Modelling of the Operating Circuit of Main Nozzle for Air-jet Looms

G.Belforte[1], G.Mattiazzo[1], F.Testore[2] and C. Visconte[1, c]

[1]Politecnico di Torino, Department of Mechanical and Aerospace Engineering, C. Duca degli Abruzzi, 24 -10129 Turin, Italy.

[2] Former Politecnico di Torino, Department of Applied Science and Technology, C. Duca degli Abruzzi, 24-10129 Turin, Italy.

[c]Orcid ID: 0000-0003-3500-9411

Abstract

This work relates to the development of a simplified analytical model describing the driving circuit of a main nozzle for air-jet looms. The model is intended as an instrument to quickly evaluate the influence of various parameters, such as pipe dimensions, valve regulations and opening/closing timing of valves, on air consumption and performance. A lumped parameter model of the system, based on the knowledge of sonic conductance and critical pressure ratio of all components, was implemented. The flow characteristics needed for simulation were experimentally determined, according to the Standards. In order to validate the model, numerical results were compared to experimental ones. The modelling methodology described is general and can be applied to circuits other than that studied herein.

Keywords: Air-jet loom, air consumption, main nozzle.

INTRODUCTION

High-speed air jets emitted by a main nozzle operate weft insertion in air-jet looms. The main nozzle works as an ejector, sucking the yarn, increasing its kinetic energy and driving it through the warp shed by friction forces. Since the main jet is scattered at a certain distance from the main nozzle, sub-nozzles are provided along the profiled reed to support the yarn during its crossing. Even though many improvements have been made to this system, the large consumption of air is probably the main drawback of this kind of loom.

Therefore, many research works have been addressed to improve the performance of main and sub-nozzles for energy saving. Many authors analysed both experimentally [1] and numerically [2-4] the influence of some parameters, including the input air pressure and the structure of nozzle core, on the internal flow field of the main nozzle. The aim was to maximize air drag force and to reduce air consumption. Some authors [5] presented an experimental work aimed at reducing air consumption by optimizing the size and the blowing time of the relay nozzles. Some other authors [6] highlighted that a correct design of the feeding duct of relay nozzles can increase their pneumatic conductance; therefore, the same effectiveness can be obtained using lower supply pressure, so to save energy.

The work herein presented deals with the development of a model describing the operating circuit of the main nozzle for air-jet looms; this model permits a fast and reliable evaluation of the influence of some major parameters, such as pipe dimensions, valve regulations and opening/closing timing of valves, on air consumption and performance. At first, a lumped parameter model of the circuit, based on the knowledge of sonic conductance and critical pressure ratio of all components, was developed. Then, the needed flow characteristics of each pneumatic component were experimentally determined, according to the Standards. Finally, numerical results were compared to experimental ones, to validate the model.

THE DRIVING CIRCUIT

Figure 1 shows a scheme of the pneumatic circuit used to drive the main nozzle of air-jet looms. The circuit is provided by: a main electropneumatic group, made up of a monostable electropneumatic valve A and a variable choke valve R_1; a monostable electropneumatic valve B; a quick-exhaust electropneumatic valve V_E; two variable choke valves R_2 and R_3; a check valve V_C; a main tank T_1; a secondary tank T_2; a pre-nozzle 1 and a main nozzle 2, placed one after the other in a tandem arrangement. The circuit has the aim to control pressure p_1 in the main tank T_1, namely the supply pressure of tandem nozzles, so to keep the weft yarn at the proper tension for the entire duration of the picking phase.

As shown, in the absence of any control signal, the so called "blow line" is active: air flows from the supply source S, at pressure p_S, to the tandem nozzles. The choke valves R_2 and R_3 control the flow rate through the blow line and, consequently, the pressure level inside the main tank T_1. In this way, the motionless weft yarn is kept tensioned, ready to be inserted.

According to the cycle time, when weft yarn insertion is needed, the main electro-pneumatic control group A is switched on and an additional flow rate fills the main tank T_1. As a consequence, pressure p_1 increases until it reaches the value needed for weft thread insertion. The stopper releases the weft yarn, which is accelerated by the high-speed jet emitted by the tandem nozzles and is ejected into the shed. Then, the main electro-pneumatic valve A is switched off.
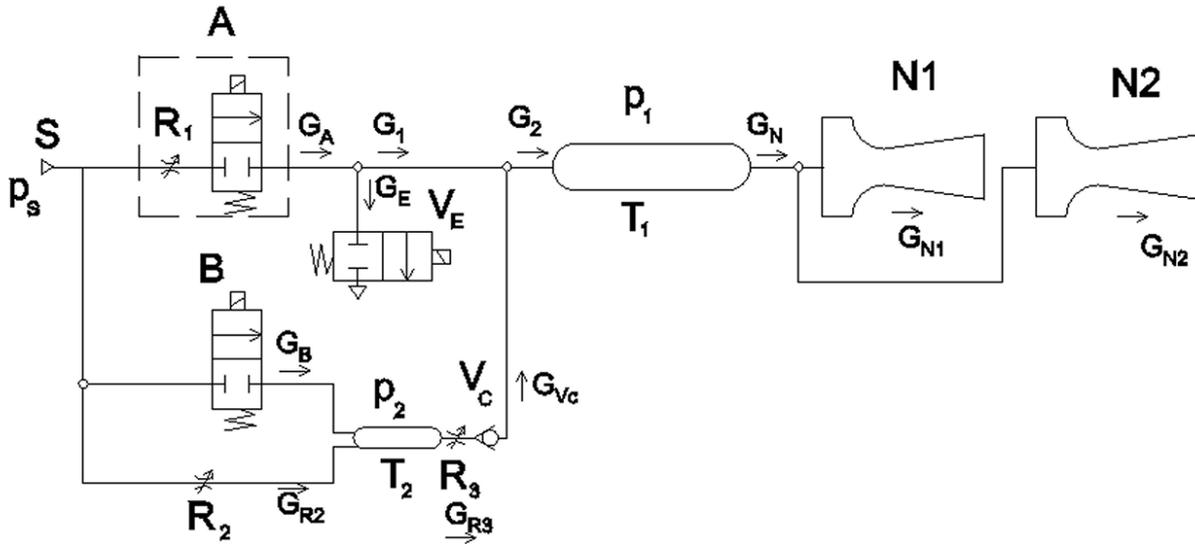
Figure 1: Scheme of the driving circuit of a main nozzle for air-jet looms

When insertion is completed, a weft cutter cuts the weft yarn at the main nozzle side; in order to maintain the yarn at the proper tension (lower than that needed for accelerating the weft yarn, but higher than that ensured by the blow-line) pressure p_1 has to be modified. Therefore, the quick exhaust valve V_E is switched-on, causing an abrupt drop of pressure p_1, and then, after a short time, is switched-off again. Later, the electro-pneumatic valve B is switched-on, providing an additional flow-rate able to set p_1 at the proper value for the cutting phase.

The modelling procedure is applied herein to this specific circuit, but it has a general applicability.

LUMPED-PARAMETER MODEL OF THE PNEUMATIC CIRCUIT

The pneumatic system previously described was modelled as a sequence of resistances and capacitances. Resistive effects were completely ascribed to pneumatic valves, while capacitive effects were attributed to connecting pipes, whose volumes are represented in Fig.1 by tanks T_1 and T_2. Inductive effects were neglected.

According to the ISO 6358 standards [7], the volumetric flow rate Q through a pneumatic component, in standard reference conditions ANR [8], can be calculated as following. It is a function of the ratio r between downstream absolute pressure P_D and upstream absolute pressure P_U by means of two parameters: sonic conductance C and critical pressure ratio b, at which the sonic state is reached.

$$Q = C \cdot P_U \cdot K_T \cdot \Phi(r; b) \tag{1}$$

K_T is a dimensionless temperature coefficient equal to:

$$K_T = \sqrt{\frac{T_N}{T_u}} \tag{2}$$

where T_u is the fluid absolute temperature during the test, while $T_N = 293.15$ K is the absolute reference temperature ANR [8].

In case of subsonic condition ($r > b$), function Ø (r; b) is:

$$\Phi = \sqrt{1 - \left(\frac{r - b}{1 - b}\right)^2} \tag{3}$$

In sonic conditions ($r<=b$), function Ø (r; b) is:

$$\Phi = 1 \tag{4}$$

Measuring the sonic flow rate Q_S, conductance C can be obtained by:

$$C = \frac{Q_S}{P_U \cdot K_T} \tag{5}$$

The critical pressure ratio b can be calculated by the following formula:

$$b = 1 - \frac{\Delta P}{P_U \cdot \left[1 - \sqrt{1 - \left(\frac{Q'}{Q_S}\right)^2}\right]} \tag{6}$$

where $\Delta P = P_U - P'$ is the pressure difference causing flow rate Q' and Q_S is the sonic flow rate.

Mass flow rate G through each component can be calculated as:

$$G = \rho_N \cdot Q \qquad (7)$$

where ρ_N is air density referred to standard reference conditions (20°C, 101325 Pa, 65% relative humidity).

Filling and exhausting of connecting pipes and tanks were treated as an isothermal process.

Finally, mass flow rate continuity was imposed at each node of the pneumatic circuit (see Figure 1). As an example, the following equation can be applied at tank 1, whose volume is Vol_1:

$$G_2 - G_{N1} - G_{N2} = Vol_1 \cdot \frac{\rho_N}{P_N} \cdot \frac{dP_1}{dt} \qquad (8)$$

The lumped parameters model so obtained was implemented and solved in the numerical simulation software Matlab-Simulink.

Experimental identification of flow characteristics

Conductance C and critical pressure ratio b of each component of the pneumatic circuit previously described were experimentally evaluated by using a special test bench, available at DIMEAS – Politecnico di Torino, designed to comply with the ISO 6358.

Figure 2 shows a scheme of the flow rate test bench, made up of: an on-off valve V; a filter F; a pressure regulator R; a flow-meter FM for flow-rate measurement; the device under test C; three ISO tubes K1, K2 and K3 equipped by three pressure gauges to measure gauge pressures p_S, p_u e p_d upstream the flow-meter, upstream and downstream the component under test, respectively; one ISO tube K4 to measure the fluid temperature; a choke valve R_V.

According to the Standards, tests were carried out setting the component upstream absolute pressure at a constant value P_u (7 bar) and gradually opening the choke valve R_V so to reduce downstream pressure P_d. Sonic flow conditions were reached when no flow-rate variations were detected varying downstream pressure. Details on the structure of the test bench and on the experimental procedure can be found in [9].
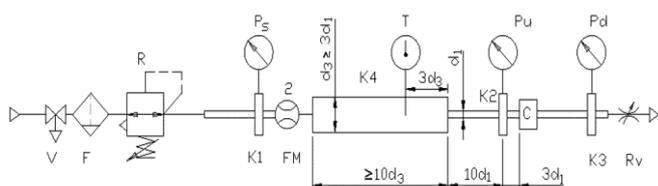

Figure 2: Flow rate test circuit according to ISO 6358.

Figure 3 shows, as an example of results, the flow rate through the main electro-pneumatic group A as a function of the downstream pressure, obtained at a given upstream pressure (p_u=7 bar absolute), varying the opening of choke valve R_V. These experimental data were processed to obtain values of sonic conductance associated to each choke valve configuration.
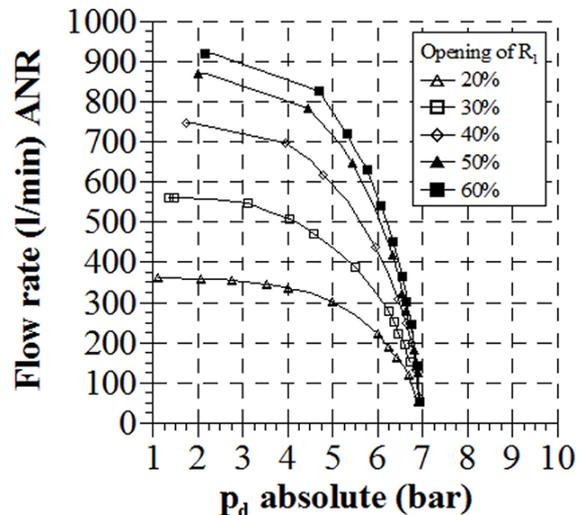

Figure 3: flow characteristic of the main electro-pneumatic group, varying the choke valve regulation

Similarly, the flow-rate characteristics of the valves V_E and B, of the choke valves R_2 and R_3, of the check valve V_C, of the pre-nozzle 1 and of the main nozzle 2 were obtained.

RESULTS AND DISCUSSION

Having set the carrier wave frequency of the cycle, valve timing and openings of choke valves R_1, R_2 and R_3 as input data, the developed model gives information on pressure level at each circuit position and, consequently, on air consumption.

First of all, in order to validate the model, numerical results were compared with experimental ones. Figure 4 compares, as an example, numerical and experimental values of pressure p_1 versus time obtained with an opening of 30% of the flow regulator R_1 and a supply absolute pressure of 5 bar. It can be seen that, even if the simulated system is more effective than the real one during the exhausting phase, the system behaviour can be forecasted with a good level of approximation.

Figure 5 and Figure 6 compare, as an example of possible output, results obtained respectively in terms of gauge pressure and flow-rate, keeping constant all parameters except the opening of R_1, which was varied from 30% to 15%. A sharp decrease of gauge pressure p_1 and of nozzles' air consumption can be noted.
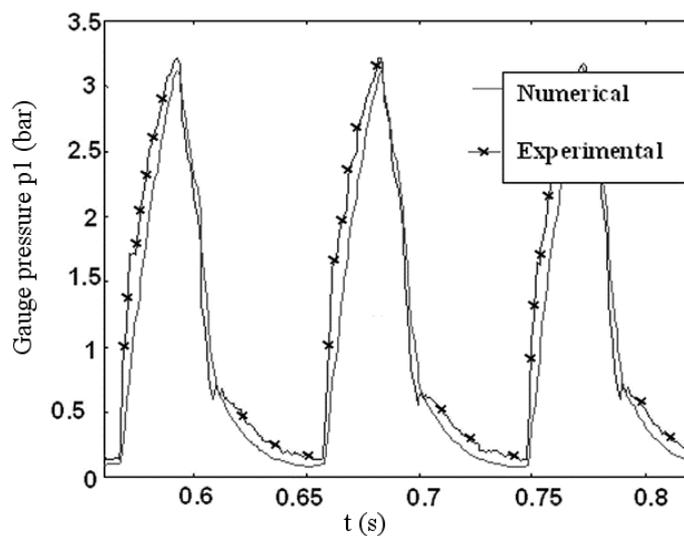
Figure 4: Comparison between numerical and experimental data.

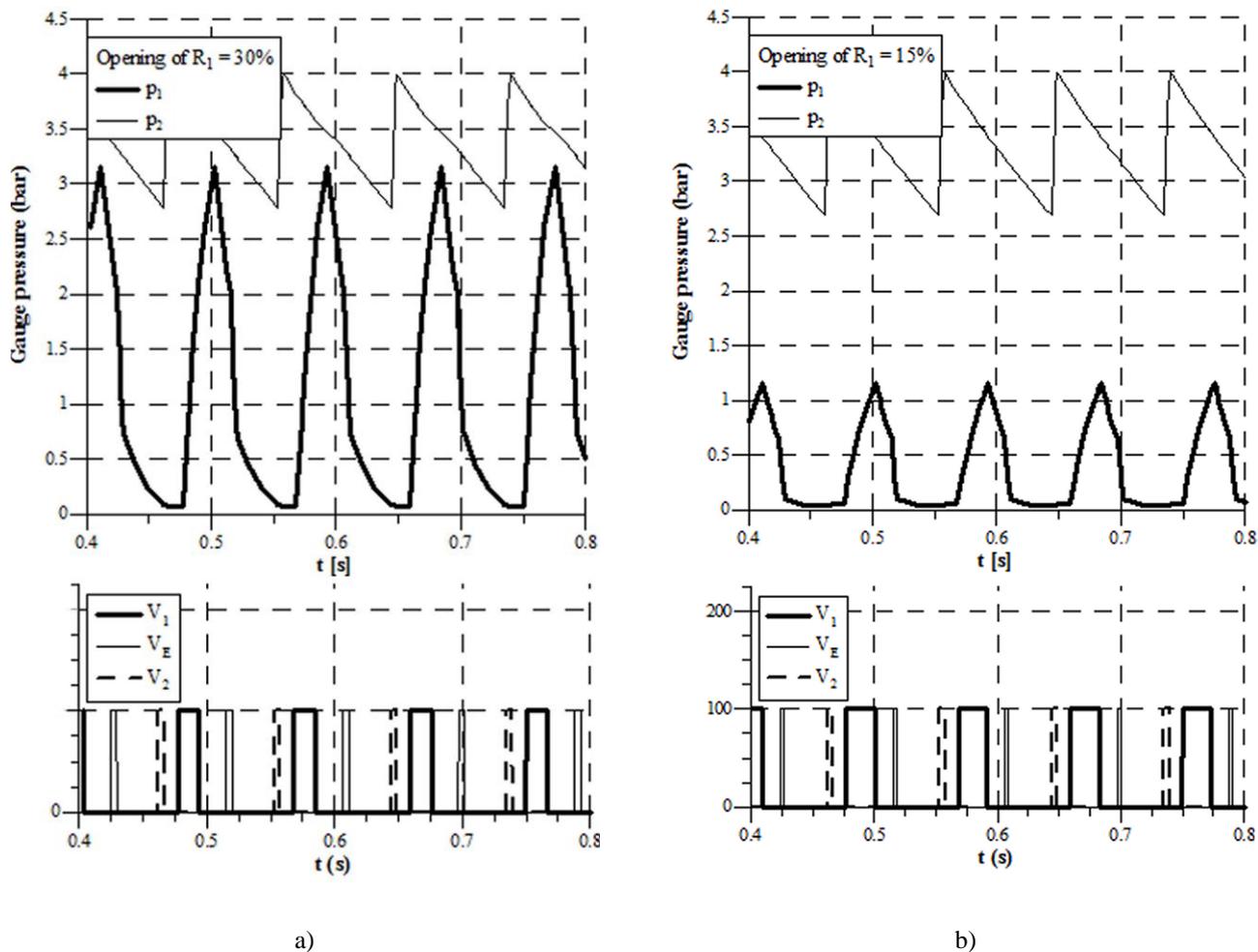
a)   b)

Figure 5: Influence of R_1 regulation on pressure levels in the circuit

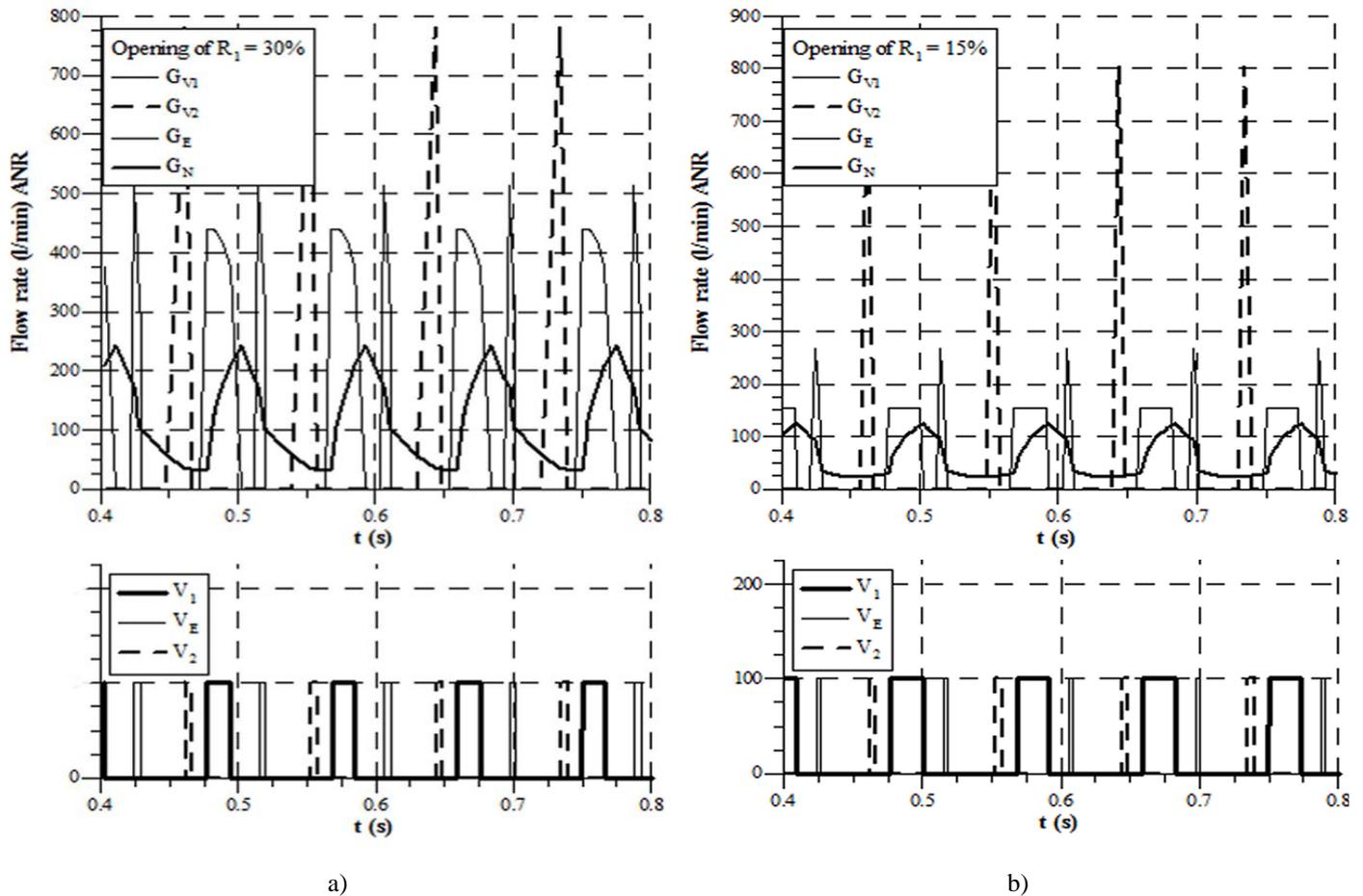a)   b)

Figure 6: Influence of R₁ on circuit flow-rate

CONCLUSIONS

A lumped parameter model describing the operating circuit of a main nozzle for air-jet looms was developed; it was conceived as a useful instrument for evaluating the influence of various parameters, such as pipe size and length, choke valve openings and valve timing, on air consumption and performance. Having validated the model by comparing numerical results with experimental ones, simulations were carried out to analyse the influence of each parameter on the system behaviour.

It was found that length and size of pipes, i.e. the additional volume filled by air inside the circuit, is the parameter mostly influencing the level of air consumption. Furthermore, a long pipe network affects negatively the system dynamic response.

The modelling methodology proposed is general and can be applied to circuits other than that studied herein.

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