Extruder temperature control with adaptive reset

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ABSTRACT: *Barrel-temperature-control schemes compensate for "error" (deviation from setpoint) by using a reset function to adjust the temperature toward the required setpoint. Unfortunately, all systems must "learn" the amount of reset whenever an offset occurs, taking a significant amount of time to reach a stable setpoint. A new system uses a unique technique that relates the reset value to extruder screw speed, which is related to the thermal load. The system relies on an internal table of screw speeds and reset values that is constructed automatically in a learning mode. The principle is simple: once the machine has learned the proper reset value for a given speed, the machine simply returns to this value. In practice, the technology requires complex control algorithms and extensive development. Laboratory data for the new control system and conventional controls demonstrate that restoration of a stable setpoint after a speed change or a disruptive upset is quickest for the new system.*

KEYWORDS: *Adaptive systems, control systems, converting machines, extruders, temperature control.*

Extruders have heating and cooling systems on their barrels for two basic reasons.

1. To provide initial heat-up and subsequent heating or cooling, depending on processing requirements
2. To provide accurate control of the inner barrel surface, which affects melt-temperature stability and product quality.

The extrusion industry has justifiably devoted a great deal of attention to the design and development of temperature-control systems for extruder barrels.

Accurate barrel control presents a difficult challenge because of the physical construction of the barrel and an extruder's processing characteristics. The thick barrel wall separates the control point, at the inner surface, from the heating or cooling source, at the outside. This not only results in a considerable temperature differential, but creates a significant thermal time lag that causes major control problems. The process itself also contributes to control difficulty, since the load demand can vary with material changes and change from heating to cooling as screw speed increases.

Conventional PID (proportional, integral, derivative) controls have special features beyond proportional output to compensate for the difficulties of control. Integral action, or reset, shifts the output to compensate for load so that the control point agrees with setpoint. The reset function is illustrated in **Fig. 1**. Derivative action, or rate, is meant to compensate for large changes. Unfortunately, both can respond only after an upset has occurred, so they are inherently limited in their response *(1)*. Recent improvements attempting to overcome these limitations include auto-tune and the application of fuzzy logic. Extruder manufacturers usually follow one of two courses. They supply machines with shallow thermocouples that appear to provide adequate control but, in fact, do not control the inner surface; or they properly supply deep thermocouples, which have the drawback of sluggish control systems *(2)*.

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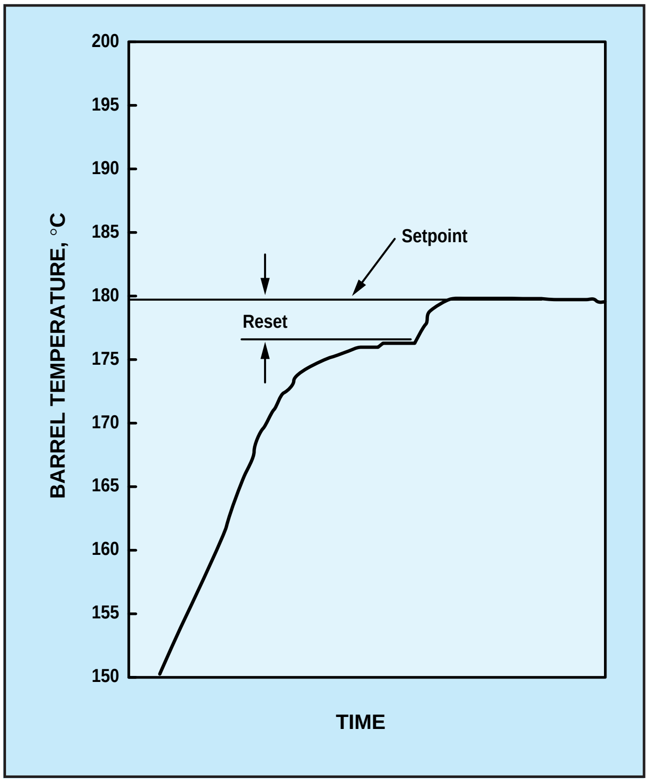
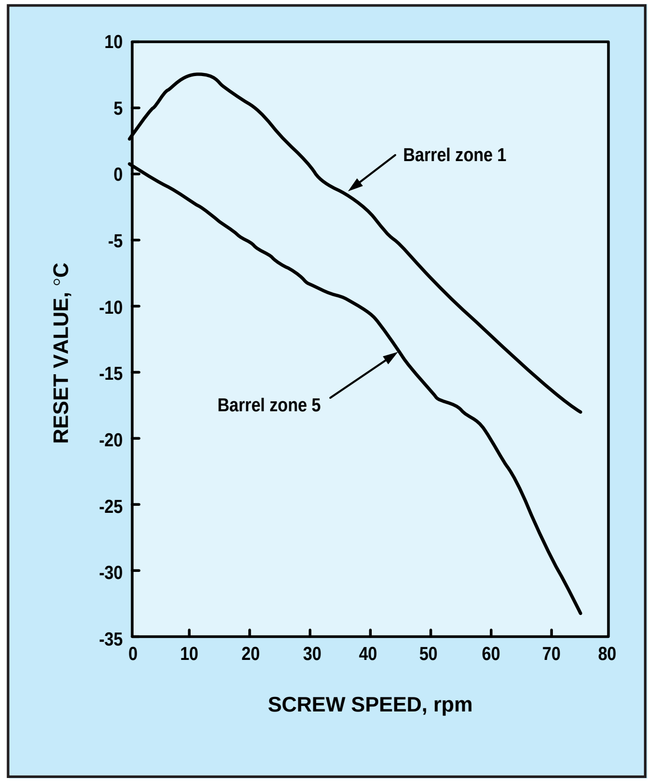
1. PID reset control; integral action (i.e., reset) shifts the output to compensate for load so that the control point agrees with setpoint



2. Adaptive reset control; reset values associated with screw speed for barrel zone 1 (barrel feed) and zone 5 (barrel discharge)



An alternative system that utilizes two thermocouples was developed and patented in 1981 *(3)*. This system monitors the temperature at the heating–cooling source as well as at the control point, providing an anticipatory feature that works as a sort of "instantaneous derivative." Reset is still achieved through a conventional automatic function. The dual-thermocouple system has proved to be superior to PID systems in stability *(4)*, but it provides little or no advantage in upset recovery time.

Objective

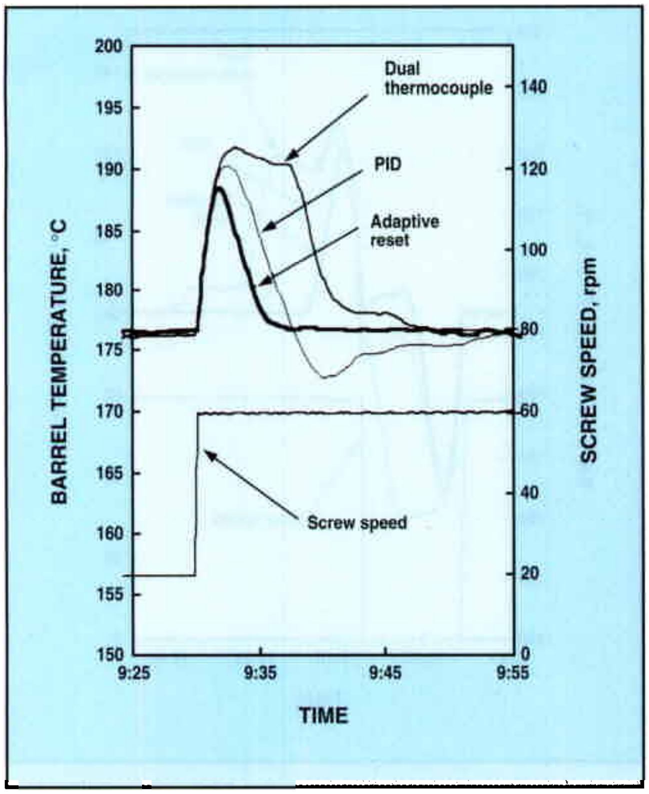
One of the most problematic manifestations of temperature-control limitations in extrusion processes occurs when the screw speed is changed, either as part of a planned sequence of string-up, changeover, or splicing, or during an unplanned event such as a shutdown or emergency stop. Barrel-temperature upsets occur in response to a change in process load that originates at the inner barrel surface. For example, a barrel zone that runs with high cooling to compensate for the screw's generation of shear heat will drastically undershoot the setpoint if the screw suddenly stops. It will then go into a heating mode in order to recover, entirely the opposite of the running mode. Upon restart, the situation reverses, requiring considerable time to reach setpoint and even more time to achieve stability.

This paper discusses the results of a development program for a barrel-temperature-control system that could quickly return to a previous stable condition by somehow "remembering" where it had been. For instance, if a particular zone was operating at a high cooling load at running speed and then was momentarily stopped, the same amount of cooling would be instantly applied as soon as the process was restarted. Extensive testing showed that the most significant control parameter that could relate the heating or cooling load to screw speed was the reset value. The amount of reset, which can be thought of as load compensation (Fig. 1), is directly proportional to the required amount of heating or cooling. The shear heat generated by an extruder screw is largely a function of screw speed, so relating this control parameter to speed is a technically sound approach.

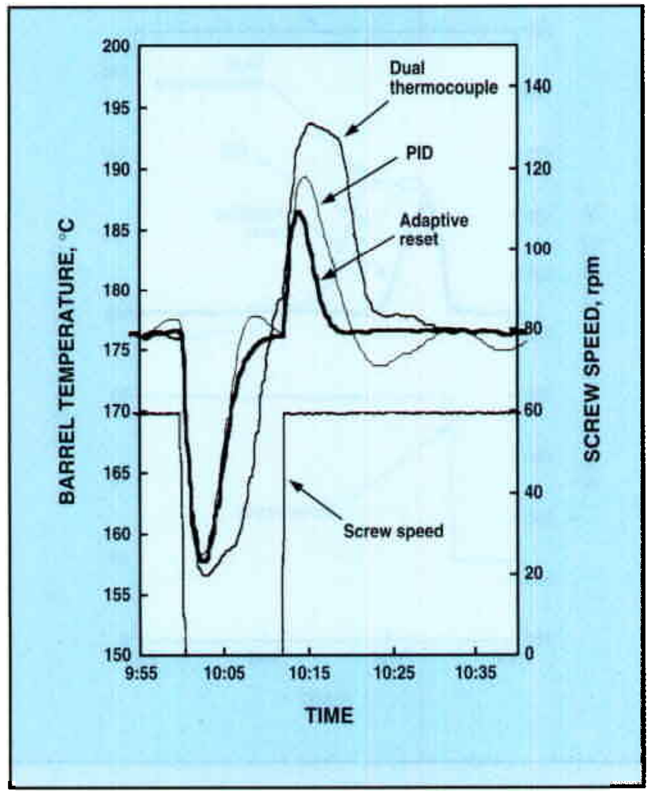
Development

A new adaptive-reset control scheme was patented in 1992 *(5)*. The control scheme is based on the proven dual-thermocouple principle, but the new system includes a memorized table of reset values vs. screw speeds. The table is automatically learned as the extruder is operated in a normal manner. Learning takes place according to the control program's rule sets and logic. Adaptive-reset tables are

3. Temperature-control response in barrel zone 1 (speed increased from 20 rpm to 60 rpm)



4. Temperature-control response in barrel zone 1 (speed reduced from 60 rpm to zero and back to 60 rpm)



stored as part of the controller's recipes for each material and screw design and then applied whenever screw speed changes. This action works as a sort of instantaneous integral. The system provides fast response, accuracy, and stability, and—for the first time—a positive method for accommodating large changes and interruptions.

Experimental

The adaptive reset system was developed and tested during extensive extrusion trials. Trials were conducted on both 63.5-mm and 114-mm extruders with various thermoplastic materials and screw designs, including combinations that required high cooling as well as high heating.

This paper presents the results of a series of trials on a 114-mm, 24:1 length-to-diameter ratio, water-cooled extruder with a barrier screw (DSB®) and a control system (EPIC II) with data-acquisition capabilities. All trials were run using a 0.9-MI (melt index) film-grade LLDPE (linear low-density polyethylene). The exact sequence was repeated three times for the three types of barrel-temperature controllers under study: auto-tuning PID, dual thermocouple, and adaptive reset. The PID controllers were discrete units that were set to the manufacturer's recommended settings and then auto-tuned. The latter two control schemes were both run in the EPIC II control system. During the dual-thermocouple trial, adaptive-reset action was disabled, but the system "learned" the reset values for the screw speeds that were applied during the final trial.

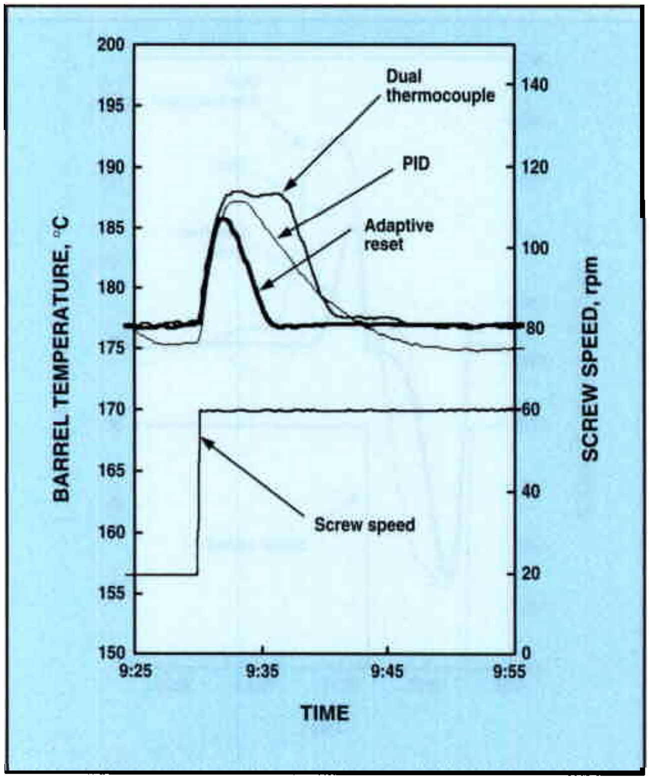
During each trial, the extruder was run at 20 rpm until the process and all barrel-zone temperatures (177°C) were stable. Screw speed was then changed to 60 rpm. After 30 min, the extruder was suddenly stopped for 12 min, restarted, and brought back to 60 rpm. All barrel-zone temperatures were monitored and recorded during the trials, as was melt temperature, the critical parameter that affects the process.

Results

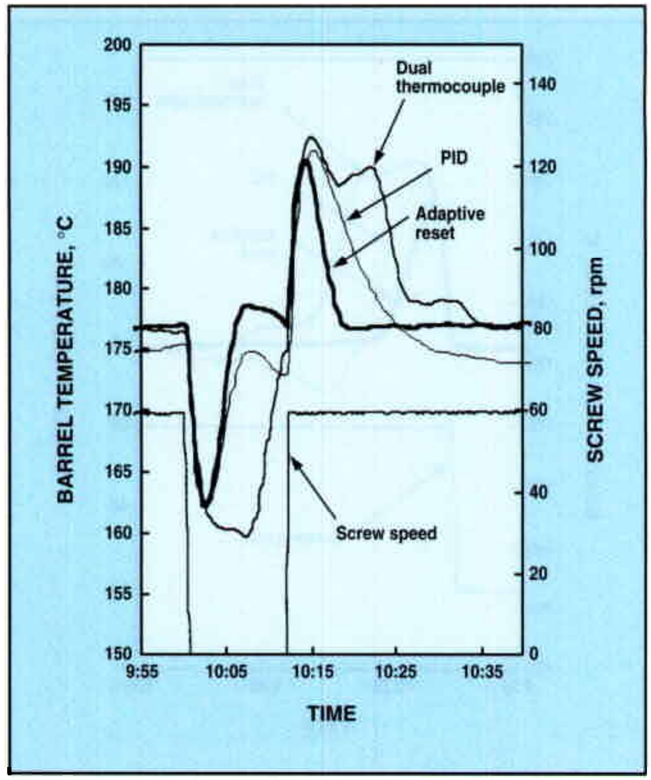
LLDPE with a 0.9 MI is a fairly high-viscosity material, demanding high torque and considerable cooling from the extruder when processed on a high-output barrier screw. The reset values associated with screw speed for barrel zones 1 and 5 are shown in **Fig. 2.** These are the values that were learned and applied by the adaptive-reset control system during the trials. The feed area, zone 1, shows a heating requirement at low speed, and then a cooling demand for speeds over 30 rpm. Zone 5 at the discharge shows an increasing cooling requirement for all speeds.

Figures 3–6 show the recorded values for the deep barrel control thermocouple over time during the three repeated trials with the three

5. Temperature-control response in barrel zone 5 (speed increased from 20 rpm to 60 rpm)



6. Temperature-control response in barrel zone 5 (speed reduced from 60 rpm to zero and back to 60 rpm)



different control systems on the time scale from the first run. Figures 3 and 4 depict results for zone 1, while Figs. 5 and 6 depict results for zone 5. Figures 3 and 5 show a screw-speed change from 20 rpm to 60 rpm, and Figs. 4 and 6 show a screw-speed change from 60 rpm to zero and back to 60 rpm. In all cases, the initial reaction to speed changes for all three controllers is identical, since the deep thermocouples are reflecting the rapid change in process load, i.e., the addition or loss of polymer shear heating from the screw. The differences in the curves after that point reflect the different performances of the three controllers.

In Fig. 3, going from 20 rpm to 60 rpm, the PID controller undershoots the setpoint as it is recovering from the initial upset and then takes a considerable amount of time, about 25 min overall, to reach setpoint. The dual-thermocouple scheme avoids undershoot but waits at the initial upset temperature longer, then goes through a reset, reaching setpoint in about 18 min. Adaptive reset shows a dramatic improvement, with no lag or overshoot, coming right back to setpoint in only 7 min.

Figure 4, with screw speeds going from 60 rpm to zero and back to 60 rpm, shows the same characteristic patterns. The PID controller undershoots and oscillates; the dual-thermocouple control hesitates and goes through an obvious reset; and the adaptive-reset control quickly returns to setpoint in about a third of the time as the other two.

Figures 5 and 6 show similar response on zone 5, except that the PID controller, operating on a zone with a higher cooling load, appears to be much slower in reaction and never reaches setpoint. The other two systems behave as they did in zone 1, with the adaptive-reset control clearly showing superior performance.

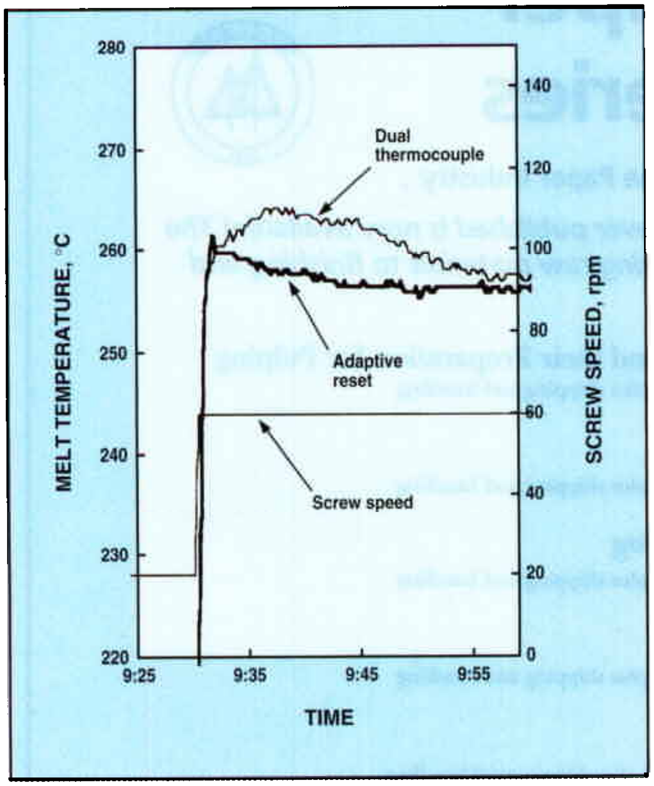
The effect of temperature control on melt temperature is shown in **Figs. 7 and** 8 for dual-thermocouple and adaptive-reset controls. These results show the dramatic improvement that a quick recovery to setpoint can have on the process. In both cases, the adaptive-reset system brought the melt temperature back to a stable condition in about half the time required by the dual-thermocouple system.

Conclusions

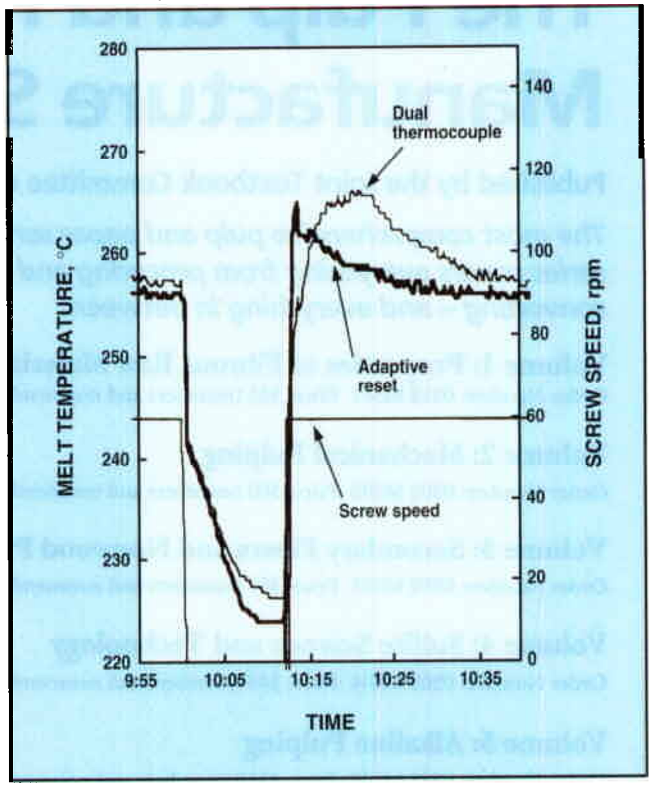
Extruder barrel-temperature control can greatly influence extrusion rate, melt temperature, product quality, and process stability. Accurate and responsive control of barrel temperatures is therefore a critical factor for efficient extrusion and high quality. Processes that include speed changes or frequent, even if unplanned, stop–start sequences need rapid recovery of barrel control.

The response of the PID controllers showed one of the weaknesses of "auto-tune"—that the automated tuning occurs with an empty, stopped extruder with no process heating or

7. Melt-temperature response to temperature control (speed increased from 20 rpm to 60 rpm)



8. Melt-temperature response to temperature control (speed reduced from 60 rpm to zero and back to 60 rpm)



cooling load. Under operating conditions, the actual load is not only different, but it can change from heating to cooling with a change in speed, as seen for zone 1 in Fig. 2. The same controller behaved differently on the two different zones, having excessive gain and overshooting on zone 1, and not enough gain on zone 5, resulting in a very slow return to setpoint.

The newly developed adaptive-reset temperature-control system showed dramatic improvement in response to screw-speed changes and start–stop events. The improved response was achieved through the use of a control scheme that automatically learns and then applies reset values according to screw speed. The adaptive-reset system also exhibits the excellent stability inherent to the dual-thermocouple control system. Adaptive reset offers extrusion processors significant improvements in quality and efficiency at no significant increase in capital cost. T

Literature cited

1. Bayless, R. F., *SPE Antec 1978 Conference Proceedings*, Society of Plastic Engineers, Greenwich, CT, p. 544.
2. Harris, H. E., *SPE Antec 1977 Conference Proceedings*, Society of Plastic Engineers, Greenwich, CT, p. 423.
3. Faillace, L., U.S. pat. 4,262,737 (1981).
4. Hasson, A., Miaw, C., and Balch, G., *SPE Antec 1986 Conference Proceedings*, Society of Plastic Engineers, Greenwich, CT, p. 979.
5. Faillace, L., U.S. pat. 5,149,193 (1992).

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