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PhD Theses

Examination of the Weft Insertion by Air Flow and the Weaving Technology on Tunnel Reed Air Jet Looms

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Examination of the Weft Insertion by Air Flow and the Weaving Technology on Tunnel Reed Air Jet Looms

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1 The subject and aim of the dissertation

The dissertation summarizes the scientific research and development work done in the interest of increasing the efficiency of air jet weaving machines used in domestic weaving plants.

Air jet weaving machines are intermittent operating equipments, during weaving the weft is inserted into the shed by the flowing air. From the central air supply tank energy derived from the air pressure fed into weaving machine at the main and relay nozzles is transformed into kinetic energy, which in turn speeds up and conveys the weft into the shed of the variously shaped air conduction tunnel. The cylindrical free air jet exiting from the nozzle mixing with the stagnant air, dissipating, slows down, receding from the nozzle its velocity decreases rapidly.

The necessary technical solutions for air jet weft insertion:

- ensuring economical air supplying for the loom,
- measuring the length of the weft intended for insertion, its unwinding from the length metering weft storage and its insertion to the shed,
- for easy weft insertion the assurance of a clean shed in the direction of insertion,
- creation and ensuring of air jet throughout the length of insertion,

At the air jet looms, because of the high weft velocity and greater fabric width farther from the main nozzle in the direction of the shot, air velocity can be maintained by the following:

- confusor drop wire air tunnel which can be
  - open metal
  - closed plastic

  provided with drop wire,
- U- shaped profile reed and relay nozzles.

To understand the weft insertion process and for the technological modifications, on the base of adequate physical and mathematical model, very precise measurements – their evaluation and numerical solutions are required. The main goals of my dissertation are as follows:

- examination of air flow path in the case of various air conductions,
- at the various air conducting solutions, the description of axial flow velocity by mathematical formulas,
- development of measuring method to determine and describe surface friction coefficient $c_f = f\left(\frac{u}{u_0}\right)$ function for multifilament weft,
- development of calculation method to determine force acting on the weft during its insertion $F^* = f\left(\frac{x}{r_0}, \frac{u}{u_0}\right)$ described by functional relationship,

- in the case of the examined two air guide methods, the comparison of the flow dynamics conditions generated in the weft tunnel, the conclusions deducible from this, pertaining to the weft moving in the air tunnel.
- possibilities for the decreasing of weft defects, by changing the pressure and actuating time of the main nozzle and relay ones.

For insertion of the weft, the followings must be in coordination with each other generated air flow actuated - controlled by the nozzles, movement of slay, and opening of the shed. To gain accurate knowledge of the air flow inserting the weft, it is expedient to examine the velocity of the air in the following places:

- at the exiting section of the nozzle,
- along the axis of the air guide tunnel in function to distance.

At the confusor drop wire weaving machine, in the course of the weft insertion air flow is generated periodically, that is 8 times a second, which calculated with the insertion time lasts about 62 ms, and the weft insertion time equals approximately to that of the half revolution of the main shaft.

In the case of the most modern profile reed machine depending on the revolution of the weaving machines main shaft, even 20 weft insertion is possible, thus the insertion time is about 25 ms.

Following the determination of flow characteristics I examined weft in relation to the air flow dynamics. From examination viewpoint the air flow can be considered as quasi-stationary.

With the large-scale fallback of output of the domestic textile industry, research and publications have also become limited, thus this dissertation can be considered as a supplement in this field.

Worldwide the air jet weaving machines are used expansively and are under continuous development. With the expected economical upswing, hopefully it will be felt domestically in the form of creating new jobs in the textile industry, namely that in the weaving industry it will manifest in the broader use of the air jet weaving machines.

2 Research work methods

Before the start of the research work, in order to clarify weft and air flow relationship, I have read through recent papers and textbooks related to the field of my research in the available literature. At the Textile Technology Laboratory of the Óbudai University I constructed measuring systems for the measurement of air jet weaving machines flow dynamics and mechanics relationship, and for measuring the variously designed air guide methods. The industrial measurements were carried out at the facilities of Csárda-Tex Kft.

The air consumption of the mass flow from the nozzles was measured by a GEMÜ RTS type air consumption meter. I measured the dynamic pressure with a Prandtl's tube of the continuous air flow in the axis of the confusor air tunnel at the fixed measuring points (Fig. 1).

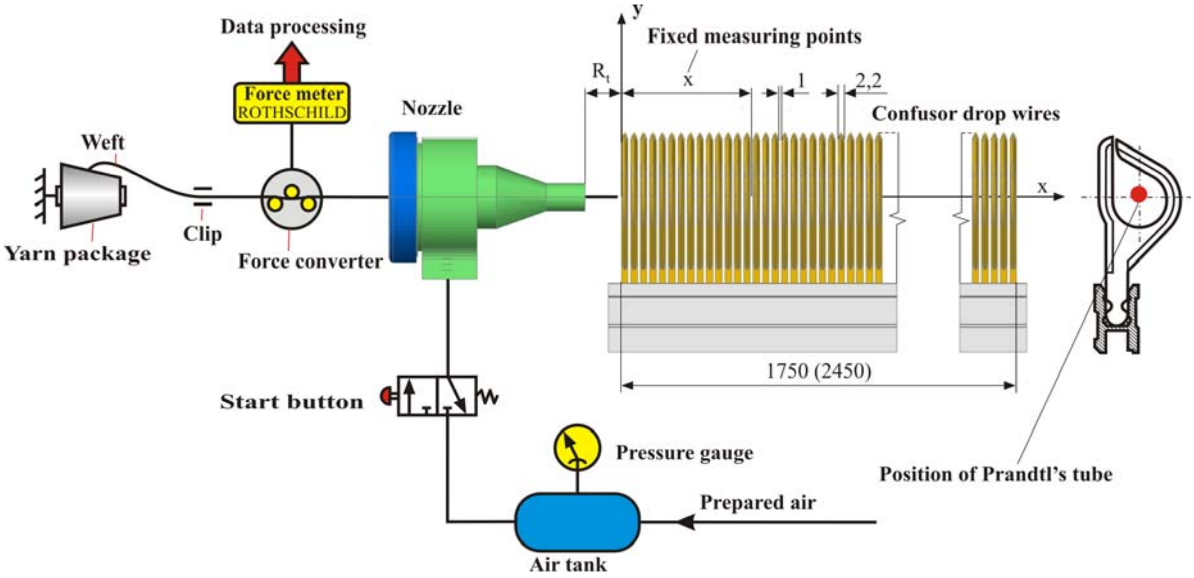

Figure 1 Measurement set-up to determine air flow velocity and force acting on the weft

Depending on the revolution of the weaving machine, the time for 1-1 weft insertion, the build and upkeep of air flow is 25-60 ms, which, considering the applicable measuring technique is a great challenge. Because of this, at the flow dynamics analyses, I used the continuous air flow and its effect on the weft as a reference point.

From the dynamic pressure, and using Bernoulli's equation air velocity can be determined. Dynamic pressure was measured via a 140PC type pressure detector connected to the Pitot tube which was moved by a stepping motor installed in the weft tunnel of the profile reed. I measured the electrical tension, which was in ratio to the dynamic pressure by interconnecting a DSO 2090 oscilloscope, this in turn was connected to a PC (Fig. 2).

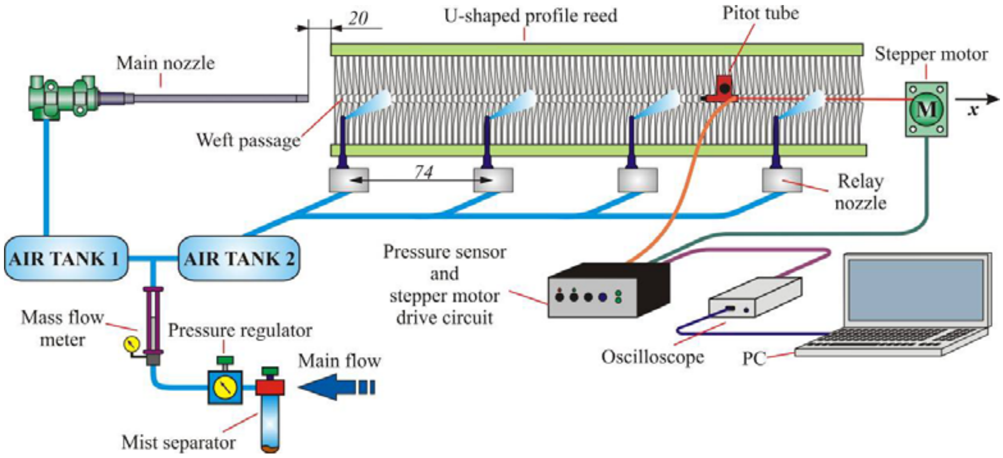

Figure.2 Setup for measuring the velocity distribution and air consumption of the profile reed air jet weaving machine

Up to now, with the developed measuring method and fixed speed movement of the Pitot-tube in the profile reed tunnel, with the continuous measurements, fuller information may be gained concerning flow conditions especially regarding contamination of the relay nozzles or their in-correct setting.

Measurement of the dynamic pressure was done along the width of the reed and without weft yarn. For measuring the force acting on the weft laid in the stationary air flow a ROTHSCHILD R-1192 type force meter was available (Fig. 1 and Fig. 3). Determination of the dimensionless surface friction coefficient $c_f = f\left(\frac{u}{u_0}\right)$ was realized on base of and based on the measuring drawn up in Figure 3.

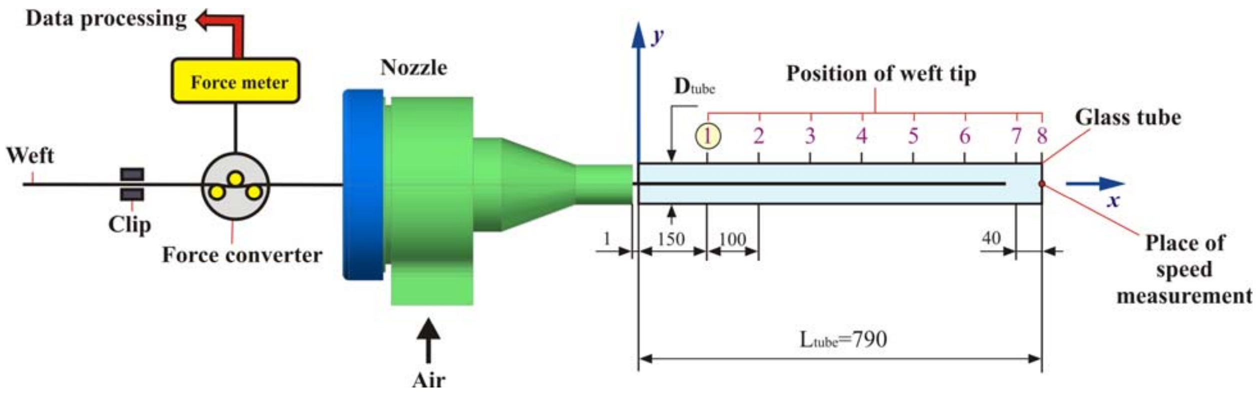

Figure.3 Laboratory measuring system for determining surface friction coefficient

The approximate functions and correlation coefficient were determined by the Microsoft Excel application.

3 Summary of the theses

In the mathematical, I treated the physical quantities in dimensionless form in which the examined physical quantities are divided by their appropriately fixed (e.g. maximum) values. Based on measurement results, even in the case of laboratory and industrial conditions, the air velocity can be determined in relation to

- the method of air guide,
- the reed width,
- the air supply pressure,
- the types of main and relay nozzles,
- the skin friction force on the weft.

Thesis 1

The results of the laboratory velocity measurements were made dimensionless by dividing them with the greatest flow velocity value measured at the exit cross section of the nozzle, and similarly the length of the reed width with the inner radius value of the nozzle used in the case of confusor drop wire. Thus the below function relationship becomes dimensionless air velocity distribution in the axis of the weft passage, which does not depend on tank pressure and reed width:

$$\frac{u}{u_0} = \frac{f_p\left(\frac{x}{r_0}\right)}{\frac{x}{r_0}} \qquad \text{or} \qquad f_p\left(\frac{x}{r_0}\right) = \frac{u}{u_0} \cdot \frac{x}{r_0} \qquad (1)$$

where:

u	along the axis of air guide air velocity is	[m/s],
u_0	the flow velocity measured at the exit cross section of nozzle	[m/s],
f_p	the dimensionless function which is typical for flows	[-],
x	measuring point in the axis of air conducting tunnel	[mm],
r_0	inner radius of nozzle	[mm].

The form of the function graph is affected by the structure of the air guide system ensuring the flow, which can be:

- a tube,
- free air jet,
- open metal confusor drop wire,
- closed plastic confusor drop wire.

In the case of closed tube the measurement results rise along $\tan\alpha = 1$ steep line, whereas in the case of free air jet it can be approximated with a horizontal line. In the case of closed plastic and open metal drop wires, I approximated each measurement result by a quadratic polinom (Fig. 4).

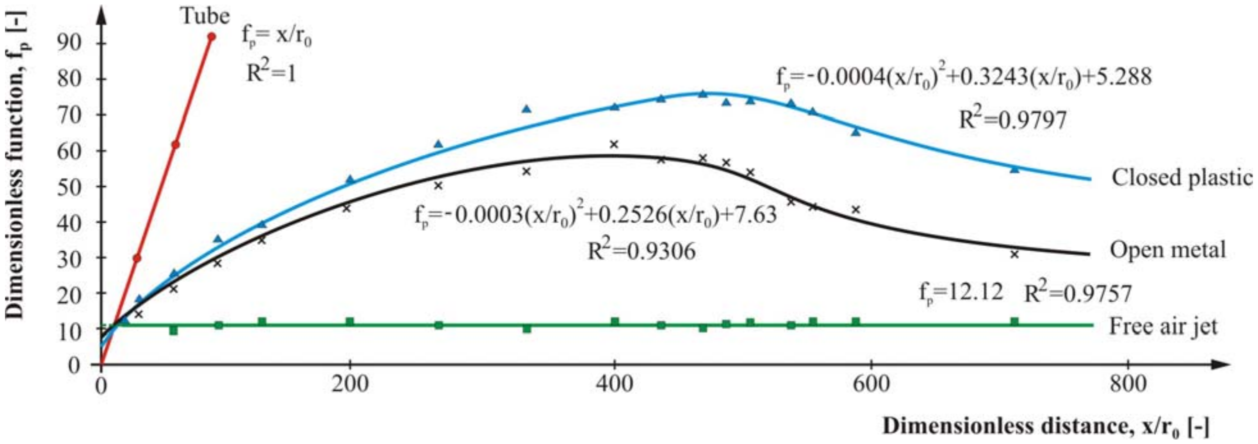

Figure 4 Closed mathematical functions typical for various air guide modes

With the aid of the function relationship shown in Figure 4, at any position in the axis of the examined air guide solutions the flow velocity based on the relationship of (1) can be determined

In the case of closed plastic drop wire, if $\frac{x}{r_0} > 7.8$:

$$\frac{u}{u_0} = \frac{f_p}{\frac{x}{r_0}} = \frac{-0.0004\left(\frac{x}{r_0}\right)^2 + 0.3243\frac{x}{r_0} + 5.288}{\frac{x}{r_0}} = -0.0004\frac{x}{r_0} + 5.288\frac{r_0}{x} + 0.3243 \,. \qquad (2)$$

Flow velocity of closed plastic drop wire in the axis direction can be determined by equation (2):

$$u = \frac{-0.0004\left(\frac{x}{r_0}\right)^2 + 0.3243\frac{x}{r_0} + 5.288}{\frac{x}{r_0}} \cdot u_0 = \left(-0.0004\frac{x}{r_0} + 0.3243 + 5.288\frac{r_0}{x}\right) \cdot u_0 \qquad (3)$$

It is evident that in textile industry practice, the possible technical solutions for efficient weft insertion can be found between the tube and the free air jet air guide mode.

Thesis 2

With the measuring method shown in Figure 3 and measuring results – in the case of laminar flow – surface friction coefficient between air flow and weft surface can be determined in the following form:

$$c_f = f\left(\frac{u}{u_0}\right) \tag{4}$$

The skin friction coefficient depends on:

- the properties of the weft yarn,
- the air flow velocity.

In the case of a given yarn type (multifilament 80 tex) and the condition of the air the change in surface friction coefficient in function of the dimensionless air velocity and based on the measurement results is well shown in Figure 5.

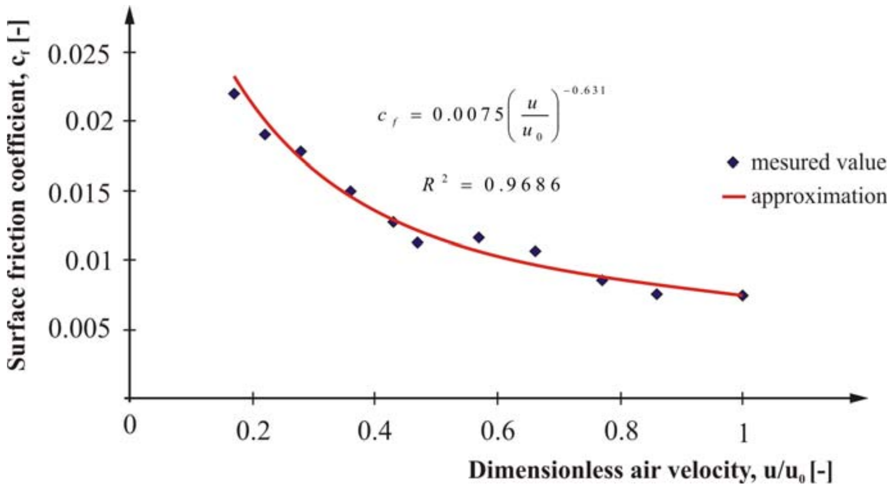

Figure 5 Surface friction coefficient changing in the case of power approach

In the case of examined multifilament weft, if the measurement results are approximated with a power function – in the examined $30\ \text{m/s} \le u \le 174.3\ \text{m/s}$ air velocity range – the determination coefficient (R^2) value can be stated as good. Thus the approximating function will be

$$c_f = 0.0075\left(\frac{u}{u_0}\right)^{-0.631} \tag{5}$$

Surface friction coefficient, in function to the increasing velocity will decrease. The explanation for this is that the increasing velocity will change the surface structure of the weft yarn.

Thesis 3

The thesis theoretically determines the value of the dimensionless force acting on the examined fixed weft in function of the dimensionless reed width and in the case of plastic confusor air guide mode being used.

The elemental surface friction force acting on fixed filament weft length has the form as the following:

$$dF_f = \frac{1}{2}\rho \cdot c_f \cdot D \cdot \pi \cdot u^2 \cdot dx. \tag{6}$$

Equation (6) is transformed by applying the values u_0 and r_0 in order to shift the dimension of force into a constant (K) that is typical for the weft:

$$dF_f = \frac{1}{2}\rho \cdot D \cdot \pi \cdot u_0^2 \cdot r_0 \cdot c_f \cdot \left(\frac{u}{u_0}\right)^2 \cdot d\left(\frac{x}{r_0}\right) \tag{7}$$

Substituting into (7) equation, the dimensionless (2) and (5) expressions:

$$dF_f = \underbrace{\frac{1}{2}\rho \cdot D \cdot \pi \cdot u_0^2 \cdot r_0 \cdot 0.0075}_{K=0.95\cdot 10^{-3}\ \mathrm{N}} \cdot \left(\frac{u}{u_0}\right)^{-0.63} \cdot \left(\frac{u}{u_0}\right)^2 \cdot d\left(\frac{x}{r_0}\right) = K \cdot \left(\frac{u}{u_0}\right)^{1.37} d\left(\frac{x}{r_0}\right), \tag{8}$$

where:

- ρ — the density of the air is: $1.2\ \mathrm{kg/m^3}$,
- D — the average diameter of the 80 tex multifilament weft is: $6.34 \cdot 10^{-4}$ m,
- u_0 — the measured flow velocity is 174.3 m/s at starting cross section of the weft tunnel
- r_0 — the radius of the examined nozzle is: $3.5 \cdot 10^{-3}$ m.

By $z = \left(\frac{x}{r_0}\right)$ substitution and examining the plastic drop wire, and based on relationship (2) the elementary force acting on the weft yarn can be calculated with the correlation shown below:

$$dF_f = K \cdot \left(-0.0004z + \frac{5.288}{z} + 0.3243\right)^{1.37} dz. \tag{9}$$

Integrating both sides of equation (9) between z_0 and z we get:

$$F_f(z) - F_f(z_0) = K \cdot \int_{z_0}^{z} \left(-0.0004z + \frac{5.288}{z} + 0.3243\right)^{1.37} dz. \qquad z_0 = 7.8 \tag{10}$$

Implementing the below substitutions and dividing it by K:

$F_f(z_0) = F_0$: at the start of air guide mode, measured force acting on the weft [N], based on measurement shown in Figure 1.: $F_0 = 2 \cdot 10^{-2}$ N.

$F_f(z) = F \quad : z > 7.8$ in the case of theoretical surface friction force acting on the weft in the axis of the confusor drop wire line [N].

The equation suitable for integration:

$$F^* = F_0^* + \underbrace{\int_{z_0}^{z} \left(-0.0004z + \frac{5.288}{z} + 0.3243 \right)^{1,37} dz}_{F_z^*} = F_0^* + F_z^*, \qquad (11)$$

where:

$z_0 = 7.8$: the starting values of integration [-],

$F^* = \frac{F}{K}$: theoretical dimensionless force acting on the weft in the confusor drop wire [-],

$F_0^* = \frac{F_0}{K} = \frac{2 \cdot 10^{-2}\,[\mathrm{N}]}{0.95 \cdot 10^{-3}\,[\mathrm{N}]} = 21\,[-]$: dimensionless force in the starting cross section of the drop wire [-].

By using the Maple program the integral values of the equation (11) with measured ones are shown in Figure 6.

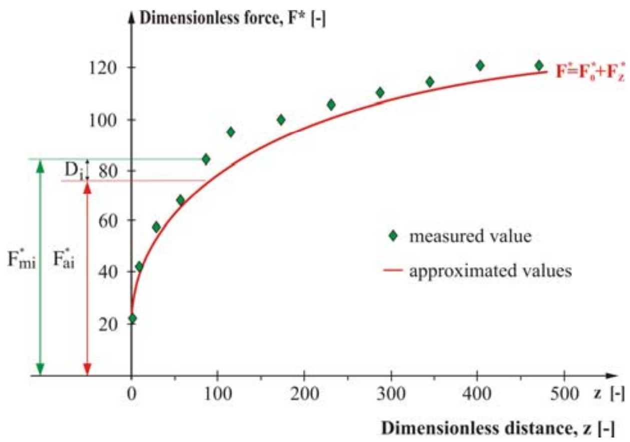

Figure 6 Comparison of the measured and approximated results in the case of closed drop wire

The dimensionless forces shown in Figure 7: $F_{mi}^* = \frac{F_{mi}}{K}$ and F_{ai}^*

where:

F_{mi}^* : measured dimensionless forces in the axis of the closed plastic drop wire [-],

F_{mi} : measured values of the forces acting on the stationary weft placed into the flow formed in the axis of the confusor drop wire (Fig. 1) [N],

K : constant typical for the examined weft [N],

F_{ai}^*: approximated dimensionless forces, which contains the measured F_0 [-].

In the case of the examined weft, the theoretically obtained solution well approximates the measured value. It can be stated that from the F_0 measured value, force acting on the weft and depending on z, can be well approximated in the air tunnel of the confusor drop wire, if the following is known: the determined dimensionless velocity distribution of the examined air guide mode (see Thesis 1), weft diameter and surface friction coefficient (see Thesis 2).

Thesis 4

For the examined confusor drop wire, profile reed air guide modes and the forces acting on the weft, the followings can be stated (Fig. 7):

- Arising from the flow conditions, in the case of confusor drop wire line air guide, air flow in the direction of insertion $\frac{x}{b} < 0.1$ range, will decrease exponentially, similarly to the starting air flow of cylindrical free air jet. In the case of $\frac{x}{b} > 0.2$, in the confusor line flow velocity will decrease less, but its value will be lower than that of the velocity measured in the profile reed tunnel. Thus surface friction force acting on the yarn will be less but more uniform.
- In the case of profile reed air guide mode, if $\frac{x}{b} > 0.1$ then flow can be considered as periodical. The average value of the insertion air velocity along the reed width will not change. Because of velocity fluctuation the force acting on the weft will change on the other hand.

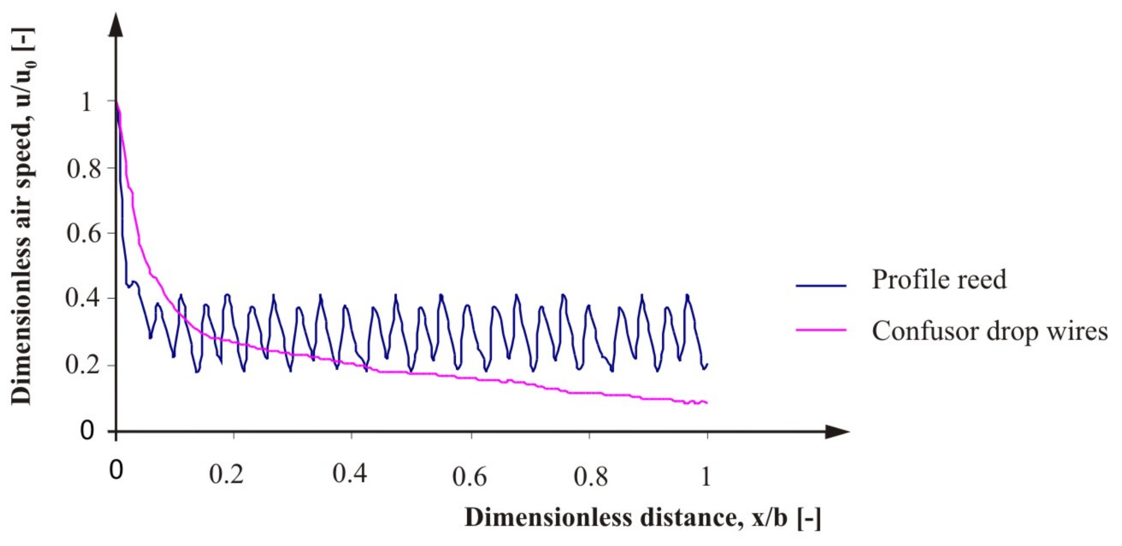

Figure 7 Comparison of air flows at the examined air guide modes

Thesis 5

Due to the measurement results and the theoretical and practical considerations in order to diminish the number of weft insertion faults the air consumption the below statement can be made:

- In the beginning the relay nozzle groups of profile reed air jet weaving machines consisted of 5 relay nozzles. At the Dornier air jet weaving machine examined under industrial conditions the relay nozzles are operated in groups of four (Fig. 8). To ensure more uniformity in the air flow generated by the relay nozzles – which carry the weft – I recommend that controlling of the flow zone be realized with smaller groups of relay nozzles or by individual relay type of controlling. By reducing the passage length of the air flow the consumption of compressed air can also be decreased.

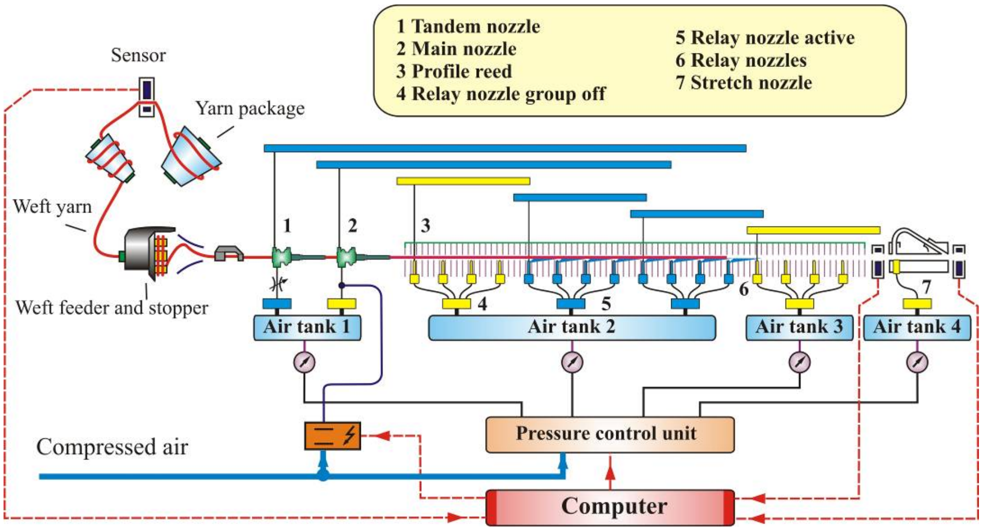

Figure 8 Schematic of air jet insertion with profile reed and air system diagram

4. Major publications concerning the research work

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5. Patkó I., Szabó L.: Vetülékbeviteli elvek összehasonlító elemzése.
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15. Bodor Á., Szabó L.: Profilbordás légsugaras szövőgép segédfúvókájának áramlástani szimulációja.
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4. Szabó, L.: Pneumatic Weft Insertion of Profile Reed in Air Jet Looms
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