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New Designed Main Nozzle of Air-Jet Weaving Machine for Optimizing Air Consumption Using CFD Simulation

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ABSTRACT

The air-jet weaving machine is widely used in the textile industry and the main nozzle and acceleration tube is one of its key components of the machine. In this paper, the influence of some parameters, including the input air pressure with air inlet length and the structure of the nozzle core and its internal diameter, on the internal flow field of the main nozzle is analyzed to get the velocity of flow at the optimum air pressure that optimizing the air consumption. The flow field inside an air-jet loom main nozzle is studied by simulating the design of the main nozzle and acceleration tube, by means of a two-dimensional model implemented in the Ansys computational fluid dynamics (CFD) code Fluent, by designing the new main nozzle by working on the structural geometry of the main nozzle and acceleration tube. In order to determine the optimum air pressure for the required air velocity with optimum air consumption to flow weft yarn in an air-jet weaving machine.

1. Introduction

Air-jet weaving machines can weave almost all kinds of yarns without any problem at higher speeds compared to the projectile and rapier systems. This makes air-jet looms a very good alternative to other weft insertion systems. However, the air-jet weaving machine has a major limitation is high-power consumption due to the use of compressed air. Therefore, intensive efforts have been made by researchers and air-jet loom makers to overcome this problem and achieve a reduction in air consumption without any decrease in loom performance and fabric quality [1].

In an air-jet weaving machine, weft insertion is the core technology. The performance of the air-jet weaving machine is limited by the control of the weft insertion principle. The weft insertion system consists of three parts: main nozzle, relay nozzles, and profiled reeds. As the first part of accelerating the weft yarn, the main nozzle is crucial for enhancing the performance of the air-jet weaving machine [2-5].

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The textile industry is an energy-intensive industry. The increasing energy costs represent a challenge for textile manufacturers as well as for the developers of textile production machines. As an example, air-jet weaving is the most productive but also the most energy-consuming weaving method. In the air jet weaving process, the weft yarn is inserted into the shed with compressed air by using different types of nozzles.

Commercial CFD code "Fluent" was performed to simulate the flow field inside the main nozzle. A numerical simulation study of the flow field in the main nozzle was implemented using the k–e model. Velocity distributions and air drag force of commonly used main nozzle and new main nozzle were compared. Simulation results showed that the new main nozzle improves flow velocity. Optimizing some parameters of the nozzle of the loom tends to reduce air consumption which has been studied in the literature. Major air consumption in air-jet weaving machines is by the nozzles is about 80 % of air consumption, so the main focus is to be on nozzles to reduce air consumption [6,7].

Many studies have been done to understand the flow characteristics and optimize the geometry of the main nozzle. The unsteady and turbulent characteristics of airflow in the main nozzle were described by Adanur and Mohamed [1], which indicates that the airflow velocity during the weft insertion process is decided by the distance and the time after the air left the nozzle. For the experimental studies on air-jet looms, there are also several studies all over the world. The structure of the main nozzle was optimized by Mohamed and Salama [8]. Their results showed that the airflow velocity from the main nozzle increases with the decrease in yarn tube and the increase in the air pressure. Besides, the larger the diameter of the main nozzle, the smaller the airflow velocity is, Ishida and Okajima [9] measured the static pressure and the influence of supply pressure and discussed the acceleration tube length, and further calculated showed the air velocity distribution in the main nozzle as well as the influence of the initial pressure and the length of the main nozzle on that. Furthermore, they also made experiments on the axial and radial velocity components.

Using computational fluid dynamics (CFD) more work has been done in cooperating and simulation. Numerical analysis of flows in the main nozzle was conducted by Oh *et al.,* [10] who analyzed the effect of supply pressure, acceleration tube length, and circular arc radius on the flow field of the main nozzle using the Baldwin– Lomax algebraic turbulence model. A numerical simulation study of the flow field in the main nozzle was implemented by Kim *et al*., [11] using the k–e model. The flow field in the main nozzle which has an acceleration tube with a small divergent angle was investigated. Kim *et al.,* [12] did an unsteady flow analysis to simulate the intermittent flow inside the main nozzle.

In air-jet loom work is done in the main nozzle diameter and realy nozzle for optimizing air consumption. More work is required in the main nozzle design for obtaining the optimum air pressure and not much focus on air inlet flow path design of the main nozzle.

Earlier studies were confined to investigating the effect of supply pressure and acceleration tube parameters on flow characteristics in the main nozzle, and on the flow field of the main nozzle. In the present study, a new main nozzle structure with changes in the parameter of air inlet diameter and the addition of throat in the air inlet that designed to improve the airflow velocity which led to attaining low pressure and improving air injection.

1.1 Air-Jet Loom Main Nozzle

Figure 1 shows the typical structure of the main nozzle used for weft insertion. The device is mainly made up of four components: a body (1), a hollow needle (2), a cylinder (3), and an acceleration tube (4). Supply air flows from duct (5) to chamber (6); the polar array of holes (8), manufactured on one of the needle shoulders, acts as a local pneumatic resistance so that air pressure in the chamber (6) can be considered constant. As a consequence, the supply flow is redistributed inside the annular passage (7), thus generating an axis-symmetric flow. The annular passage, bounded by the cone-shaped needle external surface and the cylinder internal surface, is convergent with a minimum cross-sectional area at the needle tip (nozzle throat region). At this region, a strong flow expansion occurs: the accelerated flow sucks the weft yarn (9) through the hollow needle, pulls it by friction into the acceleration tube, and releases freely into the atmosphere, while the weft yarn flies into the warp [13,14].

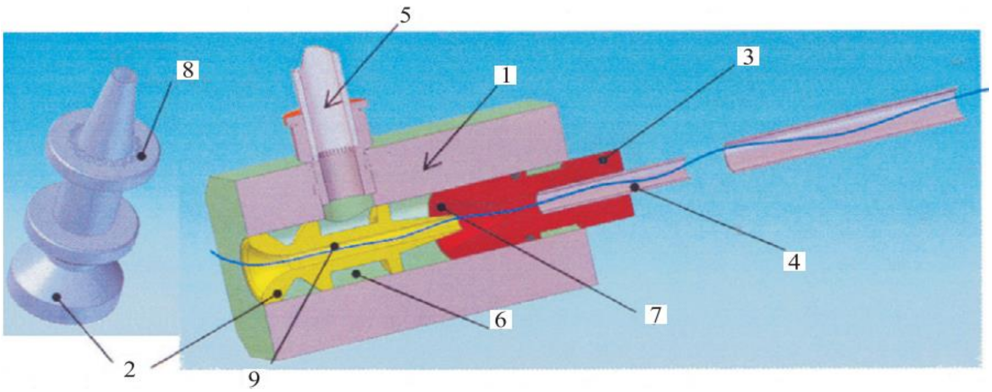

Fig. 1. Main Nozzle Structure

The main nozzle operation as an ejector is highly influenced by the relative position between the needle and the cylinder. In fact, lowering their distance results in a more intense suction effect; nevertheless, the device's pneumatic resistance is increased, so that, at constant supply pressure, the supply flow rate is reduced, together with the drag force on the yarn.

2. Methodology

2.1 Computational Fluid Dynamics Analysis of an Air-jet Loom

Main Nozzle the commercial finite-volume computational fluid dynamics (CFD) code Fluent was employed to determine numerically the main nozzle flow field and flow velocity exerted on weft yarn. Since the flow inside the main nozzle is mainly an axis-symmetric flow, a simplified two-dimensional model of nozzle A, rather than a three-dimensional model, was developed, in order to reduce the computational effort and cost in terms of CPU time and memory.

According to the mass flow-rate continuity equation, the mass flow rate from the supply duct must be equal to the mass flow rate through the annular duct. A constant mass flow rate, equal to that of common commercial nozzles, was set as the inlet boundary condition.

Figure 2 shows the flow domain as modelled. A cellulose property monofilament yarn with a diameter of 0.8 mm was considered; since the whip effect was neglected, it was placed at the nozzle axis. Major geometry parameters of the modelled nozzle are summarized [15,16].

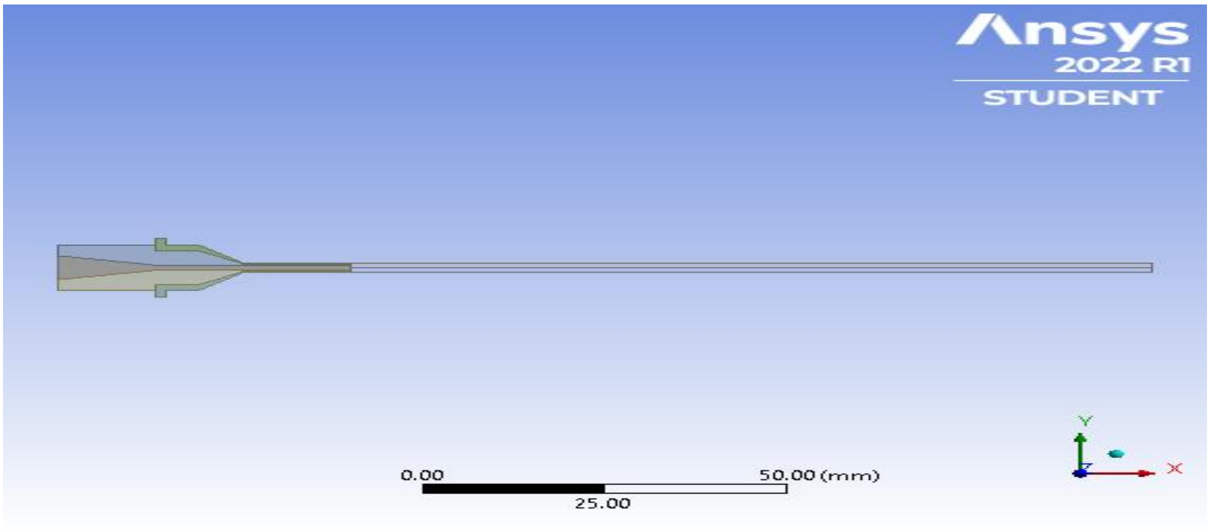

Fig. 2. Modelled Geometry of the Main Nozzle with acceleration tube

Table 1
Main Nozzle (N) dimensions without throat

Main Nozzle Diameter at the inlet	6 mm
Main Nozzle Diameter at exit	1.3 mm
Length of Nozzle	40 mm
Length of the acceleration tube	110 mm
Diameter of the acceleration tube	1.5 mm
Air inlet Diameter	4.5 mm

2.2 Boundary Conditions and Mesh Generation

Because the flow is compressible in this case, both yarn entrance 1 and airflow inlet 2 are set as pressure inlets. The exit of the accelerating tube is the pressure outlet. The gauge pressure at the yarn inlet is 101,325 Pa and the gauge pressure at the outlet is at atmospheric pressure and by varying air inlet pressure from 0.25 MPa – 0.5 MPa. No-slip and adiabatic wall boundary conditions are applied on the solid walls and enhanced wall treatment is adopted in the near-wall [17]. The fluid is set as ideal gas as assumed previously. The convergent results are obtained after approximately 5,000 iterations at transient conditions. For mesh generation, hexahedral meshes are used for the cavity of the nozzle core. The meshes of those small but critical parts, such as the throat and rectifier tanks, are gradually refined in space to improve the mesh quality and convergence speed. In the computational domain, about 71,000 nodes were provided to perform simulations with an element size of 0.00009.

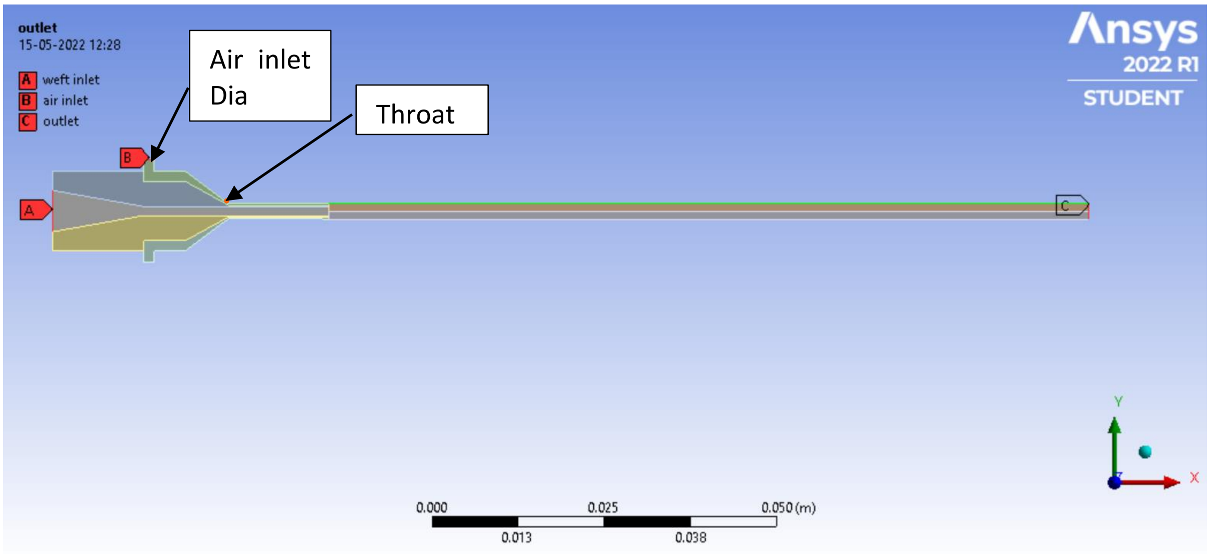

Fig. 3. Structure of new nozzle geometry

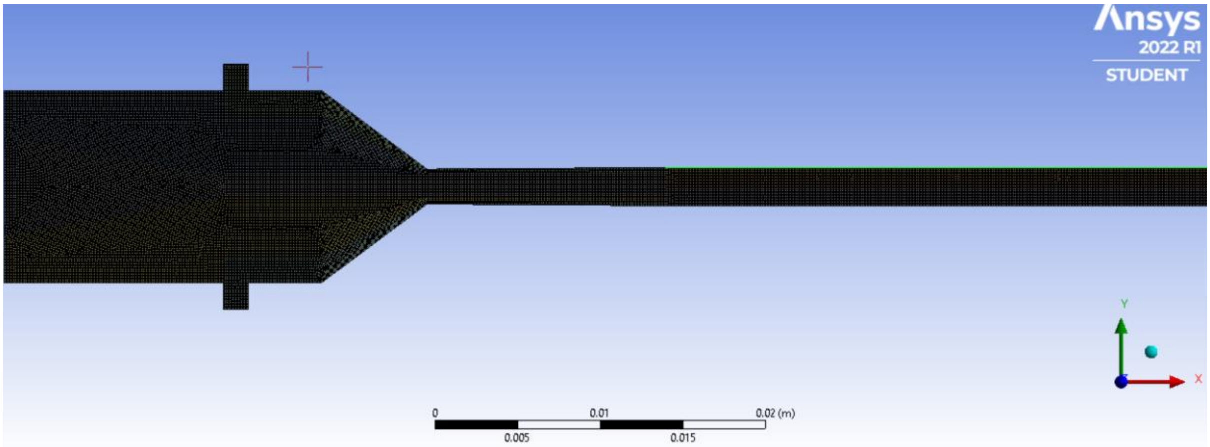

Fig. 4. Elemental Meshing of Geometry

2.3 Structure of New Main Nozzle

The new main nozzle geometry is designed by introducing the throat through the air inlet and changing its diameter to get the optimum design and efficient results and by changing the air inlet diameter to achieve the velocity at reduced air pressure. The below table shows the dimensions used in the simulation (CFD) fluent to get the velocity.

Table 2
New Main Nozzle (A) dimensions with throat

Main Nozzle Diameter at the inlet	6 mm
Main Nozzle Diameter at exit	1.3 mm
Length of Nozzle	40 mm
Length of the acceleration tube	110 mm
Air inlet Diameter	3 mm
Throat Diameter	0.25 mm

Table 3
New Main Nozzle (B) dimensions with throat

Main Nozzle Diameter at inlet	6 mm
Main Nozzle Diameter at exit	1.3 mm
Length of Nozzle	40 mm
Length of acceleration tube	110 mm
Air inlet Diameter	3 mm
Throat Diameter	0.2 mm

Table 4
New Main Nozzle (C) dimensions with throat and optimum air inlet diameter

Main Nozzle Diameter at the inlet	6 mm
Main Nozzle Diameter at exit	1.3 mm
Length of Nozzle	40 mm
Length of the acceleration tube	110 mm
Air inlet Diameter	1.5 mm
Throat Diameter	0.2 mm

3. Results and Discussion

For the main nozzle varying air inlet pressure from 0.25 MPa – 0.5 MPa. By introducing the throat in the airflow channel and by varying the throat diameter to attain high velocity. Airflow was compressed, accelerated sharply, and reached its highest value in the throat. A sudden velocity fall occurred after flow passed through the throat due to the sharp rise of the airflow channel cross-sectional area. The airflow then flowed into the acceleration tube and accelerated smoothly.

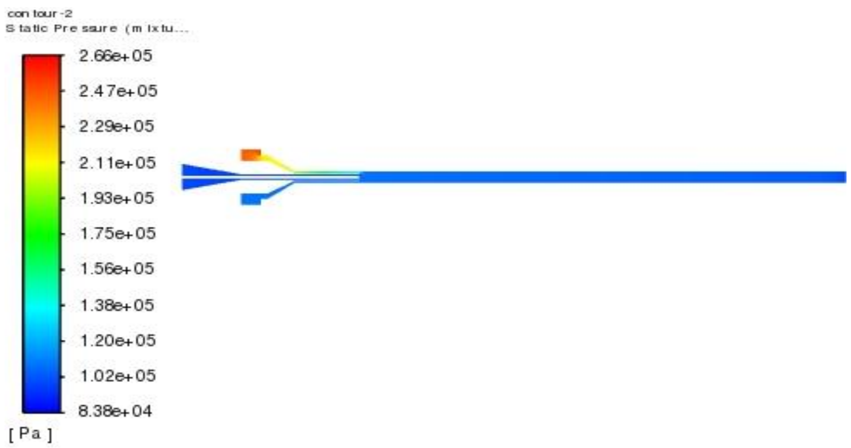

Fig. 5. Pressure contour of the commonly used main nozzle (N)

Table 5
Comparison of Velocity at the outlet of the commonly used nozzle and new nozzle with throat parameter changes

Inlet Air pressure	0.25 MPa	0.3 MPa	0.4 MPa	0.5 MPa
Velocity at outlet without throat (N)	125 m/s	146 m/s	170 m/s	192 m/s
Velocity at outlet (throat 0.25mm) A	145 m/s	160 m/s	185 m/s	205 m/s
Velocity at outlet (throat 0.2mm) B	160 m/s	178 m/s	207 m/s	230 m/s
Velocity increase (B - N)	35 m/s	32 m/s	37 m/s	38 m/s

In Figure 6 new main nozzle, another parameter that also helps in achieving high velocity is by varying air inlet diameter that the final new design of nozzle is attained with high velocity at the outlet and results are shown in Table 6.

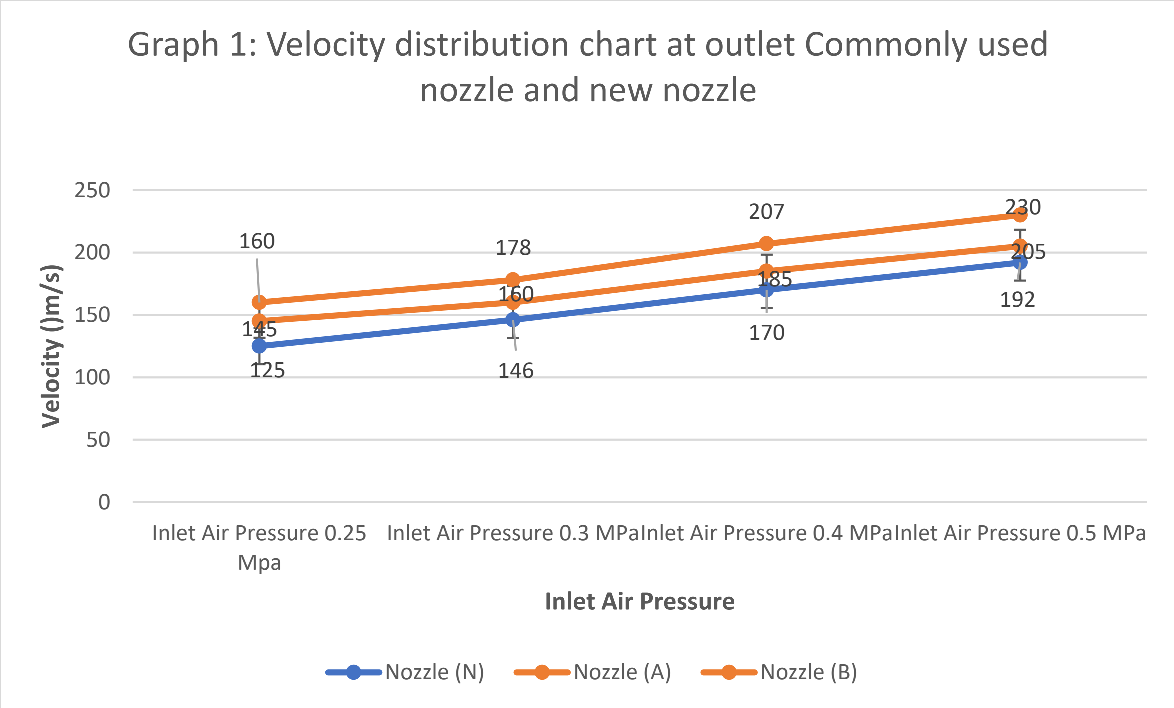

Fig. 6. Velocity distribution of chart at outlet commonly used nozzle and new nozzle

Table 6
Comparison of Velocity at the outlet of the commonly used nozzle and new nozzle with throat and varying air inlet diameter

Inlet Air pressure	0.25 MPa	0.3 MPa	0.4 MPa	0.5 MPa
Velocity at the outlet with entry length air inlet is 3 mm (throat 0.2mm) B	160 m/s	178 m/s	207 m/s	230 m/s
Velocity at outlet with entry length air inlet is 1.5 mm (throat 0.2mm) C	168 m/s	185 m/s	215 m/s	242 m/s
Velocity increase (C - B)	8 m/s	7 m/s	8 m/s	12 m/s

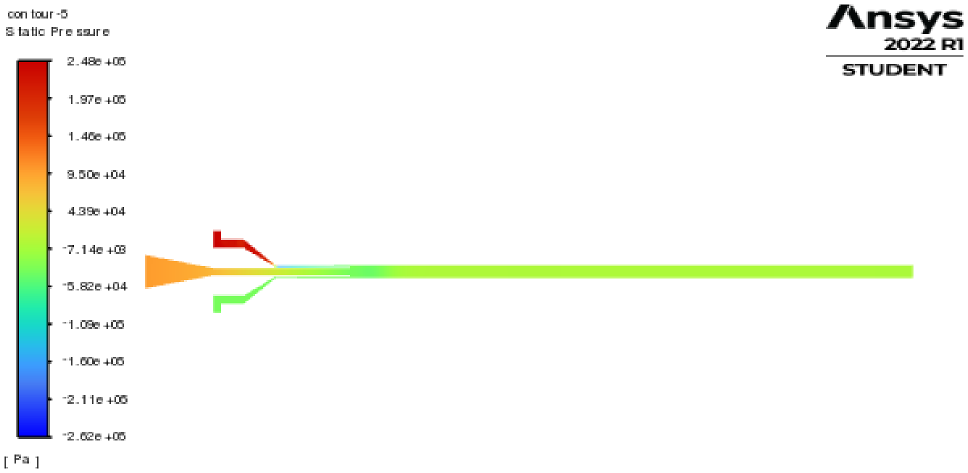

Fig. 7. Pressure Contour diagram of new main nozzle (C)

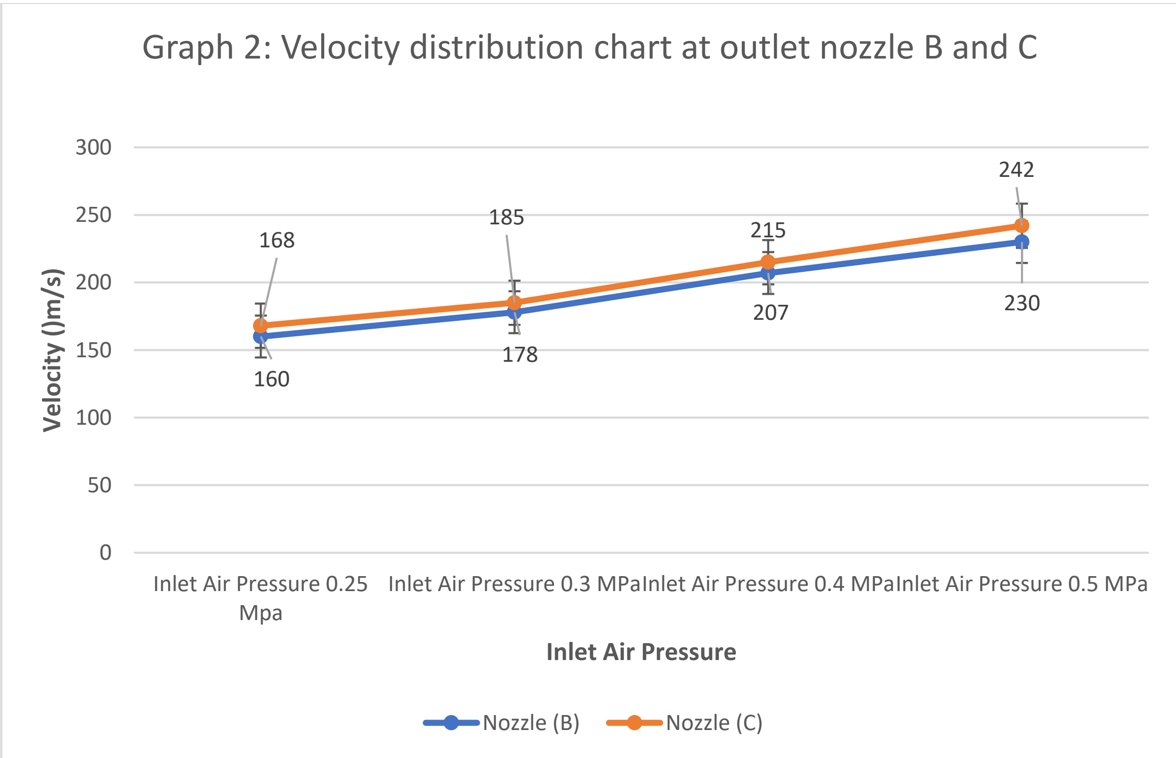

Fig. 8. Velocity distribution chart at the outlet of nozzle B and C

4. Conclusions

In this paper, a new main nozzle structure with a throat is designed to improve the airflow injection capacity of the main nozzle and decrease the backflow phenomenon in the weft injection region. A new main study shows that by introducing the throat and by optimizing its parameter the velocity of airflow in the field to the insertion of yarn increases that shows at low air pressure better air velocity is attained than the commonly used main nozzle. Which will tend to reduce air consumption in the air compression.

By introducing the throat airflow field and by changing its diameter in nozzle A and B by comparing it with the commonly used nozzle N by simulation, it is found that velocity is more at pressure levels in A and B nozzle than in nozzle N. At 0.4 MPa velocity at the outlet is 170 m/s of nozzle N and 185 m/s for nozzle A and 207 m/s for nozzle B. This shows around 22% increase in velocity from nozzle N to nozzle B. The velocity achieved at around 0.5 MPa by nozzle N is achieved by nozzle B at around 0.4 MPa. This will lead to reduced air inlet pressure which leads to reduces air consumption.

Hence above, it shows that the new design of the main nozzle increases the velocity at the same air pressure in comparison with the commonly used design of the main nozzle, which will lead to reducing air consumption.

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References
[1] Adanur, S., and M. H. Mohamed. "Weft insertion on air-jet looms: Velocity measurement and influence of yarn structure part II: Effects of system parameters and yarn structure." *Journal of the Textile Institute* 79, no. 2 (1988): 316-329. https://doi.org/10.1080/00405008808659145
[2] Oh, T. H., S. D. Kim, and D. J. Song. "A numerical analysis of transonic/supersonic flows in the axisymmetric main nozzle of an air-jet loom." *Textile Research Journal* 71, no. 9 (2001): 783-790. https://doi.org/10.1177/004051750107100907
[3] Liu, Y., and M. A. F. Kendall. "Numerical analysis of gas and micro-particle interactions in a hand-held shock-tube device." *Biomedical Microdevices* 8, no. 4 (2006): 341-351. https://doi.org/10.1007/s10544-006-9596-z
[4] Göktepe, Özer, and Orcun Bozkan. "Study on reduction of air consumption on air-jet weaving machines." *Textile Research Journal* 78, no. 9 (2008): 816-824. https://doi.org/10.1177/0040517508090493
[5] Kim, Jin Hyeon, Toshiaki Setoguchi, and Heuy Dong Kim. "Numerical study of sub-nozzle flows for the weft transmission in an air jet loom." *Procedia Engineering* 105 (2015): 264-269. https://doi.org/10.1016/j.proeng.2015.05.107
[6] Khiani, Raj Kumar, Mazhar Hussain Peerzada, and Sadaf Aftab Abbasi. "Air consumption analysis of air-jet weaving." *Mehran University Research Journal of Engineering & Technology* 35, no. 3 (2016): 453-458. https://doi.org/10.22581/muet1982.1603.15
[7] Jayawardana, S., E. A. S. K. Fernando, and G. H. D. Wijesena. "Modeling and Analysis of COmpressed Air Consumption of Air Jet Loom." *International Journal of Engineering Trends and Technology* 54, no. 3 (2017): 156-161. https://doi.org/10.14445/22315381/IJETT-V54P222
[8] Mohamed, Mansour H., and Mahmoud Salama. "Mechanics of a single nozzle air-jet filling insertion system part I: nozzle design and performance." *Textile Research Journal* 56, no. 11 (1986): 683-690. https://doi.org/10.1177/004051758605601106
[9] Ishida, Minoru, and Atsushi Okajima. "Flow characteristics of the main nozzle in an air-jet loom: part I: measuring flow in the main nozzle." *Textile Research Journal* 64, no. 1 (1994): 10-20. https://doi.org/10.1177/004051759406400102
[10] Oh, T. H., S. D. Kim, and D. J. Song. "A numerical analysis of transonic/supersonic flows in the axisymmetric main nozzle of an air-jet loom." *Textile Research Journal* 71, no. 9 (2001): 783-790. https://doi.org/10.1177/004051750107100907
[11] Kim, Heuy-Dong, Chae-Min Lim, Ho-Joon Lee, and Doo-Hwan Chun. "A study of the gas flow through air jet loom." *Journal of Thermal Science* 16, no. 2 (2007): 159-163. https://doi.org/10.1007/s11630-007-0159-3
[12] Kim, Sang Dug, Jeong Ill Seo, and Dong Joo Song. "A computational analysis of unsteady transonic/supersonic flows over backward facing step in air jet nozzle." *Journal of Mechanical Science and Technology* 21, no. 2 (2007): 336-347. https://doi.org/10.1007/BF02916294
[13] Osman, Akil, Benny Malengier, Simon De Meulemeester, Jozef Peeters, Jan Vierendeels, and Joris Degroote. "Simulation of air flow-yarn interaction inside the main nozzle of an air jet loom." *Textile Research Journal* 88, no. 10 (2018): 1173-1183. https://doi.org/10.1177/0040517517697646
[14] Belforte, G., G. Mattiazzo, F. Testore, and C. Visconte. "Experimental investigation on air-jet loom sub-nozzles for weft yarn insertion." *Textile Research Journal* 81, no. 8 (2011): 791-797. https://doi.org/10.1177/0040517510391694
[15] Pei, Zeguang, and Chongwen Yu. "Numerical study on the effect of nozzle pressure and yarn delivery speed on the fiber motion in the nozzle of Murata vortex spinning." *Journal of Fluids and Structures* 27, no. 1 (2011): 121-133. https://doi.org/10.1016/j.jfluidstructs.2010.08.007

[16] Delcour, Lucas, Jozef Peeters, and Joris Degroote. "Three-dimensional fluid-structure interaction simulations of a yarn subjected to the main nozzle flow of an air-jet weaving loom using a Chimera technique." *Textile Research Journal* 90, no. 2 (2020): 194-212. https://doi.org/10.1177/0040517519862884
[17] He, Shanshan, Yi Qian, Wenliang Xue, and Longdi Cheng. "Numerical simulation of flow field in air-jet loom main nozzle." *Autex Research Journal* 19, no. 2 (2019): 181-190. https://doi.org/10.1515/aut-2018-0053