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**Speed and Pressure Control System
Design and Simulation
for a Compression Press**

By R. H. Floersch

Published April 1981

Topical Report

Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

**Kansas City
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DESIGN AND SIMULATION FOR A COMPRESSION
PRESS

By R. H. Floersch

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Topical Report
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SPEED AND PRESSURE CONTROL SYSTEM DESIGN AND SIMULATION FOR A
COMPRESSION PRESS

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A new system design using closed loop control on the hydraulic system on compression transfer presses used to make filled elastomer parts will improve accuracy and repeatability of speed and pressure control during critical pre-cure forming stages. The present open loop system does not provide the control necessary to mold repeatably the filled elastomer products. These products form with great difficulty because of high loading levels of filler materials. The new system will mean improved wall thickness and control of loaded elastomer parts, thus reducing the amount of scrap caused by wall thickness variations.

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SUMMARY

Open loop control of the hydraulic system on compression transfer presses used to make filled elastomer parts for years has been sufficient for molding free-flowing materials not appreciably susceptible to variations in forming speed or cure pressure. Fillers at high loading levels added to an elastomer matrix hinder the flow. The flow problem becomes more difficult if the material must flow through a small cross-sectional area. High-loading levels and thin cross sections are typical of loaded elastomer parts.

The current hydraulic speed control system design results in a maximum initial ram speed that drops to zero during forming. This curved path depends on material flow properties and distribution within the mold. Repeatability of the forming operation within the existing hydraulic system cannot exist.

However, a new system design that uses closed loop control of the hydraulic system will improve accuracy and repeatability of speed and pressure control during the critical forming stages before part cure. This system will mean improved wall thickness and configuration control of loaded elastomer parts.

Closed loop hydraulic control will provide accurate, constant, and repeatable velocity and pressure control, up to the pressure transition point, by monitoring and correcting deviations from set point during the cycle and from cycle to cycle. Accuracies of ± 1 percent (26.69 kN) from set point during steady operation and less than 1 percent repeatability are expected.

The frequency response of the final control elements is critical for system settling time and overshoot requirements. Poor frequency response characteristics can cause instabilities that translate into unpredictable oscillating responses to disturbance or set point changes.

In the new design, a flow control valve manipulates flow during speed control and pressure during load control. The frequency response of the valve enables it to travel from full closed to full open to full closed 16 times each second.

The closing speed control cycle has two segments: fast close, using only the booster ram, and slow close, using the main ram area. A gain change is required in the closed loop speed circuit to compensate for the speed change, a 15 to 1 reduction. After closing, a pressure control circuit is required to maintain the desired pressing force. The opening speed circuit also has two segments: slow opening for part stripping, and fast opening to

return the ram to starting position. The entire cycle is composed of two closing speed circuits, a pressure circuit, and two opening speed circuits. The set points for those analog circuits and additional machine logic functions will be controlled by a micro-processor.

The internal electrical circuitry of the machine logic will allow both closed loop control and reversion to existing manual control. An additional option designed into the control circuitry allows constant ram speed control up to a variable transition pressure. After alteration the control mode will appear unchanged to the users.

One hypothesis proposes that flow mechanisms of the non-Newtonian filled elastomer may parallel Newtonian fluids in the laminar region; that is, higher flow rates result in lower friction factors. Conversely, as the flow rate decreases, the friction factor increases, requiring more pressure to cause motion. No means at Bendix exists to evaluate the hypothesis, because no constant speed variable pressure devices in the range of the molding machine exist. If the hypothesis is correct, the traditional molding concepts used at Bendix will be altered appreciably, which could reduce drastically the amount of scrap caused by wall thickness variation.

The speed control circuit was simulated on a digital computer to determine control modes and magnitudes of various gains. The simulations indicate that the integral mode is mandatory for minimum steady state error and for minimum settling time after the speed transition. Load control simulation is extremely difficult and highly dependent on the machine, because the flow requirements are dependent on valve leakage, which will vary among machines.

DISCUSSION

SCOPE AND PURPOSE

The intent of implementing closed loop control of the machine hydraulic system is to reduce the amount of scrap caused by wall thickness and by configuration of filled elastomers. Ram speed and pressure control currently are being accomplished open loop, through inaccurate and nonrepeatable methods. A microprocessor/analog closed loop control system will be designed, implemented, and tested to determine whether closed loop control improves part quality.

ACTIVITY

Current System Functional Description

Figure 1 shows a compression molding machine with the ram extended. The hydraulic circuit for the press is illustrated in Figure 2. The operator starts the molding cycle by energizing solenoids A, KK, and D, which causes pumps P1 and P2 to deliver fluid to the booster ram area (D_b).

Closure speed is governed by the amount of fluid allowed to bleed back to the tank through solenoid D and flow return valve FRV₂. The ram closes quickly because both pumps are delivering approximately 0.0029 m³/s (46 gal/min) of fluid into a relatively small, cross-sectional area (D_b) of the ram. A slow-down limit switch causes solenoid M to energize, redirecting the fluid to both the main ram (D_m) and booster ram (D_b) cross sections, and significantly increasing the effective cross-sectional area.

The steady-state ram speed can be calculated from the following:

$$V_r = \frac{Q_r}{A_r} \quad (1)$$

where

V_r = ram velocity (m/s);

Q_r = hydraulic fluid flow rate into the ram area (m³/s); and

A_r = ram cross-sectional area (m²).

The ram slow-down is accomplished by increasing significantly the ram area from 12645 mm² (19.6 in.²) to 192677 mm² (298.6 in.²),

Figure 1. Compression Molding Machine With Ram Extended

which amounts to a 15-fold increase in area, or for the same volume flow rate, a 15-fold decrease in ram speed. The flow rate Q_r can be manipulated to reduce or increase the ram speed by varying the opening diameter of flow return valve FRV₁ or FRV₂, depending upon the slow-close limit switch activation.

The slow-close limit switch usually is set from 2.54 cm (1 in.) to 7.62 cm (3 in.) from mold closure. Solenoid D de-energizes and solenoids M and CC energize at slow-close switch activation. The speed drops immediately to the pressing (forming) speed. The line pressure P_l increases as the molding material contacts the punch and starts to flow. The increase in line pressure is a function of flow resistance of the material in the mold. That resistance is a function of material viscosity, the shear rate, the contact area, and rate of crosslinking.

In all further discussions, the rate of crosslinking is assumed slow enough to be neglected as a variable.

As line pressure reaches 2294 kPa (333 psi), equivalent to 444.8 kN (50 tons) of molding force, the machine switches from velocity to pressure control by de-energizing solenoids KK and CC. The system flow rate drops to 0.005 m³/s (8 gal/min.) to maintain the required pressure remotely regulated by an electrically actuated relief valve (MRV in Figure 2).

To achieve a specified cure force the machine operator adjusts a potentiometer while observing a Bourdon pressure gage calibrated in force units. The operator holds the ram force constant until the specified cure time has elapsed. Then the operator reduces the pressure to 2294 kPa. The operator activates an open switch, which causes solenoids B and S to energize, directing as much as 0.0005 m³/s of hydraulic fluid to the top of the ram. The ram is held in place under no positive pressure by the counter-balance valve (CBV in Figure 2), which is adjustable and is set simply to hold the ram and mold weight. The counterbalance valve allows fluid out of the booster ram area when an opposing force greater than the ram and mold is applied to the top area of the ram through the hydraulic fluid. Stripping speed is controlled by the amount of hydraulic fluid allowed to return to the tank through the flow return valve FRV₃ in Figure 2. A fast-open limit switch is energized after the mold has traveled approximately 5.5 cm. This action de-energizes solenoid S and energizes solenoid KK, delivering the full 2.9×10^{-3} m³/s to the ram top, causing it to open at maximum speed. A stop-limit switch de-activates solenoid B, which diverts the supply fluid to the tank and stops the ram.

In summary, the cycle steps are these: fast-close with a transition to slow-close; slow-close while forming with a transition

Figure 2. Compression Machine Hydraulic Circuit (Current)

to load control; load control with final mold closure and a minimum 20-minute cure time; load relaxation with transition to stripping speed control; stripping speed control to fast-open transition, and fast-open to slow-down and stop.

For process consistency, any control system implemented must consist of the same basic steps: speed control, load control, speed control.

Closed Loop Control

As previously indicated, each of the speed control cycles has a fast-open/close segment and a slow open/close segment. The fast-open/close segments are the least important segments. The fast-close travels the majority of the ram stroke as quickly as possible, without upsetting the loose material in the mold cavity during the initial acceleration and the transition deceleration. The fast-open only returns the ram to the start position as quickly as possible. The slow-close segments are the important speed segments, and the most important portion of the speed cycle where the initial part formation occurs. If the resistance to movement of the molding compound is minimal, resulting in line pressures less than 2298 kPa (333 psi) to sustain motion, then the entire part formation will occur in the slow-close mode. The line pressure will exceed the 2298 kPa transition pressure when the two mold halves touch, or when the resistance to flow of mold compound is high and requires more energy to sustain motion.

The slow-close ram velocity is controlled currently by bleeding a portion of the fixed flow rate back to the tank through a variable opening valve. The hydraulic pumps are positive displacement that deliver either $2.9 \times 10^{-3} \text{ m}^3/\text{s}$ (46 gal/min), if both are in the circuit, or $0.5 \times 10^{-3} \text{ m}^3/\text{s}$ (8 gal/min) when only the low-volume pump is operating. Equation 1 indicates that the ram velocity is directly proportional to the volumetric flow rate coming into the ram area and inversely proportional to the ram area itself. To achieve the slowdown transitions, the ram area is altered from the booster area only to the main and booster ram areas. The maximum fast-close speed is developed when both pumps are delivering their rated capacities into the booster area.

$$V_r = \frac{2.9 \times 10^{-3} \text{ m}^3/\text{s}}{1.26 \times 10^{-2} \text{ m}^2} = 0.23 \text{ m/s} \quad (2)$$

The maximum ram velocity after slow-down, when the same volumetric flow rate is being directed at the main ram area, is

$$V_r = \frac{2.9 \times 10^{-3} \text{ m}^3/\text{s}}{0.1927 \text{ m}^2} = 0.015 \text{ m/s} \quad (3)$$

Shifting the area achieves a 15-fold decrease in speed. The speed within each segment is controlled by bleeding a portion of the $2.9 \times 10^{-3} \text{ m}^3/\text{s}$ back to the tank. Figure 3 illustrates the speed circuit schematically.

A mass balance from Figure 3 for a constant hydraulic fluid density results in:

$$Q_r = Q_p - Q_t \quad (4)$$

where

Q_r = volumetric flow into ram area (m^3/s),

Q_p = total volumetric flow (m^3/s), and

Q_t = volumetric flow returning to tank (m^3/s).

The flow rate returning to the tank can be calculated from

$$Q_t = C_v \sqrt{\frac{P_\ell - P_t}{\rho}} \quad (5)$$

where

C_v = valve flow coefficient ($\text{m}^3/\text{s-kPa}$)^{1/2}

P_ℓ = line pressure (kPa),

P_t = tank pressure (kPa), and

ρ = hydraulic fluid specific gravity.

The flow coefficient in Equation 5 is a function of the opening that can be manually adjusted, but once set usually is not altered. The tank pressure generally is ambient; therefore, Equation 5 becomes

$$Q_t = C_v \sqrt{\frac{P_\ell}{\rho}} \quad (6)$$

For a fixed opening (C_v), the flow rate returning to the tank is a function of only the line pressure. That pressure, developed in the hydraulic line, is a function of the moving mass and the flow resistance of the molding material. The line pressure required to move the ram and mold mass is minimal (less than 69 kPa); therefore, any line pressure buildup before mold closure

Figure 3. Current Hydraulic Speed

is predominantly a function of the forming resistance of the material.

Figure 4 illustrates a fictitious part preform cross section of unit depth at different forming operation stages. The hydraulic radius is used in Newtonian flow as one indicator of the resistance to flow. That is, a large hydraulic radius represents less resistance to flow than a small hydraulic radius for the same set of conditions. The hydraulic radius is defined as the cross-sectional area divided by the wetted perimeter.

$$R = \frac{\text{cross-sectional area}}{\text{wetted perimeter}} \quad (7)$$

For the cross section represented in Figure 4, the hydraulic radius is

$$R_t = \frac{x(t)D(t)}{2[x(t) + D(t)]} \quad (8)$$

Figure 4. Preform Cross-Sectional Change During Molding

The volume of the preform (V_m) in Figure 4 is a function of the mass of material (M_m) and the density (ρ_m).

$$V_m = \frac{M_m}{\rho_m} \quad (9)$$

Because no mass is being added during forming, the volume is constant if the density is constant. The volume of the preform for unit depth is

$$V_m = X(t)D(t) \quad (10)$$

The numerator of Equation 8 can be replaced with Equation 10:

$$R(t) = \frac{V_m}{2[X(t) + D(t)]} \quad (11)$$

The hydraulic radius magnitude during forming, as indicated by Equation 11, is a function of only the wetted perimeter. The wetted perimeter is a time function of the dimensions X and D . The thickness for a constant ram velocity is

$$X(t) = X_0 - V_r t \quad (12)$$

where

X_o = initial preform thickness (m),

V_r = ram velocity (m/s), and

t = time (s).

The volumetric flow rate of the material

$$\frac{dV_m}{dt} = \frac{\partial V_m}{\partial D} \frac{\partial D}{\partial t} \quad (13)$$

for a constant ram velocity. To determine D as a function of time, Equation 12 is substituted into Equation 10.

$$D(t) = V_m(X_o - V_r t)^{-1} \quad (14)$$

and the partial of Equation 14, with respect to time, is developed.

$$\begin{aligned} \frac{\partial D}{\partial t} &= (-1)V_m(X_o - V_r t)^{-2}(-V_r) \\ &= \frac{V_r V_m}{(X_o - V_r t)^2} \end{aligned} \quad (15)$$

Taking the partial of V with respect to D in Equation 10,

$$\frac{\partial V}{\partial D} = X(t) = (X_o - V_r t) \quad (16)$$

Substituting Equations 15 and 16 into Equation 13,

$$\frac{dV}{dt} = \frac{V_r V_m}{(X_o - V_r t)} \quad (17)$$

Equation 17 indicates that the volumetric flow rate increases as the mold closes, because the numerator is constant and the denominator is decreasing as a function of time. Substituting Equations 12 and 14 into Equation 11 after rearrangement results in an expression of the hydraulic radius as a function of time:

$$R(t) = \frac{V_m(X_o - V_r t)}{2[(X_o - V_r t)^2 + V_m]} \quad (18)$$

Table 1 lists the hydraulic radius as a function of time for these conditions:

$$X_o = 0.254 \text{ m}$$

$$V_m = 0.0819 \text{ m}^3$$

$$V_r = 0.0635 \text{ m/s}$$

Table 1 indicates that as the mold closes, the hydraulic radius becomes smaller, requiring more energy to sustain a constant flow rate. However, Equation 17 indicates that the volumetric flow rate is not remaining constant but increasing as the mold closes, and the hydraulic radius is decreasing, requiring a substantial increase in energy. The only way to increase the hydraulic energy input to the ram for a fixed volume flow rate (Q_r) is to increase the pressure.

$$HE = 1000 Q_r P_\ell; \quad (19)$$

where

HE = hydraulic energy (W),

Q_r = ram volume flow rate (m^3/s), and

P_ℓ = line pressure (kPa).

The flow rate returning to tank increases as line pressure increases, as indicated by Equation 6 for bleed speed control systems.

The flow rate to the ram area must decrease, as indicated by Equation 4, if the return flow rate to the tank increases. A corresponding decrease in ram velocity occurs, as indicated by Equation 1. The ram velocity is not constant in the current system; therefore, Equations 12 through 18 do not depict accurately the actual conditions. Equation 12 must be modified to include an acceleration term. However, the general relationships still hold. The acceleration term would reflect the resistance of the material to flow, because, if there were no resistance, the ram velocity would remain constant until the mold halves touched. The magnitude of that acceleration term never has been measured; consequently, the derivations showing its effect on the velocity decrease are academic.

Generally, for filled elastomers, when resistance first is encountered, the line pressure builds up rapidly until a pressure switch activates initiating transition from open loop velocity control to open loop pressure control. Pressure is remotely

Table 1. Hydraulic Radius for Increasing Time

Time (s)	Hydraulic Radius (m)
0	0.031
1	0.0286
2	0.0249
3	0.0179

controlled by adjustment of a potentiometer changing the poppet tension on valve MRV in Figure 2. The line pressure generally must be increased more than 9100 kPa (55000 N force) before the mold halves close.

Equations 12 through 18 are valid for the proposed new closed loop system, because ram velocity will be a controlled variable maintained constant. Figure 5 illustrates schematically the new flow circuit. Flow (Q_r) will be controlled to maintain ram velocity (V_r), letting pressure (P_l) float up to either the pressure transition point or to the setting of the pressure relief valve (MRV).

In Figure 5, the old pressure relief valve (MRV), set at 13790 kPa, will be used to control the upstream pressure to the flow control valve. The flow rate (Q_r) through the new flow control valve is

$$Q_r = C_v i_s (P_s - P_l)^{1/2} \quad (20)$$

where

C_v = valve flow coefficient,

i_s = valve spool position proportional to input current,

P_s = upstream or supply pressure, and

P_l = load pressure.

To maintain constant ram velocity as indicated in the preceding analysis, the load pressure must increase. To maintain a constant flow rate to the ram, the spool current must increase as the load pressure increases, which will be accomplished under feedback control. Figure 6 illustrates the general block diagram for the speed control circuit.

Figure 5. Closed Loop Hydraulic Speed Control Circuit With Flow Control Valve

In Figure 6, the output of the ram velocity controller (i_s) is the input to the valve position control circuit that controls the flow rate (Q_r) going to the ram area. As the load pressure increases, the flow rate through the valve decreases, slowing the ram. The ram velocity control circuit senses the decrease in ram velocity and increases its output to compensate for the reduced flow rate caused by the load pressure increase. Load control will begin when the load pressure builds up beyond the transition pressure point. An option is being designed into the new machine logic system to allow field selection of the current line pressure switch, or to bypass that switch and start transition when the line pressure equals or exceeds a pressure value stored in the

Figure 6. General Block Diagram of Ram Velocity Control

microprocessor. Constant velocity control can then be continued up to the maximum system pressure. Caution must be used during initial development not to coin the mold from high pressures developed over small cross sections. Under load control, the force generated (F_ℓ) is proportional to both ram cross-sectional area (A_r) and hydraulic line pressure (P_ℓ).

$$F_\ell = A_r P_\ell \quad (21)$$

The valve flow rate under load control must equal the losses from valve and ram leakage, plus any compressibility the fluid may undergo. The leakage losses are typically small under load control when compared to the high flow requirements in the velocity control mode; consequently, the high volume flow pump is dropped from the hydraulic circuit during load control. Solving Equation 20 for load pressure and substituting into Equation 21 results in an expression for load force in ram area (A_r), system pressure (P_s), leakage flow rate (Q_r), valve constant (C_v), and, finally, valve position signal (i).

$$F_r = A_r \left[P_s - \left(\frac{Q_r}{C_v} \right)^2 i^{-2} \right] \quad (22)$$

The leakage flow rate in Equation 22 will increase typically as load pressure increases, but not always, depending on the type of seal materials used in the machine construction. Figure 7 illustrates the load pressure versus valve spool position predicted by Equation 22 for leakage flow rates of 25, 50, 75, and 100 percent of maximum pump flow rate. The curve slopes in Figure 7 are extremely high; consequently, to maintain a stable closed loop response, the outer loop controller gain will have to be changed to a comparatively small value. During load control, the ability to vary set point as a function of time is desirable. A software set point recipe will be developed to allow step or ramp changes in set point as a function of time, beginning at the velocity-to-pressure transition. A series of short duration step changes in set point then can be used to replace the current DEGAS mode used to manufacture some filled elastomer parts.

Figure 8 illustrates a shortened dwell pressure set point profile with DEGAS. The pressure during closing and opening is not shown in Figure 8. After DEGAS, the pressure is ramped to the cure pressure, where it is maintained until the dwell time has elapsed. At dwell termination, the pressure is ramped back to the minimum system pressure, in preparation for the stripping cycle (mold opening).

The initial phase of part stripping is important to prevent damage to the part if it sticks partially to the punch and to the

Figure 7. Load Pressure Versus Spool Position From Equation 22

cavity, a common occurrence. The speed must be slow enough to allow the operator to separate the part without tearing it from the punch.

Figure 8. Typical Pressure Profile With Degas

Once stripped, the ram can be opened at maximum speed until it nears the end of the cylinder, where it must be slowed, then stopped. Figure 9 illustrates the effective hydraulic circuit configuration with the new flow control valve.

The low-volume pump (P_2) supplies hydraulic fluid to the top of the ram area during part stripping because velocity requirements are small. Solenoid B becomes energized and directs that output to the top of the main ram. The main ram will not move down until sufficient pressure builds up to overcome the counterbalance valve (CBV) poppet tension. Equation 1 again relates ram velocity to pump output, except that the ram area is now the top area of the ram, which is

$$A_r = \frac{\pi}{4}(D_m^2 - D_r^2) \quad (23)$$

The maximum stripping velocity, using the diameters in Figure 9, is

Figure 9. Hydraulic Circuit With Flow Control Servovalve

$$V_r = \frac{0.5 \times 10^{-3} \text{ m}^3/\text{s}}{0.0193 \text{ m}^2} = 0.0259 \text{ m/s} \quad (24)$$

A limit switch is activated to re-energize solenoid KK, which adds the hydraulic fluid output from the high-volume pump to the circuit and increases maximum speed by a factor of 5.75. That limit switch is set usually 76 to 152 mm from mold closure.

A necessary gain change or circuit change must be made at transition from load control back to velocity control, because the process gain has changed from the ram area to the inverse of the ram area. To maintain closed loop stability, the outer loop controller gain (Figure 6) must be changed to maintain a constant closed loop gain. The velocity gain also must be changed when the high volume pump is energized, because the pump flow rate increases by a factor of 5.75.

A new constant set point regulates the controlling velocity circuit at each gain transition, having a minimum of four velocity set points: fast-close, slow-close, slow-open, and fast-open.

In summary, under closed loop control the general block diagram is like that in Figure 6. During fast closure, the total pump output goes to the booster ram area, creating a fast ram velocity. A limit switch initiates ram area transfer from booster to main and booster areas, which decreases velocity 15-fold. That velocity decrease requires either a gain change or circuit change in the outer loop controller because of the large change in process gain. The ram proceeds to closure at a new slow-close set point rate. When material resistance is encountered, the hydraulic line pressure builds up but the ram continues to close at a constant rate. Transition to load control is initiated through the microprocessor, if the normal pressure switch is bypassed, or as the pressure switch makes contact, unless bypassed. A circuit change here is almost mandatory, because a different feedback variable is necessary in addition to a controller gain change required to offset the large process gains under load control.

During load control, the set point changes as a time function to develop the desired load profile. The load force drops to minimum before mold opening. At minimum system pressure, a directional valve shifts to direct fluid at the top of the ram. The outer loop control circuitry must be shifted again at this transition point, because a different feedback variable is required in addition to a controller gain change resulting from the change in the process variable gain. Under low-volume flow, the mold opens slowly at a constant rate until a limit switch reactivates the high-volume pump. An outer loop controller gain change must take place when the high-volume pump is activated to offset the increased volume flow potential.

Control System Architecture

Figure 10 illustrates the general block diagram of the hydraulic control system. The inner valve spool positioning control system and valve were purchased as a package. The process variable transducers were purchased separately, and the outer loop controllers were designed and built in-house.

The valve manufacturer's literature indicates that the valve control loop can be approximated by a second order underdamped model with a damping ratio (ζ) between 0.5 and 0.7. The closed loop natural frequency (ω_n) is dependent upon valve selection and inner loop controller gain settings. Figure 10 can be redrawn, as illustrated in Figure 11, with the inner valve loop replaced with a second order underdamped transfer function. The subscript j in Figure 11 indicates one of four possible speed segments.

Either the ram area ($A_{R,j}$) or the maximum flow rate ($Q_{m,j}$) changes in each speed segment to alter the process gain. Using block diagram algebra, the closed loop transfer function is this:

$$\frac{C(S)}{R(S)} = \frac{D(S)G_{IL}(S)G_p(S)}{1 + D(S)G_{IL}(S)G_p(S)H(S)} \quad (25)$$

where

$C(S)$ = speed variable,

$R(S)$ = set point,

$D(S)$ = controller transfer function,

$G_{IL}(S)$ = inner loop transfer function,

$G_p(S)$ = plant gain, and

$H(S)$ = feedback transducer transfer function.

Substituting the appropriate values for $D(S)$, $G_{IL}(S)$, $G_p(S)$, and $H(S)$ into Equation 25 after rearrangement results in

$$\frac{C(S)}{R(S)} = \frac{K_{p,j}K_{I,j}K_{ps,j}\omega_n^2}{S(S^2 + 2\zeta\omega_n S + \omega_n^2) + K_{p,j}K_{I,j}K_{ps,j}K_{FB,j}\omega_n^2} \quad (26)$$

where

Figure 10. General Block Diagram of Press Hydraulic Control System

Figure 11. General Block Diagram of Hydraulic Speed Control System

$$K_{ps,j} = \frac{Q_{m,j}}{A_{r,j} C_v \sqrt{P_s - P_\ell}} \quad (27)$$

To maintain a consistent closed loop response from segment to segment, the forward transfer function root locations must be the same. To maintain consistent roots, the controller constants ($K_{p,j}$ and $K_{I,j}$) must change from segment to segment to match change in process gain. Since the natural frequency of the valve spool control loop is independent of the process loop to maintain constant root locations,

$$K_{p,j+1} K_{I,j+1} K_{ps,j+1} = K_{p,j} K_{I,j} K_{ps,j} \quad (28)$$

If the integration time constant is maintained constant, Equation 28 becomes

$$\begin{aligned} K_{p,j+1} &= K_{p,j} \frac{K_{ps,j}}{K_{ps,j+1}} \\ &= K_{p,j} \frac{Q_{m,j}/A_{r,j} C_v \sqrt{P_s - P_\ell}}{Q_{m,j+1}/A_{r,j+1} C_v \sqrt{P_s - P_\ell}} \end{aligned} \quad (29)$$

In all but the slow-close speed segment of the speed control system, the difference between supply pressure and load pressure can be considered constant. Not until resistance to closure is encountered in the slow close segment will the pressure difference change; therefore, if the pressure difference is considered constant, Equation 29 becomes

$$K_{p,j+1} = \left[\frac{Q_{m,j}}{Q_{m,j+1}} \right] \left[\frac{A_{r,j+1}}{A_{r,j}} \right] K_{p,j} \quad (30)$$

The controller proportional gain (K_p) in ensuing segments must change as the change in ratio of either the maximum flow rates or the ram areas. During ram closing the area ratio changes; conversely, during ram opening the maximum flow rate ratio changes. The area ratio change during closing is a 15-fold increase; therefore, from Equation 30 the controller proportional gain must also increase by 15 fold. The flow rate ratio changes by a factor of 5.75 during ram opening, which requires an equal decrease in the ram controller gain.

Switching the gain or switching the entire circuit at transition are two ways to maintain constant root locations. Three different proportional gain speed circuits are the most effective design. Two of the circuits will be used during ram closing; the other, with a gain change during opening.

The gain change in the single opening circuit is initiated by the same limit switch that activates the high-volume pump. The switch in closing circuits is initiated from the slow-down limit switch that also effects the change in area. The two criteria for separating the closing circuits are a higher resolution feedback transducer used in the crucial slow-close segment, and nonlinearities (from increasing load pressure) in a slow-close circuit isolated from the fast-close circuit. A higher resolution feedback transducer is used during the slow-close segment to increase accuracy. Figure 12 illustrates schematically the two closing speed control circuits.

During fast-close, control relays CR 1, CR 3, and CR 4 are de-energized while CR 2 is energized. Control relay CR 2 is energized as the operator presses the maintain contact start pushbuttons and de-energized if the operator removes one or both hands from either button. When control relay CR 2 is de-energized, the proportional mode operational amplifiers (O A) are open, and the integrator capacitor is bled to ground, which results in a zero (null) set point for the valve position loop. The operator, by depressing the two start pushbuttons, provides outer loop control through operational amplifiers 1, 3, and 4. These generate the set point for the valve position control circuit. OA 1 provides the summing junction and the proportional gain. The proportional gain is adjustable by the potentiometer (β_1, R_4) in the OA circuit. The proportional mode output is the input to the integrator, OA 3, whose time constant of integration is varied by its input potentiometer ($\beta_3 R_6$). The integrator output is the input to a signal inverter, which is the set point for the valve spool positioning loop.

The proportional circuits are switched by energizing control relay CR 1, which is accomplished by the slow-down limit switch. The resistances terms R_2 and R_5 have been sized to provide a 15-fold increase in the proportional gain of the two amplifiers.

Once switched, the signal from the higher resolution 102 mm velocity transducer is amplified by OA 9 and compared with a second microprocessor-generated velocity set point. The resulting signal is amplified by OA 2, whose output is the input to the same integrator circuit. With two separate proportional circuits, some nonlinear compensation ($\beta_2 R_4$ adjustments) occurring from load pressure changes can be made without affecting the fast-close response.

The integrator circuit is common to both proportional circuits, which initially will be adjusted to influence the closed loop root locations, but once set will be common to both closing segments.

31

Control relay CR 3 is energized as line pressure reaches the pressure transition point. The closing speed circuit is isolated by the opening of contact CR 3-1. Figure 13 illustrates the pressure control circuit. The line pressure signal is amplified by OA 12 and is summed at OA 4 with a third microprocessor-supplied set point. The resulting signal is amplified by OA 4, whose gain is adjusted by potentiometer β_6R_4 . A high- and low-gain switch is provided to allow a wider range of gain adjustment for the high-process gain load control loop. A second integrator, OA 6, is provided to allow further root manipulation by potentiometer β_7R_{14} for this nonlinear segment. At the end of the pressure dwell time, the microprocessor drops the set point to the minimum pressure level.

Then, control relay CR 5 is energized, dropping all pressure in preparation for valve shifting to direct hydraulic fluid to the top of the main ram. The pressure circuit is deactivated as contact CR 1 opens. Control relay CR 3 is also de-energized as CR 5 is energized. Figure 14 illustrates the ram opening circuit. Finite control of the ram opening is not required; therefore, the lower resolution feedback transducer is adequate for accuracy. A signal inverter, OA 11, is required because of the polarity change of the transducer from closing to opening. The feedback signal again is amplified by OA 10 and summed with a fourth microprocessor-supplied set point at OA 3. The resulting signal is amplified and fed to a third integrating circuit, OA 6. Adjustments to the root locations will be made through β_4R_4 and β_5R_{10} potentiometers. Control relay CR 4 enables opening control, energized approximately one second after CR 5 energization. Control relay CR 6 causes the high-volume pump to enter the hydraulic circuit and produces a gain change to OA 3 by paralleling R_8 with R_9 . The reduction in controller gain is offset by the increased flow gain, as predicted by Equation 30.

Another factor is the criterion that during the slow-open segment, the hydraulic pressure must not exceed 6984 kPa (1000 psi), which translates into an opening force of approximately 133.4 KN (15 tons). During development, molds sometimes stick closed. The control system, to achieve the specified opening velocity, allows the pressure to build to the maximum system pressure (13788 kPa).

Compression molds are built to absorb compressive forces. The mold inserts typically are held in place by a series of bolts around their periphery, which, when placed in tension, generally fail above the 133.4 KN level. The product is a mold that tears itself in half, if the system pressure is allowed to go to maximum level, as it would if the mold halves were stuck shut.

To prevent that occurrence, an added pressure switch set for 6900 kPa will energize an over-pressure relay. That relay will

Figure 13. Pressure Control Circuit

Figure 14. Opening Speed Control Circuit

cause the press to idle at no pressure, and will lock it there until an operator unlocks it by depressing a reset pushbutton. Manual attempts then may open the stuck ram. The closed loop control system will be deactivated automatically for over-pressure or emergency conditions.

Ten additional control relays will be added to the machine logic system to achieve the desired machine response under closed loop control.

In summary, four outer loop analog control circuits were designed to accept process set points from the microprocessor and compute the set point for the inner valve loop. The circuits are switched from the same devices that initiate ram area changes, hydraulic flow rate changes, and velocity-to-pressure transition. The gain changes are commensurate with the requirements of Equations 22 and 30. The flow control valve and valve spool position controller were purchased as a unit. The hydraulic circuit has been altered to accommodate the new directional valve, flow control valve, check valve, and fluid filter. A microprocessor development system and microprocessor have been procured to generate set points, and read process information and output logic commands to the machine logic system. The remaining unanswered question is what the controller gain values should be in the flow and pressure circuits to produce the desired closed loop response.

Speed Control Simulation

A written digital simulation computer program (Appendix B) allows investigation of the gains and architecture for the velocity control mode. Three configurations were investigated: no integral mode, first order lag, and proportional-integral.

Proportional-integral was the only architecture that produced stable responses. The simulation block diagram for the proportional integral architecture is presented in Figure 15. The Y_i values in Figure 15 are stated variables requiring numerical integration, and the X_i values are intermediate calculations. Table 2 lists selected values of K_{A1} and K_{A2} as a function of the potentiometer percentage illustrated in Figure 12.

The integration time constant (τ) is the only variable in the simulation. The valve gain K_v in Figure 15 is assumed constant for all closing speeds, even though Equation 20 indicates that as the line pressure increases, the flow rate decreases. The line pressure will increase only more than a small percentage of the total ram stroke. The natural frequency (ω_n) and damping ratio (ζ) were obtained graphically from the valve manufacturer's literature. The feedback amplifier gain (K_{FBA}) boosts the feedback transducer signal to achieve a range of 0 to 10 V. The ram

Figure 15. Hydraulic Velocity Control for Press Design Option 5, Integral Mode Added

Table 2. Proportional Gain for Various Potentiometers

Potentiometer Percent	K _{A1}	K _{A2}
0	0.024	0.50
20	0.7	10.7
40	1.38	20.9
60	2.05	31.1
80	2.73	41.3
100	3.40	51.5

actuator areas are machine parameters that are constants. Gain K_c is the set point conversion gain to convert engineering units to voltage.

The integral of the squared error (ISE) and the integral of the absolute error (IAE) were used as performance indices.

$$ISE = \int_0^t x_3^2 dt \quad (31)$$

$$IAE = \int_0^t |x_3| dt \quad (32)$$

Simulations were conducted over a range of gain and time constant values. Selected simulations are illustrated in Appendix A. Small proportional gains produce overdamped results that become more underdamped, as their magnitudes are increased, eventually to become totally underdamped, as indicated in simulations 1 through 6. Small time constants of integration produce the opposite effects. By increasing its magnitude, the closed loop response tends to dampen (simulations 7 through 9).

The results of the simulation dictated the controller configuration and the gain magnitudes for the initial hardware design.

ACCOMPLISHMENTS

The early goals of this project were to design, procure, and install the hardware required to achieve closed loop ram speed and load pressure control. The first two goals have been completed.

FUTURE WORK

The next stage of the project is to install the remaining hardware, start software development, implement hardware and software, and test the resulting system.

Appendix A

RAM VELOCITY VERSUS TIME SIMULATIONS

SIMULATION 1

SIMULATION 2

SIMULATION 3

SIMULATION 4

SIMULATION 5

SIMULATION 6

SIMULATION 7

SIMULATION 8

SIMULATION 9

Appendix B

SOURCE LISTING FOR HYDRAULIC CIRCUIT SIMULATION

```
OVERLAY (HYDCI, C, C)
PROGRAM CONTRL (INPUT, OUTPUT, TAPE1=INPUT, TAPE2=OUTPUT, TAPE5)
```

```

C ... THIS ROUTINE IS A SIMULATION OF THE HYDRAULIC CONTROL CIRCUIT
C ... PROPOSED FOR CLOSED LOOP CONTROL OF COMPRESSION MOLDING
C ... MACHINES IN D/27.
C
C ... THIS VERSION INCORPORATES DESIGN OPTION # 5 FOR CLOSING SPEED
C ... CONTROLLER CONFIGURATION AND GAIN TERMS.
C ... (1) PROPORTIONAL CONTROLLER CIRCUITS SWITCHED.
C ... (2) INTEGRAL MODE HAS VARIABLE TIME CONSTANT OF INTEGRATION
C
C =====
C

```

```
COMMON/AA/X(50),P(40),Y(22),YT(22),F(10),C(9),NY,NX,NP,MMSP
COMMON/BB/XSTF(1,50),XT(9),XTH(9),IH(9),NH,IMAX,H(9)
COMMON/CC/FAMP(14),STPT(14),TIM(14),DWELL(14),JFLAG,NSEG,SP,SP1
COMMON/DD/ITY,ITX,ICY,IGX,NC,SB(12),PL,PR,IRUN,IPAGE,IX,IY,NOUT
COMMON/EE/XG(8,2),YG(8,2),MSS,NGY(8),NCX(8),NTY(8),NTX(8)
COMMON/FF/IADJ,MX,MY,JX(8),JY(8),XS(901,8),YS(901,8)
COMMON/GG/ND(20),NPT,NSP,NTM,PTIME,ISW
COMMON/HH/PTIME,ETIME,DELT,IT1(10),IT2(10),MT(3),MN(3),JD(3),MS(3)
COMMON/II/ISAMP,NTIME,NDY,IDY,CPI(20),CDO
```

```

ND(1)   = 1   READS IDENTIFIER TITLES AND INTEGRATION CONTROLS.
ND(2)   = 1   READS INITIAL CONDITIONS OF STATE VARIABLES.- Y'S
ND(3)   = 1   READS MAGNITUDES OF DELAYS. P'S
ND(4)   = 1   READS THE PARAMETER LIST. P'S
ND(5)   = 1   READS X AND Y SUBSCRIPTS TO BE PRINTED AND PLOTTED.
ND(6)   = 0   SETS INITIAL CONDITIONS OF Y'S EQUAL TO THEIR FINAL
              VALUE FROM THE PREVIOUS RUN.
ND(6)   = 1   SETS INITIAL CONDITIONS OF Y'S EQUAL TO THE VALUE
              READ IN FROM DATA CARDS.
ND(7)   = 1   SETS IPUG
ND(8)   = 1   SETS IADJ CAUSING PARADJ TO BE CALLED.
ND(9)   = 0   CAUSES SCALE TO SET SCALE LIMITS FOR EACH PLOT.
ND(9)   = 1   CAUSES SCALE TO READ IN UPPER AND LOWER LIMITS WHICH
              ARE USED ON ALL PLOTS.
ND(9)   = 2   CAUSES SCALE TO SCAN ALL PLOT DATA TO FIND LIMITS
              WHICH ARE THEN USED FOR ALL PLOTS.
ND(9)   = 3   CAUSES SCALE TO READ PLOT LIMITS FOR EACH PLOT.
ND(9)   = 4   CAUSES SCALE TO USE PREVIOUSLY DEFINED LIMITS.
ND(10)  = 1   CAUSES A NEW SETPOINT RECIPE TO BE READ IN.
ND(11)  = 1   CAUSES STORED X DATA TO BE WRITTEN TO TAPE6.

```

P'S ARE PARAMETER VARIABLES READ IN OR DEFINED IN INIFUN.
X'S ARE INTERMEDIATE VARIABLES.
Y'S ARE STATE VARIABLES.
F'S ARE STATE DERIVATIVES.
H'S ARE TIME DELAY MAGNITUDES.

PAGE NO. 2

```
C
C
C      X(1) AND Y(NSYS+1) ARE RESERVED FOR TIME.
C
C      BTIME = BEGINNING TIME
C      ETIME = END TIME
C      PTIME = PRINT OUT INTERVAL
C      DELT  = INTEGRATION STEP SIZE MUST BE .1,.2, .5 OR A MULTIPLE OF
C              10 TIMES THOSE STEP SIZE VALUES.
C
C
C
C
C      101 FORMAT(1H1,10X,46HTHE OUTPUT INTERVAL IS TOO SMALL - OUTPUT AREA,
C          *31HY EXCEEDS 1001 PTIME RESET TO ,F0.5//)
C      102 FORMAT(//,10X,23HTHE ISE OF THE LOOP IS ,1PE14.7/10X,
C          *23HTHE IAE OF THE LOOP IS ,1PE14.7)
C      103 FORMAT(20(1X,I1))
C      104 FORMAT(4(5X,2HY(,I2,4H) = ,F12.5,2X))
C      105 FORMAT(4(5X,2HX(,I2,4H) = ,F12.5,2X))
C      150 FORMAT(8(F9.4,1H ))
C      160 FORMAT(8(I2,1X))
C      161 FORMAT(I2,1X,I2,1X,I3)
C      162  FORMAT(2X,36HHYDRAULIC SPEED CONTROL 300 TON HPM.)
C      163 FORMAT(5(F12.6,2X))
C
C
C      IRUN = 0
C      1 IPAGE = 0
C        IRUN = IRUN + 1
C        READ(1,103)(ND(I),I=1,20)
C        IF(EOF(1))999,2
C      2 IBUG = ND(7)
C        JSTOP = 0
C        NSUM = 0
C        DO 3 I=1,20
C      3 NSUM = NSUM + ND(I)
C        IF(NSUM.EQ.0) JSTOP = 1
C        IF(JSTOP.EQ.1.AND.IADJ.EQ.0) GO TO 999
C        IADJ = ND(8)
C
C
C      ABOVE READS IN NDATA AND TERMINATES RUN IF NO CHANGES IN ND
C
C      CALL INPUT
C      CALL INIFUN
C      IF(NX.EQ.0) GO TO 4
C      CALL INTCAL
C      4 CALL DIFFEQ
C      CALL ALIST
C
C
C      ABOVE INITIALIZES PROGRAM AND PRINTS OUT HEADER INFO.
C
C      NSTEP = ((ETIME - BTIME)/DELT) + 0.5
C      NW = ((PTIME/DELT) + 0.5)
C      NMOG = NSTEP/NW
C      IF(NMOG.GT.1001) GO TO 6
```

PAGE NO. 3

```
GO TO 7
6 NPT = NSTEP/1001
  NW = NPT + (1./DELT)
  PTIME = NW*DELT
  WRITE(2,101)PTIME
```

```
C
C   AECVE ESTABLISHES PRINT INTERVAL
C
```

```
7 JI=1
  DO 8 I=1,MX
8  XS(JI,I) = X(JX(I))
  DO 9 I=1,MY
9  YS(JI,I) = Y(JY(I))
```

```
C
C   STORE IN PRINT MATRIX INITIAL X AND Y PRINT/PLOT VARIABLES.
C
C   PROCEED WITH PROGRAM EXECUTION BELOW.
C
```

```
  NI = 0
  DO 15 KK=1,NSTEP
  NI = NI + 1
  CALL RKINT(KK)
  IF(IBUG.NE.1) GO TO 10
  N1 = NY + 1
  WRITE(2,104)N1,Y(N1)
  WRITE(2,104)(I,Y(I),I=1,NY)
  WRITE(2,105)(I,X(I),I=1,NX)
10 IF(NX.EQ.0) GO TO 11
  CALL INTCAL
11 IF(NI.NE.NW) GO TO 15
  NI = 0
  IF(IBUG.NE.1) GO TO 12
  WRITE(2,104)N1,Y(N1)
  WRITE(2,104)(I,Y(I),I=1,NY)
  WRITE(2,105)(I,X(I),I=1,NX)
12 JI = JI + 1
```

```
C
C   STORE X AND Y DATA IN PRINT/PLOT MATRICES BELOW.
C
```

```
  IF(MX.EQ.0) GO TO 50
  DO 13 I=1,MX
  XS(JI,I) = X(JX(I))
  IF(ICX.EQ.0) GO TO 13
  IF(XS(JI,I).CE.XG(I,2)) XG(I,2) = XS(JI,I)
  IF(XS(JI,I).LE.XG(I,1)) XG(I,1) = XS(JI,I)
13 CONTINUE
```

```
C
50 IF(MY.EQ.0) GO TO 15
  DO 14 I=1,MY
  YS(JI,I) = Y(JY(I))
  IF(ICY.EQ.0) GO TO 14
  IF(YS(JI,I).CE.YG(I,2)) YG(I,2) = YS(JI,I)
  IF(YS(JI,I).LE.YG(I,1)) YG(I,1) = YS(JI,I)
14 CONTINUE
15 CONTINUE
```

PAGE NO. 4

```
C
C      NOW THAT ITERATIONS COMPLETE PRINT AND PLOT RESULTS.
C
      IF(ND(11).NE.1) GO TO 201
      WRITE(6,162)
      WRITE(6,161)MX,NP,JI
      WRITE(6,160)(JX(I),I=1,MX)
      WRITE(6,163)(P(I),I=1,NP)
      DO 200 I=1,JI
200  WRITE(6,150)(XS(I,JJK),JJK=1,MX)
      ENDFILE 6
201  CONTINUE
      NOUT = JI
      IF(ITY.EQ.0) GO TO 16
C
C      PRINT Y TABLES.
C
      CALL PRTTBL(JI,0)
16  IF(ITX.EQ.0) GO TO 17
C
C      PRINT X TABLES.
C
      CALL PRTTBL(JI,1)
17  IF(IGY.EQ.0) GO TO 18
C
C      PLOT Y DATA.
C
      NG = IGY
      CALL PLOT(YS,1,YG)
      IPAGE = IPAGE + 1
18  IF(IGX.EQ.0) GO TO 19
C
C      PLOT X DATA.
C
      NG = IGX
      CALL PLOT(XS,0,XG)
      IPAGE = IPAGE + 1
C
C      ADJUST THE PARAMETER (P'S) LIST IF IADJ = 1
C
19  IF(IADJ.NE.0) CALL PARADJ
      WRITE(2,102)Y(5),Y(6)
      IF(JSTOP.NE.0) GO TO 999
      GO TO 1
999  STOP
      END
      SUBROUTINE INPUT
C
C      COMMON/AA/X(50),P(40),Y(22),YT(22),F(10),C(9),NY,NX,NF,MMSF
      COMMON/BB/XSTR(1,50),XT(9),XTH(9),JH(9),NH,IMAX,P(9)
      COMMON/CC/RAMP(14),STPT(14),TIM(14),DWELL(14),JFLAG,NSFC,SP,SPJ
      COMMON/DD/ITY,ITX,IGY,IGX,NC,SB(12),PL,PR,JRUN,IPAGE,IY,IY,NOUT
      COMMON/EE/XG(8,2),YG(8,2),MSS,NCY(8),NGX(8),NTY(8),NTX(8)
      COMMON/FF/IADJ,MX,MY,JX(8),JY(8),XS(901,P),YS(901,P)
```

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COMMON/GC/ND(20),NPT,NSF,NTM,PTIME,ISW
COMMON/HH/BTIME,ETIME,DELT,IT1(10),IT2(10),MT(3),MN(3),JD(3),MS(3)

C
C

100 FORMAT(8F10.0)
101 FORMAT(10A8)
102 FORMAT(4(I2,1X))
104 FORMAT(8(1X,I2))
105 FORMAT(2(3A8,1X))

C
C
C

ZERO OUT ARRAYS

DO 1 I=1,8
DO 1 J=1,2
XC(I,J) = 0.0
1 YC(I,J) = 0.0
IF(ND(5).EQ.0) GO TO 3
DO 2 I=1,8
NCY(I) = 0
NCX(I) = 0
NTY(I) = 0
NTX(I) = 0
JX(I) = 0
2 JY(I) = 0
ITY=ITX=ICY=IGX=MY=MX=0
3 IF(ND(1).EQ.0) GO TO 4

C
C
C
C
C
C

READ IN TWO 80 CHARACTER TITLES, MOLD TITLE(MT), MOLD NUMBER(MN),
AND MOLD SECTION(MS). THEN READ DATE(JD), NUMBER OF Y'S, X'S,
P'S, AND H'S AS WELL AS BEGIN AND END TIMES, INTEGRATION SIZE,
AND PRINT INTERVAL.

READ(1,101)(IT1(I),I=1,10)
READ(1,101)(IT2(J),J=1,10)
READ(1,105)(JD(K),K=1,2)
READ(1,102)NY,NX,NP,NH
READ(1,100)PTIME,ETIME,DELT,PTIME
Y(NY+1) = ETIME
Y(NY+2) = DELT
N2 = NY + 2
NMAX = 2*NY + 2
4 IF(ND(2).EQ.0) GO TO 5
READ(1,100)(Y(I),I=1,NY)
GO TO 7
5 IF(ND(6).NE.0) GO TO 7
DO 6 I=1,N2
6 Y(I) = YT(I)
7 DO 8 I=1,N2
8 YT(I) = Y(I)

C
C
C
C
C

INTEGRATION CONTROLS READ IF ND(1) = 1 ABOVE. ALSO, THE INITIAL
CONDITIONS OF THE STATE VARIABLES ARE SET.

IF(ND(3).EQ.0) GO TO 9

PAGE NO. 6

```
      READ(1,100)(H(I),I=1,NH)
9 IF(ND(4).EQ.0) GO TO 10
      READ(1,100)(P(I),I=1,NP)
```

C
C
C
C
C

THE ABOVE READS THE TIME DELAY AND PARAMETER MAGNITUDE ARRAYS.

BELOW READ IN Y AND X INDEX NUMBERS FOR PRINT AND PLOT I/O.

```
10 IF(ND(5).EQ.0) GO TO 1P
      READ(1,104)(NTY(I),I=1,P)
      READ(1,104)(NGY(I),I=1,P)
      READ(1,104)(NTX(I),I=1,P)
      READ(1,104)(NGX(I),I=1,P)
```

C
C
C

DETERMINE HOW MANY OF EACH FUNCTION ARE TO BE PERFORMED.

```
      DO 11 J=1,8
      IF(NTX(J).NE.0) ITX = ITX + 1
      IF(NTY(J).NE.0) ITY = ITY + 1
      IF(NGX(J).NE.0) ICX = ICX + 1
      IF(NGY(J).NE.0) IGY = IGY + 1
11 CONTINUE
```

C
C
C

STORE PRINT X INDICES IN ARRAY JX , Y INDICES IN JY.BELOW

```
      DO 12 I=1,P
      IF(NTX(I).EQ.0) GO TO 12
      MX = MX + 1
      JX(MX) = NTX(I)
12 IF(NTY(I).EQ.0) GO TO 13
      MY = MY + 1
      JY(MY) = NTY(I)
13 CONTINUE
```

C
C
C
C

CHECK TO SEE IF PLOT X AND Y INDICES ARE THE SAME AS PRINT INDICES
IF SO DO NOT STORE INDEX. IF NOT SAME STORE INDEX IN JX OR JY.

```
      DO 17 I=1,P
      IF(NGX(I).EQ.0) GO TO 15
      DO 14 J=1,MX
      IF(NGX(I).EQ.JX(J)) GO TO 15
14 CONTINUE
      MX = MX + 1
      IF(MX.GT.8) MX = 8
      JX(MX) = NGX(I)
15 IF(NGY(I).EQ.0) GO TO 17
      DO 16 J=1,MY
      IF(NGY(I).EQ.JY(J)) GO TO 17
16 CONTINUE
      MY = MY + 1
      IF(MY.GT.8) MY = 8
      JY(MY) = NGY(I)
17 CONTINUE
```

C
C

PAGE NO. 7

```

C
C 18 IF(NP(10).NE.0) CALL RECIPE
C
C   RETURN
C   END
C   SUBROUTINE RECIPE
C
C   READS IN THE MAJOR LOOP SET POINT RECIPE.
C
C   COMMON/CC/RAMP(14),STPT(14),TIM(14),DWELL(14),JFLAG,NSFG,SP,SP1
C
C 1  FORMAT(3F10.0)
C 2  FORMAT(I2)
C
C   READ(1,2)NSEG
C
C   DO 3 I=1,NSEG
C 3  READ(1,3)RAMP(I),STPT(I),TIM(I)
C
C   JFLAG = 0
C   RETURN
C   END
C   SUBROUTINE ALIST
C
C   HEADER OUTPUT ROUTINE.
C
C   COMMON/AA/X(50),P(40),Y(22),YT(22),F(10),C(9),NY,NX,NP,MMSP
C   COMMON/BP/XSTR(1,50),XT(9),XTH(9),IH(9),NH,IMAX,H(9)
C   COMMON/CC/RAMP(14),STPT(14),TIM(14),DWELL(14),JFLAG,NSEG,SP,SP1
C   COMMON/DD/ITY,ITX,IGY,IGX,NG,SB(12),PL,PR,IRUN,IPAGE,IX,IY,NOUT
C   COMMON/GG/ND(20),NPT,NSP,NTM,PTIME,ISW
C   COMMON/HH/PTIME,ETIME,DELT,IT1(10),IT2(10),MT(3),MN(3),JD(3),MS(3)
C
C
C
C 100  FORMAT(1H1,6X,47HHYDRAULIC SPEED CONTROL 300 TON HPM RAM CLOSING,
113H ** RUN DATE ,3A8,2X,PHRUN NO. ,I2,2X,9HPAGE NO. ,I3/)
101  FORMAT(1X,I20(1H*))/)
102  FORMAT(65X,10HDESCRIPTOR/)
103  FORMAT(20X,10A8/20X,10A8//)
104  FORMAT(5X,19H* PROGRAM CONTROLS,24X,1H*)
105  FORMAT(5X,1H*,42X,1H*)
106  FORMAT(5X,24H* NUMBER OF Y EQUATIONS,4X,I3,12X,1H*)
107  FORMAT(//5X,44(1H*))
108  FORMAT(5X,24H* NUMBER OF X EQUATIONS,4X,I3,12X,1H*)
109  FORMAT(5X,28H* NUMBER OF F PARAMETERS ,I3,12X,1H*)
110  FORMAT(5X,21H* NUMBER OF H DELAYS,7X,I3,12X,1H*,16X,1H*,2X,
115H SIMULATION DATE,8X,3A8,2X,1H*)
111  FORMAT(5X,12H* START TIME,10X,F8.4,3X,10HSECONDS *)
112  FORMAT(5X,11H* END TIME,11X,F8.4,3X,10HSECONDS *)
113  FORMAT(5X,18H* OUTPUT INTERVAL,6X,F7.4,3X,10HSECONDS *)
114  FORMAT(5X,25H* INTEGRATOR STEP SIZE ,F8.4,1X,10HSECONDS */5X,
115H 44(1H*))//)
115  FORMAT(//5X,44H THE FOLLOWING ARE THE TIME DELAYS IN SECONDS/)
116  FORMAT(4(5X,2HH(,I2,4H) = ,F12.3,2X))

```


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```

117 FORMAT(/5X,28HTHE FOLLOWING IS THE PARAMETER LISTING/)
118 FORMAT(4(5X,2HP(,I2,4H) = ,F12.6,2X))
119 FORMAT(/5X,48HENSUING ARE THE INITIAL CONDITIONS OF THE STATE ,
*9H VARIABLES/)
120 FORMAT(4(5X,2HY(,I2,4H) = ,F12.5,2X))
121 FORMAT(/5X,49HENSUING ARE THE X VALUES AFTER INIFUN AND INTCAL ,
*33HBUT BEFORE THE FIRST INTEGRATION./)
122 FORMAT(4(5X,2HX(,I2,4H) = ,F12.4,2X))
123 FORMAT(40X,51(1H*))
124 FORMAT(40X,19H*** FAST CLOSE GAIN,6X,2H= ,F9.4,15H VOLTS/VOLT ***/
+40X,19H*** SLOW CLOSE GAIN,6X,2H= ,F9.4,15H VOLTS/VOLT ***/40X,
+18H*** AMPLIFIER GAIN,7X,2H= ,F9.4,15H VOLTS/VOLT ***)
125 FORMAT(40X,21H*** AMP TIME CONSTANT,4X,2H= ,F9.8,8H SECONDS,4X,
+3H***/,40X,20H*** SPOOL NAT. FREQ.,5X,2H= ,F9.4,8H RAD/SFC,4X,
+3H***/40X,25H*** SPOOL DAMPING FACT ,2H= ,F9.5,12X,3H***)
126 FORMAT(40X,17H*** BOOSTER AREA ,8X,2H= ,F9.5,6H IN**2,6X,3H***/40X
+,18H*** MAIN RAM AREA ,7X,2H= ,F9.5,6H IN**2,6X,3H***/40X,
+27H*** FEEDBACK AMP. GAIN = ,F9.5,15H VOLTS/VOLT ***)
127 FORMAT(40X,31H*** TRANSITION FAST TO SLOW AT ,F6.2,7H INCHES,3X,
+3H***)
131 FORMAT(39X,1H*,12X,16HSET POINT RECIFE,12X,1H*)
132 FORMAT(39X,42(1H*))
133 FORMAT(39X,42H* RAMP * SETPOINT * DWELL * SFCMENT *)
134 FORMAT(39X,42H* PSI/S * PSI * SEC * NO. *)
135 FORMAT(39X,1H*,F6.2,2H *,2X,F6.2,2X,3H* ,F5.2,3H *,4X,I2,5X,
*1H*)
136 FORMAT(///)

```

C

```

IPACE = IPAGE + 1
WRITE(2,100)(JD(I),I=1,3),IRUN,IPACE
WRITE(2,101)
WRITE(2,102)
WRITE(2,103)(IT1(I),I=1,10),(IT2(J),J=1,10)
WRITE(2,101)
WRITE(2,107)
WRITE(2,104)
WRITE(2,105)
WRITE(2,106)NY
WRITE(2,108)NX
WRITE(2,109)NP
WRITE(2,110)NH,(JD(J),J=1,3)
WRITE(2,111)BTIME
WRITE(2,112)ETIME
WRITE(2,113)PTIME
WRITE(2,114)DELT
WRITE(2,101)
IF(NH.EQ.0) GO TO 1
WRITE(2,115)
WRITE(2,101)
WRITE(2,116)(I,H(I),J=1,NH)
WRITE(2,101)
1 IF(NP.EQ.0) GO TO 2
WRITE(2,117)
WRITE(2,101)
WRITE(2,118)(I,P(I),I=1,NP)

```

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```
      WRITE(2,101)
2  IPACE = IPACE + 1
      WRITE(2,100) (JD(I), I=1, 3), IRUN, IPACE
      WRITE(2,101)
      WRITE(2,119)
      WRITE(2,101)
      WRITE(2,120) (I, Y(I), J=1, NY)
      WRITE(2,101)
      WRITE(2,121)
      WRITE(2,101)
      WRITE(2,122) (I, X(I), I=1, NX)
      WRITE(2,101)
      WRITE(2,101)
      IPACE = IPACE + 1
      WRITE(2,100) (JD(I), I=1, 3), IRUN, IPACE
      WRITE(2,101)
      WRITE(2,136)
      WRITE(2,123)
      WRITE(2,124) P(3), P(4), P(5)
      WRITE(2,125) P(6), P(7), P(8)
      WRITE(2,126) P(10), P(11), P(14)
      WRITE(2,127) P(12)
      WRITE(2,123)
      WRITE(2,136)
      IF (ND(10).EQ.0.AND.IRUN.EQ.1) RETURN
      WRITE(2,101)
      WRITE(2,136)
      WRITE(2,132)
      WRITE(2,131)
      WRITE(2,132)
      WRITE(2,133)
      WRITE(2,134)
      WRITE(2,132)
      WRITE(2,135) (RAMP(I), STPT(I), TIM(I), I, I=1, NSEC)
      WRITE(2,132)
      IPACE = IPACE + 1
      RETURN
      END
      SUBROUTINE INIFUN
C
C      INITILIZE FUNCTION SUBROUTINE.
C
      COMMON/AA/X(50), P(40), Y(22), YT(22), F(10), C(9), NY, NX, NP, MMSP
      COMMON/BB/XSTR(1, 50), XT(9), XTH(9), IH(9), NH, IMAX, H(9)
      COMMON/GG/ND(20), NPT, NSP, NTM, PTIMF, ISW
      COMMON/HH/BTIME, FTIME, DELT, IT1(10), IT2(10), MT(3), MN(3), JD(3), MS(3)
      COMMON/II/ISAMP, NTIMF, NDY, IDY, CDI(20), CDO
C
C
100 FORMAT(1H1, 5X, 23H** TIME DELAY VARIABLE ,11,18H EXCEEDS THE MAXIM,
      *46HUM ARRAY SIZE WHEN DIVIDED BY DELT RGM STOP **/)
C
C      IMAX = 0
      IF (NH.EQ.0) GO TO 3
```

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```
DO 1 I=1,NH
  IH(I) = H(I)/DELT + 1
  IF(IH(I).GE.IMAX) IMAX = IH(I)
  IF(IMAX.GT.500) GO TO 2
1 CCNTINUE
  GO TO 3
2 WRITE(2,100)I
  STOP
3 DO 4 I=1,NX
4 X(I) = 0.0
  X(1) = PTIME
  ISAMP = (PTIME/DELT) + 0.5
  X(11)=P(1)*P(18)
  NTIME = 0
  NDY = 0
  ISW = 0
C
  RETURN
END
SUBROUTINE INTCAL
C
C ... INTERMEDIATE CALCULATION SUBROUTINE.
C
C ... INTERMEDIATE VALUES OF EQUATIONS CALCULATED HERE FOR
C ... EACH INTEGRATION STEP.
C
COMMON/AA/X(50),P(40),Y(22),YT(22),F(10),C(9),NY,NX,NP,MMSF
COMMON/PP/XSTR(1,50),XT(9),XTH(9),IH(9),NH,IMAX,H(9)
COMMON/CC/RAMP(14),STPT(14),TIM(14),FWELL(14),JFLAC,NSEC,SF,SP1
COMMON/GG/ND(20),NPT,NSP,NTM,PTIME,ISW
COMMON/HH/BTIME,FTIME,DELT,IT1(10),IT2(10),MT(3),MN(3),JD(3),MS(3)
COMMON/II/ISAMP,NTIME,NDY,JDY,CDI(20),CDO
C
X(1) = Y(NY+1)
NTIME = NTIME + 1
IF(Y(4).GE.P(12)) ISW = 1
IF(Y(4).GE.P(16)) ISW = 2
IF(NTIME.LE.ISAMP) GO TO 1
X(2) = P(1)*P(15)
IF(ISW.EQ.1) X(2) = P(2)*P(15)
IF(ISW.EQ.2) X(2) = 0.0
IF(ISW.EQ.1) X(11) = P(2)*P(18)
IF(ISW.EQ.2) X(11) = 0.0
1 X(3) = X(2) - X(10)
X(4) = P(3)*X(3)
IF(ISW.NE.0) X(4) = P(4)*X(3)
Y(1) = ALIM(Y(1),-10.,10.)
X(5) = Y(1)
Y(3) = ALIM(Y(3),-10.,10.)
X(6) = Y(3)
X(7) = 3.85*P(9)*X(6)
X(7) = ALIM(X(7),0.0,161.7)
X(8) = X(7)/P(10)
IF(ISW.NE.0) X(8)=X(7)/P(11)
X(13)=X(8)*P(17)
```

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```
Y(4) = ALIM(Y(4),0.0,12.0)
X(12)=Y(4)
X(9)=P(13)*X(P)
X(10) = P(14)*X(9)
```

C

```
RETURN
END
FUNCTION ALIM(V,P,T)
ALIM = V
IF(V.GT.T) ALIM = T
IF(V.LT.P) ALIM = P
RETURN
END
SUBROUTINE SPADJ
```

C

```
COMMON/AA/X(50),P(40),Y(22),YT(22),F(10),C(9),NY,NX,NP,MMSP
COMMON/CC/RAMP(14),STPT(14),TIM(14),DWELL(14),JFLAG,NSEC,SP,SP1
```

C

```
THIS IS THE SET POINT ADJUSTMENT ROUTINE. THE RECIPE IS READ IN
FROM SUBROUTINE RRCIPE. SOME OF THE FEATURES OF THE ROUTINE ARE:
```

C

- C ... 1) NO RAMP MAY BE SPECIFIED IN SEGMENT 1.
- C ... 2) DWELL PERIODS ARE IN SECONDS AND APPLY TO THE SPECIFIED
C SEGMENT ONLY.
- C ... 3) THE SET POINT IN ANY SEGMENT EXCEPT 1 MAY BE SPECIFIED AS ZERO
C AND THAT SEGMENT WILL USE THE PRECEDING SEGMENTS SET POINT.
- C ... 4) TWO CONSECUTIVE SEGMENTS MUST HAVE AT LEAST ONE SET POINT
C SPECIFIED.
- C ... 5) THE DWELL IN ANY ONE SEGMENT MAY BE SPECIFIED AS ZERO AND THAT
C SEGMENT WILL BE PASSED OVER. THIS OPTION IS USUALLY USED TO
C SPECIFY A DIFFERENT SET POINT AS A START POINT FOR A RAMP.
- C ... 6) A DWELL MUST BE SPECIFIED IN A RAMP SEGMENT.
- C ... 7) NO TWO CONSECUTIVE SEGMENTS MAY BE SPECIFIED WITH A ZERO DWELL
- C ... 8) POSITIVE RAMPS ARE DEFINED BY A PLUS OR NO SIGN BEFORE THE
C RAMP RATE MAGNITUDE.
- C ... 9) DOWN RAMPS ARE DEFINED BY A NEGATIVE SIGN BEFORE THE RAMP
C RATE MAGNITUDE
- C ... 10) A RAMP SEGMENT MUST HAVE SPECIFIED A RAMP RATE, A TERMINATION
C SET POINT, AND A TERMINATION TIME LIMIT. THAT TIME LIMIT MAY
C BE SPECIFIED GREATER THAN THE ACTUAL RAMP TIME.
- C

```
IF(JFLAG.EQ.1) GO TO 2
ST = 0.0
DWELL(1) = TIM(1)*60.
JFLAG = 1
DO 1 I=2,NSEC
K=I-1
1 DWELL(I) = DWELL(K) + TIM(I)*60.
2 IF(X(1).GE.DWELL(I)) GO TO 3
SP = STPT(I)
I=1
GO TO 14
3 DO 4 I=2,NSEC
IF(X(1).GE.DWELL(I-1).AND.X(1).LT.DWELL(I)) GO TO 5
4 CONTINUE
```

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```
      RETURN
5  IRAMP = RAMP(I)
   IF(IRAMP.NE.0) GO TO 6
   GO TO 7
6  BT = DWELL(I-1)
   SLP = RAMP(I)/60.
   SP = SLP*(X(1)-BT) + STPT(I-1)
   IF(STPT(I-1).LT.50.) SP = SLP*(X(1)-BT) + STPT(I-2)
   IF(ABS(SP-STPT(I)).LT.0.5.AND.X(1).LT.DWELL(I)) GO TO 12
   IF(RAMP(I).LT.0.0) GO TO 11
   GO TO 10
7  SP = STPT(I)
   SP = STPT(I-1)
   IF(I.GT.2) GO TO 8
   GO TO 14
8  CH = SP - STPT(I-2)
   IF(CH.LT.0.0) GO TO 11
   GO TO 10
9  CH = SP - STPT(I-1)
   IF(CH.LT.0.0) GO TO 11
10 P1 = P(12)
   P2 = P(13)
   P3 = 0.0
   GO TO 14
11 P1 = P(12)
   P2 = P(13)
   P3 = 0.0
   GO TO 14
12 ADT = DWELL(I) - X(1)
   SP = STPT(I+1)
   IF(SP.LT.50.) SP=STPT(I)
   DWELL(I) = DWELL(I) - ADT
   IF(SP.EQ.STPT(I-1)) CH = SP-STPT(I-2)
   IF(CH.LT.0.0) GO TO 11
   CH = SP - STPT(I-1)
   I=I+1
   IF(I.GT.NSEC) GO TO 14
   DO 13 K=I,NSEC
13  DWELL(K) = DWELL(K-1) + TIM(K)*60.
   GO TO 10
14  X(2) = X(2)
   X(3) = X(3)
C
   MMSP = I
   RETURN
   END
   SUBROUTINE DELAY
C
C   THIS SUBROUTINE SETS UP THE DELAY PIPELINES.
C
   COMMON/BB/XSTR(1,50),XT(9),XTH(9),IH(9),NH,IMAX,I(9)
C
   ISTOP = IMAX - 1
   DO 1 KK=1,ISTOP
   IS = IMAX - KK
```

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```

      JS = IS + 1
      DO 1 II = 1, NH
1 XSTR(II, JS) = XSTR(II, IS)
C
      DO 2 II = 1, NH
      JJ = IH(II)
      XTH(II) = XSTR(II, JJ)
2 XSTR(II, 1) = XT(II)
C
      RETURN
      END
      SUBROUTINE DIFFEQ
C
C ... DIFFERENTIAL EQUATION ROUTINE.
C
C ... F VALUES ARE THE DIFFERENTIAL VALUES
      COMMON/AA/X(50), P(40), Y(22), YT(22), F(10), C(9), NY, NX, NP, MMSP
C
      WN = P(7) * P(7)
      F(1) = P(5) * X(4) / P(6)
      F(2) = Y(1) * WN - 2. * P(7) * P(8) * Y(2) - WN * Y(3)
      F(3) = Y(2)
      F(4) = X(8)
      F(5) = X(3) * X(3)
      F(6) = ABS(X(3))
C
      DO 1 LK = 1, NY
      IQ = NY + 2 + LK
1 Y(IQ) = F(LK)
C
      RETURN
      END
      FUNCTION FOL(GA, XIN, YOUT, TAU)
      IF(TAU.NE.0.0) GO TO 1
      YOUT = GA * XIN
      FOL = 0.0
      RETURN
1 FOL = (GA * XIN - YOUT) / TAU
      RETURN
      END
      SUBROUTINE RKINT(LL)
C
C RUNGE-KUTTA NUMERICAL INTEGRATION ROUTINE FOR SOLVING DIFFERENTIAL
C EQUATIONS.
C
      COMMON/AA/X(50), P(40), Y(22), YT(22), F(10), C(9), NY, NX, NP, MMSP
C
      DIMENSION YU(42), BET(3), DY(4, 20)
      DOUBLE PRECISION YU
C
      IF(LL.NE.1) GO TO 1
      BET(1) = 0.5
      BET(2) = 0.5
      BET(3) = 1.0
      N2 = NY + 2
```

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```

      NJ = NY + 1
      XV = Y(NJ)
      CALL DIFFEQ
1    DO 2 I=1,NY
2    YU(I) = Y(I)
      DO 6 K=1,4
      IF(K.EQ.1) GO TO 2
      CALL DIFFEQ
3    DO 4 I=1,NY
      IJ = I + N2
4    DY(K,I) = Y(N2)*Y(IJ)
      IF(K.EQ.4) GO TO 6
      DO 5 I=1,NY
5    Y(J) = YU(I) + RET(K)*DY(K,I)
      Y(NJ) = XV + RET(K)*Y(N2)
6    CONTINUE
      DO 7 I=1,NY
      DEL = (DY(1,I)+2.*DY(2,I)+2.*DY(3,I)+DY(4,I))/6.
      YU(I) = YU(I) + DEL
      Y(I) = YU(I)
7    CONTINUE
      Y(N1) = XV + Y(N2)
      CALL DIFFEQ
      XV = Y(N1)
      RETURN
      END
      SUBROUTINE PRTTBL(MAXLIN,IV)

```

C
C
C

THIS ROUTINE PRINTS THE SPECIFIED TABLES.

```

COMMON/DD/ITY,ITX,IGY,IGX,NG,SB(12),FL,PR,IRUN,JPAGE,IX,IY,NCUT
COMMON/EE/XG(8,2),YC(8,2),MSS,NGY(8),NCX(8),NTY(2),NTX(2)
COMMON/FF/IADJ,MX,MY,JX(P),JY(P),XS(901,P),YS(901,P)
COMMON/HH/PTIME,ETDME,DELT,IT1(10),IT2(10),MT(2),MN(2),JD(2),MS(2)
COMMON ARY(901,P),NPRT(8)

```

C
C

```

100  FORMAT(1H1,6X,47HHYDRAULIC SPEED CONTROL 200 TON HPM RAM CLOSING,
      113H ** RUN DATE ,3A8,2X,PHRUN NO. ,I2,2X,CHPAGE NO. ,I2/)
101  FORMAT(8(7X,A1,A1,I2,A1,2X))
102  FORMAT(8(2X,F12.4))
103  FORMAT(1X,120(1H*)/)

```

C
C

```

      IF(IV.EQ.0)GO TO 3
      IB = IX
      NCOL = ITX
      DO 1 I=1,MAXLIN
      DO 1 J=1,NCOL
1    ARY(I,J) = XS(I,J)
      DO 2 I=1,NCOL
2    NPRT(I) = NTX(I)
      GO TO 6
3    IB = IY
      NCOL = ITY

```

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```
DO 4 I=1,MAXLIN
DO 4 J=1,NCOL
4 ARY(I,J) = YS(I,J)
DO 5 I=1,NCCL
5 NPRT(I) = NTY(I)
```

C
C
C

STORE X OR Y DATA IN ARY MATRIX ABOVE.

```
6 LINE = 1
WRITE(2,100) (JD(I),I=1,3),IRUN,IPAGE
WRITE(2,103)
WRITE(2,101) (IB,PL,NPRT(I),PR,I=1,NCCL)
DO 7 KH=1,MAXLIN
WRITE(2,102) (ARY(KH,I),I=1,NCOL)
LINE = LINE + 1
IF(LINE.LT.55) GO TO 7
LINE = 1
IPAGE = IPAGE + 1
WRITE(2,103)
WRITE(2,100) (JD(I),I=1,3),IRUN,IPAGE
WRITE(2,103)
WRITE(2,101) (IB,PL,NPRT(I),PR,I=1,NCCL)
7 CONTINUE
```

C
C
C

ABOVE PRINTS THE DATA IN MATRIX ARY IN TABULAR FORM.

```
WRITE(2,103)
RETURN
END
SUBROUTINE PLOT(SAVE,NSS,CR)
```

C
C
C

THIS ROUTINE PLOTS THE DATA STORED IN THE SAVE MATRIX.

```
REAL LINE(101),DEL(8)
DIMENSION SAVE(901,8),IN(8)
DIMENSION CR(8,2),STEPS(10),NL(8)
```

C
C

```
COMMON/DD/ITY,ITX,ICY,ICX,NC,SB(12),PL,PR,IRUN,IPAGE,IX,IY,NCUT
COMMON/EE/XG(8,2),YG(8,2),MSS,NGY(8),NGX(8),NTY(8),NTX(8)
COMMON/FF/IADJ,MX,MY,JX(8),JY(8),XS(901,8),YS(901,8)
COMMON/HH/PTIME,ETIME,FELT,IT1(10),IT2(10),MT(3),MN(3),JD(3),MS(3)
```

C
C

DATA PLUS,PLANK/1H+,1H /

C
C

```
100 FORMAT(1H),6X,47HHYDRAULIC SPEED CONTROL 300 TON HPM RAM CLOSING,
113H ** RUN DATE ,3A8,2X,8HRUN NO. ,I2,2X,9HPAGE NO. ,I3/)
101 FORMAT(1H+,50X,9HSYMBOL = ,A1,26H, FOR COINCIDENT POINTS)
102 FORMAT(1H )
103 FORMAT(1H ,20X,A1,A1,I2,A1,2H =,F11.2,12X,9HSYMBOL = ,A1,1H,,4X,
*15HSCALE FACTOR = ,F11.3,12X,A1,A1,I2,A1,2H =,F11.2)
104 FORMAT(1H ,12X,15HTIME IN SECONDS)
105 FORMAT(////31X,20H** OUTPUT WARNING **,I5,2X,17HPOINTS WERE NOT W,
*22HITHIN THE GRAPH RANGE.)
```


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106 FORMAT(1H ,20X,101A1)
107 FORMAT(1H+,7X,F11.4)

C
C
C
C
C

IN(1) IS RESERVED FOR TIME.

IPAGE = IPAGE + 1
WRITE(2,100) (JD(I), I=1,3), IRUN, IPAGE
WRITE(2,102)

C

MSS = NSF
NN = 2
IF(MSS.EQ.1) GO TO 2
DO 1 I=1,IGX
DO 1 J=1,MX
IF(NGX(I).EQ.JX(J)) IN(I) = J
1 CONTINUE
GO TO 4
2 DO 3 I=1,IGY
DO 3 J=1,MY
IF(NGY(I).EQ.JY(J)) IN(I) = J
3 CONTINUE

C

4 CALL SCALE(NN,GR,IN)

C

DO 6 I=2,NC
IF(GR(IN(I),1).NE.0.0.CR.CR(IN(I),2).NE.0.)GO TO 5
GR(IN(I),1) = -0.1
GR(IN(I),2) = 0.1
GO TO 6
5 IF(GR(IN(I),1).NE.GR(IN(I),2)) GO TO 6
GR(IN(I),1) = GR(IN(I),1) - (0.1*FLOAT(I)*ABS(GR(IN(I),1)))
GR(IN(I),2) = GR(IN(I),2) + (0.1*ABS(GR(IN(I),2)))
6 DEL(I) = (GR(IN(I),2) - GR(IN(I),1))/10.
IF(MSS.EQ.1) GO TO 7
WRITE(2,103) (IX,PL,NGX(I),PR,GR(IN(I),1),SE(I),FEL(I),IX,PL,NGX(I)
*,PR,GR(IN(I),2),I=2,NC)
GO TO 8
7 WRITE(2,103) (IY,PL,NGY(I),PR,GR(IN(I),1),SE(I),FEL(I),IY,PL,NGY(I)
*,PR,GR(IN(I),2),I=2,NC)
8 WRITE(2,104)
IF((NG-1).EQ.1) GO TO 9
WRITE(2,101) SB(9)
9 DO 10 I=2,NC
10 GR(IN(I),2) = 100./(GR(IN(I),2) - GR(IN(I),1))

C
C
C
C
C

ABOVE SETS AND WRITES OUT PLOT INFO AND CONSTANTS.

BELOW PLOT THE DATA IN SAVE MATRIX.

NPR=0
NO = 0
DO 20 K=1,NOUT
NPR = NPR + 1

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```

      IF(K.NE.1.AND.Y.NE.NOUT) GO TO 11
      NPR = 5
11  IF(NPR.NE.5) GO TO 13
      DO 12 I=1,101
12  LINE(I) = PLUS
      GO TO 16
13  DO 14 I=2,100
14  LINE(I) = BLANK
      DO 15 I=1,101,10
15  LINE(I) = PLUS
16  DO 19 I=2,NC
      N = IFIX((SAVE(K,IN(I))-GR(IN(I),1))*GR(IN(I),2)+1.5)
      IF(N.CE.1.AND.N.LE.101) GO TO 17
      NO = NC + 1
      GO TO 19
17  IF(LINE(N).EQ.BLANK.CR.LINE(N).FQ.PLUS) GO TO 18
      LINE(N) = SP(9)
      GO TO 19
18  LINE(N) = SB(J)
19  CONTINUE
      WRITE(2,106) LINE
      IF(NPR.NE.5) GO TO 20
      WRITE(2,107) SAVE(K,IN(1))
      NPR = 0
20  CONTINUE
      IF(NO.NE.0) WRITE(2,105) NO
21  RETURN
      END
      SUBROUTINE SCALE(JJ,CR,JG)

```

```

C
C   THIS ROUTINE SCALES THE DATA FOR PLOT LIMITS.
C
COMMON/DD/ITY,ITX,ICY,ICX,NG,SB(12),PL,PR,IRUN,IPACE,IX,IY,NOUT
COMMON/GC/ND(20),NPT,NSP,NTM,PTIME,ISW
C
C   DIMENSION GR(8,2),STEPS(10),JG(8)
C   DIMENSION SGR(8,2)
C
C   DATA STEPS/1.,2.,3.,4.,5.,6.,7.,8.,9.,10./
C
100 FORMAT(2F10.0)
C
      IF(ND(9).EQ.4) GO TO 15
      IF(ND(9).EQ.0) GO TO 7
      IF(ND(9).EQ.2) GO TO 3
      IF(ND(9).EQ.3) GO TO 1
      READ(1,100)YMIN,YMAX
      GO TO 5
1  DO 2 I=2,NG
      READ(1,100)YMIN,YMAX
      SGR(JG(I),1) = YMIN
      SGR(JG(I),2) = YMAX
      GR(JG(I),1) = YMIN
2  GR(JG(I),2) = YMAX
      RETURN

```

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C

```
3 YMIN = GR(JG(2),1)
   YMAX = GR(JG(2),2)
   IF((NC-1).EQ.1) GO TO 7
```

C

```
DO 4 I=JJ,NC
  IF(YMIN.GE.GR(JG(I),1)) YMIN = GR(JG(I),1)
  IF(YMAX.LE.GR(JG(I),2)) YMAX = GR(JG(I),2)
4 CONTINUE
5 DO 6 I=JJ,NC
  SGR(JG(I),1) = YMIN
  SGR(JG(I),2) = YMAX
  GR(JG(I),1) = YMIN
6 CR(JG(I),2) = YMAX
```

C

```
IF(ND(9).EQ.1.OR.ND(9).EQ.2) RETURN
```

C

```
7 DO 14 K=JJ,NC
  YMIN = GR(JG(K),1)
  YMAX = GR(JG(K),2)
  DY = (YMAX - YMIN)/10.
  IF(DY.LE.0.0) GO TO 14
  TA = ALOC10(DY)
  IR = TA
  IF(TA.LT.0.0) IR = TA - 1.
  DY = DY*10.**(-IR) - 0.005
  DO 8 J=1,10
    IF(STEPS(J).LT.DY) GO TO 8
  I=J
  GO TO 9
8 CONTINUE
  I=10
9 CONTINUE
  IF(I.LE.10) GO TO 10
  I=I-10
  IR=IR+1
10 CONTINUE
  COR = STEPS(I)*10.**IR
  IF(I.EQ.10) IR=IR+1
  IF(YMIN.GE.0.0) GO TO 11
  MIN = YMIN/COR - .995
  GO TO 12
11 CONTINUE
  MIN = YMIN/COR + .005
12 CONTINUE
  TA = MIN*COR
  TB = TA + 10.*COR
  IF(TB.GE.YMAX) GO TO 13
  I=I+1
  GO TO 9
13 GR(JG(K),1) = TA
   GR(JG(K),2) = TB
   SGR(JG(K),1) = TA
   SGR(JG(K),2) = TB
14 CONTINUE
```

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```
      RETURN
15 DO 16 I=JJ,NC
    GR(JG(I),1) = SCR(JG(I),1)
16 GR(JG(I),2) = SCR(JG(I),2)
    RETURN
  END
  SUPRCUTINE PARADJ
```

C COMMON/AA/X(50),P(40),Y(22),YT(22),F(10),C(9),NY,NX,ND,MESP

C DIMENSION NPA(20)

C 1 FORMAT(20(I2,1X))
 2 FORMAT(I2)
 3 FORMAT(8F10.0)

C READ(1,2)JP
 READ(1,1)(NPA(J),J=1,JP)

C READ(1,3)(P(NPA(J)),J=1,JP)

C RETURN
 END
 BLOCK DATA

C COMMON/DE/ITY,ITX,ICY,ICX,NC,SB(12),PL,PR,IRUN,IFACE,JY,IY,NOUT

C DATA SB/1HC,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H*,1H8,1H+,1H./
 DATA PL,PR,IX,IY/1H(,1H),1HX,1HY/

C END

BDX-613-2483

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