Numerical analysis of flows in main nozzle with convex point in local needle and acceleration tube

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Abstract. When the thin weft yarn through the slightness acceleration tube, the weft may drift in the cavity due to the turbulence flow in the main nozzle. In order to analyse the turbulence influence during weft insertion, a kind of new main nozzle is designed by adding convex point in local needle and inside the acceleration tube. This paper focus on a numerical analysis of transonic/supersonic flows in the new main nozzle with a three-dimensional model. A compressible Reynolds Average Navier-Strokes method is used. The pressure and velocity along the center line of the main nozzle are obtained by changing the air tank pressures and number of air diversion groove.

1. Introduction
An air-jet loom inserts the weft into the shed by using the high pressure thrust force and skin friction force along the yarn. The main nozzle is a key part of an air-jet room, which is composed of body, needle, conical sleeve and acceleration tube. Currently, the aperture of acceleration tube of main nozzle is the same size in principle. The different fabrics required in the weft insertion system, the weft yarn is divided into coarse and thin weft yarn normally. If the inner diameter of the tube is too small, the coarse weft yarn is difficult to pass through the tube. However, the diameter of tube is too large, the weft yarn will drift along the axis of tube with the turbulence flow in the main nozzle.

Air flow inside the air-jet loom main nozzle shows subsonic, transonic and supersonic flow. There are some difficulties to measure the flow inside nozzle throat region by experiment because of its small cross-sectional area and composite shape. However, most important flow phenomena, such as shock waves and flow separations occur inside this nozzle throat area. Hence, a simulation approach may be necessary.

Fundamental research in flow field of main nozzle is especially necessary to design optimum shapes of the main nozzles. Mohamed and Salama [1-2] studied the effects of diameter and length of acceleration tubes on flow velocity. Okajima [3] measured velocity and pressure weft insertion channel with notched and un-notched cylindrical tube. Oh et al. [4] studied transonic flow in the main nozzle of an air-jet loom. The effects of air tank pressure, acceleration tube length and nozzle shape are investigated. sang et al. [5] studied unsteady intermittent flows in main nozzle. The pressure and Mach number behaviors along the center line of the main nozzle were presented by changing the inlet condition. Song and Shen [6] established a synthetic flow field model to compute the flow field of the air-jet loom. Liu et al. [7] analyzed the distribution of airflow velocity and static pressure along axial and radial direction in normal ZA type nozzle. Feng et al. [8] studied the internal flow fields of a new kind of main
nozzle composed of two nozzle needles connected in series. In this paper, the velocity distribution of
the airflow along the axial direction is obtained and the drag force on the weft yarn is calculated. The
simulation results show that the drag force can be improved. In this study the compressible Navier-
Stokes equations are solved to study turbulence flows inside a new type of main nozzle. We also analyze
the effect of air diversion groove on the flow field.

2. Structure and flow field model of main nozzle
The structure of a new type of main nozzle is composed of 4 parts, a nozzle body, a needle, a conical
sleeve and an acceleration tube. The difference between the new and normal nozzle is that the
acceleration tube and needle constructed a series of regular circular holes.

![Figure 1. The Schematic of new main nozzle](image)

![Figure 2. The Schematic of needle and acceleration tube](image)

Figure 1 shows the geometry configuration of main nozzle. The inner flow channel of the main nozzle
is divided into 3 parts, the compressed air acceleration channel, the weft ejection zone and the weft
acceleration zone. This paper used Solid works for geometry modeling based on the ZA type main
nozzle and adding the convex point inside the local needle and acceleration tube. As shown in Figure 2,
the axis along with the direction of the nozzle is \( x \) axis and nozzle needle entrance are the origin of the
\( xoy \) coordinate system. The main parameters of this new type of main nozzle structure model are shown
in Table 1.

| Parameter                     | Value(units) |
|-------------------------------|--------------|
| Length of acceleration tube   | 181mm        |
| Inter diameter of acceleration tube | 4mm  |
| Inter diameter of needle tip   | 6mm          |
| Inter diameter of weft inlet  | 8mm          |
| Inter diameter of air tank inlet | 10mm  |
| Throat area                   | 5.8mm\(^2\)  |
| Slot number                   | 4,6,8        |

Before the calculation, the 3D model will be meshed by professional software ICEM, because the
structure is symmetrical, only the 1/2 area can be reduced by half the number of grids, to reduce the time
iteration model. The number of meshes is about 800000, the average distortion of the grid is less than
0.9, the quality is better, and the meshes are well divided as shown in Figure 3. Then the boundary conditions are set up in the ICEM software. The boundary conditions include: pressure inlet, pressure outlet, pressure far-field, symmetrical surface and wall condition.

![Grid and boundary condition of main nozzle](image)

(a)The grid model of main nozzle needle (b)The boundary condition setting

**Figure 3.** Grid and boundary condition of main nozzle

3. **Numerical Analysis**

The outlet velocity of main nozzle of air-jet loom may 150~300m/s, and the air flow in main nozzle is turbulence flow. The motion control equations of compressible Newtonian fluid in Euler coordinates are as follows:

**Continuity equation:**

\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0
\]

(1)

The energy conservation equations:

\[
\frac{\partial (\rho T)}{\partial t} + \frac{\partial (\rho u_i T)}{\partial x_i} = \frac{\partial}{\partial x_i} \left( \lambda \frac{\partial T}{\partial x_i} \right) + S_T
\]

(2)

The Navier-Stokes equation

\[
\rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = -\frac{\partial p}{\partial x} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) + \rho g_x
\]

(3)

\[
\rho \left( \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) = -\frac{\partial p}{\partial y} + \mu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) + \rho g_y
\]

(4)

\[
\rho \left( \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) = -\frac{\partial p}{\partial z} + \mu \left( \frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) + \rho g_z
\]

(5)

The turbulence kinetic energy equation

\[
\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho u_i k)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[ \mu + \frac{\mu_t}{c_p} \right] \frac{\partial k}{\partial x_i} + G_k - \rho \varepsilon
\]

(6)

The rate of dissipation equation
\[
\frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho \varepsilon u_j)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \mu + \frac{\mu_t}{\varepsilon} \right] \frac{\partial k}{\partial x_j} + \rho C_f S \varepsilon - \rho C_2 \frac{\varepsilon^2}{k + C_\mu} \tag{7}
\]

where \( \mu_t = \rho C_f k^2 / \varepsilon \), \( \eta = S k / \varepsilon \), \( S = 2 \sqrt{S_0 S_y} \) and the parameter \( C_f \) are constant.

The numerical simulation is carried on Fluent. To implement the simulation, some assumptions are made as given below:

- The air is assumed as ideal gas.
- The air viscosity is \( \mu = \mu_0 (T / T_0)^{2/3} \).
- The out static pressure is atmosphere pressure.

This paper adopts RNG \( k - \varepsilon \) two equation models. The RNG \( k - \varepsilon \) model considers the turbulent vortex and provides an analytical formula for low Reynolds number viscous flow. The formulas can deal with the near wall region towards the correct.

4. Results and Discussion

Air supply pressure is a key parameter influence on the energy consumption and weft flight performance. Figure 4 shows the static pressure along the centerline under air supply pressure varies from 0.2Mpa, 0.3Mpa, 0.4Mpa and 0.5Mpa. The air diversion groove of needle is number 6. It is seen from Figure 4 that there is a negative pressure zone near axis position 50mm and the negative pressure value increases with the increase of gas supply pressure. Oh, and Kim5 had shown the pressure plot of normal main nozzle and the length of negative pressure zone is about 20mm. In this paper, we can see the length of negative pressure zone is 50mm. The extension of the negative pressure area can increase the external air flow into the main nozzle and increase the rates of weft insertion.

Figure 5 shows the airflow velocity along the nozzle center under air supply pressure varies from 0.2, 0.3, 0.4 and 0.5Mpa. As shown in Figure 5, the airflow velocity at the acceleration tube exit is raised with increasing air tank pressure. It is beneficial for the weft insertion. When the air supply pressure is increased over 0.5Mpa, the improvement of the airflow velocity outside the acceleration tube is not obvious.

Figure 6 plots the static pressures along centerline with various number of air groove. The air supply pressure is 0.2Mpa. The air diversion groove of the needle is divided into number 6, 8 and 10, respectively. As seen from Figure 6, all air pressures near the outlet of the needle are less than the
atmospheric pressure and form a negative pressure zone. Then, the weft yarn could be sucked into the acceleration tube.

![Figure 6. The static pressure along centerline at air supply pressure 0.2Mpa](image)

![Figure 7. Airflow velocity distribution along centerline at air supply pressure 0.5Mpa](image)

Figure 7 shows the air velocity along the centerline with various number of air groove. The air supply pressure is 0.5Mpa. It is seen from Figure 7 that the velocity is increase with the number of air diversion groove increasing. Hence, it is an effect way increasing the number of air diversion groove for improvement the rate of weft insertion.

Figure 8 shows the velocity contours and streamline of the symmetric surface from axis position 0.025m to 0.08m. The air supply pressure is 0.5Mpa. As can be seen from Figure 8 that there is obviously vertex flow at the end of the nozzle needle. Because the sharp change at the throat of needle. This vertex causes the velocity of the weft yarn fluctuation.

![Figure 8. Airflow velocity contours and streamline of needle with 8 air diversion groove at symmetry surfaces](image)

5. Conclusion
(1) Adding the convex point inside the needle and acceleration tube, the length of negative pressure zone is extended to 50mm more than the normal ZA type main nozzle. It helps increase the rates of weft insertion.

(2) It is an effect way increasing the number of air diversion groove to improve the rate of weft insertion.

(3) There is obvious vertex flow due to the sharp change at the outlet of the nozzle needle.
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