inside the nozzle during nozzle-ring and nozzle-winding is given in Table 3. When the yarn passes through the centre of the nozzle in case of nozzle-ring and nozzle-winding, there is reduction in number of hairs of

Table 2. Hairiness values of ring and nozzle wound yarns during first winding

			Number of hairs/800 m length of yarn							
Sample code*	Twist direction	Airflow direction**	N1	N2	N3	N4	N6	N8	N10	S3
C	Z		23187	2351	650	329	61	7	1	1048
NWZ	Z	U	22263	2205	563	270	50	2	0	885
NWZ	Z	D	24710	2482	771	421	108	1	0	1301
C	S		23140	2363	690	309	69	9	0	1077
NWS	S	U	21995	2235	599	256	53	2	0	910
NWS	S	D	23347	2341	725	413	84	7	0	1229

*C: as spun yarn, NWZ: 1st winding with Z-nozzle, NWS: 1st winding with S-nozzle, **U: upward, D: downward.

Table 3. Hairiness values of yarns in nozzle-ring and nozzle-winding eccentric series

	Number of hairs/800 m length of yarn							
Sample code	N1	N2	N3	N4	N6	N8	N10	S3
Spun yarn	23043	2265	668	316	68	7	1	1060
Centre N-R*	18186	1496	353	125	36	1	0	515
Centre N-W**	22263	2205	563	270	50	2	0	885
LE N-R+	24195	2486	774	341	81	1	0	1197
LE N-W	25434	2628	910	429	110	2	0	1451
RE N-R	23503	2378	768	372	72	1	0	1213
RE N-W	26725	2675	870	425	98	1	0	1394
FE N-R	23724	2419	728	347	77	1	0	1153
FE N-W	26579	2379	893	453	117	0	0	1463
BE N-R	24425	2332	708	331	86	1	0	1126
BE N-W	26894	2821	928	459	125	0	0	1512

*N-R: nozzle-ring, **N-W: nozzle-winding, +LE: left eccentricity of 1 mm, RE: right eccentricity of 1 mm, FE: forward eccentricity of 1 mm, BE: backward eccentricity of 1 mm.

entire hair length groups. The reason might be that yarn is stable at the centre of the nozzle. When the yarn is placed inside the nozzle away from the nozzle axis at positions LE, RE, BE and FE i.e. yarn is placed eccentric, yarn hairiness increases. This can be ascribed to the fact that, when the yarn is eccentric in the nozzle, it is rubbing with the wall of the nozzle, thereby raising the hairs from the yarn body. Also from Figure 4, when the yarn is at the wall of the nozzle instead of centre, resultant air velocity is very high enough (avg. resultant velocity 15000 m/min) to throw the yarn from one wall to other. Yarn remains unstable in eccentric condition, thereby increasing hairiness.

Comparison of Nozzle-ring and Nozzle Wound Yarns with Ring Yarns

The tenacity of nozzle-ring (NRZ and NRS) and nozzle wound (NWZ and NWS) yarns is slightly better than ring yarns (C) (Table 4 and 5) which is not statistically significant. The slight improvement in tenacity is may be due to the tight wrapping of the surface fibres around the yarn body, increasing the transverse force acting on the yarn core and increasing the frictional contact between the fibres, which ultimately increases the yarn strength. There is also not much change in the value of the breaking elongation of nozzle-ring and nozzle wound yarns in comparison to that of ring yarns.

Yarn unevenness characteristics are shown in Table 4 and 5. There is a slight increase in the unevenness of nozzle-ring and nozzle wound yarns in comparison with the ring yarns, but the difference is not significant. The overall change in yarn evenness is probably due to the concentration of the mass in a very short length brought about by the swirling action of air [3]

Table 4. Tensile and unevenness properties of ring yarns in comparison to nozzle-ring yarns in upward airflow

Sample code	Twist direction	Tenacity, cN/tex	Elongation, %	Thin places	Thick places	Neps	U %	Imperfection/ km
				−50 %	+50 %	+200 %		
C	Z	17.40	5.79	20	149	152	12.25	321
NRZ	Z	17.56	5.82	22	151	154	12.30	327
C	S	17.45	5.81	22	147	149	12.24	318
NRS	S	17.59	5.86	24	148	151	12.31	323

Table 5. Tensile and unevenness properties of ring yarns in comparison to nozzle wound yarns in upward airflow

Sample code	Twist direction	Tenacity, cN/tex	Elongation, %	Thin places	Thick places	Neps	U %	Imperfection/ km
				−50 %	+50 %	+200 %		
C	Z	17.50	5.95	21	146	149	12.29	316
NWZ	Z	17.60	6.13	22	149	153	12.33	324
C	S	17.45	5.81	22	147	150	12.27	319
NWS	S	17.55	6.11	23	149	153	12.31	325

Conclusions

CFD (computational fluid dynamics) analysis of airflow pattern gives an insight into mechanism of hairiness reduction. Hairiness can be reduced using nozzle-ring spinning and nozzle-winding operations with nozzles placed such a way to create upward airflow. A significant hairiness reduction of 49-51 % for S3 values in nozzle-ring and 15 % in nozzle-winding is observed from the values for ring yarns. Axial direction of air currents inside the nozzle in combination with the direction of majority hairs plays an important role in the efficiency of hairiness reduction of yarns. Yarn passing through the centre of the nozzle gives best result in terms of hairiness reduction. Nozzle-ring and nozzle wound yarns have slightly better tensile strength compared to ring yarns. Unevenness of nozzle-ring and nozzle wound yarns is slightly higher than that of the ring yarns. There are no significant differences between regular yarns and yarns processed through nozzles in terms of tensile and unevenness characteristics.

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