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# Identification of Control System for Process Variations of Extruders - A Survey

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**Abstract:** The extrusion of PVC polimers with a single screw has been studied. Experimentally, the pressures and temperatures were measured at the end of each stage, for different processing conditions (screw speed, die geometry etc.). Screw pulling experiments have allowed to observe the partially filling of the screw sections. The evolutions of the pressure and the temperature all along the screw, as well as the filling length of the screw are then obtained. The theoretical results are in good agreement with the experimental measurements. When characteristics of the system are examined, it becomes clear that a commonly used proportional plus integral plus derivative PID controller cannot meet such performance specifications for this kind of system. In order to achieve the required performance, a control strategy that parameter PID is formulated. This control strategy proves to be very effective in achieving the referred specifications.
**Keywords:** Barrel temperature; Polymer processing; PID control; Viscosity

## INTRODUCTION

A high quality extrusion is essentially characterized by a precisely controlled output volumetric flow; this can be achieved by finally regulating the temperature and the pressure of the die at the output of the extruder. Traditionally, the control of the output temperature and pressure is obtained by open loop tuning of the rotating screw speed and the electric heater set points; this is usually done by an expert human operator. The current challenge is to develop a cost effective fully automatic control of the output flow, which can consistently guarantee high quality product. In the literature, a few works on identification and control of plasticating extruders have appeared in system identification[1].

A continuously increasing number of commercial products are produced by polymer extrusion using plasticating extruders, which are among the most widely used equipments in polymer process industry. The extrusion process has a standard setup including a feeding section, a barrel and a head with a die for shaping. In the feeding section, the solid polymer is fed in to the extruder through a hopper in the form of pellets or irregular smal l bits. Then, the polymer is transported along the barrel by means of a rotating screw. The barrelwall is equipped with a number of electric heaters which melt the polymer. The material is melted and pushed towards the die where the extrude d final product is shaped and expelled. During the process, the polymer under goes very complex thermo mechanical transformations inducing strong changes in the physical properties of the material [2].

Worldwide, extruder lines are the largest converters of plastics and can be considered the most important production machinery in the plastic industry. Commercially, extrusion lines are target to give advantages with regard to operating cost (output per hour). It is possible to produce throughout extrusion films, sheets, profiles, pipes, tubes, rods, wire coverings, coatings, filaments, blown shapes and many others. Pipes are one of the most important parts made by extrusion, and it has a wide range of applications, especially in the industry. The two main reasons that make them attractive to the processors and markets are their almost unlimited range of applications and their continuous production capabilities to meet new market challenges [3].

## THE EXPERIMENTAL PARAMETERS

This work makes on a Single Screw Extruder (SSE). Specifically, it has been developed on the SSE L/D 24, situated at the ARGE laboratory (Fig.1). This work is developed by the University of Batman / Turkey.

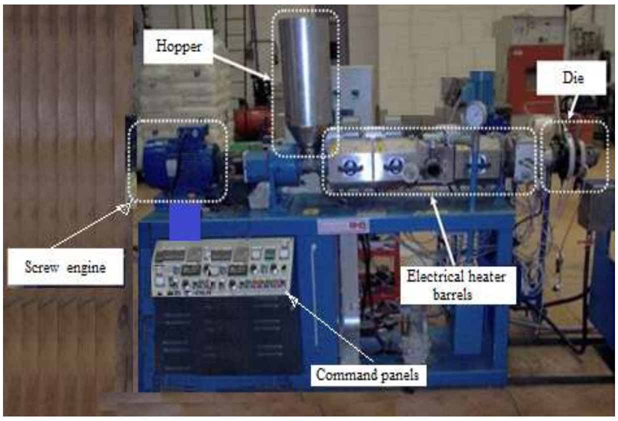



**Fig-1: Extruder**
(The SSE L / D 24 at the ARGE laboratory )

A SSE is mainly included by five main parts : the hopper, the screw engine, the electrical heater barrel, command panel and the die.

**The Input Parameters**

The Input parameters are control variables, Engine command is one variable. The screw electrical engine is driven by an inverter whose command voltage Vs can be modulated in the range 0 – 4 Vs (response to a speed range of about $n_s$ = 0 –175 rpm). On / off heater relay commands are four variables. The Extruder is fitted with four heater bands. These are electric resistances which can be switched on / off by means of electromechanical relays. More specifically, four heaters are located in the barrel. The input variables $Vb_1$…..$Vb_4$ . Thus are the response duty cycles of the screw engine signals.

**The Output Parameters**

Output variables are measured variables, Heaters temperature sensors are four variables. Each heater is fitted with a local temperature sensor (thermocouple with range from -30 $^oC$ to 300 $^oC$).The heater temperature measurement s are named $Tb_1$,….,$Tb_4$. Output temperature sensor is one variable. A temperature sensor is placed in the extrusion head at about 5 cm from the output die. The temperature sensor is a needle probe. The measured signal is named $T_d$ .

Output pressure sensor is one variable. The pressure transducer is placed at the contact inter face between the metal and the material; the measured signal is named $P_d$ . All the I/O signal s are sent to a PC based standard I / O card . The system is multi rate: the sampling time is 2 s for the temperature sensors and heaters relay. Fig.2. shows input/output variables of the system.

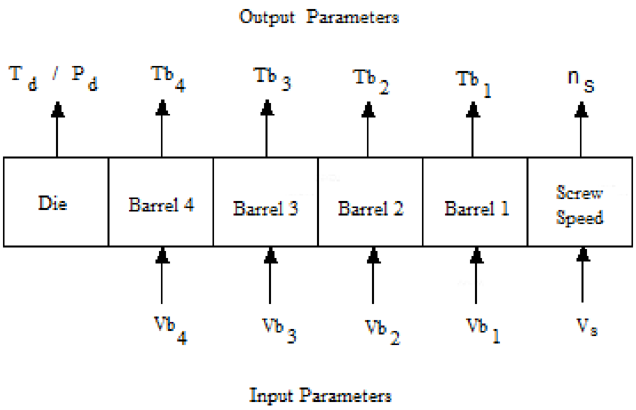



**Fig-2: Input and output parameters of extruder controls**

**THE CONTROL SYSTEM**

The control system includes autotuning, multiple PID applied to different barrels and different system of control action, as shown in Fig. 3. The block diagram of a typical process control loop is shown in Fig. 3. Control system can be defined as, where disturbance is next barrel temperatures and adjusting temperatures. Output is barrel temperature and input is set point or reference barrel temperature [4].

The cycle scheme of the controller loop of the extruder is show in Fig. 3 . Notice that the controller is characterized by the following I / O variables, controller inputs are reference values of the output temperature and pressure $T_d$ and $P_d$, measurement of the response actual output temperature and pressure ( $T_d$ and $P_d$), measurement of the four local temperatures of the wall of the barrel and head ($Vb_1$ ….$Vb_4$ ).

Controller outputs are screw engine inverter command voltage ( Vs), screw engine comma nds of the four heater s ( $Vb_1$….$Vb_4$ ).

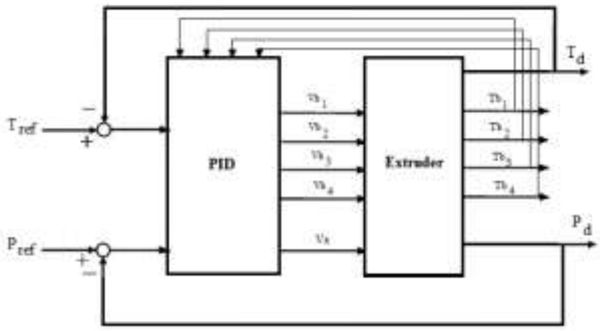



**Fig-3: Control closed loop**

In principle, the internal structure of the controller in Fig. 3 can be very complicated, notice. The SSE has been trimmed to a steady state act and single steps on the screw engine inverter command voltage $V_s$ on the PWM commands of the four heaters (the same step have been applied simultaneously to all the heaters) have been applied. The set points $Tb_1$….$Tb_4$ of the four values can be simply set at the same value Tb, however notice that the control architecture proposed in Fig. 3. It is convenient to set the reference of the first heaters at a little lower value. The dynamic act of the relation ship between $Vb_i$ and $Tb_i$ has been modeled and estimated from data [5].

The other hand, start up parameters and run time parameters are than out put go into controller. Preset point values go into reference side. Temperature measurement maked by temperature sensor. Control algorithm is PID. Where *G*p (*s*) denotes the transfer function of the process plus actuator, and *G*c (*s*) denotes the controller. A reasonable approximation of a barrel barrel temperature control process is an integrator plus dead time plus remain which may represent the actuator Dynamics [6].

The estimated transfer function $F_1$ ( s) from $Vb_1$ to $Tb_1$ is:

$$G_1(s) = \frac{861.4}{1+1233\,s}\, e^{-99.7\,s} \qquad (1)$$

Eq.(1) describes the energy transfer from the electric resistance to the barrel walls. The transfer function parameters can be related to physical phenomena as follows, the gain represents the heat generation into the resistance by Joule effect. In fact , the heat generated is proportional to the input voltage at fixed current. The pole represents the internal energy variation of the barrel wall as a consequence of its temperature increase. Thus, the time constant is related to the thermal capacitance of the barrel wall into the first heater band. Notice that the delay is very short with respect to the time constant of the system. In fact, it does not have a real physical meaning [7]. However, the delay is necessary to avoid the use of a higher order model to effectively describe the system step response at short times (Fig. 4). On the main of (1) the PID parameters ha ve been tuned (proportional gain $K_p$= 0.0122 ; integral time $T_i$ = 249.7; derivative time $T_d$ =57.3). Fig. 4 shows the closed loop performance.

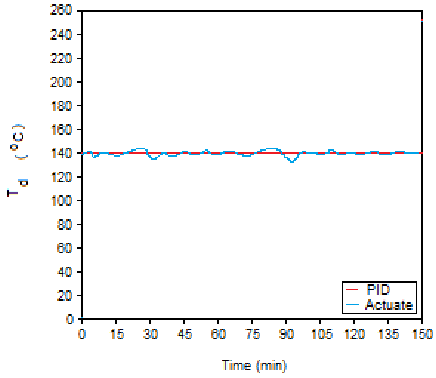



**Fig-4: T ref and $T_d$ of PID controller responses**

The tuning procedure is enhanced by recognizing that different barrels action differently; for example, since the die barrel has a higher heat distribution rate than the other barrels. It actions more like a remain process than an compound process, permitting a faster compound action by the PID controller. Extruder screws are more and more used in the PVC industry. In order to improve the through puts and the operating conditions, screw designs have to be optimized. For that purpose, trial and error are no more sufficiant and it becomes necessary to clearly understand and if possible to compute what happens into the machine during the extrusion process [8].

The output temperature control scheme is constituted by a SISO control loop. The measured / controlled variable is the output temperature $T_d$, the input (control) variable is the set point $T_{ref}$ of the four temperatures iner loops, the reference signal is the referred value of the output temperature $T_d$. Also this control loop is implemented with a classical PID structure, tuned with a model based indirect approach. The estimated transfer function $G_T(s)$ from $T_{ref}$ to $T_d$ is

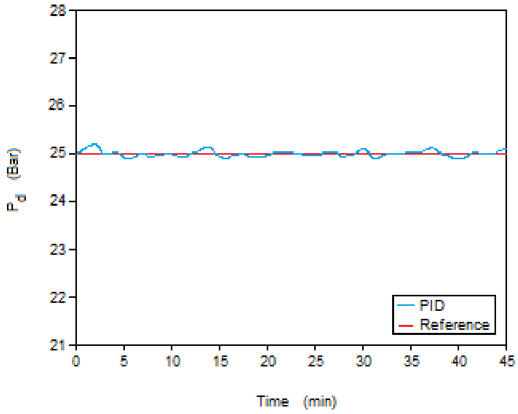
$$G_T(s) = \frac{0.71}{1+389.14}\, e^{-108.65\, s} \qquad (2)$$

Eq. (2) is physical meaningful and the transfer function parameters can be easily understood as follows, the unitary gain is an obvious consequence of well performing local temperature control loops. The pole represents the internal energy variation heater band walls and the polymer mass as a consequence of the temperature increase [9].

Notice that this is a sort of mean value for all the heater bands. The delay represents the polymer transport delay along the extruder. This delay is also evident by visual inspection of Fig.5. On the main of (2) the PID parameters have been tuned (proportional gain $K_P$ = 3.4328, integral time $T_i$ = 225.11, derivative time $T_d$ = 61.10. Control of the output pressure also the output pressure control scheme is constituted by a SISO PID based control loop . The measured /controlled variable is the output pressure Pd , the input variable is the screw engine inverter command voltage Vs, the reference signal is the referred value of the output pressure $P_{ref}$. The estimated transfer function $G_P$ (s) from Vs to $P_d$ is.

$$Gp(s) = \frac{3.4}{1+0.9534\, s}\, e^{-0.1031\, s} \qquad (3)$$

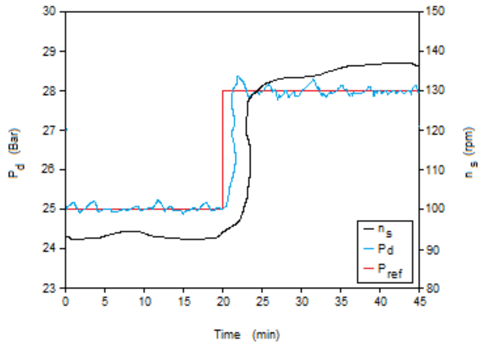
Eq. (3) represents the relationship between the inverter command voltage and the output pressure and its parameters have the following menaning, the gain represents the proportional relation between the applied voltage and the screw revolution speed. The pole represents the energy transfer by friction from the screw to the polymer. The delay is related to the propagation of the pressure front wave into the polymer [10]. On the main of (3) the PID parameters have be entuned (proport ional gain $K_P$ = 1.9823, integral time $T_i$ = 0.1935 derivative time $T_d$ =0.05672. Fig. 5 shows the $P_{ref}$ and the $P_d$ control performance.




**Fig−5: $P_d$ ref and $P_d$ of PID controller responses**

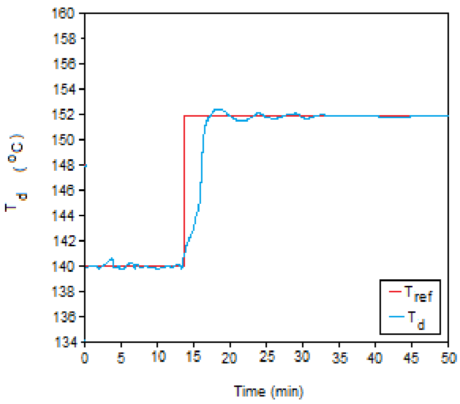
## THE TESTING RESULTS

The all control system described has been extensively experimentally tested. A small set of experiments is briefly illustrated and discussed. The aim of these experiments is to enlighten the main features of the designed control architecture [11]. The test described in Fig. 6 is a simple step hange in the set point of the output pressure (from 25 to 28 bars). The responses of $P_d$ are depicted. Notice that the pressure loop quickly reacts to this change, and smoothly brings the output pressure at the new steady state value.




**Fig−6: $P_{ref}$ and $P_d$ with $n_s$ of PID controller responses**

It is interesting to see that the output temperature is unaffected by the pressure change but notice that (in order to maintain the temperature around the set point Tref = 140 $^oC$) the temperature feedback control loop increases the value of the control variable $T_d$. Thus as already remarked, the two control loops are not decoupled. But, thanks to the frequency decoupling property of the system, the two independently designed SISO loops are able to correctly regulate the output variables $P_d$ and $T_d$. The dual test described in Fig. 6 is a step change in the set point of the output temperature (from 140 $^oC$ to 152 $^oC$).




**Fig−7: $T_{ref}$ and $T_d$ of PID controller responses**

Notice that the feedback control system is able to correctly regulate the output variables at the set point values, regardless the change in the feeding material. Note that the control system quickly reacts to this disturbance and settles the temperature to 140 $^{o}$C in less than 15 min and the pressure to 25 bar in less than 5 min. Notice that the higher variance of the output pressure experienced in the new condition is cause to a less uniform input material and to an higher screw speed. A matter of fact, recall that all the parameters of the control system have been tuned using PVC [12].

A lastly experiment, the act of the feedback controlled extruder has been compared with the act of an extruder fitted with a mechanical pump (and no feedback control). Essentially, it is a common practice to introduce a pump in the extrusion line to steady state the pressure of the PVC at the out put. Fig. 8. and Fig. 9. shows this results.

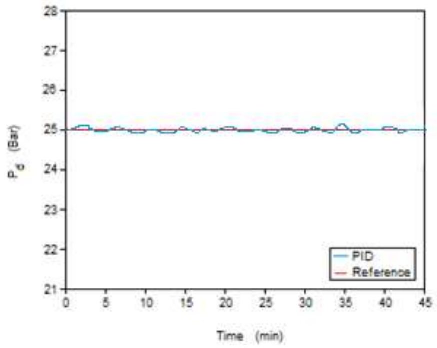



**Fig-8: $P_d$ ref and $P_d$ of PID controller responses with no pump**

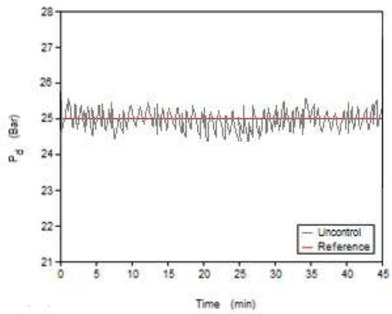



**Fig-9: $P_d$ ref and $P_d$ of Uncontrol responses with pump**

The pressure is sensitivity controlled at the referred value in state of experiment. But the pressure different is higher when the mechanical pump is used this is cause to vibrations made by the pump. This simple experiment shows that the feedback control of the output pressure is a feasible and cost effective alternative to the use of a mechanical pump that the pump is an expensive part, which requires maintenance and is subject to mechanical unsuccessful. The feedback control scheme in spite of has many advantages, it is more allowable, it is less failure prone and it can settle mean controlling methods (e. g. different of reference values.) [13].

## CONCLUSION

It may be used in order to optimize the screw geometry study is going on by testing PVC of plastic polimers and other screw geometries of different extruder construction. The performance of the overall control system can be considered satisfactory from all points of view, the system reacts rapidly to changes in the operation conditions and effectively rejects disturbances cause to changes in the quality and type of PVC, the control achieved provides very small steady state errors both for pressure and temperature.

In this study a feedback control system for real time control of temperature and pressure of the material in a SSE has been designed and experimentally tested. Control of temperature and pressure has been effectively achieved by means of a simple but effective control algorithm based on two independent outer SISO loops, and four identical inner SISO loops for local temperature control.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**Nomenclature**

| | |
|---|---|
| **SISO** | Single Input Single Output |
| **MIMO** | Multi Input Multi Output |
| **PWM** | Power Watt Motors |
| **PID** | Proportional Integral Derivative |
| **SSE** | Single Screw Engineer |
| **PC** | Personal Computer |

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