

Material Transport with Air Jet

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Abstract: In the field of industry, there are only a very few examples of material transport with air jet, and one of these is the air jet loom. In this weaving technology, the weft (the transversal yarn of the fabric) is shot by air jet. This paper will set up the mathematical model of yarn end movement. For a special case, I will specify a solution of the model.

1 Brief Description of Air Jet Looms

In air-jet looms, the weft is introduced into the shed opening by air flow.

The energy resulting from air pressure is converted into kinetic energy in the nozzle. The air leaving from the nozzle transfers its pulse to stationary air and slows down.

To this end, in order to achieve a larger rib width, V. Svaty developed in 1947 a confuser, which maintains air velocity in the shooting line.

The confuser drop wires are profiles narrowing in the direction of shoot, and they are of nearly circular cross section open at the top. These drop wires are fitted one behind the other as densely as possible. Therefore, they prevent in the shooting line the dispersion of air jet generated by the nozzle.

Fig. 1.1 shows the arrangement and design of the confuser drop wires applied in machines of the P type, as well as the arrangement schematic of weft intake. The nozzle (1) is secured to the machine frame, and the confuser drop wires (2) and the suction pipe (3) are fixed to the loose reed.

The confuser drop wires are profiles narrowing in the flow direction, and they have a conicity of 6° . These profiles (section A) may be made of metal (Fig. 1.1 a) or plastic (Fig. 1.1 b).

To be considered almost as a closed ring from the aspect of flow, a baffle plate of nearly circular cross section is placed on top of the latter.

In the top part – in comparison with the metal confuser – they substantially reduce the air outflow, and therefore the reduction of air jet velocity will be smaller in the direction of shoot in the confuser drop wires.

The slay (1) is oscillated by a specific drive mechanism, to make sure that during the shoot, the swinging motion of confuser drop wires does not possibly influence the conditions of flow. This is because in case the displacement of the confuser drop wires is large during the shoot, the air flow conditions are unfavourable from the aspect of introducing the weft into the shed, and hence the warps may reach into the inner space of the confuser.

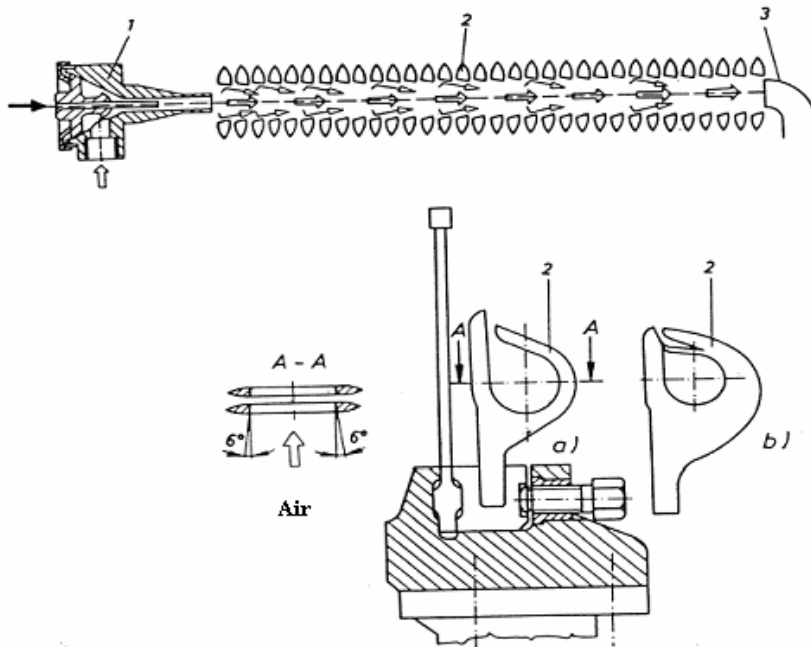


Figure 1.1

Arrangement and design of the confuser drop wires applied in a type P machine

a/ metal confuser and its fixing,

b/ plastic confuser

In a type P machine, the nozzle is secured to the machine frame, while the confuser drop wires swing with the rib (Fig. 1.2).

During the shoot, the nearly stationary position of the slay is ensured by an eccentric articulated movement. In machine P 165 mentioned as an example, the introduction of the weft is carried out in 0.08 sec, four times in a second.

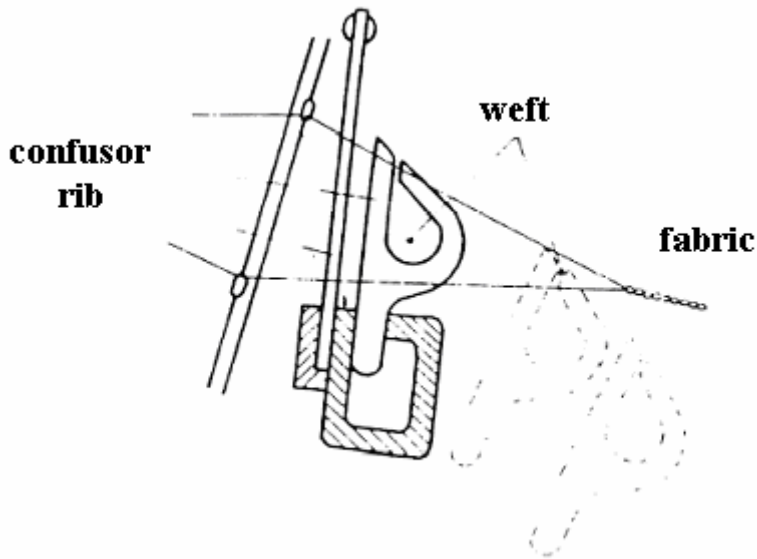


Figure 1.2
Movement of the confuser drop wires

By the application of the confuser drop wires, a rib width of $b=165$ cm was achieved. This is where the name of loom type P 165 comes from. The confuser drop wires cover 75 to 85% of the rib width.

The design of the loom nozzle is shown in Fig. 1.3, indicating the velocity patterns of the air leaving the nozzle, in addition to the weft.

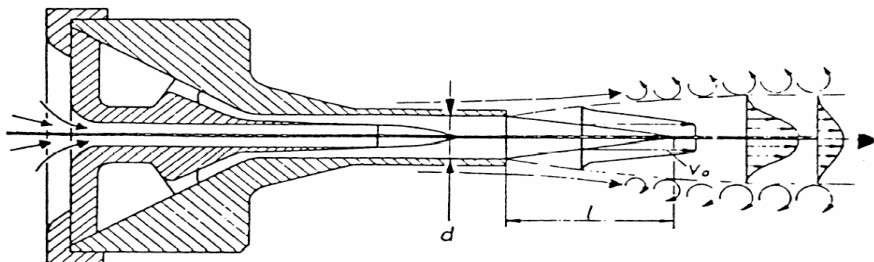


Figure 1.3
Velocity distributions evolving in the nozzle

In front of the nozzle there is a yarn box, the function of which is to store one shoot of yarn. The box is designed in a way that the yarn can be removed from it almost without resistance.

One type of these boxes is the pneumatic yarn box (Fig. 1.4).

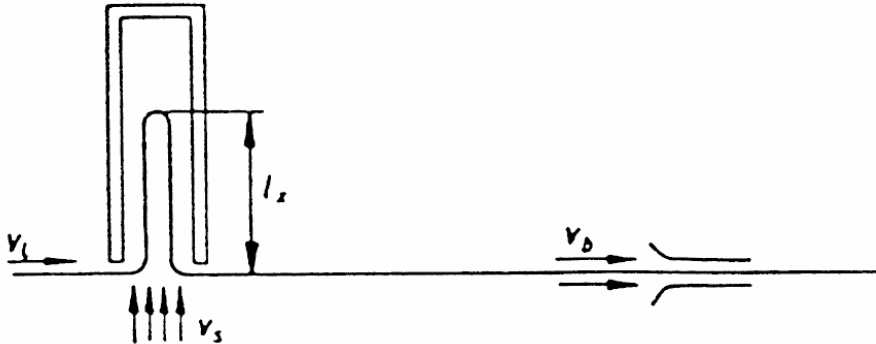


Figure 1.4
Pneumatic yarn box

The pneumatic yarn box has a simple design, and it stores the yarn of specified length in a tube with a slow airflow, in the form of a loop. For introducing the weft, depending on the structure of the yarn, compressed air of 1.5 to 3.0 bar pressure is required.

2 Relationship between Yarn and Air

The equilibrium of forces imposed on the yarn placed into the airflow:

$$\frac{d}{dt} I = \int_{x=0}^1 dF_1 + F_s \quad (2.1)$$

where

I : pulse of the yarn

F_1 : force resulting from the liquid friction of yarn and air

F_s : force resulting from the friction between yarn and a different solid body.

Hereinafter the friction force F_s will be disregarded, because the yarn comes out of the storing box almost without friction.

Inside the nozzle, the yarn proceeds in the yarn guide, and it is only exposed to the carrying air after leaving the nozzle.

The paper [33] deals with nozzles, in which the yarn proceeds along the nozzle over a distance of approx. 100 to 150mm, and the yarn is already exposed to the air within the nozzle. This paper only deals with the relationship between the flow outside the nozzle and the yarn. Furthermore, using the consideration as a point of

departure that the magnitude of friction force does not depend on the size of the surfaces in friction and that the weft intake is a quasi-stationary process, in addition to concentrating strictly on the relationship between the yarn and the air, the friction force F_s is disregarded.

Therefore, the model to be set up will not be comprehensive, but it will be appropriate for defining the basic characteristics of the yarn/air relationship evolving along the axis of intake.

Hence, the mechanical equilibrium describing the relationship between the weft of the pneumatic loom P165 and the weft intake flow is as follows:

$$\frac{d}{dt}I = \int_{x=0}^1 dF_1 \quad (2.2)$$

The relationship between the yarn and the air is shown in Fig. 2.1.

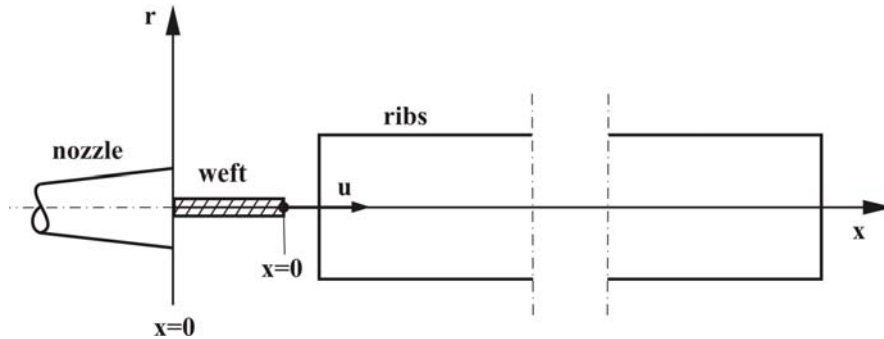


Figure 2.1
Relationship between yarn and air

- u: yarn end velocity at the examined point
- v: air velocity at the examined point
- m: mass of yarn surrounded by air jet
- ρ_i : air density
- A: length of yarn protruding from the nozzle at the start of intake
- C: yarn resistance factor
- D_f : characteristic yarn diameter
- ρ_f : yarn density

Using the symbols above, equation (2.2) is:

$$\frac{d}{dt}(\mu) = \int_{x=0}^x dF_f \quad (2.3)$$

where

$$F_f = \frac{\rho_1}{2} CD_f \pi (v - u)^2 x \quad (2.4)$$

with differential rates:

$$dF_f = \frac{\rho_1}{2} CD_f \pi (v - u)^2 dx \quad (2.5)$$

the yarn mass is:

$$m = \rho_f \cdot \frac{D_f^2 \pi}{4} x \quad (2.7)$$

substituting (2.7) and (2.6) into (2.2):

$$\frac{d}{dt} \left(\rho_f \cdot \frac{D_f^2 \pi}{4} x u \right) = \int_{x=0}^x \frac{\rho_1}{2} CD_f \pi (v - u)^2 dx \quad (2.8)$$

by introducing the following symbols:

$$\rho_f \cdot \frac{D_f^2 \pi}{4} = Z \quad \text{and} \quad \frac{\rho_1}{2} CD_f \pi = B \quad (2.9)$$

the new form of equation (2.8) is:

$$Z \frac{d}{dt} (xu) = B \int_{x=0}^x (v - u)^2 dx \quad (2.10)$$

after performing the specified derivation

$$Z \left(u \frac{dx}{dt} + x \frac{du}{dt} \right) = B \int_{x=0}^x (v - u)^2 dx \quad (2.11)$$

$$\frac{dx}{dt} = u$$

The equation describing the movement of yarn end is:

$$Z \left(u^2 + x \frac{du}{dt} \right) = B \int_{x=0}^x (v-u)^2 dx \quad (2.12)$$

After making the equation dimensionless by the highest flow rate (V) prevailing in the entrance cross section of the drop wires, and by the length of protruding yarn end (A), the dimensionless kinetic equation of the yarn end is:

$$\left(\frac{u}{V} \right)^2 + \left(\frac{x}{A} \right) \frac{d \left(\frac{u}{V} \right)}{d \left(\frac{tV}{A} \right)} = \frac{AB}{Z} \int_{\left(\frac{x}{A} \right)=0}^{\left(\frac{x}{A} \right)} \left[\left(\frac{v}{V} \right) - \left(\frac{u}{V} \right) \right]^2 d \left(\frac{x}{A} \right) \quad (2.12)$$

The dimensionless quantities featuring in (2.12) are:

$$\frac{u}{V} = u^* ; \quad \frac{x}{A} = \xi ; \quad \frac{v}{V} = v^* ; \quad \frac{tV}{A} = T ; \quad \frac{AB}{Z} = K$$

With the new symbols, the dimensionless kinetic equation is:

$$u^{*2} + \xi \frac{du^*}{dT} = K \int_{\xi=0}^{\xi} (v^* - u^*)^2 d\xi \quad (2.13)$$

3 Solution of the Dimensionless Equation Describing the Yarn Movement

$$u^{*2} + \xi \frac{du^*}{dT} = K \int_{\xi=0}^{\xi} (v^* - u^*)^2 d\xi \quad (3.1)$$

On the right-hand side of the kinetic equation, the integrated square of relative velocity is featured. Due to squaring, the square of relative velocity is always positive, which could lead to calculation troubles. In the course of a computer solution, in order to avoid sign problems resulting from eventual automatisms, it is advisable to modify (3.1) as follows:

$$u^{*2} + \xi \frac{du^*}{dT} = K \int_{\xi=0}^{\xi} (v^* - u^*) \sqrt{(v^* - u^*)^2} d\xi \quad (3.2)$$

The dimensionless flow rate (v^*) featuring in the equation (3.2) is only subject to the place, i.e.:

$$v^* = f(\xi)$$

while the yarn end velocity is subject to the time, too, i.e.:

$$u^* = f(T; \xi)$$

If it is assumed that the yarn behaves as a rigid body during its movement, when calculating the right-hand side integral in (3.2) $u^* \neq f(\xi)$ i.e. the yarn end velocity is not subject to the place, therefore

$$u^* = f(T)$$

in the course of solving (3.2), the initial condition is:

$$u^* = 0; \quad \xi = 1$$

that is

$$\frac{du^*}{dt} = K \int_{\xi=0}^{\xi} v^{*2} d\xi \quad (3.3)$$

By numeric integration from (3.2), at time $T = 0$, at place $\xi = 1$ (at the moment of

starting the yarn), the initial acceleration $\frac{du^*}{dt}$ can be calculated. After a time ΔT has passed – during which the rate of acceleration is assumed to be constant – the position of the yarn end

$$\xi = 1 + \frac{1}{2} \frac{du^*}{dT} \Delta T^2 \quad (3.4)$$

and the velocity of the yarn end

$$u^* = \frac{du^*}{dT} \Delta T \quad (3.5)$$

can be calculated in a rough correlation.

And then, from (3.2), the rate of ξ acceleration applying to place $\frac{du^*}{dt}$ can be calculated by the following formula:

$$\frac{du^*}{dT} = \frac{K}{\xi} \int_{\xi=0}^{\xi} (v^* - u^*) \sqrt{(v^* - u^*)^2} d\xi - \frac{u^{*2}}{\xi} \quad (3.5)$$

the new position of the yarn end is:

$$\xi = \xi_{el\delta z\delta} + \frac{1}{2} \frac{du^*}{dT} \Delta T^2 + u_{el\delta z\delta}^* \Delta T \quad (3.7)$$

and here the velocity of the yarn end is:

$$u^* = u_{el\delta z\delta}^* + \frac{du^*}{dT} \Delta T \quad (3.8)$$

where the 'previous' index is a distinguishing symbol of the place of calculation directly preceding the actual calculation and of the velocity applying there.

In the course of a numeric solution, the equation must be solved by the rate $\Delta T =$ constant, and the change in the velocity of the yarn end subject to the place is to be determined:

$$u^* = f_1(\xi)$$

Next, by reducing the value ΔT , a new velocity distribution can be defined:

$$u^* = f_2(\xi)$$

The solution is to be repeated – always with a smaller ΔT – until the square sum of the deviations of the two solutions following each other will be smaller than a pre-specified rate (H). The value of constants required for the solution is: on the basis of mine measuring [].

$$K = \frac{AB}{2} = A \frac{\frac{\rho_1}{2} CD_f \pi}{\rho_f \cdot \frac{D_f^2 \pi}{4}} = 2 \frac{\rho_1}{\rho_f} \frac{AC}{D_f} \quad (3.9)$$

the rate of K is, if:

$$\rho_f = 1.2 \text{ kg/m}^3$$

$$\rho_f = 800 \text{ kg/m}^3$$

$$D_f = 0.002\text{m}$$

$$A = 0.02\text{m}$$

$$C = 0.3$$

$$V = 72\text{m/s}$$

$$\mathbf{K} = 9 \cdot 10^{-3}$$

$$T = 20$$

$$H = 0.001$$

The solution is shown in diagram 3.1. The solution resulted in the rates $\Delta T = 6.5$ and $H=0.00085$. We have made the solution of (3.2) only up to the place (ξ) as long as the following situation prevailed

$$v^* \geq u^*$$

It is shown by diagram 7.1 that the yarn end velocity in the first quarter of the trajectory reaches its nearly constant value, the rate with which it covers most of the trajectory.

Furthermore, in the case of the value $\xi_k = \xi = 55$, the flow rate of the yarn end and of the transport air will be equal, that is:

$$v^* = u^*$$

In the range $1 < \xi = \xi_k$, the velocity of the yarn end is lower than that of the air, and therefore the trajectory of the yarn is definite and straight. We have solved equation (3.2) for this range only, that is:

$$\xi \leq \xi_k$$

In diagram 3.1 in range $\xi > \xi_k$, the rate u^* has been shown for guidance only. In this range the yarn does not behave as a rigid body, and therefore the starting equation (2.2) is not suitable for describing the motion. By means of the model set up, the yarn end velocity can be calculated up to the rate of $\xi = \xi_k$.

In the interval $1 < \xi \leq \xi_k = 55$, the air velocity is higher than the yarn end velocity. Therefore, in this section the trajectory of yarn end is straight. In the range $\xi > \xi_k = 0.5$ the yarn end velocity is higher than that of the transport air.

Therefore, in this section of the intake, the trajectory of yarn end cannot be defined as it only depends on spontaneous circumstances. It frequently happens in this range that the yarn end 'comes back' i.e. it is looped. If the suction aperture at the end of the rib is unable to straighten this loop, a weaving defect occurs. If the weaving width is shorter than the critical distance (ξ_k) no weaving defect is generated due to flow technology reasons.

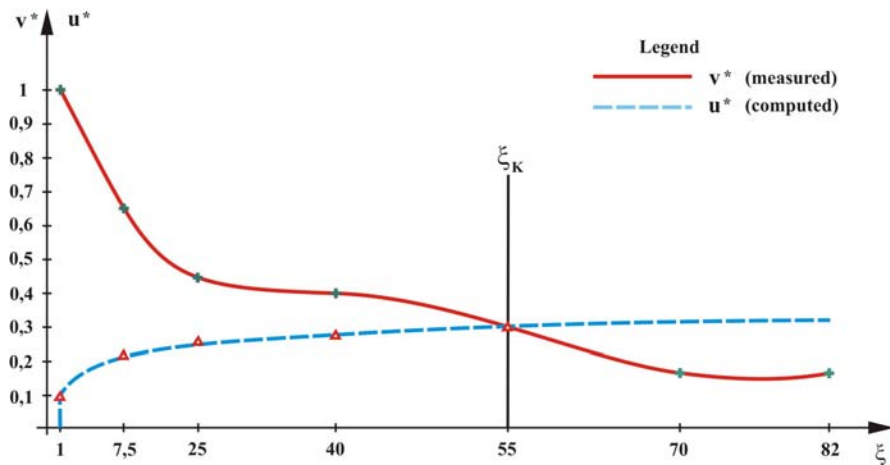


Diagram 3.1

The weaving width of the machine P165 is 165 cm, which corresponds to $\xi = 82.5$ in our dimensionless system. Consequently, on looms P 165, with technological data associated with $K = 0.009$ and with the measured – by me - function $v^* = f(\xi)$, the weaving defect resulting from the weft intake may not be (fully) avoided. The only way to exclude a weaving defect is raising the critical distance to above the weaving width (fabric width). There are two possibilities to do so:

- changing the rate of parameter K ,
- $v^* = f(\xi)$ changing the function relationship.

4 Impact of K on Weft Movement

According to (3.3), the material and flow characteristics of parts contributing to the movement feature in the dimensionless K , like the density of air, the density, diameter and air resistance factor of the yarn, as well as the length (A) of the yarn protruding from the nozzle in a stationary position ($v^* = 0$).

If $A = 0$ then $K = 0$, i.e. the yarn may not be started.

The relationship between the initial acceleration valid at the moment of starting the yarn and K according to (3.3) is the following:

$$\frac{du}{dT} = KQ \quad (4.1)$$

Where the result of integration specified by Q is constant.

By increasing the K rate, the initial acceleration of the yarn end can be increased, but at the same time the risk that the yarn end will break off increases. In the calculation shown in diagram 3.1, at $\xi=1$, the rate of initial acceleration is, which represents with the assumed values the initial acceleration

$$\frac{du}{dt} = 2566 \frac{m}{s^2}$$

of the yarn end.

5 Impact of Air Velocity (V^*) on Weft Movement

According to diagram 3.1, the critical distance (ξ_k) increases, if the air velocity (v^*) rises along the shooting line.

Increasing the air velocity may be provided by:

- increasing the supply pressure
- by designing an appropriate nozzle shape.

Increasing the supply pressure may only be imagined within a short interval, and the extent of increase heavily depends on the material characteristics of the weft.

This is because in case the supply pressure is higher than permissible, the yarn will be torn off the nozzle.

According to the description, increasing the flow rate is only possible with an appropriate nozzle shape (Laval-tube).

Conclusions

I investigated the critical distance (ξ_k) of weaving width. I specified the impact of K – which was founded by me – and the dimensionless air velocity (v^*) on weft movement.

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