Closed-loop control improves die-casting performance

By C. Thibault and M. Funke

Hot-chamber die-casting machines traditionally have been equipped with open-loop controls to operate the hydraulic systems that power the injection function. At the start of the cycle, hydraulic fluid flowing into the injection cylinder rapidly accelerates the injection plunger, but then it travels at roughly constant velocity while it pushes liquid metal into the mold. When the mold and runner system are full, all moving components of the injection system — piston, plunger, and hydraulic fluid — come to a halt due to the incompressibility of the metal. The rapid increase in pressure within the mold can cause a water-hammer effect, which often produces flash on the castings. Removal of flash requires expensive trimming and deburring in post-production operations.

More precise control of the pressure and flow rate of the hydraulic fluid supplied to the injection cylinder could eliminate these expenses. For this reason, closed-loop control of injection systems has been applied on large, conventional die-casting machines — which have relatively long plunger strokes and injection times — for several years. However, small die-casting machines, with much shorter plunger strokes and injection times (resulting in faster cycle speeds), had proven more difficult to adapt to closed-loop control.

Design challenges

Nevertheless, when a team at Techmire Ltd. set out in August 1998 to develop a new series of high-speed, multiple-slide die-casting machines, its members were determined to include a closed-loop shot-profiling system that would offer greater reliability and repeatability — while still meeting the company's standards for performance and quality. Prior to this project, Techmire had used closed-loop technology for its line of plastic injection-molding machines but not for die casting. The design team enlisted Moog Inc.'s Industrial Controls Div. (ICD) — with experience in both die casting and closed-loop systems — to help them make this project happen.

A design goal of faster cycle time and improved product quality called for hydraulic controls with better response.

The new machines — christened the NTX Series — would feature a heavy-duty, rigid clamping system to accommodate high pressures in the liquid-metal cavities and high injection velocities. Specific performance goals were:

- cycle speeds up to 25 shots per minute — to compete with existing open-loop machines (in other words, the closed-loop system must be at least as fast as open-loop systems)
- visible improvement in part quality, so parts could proceed to the next process without secondary finishing operations, and
- the repeatability of the closed-loop velocity and pressure controls must be maintained over

44NTX high-speed, multiple slide, hot-chamber die-casting machine benefits from closed-loop control of pressure and velocity in injection-cylinder circuit.

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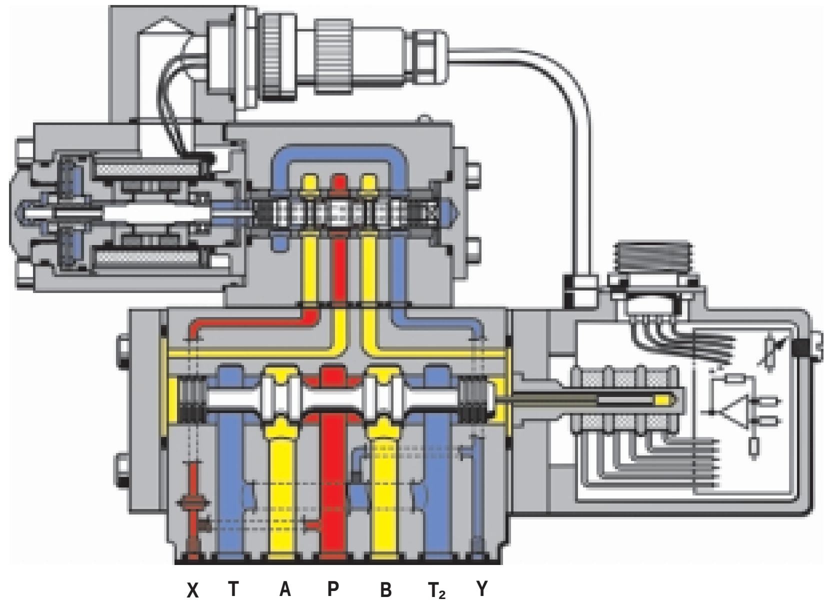
an 8-hour production run.

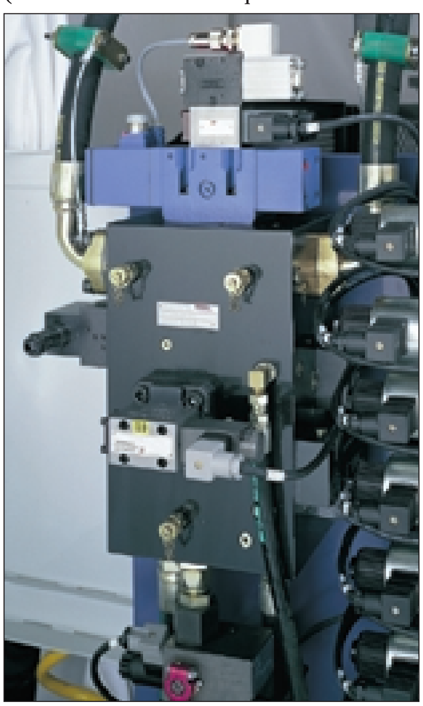
Hydraulic system details

From a technical standpoint, the biggest design hurdle was finding a way to switch the injection process from velocity control to pressure control within a 15- to 20-ms window over an injection piston stroke of approximately 1 in. To understand how the closed-loop system works, it is important to cover some of the key functionality of the NTX machine. To cycle at very high speeds, the design interconnects a fixed-vane pump and two piston-type accumulators to provide the hydraulic flow needed for fast response. The accumulators can provide as much as 80% of the flow needed by the injection cylinder. The same arrangement maintains constant pressure during cylinder extension.

The NTX hydraulic circuit is divided into two main sections: functions and injection. The functions manifold supplies and controls the toggle cylinders (which lock the mold halves together), the feeder piston (which starts liquid flow), and movement of the gooseneck (which connects the liquid-metal reservoir to the injection cylinder). A heat exchanger in the return line controls oil temperature, and a return-line filter keeps the fluid clean.



Cross-sectional view of Moog ICD's D681 2-stage servo-proportional valve with direct-drive D633 pilot valve at upper left. Porting pattern code: *X* — pilot pressure; *T* — tank pressure; *A* — to injection cylinder; *P* — system pressure; B — to cylinder; T_2 — tank pressure; and *Y* — pilot return.

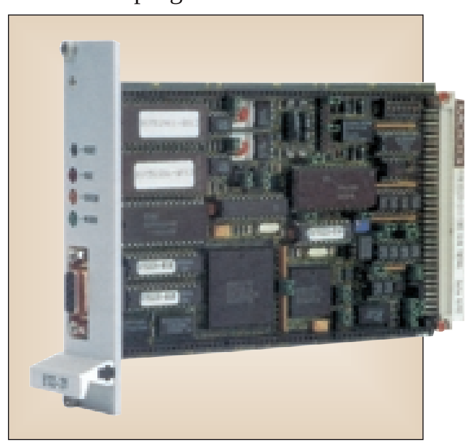


Blue servo-proportional valve mounts atop injection manifold which also includes cartridge valves that connect the pressure system to the injector cylinder and a solenoid-actuated directional valve that ports pilot pressure to the cartridge valves. At right are directional control valves mounted on the functions manifold.

The injection manifold — designed by Moog ICD — contains the valves that control the programmed movement of the injection cylinder. Moog ICD's other major contributions to the closed-loop control developed for the NTX are the D681 Series servo-proportional valve that meters fluid out of the injection cylinder and the M2000 servo controller that programs the valve. A pressure filter at the inlet of this manifold protects the valve.

The 2-stage D681 Series valve was selected because of its high dynamic response. It can provide 100% step response in 12 ms. Its pressure range is up to 5000 psi, and its maximum rated flow is 20 gpm at 75-psi Δp/land. Its D633 pilot valve is driven by a permanent-magnet differential linear-force motor. The permanent magnets provide part of the force required to shift the pilot-valve spool electromagnetic flux generated by the command signal. The motor generates force (and stroke) in both directions from its neutral mid position. The force and stroke are proportional to command current.

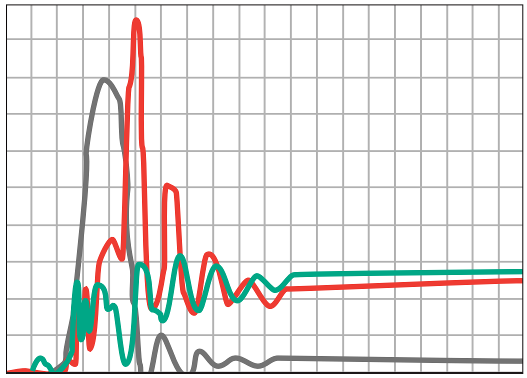
The M2000 digital 2-axis servo-controller card offers great flexibility, precision, and high-speed logic sequencing — as well as the ability to create an advanced control algorithm. Using this combination of products, Moog designed and deployed a system that operates in two distinct phases — velocity and pressure. During the velocity phase at the start of the cycle, a predetermined profile controls the velocity of the injection piston, yielding optimum fill characteristics by ensuring proper delivery of liquid metal to the mold. As many as three variable-velocity profiles can be programmed.



M2000 programmable servo controller card includes real-time function blocks, user-defined control-loop structures, PC-based programming interface, integral Motion Control Language, trajectory generator for smooth motion, error-detection and shut-down system, and online control-loop tuning.

Net hydraulic pressure applied to the injection piston is controlled during the pressure phase. This allows the control to rapidly decelerate the injection piston, while greatly reducing the harmful water-hammer effect. This is accomplished without increasing the injection-cycle time. Two variable-pressure profiles can be programmed.

Throughout both phases, the injection piston is accurately controlled by frequent comparison of actual values with required values, as well as precise control of the outflow of hydraulic fluid from the injection cylinder. The transition from the velocity phase to the pressure phase is accomplished in a smoothly controlled and repeatable manner based on the position of the injection piston.



Plots of injection-piston velocity (gray), pressure under open-loop control (red), and pressure under closed-loop control (green) vs. time dramatically illustrate how more sophisticated closed-loop control dramatically reduces undesirable pressure spike than can produce flash.

Performance benefits

Techmire's 44NTX machine has a 3- or 4-second cycle time, while the company's larger machines require 5 seconds to cycle. The NTX closed-loop system controls the injection process from start to finish, resulting in stable system performance and ideal cavity-fill parameters. The Moog-designed system automatically transitions from velocity control to pressure control during each injection cycle. The machine casts high-quality parts, with consistent density and surface finish.

When compared to conventional open-loop systems, closed-loop systems have these advantages:

- the ability to select the optimum injection profile for each mold
- a substantial reduction of peak metal pressure — that can lead to flash — at the end of the injection cycle
- an increased operating window of the die-casting machine; and
- a reduction in the effects of process variations, caused by wear of machine components and changes in hydraulic fluid viscosity due to temperature, that can produce inconsistent castings.

In addition, setup of the closed-loop injection control system is user-friendly. The switch-over point from the velocity phase to the pressure phase is determined by taking a few trial shots and observing the actual pressure and displacement profiles during compaction. H&P