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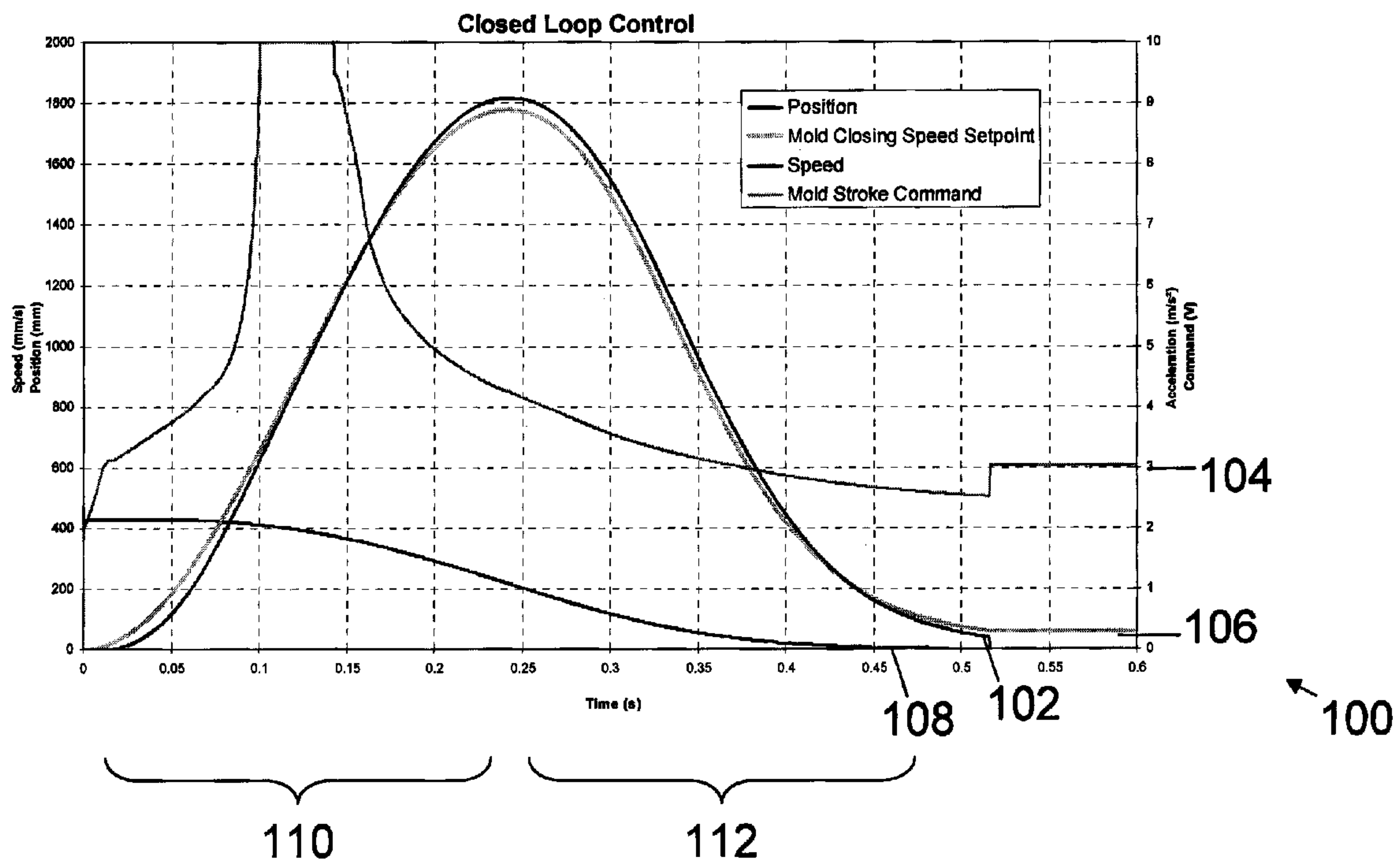
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(54) Title: MOLD ACTUATOR STROKE CONTROL



(57) Abrégé/Abstract:

The present invention can provide closed loop control with feed forward compensation for a movable platen of an injection molding machine. The closed loop control is on velocity and acceleration. The acceleration is computed from net force (pressure multiplied by cylinder area) and moving mass. Feed forward compensation is obtained from the velocity profile

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ABSTRACT

The present invention can provide closed loop control with feed forward compensation for a movable platen of an injection molding machine. The closed loop control is on velocity and acceleration. The acceleration is computed from net force (pressure multiplied by cylinder area) and moving mass. Feed forward compensation is obtained from the velocity profile

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Mold Actuator Stroke Control**TECHNICAL FIELD OF THE INVENTION**

[0001] The present invention relates to injection molding machinery. More specifically, the present invention relates to the control systems used to open and close a mold.

BACKGROUND OF THE INVENTION

[0002] Some examples of known molding systems are: (i) the HyPET™ Molding System, (ii) the Quadloc™ Molding System, (iii) the Hylectric™ Molding System, and (iv) the HyMet™ Molding System, all manufactured by Husky Injection Molding Systems Ltd.

[0003] FIG. 1 is the perspective view of a molding system 20 (preferably an injection molding system hereafter referred to as the “system 20”) according to the first exemplary embodiment. The system 20 is used to mold one more molded articles (not shown). The system 20 includes components that are known to persons skilled in the art and these known components will not be described here; these known components are described, by way of example, in the following references: (i) Injection Molding Handbook by Osswald/Turng/Gramann ISBN: 3-446-21669-2; publisher: Hanser, and (ii) Injection Molding Handbook by Rosato and Rosato ISBN: 0-412-99381-3; publisher: Chapman & Hill.

[0004] The system 20 includes (amongst other things): (i) an injection-type extruder 22 (hereafter referred to as the “extruder 22”), (ii) a hopper 24, (iii) a control cabinet 26, (iv) a human-machine interface, hereafter referred to as the “HMI 28”, (v) a stationary platen 30, (vi) a moveable platen 32, and (vii) an ejector assembly 34 (described in greater detail below). FIG. 1 depicts an approximate location of the ejector assembly 34 relative to the system 20. The extruder 22 has a barrel and a reciprocating screw disposed in the barrel. Alternatively, the extruder 22 could be a two stage shooting pot configuration. The hopper 24 is coupled to a feed throat of the extruder 22 so as to deliver pellets of moldable material to the extruder 22. The extruder 22 is configured to: (i) process the pellets into an injectable molding material, and (ii) inject the injectable material into a mold that is held closed by the platens 30, 32 after the platens 30, 32 have been stroked together. The control cabinet 26 houses control equipment that is used to control the system 20. The HMI 28 is coupled to the control equipment, and the HMI 28 is used to assist an operator in monitoring and controlling operations of the system 20.

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[0005] The stationary platen 30 is configured to support a stationary mold portion of a mold (not shown). The moveable platen 32 is configured to: (i) support a moveable mold portion of the mold, and (ii) move relative to the stationary platen 30 so that the mold portions of the mold (neither shown) may be separated from each other or closed together. A mold stroke actuator 36 (hereafter referred to as the “actuator 36”) is coupled to the platens 30, 32. Preferably, there are two platen stroke actuators, each of which are mounted, respectively, at opposite diagonal corners of the platens 30, 32. The mold stroke actuator 36 is used to stroke the moveable platen 32 relative to the stationary platen 30. Preferably, during mold closure, the actuator 36 decelerates shortly before achieving contact between the two mold halves to reduce the impact and preserve the lifespan of the mold.

[0006] The stationary platen 30 supports four clamp actuators 38 that are each positioned in respective corners of the stationary platen 30. Four tie bars 40 each extend from their respective clamp actuators 38 toward respective corners of the moveable platen 32. The tie bars 40 are lockable relative to the moveable platen 32 by usage of respective tie-bar locks 41 that are each supported in respective corners of the moveable platen 32.

[0007] Fig. 2 provides a graph showing various defined and measured performance parameters for a typical mold stroke actuator during a mold close operation, such as the one used on the above systems. In this system, an operator calibrates the maximum daylight between the movable and stationary mold halves. Line 80 shows the position of movable platen 32 as it moves from the fully open position to the fully closed position. In this example, the maximum daylight is just over 400 mm. The operator further defines the period of the mold close operation, which in this example is just under 0.5 seconds.

[0008] An open loop control system 78 regulates the velocity of the movable platen 32 based upon elapsed time in order to achieve this cycle time. An idealized velocity profile 82 is provided by a lookup table. For each moment of the actuator stroke cycle, a closing velocity set point is provided for movable platen 32. Thus, at $T=0$ seconds the velocity setpoint is 0 mm/s. At $T=0.1$ seconds, the velocity set point peaks at just over 1600 mm/s and then begins decelerating to avoid the mold halves from crashing together. The acceleration is linear, causing a sharp peak for the velocity profile.

[0009] The actual velocity 84 of movable platen 32 deviates from the velocity profile 82, given

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the large inertial mass of the movable platen 32 as well as measurement latency in the system. For example, from $T=0$ seconds to $T=0.2$ seconds, the movable platen is slower than its setpoint and from $T=0.2$ seconds to $T=0.475$, the movable platen 32 is faster than its target set point.

[00010] A mold stroke command 86 indicates the control voltage used to open or close a valve in system 20's hydraulic circuit, thereby increasing or decreasing hydraulic pressure within actuator 36. Changes to the hydraulic pressure within actuator 36 accelerates or decelerates the movable platen 32.

SUMMARY OF THE INVENTION

[00011] According to a first aspect of the present invention, there is provided a controller for a mold stroke actuator connected to a movable platen, the controller operable to receive operational measurements and change the output of the mold stroke actuator using a closed loop control system.

The present invention can provide closed loop control with feed forward compensation for a movable platen of an injection molding machine. The closed loop control is on velocity and acceleration. The acceleration is computed from net force (pressure multiplied by cylinder area) and moving mass. Feed forward compensation is obtained from the velocity profile

The invention provides a predetermined velocity profile that is optimized for mold stroke to achieve its fastest mold close and mold open times with a minimum of jerky motion. The invention further provides a closed loop control system and method that controls the mold stroke to track the predetermined velocity profile. The invention also provides auto-calibration of a mold stroke valve, which can have considerable tolerance variations.

BRIEF DESCRIPTION OF THE DRAWINGS

[00012] Exemplary embodiments of the present invention will now be described with reference to the accompanying drawings in which:

Fig. 1 is a perspective view of a prior art molding machine;

Fig. 2 is a graph showing a prior art open loop control system for the molding machine of Fig. 1;

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Fig. 3A and 3B are hydraulic schematics for a mold stroke actuator for the molding machine of Fig. 1 in accordance with a non-limiting embodiment of the invention; and

Fig. 4 is a graph showing a closed loop control system for a molding machine in accordance with a non-limiting embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[00013] The inventors have determined that known prior-art closed loop control systems such as PIDs do not work well for mold stroke actuators. The large mass of the movable platen and mold half coupled with a relatively small actuator caused significant latency in the system. The natural operational frequency of the system is low and error correction generates instability in the system. Even with modern processing architecture, control systems do not update quickly enough to achieve smooth operation. When the machine is running quickly, the mold stroke motion can become rough and jerky. Reliability and repeatability are not easily achieved with an open-loop control system, and machines can experience considerable variation which requires manual calibration of the valves and the machine.

[00014] In contrast, the present control loop system obviates these problems, and can result in reduced cycle time, improved mold open position repeatability, and reduced machine shaking and vibrations.

[00015] Referring now to Fig. 3A and 3B, the operation of actuator 36 is described in greater detail. Fig. 3A provides a schema for a mold close operation, and Fig. 3B provides a schema for a mold open operation. For simplicity, pilot lines have been omitted. Actuator 36 is operable to linearly translate movable platen 32 between an open and a closed position and is motivated by a hydraulic circuit 50. As used herein, the movable platen 32 includes the attached mold, unless otherwise stated.

[00016] Hydraulic circuit 50 can include a pump 52, an optional accumulator 54, the actuator 36, a circuit switch (not shown), proportional shutoff valves 58, 60, and 68, pressure sensors or gauges 62, and a tank 64. In the circuit shown, pump 52 is a unidirectional, fixed displacement pump, but other types of pumps can be used, depending on the configuration of the machine 20. Actuator 36 is a double-acting piston. Preferably, the circuit switch (not shown) is a 5 ports / 3 position directional valve as is known to those of skill in the art that provides regenerative fluid capacities to actuator 36. One port of the circuit switch leads to the cylinder side of actuator 36, another port leads the rod side 60A of actuator 36, another port leads to

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pump 52, another port leads to tank 64, and yet another port leads back to rod side 60A. The pressure gauges 62 measure the difference in pressure between the cylinder and rod sides of actuator 36. As is known to those of skill in the art, proportional valves 58 and 60 can have wide operational tolerances, approaching as much as 10% between valves.

[00017] As shown in Fig. 3A, in order to move the movable platen 32 to the closed position, the switch is in the first position so that flow from the pump 52 and/or accumulator 54 is directed to cylinder side of actuator 36 in order to motivate the movable platen 32 to move towards the stationary platen 30. Hydraulic fluid from rod side of actuator 36 is directed back to the cylinder side as part of a regenerative circuit to improve performance and minimize the amount of hydraulic fluid required by machine 20.

[00018] As shown in Fig. 3B, in order to move the movable platen 32 to the open position, the switch is in a second position so that the flow from pump 52 (and less likely, accumulator 54) is directed to the rod side of actuator 36 in order to motivate the movable platen 32 away from the stationary platen 30. Hydraulic fluid from cylinder side of actuator 36 drains to tank 64. Greater or lesser flow control can be provided by the restriction/expansion of shut-off valves 60, greater or lesser outputs from pump 52, or greater or lesser discharges from accumulator 54.

[00019] Referring now to Fig. 4, a control system 100 is described to regulate mold stroke closure for the injection machine 20 and the like. Control system 100 defines a predetermined velocity profile 102 that is generally sinusoidal and divided between an acceleration phase 110 and a deceleration phase 112 of the movable platen 32 as it moves from the open to closed position. That is to say, movable platen 32 accelerates and decelerates in a generally symmetrical fashion that can be graphed over time as a sine function. Velocity profile 102 graphs the ideal, predetermined velocity (in mm/s) of movable platen 32 over time (in s). As is described in greater detail below, acceleration of movable platen 32 is a function of time, and deceleration is a function of position. A similar velocity profile is provided to move the movable platen 32 from the closed position to the open position.

[00020] A mold stroke command 104 indicates the control voltage (V) used to open or close the valve 58 (during mold close), thereby increasing or decreasing hydraulic pressure within actuator 36. Changes to the hydraulic pressure within actuator 36 accelerates or decelerates the movable platen 32. During mold open, the control voltage regulates valve 60.

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[00021] The actual velocity 106 of movable platen 32 is measured in real-time (mm/s). As is discussed in greater detail below, control loop 100 with feed forward error correction continually adjusts the actual velocity 106 of movable platen 32 to better map to the desired velocity profile 102.

[00022] Position 108 shows the measured position of movable platen 32 relative to the closed position (in mm) over time. Fig. 4 shows movable platen 32 moving from the fully open position to the fully closed position (approx. 400 mm in the example provided by Fig. 4).

[00023] As mentioned previously, in control system 100 the acceleration of movable platen 32 is based on time during the acceleration phase 110, but the deceleration of movable platen 32 during the deceleration phase 112 is based upon the position of the platen. Control system 100 corrects for velocity, acceleration and position, and also provides feed forward correction.

[00024] The target velocity of movable platen 32 for any point of the velocity profile 102 during the acceleration phase is determined by time, and is defined by the following equations.

[00025] Acceleration for any point of time during the acceleration phase 110 of velocity profile 102 is defined by the function:

$$a(t) = a_{\max} \sin(\omega t) \text{ where}$$

$$a_{\max} = \frac{0.9F_{\max}}{m}$$

$$\omega = \sqrt{\frac{2\pi a_{\max}}{x_{\max}}} \text{ and where}$$

$a(t)$ = acceleration of movable platen 32 at time t

$a_{\max}$ = Maximum acceleration of movable platen 32

ω = Circular frequency of the sinusoidal profile

$F_{\max}$ = Maximum force applicable by mold stroke actuator 30

m = Moving mass of movable platen 32 (including the attached mold)

$x_{\max}$ = Distance travelled by movable platen 32 between the open and closed positions

[00026] Given the above determination of acceleration, velocity profile 102 during the acceleration phase 110 can be defined as follows:

$$v_{acc} = \text{Max}(v_{acc}(t-1), v_{acc}(t-1) + a(t) \Delta t) \text{ where}$$

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v_{acc} = Velocity profile 102 during the acceleration phase 110

$v_{acc}(t-1)$ = Velocity during acceleration at time $t-1$ or previous scan

[00027] The maximum velocity of movable platen 32 (which may exceed the peak velocity of velocity profile 102) is determined as follows:

$$v_{max} = \frac{2 x_{max}}{T} \text{ where}$$

$$T = \frac{2\pi}{\omega}$$

v_{max} = Maximum velocity of movable platen 32

T = Period of the sinusoidal profile, i.e., the duration of the mold stroke operation

[00028] The target velocity of movable platen 32 for any point of the velocity profile 102 during the deceleration phase 112 is determined by the measured position of movable platen 32 (to prevent mold crash), and is defined by the following equations.

[00029] The velocity of movable platen 32 during deceleration can be determined as follows:

$$v_{decel} = v_{avg} - v_{span} \cos \left\{ \text{Max} \left(\pi, 2\pi \frac{v_{max} - \sqrt{2 a_{decel} (x(t) - x_o)}}{v_{max}} \right) \right\}$$

$$v_{avg} = \frac{v_{max} + v_{contact}}{2}$$

where

$$v_{span} = \frac{v_{max} - v_{contact}}{2}$$

$$a_{decel} = \frac{v_{max}}{2T} = \frac{a_{max}}{2\pi}$$

v_{decel} = Velocity of movable platen 32 during deceleration

v_{avg} = Average velocity of movable platen 32

v_{span} = Velocity span, i.e., a period where the movable platen 32 moves at its peak velocity (and can be 0)

v_{max} = Maximum velocity of movable platen 32

$v_{contact}$ = Contact velocity or final velocity of movable platen 32 when it reaches the fully closed position

a_{decel} = Position based deceleration, which provides an estimate of the required deceleration based upon time (i.e., assuming a perfect sinusoidal profile)

$x(t)$ = Position at time t

x_o = Safety distance (typically set to 0 mm)

a_{max} = Maximum acceleration

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[00030] Given the above definitions, the velocity profile 102 can be defined for any point along the mold stroke by the following equation:

$$v_{sp}(t) = \text{Min}(v_{acc}(t), v_{max}(t), v_{decel}(t)) \text{ where}$$

$$v_{sp}(t) = \text{Velocity setpoint for movable platen 32 at time } t$$

$$v_{acc}(t) = \text{Velocity during acceleration at time } t$$

$$v_{decel}(t) = \text{Velocity during deceleration at time } t$$

$v_{max}(t)$ and $v_{decel}(t)$ will always meet in the middle of the mold stroke, thus providing symmetry for the velocity profile 102.

[00031] Control system 100 compensates when the actual velocity 106 deviates from the velocity profile 102. A PID controller or the like is used to perform the compensation functions. Control system 100 does not simply correct for errors in velocity of movable platen 32, but can correct for other factors as well. Errors in the position of movable platen 32 (i.e., $e_p(t)$) are preferably zeroed out. Also, as the acceleration of the movable platen 32 is very difficult (and/or expensive requiring accelerometers) to measure directly, these errors (i.e., $e_a(t)$) are preferably zeroed out. Instead, acceleration based upon the force provided by actuator 36 is used ($a_f(t)$) based on the pressure differential between cylinder and rod sides of actuator 36 (and measured by pressure gauges 62).

[00032] The corrected velocity can be defined as follows:

$$v_{corrected}(t) = e_v(t) k_p + e_p(t) k_i + e_a(t) k_d + e_{af}(t) k_{df} + v_{sp} \text{ where}$$

$$e_v(t) = v_{sp}(t) - v_{pv}(t) \quad e_p(t) = x_{sp}(t) - x_{pv}(t)$$

$$e_a(t) = a_{sp}(t) - a_{pv}(t) \quad e_{af}(t) = a_{sp}(t) - a_f(t) \quad \text{and where}$$

$$a_{sp}(t) = \frac{dv_{sp}}{dt} \quad a_f(t) = \frac{P_A(t)A_A - P_B(t)A_B - F_f(v)}{m}$$

$v_{corrected}(t)$ = Velocity output at time t , after being corrected by the closed loop feedback

$$e_v(t) = \text{Error in velocity at time } t$$

$$e_p(t) = \text{Error in position at time } t$$

$$e_a(t) = \text{Error in acceleration at time } t$$

$$e_{af}(t) = \text{Error in acceleration force at time } t$$

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 k_p = Proportional gain k_i = Integral gain (often zeroed out) k_d = Derivative gain (often zeroed out) k_{df} = Derivative gain for acceleration force $v_{sp}(t)$ = Velocity setpoint at time t $v_{acc}(t)$ = Velocity during acceleration at time t $v_{max}(t)$ = Maximum velocity at time t entered by the user $v_{decel}(t)$ = Velocity during deceleration at time t

$$\left. \begin{array}{l} v(t) = \text{Velocity at time } t \\ x(t) = \text{Position at time } t \\ a(t) = \text{Acceleration at time } t \end{array} \right\} \text{Subscripts }_{sp} \text{ and }_{pv} \text{ denote setpoint and actual value}$$
 $a_f(t)$ = Calculated acceleration force at time t $P_A(t)$ = Pressure in the cylinder side of the actuator 30 at time t $P_B(t)$ = Pressure in the rod side of the actuator 30 at time t A_A = Cylinder area A_B = Rod area $F_f(v)$ = Friction force as a function of velocity m = Moving mass

For an actuator 36 having a regenerative hydraulic circuit, the following equation defines the voltage required to enlarge or reduce the opening in the proportional valve:

[00033]
$$v_{ref} = \frac{v_{corrected}(t) \sqrt{\Delta P_{ref}}}{\sqrt{P_s(t) - P_A(t)} + z(V) \sqrt{P_B(t) - P_A(t)}} \quad \text{where}$$

$$z(V) = \frac{k_B(V)}{k_A(V)}$$

$v_{ref}(t)$ = Reference velocity at time t , which is used to determine the command voltage to the valve from a reference table (look - up table)

$v_{corrected}(t)$ = Velocity output at time t , after being corrected by closed loop feedback

 ΔP_{ref} = Pressure drop used in the reference (look - up) table $P_s(t)$ = Supply pressure at time t $P_A(t)$ = Pressure in the cylinder side of the actuator 30 at time t $P_B(t)$ = Pressure in the rod side of the actuator 30 at time t $z(V)$ = Ratio of flow resistance as a function command voltage to the valve $k_B(V)$ = Flow resistance of valve from rod to cylinder side $k_A(V)$ = Flow resistance of valve from supply to cylinder side

[00034] Given the above equations, an operator can set a target speed, and control system

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100 will calculate the required period and velocity profile. Alternatively, an operator could set a target period, and control system 100 will calculate the required velocity. For all speeds from 0 to $v_{\max}$ where the target speed is v_n

$$T_n = T \left(\frac{v_{\max}}{v_n} \right)^p \quad p = \text{power index} = 0, \dots, 0.25, \dots, 0.5, \dots, 1$$

$$T_{n(\max)} = \frac{2x_{\max}}{v_n} \quad , \quad T_n \leq T_{n(\max)} \quad , \quad 0 \leq n \leq 1$$

[00035] The presently preferred value for $n = 0.25$

$$\omega_n = \frac{2\pi}{T_n}$$

$$a_n = \frac{v_n \omega_n}{2}$$

$$a(t) = a_n \sin(\omega_n t)$$

[00036] In an idealized system, where the actual velocity follows tightly with the velocity setpoint, then deceleration of movable platen 32 would start at the midpoint (assuming that there was no interval where movable platen 32 moved at a constant velocity) and could be simply determined as follows:

$$a_{\text{decel}} = \frac{v_{\max}}{2T} = \frac{a_{\max}}{2\pi}$$

[00037] However, in practice, using the above equation would cause movable platen 32 to lag and decelerate too late. Preferably, when the actual velocity 106 of movable platen 32 lags behind velocity profile 102, or if the actual velocity 106 is greater than the setpoint defined by velocity profile 102, the deceleration reference is determined as follows. The starting time of the deceleration phase 112 (i.e., when deceleration begins) can be calculated as

$$t_{\text{decel}} = t_{\text{accel}} + t_{\text{const_sp}}$$

$$t_{\text{accel}} = \frac{T_n}{2} \quad \text{subscript } n \text{ indicates for a given speed}$$

$$t_{\text{const_sp}} = \frac{v_n}{\Delta x} \quad v_n = \text{velocity setpoint (minimum to maximum)}$$

$$\Delta x = x_{\max} - x_o - x_{\text{accel}} - x_{\text{decel}} \quad \text{where}$$

$$x_{\max} = \text{mold stroke setpoint or actual mold open position}$$

$$x_o = \text{safety distance}$$

$$x_{\text{accel}} = x_{\text{decel}} = \frac{v_n T_n}{4}$$

[00038] The starting point for the deceleration of movable platen 32 is defined as follows:

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$$x_{start_SP} = \frac{\pi \max(v_n, v_{PV})^2}{4a_n} - x_o$$

v_{PV} = actual velocity at time t

$$a_n = \frac{v_n \omega_n}{2}$$

[00039] Deceleration of movable platen 32 is dynamically calculated to correct for errors:

if $t > t_{decel}$ or $x(t) < x_{start_SP}$ (i.e., the mold is closed) or $x(t) > x_{start_SP}$ (i.e., the mold is open)

$x_{start_decel} = x(t)$ latched!

$$a_{decel} = \min \left(a_{decel_max}, \frac{v_n^2}{8(x_{start_decel} - x_o)} \right)$$

$$a_{decel_max} = \frac{a_{max}}{2\pi}$$

[00040] The present invention provides a control system for a mold system that achieves faster mold close and open times than known prior-art open loop control can attain. The present invention can provide a smooth mold stroke motion and improved mold stroke repeatability. The present invention can provide ease of set-up, auto valve calibration and no need for machine calibration. The present invention can further provide optimized velocity profile to close and open mold with the fastest times and smooth motion. The present invention can provide closed loop control with feed forward compensation. The closed loop control is on velocity and acceleration. The acceleration is computed from net force (pressure multiplied by cylinder area) and moving mass. Feed forward compensation is obtained through compensation of the pressure drop across the valve.

[00041] While the present invention has been described with respect to what is presently considered to be the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, the invention is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

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WHAT IS CLAIMED IS:

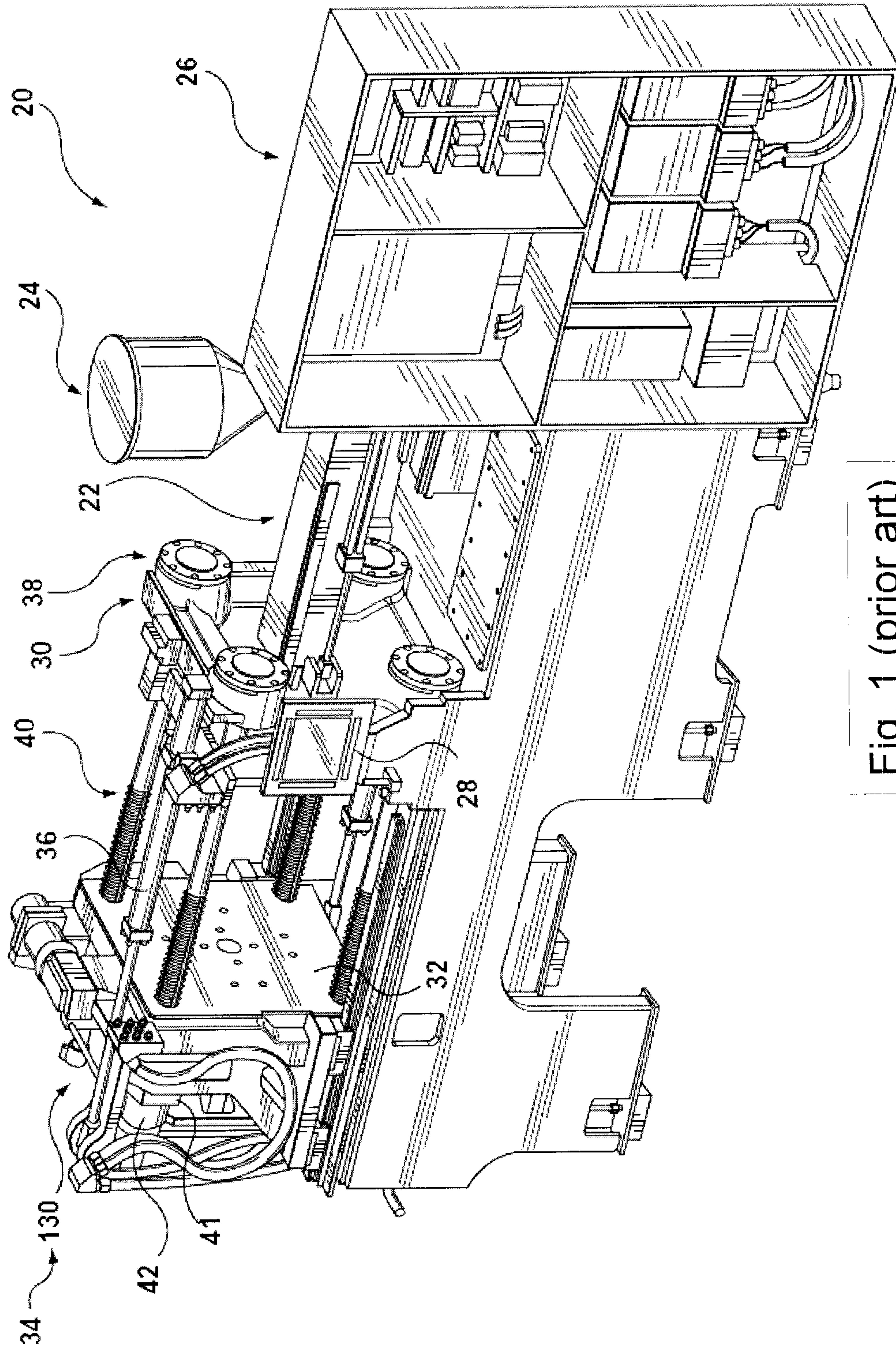
1. A controller for a mold stroke actuator connected to a movable platen,
the controller defining a predetermined velocity profile for the movable platen, the predetermined velocity profile being generally sinusoidal and including an acceleration phase and a deceleration phase, the acceleration phase being a function of time and the deceleration phase being a function of position of the movable platen;
the controller being operable to receive operational measurements relating to the movable platen and to adjust the output of the mold stroke actuator based on the operational measurements using a closed loop control system to compensate for deviations from the predetermined velocity profile.
2. The controller of claim 1, wherein the predetermined velocity profile is sinusoidal.
3. The controller of claim 1 or 2, wherein the controller uses at least acceleration of the movable platen to adjust the output of the mold stroke actuator and the acceleration of the movable platen is computed from net force outputted by the mold stroke actuator and the moving mass of the movable platen.
4. The controller of claim 3, wherein the net force is determined by multiplying pressure in a hydraulic cylinder by the area of the hydraulic cylinder.
5. The controller of any one of claims 1 to 4, wherein the control system further comprises feed forward compensation.
6. The controller of claim 5, wherein the feed forward compensation is determined by measuring a drop in pressure across a circuit switching valve associated with the hydraulic cylinder.
7. The controller of any one of claims 1 to 6, wherein the operational measurements include the velocity of the movable platen.

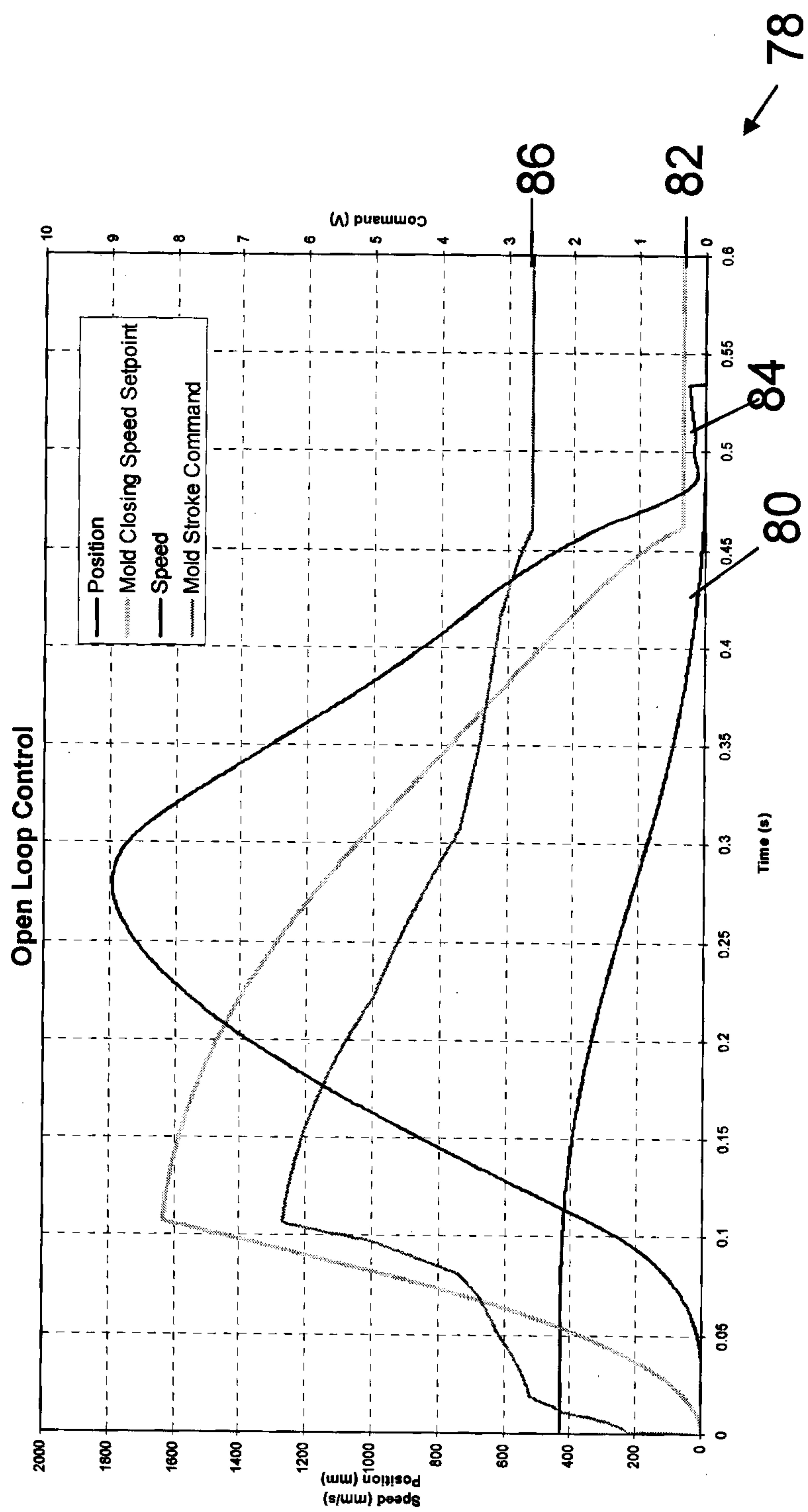
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8. The controller of claim 7 wherein:

the controller compares the predetermined velocity profile to the measured velocity of the movable platen; and

if there is a difference between the predetermined velocity profile and the measured velocity, the controller adjusts the output of the mold stroke actuator using a closed loop control system.



**Fig. 2 (prior art)**

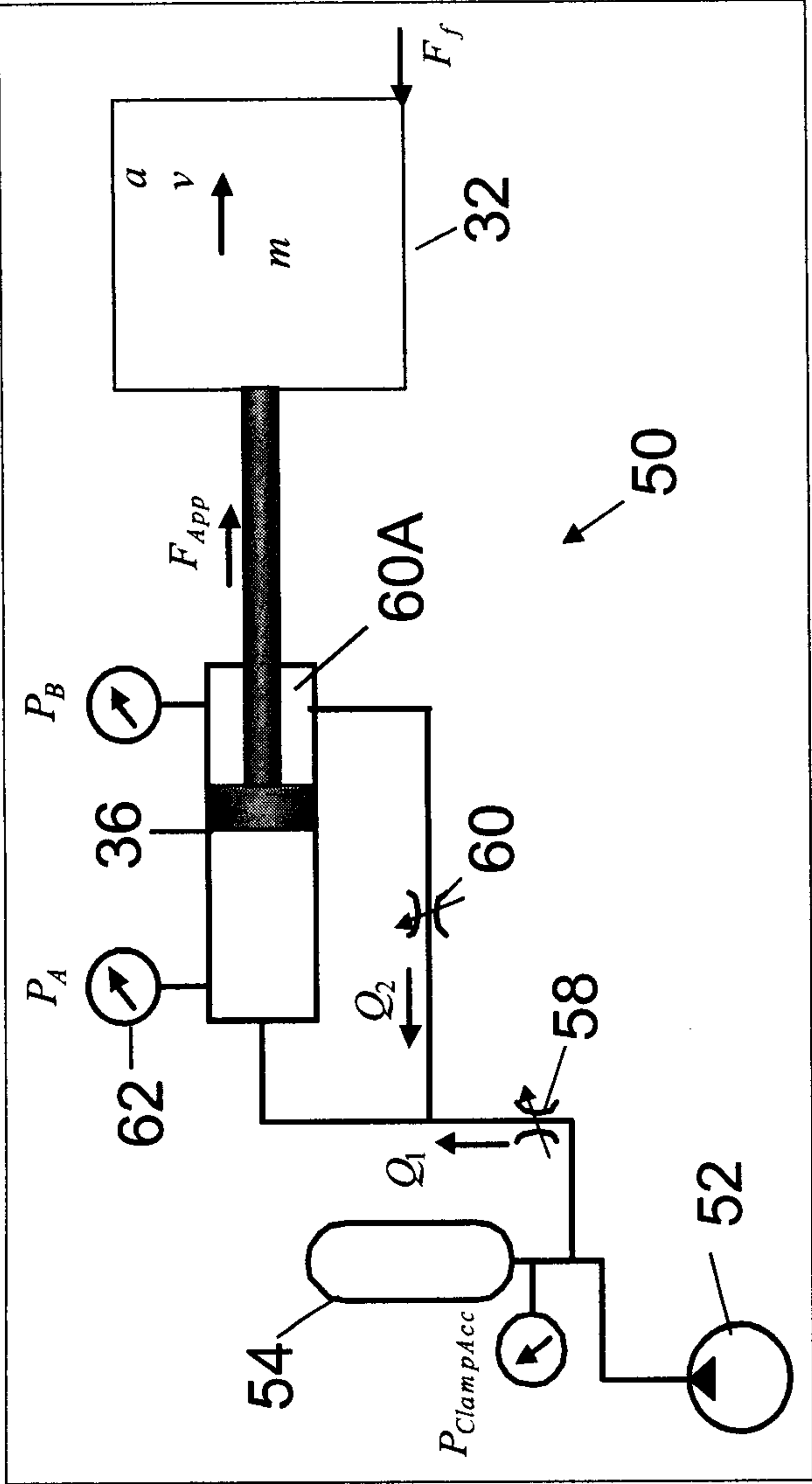


Fig. 3A

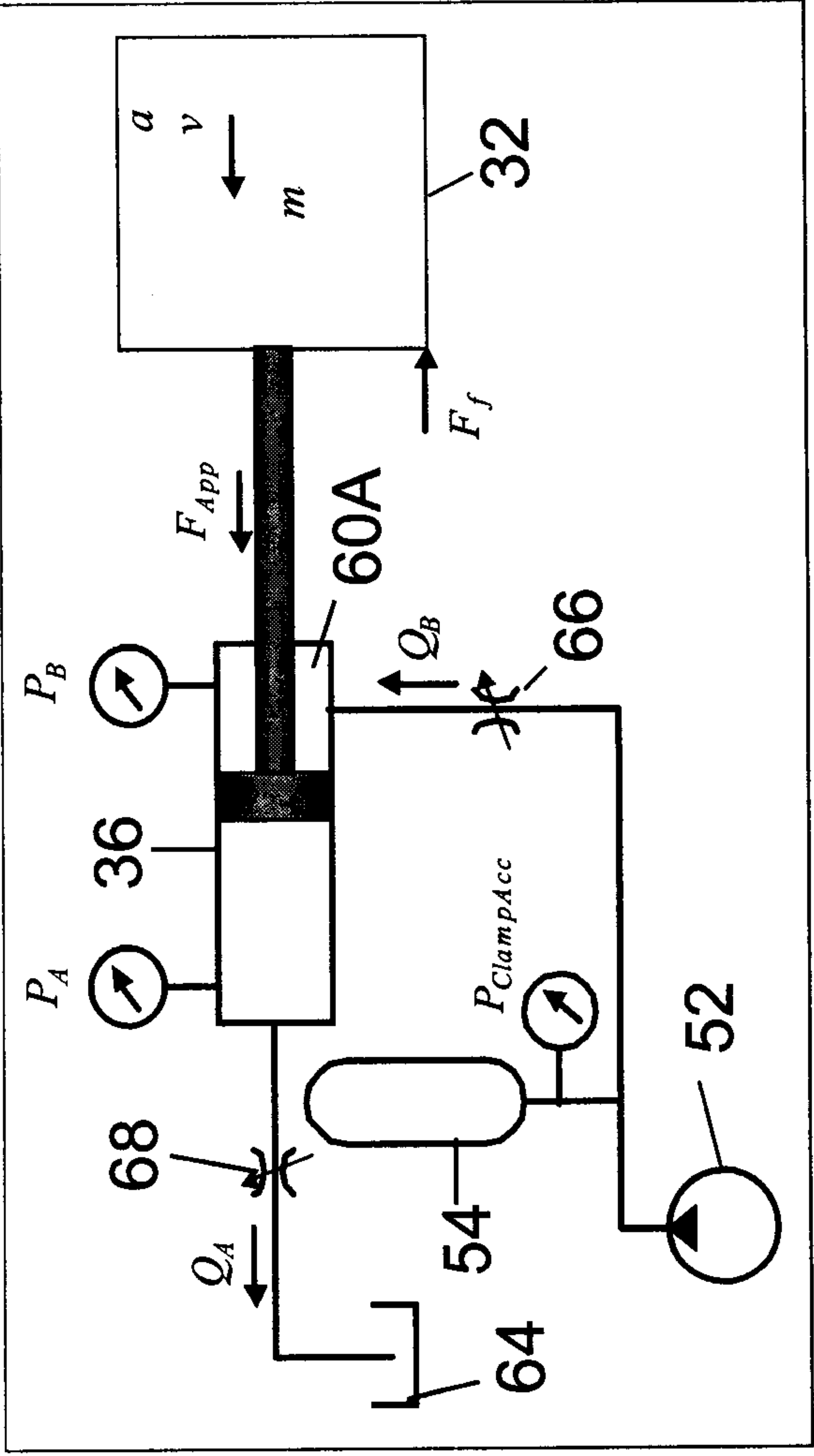


Fig. 3B

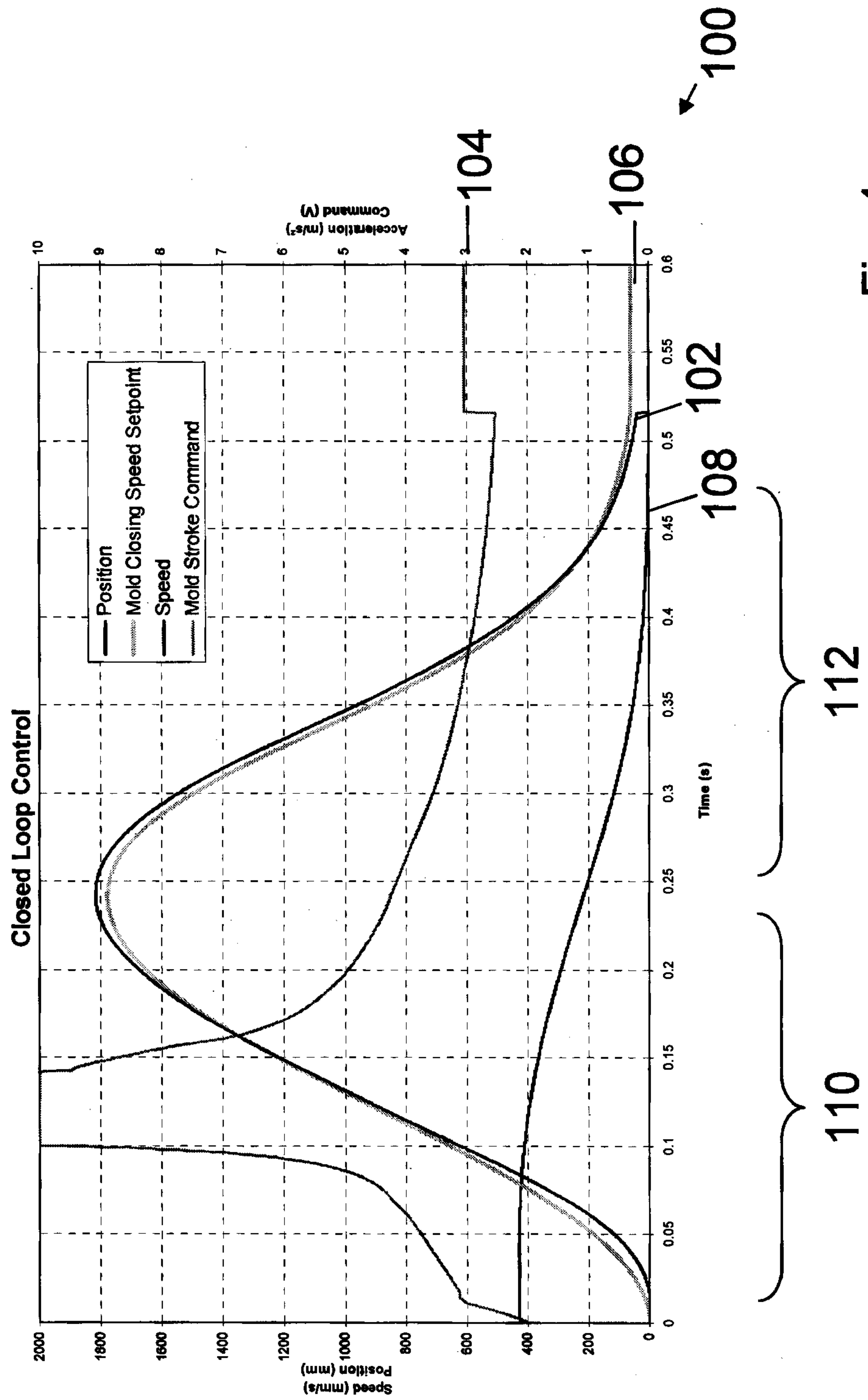
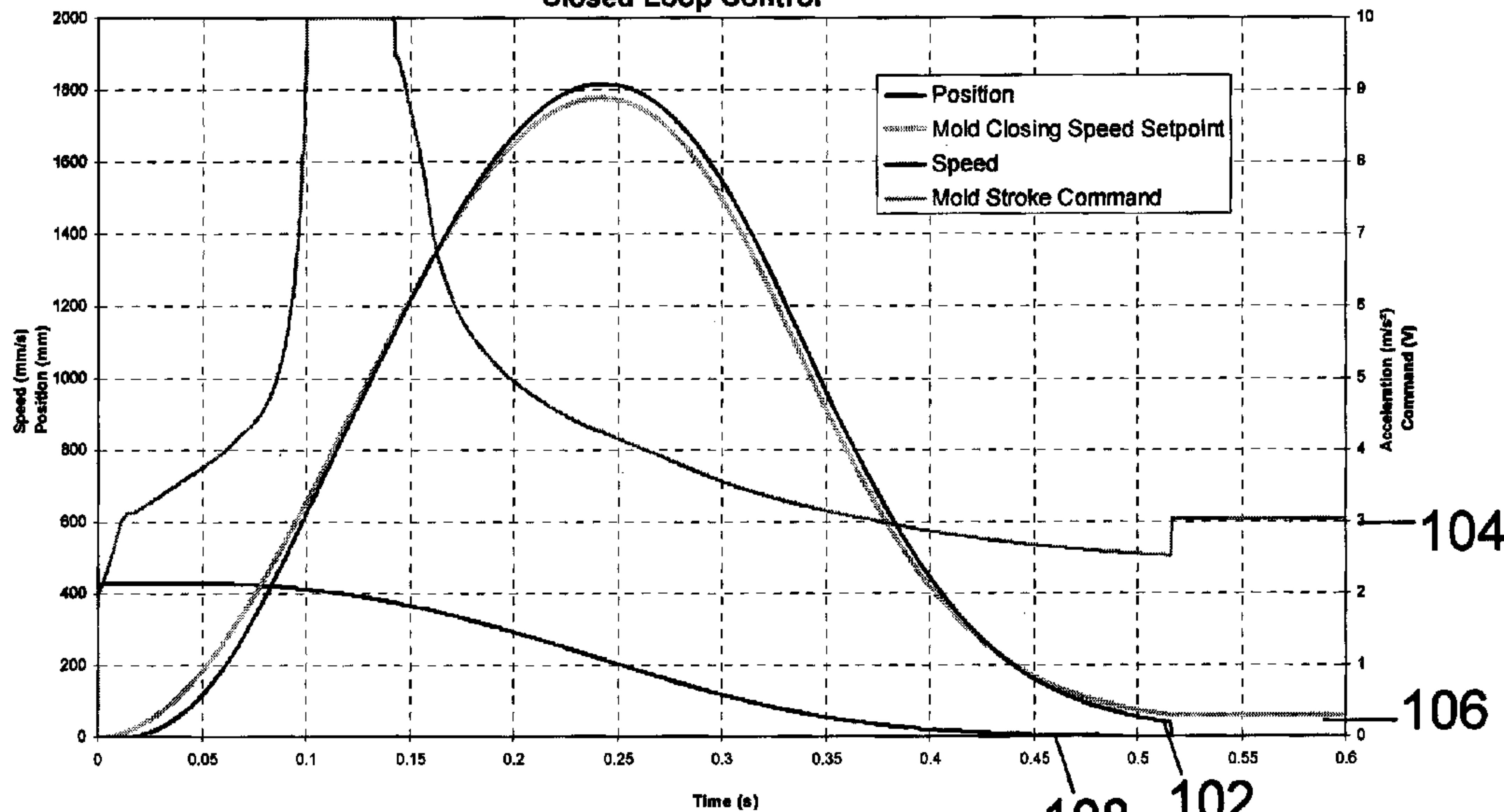


Fig. 4

Closed Loop Control



100

108

102

106

104

112

110