A COMPUTATIONAL APPROACH TO DESIGN THE GEOMETRY OF THE AIR-TWIST NOZZLE

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Air-twist 노즐 형상 설계의수치적 연구

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Spandex yarn requires a twisting process during winding and unwinding processes at the textile industry. The air-twist nozzle is widely used as part of the winding and unwinding. This paper describes computational approach to design the geometry of the air-twist nozzle. The nozzle has circular yarn-channel and the air-inlet which is perpendicularly connected to the yarn-channel with yarn-loading slit. The air-inlet of the nozzle is designed while measurements of the yarn-channel are fixed. The airflow inside the air-twist nozzle is simulated by using Computational Fluid Dynamic model. The Ansys CFX was used to perform steady simulations of the airflow for the air-twisting process. The vortical structure and the airflow pattern such as velocity streamline, vorticity, velocity of the air-twist nozzle are discussed. Computational results are compared with experimental results in this paper.

Key Words : Air-Twist Nozzle, Vorticity, Air-Inlet

1. INTRODUCTION

The purpose of this study was to design and produce the air-twist nozzle for winding and unwinding of spandex yarn. The geometry of the nozzle is similar as previous one [1]. The nozzle has the yarn-channel and the air-inlet with yarn-loading slit. The length and the diameter of the yarn-channel are fixed and the air-inlet of the air-twist nozzle is designed. Developed nozzle is used as set of the same nozzles in the industry. The twin air-jet nozzle system is designed and developed for ring spinning [2]. It shows the effect of different combinations of pressures of air administered inside both the nozzles on the yarn quality aspects such as tensile properties and hairiness. The twisting system of air-jet spinning was composed of two nozzles [3]. The influences of the nozzle parameters were investigated by analyzing computational and experimental results [4]. The air-twist nozzle is developed by customer's request. This paper presents a computational approach to simulate the air vortex in the air-twist nozzle and comparisons with experimental results. The studies of the air-twist nozzle focus on effects of the air-inlet shapes with the yarn-loading slit on the air-twisting process.

2. COMPUTATION METHODS AND CONDITIONS

The air-twist nozzle consists of the yarn-channel, a yarn-loading slit and air-inlet in the middle of the yarn channel. At the beginning of the air-twisting process, a bundle of filaments is open at the entry of the yarn channel. The filaments twist when they meet the compressed jet flow from the air-inlet, and this is a periodical process. The average number of twists per inch is determined by counting the number of twists in one meter of yarn. Computational fluid Dynamics (CFD)

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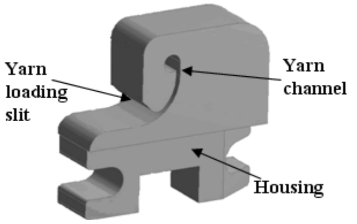


Fig. 1 Basic geometry of the air-twist nozzle

models have been developed to simulate the airflow pattern inside the air-twist nozzles. Ansys CFX 10.0 software solves the three-dimensional compressible flow by finite volume method [5]. The purpose of the research is to develop an air-twist nozzle geometry which has well-twisted motion with reasonable vorticity strength and velocity. The effects of the air-inlet shape are presented with the yarn-loading slit. The basic geometry of the air-twist nozzle is shown in Fig. 1.

The ANSYS Workbench provides the geometry and CFX-Pre is used for initial problem set-ups. CFX-Solver solves the high-speed, highly-separated flow problems, and CFX-Post displays computational planes, cutting planes, walls and vector quantities. Standard two-equation turbulence models often fail to predict the onset and the amount of flow separation under adverse pressure-gradient conditions. The k-ω based Shear Stress Transport (SST) gives highly accurate predictions of the onset and the amount of flow separation under adverse pressure gradients, by the inclusion of transport effects into the formulation of the eddy-viscosity. [6].

The computational domain of the air-twist nozzle is shown in Fig. 2. The yarn-channel shape is circular with 1mm diameter and 3.5 mm length. The air-inlet is rectangular shape of 2 mm x 0.25 mm at the connected part with the yarn-channel [1]. The yarn-loading slit size is same as the air-inlet. The width and length are selected as design parameters for computations. The air-inlet of the air-twist nozzle is chosen to design. The width and length change to develop well twisted airflow inside of the nozzle. The air-inlet shape is changed. It is divided into 2 and 3 small inlets for the special air-inlet design.

The computational grid is generated by tetrahedral unstructured grid. Dense grid distributions around the air-inlet provide a more accurate prediction of flow separation and vortices. The number of mesh elements is different for each case. It is based on face and body space, the minimum face space is 0.0001 mm while the maximum is 0.1mm. The boundary conditions are imposed as follows: “wall” for the nozzle body, “inlet” at the air-inlet of the nozzle, “outlets” at both ends of the yarn-channel and “opening” at the yarn-loading slit. All walls are treated as viscous adiabatic surfaces with a no-slip velocity condition. The working fluid is air. The inlet conditions are subsonic flow with 10kPa pressure, 15 C temperature and different inlet pressures for the selected geometry. The outlet boundary is modeled as subsonic flow, average static pressure with 0 Pa.

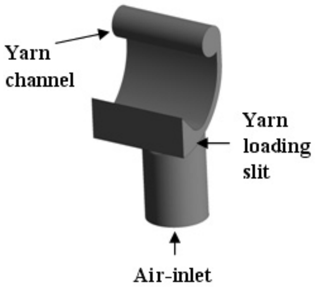
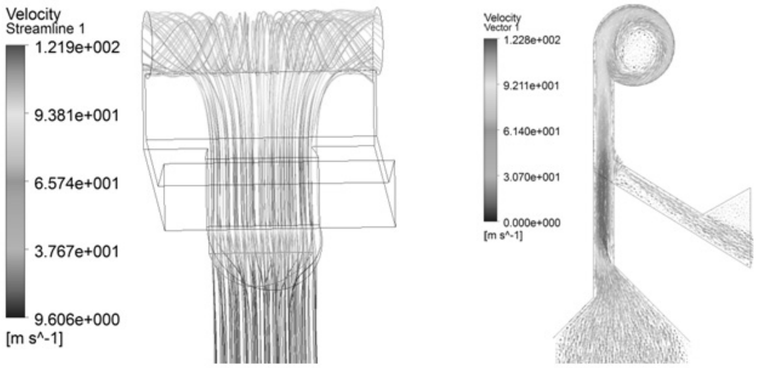


Fig. 2 Simulation domain

3. RESULTS AND DISCUSSION

The length and the width of the air-inlet are changed case by case according to computational results. The length and diameter of the yarn-channel are 3.5 mm and 1 mm. The length of the original case is 2 mm, and the width of the original case is 0.25 mm. The length is reduced from 2 mm to 1 mm and the width is reduced from 0.25 mm to 0.2 mm according to computational results. The results are compared such as twists, vorticity and velocity of flow characteristics. The yarn-loading slit is changed from case 3 as shown in Fig.3. The slit is connected smoothly to the air-inlet. The purpose of the simulations is to develop the air-twist nozzle geometry which has well-twisted motion with reasonable vorticity strength and velocity. The nozzle is designed in this research.

The first case (case 1) has original yarn-loading slit. The width and length of the air-inlet are 0.25 mm x 2 mm. The compressed-air twists around the air-inlet once and flows out through the ends of the yarn. The airflow at the ends of the yarn-channel flows out. In case 2, the length of the air-inlet is reduced to 1.7 mm, while the length is 0.25 mm. The compressed air forms twists at the center part of the yarn-channel and flows out at the ends of the yarn channel as shown in Fig.4. a). Mass flow rate is high and the air flows out through the ends



a) Velocity streamlines and vectors (cross section view, Case2)

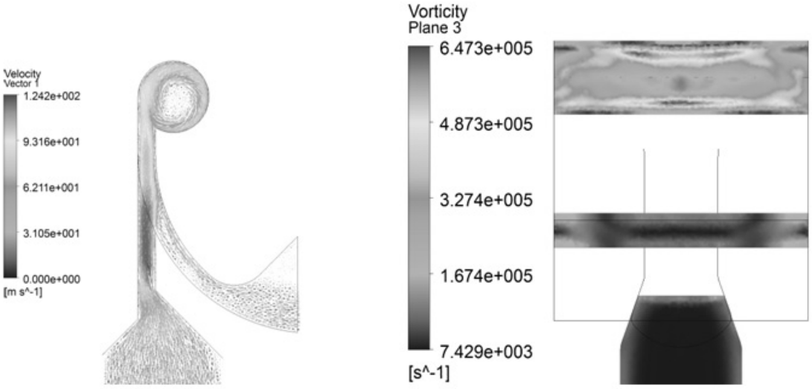


Fig. 3 b) Velocity vectors and vorticity (cross section and center view)

and the yarn-loading slit. Case 3: The width of the air-inlet is reduced to 0.23 mm as well as the yarn-loading slit. The length is 1.7mm. The yarn-loading shape is connected smoothly to the air-inlet. Velocity is relatively higher with changed yarn-loading slit. The twists are well-developed at the center part of the yarn channel. Results are similar with case 2. The compressed-air twists once and flows out. Vorticity is high at the center of the yarn channel and it is similar to case 2. The air-consumption is high but the twisted airflow is only at the center of the yarn-channel. Case 4: The length and width are decreased to 1 mm and 0.2 mm to make airflow twist well inside of the yarn-channel with low air-consumption. It improves velocity and vorticity as shown in Fig. 4. b). The twists are around the air-inlet juncture and the airflow twists again before flows out. The compressed air forms more twists along the yarn-channel. Case 4 gives desired results and the air-inlet size fits to the yarn-channel size with low air-consumption. The width and length of the air-inlet are 0.2 mm and 1 mm with smooth connected yarn-loading slit. The diameter and the length of the yarn-channel are 1 mm and 3.5 mm.

3.1 EFFECTS OF THE AIR-INLET SHAPES

The length and width of the air-inlet are 1 mm and 0.2 mm (case 4). The inlet shape is changed to obtain vorticity uniformity. The air-inlet of the air-twist nozzle is divided into 2 small air-inlets to have well twisted and uniform vorticity airflow along the yarn-channel. The width and length are 0.25 mm and 0.5 mm. The size of between two small air-inlets is 0.3 mm. Total length of the air-inlet is 1.0 mm. Computational results show vorticity differences at the air-inlets and sizes between air-inlets. Figure 4 presents the geometry of the air-inlet and vorticity contour plot. Vorticity is not uniform at the center as well as at the ends of the yarn-channel. There are short twists between the air-inlets which disturb the

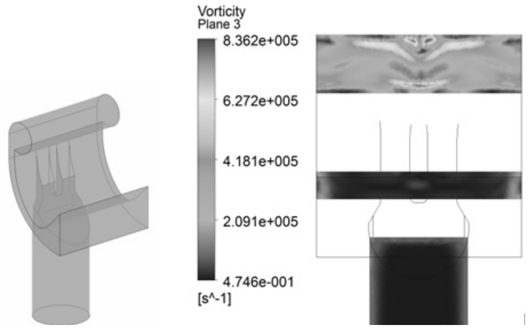


Fig. 4 Vorticity contour plot for 2 air-inlets

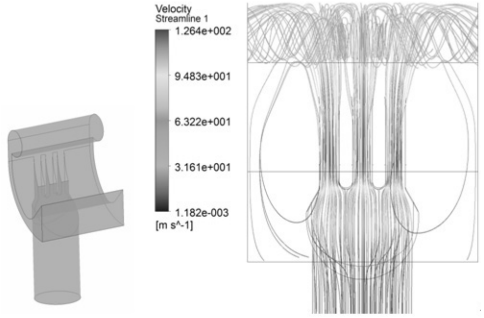


Fig. 5 Velocity streamline for 3 air-inlets

airflow to twist. Size of between air-inlets is decreased to 0.2 mm and air-inlet divided into 3 small inlets with 0.35 mm. Mass flow of the air-inlets is assumed same. There are small twisting airflows between small air-inlets. The velocity streamline with small twists are shown in Fig. 5. The vorticity has non-uniformity and velocity differences are high at the small air-inlets and between air-inlets.

The size of the air inlets are reduced to 0.1 mm. Vorticity has uniformity and velocity differences are not high. In this case, manufacturing of the air-inlets can has problems to make. The air-inlet has positive results when it is 1 mm and 0.2 mm in the length and width (case4). Case 4 has relatively uniform vorticity with 10kPa the inlet pressure while the temperature is 15 C. The vorticity is high at the center of the yarn channel, and it starts to decrease while the airflow passes the juncture of the air-inlet and the yarn channel.

3.2 EXPERIMENTAL RESULTS OF THE NOZZLE

The efficiency of the air-twist nozzle has direct influence on uniform tension at the unwinding process. Experiments for the three air-inlets and Case 4 are carried out. Case 4 satisfies twisting efficiency and the running line tension is better than in the air-twist nozzle with three air-inlets. These observations are supported by the computational results shown. Under the adjustable condition of lower air flux, the air-twist nozzle shows better performance in flux uniformity, twisting efficiency, and running tension. The measurements of the running line tensions of yarns are held by Digital Tension Meters device [8].

4. CONCLUSION

Different cases of the air-inlet of the air-twist nozzle were investigated. This air-twist nozzle was developed for the customer's request. The vorticity describes the rotational characteristics of the airflow of the air-twist nozzle. The air-inlet of air-twist nozzle was designed. The airflow forms the twists at the center of the yarn channel. The vorticity is high at the center of the yarn-channel and it decreases as the air flows out through the body of the yarn-channel. The vorticity is relatively uniform when the inlet pressures are low. The nozzle twists airflow well through the yarn-channel, with proper vorticity strength and velocity. Experimental and computational results show that Case 4 produces optimum results.

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