Experiments of Flow of Air Jet Loom with Air Guides

Part 1 : Characteristics of Flow Injected into Air Guides

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Abstract

Flow characteristics of air guides of an air jet loom have been experimentally investigated. We compare the flow in air guides with the flow jetted free in atmosphere to clarify the effects of air guides.

The main results are as follows:

- (1) A flow field in air guides can be classified into two regions.
- (2) The first region is found at the up-stream part of guides and the distribution of the axial velocity along guides shows very similar features to a free jet flow.
- (3) The other region is at the down-stream part. The axial velocity slightly decreases along guides and the distribution of radial velocity can be expressed by the power law of about $1/6$.

1. Preface

Recent years, aiming at the rationalization of manufacturing process of spun or cellulose filament yarns, introductions of air jet looms (hereinafter abbreviated as AJL) which blow off wefts by air are rapidly progressing.

The weft insertion force of AJL is given by the friction between the surface of yarns and air. But comparing the water of water jet looms, air density and viscosity coefficient are low, and the jet flow from a nozzle tends to diffuse very rapidly^[1]. To give the weft stronger insertion force, therefore, it is important to solve such a technical problem not to diffuse the air flow running the whole reed space and to let it reach a distant place. Technologies corresponding the above have led various types of insertion systems on commercial looms from various manufacturers. They are classified into 3 kinds having advantages, disadvantages respectively^[2]:

- (1) Air guide system
- (2) Modified reed and auxiliary nozzle system
- (3) Joint use of above (1) & (2) ; namely an air guide system with auxiliary nozzles.

The variety of insertion systems of commercial looms shows the complexity of air jet insertion. To get high performance in economy, fabric quality, fabric diversification, present AJLs have still many problems to blow off the weft to a distant place reliably and effectively.

Anderson and Stabs^[3] studied the tensile stresses of various fibers in air stream, but they are not the research of AJL itself. Duxbury^[4] made a research on AJL for the first time, but it was mainly on Maxbo-Mp

type AJL.

Afterwards Uno and Ishida^[5] made a series of fundamental research, which brought technical problems clear. There are also many other investigations by Mohamed, Salama^[6], Yoshida^[7] and special agencies in Czechoslovakia, USSR, East Europe and etc.^[8].

In this report, the authors will study the general flow characteristics such as velocity distributions of air in air guides, especially the function of air guides and characteristics of air flow. In the 2nd report, fundamental data on the assessment criterion of air guides will be shown by comparing air flows in tubes of several different inner diameters with slits.

2. Experimental Device and Measuring Method

2.1 Experimental device

The form and main dimensions of the main nozzle used in this research is shown in Fig. 1. The nozzle was newly manufactured by us based on Nissan AJL type LA-21 which is for filament fabrics. The main dimensions are: Inner diameter of acceleration tube (d) is 6.0mm ϕ , disclosure length of the yarn in the air flow in the acceleration tube is 11mm, outside diameter of the needle is 3.7mm ϕ , its inside diameter is 3.0mm ϕ , sectional area of air jet is 17.5mm².

Figure 2 shows the form and main dimensions of air guides used in this research. The air guide is exactly the same as that of Nissan AJL type LA-21 for filament fabrics. The main dimensions are : Inner diameter of aperture (D) is 18mm ϕ , thickness is 2.15mm, clearance 0.7mm, taper of aperture is 3.5°, aperture opening is

Fig. 1 Form and main dimensions of main nozzle

Fig. 2 Form and main dimensions of air guide

0.9mm. Total length of air guides is 100 cm, consisting of 5 blocks, each of which is 20 cm long.

2.2 Measuring method of velocity, quantity and pressure of flow

We made a series of measurements in this research by the following device: The slay is fixed on a holder, the nozzle and air guides being attached as shown in Fig. 3. We assumed the coordinates as shown in Fig. 4. Compressed air from a source compressor is fed through a filter, a receiver, an air dryer, a pressure regulator, a small receiver, a Bourdon tube pressure gauge and a flow meter.

In Fig. 3, G is the distance between the nozzle and the first air guide, L is the distance from the entrance, $X(=$

Fig. 3 Relative position of nozzle to air guides

Fig. 4 Air guide and coordinates for measurement

$G+L$) is the distance from the nozzle exit. Every measurement is done under the stationary flow, not under intermittent flow, and flow velocity is measured by a digital manometer (Okano Seisakusho Type DP-1000A), while moving a Pitot static tube on a XYZ table. Flow quantity is determined by integrating the velocity distribution. Static pressure in case of free flow is obtained by a Static Probe which is a disc of 10mm ϕ diameter with 0.5mm ϕ hole. Static pressure on the wall surface of the air guide is measured by an injection-needle of 0.6 mm ϕ outer diameter (0.5mm ϕ inner diameter) provided at the inner surface of the smaller curvature side.

3. Results of Experiments

3.1 Air flow from the main nozzle in free atmosphere

3.1.1 Distribution of air flow

Figure 5 shows velocity distributions of air from the nozzle at 1.0 kg/cm²G. It shows that the air flow from the nozzle has a velocity dent through the distance of $5d$ from the nozzle exit, and the maximum dent is in the center part of the flow.

The velocity dent is caused by the back flow inside the needle of the nozzle shown in Fig. 1, but disappears perfectly at the distance over $5d$ from the nozzle exit. After that, the velocity distribution has the maximum value on the nozzle center axis, and damps as it goes away radially from that axis.

In Fig. 5, we measure at each distance (X) the maximum velocity (V_{max}), and the flow radius (b) at which

Fig. 5 Velocity distribution of air from the nozzle to the free atmosphere

Fig. 6 Dimensionless indication of free jet from the nozzle

the velocity becomes $1/2$ of V_{max} . Thus the flow diameter (Z) is made dimensionless by Z/b as shown in Fig. 6.

In Fig. 6, the velocity distributions on the planes vertical to the nozzle axis are on the common curve if X/d is over 6.7. Figure 7, meanwhile, shows the results where air pressures are altered from 1.0 to 2.0 and 3.0 kg/cm²G. The velocity distributions are still similar irrespective of the pressure.

Fig. 7 Velocity distributions of free jets when pressure changed

Fig. 8 Static pressure distribution in radial direction at each different distance

3.1.2 Distribution of static pressure

Figure 8 shows the relation between the static pressure distribution in the radial direction and the distance from the nozzle. The distribution has negative pressure in the vicinity of the nozzle axis, and becomes more negative in some extent as it goes away from the center axis. It finally approaches to the atmospheric pressure. The negative pressure in the vicinity of the center is the largest as it approaches to the nozzle exit. The position at which the negative pressure is the maximum goes away from the center axis as the distance from the nozzle exit increases.

3.1.3 Air flow diameter and quantity of the flow

We define the dimensionless mean diameter ($Z_{1/2}/d$)

Fig. 9 Mean diameter of air flow at various distances from nozzle

and show the relation between it and the distance from the nozzle in Fig. 9, where $Z_{1/2}$ is the flow diameter and is equal to $2b$. According to the momentum conservation and the mixture theory, the flow diameter is generally proportional to the distance from the nozzle. In this experiment, it is indicated also nearly as $Z_{1/2}/d=0.4X/d+1$.

Fig. 10 Air quantity and the distance from the nozzle

Figure 10 shows the air quantity which changes according to the distance from the nozzle. The dimensionless quantity of air flow (Q/Q_0) [(air flow quantity Q)/(air quantity at the nozzle exit Q_0)] increases as the distance becomes larger. It shows that the jet flow absorbs the surrounding atmosphere considerably as it goes further from the nozzle. The air flow quantity (Q/Q_0) and the distance (X/d) are proportional in the range of $5 \leq X/d \leq 16.7d$. This is because both the flow diameter ($Z_{1/2}/d$) is proportional to the distance (X/d) as shown in Fig. 9, and the velocity at the flow center of the jet (V) is inversely proportional to X/d as shown in Fig. 12.

The relation between the air flow quantity (Q/Q_0) and the distance (X/d) can be approximated to $Q/Q_0=0.3 \times [(X-X_0)/d]$, where the apparent origin of the jet flow is assumed at X_0 . This result is nearly equal to the proportional constant of $X/d=0.32$ by Albertson^[10].

Fig. 11 Air velocity distributions in air guides at various distances from the nozzle

3.2 Flow characteristic in air guides

3.2.1 Flow direction

Figure 11 shows the air velocities (V_x) on the center axis of the air guide when $G=1.7d$, together with the free flow velocities without air guides.

V_x is nearly equal to the velocity of the free flow up to approximately $15d$ (corresponding to $4.4D$ from the entrance of the guide). V_x becomes the maximum at about $5d$ distant from the exit, because the velocity at the nozzle exit is the largest. Owing to the similarity of the air velocity distribution seen in Fig. 7, this $5d$ distance does not so differ through different jet pressure. V_x , then, decreases in inverse proportion to the distance from the nozzle.

Anyway, though the first guide is set at the $1.7d$ from the nozzle exit, the air guide effect against the velocity decline begins $15d$ away from the nozzle exit. This $X=15d$ does not change fairly by the jet pressure. The air velocity after $X=15d$, damps nearly linearly as the flow goes away from the nozzle.

Fig. 12 Dimensionless flow velocity in the air guide

Figure 12 shows dimensionless ratios of V_x to the maximum flow velocity (V_{max}) when the origin of coordinates is the entrance of the guide. All air velocity distributions are similar each other regardless of the jet pressure. As mentioned above, V_x can be classified into 2, namely one is the same as that of the free jet

flow, and the other that corresponding to the guide characteristic.

3.2.2 Radial direction

Figure 13 shows the relation between the flow velocity distribution in the radial direction and the distance from the nozzle. As V_x is nearly the same as that of the free jet flow when $X/d \leq 15$, first the characteristics of radial distribution of flow velocity will be studied.

Fig. 13 Velocity distributions in air guides in radial direction at different distance from nozzle

Fig. 14 Comparison of air flow velocity distributions between free jet and guided flow

Figure 14 shows the comparison between the radial velocity distributions at $X=3.3d$, $15d$ and those of the free jet flow. At $X=3.3d$, the velocity distributions in the radial direction are the same irrespective of free or guided flow. But at $X=15d$, they are different and faster with guided flow than with free jet except at the vicinity of the center axis. Thus, the guided jet flow is considered intruded by the outside air through gaps of air guides, and gradually forms the velocity distribution different from the free jet, until it reaches the distance $X=15d$ at which the static pressure on the wall surface is negative.

If the flow reaches near $X=15d$, the change of flow velocity starting from the wall surface attains to the guide center axis, afterwards showing the distribution characteristic of air guides which is completely different from that of the free jet.

So, we will consider this characteristic velocity distribution after $X=15d$. Figure 15 is the dimensionless indication of Fig. 13, in which the distance from the guide center axis is divided by the diameter of the guide, and the flow velocity along the horizontal axis by the maximum flow velocity at the guide center. The velocity distributions after $X \geq 15.8d$ ($L \geq 4.7D$) are almost similar

Fig. 15 Dimensionless flow velocity distributions inside air guides

Fig. 16 Application of $1/n$ power law to flow velocity distribution in air guides

each other until the guide exit at $X=168.3d$, ($L=55.6D$).

In Fig. 16 $(V/V_{\max})/(Z'/(1/2)D)$ are plotted on logarithmic coordinates, in which Z' is the distance from the inner downside wall surface of the tube, and $Z'=Z+1/2D$. There is the relation $(V/V_{\max})=(Z'/(1/2)D)^{1/6}$ between $(V/V_{\max})$ and $(Z'/(1/2)D)$, and it differs in some extent from the $1/7$ power law of a turbulent flow in a smooth tube, because the guide walls are not uniform with many gaps.

Fig. 17 Comparison of flow velocity distributions along Z and Y -axes in air guides

Figure 17 shows the comparison of velocity distributions along Z and Y -axes in air guides. Both distributions show almost the same shapes. The guide shapes are not symmetric as seen in Fig. 2, and guides have slits at their top side for slipping out the wefts. So the similarity of the flow distributions indicate that the air flowed into or out of guides goes not chiefly through slit parts, but mainly through gaps between guides.

3.2.3 Air flow quantity

Figure 18 shows the change of flow quantity in air

Fig. 18 Change of air flow quantity in the air guide

guides. First, the air flow quantity increases as the flow goes away from the nozzle until $X=15d$. That is to say, in this range the flow absorbs the outside air positively, and flow quantity (Q) becomes the maximum at $X=15d$. In the range of $X>15d$, the flow quantity decreases owing to the air leakage from guides. In this experiment, the final preservation rate of air flow quantity [(flow quantity at guide exit)/(air flow quantity at guide entrance) $\times 100\%$] is about 54%.

3.2.4 Static pressure on wall surface

Figure 19 shows the static pressure on the wall surface

Fig. 19 Static pressure on wall surface of air guide

of guides in case of $G=1.7d$. It is negative until $X=15d$, and a little positive afterwards. Comparing the above with Fig. 18, it is understood that the air outside of the guides is absorbed in the range in which the static pressure on the wall is negative, and that the inside air leaks out in the range the static pressure is positive.

4. Conclusion

In this research several characteristics of air flow in air guides are studied to improve the function of AJL

with an air guide system.

Main results acquired are as follows:

(1) Air flow velocity distributions in the axial direction on the air guide center are classified into 2 main regions ; One is nearly the same as that of the free air flow, and the other the region in which the preventing effect of air guides against velocity decline is active.

(2) Air quantity change through air guides in the flow direction corresponds quite well to the static pressure change on the guide wall surface.

(3) Change of the maximum flow velocity in the direction of flow becomes similar irrespective of the jet pressure when it is divided by the maximum flow velocity at the entrance of the guide, as far as the clearance between the nozzle and the guide is the same.

(4) Radial distribution of flow velocity in the guide has almost the same curve as that of the free jet in the vicinity of the guide entrance. As the flow goes away from the entrance, air is absorbed from outside through guides, and the distribution form in the vicinity of the guide surface is deformed. Thereafter, the forms of velocity distributions correspond to the guide characteristic, and become similar if the velocity is divided by

the maximum velocity at each section. The 1/6 power law can roughly be applied to it.

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