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WEFT INSERTION THROUGH OPEN PROFILE REED IN AIR JET LOOMS

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ABSTRACT: *The air jet looms are widespread in the textile industry because of their high productivity and versatility. In air jet weaving the weft yarn is transported through the weft passage by means of flowing air. The weft yarn ejected with high speed air flow is carried by the drag force caused by friction between the yarn and the air that comes through the nozzles from a high pressure tank, though the energy consumption is much bigger than that of the other weaving machine types. The aim of this analysis is to determine the distribution of the flow velocity in the weft passage. The air flow velocity at the exit of the accelerating tube and in the U-shaped cross section profile reed determines the motion of the yarn in weft passage. The velocity distribution of air flow without weft yarn was measured and examined at different tank pressures. The velocity distribution of air flow coming from the main and relay nozzles in the weft passage was measured by Pitot tube. The measured data in laboratory are approximated with Fourier series by means of Discrete Fourier Transform which makes possible to determine the air velocity of weft insertion. Knowing the maximum speed of the air velocity at the inlet of the profile reed the service data can be obtained in any location in the weaving width.*
KEYWORDS: *Air jet loom, weft passage, profile reed, main nozzle, relay nozzle, weft insertion*

INTRODUCTION

Intermittent weaving machines have the property that the weft is repeatedly laid into shed and tightened to the selvedge one after the other. This procedure is repeated during the whole weaving. The structure of these weaving machines is designed according to the characteristics of weft insertion. Figure 1 shows classification of weaving machines.

It is a general characteristic of weaving machines without shuttle that the length of one shoot of yarn is measured by the weft accumulator and it is removed and taken into the shed by the air flow of the main nozzle and relay nozzles. The weft is cut on the side of the main nozzle with each shoot at the selvedge.

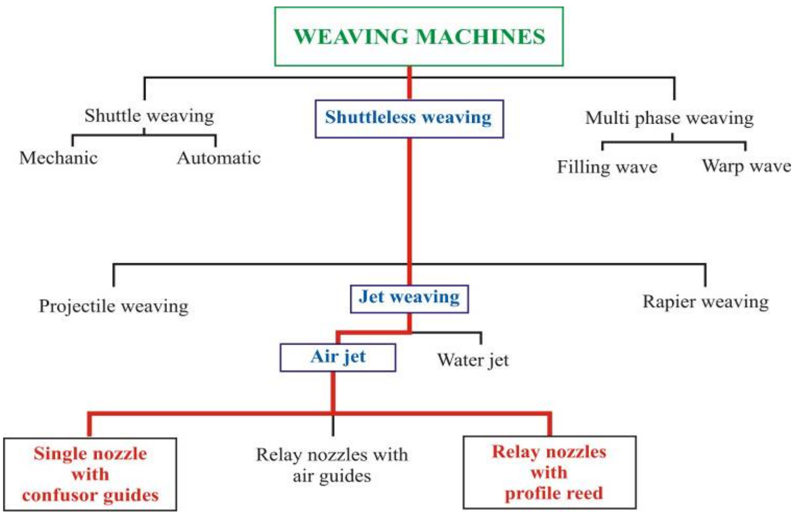

Figure 1. Classification of weaving machines

The first commercial machine was the Maxbo air jet weaving machine which was introduced by Max Paabo and first exhibited in Sweden in 1951 weaving cotton cloth 80 cm wide with a frequency of 350 picks a minute. In 1969 Te Strake developed the filling insertion system with main nozzle, relay nozzles and U-shaped cross section profile reed.

The air jet weaving machine combines high performance with low manufacturing requirements. It has an extremely high insertion rate. The advantages of air jet looms are [1]:

- *high filling insertion rates*
- *high productivity*
- *low initial outlay*
- *simple operation and reduced hazard because of few moving parts*
- *reduced space requirements*
- *low noise and vibration levels*
- *low spare pats requirement*
- *reliability and minimum maintenance.*

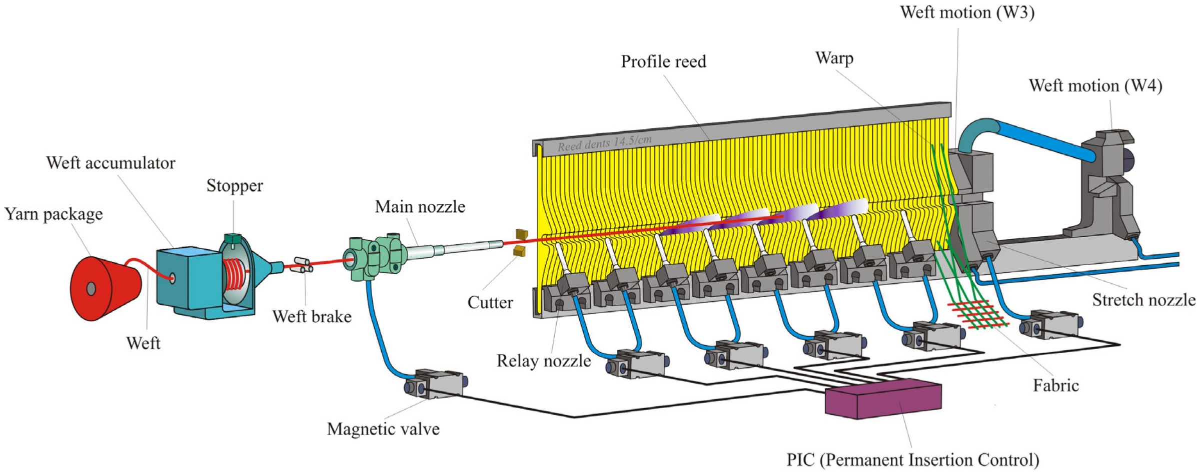

Figure 2. Air jet filling insertion with open profile reed

Air jet weaving machines are under constant development. Current research is mainly focused on interaction between air and yarn as well as the guide system to increase the yarn velocity.

INSERTION CONFIGURATIONS, NOZZLES AND YARN FLIGHT IN THE WEFT PASSAGE OF PROFILE REED

The movement of the inserted yarn in weft passage is a complex motion. It is not a positively controlled process. Three different systems have been used on commercial air jet looms (Figure 1):

1. *Single nozzle, confusor guides and suction on the other side (Figure 3)*
2. *Multiple nozzles with guides*
3. *Relay nozzles with profile reed (Figure 2).*

In system 1 a single nozzle is used to insert the yarn with air guide. Confusor drop wires are placed across the entire width to guide the air stream which is injected into the open shed Figure 3). Weaving machines with this configuration are of limited reed width (about to165 cm) [4, 5].

In system 2 in addition to the main nozzle relay nozzles are used. They are arranged across the warp width at certain intervals and inject air sequentially and in groups in the direction of yarn movement. System 3 has reed dents built in the reed and relay nozzles (also called subnozzles) across the open warp (Figures 4 and 5). With the profile reed, the restriction on warp density also less severe than in the case of the confusor guide system. Although all the three systems have been used on air jet looms, system 3 relay nozzles with profile reed is the standard in the market today [1].

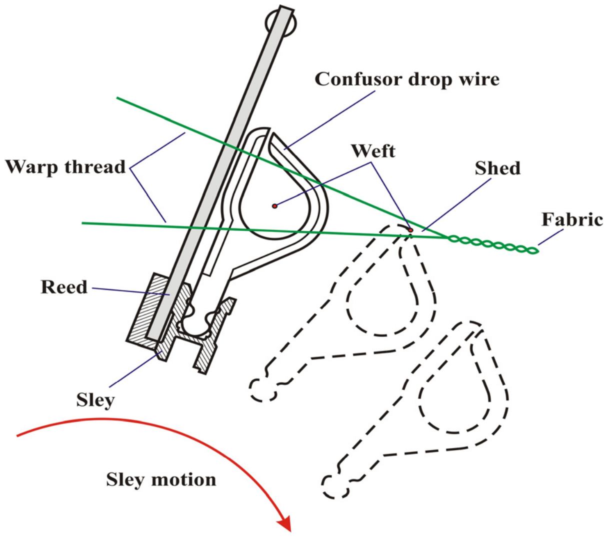

Figure 3. Displacement of confusor drop wire

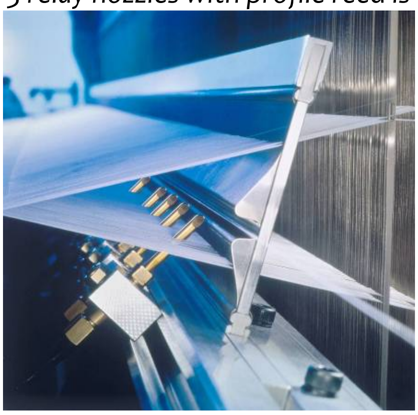

Figure 4: Relay nozzles and profile reed on an open shed

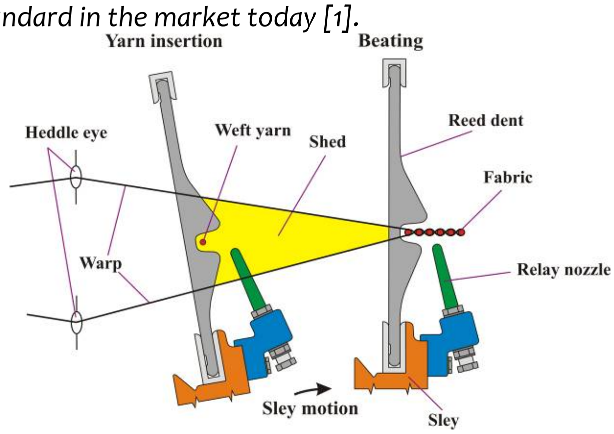

Figure 5: Yarn insertion system with relay nozzles and open profile reed

Relay nozzles are placed along the reed width on the sley (Figures 2 and 4). A relay nozzle can have either single circle hole or two holes or nine holes or multiple holes (19 of them), as well as single hole of different shapes (rectangle, ellipse or star) (Figure 6).

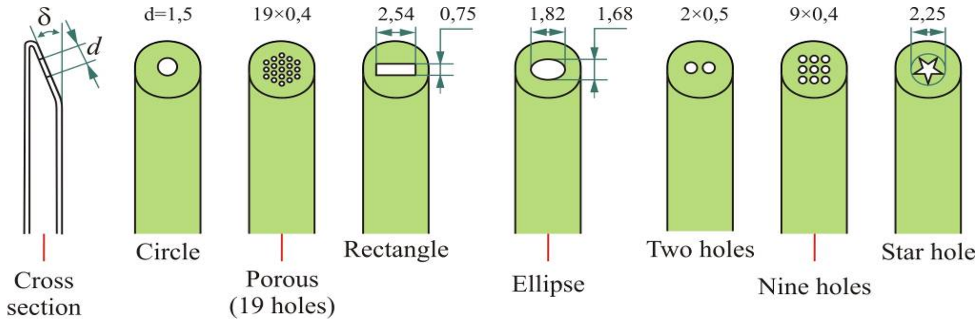

Figure 6. Commercial relay nozzles [8]

DYNAMICS OF YARN INSERTION WITH AIR IN WEFT PASSAGE ON PROFILE REED AIR JET LOOMS

In the nozzles the compressed air generates kinetic energy. The air erupting from the circular cross section slot at high speed grabs the weft yarn into the middle of the nozzle and accelerates it to high speed. The transporting substance, the air has a complicated flow. The exact theoretical and mathematical description of the flow is not known.

The propelling force on a weft yarn placed in a stream of air consists of skin friction (equal to the sum of all shear stresses taken over the surface of the yarn). This force parallel to the undisturbed initial velocity is referred to as the friction force F_f as shown in Figure 7.

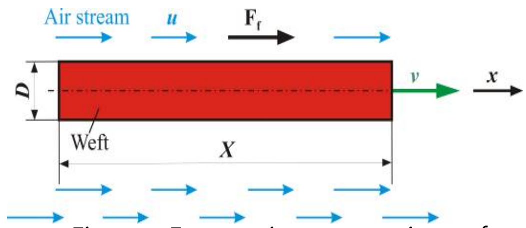

Figure 7. Force acting on a moving weft yarn in air flow

The propelling force to move the weft yarn in air jet insertion is provided by friction between the air and yarn surface and given by the following form:

$$F_f = \frac{\pi}{2}\rho \cdot c_f \cdot D \cdot X \cdot (u-v)^2 \tag{1}$$

where: ρ - air density; $[kgm^{-3}]$, c_f - skin friction coefficient; [-], D - weft yarn diameter; [m], X - weft yarn length subject to air flow; [m], u - air velocity; $[ms^{-1}]$, v - weft yarn velocity; $[ms^{-1}]$.

This force is proportional to the square of the relative velocity between the air stream and yarn. The propelling force increases with grow of the air velocity and the weft yarn diameter. The dimensionless coefficient c_f depends on Reynolds number. The turbulence of the air flow slows down the moving of the weft yarn. This causes deviation of the yarn from the centre of the flow. Therefore the turbulence level should be minimal. However, it is impossible to insert the yarn in laminar flow because the air velocity would be very low [1]. The force acting on the weft in the accelerating tube of the main nozzle can be written by the following formula (Figure 6 and 7):

$$F_{mf} = \frac{\pi}{2}\rho \cdot c_f \cdot D \cdot L \cdot (u-v)^2 \tag{2}$$

where: F_{mf} - air friction force on the yarn by relay nozzles in the main nozzle; [N], L - length of the acceleration tube; [m].

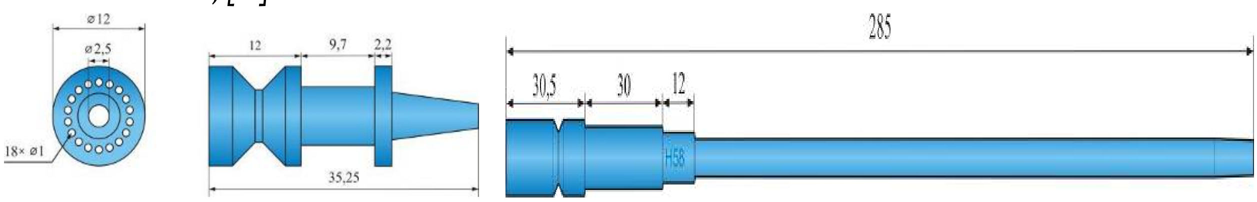

Figure 8. Schematic diagram of main nozzle needle and acceleration tube [6]

The equation of motion for the weft in air flow, based on Newton's second law, can be written as (Figure 9) [2]:

$$m \cdot a = m \cdot \frac{d^2 s}{dt^2} = F_{mF} + F_{rf} - F_1 \tag{3}$$

where: m - total yarn mass involved in the motion; [kg], a - acceleration of the weft tip; $[m \cdot s^{-2}]$; s - length of the inserted weft; [m], F_{rf} - air friction force on the yarn by relay nozzles; [N]. F_1 - take down force; [N].

According by the weft yarn is stressed or loose in the open shed its mass has to be determined in different way (Figure 9). In case of stressed weft yarn:

$$m = l \cdot T_{tex} \cdot 10^{-6} \quad (4)$$

and for the loose weft yarn

$$m = (l + s) \cdot T_{tex} \cdot 10^{-6} \quad (5)$$

where: l - length of the stressed weft; [m], s - length of the inserted weft; [m], T_{tex} *- linear density of the weft; [tex].*

The formula of beginning accelerating motion section for the stressed weft yarn in air flow, based on Newton's second law, can be written as follows:

$$a = \frac{dv}{dt} = \frac{\sum F}{m} = \frac{10^6}{l \cdot T_{tex}} \cdot \left(F_{mf} - F_1\right). \quad (6)$$

For loose weft when the speed of yarn is approximately constant:

$$a = \frac{dv}{dt} = \frac{\sum F}{m} = \frac{10^6}{(l + s) \cdot T_{tex}} \cdot \left(F_{mf} + F_{rf} - F_1\right) = 0. \quad (7)$$

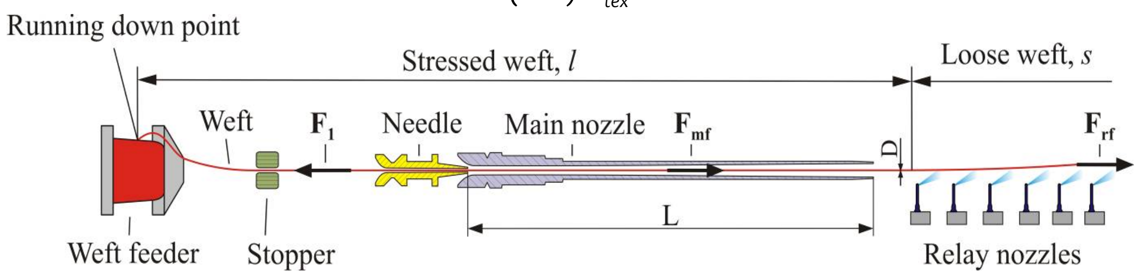

Figure 9. Weft motion in air flow of the main and relay nozzles

ARRANGEMENT OF PROFILE REED AIR JET LOOMS, MEASURING LAYOUT AND MATHEMATICAL METHOD

In the Textile Workshop of Óbuda University there was examined the flow conditions of air jet weaving machines under laboratory and industrial conditions (Figures 13 and 14). Figure 11 shows the layout of the laboratory bench.

We made the bench from parts used on weaving machines based on the actual dimensions of the weaving machine, which is suitable to measure the velocity distribution developing in the axis of the insertion $u = f(x)$*. When designing the bench our aim was that the actual weaving machine conditions should be simulated as large extent as possible. Measuring on operating machines is not possible due to the swaying of the reed.*

Figure 10 shows the outline of main parts of the profile reed air jet weaving machines. Weft yarn is drawn from a filling supply package by the filling feeder insertion by means of a stopper.

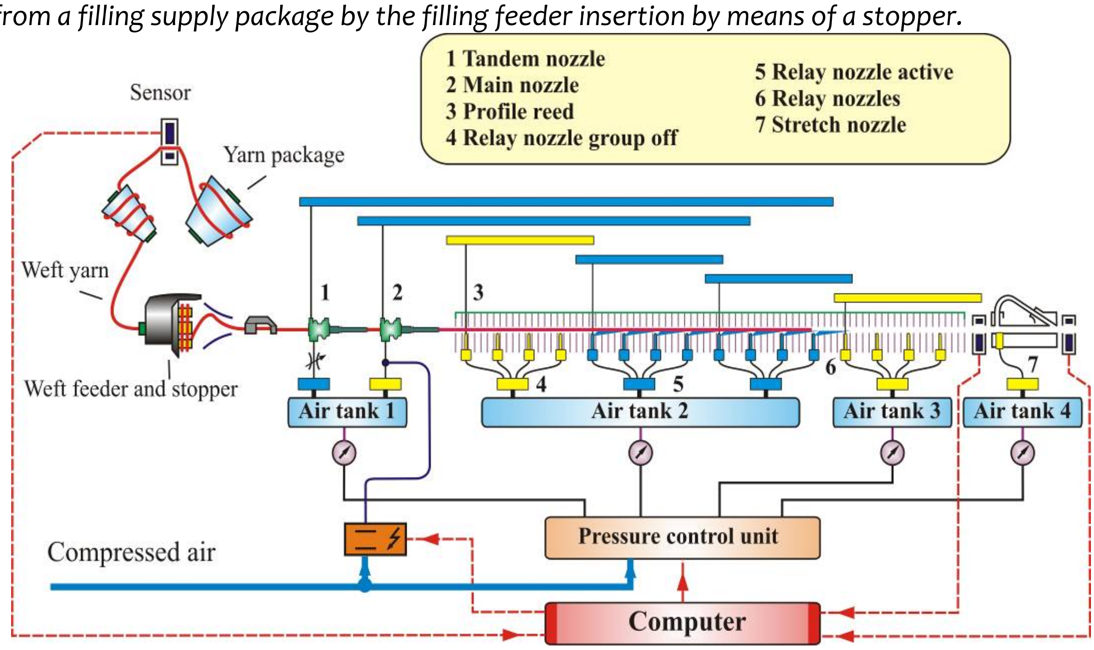

Figure 10. Schematic of air jet insertion with profile reed and air system diagram

The arrangement of the experimental equipment is shown in Figure 11. Experimental equipment included the bench test board with a U-shaped profile reed segment, main nozzle, relay nozzles, a pressure sensor and a stepper motor. The profile reed segment had an overall length of 750 mm, a density of 14.5 dents/cm, profile dents with a thickness of 0.24 mm and a cavity ratio of 65 %. The compressed air from the main air tank was led to the main nozzle and to the groups of the four relay nozzle through a pressure regulator and a mass flow meter (Figure 11).

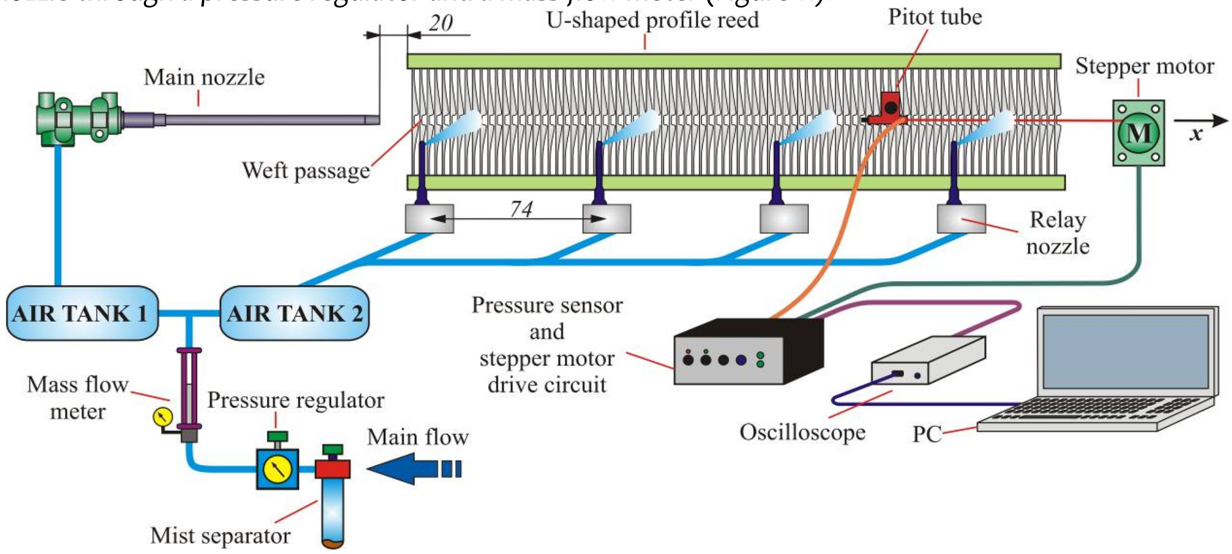

Figure 11. Schematic diagram of the test apparatus

The direction of the velocity measurement was the x-axis. Figure 12 shows position of the measuring point in the U-shaped weft passage. A Pitot tube was used for measurement of the air velocity along the axis of the air flow into the profile reed segment. The output change in pressure Δp value from the Pitot tube was proportional to air velocity. The data Δp measured by an analogue pressure sensor were converted to digital values by a DSO 2090 oscilloscope and a personal computer (Figure 11). Pitot tube was driven by a stepper motor and it was moved with constant speed.

The supply air pressure to the main nozzle and the relay ones was set with a pressure regulator to a gauge pressure 5 bar. The supply mass flow rate $\dot{m}_0$ at this time was $6\,g \cdot s^{-1}$ under standard conditions of $20^{\circ}C$ and 1 bar.

The velocity distribution along the profile reed cannot be expressed by a closed formula in function of x. Therefore was applied the Discrete Fourier Transform (DFT) to the velocity of the air flow in order to determine the approximate velocity in any x location.

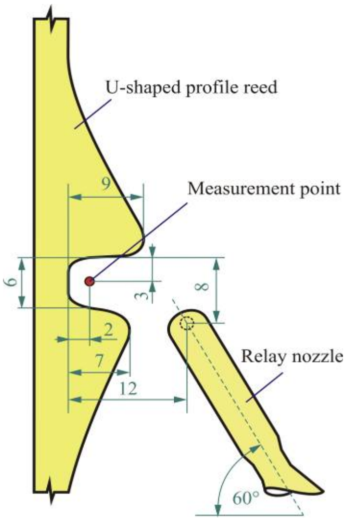

Figure 12. Measurement point of air velocity in the weft passage [7]

Figure 13. Layout of measuring bench

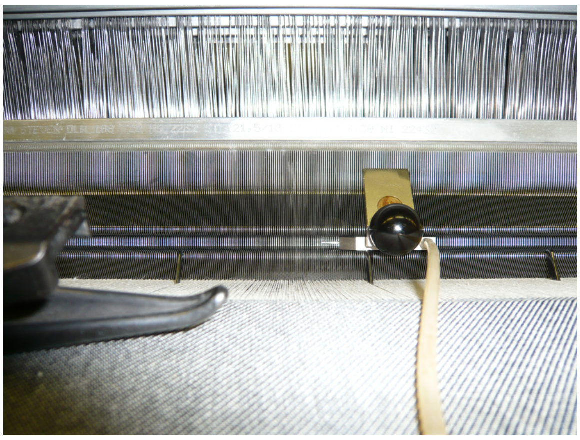

Figure 14. Pitot tube in the weft passage

Generally the approximation by the Fourier series for a function $f(x)$ with a period p:

$$f(x)=\frac{a_o}{2}+\sum_{k=1}^{\infty}(a_k\cdot\cos\frac{2k\pi}{p}x+b_k\cdot\sin\frac{2k\pi}{p}x) \qquad x\in(0,p) \tag{8}$$

where the Fourier coefficients a_k and b_k :

$$a_k=\frac{2}{p}\int_0^p f(x)\cos\frac{2k\pi}{p}xdx \quad \text{and} \quad b_k=\frac{2}{p}\int_0^p f(x)\sin\frac{2k\pi}{p}xdx. \tag{9}$$

In this discrete case and if $k=0$:

$$a_o=\frac{2}{p}\int_0^p f(x)dx \Rightarrow \frac{a_o}{2}=\frac{\int_0^p f(x)dx}{p}\cong\frac{\sum_{i=0}^{n-1}u_i}{n} \tag{10}$$

where: n - number of measurements in equidistant points $n=935$; [-]; u_i - measured velocities along the reed width at $i\cdot\Delta x\,(\Delta x=0.08\,cm)$; $[m\cdot s^{-1}]$.

$$a_k=\frac{2}{n}\cdot\sum_{i=0}^{n-1}u_i\cdot\cos\frac{2\pi ki}{n} \quad \text{and} \quad b_k=\frac{2}{n}\cdot\sum_{i=0}^{n-1}u_i\cdot\sin\frac{2\pi ki}{n} \qquad k=1,2,\dots r-1 \tag{11}$$

The approximate value of the at any x can be obtained:

$$u=\frac{a_o}{2}+\sum_{k=1}^{r-1}[a_k\cdot\cos(\frac{2\pi k}{n}x)+b_k\cdot\sin(\frac{2\pi k}{n}x)] \qquad x\in(0,p) \tag{12}$$

MEASURING RESULTS AND DISCUSSION

Examination of velocity of air flow in the weft passage has been given the next measuring results. The values of the air flow velocity distribution along the weft passage depend on two variables: pressure of main tank and distance in the direction x.

The maximum air velocity at the entrance of the profile reed u_o is $268.94\,m\cdot s^{-1}$. Figure 15 sows the velocity distribution at $p_t=5\,bar$ tank pressure. In Excel Visual Basic program has been written to obtain the numerical values of the velocity.

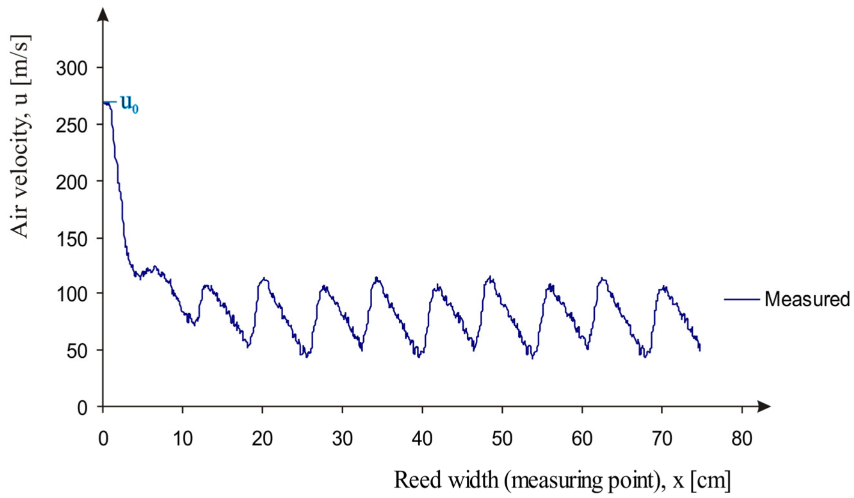

Figure 15. Distribution of the air velocity in the x-axis

The velocity of air flow in the weft passage decreases rapidly to $x=5\,cm$ and at this point the air velocity is $113.23\,m\cdot s^{-1}$. Influence of the first relay nozzle stands out in range $5\,cm<x<11.8\,cm$ and subsequently periodical with $x=7.4\,cm$ periodicity. Figures 16 and 17 showed the simulation of the flows from the main nozzle and from a relay nozzle.

Figure 18 shows the Fourier approximation in undimensioned form obtained by division with the maximum speed u_o and of the data $i\cdot\Delta x$ with the reed width w. The character of dimensionless function does not depend on main tank pressure p_t.

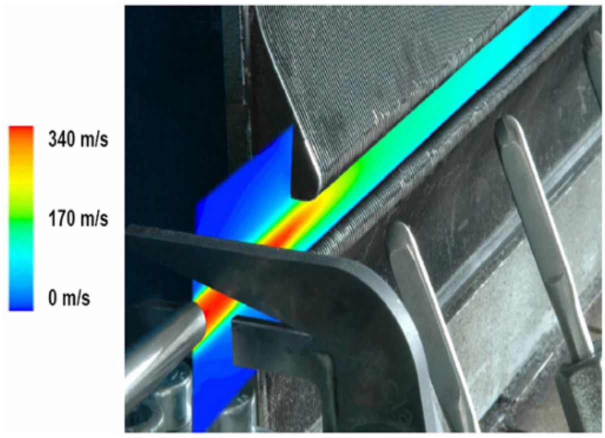

Figure 16: Air flow from main nozzle [3]

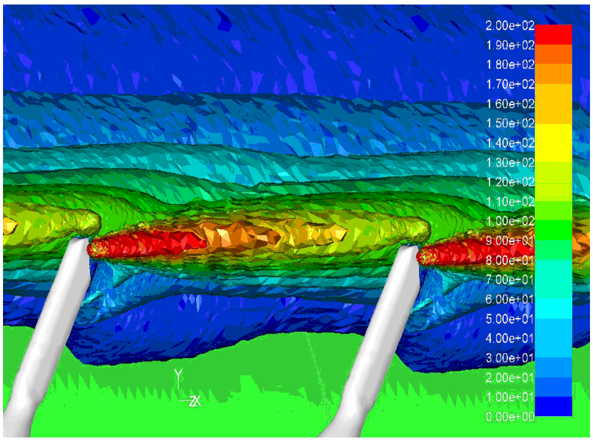

Figure 17: Air flow from relay nozzles [9]

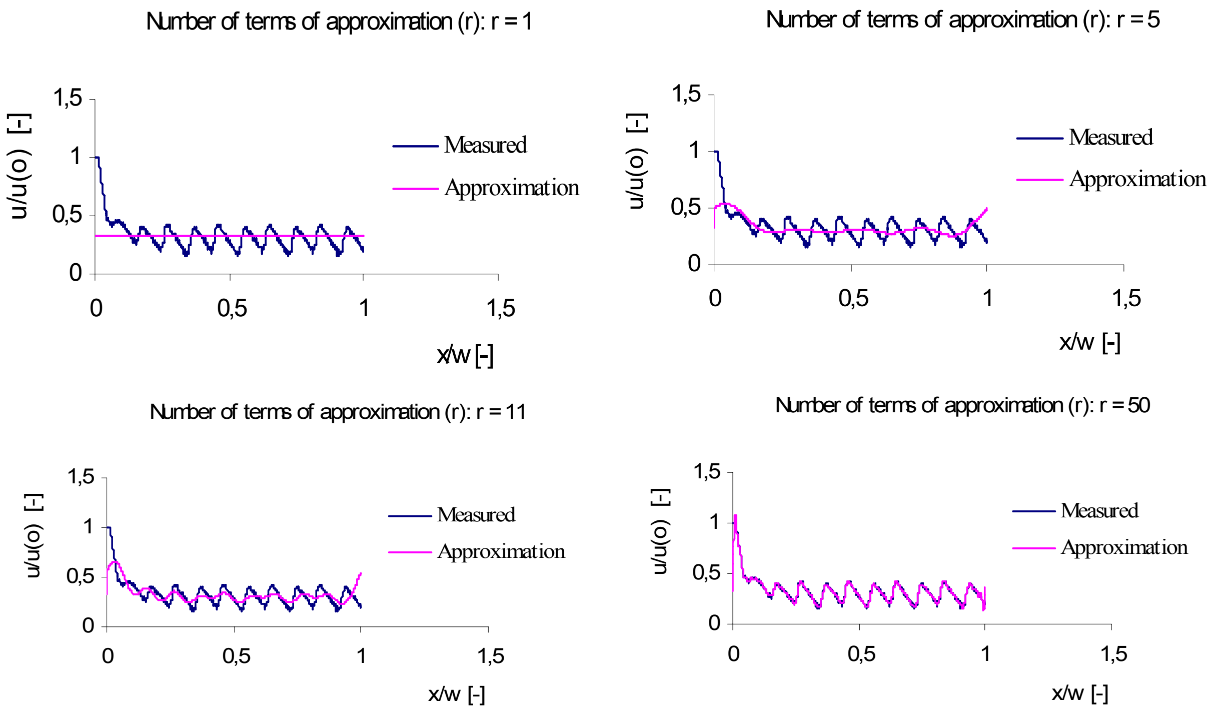

Figure 18. The approximation of the Fourier series with growing number of terms

CONCLUSIONS

This paper dealt with the U-shaped profile reed air guidance solution. The velocity distribution in the weft passage was investigated. Weft insertion through weft passage by air is a very complicated process.

Main research findings:

- *The air flow field in the weft passage may be divided into two parts.*
- *The first part, the only effect of main nozzle, the initial section, where the characteristics of axial velocities are similar to the flow of free air jet. The velocity of air flow in this range decreases rapidly.*
- *The second part, effect of relay nozzles, is the nearly periodical part of flow.*

In this research there is determined the characteristics of the axial velocities in the U-shaped weft passage. The main results are summarized as follows:

1. *The ratio of the variation in axial velocities u/u_0 was determined independently of the main tank pressure.*
2. *The DFT is suitable for the calculation of the approximate axial air velocities in weft passage if the maximum air velocity u_0 is known at the entry point of the profile reed.*

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