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MODELING OF THE TEMPERATURE CONTROL SYSTEM OF THE PLASTIFICATION CYLINDER OF INJECTION MOLDING MACHINE

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Abstract: *At present the development of industry of plastic products tends to grow up the quality of products obtained by this method and increase productivity. The common denominator on quality, productivity and cost efficiency in producing plastic objects, it is thermal process that must ensure the material plastification in cylinder of plastification of machine for injection of the plastical materials.*

In this paper is elaborated a mathematical model describing the thermal process heating plasticizing cylinder for injection molding machine with consideration of thermal influence between of heating zones and cyclic variation of material speed in the cylinder. On the basis of elaborated mathematical model were simulated transient processes at start and in working regime of the machine with different types of regulators in the temperature control system in each thermal zone. Was made a comparison between the quality of transient process with regulators P, PI, PID granted Ziegler-Nichols method and the results obtained with the fuzzy controller.Profound study of transient processes in Simulink Matlab allowed optimize the regulators for temperature control system for each heating zone. Implementation in practice of a system of adjusting and control of plastic injection machine was in the company The electro-SV Implementing of this system is based on a universal controller of at the company .

Keywords: *plastification, plastics, Injection Moulding Machine, plastification cylinder*

1. INTRODUCTION

Processing by injection is the technological process by which plastics , brought in a state of flowing is introduced under pressure into a mold for formation. After filling the mold, the material is kept under pressure and hardened by cooling for thermoplastic and heating for thermosetting polymers. The advantages of formation by injection consist in possibility of obtaining objects with complicated shapes different sizes and form a very wide range of polymers. The operations are automated and machines have a high performance.[3]

Processing conditions depend on the properties of the material, technological parameters of processing and also of the technical and technological parameters of plastic injection machines.

At present the development of plastics products tends to rise the quality of products obtained by this method and and also to grow the productivity proces. The common denominator of the quality, productivity and cost in production proces is the heating process. This is possible only by designing of the machines with parameters take into account the specific properties of processed materials and ensure the specific of the technological process.

The study object is an injection molding machine type ДЕ3330 Ф1 (Fig. 1) [7] with a control system based on electromagnetic relays which ensures the working cycle of the machine for the different regimes and a temperature control system for injection unit which consists of four discrete PID controllers with static power relays and resistive electrical heaters.

Figure 1. General view of the ДЕ 3330 Ф1 type machine [7]

The main purpose of this paper is to design and simulate the optimal thermal control system of the plastification cylinder of injection machine based on the analysis of transient and stationary process with different types of digital controllers: P, PI, PID and fuzzy.

To come to ours main purpose we have to solve some basically problems as:

- ✓ The analysis of the processes, and its particularities of the operating regimes of the machine.
- ✓ Adapting of the mathematical model that describes the physical nature of the process without losing the physical sense and the simulation in Matlab.
- ✓ Determination of the criteria for granting the temperature control system, and the calculation of the coefficients for selected regulators.

2. THE MATHEMATICAL MODEL OF THE INJECTION MOLDING MACHINES

2.1 Calculation of the thermal regime of the plastic injection machines

Calculation of the thermal regime processing of plastics is very important to designing and exploitation this type of machines, given the fact that thermoplastic materials processed are sensitive to changes in temperature.

In general in any screw casting machine we have more temperature zones on the length of plastification cylinder. From technological point of view for each type of material it is recommended that each area to have a certain temperature. For the calculation of thermal areas of plastification of castings machines is necessary to determine the amount of heat released during to the plastic deformation of the polymer on each area of the machine, which is determined by: the geometry of the screw, the number of rpm, polymer viscosity, length of area. This energy can be determined by using the following empirical relationship[5]:

$$Q_{pl} = 110330.5 \cdot d_1^2 \cdot m^2 \cdot \eta \cdot l / h \quad (1)$$

where: d_1- effective diameter of the screw, m;
m - number of revs, rpm;
η- effective viscosity of the material (kg/h)/m^2;
h - screw channel depth, m;
l - the length of thermal area, m.

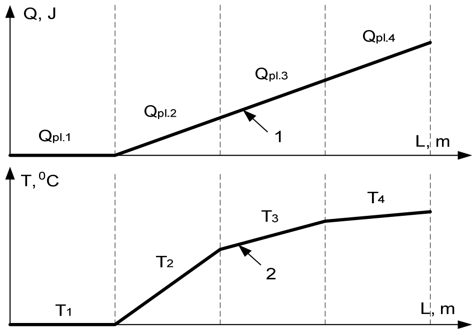

Figure 2. Eliminated energy curve to plasticizing material (1) and temperature curve in each zone of injection unit (2) [5]

2.2 The mathematical model of starting regime of the injection unit

For the elaboration of the mathematical model of the start thermal regime for machine and to modeling the process we use the method of blocks. It is supposed that in the starting regime all elementary blocks in each zone are with concentrated parameters. In such conditions the scheme will have the following structure shown in Figure 3

where: $T_{\hat{\imath}nc}$.; T_{cil}.; T_{melc}; T_{iz}.- average temperature of the heater, cylinder, screw and insulation,
Q_{el} – the power delivered for heaters, W;

According to the structural scheme are elaborated equations of thermal balance in differential form for each block:

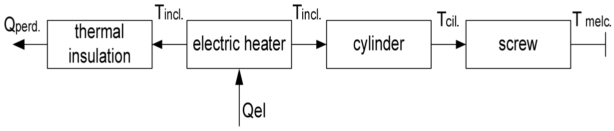

Figure 3 Block diagram of the mathematical model of a region of injection unit [5]

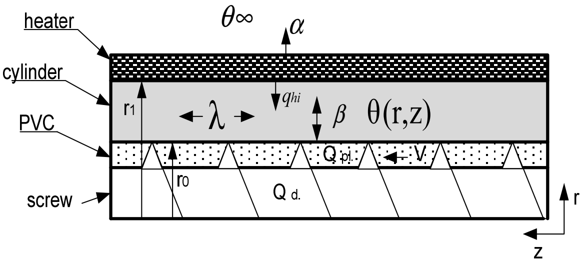

Figure 4. Heat flow in the heating cylinder [2]

- for heater

$$\frac{d}{d\tau}(m_{inc.}c_{inc.}T_{inc.}) = Q_{el.} - \frac{\lambda_{inc.} \cdot S_{inc.}}{2h_{inc.}}(T_{inc.} - T_{cil.}) \quad (2)$$

- for insulation

$$\frac{d}{d\tau}(m_{iz.}c_{iz.}T_{iz.}) = \frac{\lambda_{inc.} \cdot S_{inc.}}{2h_{inc.}}(T_{inc.} - T_{iz.}) - \\ -\alpha_1 \cdot S_{extern}(T_{iz.} - T_{mediu}) \quad (3)$$

- for zone cylinder

$$\frac{d}{d\tau}(m_{cil.}c_{cil.}T_{cil.}) = \frac{\lambda_{inc.} \cdot S_{inc.}}{2h_{inc.}}(T_{inc.} - T_{cil.}) - \\ -k_T \cdot S_{cil.}(T_{cil.} - T_{melc}) \quad (4)$$

- for screw zone

$$\frac{d}{d\tau}(m_{melc.}c_{melc.}T_{melc.}) = k_T \cdot S_{cil.}(T_{cil.} - T_{melc}) \quad (5)$$

In the relationships (2-5) we have: M_{inc}., M_{iz}., M_{cil}., M_{melc},- the weight of heaters, insulation, cylinder, screw, kg;

c_{inc}, c_{iz}., c_{cil}.,c_{melc} – the specific heat of material, kcal/kg°C;

$\lambda_{înc}$., $h_{înc}$., $S_{înc}$.- thermal conductivity of material [W/m·^{0}C], the heater thickness, m; and total area of the heater m^2;

α_1 - heat transfer coefficient from the external surface of the insulation in the external environment [W/(m^2·^{0}C)];

k_T – heat transfer coefficient from the internal surface of the cylinder through the air between cylinder and screw, [W/(m^2·^{0}C)];

T_{med} – the ambient temperature, ^{0}C

2.3 The mathematical model of the injection unit in continuous working regime

The thermal calculation of injection unit in starting regime aims to determine necessary power for heaters of the plastification zones and which ensure the temperature required for processing the polymers in injection unit.

To elaboration the mathematical model of the injection unit in the normal work regime we have take into consideration the movement of material through the cylinder. Was specified above if the material is in the areas of plastification and dosage, the structure of the flow of material is subject to a diffuse model with a single parameter, the load area (first technology area) movement structure of material in corresponding to the model of the ideal moving .

The mathematical model of the heating model for a zone of plastification in normal exploitation, is developed with consideration to the fact that in this area begin removing heat from plastic deformation of the material and cylinder temperature to moving the material is a constant size determined by type of processed material.

Block diagram of mathematical model is present in figure 5:

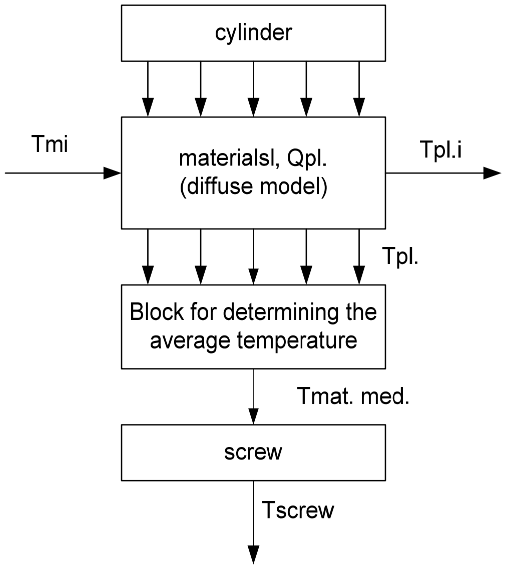

Figure 5. Block diagram of the mathematical model which describe the thermal working regime for plastification area [5]

For each block are elaborated equations heat balance in differential form:

1) for the cylinder:
   $T_{cil.i}(l,\tau)$ = const, i- thermal zone number (i= 1,2,3);
2) for material taking into account that the flow structure of the material is described by a diffuse model with a parameter:

$$\begin{aligned}
&\frac{d}{d\tau}\left(\overline{\Delta S}_i \Delta l\, \overline{\rho_{Mi} c_{Mi}} T_{Mij}\right) = \\
&= u_M \Delta S_i \overline{\rho_{Mi} c_{Mi}} \cdot (T_{Mij-1} - T_{Mij}) + \\
&+ u_M \Delta S_i \overline{\rho_{Mi} c_{Mi}} \cdot (T_{Mij+1} - T_{Mij}) + \\
&+ Q_{pl} + k_{cil.-mat.} \Delta S_{cil.i.j} (T_{cil.i} - T_{Mij}) \\
&+ k_{mat.-melc.} S_{melc} (\overline{T_{med.i.}} - T_{melc.i})
\end{aligned} \qquad (6)$$

where: $\overline{\Delta S}_i$ - the average of the surface of the cross section of thermal zone;

Δl - elementary length of the area;

Q_{pl} - heat from of plastic deformation on the length Δl;

$k_{cil.-mat.}$ - heat transfer coefficient of the cylinder to material;

$\Delta S_{cil.i.j}$ - heat transfer surface of the cylinder to the material on the length Δl;

$T_{cil.i}$ - cylinder temperature; T_{Mij} - temperature of the material in zone j; j- index of thermal zone section [3]

3) for block which determining average temperature [3]

$$\overline{T_{mat.i}} = \frac{1}{n}\sum_{j=1}^{n} T_{Mij} \qquad (7)$$

Based on equations (6-7) with prescribed initial conditions is calculated heating of the material which moving through the cylinder in length of the thermal zone. [3]

3. THE TEMPERATURE CONTROL SYSTEM SIMULATION

The equations (2-7) describe only thermal processes in the system without automatic temperature control loops.

In this subparagraph is elaborated a model which allows to simulate transient processes in the system with the temperature controllers for each zone separately and which allows to determine the optimal parameters of regulators for functioning the system as a whole and to consider the influence of heat between neighboring zones.

The influence of the areas was modeled in the basis of law to transfer the heat between objects at different temperatures and temperature gradients of zones the active part of the injection unit of machine, this allows us to determine the influence of each zones and to regulate the system temperature in zones when there is this influence.

Also in this model is simulated the elimination of heat by the material processed in depending on the coefficient of viscosity and pressure exerted on it during the injection.

As an example in Figure 6 is shown the scheme of the model with fuzzy regulator.

The simulation of model with regulators P, PI, PID was performed also with this scheme then where they were replaced with the fuzzy controllers so that we simulated the model with different regulators and performed a qualitative analysis of transient processes with different types of regulators.

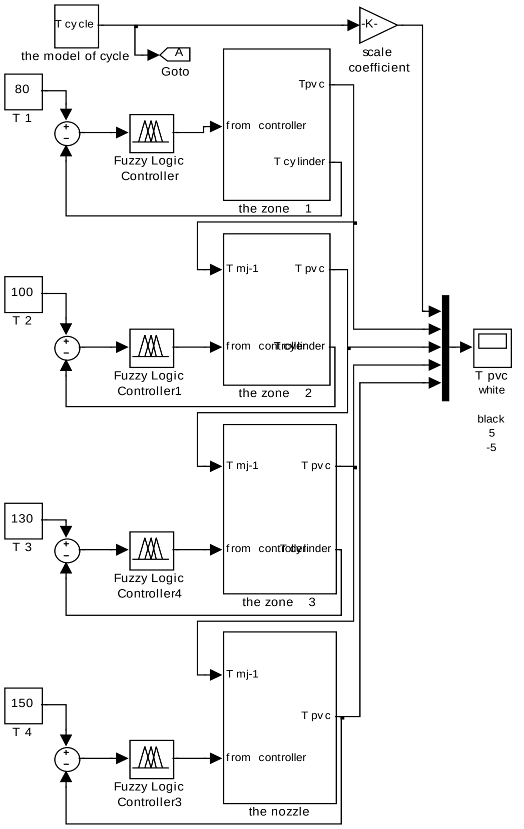

Figure 6 Simulink model of the temperature control system

The results obtained in simulation the model without temperature control system:

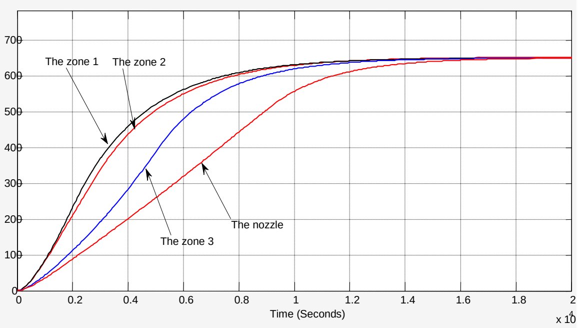

Figure 7 The temperature variation in each zone of the cylinder in starting regime without a regulating system

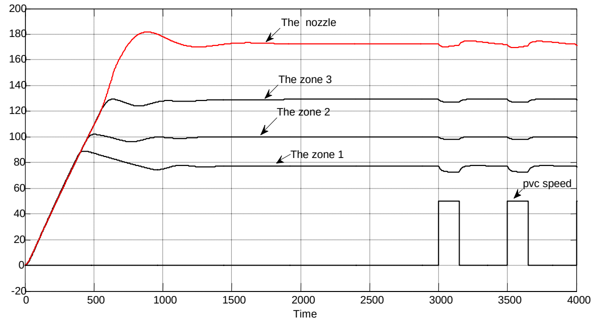

Figure 8 The temperature variation of material with PID regulator

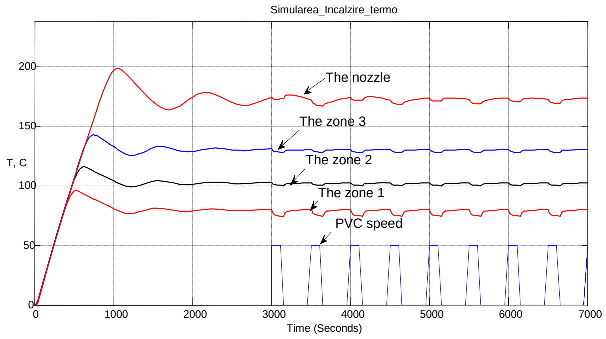

Figure 9 The temperature variation of material with PI regulator

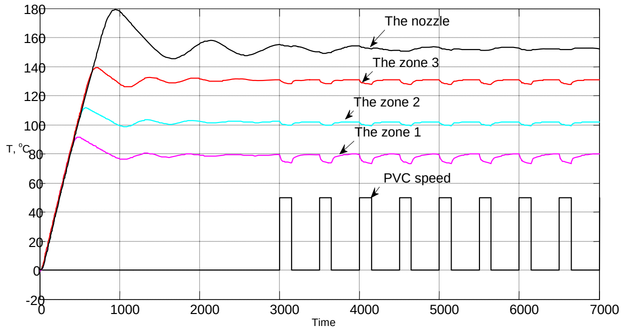

Figure 10 The temperature variation of material with Fussy regulator

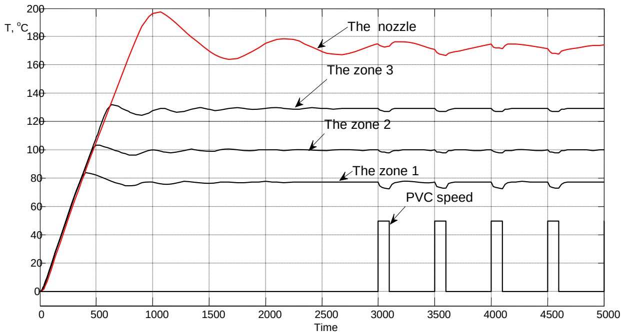

Figure 11 The temperature variation of material with P regulator

Simulation of the heating system of injection unit allows us to observe the temperature changes in every heating zone of cylinder in starting regime of the machine and working regime under a cyclic speed variation of material processed through the plastification cylinder.

The comparative analysis of the results of figure 7-10 are resulting that the best performance for this system is ensures with a PID controller, with a minimum override of temperature in the nozzle of only 7%, stationary error of 1.4 %, the transitory time is 1000 s.

The influence of the zones is more pronounced when the temperature difference between zones is higher which causing an error occurs the temperature control to the zone to which is prescribed lower temperature.

CONCLUSIONS

The resultants of this work are:

1. Was elaborated a mathematical model of the plastification cylinder of injection molding machine by analyzing the physical process of plastification with elimination an amount of heat of processed material under the influence of pressure exerted by the screw. The model is liable to be user for the different types of machines with different constructive parameters of the injection unit.

2. Computer simulation permitted to optimization of static and dynamic process of the automatic control system of temperature of the real machine in report to rapidity and exclusion of oscillations and override of temperature to the thermal areas of the plastification cylinder and nozzle.

3. The results of this study was used to modernization the control system with PLC of plastic injection machine type ДЕ 3330 Ф1 [7]. To practical tests of the upgraded machine, has been demonstrated that digital temperature control for each thermal area ensure to the slow output to stationary regime, avoiding thermal shocks that lead to increase of the reboot, maintaining constant parameters and compensating disturbing factors .

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