Effects of groove type on airflow speed and pressure during rotor spinning process

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Abstract. Groove type is critical to the compactness of fibrous ring in groove and cohesion between fibers. The effect of groove type to high speed airflow during rotor spun yarn spinning process was investigated. Airflow speed and static pressure of G, T, U and S grooves of the 36 mm diameter rotor were studied by Fluent Software respectively. The results showed that under the same conditions, speeds in four slotted size were G>T>U>S within the range from 0º to 360º in groove. At 0º and 360º positions, the static pressures were G>S>U>T. While for the rest of angle position, the static pressures were S>U>T>G. Taking T slot as example, static pressures of the rotors were between -7330.80 Pa and -13719.63 Pa. High speed airflows were divided into two streams as soon as they enter into the inner wall of rotor (0º point), one clockwise and one reverse direction, which joined together at point of 180º. This phenomenon gives light to understand fiber strands stretch and twisting as yarn in rotor which can be used to optimize spinning parameters during spinning and design new rotor type.

Keywords: groove, numerical simulation, airflow field, speed, pressure.

1. Introduction

Rotor spinning is well known for its high output with wide raw materials [1-3]. During rotor spinning process, under the action of the centrifugal force of rotor rotation and fibers slip into the groove after they enter the slipped wall of the rotor by the high negative pressure, then the fibers gathered and twisted to form rotor spun yarn [4].

Coruh et al. studied the effect of the nozzle type as one of the most important parts of the open-end rotor spinning system on yarn quality and found that the nozzle type mostly affects yarn quality and yarn tenacity [5]. Roudbari et al. investigated effect of an increase in opening roller width on yarn quality including tenacity, strain at peak, work of rupture, evenness, imperfections, hairiness and fibre
extent within the yarn structure and reported that an increase in fibre opening in lower level improves yarn quality [6]. Esfahani et al. investigated the influence of the navel and rotor type on the tenacity, elongation at break, mass irregularity, total number of imperfections, hairiness, and twist difference values of viscose rotor spun yarns, and found that samples showed a lower value of twist difference produced by a G-type rotor than a T-type rotor [7]. Groove type is critical to the compactness of fibrous ring in groove and cohesion between fibers [8]. There are mainly G, T, U and S types of groove.

In this paper, effects of groove types on airflow speed and pressure during rotor spinning process will be discussed by simulation rotor spinning process through a 3D model with ANSYS software which may favor the fiber strands stretch and twisting as yarn.

2. Models and experiments

The airflow during rotor spinning process obey mass conservation and momentum conservation in view of fluid mechanics [9-12].

Mass conservation equation

$$\frac{\partial}{\partial x_k} \left( \rho u_k \right) = 0$$  \hspace{1cm} (1)

Where $u_k$ is the air velocity of $x_k$ direction, and $\rho$ is air density.

Momentum conservation equation

$$\frac{\partial \rho u_k}{\partial x_k} = -\frac{\partial p}{\partial x_k} + \frac{1}{Re} \frac{\partial \tau_{ij}}{\partial x_j}$$  \hspace{1cm} (2)

Where $\rho$ is air density, $u_k$ is the air velocity of $x_k$ direction, $p$ is air pressure, $Re$ is Reynolds number, and $\tau_{ij}$ is tensor of Newton fluid viscous stress.

$$\tau_{ij} = \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \frac{2}{3} \mu \frac{\partial u_k}{\partial x_k} \delta_{ij}$$  \hspace{1cm} (3)

Where $\mu$ is coefficient of dynamic viscosity, and $\delta_{ij}$ is the function of Komecker delta.

Standard k-\( \varepsilon \) turbulent model is applied to simulate the motion of air flow in rotor.

$$\frac{\partial \rho k}{\partial t} + \frac{\partial (\rho u_i k)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \frac{\mu + \mu_t}{\sigma_t} \frac{\partial k}{\partial x_j} \right] + G_k + C_{\mu} \varepsilon - \rho \varepsilon Y_k + S_k$$  \hspace{1cm} (4)

$$\frac{\partial \rho \varepsilon}{\partial t} + \frac{\partial (\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \frac{\mu + \mu_t}{\sigma_t} \frac{\partial \varepsilon}{\partial x_j} \right] + C_{\mu} \varepsilon - \frac{C_{\mu} \varepsilon^2}{k} + S_k$$  \hspace{1cm} (5)
Where $G_k$ is the item caused by turbulent kinetic energy $k$ which is generated by the average velocity gradient, $G_b$ is the item caused by turbulent kinetic energy $b$ which is generated by buoyancy, $Y_M$ is on the behalf of pulsation expansion in the compressible turbulent flow, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ are experimental constants, $\sigma_k$ and $\sigma_\varepsilon$ are Prandtl numblers according to turbulent energy $k$ and dissipative energy $\varepsilon$ separately, $S_k$ and $S_\varepsilon$ are source terms defined by users.

According to the recommended value by Launder et al. [13] and experimental verification, in this paper, model constants are determined as $C_{1\varepsilon}=1.42$, $C_{2\varepsilon}=1.68$, $C_{3\varepsilon}=0.09$, $\sigma_k=1.0$, $\sigma_\varepsilon=1.3$.

It’s supposed that the airflow speed of inlet is 0.0054 m$^3$/s and the pressure of outlet is -8000Pa according to experiments while rotor wall is set as rotational moving wall with the speed of 120000r/min (Diameter 36 mm with G, T, U and S respectively). Angles of groove slot are 35°, 45°, 80° and 85° for G, T, U and S respectively. SIMPLE algorithm (Semi-Implicit Method for Pressure-Linked Equations) is used to solve the pressure and velocity coupled. Standard k-turbulent model is applied as the method of turbulent numerical simulation. As the development of turbulences is not sufficient, wall function method is used here. No slip boundary conditions are used in the wall. Geometric model of spin box was shown by Figure 1.

Rotor spinning process was recorded by olympus i-speed3 in RF30C. Spinning unit is modified by clear plastic.

![Figure 1. Geometric model of rotor spinning unit.](image-url)

### 3. Results and discussion

Angle orders of four grooves type are G<T<U<S (35°, 45°, 80° and 85° respectively). Figure 2-3 demonstrate that airflow speed orders are (S) $S_G>S_T>S_U>S_S$, pressure (P) $P_G<P_T<P_U<P_S$, hence the absolute value of negative pressure, $P_G>P_T>P_U>P_S$. It can be concluded that for grooves with small angle, airflow speeds achieve higher value and negative pressure are stronger. As experiments [4] demonstrated that yarns showed better quality when produced by rotors small angle grooves, it can be said that higher airflow speed and stronger negative pressure can improve yarn quality.

On the other side, short fibers are easier to combine and twist in groove with larger angle which is essential to yarn forming. For fibers which are soft and long, such as cotton, polyester, viscose yarns
can be produced by G and T groove rotors which have smaller angles, while for fibers which are short and have high flexural rigidity which have larger angles, such as hemp, tough silk and wool, yarns can be produced by U and S groove rotors as experiments [4] have shown. And also thinner yarn can be produced by G and T which contains fewer fibers in cross section, while thicker yarn can be produced by U and S which contains more fibers in cross section.

The cross point of groove and the extension of fiber transport channel is set as 0° (also as 360°), following clockwise. High speed airflows were divided into two streams as soon as they enter into the inner wall of rotor (0° point), one clockwise and another reverse direction, which joined together at point of 180°, as demonstrated by Figure 3.

![Figure 2. Static pressure (Pa) distribution of groove wall (a) G (b) T (c) U (d) S.](image)

During rotor spinning process, the fibers enter the incline wall which is called the slipped wall inside the rotor and are circulated and piled up into rings like laminated layers, called ‘fibrous ring’ or ‘yarn ring tail’, which exerts a big doubling effect. When the piecing yarn enters the rotor, it will be
thrown into the collecting groove and joined with the ‘fibrous ring’. Then the delivery rollers deliver the yarn out and at the same time the rotor rotation twists the yarn tail. Twists were delivered from yarn tail to fibrous ring as figured out by Figure 4-5 from 90° to 0°. Compared with the reverse direction, speeds of clockwise airflow are faster and pressures are stronger, which can help fiber strands stretching and twisting as yarn which also be clarified by Figure 3.
Figure 3. Airflow speed (m$^3$/s) of groove wall (a) G (b) T (c) U (d) S.

Figure 4. Twisting process of rotor spun yarn.
4. Conclusion
Airflow characteristics in rotors with G, T, U and S grooves of the 36 mm diameter during rotor spinning process were simulated and analyzed respectively. There are mainly two interesting and useful points. First, airflow speed (S) shows the order of $S_G > S_T > S_U > S_S$, pressure (P) $P_G < P_T < P_U < P_S$ (hence the absolute value of negative pressure, $P_G > P_T > P_U > P_S$). It can be concluded that, airflow speeds achieve higher value and negative pressures are stronger in grooves with small angle, which can enhance yarn quality especially thinner yarn. On the other side, short and rigid fibers are easier to combine and twist to form yarn in groove of larger angle. Second, high speed airflow were divided into two streams as soon as they enter into the inner wall of rotor (0° point), one clockwise and another reverse direction, which joined together at point of 180°. This phenomenon gives light to understand fiber strands stretch and twisting as yarn in rotor which can be used to optimize spinning parameters during spinning and design new rotor type.

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