RESEARCH ARTICLE

Barrel temperature control for quality of thermoplastic polymers in the extrusion process

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Abstract: In this paper, the design procedure; modeling and controller design, testing are presented. Extensive tests have shown that the system reacts rapidly to changes in the operating conditions and effectively rejects disturbances due to unexpected changes in the quality of the material. This paper is the design and experimental testing of a feedback control system for the regulation of the volumetric flow in a polymer single screw extruder. Extruder temperature control is a challenging control problem. The problem becomes even more challenging when multiple barrel are included, such as in barrel temperature control for extruders. When characteristics of the system are examined, it becomes clear that a commonly used proportional plus compound 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 utilizes techniques such as model predictive control, autotuning, and multiple parameter PID is formulated. This control strategy proves to be very effective in achieving the desired specifications.

Keywords: Barrel temperature; Polymer processing; PID control; Extruder

1. Introduction

Worldwide, extruder lines are the largest converters of plastics and can be considered as the most important production machinery in the plastic industry. Commercially, extrusion lines are a target to give advantages with regard to operating cost. 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. 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 secti on, 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 [1].

Then, the polymer is transported along the barrel by means of a rotating screw. The barrelwall is equ ipped 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. A high quality extrusion is essentially characterized by a precisely regulated output volumetric flow; this can be achieved by finally regulating the temperature and the pressure of the die at the output of the extrude r.Traditionally, the regulation 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 [2].

The current challenge is to develop a cost effective fully automatic regulation of the output flow, which canconsistently guarantee high qua lity product.In the literature, a few works on identification and control of plasticating extruders have appeared in system identification. In the literature, a researches on identification and control of plasticating extruders have appeared. In system identification methods are applied to the problem of modeling a singlescrew extruder; specifically, discrete time dynamic models of the dependence of the output temperature and

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pressure on the screw revolution speed are predictd from I/O value. Moreover, linearity of the extrusion process has been verified on a wide range of operatingconditions [3].

The dynamic relation ship between the screw speed and the output die temperature and the melt pressure (the pressur e transducer was placed in the barrel before the head) has been empirically modeled, and a comparison between the performances of a PI controller and a self tuning regulator for melt pressure control is provided. More recently, other related problems have been considered (see e.g. viscosity control and identification and control of the web formation processes during polymer film extrusion.To the best of our knowledge, a detailed description of the overall control system for a plasticating extruder have never been proposed in the open literature. The goal of this work is to fill this gap, and to propose a comprehensive and detailed description of this control system [4].

The plasticating extruder is one of the main pieces of equipment used in the polymer processing industries. As plastics is found more uses, with more stringent quality specifications, the methods of increasing polymer production while improving product quality are needed. Extrusıon molding is the most widely used process in manufacturing plastic products. Since the quality of extrusıon coated plastic parts are mostly influenced by process conditions, how to determine the optimum process conditions becomes the key to improving the part quality. Researches used a measuring device to measure the torque of the plastified polymer at the single screw tip [5]. Researches designed a controller using an in line wedge rheometer as the sensor to control the extrusion of PVC with desired viscosity [6]. Researches developed a fuzzy controller using an in line viscometer to control the melt viscosity during extrusion processing [7]. It is most effective to maintain product quality utilising viscosity control, because a polymers viscosity correlates with its composition and molecular distribution and hence the characteristic of the material. In view of this, more and more researches are aimed at using viscosity measuring instruments as sensors to control the quality of the products [8].

2. Process and unites

Contrary to thermoplastics, little attention has been paid until now to the PVC extrusion. Recently, different research programs have been developed to remedy this lack. Experimental and theoretical works on single stage extruders have been pub published by and experimentations on single and theoretical approaches of the two stage extrusion process have been developed in the case of thermoplastic materials but always for isothermal flow. In the present study, experimentations have been carried out with PVC compounds on a single stage vented screw. The results have permittede to define a theoretical approach leading to a complete description of the flow into the screw The most used plastic for application in extrusion is PVC. PVC dry blends allow the processor to take advantages of using their own compounding formulations that should provide costs advantages [9].

Barrel temperature control in an extrusion process machine presents severe challenges to achieving satisfactory Control (Fig. 1). In extruder, plastic in the form of a granular solid is fed into the barrel, where it is melted so that it can be injected into the mold in a liquid state. The control of the temperature with in the barrel is critical to the quality of the molded product. This is particularly true for some temperature sensitive plastics which can tolerate only very small temperature deviations from the set point. Therefore it is important to have a very tight temperature control during production to ensure consistent product quality. Further, when the machine is started up from a cold state, it is desired that the temperature be brought to its set point usually several hundred degrees Centigrate as rapidly as possible and without much over shoot. Since it may take from 10 minutes to a couple of hours, depending on the size of the barrel and the power rating of the barrel heater, to bring the barrel temperature to its set point, the startup period can have an important effect on productivity. The specification on deviation is also often critical, as in the case of large, well insulated barrels that take a long time to cool down [10].

In briefly, the performance specifications for barrel temperature (Tb_1 , Tb_2 , Tb_3 , Tb_4) control are bring the barrel temperature up to set point as fast as the system capacities without over shoot and maintain the barrel temperature within plusor minus one to two degrees centigrate during the production run. In extruder (**Figure 1**) the piston and spreader that are the key components of piston type machines are replaced by a rotating screw that moves back and forth like a piston within the heating cylinder. As the screw rotates, the flights pick up the feed of granular material dropping from the hopper and force it along the heated wall of the barrel, thereby increasing the rate of heat transfer and also generating considerable heat by its mechanical work. The screw, moreover, promotes mixing and homogenization of the plastic material. As the molten plastic comes off the end of the screw, the screw moves back to permit the melt to accumulate. At the proper time the screw is pushed forward without rotation, acting just like a piston and forcing the melt through the nozzle into the mold. The size of the charge per shot is regulated by the back travel of the screw. The heating and homogenization of the plastics material are controlled by the screw rotation speed and wall temperatures.

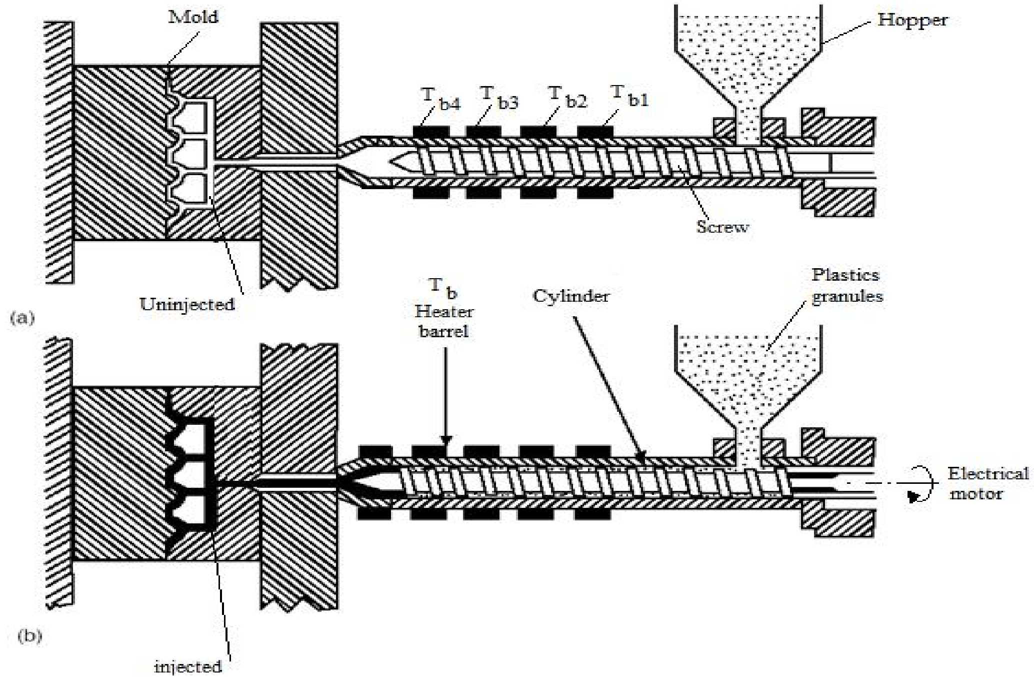

Figure1. Screw injection molding machine, (a) in the backward position and (b) in the forward position.

3. Control strategy

The control strategy incorporates autotuning, multiple PID applied to different barrel barrels and different regimes of control action, as shown in Fig. 2. The block diagram of a typical process control loop is shown in Fig. 2. Control strategy 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.

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 Gp (s) denotes the transfer function of the process plus actuator, and Gc (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 [11].With the transfer function given by Eq. 1.

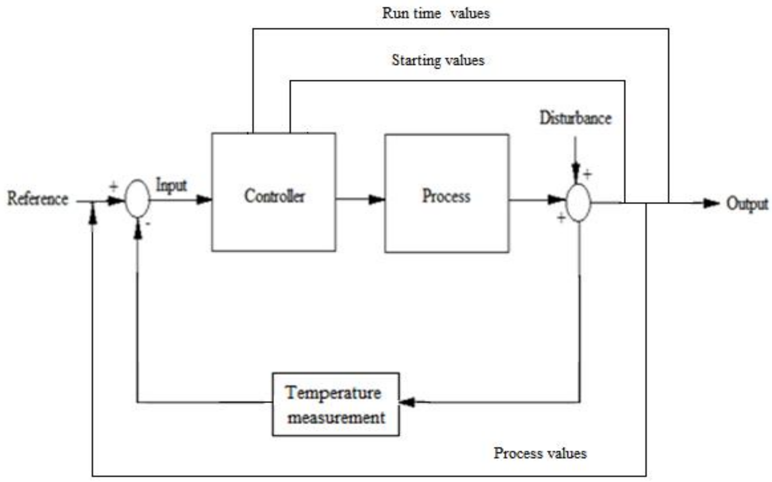

Figure 2. Control closed loop

Laplace Equation for transfer function of process:

$$G_p(s) = \frac{K.e^{-Ts}}{s.(1+\tau.s)} \quad (1)$$

where K is the process gain, T is the process dead time, and τ is the remain time constant.

Consider a proportional plus compound PI controller applied to the above process and laplace equation for transfer function of PI controller:

$$G_c(s) = Kp.(1 + \frac{1}{\tau_i.s}) \quad (2)$$

where Kp is the proportional gain and τ_i is the compound time constant of the controller. In the case of negligible dead time [i.e., T in Eq. (1) is zero),the open loop transfer function for the system of Fig. 1 is

$$G_L(s) = G_c(s) \,.\, G_p(s) = K_L \cdot \frac{(1+\tau_i.s)}{s^2(1+\tau.s)} \quad (3)$$

where K_L denotes the open loop gain. The addition of derivative action to the PI controller of Eq. 2 results in the PID controller and laplace equation for transfer function of PID (Proportional plus compound plus derivative) controller:

$$G_c(s) = Kp.\left(1 + \frac{1}{\tau_i.s}\right).(1 + \tau_D.s) \quad (4)$$

where τ_D is the derivative time constant. This third tuning parameter provides an additional degree of freedom in satisfying control specifications.The open loop transfer function of Fig.1 with PID control becomes

$$G_L(s) = G_c(s) \,.\, G_p(s) = K_L \cdot \frac{(1+\tau_i.s).(1+\tau_D.s)}{s^2(1+\tau.s)} \quad (5)$$

where, consistent with accuracy design practice, the derivative time constant τ_D is set to a value lower than the compound time constant τ_i. When the tuning stage, model parameters in Eq. 6. This parameters are time constant, gain and dead time that these are saved. Either a reaction curve technique or least square method can be used to identify the process model. Two sets of PID tuning parameters are determined, startup PID and run time PID as in Equals 7 and 8. The design procedure for selection of the parameters for Equals 7 and 8 are defined [12].

$$\text{Model}: \frac{\hat{K}.e^{-\hat{T}s}}{s.(\hat{\tau}s+1)} \quad (6)$$

$$\text{Startup PID}: Kp_1.(1+\frac{1}{\tau i_1.s}).(1+\tau D_1.s) \quad (7)$$

$$\text{Run time PID}: Kp_2.(1+\frac{1}{\tau i_2.s}).(1+\tau D_2.s) \quad (8)$$

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. Fig. 3 shows the startup action of an extrusion system on the first start up precede to any tuning. Autotuning is done when this start up stage with the results stored in memory.

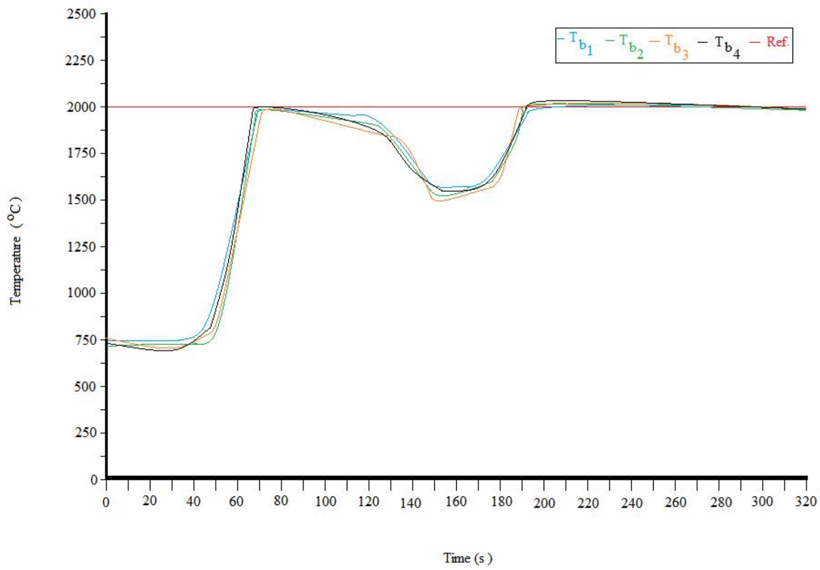

Figure 3. Reference and barel temperatures control in first start up

Fig. 4 shows a typical startup of a four barrel process, after auto tuning. As shown in Figs. 3 and 4, the system capacities the set point as fast as the system capacities in about 350 sn for a set point of 2000 °C without any deviation and the temperature is maintained within a one to two degree band about the set point during the production run. The above control scheme provides a good solution for a heating only type of barrel temperature control. If both heating and cooling are included, the control problem is more complicated due to the very different dynamics between the heating and cooling cycles.The above solution is very effective and also very robust. The robustness comes from the fact that PID based controls are used.

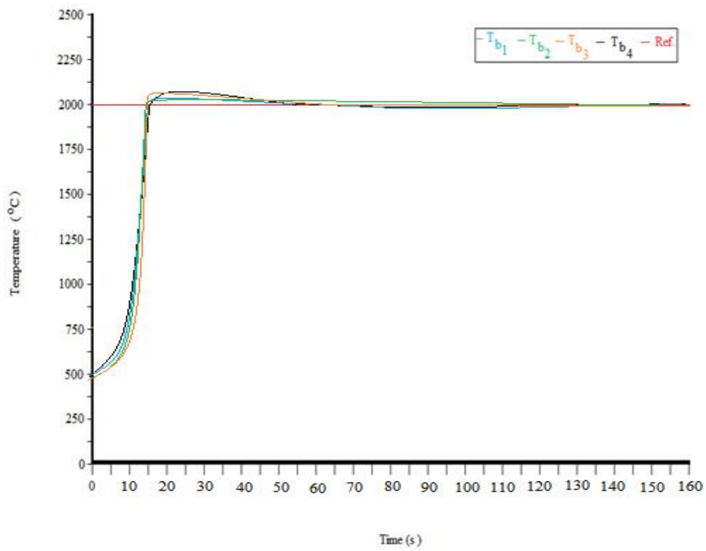

Figure 4. Reference and barel temperatures control in typical start up

5. Conclusions and future work

In this work the control strategy can be embedded within any digitally implemented barrel temperature control system. The only information required of the user in setting up the system are the typical PID setup parameters, e.g., PID type, sampling time, etc. The control strategy that can be employs a combination of several of the control techniques described above is proven to be very effective for this type of process. The performance of the overall control system can be consider ed satisfactory from all poin ts of view, the system reacts rapidly to changes in the operation conditions and effectively rejects disturbances due to changes in the quality and type of the material, the regulation achieved provides very small steady state errors both for pressure and temperature.

The extrusion process requires some adjustments, mainly in terms of cooling system, die and resin preparation. PVC requires special attention because, it cannot be processed without the use of plasticizers and heat stabilizers, which increases the cost of production due the high price of this additives. It may be used in order to optimize the screw geometry study is going on by testing different pvc polimers and other screw geometries.

Acknowledgements

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