International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 4 (2017) pp. 549-553

Pressure Control in a Low-Pressure Casting Furnace

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Abstract

The casting of light alloy components is a technology commonly used in aeronautic industry. This operation is possible, for example, using a low-pressure casting system, where it is important to control the temperature but also the maximum value and the time history of the pressure inside the furnace. For this reason it becomes important to study the pressurization circuit.

In this paper a theoretical and experimental study of the pressurization circuit of a low-pressure casting furnace is presented, to individuate the temporal behaviour of the pressure inside the furnace.

Particular attention has been paid to the experimental characterisation of the proportional valve with current-driven electro-pneumatic pilot. The opening of the principal valve is a function of the current of the pilot-valve. The characteristics, in terms of flow coefficients and response time, have been evaluated as a function of the upstream pressure and of the pilot current.

A lumped parameters model has been developed, in which it is possible to vary the following parameters: type of valve and its coefficients, volume and temperature of the furnace, size of connecting pipes and supply pressure.

The resistive and capacitive effects have been considered for the tube model but the inductive effect has been neglected. For the furnace only the capacitive effect has been take into account.

The influence of the different parameters on the furnace pressure has been evaluated; experimental results obtained from tests on single components have used to find the parameters of the numerical model.

The validation of the whole pressurizing furnace circuit model has been made with an experimental set-up properly realised. For every working condition, a good agreement between numerical and experimental time history of the pressure inside the furnace has been obtained.

A further model validation has been made by using experimental results obtained by an existing foundry circuit. Also in this case good agreement has been obtained.

Keywords: Low-pressure furnace, pneumatic model, casting.

INTRODUCTION

The gravity casting is a technology used to produce alloy's components. If the geometry became complicated it is possible to have difficult during the casting, which produce a not complete fill up of the mould, especially for very thin thickness. The result is a spoiled casting.

If the gravity casting has been done with a little over-pressure it is possible to improve the fill up of the mould and a best final quality of the component has obtained. In this way a low-pressure casting furnace is realised.

In a low-pressure casting furnace [1] working an important parameter in the pressure, besides at the temperature. Then it is very important to regulate and to control the pressure behaviour inside the furnace, but also to calculate the outline of the pressure curve.

Purpose of this work is to study the pressurization circuit of a low-pressure casting furnace using a theoretical model properly developed.

The model takes into account the valve's coefficients (conductance, critical ratio, response time experimentally measured), the parameters of the furnace (volume and temperature), the connecting pipe's geometry (diameter and length) and the furnace supply pressure.

An experimental test rig has been made to validate the model.

DYNAMIC MODEL OF THE PRESSURISATION CIRCUIT OF THE LOW-PRESSURE FURNACE

The numerical model of the low-pressure gas furnace pressurisation circuit has been created in Matlab-Simulink ambient.

Figure 1 shows the general scheme of the system.

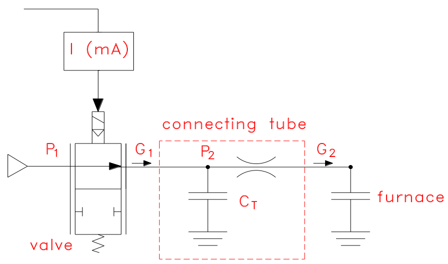

Figure 1: Scheme of the low-pressure furnace

The model has been developed using the lumped parameters and it gives the possibility to set up the following coefficients:

- the conductance, the critical ratio and the time response of the control valve;
- the diameter and the lengths of the connecting tubs (between valve and furnace);
- the working temperature and the volume of the furnace;
- the supply pressure of the furnace.

The model takes into account the capacitive and the resistive effects of the connecting tubs, while the inductive effect has been neglected. The furnace has been modelled take into account only the capacitive parameter.

The model of the low-pressure gas furnace pressurisation circuit allows to change the type of valves (proportional or digital one) and to verify the influence on the global system performance.

The first step was to define the parameters of the circuit components.

The experimental results obtained with the valve have been used for the numerical model.

The connecting tube has been considered like a component with a certain flow coefficients (conductance and critical ratio), which was calculated using a mathematical programme properly developed. In particular the flow coefficients are a function of the length and the internal diameter. [2]

Constant temperature (equal to standard temperature) has been considered for the resistive effect of the tube. The internal volume of the tube has been considered like a fixed pneumatic capacity and a continuity equation has been used.

The valve mass flow can be evaluated using the formula of International Standard [3].

The furnace has been considered like a fixed volume and the inside pressure P_F can be calculated with the following equation:

$$P_F = P_a + \frac{P_a \cdot T_a}{V_a \cdot \rho_0 \cdot T_0} \cdot \left(\int_0^t G(t)dt - \left(\frac{T_a - T_b}{T_a} \right) \cdot e^{-Kt} \cdot \int e^{Kt} G(t)dt \right)$$

where: P_a, V_a, T_a are respectively the pressure, the furnace volume and the test temperature; T_b is the furnace temperature, that can be different from that of test.

If it is used a flow proportional valve the proposed model allows to use different law of current control signal.

EXPERIMENTAL TESTS ON THE CONTROL VALVE

The flow proportional valve (made by Samson) has an electro-pneumatic positioner (pilot). The positioner must be supplied by air at maximum pressure of 6 relative bar and it is droved by current (I=4÷20 mA).

The switching of the pilot valve allows the opening of the principal valve, as a function of the current. Then the flow-rate thought the valve as a function of the upstream pressure, the downstream pressure and the pilot current.

The valve has been experimentally tested, to evaluate the static and the dynamic performance. In particular:

- the flow –rate curves and the flow coefficients (conductance and critical ratio [3]);
- the response time, in terms of opening time of the valve;
- the downstream pressure and the shutter’s lift during the switching of the valve.

The flow-rate curves have been obtained using the experimental test bench realised at the Mechanical Department [4, 5]. The test have been carried out at constant upstream pressure p_m and varying the downstream pressure p_v, the flow-rate Q through the valve has been measured by a computerized system and the flow coefficients have been calculated.

For constant upstream pressure p_m = 6 bar the curves flow-rate Q vs. downstream pressure p_v have been obtained for different value of pilot current I (I = 8, 12, 14, 16, 18, 20 mA). The curves are shown in Fig. 2.

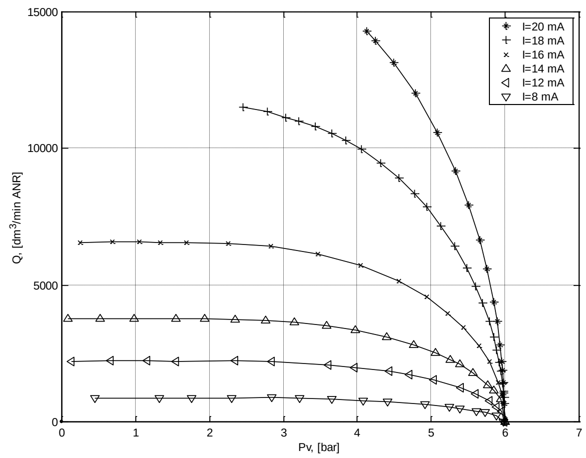

Figure 2: Flow-rate curves for p_m=6 bar and different currents I

Similar behaviour has been obtained for different values of upstream pressure.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 4 (2017) pp. 549-553
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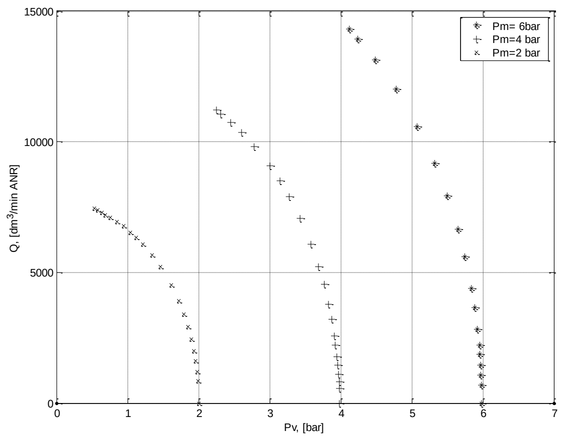

Figure 3: Flow-rate curves for I=20mA and different p_m

Figure 3 shows for a current I=20 mA the flow-rate curves for three different value of upstream pressure p_m (p_m = 2-4-6 bar).

Using the experimental results it has been possible to extract the outline of the conductance as a function of the pilot current of the valve itself. This curve has shown in fig. 4.

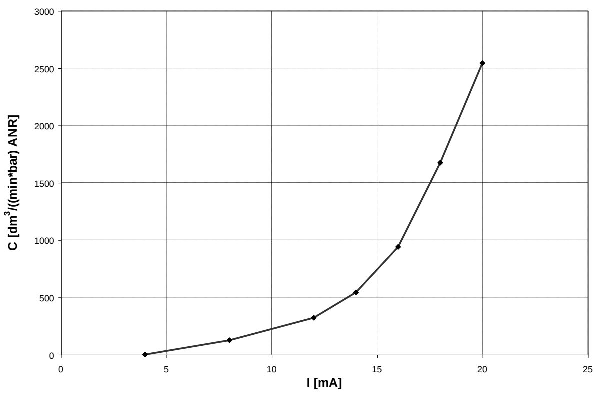

Figure 4: Conductance C vs. pilot current I

The experimental evaluation of the switching time allows the dynamic characterisation of the valve, but also an evaluation of the time response of the full circuit where the valve is inserted.

The switching time has been obtained with experimental tests using a step command signal that is sending to the valve a reference signal and recording the variation of the command signal and the corresponding pressure output signal.

The International Standard [6] establishes the procedure for this type of tests on pneumatic valves when a step signal is used.

The tests have been made using a positive step between two current values (4-12 mA, 4-16 mA, 4-20 mA), correspondent to the opening 's valve, and a negative step between two current values (12-4 mA, 16-4 mA, 20-4 mA), correspondent to the closing's valve. The valve output pressure and the current signal have been measured as a function of the time.

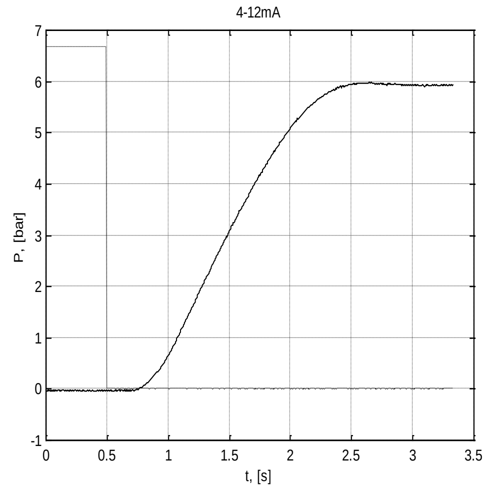

Figure 5: Output pressure vs. time for increasing current I (4-12 mA) and p_m=6 bar

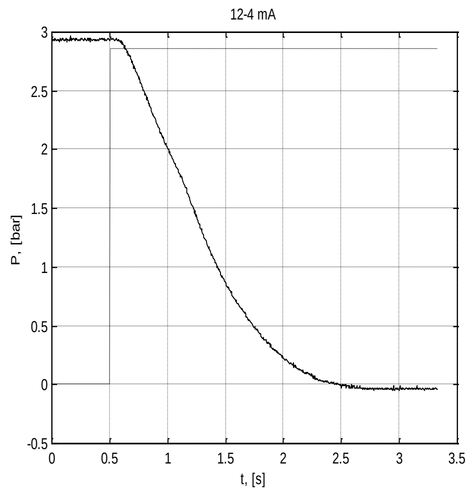

Figure 6: Output pressure vs. time for decreasing current I (12-4 mA) and p_m=6 bar

Figures 5 and 6 show the results obtained for positive step (increasing current between 4 mA and 12 mA) and negative step (decreasing current between 12 mA and 4 mA) respectively, using an upstream pressure of 6 bar.

Curves with similar behaviour have been obtained also for the other different current values.

EXPERIMENTAL VALIDATION OF THE MODEL

To validate the Matlab-Simulink model a properly test bench has been built. The scheme of is shown in Fig. 7. The most important components are: the tank (volume V = 100 dm^3); the valve; the connecting tubes (internal diameter d = 10 mm and length L), the transducers T_1 e T_2 to measure the control current of the valve and the pressure in the tank

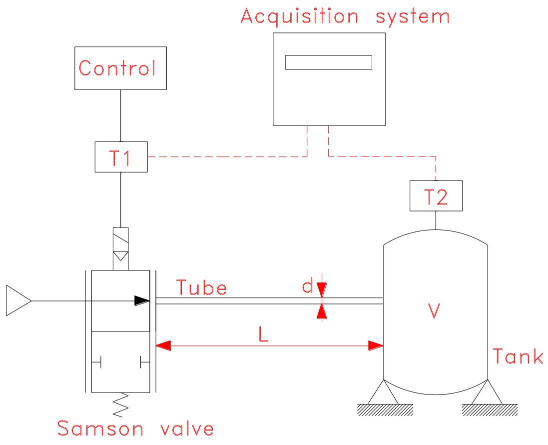

Figure 7: Experimental test bench

Two series of tests has been made using two different lengths of connecting tube L (L = 0.5 m e L = 5 m).

For the control current of the valve three different values has been used (8, 12, 20 mA).

A similar behaviour of the control current signal has been used to validate the proposed model.

Figure 8 shows, as a function of the time, the experimental Pe and theoretical Pt pressure inside the tank obtained with: control current I = 20 mA, total length of the tubes L = 5 m.

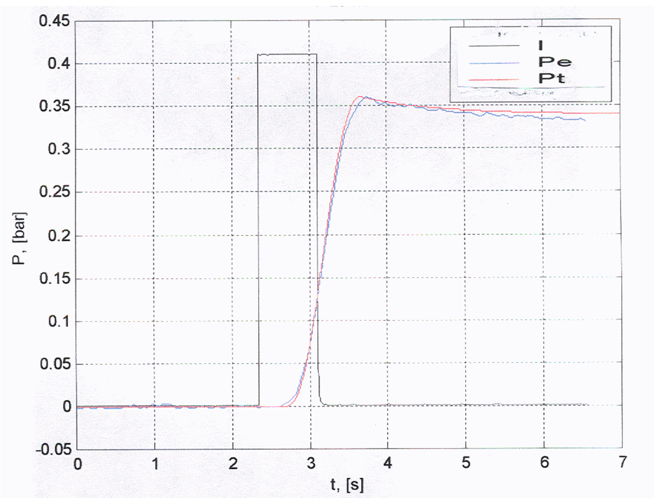

Figure 8: Experimental and theoretical pressure inside the tank

It is possible to note a good correspondence between experimental and theoretical results. This kind of performance has been obtained also using other different working condition (current I, length L, volume V). Then it is possible to conclude that the global circuit model has been validated.

To achieve a further validation of the model, different laws of the current signal have been used to obtain the pressure behaviour in a real casting furnace.

Figure 9 shows, as a function of the time, the experimental Pe and theoretical Pt pressure inside the furnace. Also in this case it is possible to note a good agreement between experimental and theoretical results.

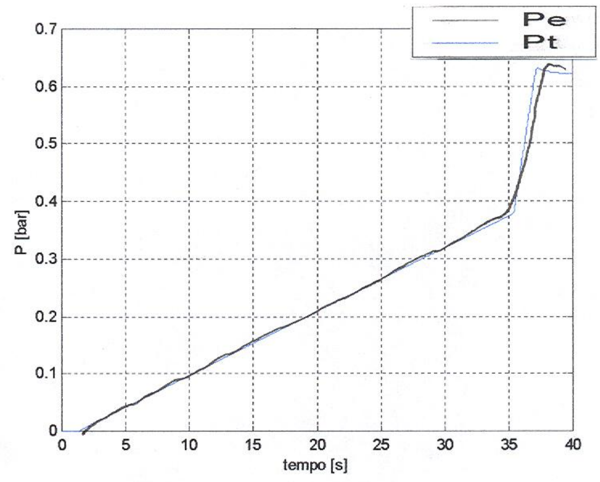

Figure 9: Experimental and theoretical pressure inside the furnace

CONCLUSIONS

In this paper a theoretical and experimental study of the pressurization circuit of a low-pressure casting furnace is presented, to individuate the temporal behaviour of the pressure inside the furnace.

The most important valve of the circuit has been experimentally tested, to evaluate the flow coefficients and the dynamic response.

The experimental results have been used for the model developed in Matlab-Simulink.

A properly test rig has been made to reproduce the pressurization circuit. The pressure behaviour, as a function as a time, has been measured for different low current.

The experimental and theoretical pressure (obtained with the model) have been compared with a good correspondence.

Another validation's model has been made using experimental results obtained with a real casting furnace and also in this case a good agreement has been obtained.

Take into account the good correspondence of theoretical model and the experimental result it is possible to consider the proposed model to simulate the pressure inside a real low-pressure casting furnace.

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