the intention of this presentation to explore or summarize this body of literature. This discussion will acquaint you with the latest developments in the quality of temperature control, present both the component and systems approaches, and provide an insight into what the future holds.

The viscosity of the melt and the speed and pressure of injection determine whether an acceptable molded part is produced. Viscosity is a function of the temperature of plastics, and temperature is a result of the forces of screw rpm, back pressure, and externally applied heat. Injection machine control specialists are generally agreed that one-third of the melt temperature is derived from external heat. Closed loop temperature control thus deserves in-depth attention.

Many excellent instruments are available today as a result of reliable and cost-effective solid state and digital technologies. The temperature control result is, of course, no better than the quality of other components and installation practices employed on the machine. Too many times we find the advantages of a sophisticated temperature control (TC) instrument completely negated by poor installation techniques. Before deciding prematurely that the instrument is at fault, you should make the following checks:

1. Is the thermowell too big for the TC protection tube? Air is an excellent insulator.
2. Is there contamination inside the thermowell? Rust, scale, and residue prevent proper contact of the protection tube with the thermowell.
3. Is the TC junction partially open?
4. Are there oxidation and corrosion inside the protection tube?
5. Is the proper extension wire being used: Copper wire allows another thermocouple junction.
6. Is extension wire polarity observed? A single reversal will give a downscale reading; a double reversal will result in an erratic input to the controller.
7. Are wire terminations properly isolated? False cold junctions are a common problem.
8. Is the cold junction compensation at the extension wire termination on the controller working properly? A poorly positioned or poorly connected compensation component will allow the input to vary.
9. In the panel, are the thermocouple leads isolated from the ac wiring as required? Are the TC wiring and the ac wiring run in separate conduits from the control cabinet to the machine as required?
10. Is the control cabinet thermal environment within the specification of the controller? Excessive cabinet temperatures can cause a controller to drift.
11. Examine the power contactor. If it is a mechanical contactor, deterioration of the contacts can result in reduced power delivered to the heaters.
12. Are the heaters sized correctly? Modern temperature controllers can compensate for limited missizing, but cannot substitute for proper design.
13. Heater bands must be secured tightly to the barrel; again, air is an excellent insulator.
14. Check the voltage being supplied to the heaters. High voltage leads to premature heater failure.
15. Inspect wiring terminations at the heater band; connections must be secure.

If the integrity of the heating system has been verified, your attention can now be turned to the advantages of modern temperature control instrumentation. To demonstrate the improvements available during the past 15 years, a comparison of three basic instrument designs is helpful. Millivoltmeter designs can hold setpoint within 20 to 30 degrees; solid state designs can hold within 10 to 20 degrees; microprocessor-based designs typically hold setpoint within 2 to 5 degrees.

Microprocessor-based designs provide several distinct advantages. Already mentioned is the inherent ability to control the temperature at setpoint. Sometimes they do too well. There are reports, in fact, where the customer claimed the controller was not working, because the process reading was the same as setpoint for an entire shift. Microprocessors extent of compression must be properly controlled. When this event is close at hand, a dramatic rise in hydraulic and cavity pressure is experienced, as seen in Fig. 11-14. Sensing the dramatic rise in hydraulic pressure will place the end of fill at its proper time without the use of a timer. Connecting the detection of this event to a specific region (see Fig. 11-14) allows higher injection pressures during fill if they are needed.

Pack and Hold. In the case of pack and hold, the proper parameter has already been selected—pressure. However, the methods of pressure control can be improved. The level of pressure in pack or hold and the dynamic performance are important, and ways to improve them are discussed later.

Plastication. Proper melt viscosity is the desired end for the plastication phase of a machine cycle. There is not yet a good way to tell if the plastication phase has done its job properly until the next part is made. This might be fertile ground for the development of a transducer to measure viscosity at the tip of the screw as feedback to an algorithm for control of screw speed and back pressure. In the absence of such a device, attempts are made to keep the energy added to plastication as repeatable as possible. The three parameters that are controllable in the addition of energy to the melt are screw speed, back pressure, and barrel temperature. Speed and pressure control on standard machines imply flow and pressure valves, and each of these devices bring with them short- and long-term variations. Ways to improve flow and pressure control are discussed later. Temperature, the third controllable parameter, appears to have sufficient control with the state-of-the-art devices.

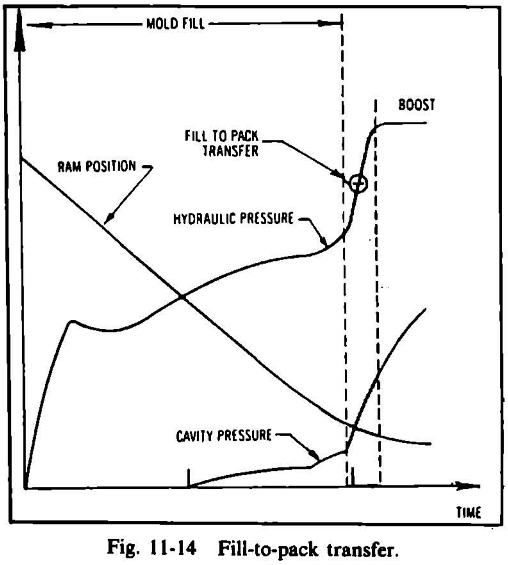

Fig. 11-14 Fill-to-pack transfer.

In summary, most variables can be eliminated through the use of two parameters, velocity and pressure. The more repeatable, the more dynamically controllable these parameters are made to be, the better the ability an injection molding machine will have to mold a part. Figure 11-15 seems to demonstrate the repeatability brought to making a part with improved parameter control. This figure shows the difference in cavity pressure repeatability with open loop and closed loop machine control.

What Enables Parameter Controllability?

Closed loop servo control is the best known way to control a parameter. Closed loop theory says that a parameter is measured with a sufficiently accurate transducer. The signal from the transducer, representing the parameter's value, is compared with a desired signal level for the parameter. The difference or error is amplified as much as possible before being sent to a control element for correction of the parameter. Figure 11-16 depicts a closed loop control of ram speed or pressure (force). A transducer (one for speed and one for pressure) measures the parameter under control. It creates a feedback voltage in accordance with its transfer function (H) in volts per unit pressure or volts per unit velocity. A summing junction compares the feedback voltage to one commanded by the process controller. The difference is sent to the forward loop elements (amplifier, control valve, and ram piston) whose lumped parameter transfer function is G, with units of speed per volt or pressure per volt. Using the lumped parameter transfer functions, the servoloop transfer function can be expressed mathematically as equation (11–

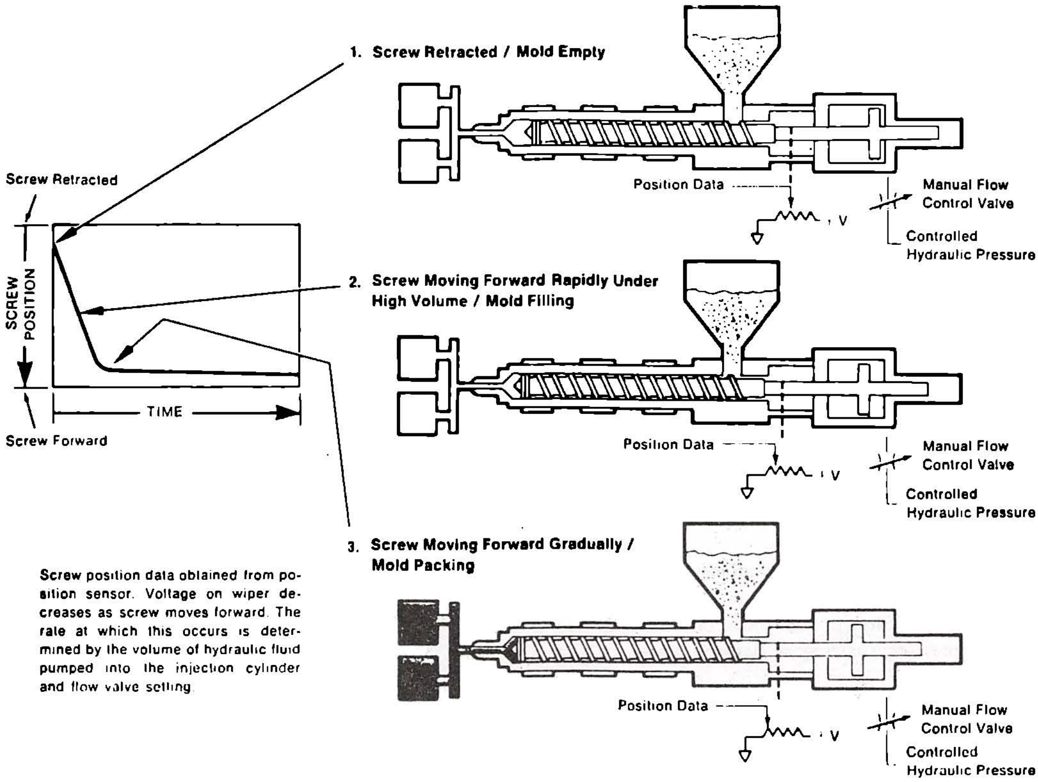

Fig. 11-29 Screw travel during rotation.

into two major phases: mold filling and mold packing. As shown in Fig. 11-30, screw movement occurs primarily during the mold filling phase while mild pressure buildup takes place in the mold packing phase. The association of screw movement with mold filling and mold pressure with mold packing is important and should be remembered.

Attempting to control the molding process using ram position only or mold pressure only as the measured variable and adjusting primary injection pressure as the control function is not satisfactory because both mold filling and mold packing take place with the same injection pressure value. Changing the primary injection pressure affects both phases of the injection cycle. For example, assume that a new batch of material with a lower melt index has been put into the feed hopper. Since the melt index is lower (apparent viscosity is higher), ram screw speed under a given primary injection pressure will decrease. This means that the mold will fill more slowly, and mold pressure buildup will occur later. Depending on the change in the material, the mold pressure will also decrease. The effect of the material change on ram screw speed and mold pressure is shown in Fig. 11-30.

To compensate for the material change and get the average injection rate back to normal, the primary injection pressure could be increased. Increasing primary injection pressure will increase the average injection rate but at the same time lowers the apparent viscosity by the effect of shear stress/shear rate applied to the material. Dynamically, this apparent lower viscosity carries over to the packing phase to a point that would result in increased mold pressure, overpacking, and a heavier part with stresses. The effects of the increased injection pressure are shown in Fig. 11-31.

The ram curve and thus the average injection rate have returned to their original value, but mold pressure due to the change in apparent material viscosity peaks out at a higher value, resulting in an overpacked, more