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ANALYSIS OF CHECK VALVE DISC MOTION DURING A FLOW TRANSIENT

G. M. Fuls

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CONTENTS

This report contains an analysis of the dynamics of a check valve disc under the influence of a flow transient. The developed equations have been programed for the Philco-2000 digital computer in FORTRAN as the SLAM Code. The Code input consists of the characteristics of the valve and the flow transient. The output of the code includes the dynamics of the valve disc as a function of time and the pressure surge induced by valve closure.

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I. INTRODUCTION

The components of the main coolant system of a multiple loop pressurized water reactor plant are subjected to cyclic stresses when a check valve slams shut and produces a water hammer pressure surge. Fatigue failure under these conditions can be avoided by design, provided that the magnitudes of the stresses are known. Valve part stresses resulting from impact loads must also be known for proper design of the valve. These stresses can be calculated from the valve component velocities resulting from a flow transient on either closing or opening the valve.

This study predicts the impact velocities of the disc and the pressure surge resulting from extinguishing a fluid velocity. The numerical computations necessary for an iterative solution of the second order, nonlinear differential equation are performed by the SLAM Code (Bettis Code MO188),* utilizing the flow transient and the valve parameters which can be determined from the design of the valves.

II. ANALYSIS

A. Method

This analysis develops the equations of motion of a simple swing disc check valve from Newton's Second Law. After this development is complete, the modifications of the analysis necessary for application to other types of valves are described.

The basic assumptions necessary are as follows.

1. All valve springs are massless and linear.
2. The drag coefficient of the valve disc for a given orientation with respect to flow is independent of whether the flow is forward or reverse.

*The SLAM Code is an extension of a valve analysis originally performed at Knolls Atomic Power Laboratory.

3. The added inertia of the disc resulting from the fact that the disc is in water is independent of whether the flow is forward or reverse.
4. Friction other than that resulting from viscous effects of the fluid is negligible.

For a rotating mass, Newton's Second Law takes the form

$$J \ddot{\theta} = T \quad , \qquad (1)$$

where J is the disc moment of inertia, $\ddot{\theta}$ is the disc angular acceleration, and T is the torque.

The torques acting on the disc during a transient are those caused by spring displacement, drag on the disc as a result of a relative velocity between the disc and the fluid, and the buoyant weight of the disc. The spring torque is the product of the spring constant and the angular displacement of the spring. Thus,

$$T_s = k_s (\theta_I - \theta) \quad ,$$

where T_s is the spring torque, k_s is the spring constant, θ is the angular displacement of the disc, and θ_I is the initial angular spring displacement. The valve parameters for a simple swing disc check valve are shown in Figure 1.

The disc weight torque is equal to the product of the buoyant weight of the disc, the distance from the pivot point to the center of gravity of the disc, and the sine of the angle this line makes with the vertical. Thus,

$$T_W = -W_b \bar{r} \sin \theta \quad ,$$

where T_W is the disc weight torque, W_b is the buoyant weight of the disc, $\bar{r}$ is the radial distance from the center of gravity to the pivot point, and θ is the angular displacement of the disc from the vertical line down from the pivot point and is positive in the opening direction of the disc.

The drag of the disc is equal to the product of the drag coefficient and the square of the velocity of the disc relative to the fluid. Thus,

$$D = (K/2g) (V_R)^2 \quad ,$$

where D is the drag, K is the drag coefficient, g is the gravitational constant, and V_R is the relative velocity which is positive in the opening direction of the valve.

If the thickness of the disc is small in comparison with its face area, the disc may be treated as a surface; the magnitude of the absolute velocity of this surface is equal to the product of the angular velocity of the disc and the radial distance from the pivot point about which it rotates to the center of area of the disc surface. Thus,

$$V_D = r_p \dot{\theta}/12 \quad , \qquad (2)$$

where V_D is the magnitude of the vector velocity of the disc, r_p is the radial distance from the pivot point to the center of the disc face area, and $\dot{\theta}$ is the angular velocity of the disc.

Thus, the velocity vector of the disc relative to the fluid is

$$\vec{V}_R = \vec{V}_F - \vec{V}_D \quad ,$$

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where V_D is the magnitude of the vector velocity of the disc, r_p is the radial distance from the pivot point to the center of the disc face area, and $\dot{\theta}$ is the angular velocity of the disc.

Thus, the velocity vector of the disc relative to the fluid is

$$\vec{V}_R = \vec{V}_F - \vec{V}_D \quad ,$$

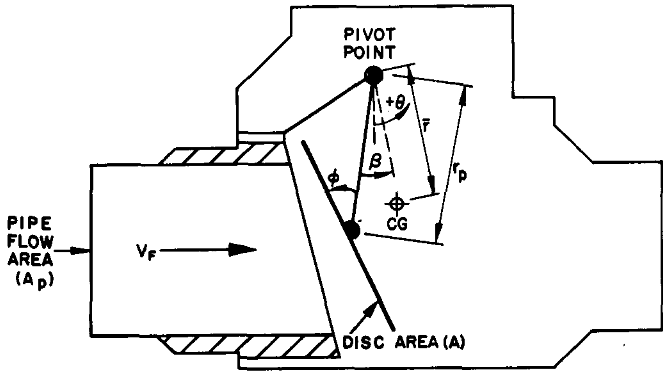

Figure 1. Simple Swing Disc Check Valve.

where $\vec{V}_F$ is the velocity vector of the fluid and $\vec{V}_R$ is the relative velocity vector.

It is assumed that the path of the center of disc area lies in a plane and that the axis of the check valve also lies in the same plane. A set of coordinates is chosen such that the X-axis is coincidental with the axis of the check valve, and such that the Y-axis (positive in the direction of the disc pivot point) lies in the plane of the path of the center of the disc (Figure 2). Then, the relative velocity may be written

$$\vec{V}_R = \left(\left|V_F\right|\vec{i} + 0\vec{j}\right) - \left(\left|\vec{V}_D\right| \text{Cos } \eta\vec{i} + \left|\vec{V}_D\right| \text{Sin } \eta\vec{j}\right) \quad , \tag{3}$$

where $\vec{i}$ is the unit vector along the X-axis, $\vec{j}$ is the unit vector along the Y-axis, V_F is the fluid velocity, and η is the angle between the disc velocity vector and the X-axis. Since the fluid velocity is parallel to the X-axis, the vertical component of the fluid velocity is zero.

Rewriting Equation (3) and substituting from Equation (2),

$$\vec{V}_R = \left(V_F - \frac{r_p\dot{\theta}}{12} \text{Cos } \eta\right)\vec{i} - \left(\frac{r_p\dot{\theta}}{12} \text{Sin } \eta\right)\vec{j} \quad . \tag{4}$$

The angle the vector $\vec{V}_R$ makes with the X-axis is

$$\gamma = \text{Tan}^{-1}\left(\frac{-r_p\dot{\theta} \text{ Sin } \eta}{V_F - \frac{r_p\dot{\theta}}{12} \text{Cos } \eta}\right) \quad . \tag{5}$$

Defining ϕ as the angle measured from $\bar{r}$ to the disc face, positive in the same direction as θ, and β as the angle measured from r_p to $\bar{r}$, also positive in the same direction as θ, then the angle χ between the perpendicular to the disc face and the relative velocity vector is

$$\chi = \phi + \theta - \gamma \quad ; \tag{6}$$

and

$$\eta = \theta - \beta \quad . \tag{7}$$

It is assumed that the velocity of the disc relative to the fluid results in a single force which is perpendicular to the disc face and proportional to the square of the magnitude of the relative velocity. With this assumption

$$D_F = \frac{K\rho A}{144\,(2g)}\left(\left|V_R\right|\right)^2$$

where D_F is the net drag force on the disc, ρ is the density of the fluid, $V_R = \left|\vec{V}_R\right|$, g is the gravitational constant, and A is the area of the disc face. The moment or torque exerted by this force is equal to the

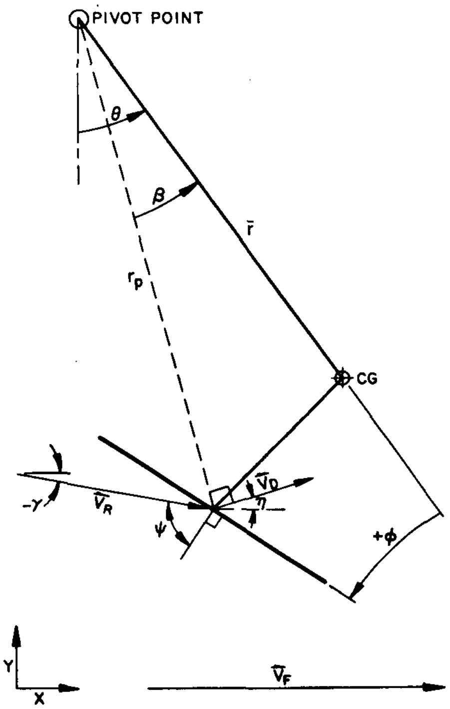

Figure 2. Force Diagram.

product of the net force, the radius arm, and the cosine of the angle $\phi + \beta$, or

$$T_D = D_F \, r_p \, \text{Cos}\,(\phi + \beta) \quad ,$$

where T_D is the torque on the disc due to the viscosity of the fluid.

Substituting,

$$T_D = \frac{K\rho A}{144\,(2g)} \left(\left| \bar{V}_R \right| \right)^2 r_p \, \text{Cos}\,(\phi + \beta) \quad ;$$

and substituting again from Equations (4) and (7),

$$T_D = \frac{K\rho A}{144\,(2g)} \left\{ \left[V_F - \frac{r_p \dot{\theta}}{12} \, \text{Cos}\,(\theta - \beta) \right]^2 + \left[\frac{r_p \dot{\theta}}{12} \, \text{Sin}\,(\theta - \beta) \right]^2 \right\} r_p \, \text{Cos}\,(\phi + \beta) \quad . \qquad (8)$$

Equation (8) represents the drag torque on the disc. The drag coefficient is determined by the angle χ between the vertical to the disc face and the relative velocity. This angle is given by a combination of Equations (5), (6), and (7). Thus,

$$\chi = \phi + \theta - \text{Tan}^{-1} \left[\frac{-12\, r_p \dot{\theta} \, \text{Sin}\,(\theta - \beta)}{12\, V_F - r_p \dot{\theta} \, \text{Cos}\,(\theta - \beta)} \right] \qquad (9)$$

In order to accurately account for the sign of the drag torque, Equation (8) must be multiplied by the fluid velocity divided by the absolute value of the fluid velocity, or $V_F / \left| V_F \right|$.

The disc moment of inertia J in Equation (1) consists essentially of two parts: the moment of inertia of the disc due to its own mass and the added inertia due to immersion of the disc in a fluid. Thus,

$$J = J_D + J_A \quad ,$$

where J_D is the moment of inertia of the disc, and J_A is the added moment of inertia of the disc. Then, from Equation (1)

$$J \ddot{\theta} = (J_D + J_A)\, \ddot{\theta} = \sum T$$

$$= T_s + T_w + T_D \quad ,$$

or

$$\ddot{\theta} = \left\{ -W_b \bar{r} \sin\theta + \frac{V_F}{|V_F|} \frac{K\rho A}{144\,(2g)} \left\{ \left[V_F - \frac{r_p \dot{\theta}}{12} \cos(\theta - \beta) \right]^2 + \left[\frac{r_p \dot{\theta}}{12} \sin(\theta - \beta) \right]^2 \right\} r_p \cos(\phi + \beta) - k_s (\theta - \theta_I) \right\} \Big/ (J_D + J_A) \; . \tag{10}$$

All of the above variables necessary for the solution of the equation (except velocity as a function of time, and the drag coefficient and added inertia as functions of disc position) are easily determinable from the design drawings of the valve.

Statistical studies have shown that the mass of the disc has only a minor effect on the dynamics of the check valve in comparison with the importance of other parameters such as the flow transient and radial distances to the center of area and center of mass. Therefore, since the added moment of inertia of the disc due to its presence in a fluid is a result of an apparent increase in mass or "virtual mass," a large error in predicting or measuring the added moment of inertia of the disc has only a very small effect; for many valves this effect may be assumed to be negligible.

There are numerous methods available for predicting the flow transient; it is assumed the programer will have one of these methods already chosen.

The drag coefficient may be determined from simple steady-state tests on the check valve and use of Equation (10) with the velocity and acceleration of the disc equal to zero. However, since it is often not feasible to perform these tests, some estimate of the drag coefficient must be made. Again, statistical studies have shown that fairly large errors in the drag coefficient have minor effects on the pressure surge from the check valve slam, although disc position as a function of time may vary widely. The values for the drag coefficient as a function of the relative disc face angle given for Card 11 of Section IV, Program (Code) Input, are average values for numerous valves. Deviations of the drag coefficient by plus or minus half a decade for a given face angle have a negligible effect on the final results of the program.

For an iterative solution of the differential equation (Equation 10), two additional equations for $\dot{\theta}$ and θ are required. These are

$$\theta_{t+dt} = \frac{(dt)^2}{6} (\ddot{\theta}_{t+dt} + 2\,\ddot{\theta}_t) + dt\,\dot{\theta}_t + \theta_t \tag{11}$$

and

$$\dot{\theta}_{t+dt} = \frac{dt}{2} (\ddot{\theta}_{t+dt} + \ddot{\theta}_t) + \dot{\theta}_t \;, \tag{12}$$

where dt is the finite difference increment, the subscript, t is the beginning of the finite difference increment, and t+dt is the end of the finite difference increment.

In finite difference form the acceleration equation is

$$\ddot{\theta}_{t+dt} = \left\{ - W_b \bar{r} \operatorname{Sin} \theta_{t+dt} + \left(\left[\left| V_F - \frac{\dot{\theta}_{t+dt} r_p}{12} \operatorname{Cos} (\theta_{t+dt} - \beta) \right| \right]^2 + \left[\frac{r_p \dot{\theta}_{t+dt}}{12} \operatorname{Sin} (\theta_{t+dt} - \beta) \right]^2 \right) \frac{r_p KA}{9273.6} \operatorname{Cos} (\phi + \beta) \frac{V_F}{|V_F|} - k_s (\theta_{t+dt} - \theta_I) \right\} \Big/ (J_D + J_A) \ , \qquad (13)$$

with both J_A and K evaluated at θ_t.

B. Articulated and Linear Type Valves

For an articulated or doubly pivoted check valve (Figures 3A and 3B), these equations are also valid provided that the assumption is made that the disc pivots about only one pivot at a time. In other words, the disc rotates about a given pivot from the fully open position to an intermediate position between the fully open position and the seated position. At this point the disc ceases to rotate about the original pivot and rotates instead about a different pivot until the disc is seated. Where the pivot point changes the angle measured from the vertical line down from the pivot point to the line connecting the pivot point and the center of gravity of the disc is called the angle of articulation. Thus, with proper values assigned to the parameters the above equations are valid for each range of rotation.

For a check valve with a linear motion disc the equations require modification and redefinition of the parameters. Thus,

θ = Linear displacement of the disc from the seat (inches)

$\dot{\theta}$ = Linear velocity of the disc (in./sec)

$\ddot{\theta}$ = Linear acceleration of the disc (in./sec^2)

θ_I = Initial linear spring displacement (inches)

k_s = Linear spring constant (lb/in.)

W_b = Bouyant weight component parallel to the axis of motion (pounds)

J_D = Mass of the disc (lb sec^2/in.)

J_A = Added mass of the disc due to its immersion in fluid (lb sec^2/in.)

Then,

$$\ddot{\theta}_{t+dt} = \frac{- W_b + \left| V - \frac{\dot{\theta}_{t+dt}}{12} \right| \left(V - \frac{\dot{\theta}_{t+dt}}{12} \right) \frac{K \rho A}{9273.6} - k_s (\theta_{t+dt} - \theta_I)}{J_D + J_A} \ . \qquad (14)$$

C. Method of Solution by the SLAM Code

These equations are solved by the SLAM Code (MO188) written in FORTRAN for the Philco-2000 computer. The method of solution is to assume that the values of displacement, velocity, and acceleration at the end of the time increment are the same as at the beginning. The displacement at the end of the time

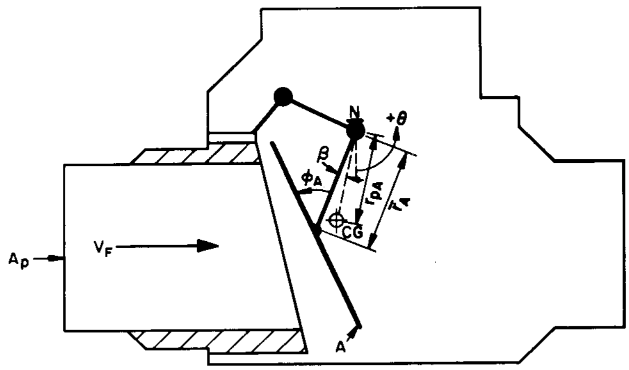

Figure 3A. Articulated Check Valve Showing Disc Rotating about Pivot Point N.

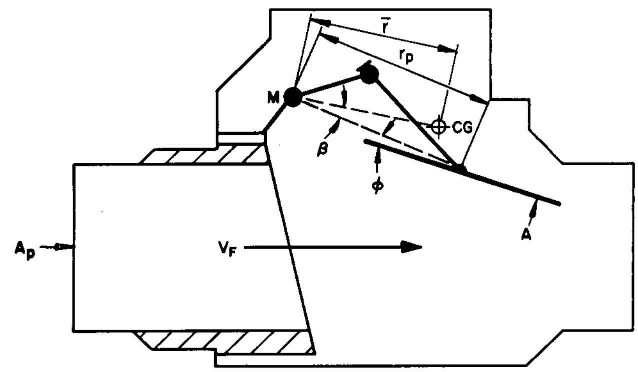

Figure 3B. Articulated Check Valve Showing Disc Rotating about Pivot Point M after Articulation.

increment is determined from Equation (11). The velocity at the end of the time increment is determined from the new displacement and Equation (12). With this velocity and displacement the acceleration is determined at the end of the time step from Equation (13). The next time step is undertaken if the assumed and calculated accelerations are within a specified convergence criterion. If the accelerations are not within the specified convergence criterion, the velocity, acceleration, and displacement at the end of the time step are assumed equal to the values calculated and the calculation for the time step is repeated.

Appropriate tests for changing pivots, reaching the fully open or fully closed position, and reaching the time limit are performed after each time step.

At the completion of a closing transient the pressure surge is determined based on the assumption that the velocity goes instantaneously to zero at valve closure. The pressure surge is also calculated by the swept-out volume theorem for comparison. (This calculation requires the cross-sectional flow area of the pipe, Ap.)

III. PROGRAM LIMITATIONS

The limitations of the computer program are as follows:

1. The program will not predict repetitive check valve slam.
2. The program cannot accommodate a fluid velocity transient that passes through a maximum or minimum, but it can accommodate one that approaches or attains a steady-state condition.
3. The program can accept only steady-state initial conditions as input data.

IV. PROGRAM (CODE) INPUT

The SLAM Code is designed to run successive problems, retaining in memory all input data from the previous problem and changing only those parameters for which input cards are supplied in the succeeding problem. Each input card is numbered to identify the input information; thus, the sequence of input cards may be in any order with the following three specific exceptions:

1. Cards 1, 2, and 3 must always be in sequence and should be treated as a single card since their position in the problem deck does not matter, provided that the other specific exceptions are observed. If one of these three cards is present, all three must be present.
2. Card 23 must be the last card of that group of cards corresponding to a particular problem.

3. Card 24 must be the last card of the input deck. In a sequence of problems only one 24 card will be present, and it must be the last card of the input deck.

NOTE: This does not eliminate the need for a blank card after each input deck required by some computer installations. This blank card is not considered part of the input deck.

The information on the various cards is shown symbolically in Figure 4 and is described below with an explanation of the symbols in parentheses.

Card 1 a. Column 10: Punch a 1.

Card 2 a. Column 10: Punch a 2.

b. Columns 11 to 70 inclusive: This space is available for any information the programer desires to place there. The limitation is that only those characters available on the key punch may be used. This information is reproduced at the top of each page of the problem output.

Card 3 a. Column 10: Punch a 3.

b. Columns 11 to 70 inclusive: Same as Card 2.

GENERAL NOTE: The information in the following cards in columns 11 to 70 must contain a decimal in each 10-column spacing, but the information may be placed anywhere within the 10 columns.

Card 4 a. Column 10: Punch a 4.

b. Columns 11 to 20 inclusive: A blank or zero provides the standard output format with the output printed after each time step. The number 1. provides the output after each ten time steps and after the final time step. The number 2. provides only the final conditions.

c. Columns 21 to 30 inclusive: A blank or zero provides an input edit. The number 1. eliminates the input edit.

d. Columns 31 to 40 inclusive: A blank or zero is used for a simple or singly-pivoted swing-type check valve. The number 1. is used for an articulated or doubly pivoted check valve. The number 2. is used for a check valve with a linear motion disc.

e. Columns 41 to 50 inclusive: A blank or zero indicates a closing transient. The number 1. indicates an opening transient from the closed position. The number 2. indicates an opening transient from an intermediate position.

NOTE: If all options chosen are zero, this card may be eliminated.

Card 5 a. Column 10: Punch a 5.

b. Columns 11 to 20: Fluid density (RHO) (lb/ft^3)

c. Columns 21 to 30: Initial fluid velocity (VIN) (ft/sec)

d. Columns 31 to 40: Speed of sound in fluid (CSOUND) (ft/sec)

e. Columns 41 to 50: Fluid velocity which would occur in the loop provided the check valve is not present; corresponds to the differential pressure necessary to hold the check valve closed and is required only for the opening transient (VMIN) (ft/sec)

TITLE MEMORY AID   ANALYST ______   DATE __-__-19__   SHEET __ OF __   IDENTIFICATION

FORTRAN INPUT FORM

	11–20	21–30	31–40	41–50	51–60	61–70
1						
2	ANYTHING MAY BE WRITTEN IN COLUMNS 11 TO 70 INCLUSIVE					
3	ON CARDS 2 AND 3					
4	SHORT OUT NO INPUT ARTICU/LIN OPENING					
5	RHO (#/ft^3)	VIN (ft/sec)	CSOUND (ft/sec)	VMIN (ft/sec)	AREAP (in^2)	BETA (deg)
6	AODI (deg)	AODF (deg)	PHI (deg)	DVΦL (in^3)	W (#)	RHΦM (#/ft^3)
7	RBAR (in)	RPC (in)	SPRINK (in#/deg)	THETAI (deg)	DISCJ (in#/sec^2)	AREA (in^2)
8	THET (1) (deg)	Increasing				
9						THET (12)
10	DRAG (1)					
11						DRAG (12)
12	ADDJ (1) (in#sec^2)					
13						ADDJ (12)
14	ANG (1) (deg)	Increasing				
15						ANG (12)
16	EPSILO (sec^{-2})	TIMES (sec)	DT (sec)			
17	V (1) (ft/sec)					
18						V (12)
19	TV (1) (sec)					
20						TV (12)
21	AAS (deg)	PHIA (deg)	RBARA (in)	RPCA (in)	SPRNKA (in#/deg)	THETAA (deg)
22	DISCJA (in#	BETAA (deg)				
23	sec^2)					
24						

Figure 4. Memory Aid for Input.

f. Columns 51 to 60 inclusive: Flow area of pipe (AREAP) (in.^{2})

g. Columns 61 to 70 inclusive: Singly Pivoted Valve - Angle between the line from the pivot point to the center of the disc face area and the line from the pivot point to the center of gravity. Angle is positive in the disc opening direction (BETA). (degrees)

Articulated Valve - Angle is the same as for the singly pivoted valve but is in the range from articulation to the fully open disc position (BETA). (degrees)

Card 6 a. Column 10: Punch a 6.

b. Columns 11 to 20 inclusive:

Pivoted Valve - Angle between the vertical line down from the pivot point and the line from the pivot point to the center of gravity when the disc is in the fully open position. Angle is positive in the opening direction. (AODI - A stands for Angle, OD stands for the zeroth derivative, and I stands for the initial position of the closing transient.) (degrees)

Linear Motion Valve - Distance from the seated to the fully open disc position (AODI is still used). (inches)

c. Columns 21 to 30 inclusive:

Pivoted Valve - Angle between the vertical line down from the pivot point and the line from the pivot point to the center of gravity with the disc in the fully closed position. Angle is positive in the disc opening direction (AODF - F for final position). (degrees)

Linear Motion Valve - blank

d. Columns 31 to 40 inclusive:

Singly Pivoted Valve - Angle between the line from the pivot point to the center of gravity and the line through the plane of the disc face. Angle is positive in the same direction of rotation (clockwise or counterclockwise) as in b and c above (PHI). (degrees)

Articulated Valve - Angle is the same as for the singly pivoted valve but is in the range from articulation to the fully open position (PHI). (degrees)

Linear Motion Valve - blank

e. Columns 41 to 50 inclusive: Volume of the disc (DVϕL) (in.^{3})

f. Columns 51 to 60 inclusive: Weight of the disc in air (W) (pounds)

g. Columns 61 to 70 inclusive: Density of the disc metal (RHϕM) (lb/ft^3)

NOTE: If e. and f. are both other than zero, g. is ignored whether it is other than zero or not. If either e. or f. is other than zero, g. is used if it is other than zero, and the density of steel is used if g. is zero.

Card 7 a. Column 10: Punch a 7.

b. Columns 11 to 20:

Singly Pivoted Valve - Radial distance from the pivot to the center of gravity (RBAR). (inches)

Articulated Valve - Radial distance from the pivot to the center of gravity in the range from articulation to the fully open disc position (RBAR). (inches)

Linear Motion Valve - blank.

c. Columns 21 to 30:

Singly Pivoted Valve - Radial distance from the pivot to the center of disc face area (RPC - Radius Pivot to the Center of area) (inches)

Articulated Valve - Radial distance from the pivot to the center of the face area in the range from articulation to the fully open disc position (RPC). (inches)

> NOTE: *This information is required only if it is different from the information in b above.*

d. Columns 31 to 40:

Singly Pivoted Valve - Spring constant (SPRINK). (in. lb/deg)

Articulated Valve - Spring constant for the range from articulation to the fully open position (SPRINK). (in. lb/deg)

Linear Motion Valve - Spring constant (SPRINK) (lb/in.)

e. Columns 41 to 50:

Singly Pivoted Valve - Preload spring displacement when the disc is on its seat (THETAI). (degrees)

Articulated Valve - Preload spring displacement at the point of articulation for the range from articulation to the fully open position (THETAI). (degrees)

Linear Motion Valve - Preload spring displacement (THETAI). (inches)

f. Columns 51 to 60:

Singly Pivoted Valve - Moment of inertia of the disc (DISCJ). (in. lb sec^2)

Articulated Valve - Moment of inertia of the disc from articulation to the fully open position. (in. lb sec^2)

Linear Motion Valve - Mass of the disc. (lb sec^2/in.)

g. Columns 61 to 70 inclusive: Disc face area (AREA). ($in.^2$)

Card 8 a. Column 10: Punch an 8.

b. Columns 11 to 70 inclusive: Values of position (see Card 11).

Card 9 c. Column 10: Punch a 9.

d. Columns 11 to 70 inclusive: Values of position (see Card 11).

Card 10 a. Columns 9 and 10: Punch a 10.

b. Columns 11 to 70 inclusive: Values of the drag coefficient (see Card 11).

Card 11 c. Columns 9 and 10: Punch an 11.

d. Columns 11 to 17 inclusive: Values of the drag coefficient.

Cards 8, 9, 10, and 11 provide space for table input of the drag coefficient as a function of position. Using a plot of the log of the drag coefficient versus position, there is sufficient space to represent this plot by up to eleven straight line segments. The disc positions (angle the disc face makes with the vertical, $\theta + \phi$, in degrees for pivoted motion valves and in inches for linear motion valves) corresponding to the points chosen are listed in decimal form in increasing value in succeeding ten-column spacings (without skipping any 10-column spacing), beginning with Column 11 on Card 8 and continuing to Column 70, then to Column 11 on Card 9 and continuing to Column 70. If no data other than the 9 punch in Column 10 of Card 9 are contained on Card 9, this card may be eliminated. The dimensionless drag coefficients corresponding to the data points chosen are listed on Cards 10 and 11 in the same position as on Cards 8 and 9. Again, Card 11 may be eliminated if it contains no information other than the 11 punch in Columns 9 and 10. For example, suppose the entire semilog plot may be represented between the points (K = 1500, $\theta = -30°$) and (K = 0.0096, $\theta = 85°$). This information may be supplied by -30. in Columns 11 to 20 of Card 8, 85. in Columns 21 to 30 of Card 8, 1500. in Columns 11 to 20 of Card 10, and 0.0096 in Columns 21 to 30 of Card 10, with Cards 9 and 11 eliminated. In the absence of more reliable data, these values may be used as an approximation of the drag coefficient for swing-type check valves. [THET(I), I = 1, 12 and DRAG(I), I = 1, 12]

Card 12	a.	Columns 9 and 10: Punch a 12.	
	b.	Columns 11 to 70: Values of added inertia (see Card 15).	
Card 13	a.	Columns 9 and 10: Punch a 13.	
	b.	Columns 11 to 70: Values of added inertia (see Card 15).	
Card 14	a.	Columns 9 and 10: Punch a 14.	
	b.	Columns 11 to 70: Values of position (see Card 15).	
Card 15	a.	Columns 9 and 10: Punch a 15.	
	b.	Columns 11 to 70: Values of position.	

Cards 12 to 15 inclusive contain the added moment of inertia (for pivoted valves) and added mass (for linear motion valves) of the disc resulting from its immersion in a fluid. The information is supplied in the same manner as the drag coefficient except that a linear plot is used rather than a semilog plot. The disc position in degrees for the pivoted valve and in inches for the linear motion valve is contained in increasing values on Cards 14 and 15, and the added inertia or mass is contained on Cards 12 and 13. If the added inertia or mass is independent of position, this constant may be contained in Columns 11 to 20 of Card 12 and Cards 13, 14, and 15 are eliminated. [ADDJ(I), I = 1, 12 and ANG(I) I = 1, 12]

Card 16	a.	Columns 9 and 10: Punch a 16.	
	b.	Columns 11 to 20 inclusive: θ convergence criterion on acceleration. The difference between the assumed acceleration and calculated acceleration must be less than or equal to this value (EPSILO).	(sec^{-2})
	c.	Columns 21 to 30 inclusive: Maximum running time of the problem (TIMES).	(seconds)
	d.	Columns 31 to 40 inclusive: Finite difference increment (DT).	(seconds)
Card 17	a.	Columns 9 and 10: Punch a 17.	
	b.	Columns 11 to 70: Values of velocity (see Card 20).	
Card 18	a.	Columns 9 and 10: Punch an 18.	
	b.	Columns 11 to 70: Values of velocity (see Card 20).	
Card 19	a.	Columns 9 and 10: Punch a 19.	
	b.	Columns 11 to 70: Values of time (see Card 20).	
Card 20	a.	Columns 9 and 10: Punch a 20.	
	b.	Columns 11 to 70: Values of time.	

Cards 17, 18, 19, and 20 are for the input of the flow transient as a function of time. This allows representation by up to eleven straight line segments of a linear plot of velocity versus time. The time in seconds is contained on Cards 19 and 20 in increasing values. The corresponding velocities in ft/sec are on Cards 17 and 18. This information must be supplied as on Cards 8 to 11 inclusive. [V(I), I = 1, 12 and TV(I), I = 1, 12]

Card 21 This card is required only for an articulated valve.

a. Columns 9 and 10: Punch a 21.

b. Columns 11 to 20 inclusive: Angle between the vertical line down from the pivot point and the line from the pivot point to the center of gravity when the pivot about which the disc rotates is in the range nearest the closed position (AAS - Angle at which Articulation Stops). (degrees)

c. Columns 21 to 30 inclusive: Angle between the line from the pivot point to the center of gravity of the disc and the line through the plane of the disc face. Angle is in the range from articulation to the fully seated position (PHIA: PHI Articulated). (degrees)

d. Columns 31 to 40 inclusive: Radial distance from the pivot point to the center of gravity between articulation and the fully seated position (RBARA - RBAR Articulated). (inches)

e. Columns 41 to 50 inclusive: Radial distance from the pivot point to the center of the disc face area when the disc is in the range between articulation and the fully seated position (RPCA). (inches)

NOTE: This information is required only if different from d above.

f. Columns 51 to 60 inclusive: Spring constant in the same range as above (SPRNKA). (in. lb/deg)

g. Columns 61 to 70 inclusive: Initial spring displacement in the same range as above (THETAA). (degrees)

Card 22 This card is required only for an articulated valve.

a. Columns 9 and 10: Punch a 22.

b. Columns 11 to 20 inclusive: Disc moment of inertia in the same range as for Card 21 (DISCJA). (in. lb sec^2)

c. Columns 21 to 30 inclusive: Angle between the line from the pivot point to the center of the disc face area and the line from the pivot point to the center of gravity. Angle is positive in the disc opening direction in the same range as for Card 21 (BETAA). (degrees)

Card 23 a. Columns 9 and 10: Punch a 23.

Card 24 a. Columns 9 and 10: Punch a 24.

The <u>minimum</u> cards required for the first problem in a sequence are as follows:

1. Single Pivot - Cards 5, 6, 7, 8, 10, 12, 16, 17, 19, and 23.
2. Articulated - Same as Single Pivot plus Cards 4, 21, and 22.
3. Linear - Cards 4, 5, 6, 7, 8, 10, 12, 16, 17, 19, and 23.

Additional cards may be required, and Cards 1, 2, and 3 should be included for problem identification.

The second problem in the sequence should contain at least one data card and a Card 23. However, Cards 1, 2, and 3 should be included with the problem identification for later convenience.

The last problem in the sequence must contain a 24 Card.

Columns 1 to 8 inclusive and Columns 71 to 80 inclusive on all cards may contain any information the programer may desire. These columns are ignored by the code and have no effect whatsoever.

V. TERMINOLOGY

Symbol	Definition	Dimension
A	Area of the disc face	inches^2
A_p	Area of the valve pipe	inches^2
β	Angle measured from r to $\bar{r}$, positive in the same direction as θ	degrees
χ	Angle between the relative velocity vector and the perpendicular to the disc face	degrees
D	Drag	feet
D_F	Net drag force on the disc	pounds
dt	Finite difference increment	seconds
η	Angle between the disc velocity vector and the X-axis	degrees
g	Gravitational constant	ft/sec^2
$\vec{i}$	Unit vector along the X-axis	1
$\vec{j}$	Unit vector along the Y-axis	1
J	Disc moment of inertia	in. lb sec^2
J_A	(1)* Added moment of inertia of the disc	in. lb sec^2
	(2)* Added mass of the disc	$\text{lb sec}^2\text{/in.}$
J_D	(1) Moment of inertia of the disc	in. lb sec^2
	(2) Mass of the disc	$\text{lb sec}^2\text{/in.}$
K	Drag coefficient	1
k_s	(1) Spring constant	in. lb/rad
	(2) Spring constant	lb/in.
ϕ	Angle measured from $\bar{r}$ to the disc face, positive in the same direction as θ	degrees
$\bar{r}$	Radial distance from the pivot point to the center of gravity	inches

*The (1) refers to the definition when applied to a swing disc check valve, and the (2) refers to the definition when applied to a linear motion disc check valve.

Symbol	Definition	Dimension
r_p	Radial distance from the pivot point to the center of disc face area	inches
ρ	Density of the fluid	lb/ft^3
T	Torque	in. lb
T_D	Torque on the disc due to the viscosity of the fluid	in. lb
T_s	Spring torque	in. lb
T_w	Weight torque	in. lb
θ	(1) Angular displacement of the disc from the vertical line down from the pivot point; angle is positive in the disc opening direction.	radians
	(2) Displacement of the disc from the fully closed position	inches
θ'	(1) Angular velocity of the disc	rad/sec
	(2) Linear velocity of the disc	in./sec
θ''	(1) Angular acceleration of the disc	rad/sec^2
	(2) Linear acceleration of the disc	$in./sec^2$
θ_I	(1) Initial angular spring displacement	degrees
	(2) Initial linear spring displacement	inches
$\vec{V}_D$	Vector velocity of the disc	ft/sec
$\vec{V}_F$	Vector velocity of the fluid	ft/sec
V_F	Magnitude of the fluid velocity = $\left\| \vec{V}_F \right\|$	ft/sec
$\vec{V}_R$	Vector velocity of the disc velocity vector relative to the fluid velocity vector	ft/sec
V_R	Magnitude of the disc velocity relative to the fluid velocity	ft/sec
W_b	(1) Buoyant weight of the disc	pounds
	(2) Buoyant weight component of the disc parallel to the axis of disc motion	pounds

Subscripts

t	Beginning of the time step	
t + dt	End of the time step	

```
D0188    $ ALTC2 FULSG    36901364DEBUG
         I        D188
                  ABSOLUTE$
                  IDENTIFYF
         IOUNITSFDTI,8T,12,10,22,BUFER1-DTO,10T,,,22,BUFER2,BUFER3$
      DIMENSION CARD(10),CARDO(10),ANG(12),DRAG (12),THET(12),VEL(12),TV
     1(12),STORE(12),ADDJ(12)
      GO TO 557
  102 STOP
    2 FORMAT (10X,10A6,2X)
    3 FORMAT (8X,I2,6F10.5)
    4 FORMAT (1H1,25X,52HSLAM  CODE M0188    CHECK VALVE SLAM PRESSURE S
     1URGE.,25X,6HPAGE   ,I3)
    5 FORMAT (1H0,10A6)
    6 FORMAT (95HD THERE IS AN INCORRECT INPUT CARD SEQUENCE.  THIS PROB
     1LEM DID NOT RUN.                                )
    7 FORMAT (8X,I2)
    8 FORMAT (1H0,5X,12HINPUT  EDIT.)
   10 FORMAT (36H0THE FOLLOWING PROBLEMS DID NOT RUN.)
   11 FORMAT (1H 10A6)
   12 FORMAT (43H0DENSITY OF FLUID             (LBS/FT CUBE)=F13.4,4X,42H
     1INITIAL FLUID VELOCITY           (FT/SEC)=F13.4)
   14 FORMAT (43H SPEED OF SOUND                     (FT/SEC)=F13.4,4X,42H
     1FULL OPEN ANGLE FROM VERTICAL       (DEG)=F13.4)
   15 FORMAT (43H FULL CLOSED ANGLE FROM VERTICAL      (DEG)=F13.4,4X,42H
     1DISC FACE ANGLE                     (DEG)=F13.4)
   16 FORMAT (43H FINITE DIFFERENCE INCREMENT          (SEC)=F13.4,4X,42H
     1PIPE AREA                         (IN SQ)=F13.4)
   17 FORMAT (43H PIVOT TO CG ARM                       (IN)=F13.4,4X,42H
     1PIVOT TO CENTER OF AREA              (IN)=F13.4)
   18 FORMAT (43H SPRING CONSTANT               (IN-LBS/DEG)=F13.4,4X,42H
     1INITIAL SPRING DISPLACEMENT         (DEG)=F13.4)
   19 FORMAT (43H DISC INERTIA                (IN-LB-SEC SQ)=F13.4,4X,42H
     1DISC FACE AREA                    (IN SQ)=F13.4)
   20 FORMAT (43H CONVERGENCE CRITERION             (/SEC SQ)=F13.4,4X,42H
     1MAXIMUM INTEGRATION TIME            (SEC)=F13.4)
   21 FORMAT (1H0,18X,4HDRAG,31X,13HADDED INERTIA,33X,5HWATER)
   22 FORMAT (1H ,14X,11HCOEFFICIENT,28X,12HDUE TO WATER,32X,8HVELOCITY)
   23 FORMAT (1H ,8X,5HANGLE,16X,5HVALUE,15X,5HANGLE,16X,5HVALUE,15X,5HT
     1IME,14X,8HVELOCITY)
   24 FORMAT (1H )
   25 FORMAT (1H ,F15.4,5F20.4)
   26 FORMAT (10H0  OUTPUT )
   28 FORMAT (1H0,9X,9HANGLE  OF,4X,8H  DISC  ,5X,10H   DISC    ,6X,10H
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  1WEIGHT  ,5X,10H   FLOW   ,5X,10H  SPRING  ,5X,10H  INERTIA ,5X,9H
  2 WATER  )
29 FORMAT (5H TIME,5X,9H  DISC   ,5X,8HANGULAR ,5X,10H ANGULAR  ,5X,1
  10H  MOMENT  ,5X,10H  MOMENT  ,5X,10H  MOMENT  ,5X,10H  MOMENT  ,5X
  2,9H VELOCITY)
30 FORMAT (1H ,9X,9HFROM VERT,5X,8HVELOCITY,5X,10H ACCELER. )
31 FORMAT (6H (SEC),4X,9H(DEGREES),5X,9H(RAD/SEC),3X,12H(RAD/SEC SQ),
  15X,8H(IN-LBS),7X,8H(IN-LBS),7X,8H(IN-LBS),8X,8H(IN-LBS),6X,8H(FT/S
  2EC))
32 FORMAT (1H ,F5.3,     2F13.4,5F15.4,F14.4)
33 FORMAT (1H /// 101H THE CONDITIONS OF THE CALCULATIONS EXCEEDED TH
  1E VALUES OF THE INPUT TABLES FOR THE DRAG COEFFICIENT.)
34 FORMAT (24H0THE INITIAL VALVE ANGLE,54X,7H(DEG) =F12.4)
35 FORMAT (85H THE EXTINGUISHED VELOCITY BASED ON THE EQUATIONS OF MO
  1TION                (FT/SEC) =F12.4)
36 FORMAT (85H THE DELTA P CORRESPONDING TO THIS EXTIGUISHED VELOCITY
  1                       (PSI) =F12.4)
37 FORMAT (85H THE EXTINGUISHED VELOCITY BASED ON THE SWEPT OUT VOLUM
  1E THEORY            (FT/SEC) =F12.4)
38 FORMAT (51H1THIS PROBLEM EXCEEDED THE SPECIFIED TIME LIMIT OF ,
  1 F3.1 , 10H SECONDS. )
39 FORMAT (43H DISC VOLUME                        (IN CUBE)=F13.4,4X,42H
  1WEIGHT OF DISC                        (LBS)=F13.4)
40 FORMAT (43H DISC VOLUME                        (IN CUBE)=F13.4,4X,42H
  1DENSITY OF DISC METAL                 (LBS)=F13.4)
41 FORMAT (43H WEIGHT OF DISC                         (LBS)=F13.4,4X,42H
  1DENSITY OF DISC METAL         (LBS/FT CUBE)=F13.4)
42 FORMAT (43H DISC ANGLE FOR PIVOT CHANGE            (DEG)=F13.4,4X,42H
  1DISC FACE ANGLE AFTER PIVOT CHANGE  (DEG)=F13.4)
43 FORMAT (43H PIVOT TO CG ARM AFTER PIVOT CHANGE   (IN)=F13.4,4X,42H
  1PIVOT TO CENTER OF AREA AFTER CHANGE (IN)=F13.4)
44 FORMAT (43H SPRING CONSTANT AFTER CHANGE (IN-LBS/DEG)=F13.4,4X,42H
  1IN SPRING DISPLACE AFTER CHANGE      (DEG)=F13.4)
45 FORMAT (43H DISC INERTIA AFTER CHANGE  (IN-LB-SEC SQ)=F13.4,4X,42H
  1FINITE DIFFERENCE INCREMENT          (SEC)=F13.4)
46 FORMAT (1H ///  97H THE CONDITIONS OF THE CALCULATIONS EXCEEDED TH
  1E VALUES OF THE INPUT TABLES FOR VELOCITY VS TIME.)
47 FORMAT (1H ///  93H THE CONDITIONS OF THE CALCULATIONS EXCEEDED TH
  1E VALUES OF THE INPUT VALUES AT STATEMENT 242.)
48 FORMAT (1H /// 108H THE CONDITIONS OF THE CALCULATIONS EXCEEDED TH
  1E VALUES OF THE INPUT VALUES FOR THE ADDED MOMENT OF INERTIA.)
49 FORMAT (1H ///  93H THE CONDITIONS OF THE CALCULATIONS EXCEEDED TH
  1E VALUES OF THE INPUT VALUES AT STATEMENT 281.)
50 FORMAT (1H ///  93H THE CONDITIONS OF THE CALCULATIONS EXCEEDED TH
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  1E VALUES OF THE INPUT VALUES AT STATEMENT 138.)
51 FORMAT ( 57H0THE ARTICULATED VALVE HAS CHANGED PIVOTS AT THIS POIN
  1T. ///)
52 FORMAT (  1H /// 104H THE INITIAL VELOCITY IS SUFFICIENT TO CLOSE
  1THE VALVE. THUS THE TRANSIENT IS FROM THE CLOSED POSITION.    )
53 FORMAT (1H ///  93H THE CONDITIONS OF THE CALCULATIONS EXCEEDED TH
  1E VALUES OF THE INPUT TABLES AT STATEMENT 297.)
54 FORMAT (1H ///  93H THE CONDITIONS OF THE CALCULATIONS EXCEEDED TH
  1E VALUES OF THE INPUT TABLES AT STATEMENT 300.)
55 FORMAT ( 1H /// 20H THE VALVE IS OPEN. )
56 FORMAT (43H VELOCITY TO HOLD DISC SEATED      (FT/SEC)=F13.4)
57 FORMAT (43H SPEED OF SOUND                    (FT/SEC)=F13.4,4X,42H
  1FULL OPEN POSITION                      (IN)=F13.4)
58 FORMAT (43H SPRING CONSTANT                   (LBS/IN)=F13.4,4X,42H
  1INITIAL SPRING DISPLACEMENT             (IN =F13.4)
59 FORMAT (43H CROSS-SECTIONAL AREA               (IN-SQ)=F13.4,4X,42H
  1FINITE DIFFERENCE INCREMENT            (SEC)=F13.4)
60 FORMAT (1H ,7X,8HPOSITION,14X,5HVALUE,13X,8HPOSITION,13X,5HVALUE,
  116X,4HTIME,13X,8HVELOCITY)
61 FORMAT (5H TIME,6X,8H  DISC  ,5X,8H  DISC  ,5X,10H   DISC   ,5X,
  110H   FLOW   ,5X,10H  SPRING  ,5X,10H INERTIA  ,5X,9H   WATER  )
62 FORMAT (1H ,9X,9H POSITION,5X,8HVELOCITY,5X,10H ACCELER. , 5X,
  110H  FORCE   ,5X,10H  FORCE   ,5X,10H  FORCE   ,5X,9H VELOCITY )
63 FORMAT (6H (SEC),5X,8H(INCHES),5X,8H(IN/SEC),5X,11H(IN/SEC SQ),4X,
  110H (POUNDS) ,5X,10H (POUNDS) ,5X,10H (POUNDS) ,5X,9H (FT/SEC) )
64 FORMAT (1H /// 93H THE CONDITIONS OF THE CALCULATIONS EXCEEDED THE
  1 VALUES OF THE INPUT TABLES AT STATEMENT 338.)
65 FORMAT (1H ,F5.3,     2F13.4,4F15.4,F14.4 )
66 FORMAT (43H CONVERGENCE CRITERION             (INCHES)=F13.4,4X,42H
  1MAXIMUM INTEGRATION TIME               (SEC)=F13.4)
67 FORMAT (1H0,23H THE OPTIONS CHOSEN ARE /  11H OPTION 1 = I3   ,7X,
  110HOPTION 2 =I3   ,7X,10HOPTION 3 =I3   ,7X,10HOPTION 4 =I3)
68 FORMAT (27H0THE INITIAL VALVE POSITION,48X,9H(INCHES)=F12.4)
69 FORMAT (1H  ///  69H THE FINITE DIFFERENCE INCREMENT CHOSEN FOR TH
  1IS PROBLEM IS TOO LARGE   /
  261H FOR CONVERGENCE. IT HAS BEEN DECREASED BY A FACTOR OF 10 TO F5
  3.4,9H SECONDS.  /// )
70 FORMAT (1H  ///  69H THE DECREASED FINITE DIFFERENCE INCREMENT HAS
  1 NOT BEEN SUFFICIENT TO  /  69H PROMOTE CONVERSION AFTER 500 ITERA
  2TIONS. IT IS RECOMENDED THAT THE  /  69H INPUT DATA BE REVIEWED AN
  3D IF NO INPUT ERRORS ARE DETECTED THAT THE / 69H PROBLEM BE RESUBM
  4ITTED WITH A SMALLER FINITE DIFFERENCE INCREMENT.              )
71 FORMAT (1H  /// 69H THE ARTICULATED VALVE REQUIRES A MUCH SMALLER
  1FINITE DIFFERENCE      / 69H INCREMENT BETWEEN THE CLOSED POSITIO
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   2N AND THE POSITION FOR              /   69H ARTICULATION THAN AFTER
   3ARTICULATION. THEREFORE, DURING THE FORMER   /69H INTERVAL, THE S
   4PECIFIED INCREMENT IS REDUCED BY A FACTOR OF 10.        ///  )
  72 FORMAT (43H PIPE AREA                             (IN SQ)=F13.4)
  73 FORMAT (2H1,10X,82HSLAM  CODE M0188    CHECK VALVE SLAM PRESSURE S
   1URGE.     COMPILED  OCTOBER 1962.       )
  74 FORMAT ( 85H ANGLE BETWEEN LINES FROM PIVOT TO CG AND CENTER OF AR
   1EA                            (DEG)= F13.4)
  75 FORMAT ( 85H ANGLE BETWEEN LINES FROM PIVOT TO CG AND CENTER OF AR
   1EA AFTER PIVOT CHANGE    (DEG)= F13.4)
 557 WRITE OUTPUT TAPE 10,73
 100 READ INPUT TAPE 8,3,I1,(STORE(I2),I2=1,6)
C     CARD    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15
      GO TO (101,142,142,206,151,152,153,154,156,158,160,162,164,166,168
     1,170,171,173,175,177,255,263,                        179,102),I1
C      16  17  18  19  20  21  22                           23  24
C     THE PRECEDING TWO STATEMEN READ AND STORE INPUT DATA
 206 JUMP1=STORE(1)
C     A 1. IN COLUMNS 11-20 CAUSES PRINT OUT AT EVERY TENTH TIME INCRE-
C     MENT. A 2. ELIMINATES ALL INTERMEDIATE DATA.
      JUMP2 = STORE(2)
C     A 1. IN COLUMNS 21-30 ELIMINATES THE INPUT EDIT.
      JUMP3 = STORE(3)
C     A 1. IN COLUMNS 31-40 INDICATES AN ARTICULATED VALVE.
C     A 2. IN COLUMNS 31-40 INDICATES A LINEAR MOTION VALVE.
      JUMP4 = STORE(4)
C     A 1. IN COLUMNS 41-50 INDICATES AN OPENING TRANSIENT FROM CLOSED
C     POSITION AND A 2. INDICATES AN OPENING TRANSIENT FROM SOME INTER-
C     MEDIATE ANGLE
      JUMP5 = STORE(5)
      JUMP6 = STORE(6)
      GO TO 100
 101 I3 = 1
      READ INPUT TAPE 8,2,CARD,CARDO
      GO TO 100
 142 JUMP = 1
      WRITE OUTPUT TAPE 10,6
C     FOR ANY PROBLEM, CARDS 1,2 AND 3 MUST BE IN SEQUENCE. IF NOT IN
C     SEQUENCE, THE PROBLEM AND ALL OTHERS PRECEDING A 24 CARD ARE NOT
C     PERFORMED.
      I10 = I10 + 2
 143 READ INPUT TAPE 8,7,I1
      IF ( I1-1 ) 102,144,145
 145 IF ( I1-22) 143,102,102
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  144 READ INPUT TAPE 8,2,CARD,CARDO
      IF (55-I10) 148,147,147
  148 I3 = I3 +1
      WRITE OUTPUT TAPE 10,4,I3
      I10 = 2
  147 GO TO (149,150),JUMP
  149 WRITE OUTPUT TAPE 10,10
  150 WRITE OUTPUT TAPE 10,5,CARD
      WRITE OUTPUT TAPE 10,5,CARDO
      I10 = I10 + 5
      JUMP = 2
      GO TO 143
  151 RHO = STORE(1)
      VIN = STORE(2)
      CSOUND = STORE(3)
      VMIN = STORE(4)
      AREAP = STORE(5)
      BETA =STORE(6)
C     THIS SEQUENCE STORES DATA ON CARD 5.
      GO TO 100
  152 AODI   = STORE(1)
      AODF   = STORE(2)
      PHI    = STORE(3)
      DVOL   = STORE(4)
      W      = STORE(5)
      RHOM   = STORE(6)
C     THIS SEQUENCE STORES DATA ON CARD 6.
      GO TO 100
  153 RBAR   =STORE(1)
      IF ( STORE (2)) 253,252,253
  252 RPC  =  STORE(1)
      GO TO 254
  253 RPC  =  STORE(2)
  254 SPRINK = STORE(3)
      THETAI =STORE(4)
      DISCJ=STORE(5)
      AREA = STORE (6)
C     THIS SEQUENCE STORES DATA ON CARD 7.
      GO TO 100
  154 DO 155 I11=1,6
  155 THET(I11) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 8.
      GO TO100
  156 DO 157 I11=1,6
```

```
  157 THET(I11 + 6) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 9.
      GO TO 100
  158 DO 159 I11=1,6
  159 DRAG(I11) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 10.
      GO TO 100
  160 DO 161 I11=1,6
  161 DRAG (I11+6) = STORE (I11)
C     THIS SEQUENCE STORES DATA ON CARD 11.
      GO TO 100
  162 DO 163 I11=1,6
  163 ADDJ(I11) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 12.
      GO TO 100
  164 DO 165 I11=1,6
  165 ADDJ(I11+6) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 13.
      GO TO 100
  166 DO 167 I11 = 1,6
  167 ANG(I11) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 14.
      GO TO 100
  168 DO 169 I11=1,6
  169 ANG(I11+6) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 15.
      GO TO 100
  170 EPSILO =STORE(1)
      TIMES  =STORE(2)
      DT     =STORE(3)
C     THIS SEQUENCE STORES DATA ON CARD 16.
      GO TO 100
  171 DO 172 I11=1,6
  172 VEL(I11) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 17.
      GO TO 100
  173 DO 174 I11 = 1,6
  174 VEL(I11+6) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 18.
      GO TO 100
  175 DO 176 I11=1,6
  176 TV(I11) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 19.
      GO TO 100
```

```
  177 DO 178 I11=1,6
  178 TV(I11+6) = STORE(I11)
C     THIS SEQUENCE STORES DATA ON CARD 20.
      GO TO 100
  255 AAS    = STORE(1)
      PHIA   = STORE(2)
      RBARA  = STORE(3)
      IF ( STORE(4)) 260,261,260
  261 RPCA   = STORE(3)
      GO TO 262
  260 RPCA   = STORE(4)
  262 SPRNKA = STORE(5)
      THETAA = STORE(6)
C     THIS SEQUENCE STORES THE DATA ON CARD 21.
      GO TO 100
  263 DISCJA=STORE(1)
      BETAA=STORE(2)
      GO TO 100
C     THIS SEQUENCE STORES THE DATA ON CARD 22.
  179 JEST2 = JUMP2+1
      RTEM1 =RBAR
      RTEM2 =RPC
      ATEM2 =BETA
      PHITEM=PHI
      SKTEM  = SPRINK
      THETAT=THETAI
      DJTEM =DISCJ
      JEST1=JUMP1 + 1
      I21 = 0
      I22 = 0
      I23 = 0
      JEST3 = JUMP3 + 1
      JUMP14=JEST3
      JEST4 = JUMP4 + 1
      JEST5=JUMP5+1
      I3=1
      WRITE OUTPUT TAPE 10,4,I3
      WRITE OUTPUT TAPE 10,5,CARD
      WRITE OUTPUT TAPE 10,11,CARDO
      I10 = 6
      WRITE OUTPUT TAPE 10,67,JUMP1,JUMP2,JUMP3,JUMP4
      I10=I10+4
      GO TO(207,503),JEST5
  207 GO TO (209,210), JEST2
```

```
209 WRITE OUTPUT TAPE 10,8
    WRITE OUTPUT TAPE 10,12,RHO,VIN
    GO TO (321,321,322), JEST3
322 WRITE OUTPUT TAPE 10,57,CSOUND,AODI
    GO TO 264
321 WRITE OUTPUT TAPE 10,14,CSOUND,AODI
    WRITE OUTPUT TAPE 10,15,AODF,PHI
    GO TO (264,265,264), JEST3
265 WRITE OUTPUT TAPE 10,42,AAS,PHIA
264 IF  ( W )  230,231,230
230 IF (DVOL) 232,233,232
232 WRITE OUTPUT TAPE 10,39,DVOL,W
    WBOUY =  W -(RHO * DVOL / 1728.)
    GO TO 234
231 IF (RHOM) 235,236,235
236 RHOM = 487.
235 WRITE OUTPUT TAPE 10,40,DVOL,RHOM
    WBOUY =  DVOL          * (RHOM -RHO) / 1728.
    W = DVOL * RHOM /1728.
    GO TO 234
233 IF (RHOM) 237,238,237
238 RHOM = 487.
237 WRITE OUTPUT TAPE 10,41,W,RHOM
    WBOUY =  W*( 1  - (RHO /RHOM))
234 GO TO (324,325,326), JEST3
324 WRITE OUTPUT TAPE 10,17,RBAR,RPC
    GO TO 266
325 WRITE OUTPUT TAPE 10,17,RBAR,RPC
    WRITE OUTPUT TAPE 10,43,RBARA,RPCA
266 WRITE OUTPUT TAPE 10,18,SPRINK,THETAI
    GO TO (268,269,100), JEST3
269 WRITE OUTPUT TAPE 10,44,SPRNKA,THETAA
268 WRITE OUTPUT TAPE 10,19,DISCJ,AREA
    GO TO (270,271,100), JEST3
271 WRITE OUTPUT TAPE 10,45,DISCJA,DT
    WRITE OUTPUT TAPE 10,20,EPSILO,TIMES
    WRITE OUTPUT TAPE 10,72,AREAP
    GO TO 272
326 WRITE OUTPUT TAPE 10,58,SPRINK,THETAI
    WRITE OUTPUT TAPE 10,59,AREA,DT
    WRITE OUTPUT TAPE 10,66,EPSILO,TIMES
    WRITE OUTPUT TAPE 10,72,AREAP
    WRITE OUTPUT TAPE 10,74,BETA
    WRITE OUTPUT TAPE 10,75,BETAA
```

```
      GO TO 272
  270 WRITE OUTPUT TAPE 10,20,EPSILO,TIMES
      WRITE OUTPUT TAPE 10,16,DT   ,AREAP
      WRITE OUTPUT TAPE 10,74,BETA
  272 GO TO (309,310,310),JEST4
  310 WRITE OUTPUT TAPE 10,56,VMIN
  309 WRITE OUTPUT TAPE 10,21
      WRITE OUTPUT TAPE 10,22
      GO TO (327,327,328), JEST3
  327 WRITE OUTPUT TAPE 10,23
      GO TO 329
  328 WRITE OUTPUT TAPE 10,60
  329 WRITE OUTPUT TAPE 10,24
      WRITE OUTPUT TAPE 10,25,(THET(I1),DRAG(I1),ANG(I1),ADDJ(I1),
     1TV(I1),VEL(I1),I1=1,12)
      I3= 2
      WRITE OUTPUT TAPE 10,4,I3
      WRITE OUTPUT TAPE 10,5,CARD
      WRITE OUTPUT TAPE 10,11,CARD
  210 IF (RHOM) 247,248,247
  248 RHOM=487.
  247 WRITE OUTPUT TAPE 10,26
      IF (W) 352,353,352
  353 W =  DVOL * RHOM / 1728.
  352 GO TO (331,331,330), JEST3
  330 WRITE OUTPUT TAPE 10,61
      WRITE OUTPUT TAPE 10,62
      WRITE OUTPUT TAPE 10,63
      GO TO 332
  331 WRITE OUTPUT TAPE 10,28
      WRITE OUTPUT TAPE 10,29
      WRITE OUTPUT TAPE 10,30
      WRITE OUTPUT TAPE 10,31
  332 I10=13
      WRITE OUTPUT TAPE 10,24
  180 CONTINUE
  228 GO TO (287,288,287), JEST4
  287 ATEM=AODI
      GO TO289
  288 ATEM = AODF
  289 DO 104 I2=2,12
      IF(ATEM+PHITEM-THET(I2)) 130,105,104
  104 CONTINUE
  131 WRITE OUTPUT TAPE 10,33
```

```
      GO TO 100
  105 DCOE =  DRAG(I2)
      GO TO 354
  130 EXPON=(ATEM+PHITEM-THET(I2-1))/(THET(I2)-THET(I2-1))
      DCOE  = ((DRAG(I2)/DRAG(I2-1))**EXPON) *DRAG(I2-1)
  354 GO TO (107,290,107),JEST4
  294 JEST4 =2
      WRITE OUTPUT TAPE 10,52
  290 V = VMIN
      GO TO (286,286,335), JEST3
C     THET  =ANGLES CORRESPONDING TO INPUT DRAG COEFFICIENTS (DEG)
C     DRAG  =INPUT DRAG COEFFICIENT. (NONE)
C     THE ABOVE IS A LINEAR INTERPOLATION ON A SEMI-LOG PLOT
C     THIS IS DCOE CORRESPONDING TO ATEM
  107 GO TO (370,370,371), JEST3
  371 V=SQRTF((9273.6*(SKTEM*(ATEM-THETAT)+WBOUY))/(DCOE*RHO*AREA))
      GO TO 372
  370 V =SQRTF((((SKTEM*((ATEM        )-THETAT))+(WBOUY*RTEM1*SINF(ATEM
     1/57.3)))*9273.6)/(DCOE*RHO*AREA*RTEM2*COSF((PHITEM+ATEM2)/57.3)))
  372 IF (VIN - V) 108,109,109
C     THIS IS VELOCITY TO HOLD ATEM
C     V      =VELOCITY OF FLUID (FT / SEC
C     VIN    =INITIAL VELOCITY OF FLUID (FT / SEC)
C     THIS DETERMINES INITIAL DISC ANGLE IF NOT FULL OPEN.
C     AREA   =AREA OF DISC   (IN SQ )
  108 ATEM = ATEM -.05
      GO TO (373,374,373), JUMP14
  374 IF(ATEM-AAS-PHIA+PHI)375,375,293
  375 GO TO (376,377,377), JEST4
  376 JEST3=1
      WRITE OUTPUT TAPE 10,51
      I10=I10+10
  377 RTEM1=RBARA
      RTEM2 =RPCA
      ATEM2 =BETAA
      SKTEM=SPRNKA
      PHITEM=PHIA
      THETAT=THETAA
      DJTEM=DISCJA
      JUMP14=1
      ATEM=ATEM-PHIA+PHI
      DT=DT/10.
      I23=1
      WRITE OUTPUT TAPE 10,71
```

```
      I10=I10+10
      GO TO 293
  373 IF (ATEM-AODF) 294,294,293
  293 IF (ATEM+PHITEM-THET(I2-1)) 132,133,130
  132 I2 = I2 - 1
      GO TO 130
  133 DCOE  = DRAG (I2-1)
      GO TO 107
  335 AODT = ATEM
      GO TO 336
  109 GO TO (286,379,335),JEST3
  379 GO TO (286,286,380),JEST4
  380 GO TO (286,381), JUMP14
  381 JEST3=1
  286 AODT  = ATEM / 57.3
  336 A1DT  = A1DI
      A2DT=A2DI
      A2DTDT=A2DI
C     AODT  =ANGLE OF DISC CCW FROM VERTICALLY DOWN.A STANDS FOR ANGLE,
C             OD STANDS FOR ZEROTH DERIVATIVE AND T STANDS FOR TIME T
C     AODI  =INITIAL ANGLE OF DISC
C     A1DT  =FIRST DERIVATIVE OF ANGLE AT TIME T. (RAD/SEC)
C     AIDI  =INITIAL VALUE OF FIRST DERIVATIVE.   (RAD/SEC)
C     A2DT  =SECOND DERIVATIVE AT TIME T. (RAD/SEC SQ)
C     A2DI  =INITIAL VALUE OF SECOND DERIVATIVE. (RAD/SEC SQ)
C     AODTDT=AOD AT T+DT
C     A1DTDT=A1D AT T+DT
C     A2DTDT=A2D AT T+DT
C     DT=TIME INCREMET FOR FINITE DIFFERENCE METHOD OF INTEGRATION.(SEC)
      GO TO (295,297,297), JEST4
  295 DO 241,I2=2,12
      IF (VIN - VEL( I2))241,240,239
  241 CONTINUE
      WRITE OUTPUT TAPE 10,46
      GO TO 100
  240 TIME1 = TV(I2)
C     TV IS TIME OF INPUT VELOCITY VEL (FT/SEC) (SEC)
      GO TO 242
  297 DO 298 I2 =2,12
      IF (VIN - VEL(I2)) 239,240,298
  298 CONTINUE
      WRITE OUTPUT TAPE 10,46
      GO TO 100
  239 TIME1 =(((TV(I2) -TV(I2-1))*  (VIN- VEL(I2))) / (VEL(I2)-VEL(I2-1)
```

```
     1))+ TV (I2)
C      THIS DETERMINES TIME AT WHICH COAST DOWN BEGINS.
  242 GO TO (299,300,300), JEST4
  299 DO 110 I20=2,12
      IF ( V - VEL( I20 )) 110,111,112
  110 CONTINUE
      WRITE OUTPUT TAPE 10,46
      GO TO 100
  300 DO 301 I20=2,12
      IF (V-VEL(I20)) 112,111,301
  301 CONTINUE
      WRITE OUTPUT TAPE 10,46
      GO TO 100
  111 TIME = TV( I20
      I20 = I20 + 1
      GO TO 243
  112 TIME = (((TV(I20)- TV(I20-1))*(V-VEL(I20)))/(VEL(I20)-VEL(I20-1)))
     1+ TV(I20)
C      THIS DETERMINES POINT FROM WHICH CLOSURE BEGINS.
  243 IF (ADDJ(2)) 200,201,200
C      IF THE SECOND VALUE INPUT FOR ADDJ IS ZERO,ADDJ IS ASSUMED A CONS-
C      TANT OVER ENTIRE ARC.
  201 JUMP13=1
      ADDJI =ADDJ(1)
      GO TO 135
  200 GO TO (337,337,338), JEST3
  337 DO 202  I2 =1,12
      IF (( AODT *57.299) - ANG (I2)) 204,203,202
  202 CONTINUE
      WRITE OUTPUT TAPE 10,48
      GO TO 100
  338 DO 339 I2 =1,12
      IF (AODT - ANG(I2)) 340,203,339
  339 CONTINUE
      WRITE OUTPUT TAPE 10,48
      GO TO 10C
  340 ADDJI=((( AODT -ANG(I2-1))/(ANG(I2)-ANG(I2-1)))*(ADDJ(I2)-ADDJ(I2-
     11))) +ADDJ(I2-1)
      GO TO 205
  203 ADDJI = ADDJ(I2)
      GO TO 205
  204 ADDJI = ((( (AODT * 57.3)- ANG (I2-1)) / ( ANG (I2) - ANG (I2 - 1)
     1)) * ( ADDJ (I2) - ADDJ( I2 - 1))) + ADDJ (I2-1)
  205 JUMP13=2
```

```
  135 IF (TIME - TV(I20)) 244,246,246
  246 I20=I20+1
  244 VTEM  =((TIME+DT-TV(I20))*(VEL(I20)-VEL(I20-1)))/(TV(I20)-TV(
     1I20-1))+VEL(I20   )
  118 A1DTDT=(((A2DTDT+A2DT)*DT)/2.)+A1DT
      A0DTDT=(((DT**2)/6.)*(A2DTDT+(2.*A2DT)))+(DT*A1DT)+A0DT
      GO TO (341,341,342), JEST3
  342 STORQ = SKTEM * (A0DTDT - THETAT)
      DTORQ = ABSF(V - (A1DTDT/12.)) *(V-(A1DTDT/12.))*AREA*DCOE*RHO /
     19273.6
      ATORQ = DTORQ - STORQ
      A2DC  = ATORQ / ((W /32.2) + ADDJI)
      GO TO 343
  341 WTORQ = WBOUY * RTEM1 * SINF (A0DTDT)
C     WTORQ =WEIGHT TORQUE (IN-LBS)
C     RTEM1 = DISTANCE CG TO PIVOT (IN)
      STORQ = SKTEM * (( A0DTDT * 57.3 ) - THETAT)
C     STORQ =SPRING TORQUE (IN-LBS)
      DTORQ= DCOE*RHO*AREA*RTEM2*COSF((PHITEM+ATEM2)/57.3)*V/ABSF(V)
     1/9273.6*(     (V-RTEM2/12.*A1DTDT*COSF(A0DTDT-ATEM2/57.3))**2+
     3                                            ( RTEM2/12.*A1DTDT*SINF
     4(A0DTDT-ATEM2/57.3)))
C     DTORQ = DRAG TORQ  (IN-LBS)
C     A2DC  = CALCULATED ACCELERATION (/SEC SQ)
      ATORQ =DTORQ - WTORQ - STORQ
      A2DC  = ATORQ / (DISCJ + ADDJI)
C     DISCJ = DISC MOMENT OF INERTIA  (IN-LB-SEC SQ)
C     ADDJI = ADDED MOMENT OF INERTIA (IN-LB-SEC SQ)
  343 TEST = ABSF (A2DC -A2DTDT)
  553 IF ( TEST  - EPSILO )  116,116,117
  550 I22 =0
      I23 =I23+1
      GO TO (551,552), I23
  551 DT = DT / 10.
      WRITE OUTPUT TAPE 10,69,DT
      A0DTDT =A0DT
      A1DTDT =A1DT
      A2DTDT =A2DT
      I10 = I10 + 10
      GO TO 244
  552 DT = 10. * DT
      WRITE OUTPUT TAPE 10,70
      GO TO 100
      IF(A0DTDT-1.0E10) 118,118,550
```

```
117 A2DTDT= A2DC
    GO TO 118
116 A0DT = A0DTDT
    A1DT = A1DTDT
    A2DT = A2DC
    TIME = TIME + DT
    V=VTEM
    TAU = TIME - TIME1
    WTORQ = - WTORQ
    STORQ = - STORQ
    I22 = 0
C   TAU = ELAPSED TIME FROM INITIATION OF CLOSURE
    STORE1=A0DT * 57.3
    IF (I10 -60) 181,182,182
182 I3 = I3+1
    WRITE OUTPUT TAPE 10,4,I3
    WRITE OUTPUT TAPE 10,5,CARD
    WRITE OUTPUT TAPE 10,11,CARD0
    WRITE OUTPUT TAPE 10,26
    GO TO (344,344,345), JEST3
345 WRITE OUTPUT TAPE 10,61
    WRITE OUTPUT TAPE 10,62
    WRITE OUTPUT TAPE 10,63
    GO TO 346
344 WRITE OUTPUT TAPE 10,28
    WRITE OUTPUT TAPE 10,29
    WRITE OUTPUT TAPE 10,30
    WRITE OUTPUT TAPE 10,31
346 WRITE OUTPUT TAPE 10,24
    I10 =15
181 GO TO (355,356,183), JEST1
356 I21 = I21 +1
    IF (I21 -10) 183,358,358
358 I21 = 0
355 GO TO (347,347,360), JEST3
360 STORE1 = A0DT
    WRITE OUTPUT TAPE 10,65,TAU,STORE1,A1DT,A2DT,DTORQ,STORQ,ATORQ,V
    I10=I10+1
361 GO TO (349,350,350), JEST4
349 IF ( A0DT ) 351,351,119
350 IF (A0DI-A0DT) 506,506,119
506  GO TO (507,508,507),JEST1
508 WRITE OUTPUT TAPE 10,65,TAU,STORE1,A1DT,A2DT,DTORQ,STORQ,ATORQ,V
507 GO TO 501
```

```
351 DPVEL = (RHO * V* CSOUND) / 4636.8
    SOVOL = AREA * ATEM
    GO TO (505,502,505), JEST1
502 WRITE OUTPUT TAPE 10,65,TAU,STORE1,A1DT,A2DT,DTORQ,STORQ,ATORQ,V
505 GO TO 281
347 WRITE OUTPUT TAPE 10,32,TAU,STORE1,A1DT,A2DT,WTORQ,DTORQ,STORQ,
   1ATORQ,V
    I10 = I10 + 1
183 GO TO (282,283,361), JEST3
282 GO TO (302,303,303), JEST4
302 IF (( AODF /57.3)-AODT) 119,122,122
303 IF (( AODI /57.3) - AODT) 304,304,119
304 GO TO (501,500,501), JEST1
500 WRITE OUTPUT TAPE 10,32,TAU,STORE1,A1DT,A2DT,WTORQ,DTORQ,STORQ,
   1ATORQ,V
501 WRITE OUTPUT TAPE 10,55
    I23 = I23 + 1
    GO TO (100,556), I23
556 DT  = DT * 10.
    GO TO 100
283 GO TO (305,306,306), JEST4
305 IF (AODT*57.3-AAS-PHIA+PHI)284,284,119
306 IF (( AAS / 57.3) - AODT) 307,307,119
307 JEST3 = JEST3 -1
    WRITE OUTPUT TAPE 10,51
    I10 = I10 +10
    RTEM1 = RBAR
    RTEM2 =RPC
    ATEM2 =BETA
    PHITEM=PHI
    SKTEM = SPRINK
    THETAT= THETAI
    DJTEM = DISCJ
    A1DT  = (A1DT * RBARA) /RBAR
    AODT=AODT+((PHIA-PHI)/57.3)
    DT=DT*10.
    I23=I23-1
    GO TO 119
284 WRITE OUTPUT TAPE 10,51
    DT=DT/10.
    I23=I23+1
    IF (I10-50) 999,999,998
999 I3=I3+1
    WRITE OUTPUT TAPE 10,4,I3
```

```
      WRITE OUTPUT TAPE 10,5,CARD
      WRITE OUTPUT TAPE 10,11,CARDO
      WRITE OUTPUT TAPE 10,26
  996 WRITE OUTPUT TAPE 10,28
      WRITE OUTPUT TAPE 10,29
      WRITE OUTPUT TAPE 10,30
      WRITE OUTPUT TAPE 10,31
  995 WRITE OUTPUT TAPE 10,24
      I10=15
  998 WRITE OUTPUT TAPE 10,71
      I10=I10+10
      AODT=AODT-((PHIA-PHI)/57.3)
      I10 = I10 + 10
      JEST3 = JEST3 - 1
      RTEM1 =RBARA
      RTEM2 =RPCA
      ATEM2 =BETAA
      SKTEM = SPRNKA
      PHITEM=PHIA
      THETAT=THETAA
      DJTEM =DISCJA
      A1DT  =(A1DT *RBAR) / RBARA
  119 IF (TAU -TIMES) 138,138,229
  122 DPVEL =(RHO * V *CSOUND) /(4636.8)
C     DPVEL = EXTINGUISHED VELOCITY DELTA P
      GO TO (503,504,503), JEST1
  504 WRITE OUTPUT TAPE 10,32,TAU,STORE1,A1DT,A2DT,WTORQ,DTORQ,STORQ,
     1ATORQ,V
  503 JEST3= JUMP3+1
      GO TO (276,277), JEST3
  276 SOVOL = AREA * COSF(PHI / 57.3) * RPC *((ATEM - AODF)/57.3)
      GO TO 281
  280 SOVOL =AREA/57.3*((COSF(PHI/57.3)*RPC*(ATEM-AAS-PHIA+PHI))+(COSF
     1(PHIA/57.3)*RPCA*(AAS-AODF)))
      GO TO 281
  277 IF(ATEM-AAS-PHIA+PHI) 279,279,280
  279 SOVOL = AREA * COSF(PHIA/57.3) * RPCA * (ATEM - AODF)/57.3
C     CSOUND=SONIC VELOCITY
C     SOVOL = SWEPT OUT VOUME OF DISC. (IN CUBE)
C     TIMES = TIME AT WHICH PROBLEM IS TO STOP
C     TZERO = TIME AT WHICH VELOCITY PASSES THROUGH ZERO
  281 DO 125  I2=1,12
      IF (VEL(I2)) 123,124,125
  125 CONTINUE
```

```
      WRITE OUTPUT TAPE 10,46
      GO TO 100
  124 TZERO = TV(I2)
      I2=I2+1
      GO TO 129
  123 TZERO = ((TV(I2)- TV(I2-1))*VEL(I2-1)/(VEL(I2-1)-VEL(I2))+TV(I2-1)
     1)
  129 RFVOL1= 0.
C     RFVOL = INTEGRATED REVERSE FLOW VOLUME.
      RFVOL =0.5*(TZERO-TV(I2)) *VEL(I2)*AREAP *12.
      IF (SOVOL -RFVOL) 128,126,127
  126 VTEM = VEL(I2)
      GO TO 136
  127 RFVOL1 = RFVOL
      I2=I2+1
      RFVOL =RFVOL1+(TV(I2-1)-TV(I2))*0.5*(VEL(I2)+VEL(I2-1))*AREAP*12.
      IF ( SOVOL - RFVOL ) 400,126,127
  400 TTEM1 = TV(I2-1)
      TTEM2 = TV (I2-1)
      VTEM1 = VEL(I2-1)
      GO TO 362
  128 TTEM1 = TZERO
      TTEM2 = TZERO
      RFVOL1 = 0.
      VTEM1 = 0.
  362 TTEM2 = TTEM2 + DT
      VTEM = (VEL(I2)-VEL(I2-1))*(TTEM2-TV(I2))/(TV(I2)-TV(I2-1))+VEL
     1(I2)
      RFVOL=RFVOL1+((TTEM1-TTEM2)*0.5*(VTEM+VTEM1)) *AREAP*12.
      IF (SOVOL -RFVOL) 136,136,362
  136 DPVOL =(RHO * CSOUND * VTEM ) / (4636.8)
      I23 = I23 + 1
      GO TO (554,555,994), I23
  994 DT=DT*100.
      GO TO 554
  555 DT = DT * 10.
  554 IF (I10-50) 185,184,184
  184 I3 = I3 + 1
      WRITE OUTPUT TAPE 10,4,I3
      WRITE OUTPUT TAPE 10,5,CARD
      WRITE OUTPUT TAPE 10,11,CARDO
      WRITE OUTPUT TAPE 10,26
  185 GO TO (509,510,509),JEST3
  510 WRITE OUTPUT TAPE 10,68,ATEM
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      GO TO 511
  509 WRITE OUTPUT TAPE 10,34,ATEM
  511 WRITE OUTPUT TAPE 10,35,V
      WRITE OUTPUT TAPE 10,36,DPVEL
      WRITE OUTPUT TAPE 10,37,VTEM
      WRITE OUTPUT TAPE 10,36,DPVOL
      GO TO 100
  138 DO 139 I2=2,12
      Z=    AODT*57.3+PHITEM-ATANF(-RTEM2*A1DTDT*SINF(AODT-ATEM2/57.3)
     1/(12.*V-RTEM2*A1DTDT*COSF(AODT-ATEM2/57.3)))
      IF (Z-THET(I2)) 141,140,139
  139 CONTINUE
      WRITE OUTPUT TAPE 10,33
      GO TO 100
  140 DCOE = DRAG(I2)
      GO TO (135,200) , JUMP13
  141 EXPON= (Z-THET(I2-1))/(THET(I2)-THET(I2-1))
      DCOE=  (( DRAG (I2) / DRAG (I2-1)) ** EXPON) * DRAG(I2-1)
      GO TO (135,200) , JUMP13
  229 WRITE OUTPUT TAPE 10,38,TIMES
      GO TO 100
      END(0,1,0,1,0)
                COMPLETE
```

VII. SAMPLE PROBLEM

A. Input

```
 1
 2THIS IS A SAMPLE PROBLEM OF A SIMPLE SWING TYPE CHECK VALVE
 3FOR THE SLAM (M0188) CODE.
 562.4        30.        5000.                  75.       10.
 675.        -20.        10.        60.
 7   5.       6.                                 7.        70.
 8  -30.       85
10   1500.   .0096
12
16   .05      3.        .01
17   30.     -25.        -25.
19    0.     1.25        3.
23
 1
 2THIS IS A SAMPLE PROBLEM OF AN ARTICULATED SWING TYPE CHECK
 3VALVE FOR THE SLAM (M0188) CODE.
 4   1.                    1.
21  30.      -10.        6.        5.
22  10.      - 5.
23
24
```

SLAM CODE M0188 CHECK VALVE SLAM PRESSURE SURGE.

THIS IS A SAMPLE PROBLEM OF A SIMPLE SWING TYPE CHECK VALVE
FOR THE SLAM (M0188) CODE.

THE OPTIONS CHOSEN ARE
OPTION 1 = 0 OPTION 2 = 0 OPTION 3 = 0 OPTION 4 = 0

INPUT EDIT.

DENSITY OF FLUID	(LBS/FT CUBE)=	62.4000	INITIAL FLUID VELOCITY	(FT/SEC)=	30.0000
SPEED OF SOUND	(FT/SEC)=	5000.0000	FULL OPEN ANGLE FROM VERTICAL	(DEG)=	75.0000
FULL CLOSED ANGLE FROM VERTICAL	(DEG)=	-20.0000	DISC FACE ANGLE	(DEG)=	10.0000
DISC VOLUME	(IN CUBE)=	60.0000	DENSITY OF DISC METAL	(LBS)=	487.0000
PIVOT TO CG ARM	(IN)=	5.0000	PIVOT TO CENTER OF AREA	(IN)=	6.0000
SPRING CONSTANT	(IN-LBS/DEG)=	0.0000	INITIAL SPRING DISPLACEMENT	(DEG)=	0.0000
DISC INERTIA	(IN-LB-SEC SQ)=	7.0000	DISC FACE AREA	(IN SQ)=	70.0000
CONVERGENCE CRITERION	(/SEC SQ)=	0.0500	MAXIMUM INTEGRATION TIME	(SEC)=	3.0000
FINITE DIFFERENCE INCREMENT	(SEC)=	0.0100	PIPE AREA	(IN SQ)=	75.0000

ANGLE BETWEEN LINES FROM PIVOT TO CG AND CENTER OF AREA (DEG)= 10.0000

DRAG COEFFICIENT		ADDED INERTIA DUE TO WATER		WATER VELOCITY	
ANGLE	VALUE	ANGLE	VALUE	TIME,	VELOCITY
-30.0000	1500.0000	0.0000	0.0000	0.0000	30.0000
85.0000	0.0096	0.0000	0.0000	1.2500	-25.0000
0.0000	0.0000	0.0000	0.0000	3.0000	-25.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

SLAM CODE M0188 CHECK VALVE SLAM PRESSURE SURGE.

THIS IS A SAMPLE PROBLEM OF A SIMPLE SWING TYPE CHECK VALVE
FOR THE SLAM (M0188) CODE.

OUTPUT

TIME (SEC)	ANGLE OF DISC FROM VERT (DEGREES)	DISC ANGULAR VELOCITY (RAD/SEC)	DISC ANGULAR ACCELER. (RAD/SEC SQ)	WEIGHT MOMENT (IN-LBS)	FLOW MOMENT (IN-LBS)	SPRING MOMENT (IN-LBS)	INERTIA MOMENT (IN-LBS)	WATER VELOCITY (FT/SEC)
0.012	64.7000	0.0000	-0.0000	-66.6421	66.6421	0.0000	-0.0000	29.4867
0.022	64.6997	-0.0014	-0.2776	-66.6419	64.6986	0.0000	-1.9434	29.0467
0.032	64.6979	-0.0055	-0.5503	-66.6409	62.7890	0.0000	-3.8519	28.6067
0.042	64.6929	-0.0124	-0.8167	-66.6382	60.9216	0.0000	-5.7166	28.1667
0.052	64.6832	-0.0218	-1.0755	-66.6328	59.1047	0.0000	-7.5282	27.7267
0.062	64.6674	-0.0338	-1.3255	-66.6241	57.3454	0.0000	-9.2787	27.2867
0.072	64.6440	-0.0483	-1.5659	-66.6112	55.6496	0.0000	-10.9616	26.8467
0.082	64.6116	-0.0651	-1.7959	-66.5934	54.0219	0.0000	-12.5715	26.4067
0.092	64.5689	-0.0842	-2.0148	-66.5698	52.4660	0.0000	-14.1038	25.9667
0.102	64.5147	-0.1053	-2.2222	-66.5399	50.9845	0.0000	-15.5554	25.5267
0.112	64.4478	-0.1285	-2.4177	-66.5028	49.5791	0.0000	-16.9236	25.0867
0.122	64.3671	-0.1536	-2.6010	-66.4579	48.2510	0.0000	-18.2069	24.6467
0.132	64.2714	-0.1805	-2.7720	-66.4045	47.0005	0.0000	-19.4041	24.2067
0.142	64.1599	-0.2090	-2.9307	-66.3421	45.8274	0.0000	-20.5147	23.7667
0.152	64.0316	-0.2391	-3.0770	-66.2700	44.7312	0.0000	-21.5388	23.3267
0.162	63.8857	-0.2705	-3.2110	-66.1876	43.7108	0.0000	-22.4768	22.8867
0.172	63.7214	-0.3032	-3.3328	-66.0942	42.7649	0.0000	-23.3293	22.4467
0.182	63.5380	-0.3371	-3.4425	-65.9894	41.8920	0.0000	-24.0974	22.0067
0.192	63.3349	-0.3720	-3.5403	-65.8726	41.0903	0.0000	-24.7822	21.5667
0.202	63.1115	-0.4078	-3.6264	-65.7431	40.3580	0.0000	-25.3851	21.1267
0.212	62.8673	-0.4445	-3.7011	-65.6004	39.6929	0.0000	-25.9075	20.6867
0.222	62.6020	-0.4818	-3.7644	-65.4440	39.0930	0.0000	-26.3510	20.2467
0.232	62.3151	-0.5197	-3.8168	-65.2733	38.5560	0.0000	-26.7173	19.8067
0.242	62.0063	-0.5579	-3.8583	-65.0878	38.0795	0.0000	-27.0083	19.3667
0.252	61.6756	-0.5966	-3.8893	-64.8870	37.6615	0.0000	-27.2254	18.9267
0.262	61.3226	-0.6355	-3.9102	-64.6702	37.2991	0.0000	-27.3711	18.4867
0.272	60.9472	-0.6745	-3.9210	-64.4371	36.9903	0.0000	-27.4468	18.0467
0.282	60.5495	-0.7136	-3.9221	-64.1870	36.7323	0.0000	-27.4548	17.6067
0.292	60.1295	-0.7526	-3.9139	-63.9196	36.5225	0.0000	-27.3971	17.1667
0.302	59.6870	-0.7916	-3.8965	-63.6342	36.3584	0.0000	-27.2757	16.7267
0.312	59.2223	-0.8306	-3.8704	-63.3302	36.2374	0.0000	-27.0928	16.2867
0.322	58.7353	-0.8691	-3.8359	-63.0074	36.1564	0.0000	-26.8510	15.8467
0.332	58.2263	-0.9075	-3.7932	-62.6650	36.1126	0.0000	-26.5524	15.4067
0.342	57.6955	-0.9451	-3.7429	-62.3027	36.1022	0.0000	-26.2005	14.9667
0.352	57.1433	-0.9823	-3.6855	-61.9201	36.1218	0.0000	-25.7983	14.5267
0.362	56.5699	-1.0188	-3.6214	-61.5168	36.1670	0.0000	-25.3498	14.0867
0.372	55.9758	-1.0547	-3.5513	-61.0924	36.2334	0.0000	-24.8590	13.6467
0.382	55.3614	-1.0898	-3.4758	-60.6465	36.3161	0.0000	-24.3304	13.2067
0.392	54.7271	-1.1242	-3.3956	-60.1789	36.4098	0.0000	-23.7692	12.7667
0.402	54.0733	-1.1577	-3.3115	-59.6893	36.5085	0.0000	-23.1808	12.3267
0.412	53.4005	-1.1904	-3.2245	-59.1773	36.6058	0.0000	-22.5715	11.8867
0.422	52.7093	-1.2222	-3.1355	-58.6427	36.6945	0.0000	-21.9483	11.4467
0.432	52.0001	-1.2531	-3.0455	-58.0854	36.7668	0.0000	-21.3187	11.0067
0.442	51.2734	-1.2831	-2.9559	-57.5052	36.8142	0.0000	-20.6910	10.5667
0.452	50.5298	-1.3122	-2.8678	-56.9019	36.8274	0.0000	-20.0745	10.1267
0.462	49.7698	-1.3405	-2.7827	-56.2753	36.7965	0.0000	-19.4788	9.6867
0.472	48.9938	-1.3679	-2.7021	-55.6253	36.7106	0.0000	-18.9148	9.2467

SLAM CODE M0188 CHECK VALVE SLAM PRESSURE SURGE.

THIS IS A SAMPLE PROBLEM OF A SIMPLE SWING TYPE CHECK VALVE
FOR THE SLAM (M0188) CODE.

OUTPUT

TIME (SEC)	ANGLE OF DISC FROM VERT (DEGREES)	DISC ANGULAR VELOCITY (RAD/SEC)	DISC ANGULAR ACCELER. (RAD/SEC SQ)	WEIGHT MOMENT (IN-LBS)	FLOW MOMENT (IN-LBS)	SPRING MOMENT (IN-LBS)	INERTIA MOMENT (IN-LBS)	WATER VELOCITY (FT/SEC)
0.482	48.2023	-1.3945	-2.6277	-54.9519	36.5582	0.0000	-18.3937	8.8067
0.492	47.3958	-1.4205	-2.5611	-54.2549	36.3274	0.0000	-17.9275	8.3667
0.502	46.5746	-1.4458	-2.5041	-53.5342	36.0052	0.0000	-17.5289	7.9267
0.512	45.7390	-1.4708	-2.4586	-52.7895	35.5793	0.0000	-17.2102	7.4867
0.522	44.8892	-1.4953	-2.4265	-52.0206	35.0349	0.0000	-16.9857	7.0467
0.532	44.0254	-1.5195	-2.4097	-51.2275	34.3594	0.0000	-16.8681	6.6067
0.542	43.1478	-1.5437	-2.4101	-50.4096	33.5388	0.0000	-16.8708	6.1667
0.552	42.2564	-1.5679	-2.4296	-49.5668	32.5598	0.0000	-17.0070	5.7267
0.562	41.3510	-1.5922	-2.4699	-48.6985	31.4096	0.0000	-17.2890	5.2867
0.572	40.4316	-1.6172	-2.5323	-47.8043	30.0785	0.0000	-17.7259	4.8467
0.582	39.4976	-1.6429	-2.6181	-46.8834	28.5566	0.0000	-18.3268	4.4067
0.592	38.5486	-1.6697	-2.7282	-45.9349	26.8375	0.0000	-19.0973	3.9667
0.602	37.5839	-1.6976	-2.8628	-44.9578	24.9182	0.0000	-20.0395	3.5267
0.612	36.6028	-1.7271	-3.0216	-43.9510	22.8001	0.0000	-21.1509	3.0867
0.622	35.6044	-1.7582	-3.2033	-42.9132	20.4902	0.0000	-22.4229	2.6467
0.632	34.5876	-1.7912	-3.4056	-41.8429	18.0037	0.0000	-23.8392	2.2067
0.642	33.5512	-1.8264	-3.6247	-40.7385	15.3653	0.0000	-25.3731	1.7667
0.652	32.4941	-1.8638	-3.8550	-39.5982	12.6132	0.0000	-26.9850	1.3267
0.662	31.4149	-1.9035	-4.0882	-38.4202	9.8026	0.0000	-28.6176	0.8867
0.672	30.3123	-1.9455	-4.3130	-37.2025	7.0117	0.0000	-30.1909	0.4467
0.682	29.1849	-1.9896	-4.5135	-35.9434	4.3491	0.0000	-31.5943	0.0067
0.692	28.0318	-2.0356	-4.6682	-34.6410	1.9638	0.0000	-32.6772	-0.4333
0.702	26.8519	-2.0827	-4.7641	-33.2939	-0.0550	0.0000	-33.3489	-0.8733
0.712	25.6452	-2.1285	-4.3948	-31.9016	1.1379	0.0000	-30.7637	-1.3133
0.722	24.4132	-2.1717	-4.2374	-30.4654	0.8036	0.0000	-29.6619	-1.7533
0.732	23.1567	-2.2140	-4.2788	-28.9863	-0.9650	0.0000	-29.9513	-2.1933
0.742	21.8754	-2.2588	-4.6668	-27.4636	-5.2037	0.0000	-32.6673	-2.6333
0.752	20.5669	-2.3098	-5.5266	-25.8944	-12.7918	0.0000	-38.6862	-3.0733
0.762	19.2261	-2.3726	-7.0156	-24.2725	-24.8366	0.0000	-49.1091	-3.5133
0.772	17.8443	-2.4544	-9.3248	-22.5871	-42.6866	0.0000	-65.2737	-3.9533
0.782	16.4080	-2.5645	-12.6838	-20.8212	-67.9652	0.0000	-88.7864	-4.3933
0.792	14.8977	-2.7147	-17.3644	-18.9504	-102.6003	0.0000	-121.5507	-4.8333
0.802	13.2864	-2.9200	-23.6930	-16.9400	-148.9109	0.0000	-165.8509	-5.2733
0.812	11.5374	-3.1987	-32.0702	-14.7426	-209.7485	0.0000	-224.4911	-5.7133
0.822	9.6023	-3.5739	-43.0065	-12.2954	-288.7504	0.0000	-301.0458	-6.1533
0.832	7.4177	-4.0749	-57.1794	-9.5161	-390.7400	0.0000	-400.2560	-6.5933
0.842	4.9014	-4.7385	-75.5418	-6.2979	-522.4947	0.0000	-528.7926	-7.0333
0.852	1.9469	-5.6139	-99.4946	-2.5042	-693.9579	0.0000	-696.4620	-7.4733
0.862	-1.5852	-6.7676	-131.2548	2.0391	-920.8225	0.0000	-918.7834	-7.9133
0.872	-5.8806	-8.2974	-174.7041	7.5520	-1230.4806	0.0000	-1222.9286	-8.3533
0.882	-11.1961	-10.3616	-238.1548	14.3121	-1681.3961	0.0000	-1667.0839	-8.7933
0.892	-17.9175	-13.2762	-344.7949	22.6767	-2436.2411	0.0000	-2413.5645	-9.2333
0.902	-26.7435	-17.9333	-586.6359	33.1694	-4139.6209	0.0000	-4106.4514	-9.6733

SLAM CODE M0188 CHECK VALVE SLAM PRESSURE SURGE.

THIS IS A SAMPLE PROBLEM OF A SIMPLE SWING TYPE CHECK VALVE
FOR THE SLAM (M0188) CODE.

OUTPUT

THE INITIAL VALVE ANGLE	(DEG) =	64.7000
THE EXTINGUISHED VELOCITY BASED ON THE EQUATIONS OF MOTION	(FT/SEC) =	-9.6733
THE DELTA P CORRESPONDING TO THIS EXTIGUISHED VELOCITY	(PSI) =	-650.8982
THE EXTINGUISHED VELOCITY BASED ON THE SWEPT OUT VOLUME THEORY	(FT/SEC) =	-7.9200
THE DELTA P CORRESPONDING TO THIS EXTIGUISHED VELOCITY	(PSI) =	-532.9193

SLAM CODE M0188 CHECK VALVE SLAM PRESSURE SURGE.

THIS IS A SAMPLE PROBLEM OF AN ARTICULATED SWING TYPE CHECK
VALVE FOR THE SLAM (M0188) CODE.

THE OPTIONS CHOSEN ARE
OPTION 1 = 1 OPTION 2 = 0 OPTION 3 = 1 OPTION 4 = 0

INPUT EDIT.

DENSITY OF FLUID	(LBS/FT CUBE)=	62.4000	INITIAL FLUID VELOCITY	(FT/SEC)=	30.0000
SPEED OF SOUND	(FT/SEC)=	5000.0000	FULL OPEN ANGLE FROM VERTICAL	(DEG)=	75.0000
FULL CLOSED ANGLE FROM VERTICAL	(DEG)=	-20.0000	DISC FACE ANGLE	(DEG)=	10.0000
DISC ANGLE FOR PIVOT CHANGE	(DEG)=	30.0000	DISC FACE ANGLE AFTER PIVOT CHANGE	(DEG)=	-10.0000
DISC VOLUME	(IN CUBE)=	60.0000	WEIGHT OF DISC	(LBS)=	16.9097
PIVOT TO CG ARM	(IN)=	5.0000	PIVOT TO CENTER OF AREA	(IN)=	6.0000
PIVOT TO CG ARM AFTER PIVOT CHANGE	(IN)=	6.0000	PIVOT TO CENTER OF AREA AFTER CHANGE	(IN)=	5.0000
SPRING CONSTANT	(IN-LBS/DEG)=	0.0000	INITIAL SPRING DISPLACEMENT	(DEG)=	0.0000
SPRING CONSTANT AFTER CHANGE	(IN-LBS/DEG)=	0.0000	IN SPRING DISPLACE AFTER CHANGE	(DEG)=	0.0000
DISC INERTIA	(IN-LB-SEC SQ)=	7.0000	DISC FACE AREA	(IN SQ)=	70.0000
DISC INERTIA AFTER CHANGE	(IN-LB-SEC SQ)=	10.0000	FINITE DIFFERENCE INCREMENT	(SEC)=	0.0100
CONVERGENCE CRITERION	(/SEC SQ)=	0.0500	MAXIMUM INTEGRATION TIME	(SEC)=	3.0000
PIPE AREA	(IN SQ)=	75.0000			

DRAG COEFFICIENT		ADDED INERTIA DUE TO WATER		WATER VELOCITY	
ANGLE	VALUE	ANGLE	VALUE	TIME,	VELOCITY
-30.0000	1500.0000	0.0000	0.0000	0.0000	30.0000
85.0000	0.0096	0.0000	0.0000	1.2500	-25.0000
0.0000	0.0000	0.0000	0.0000	3.0000	-25.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

SLAM CODE M0188 CHECK VALVE SLAM PRESSURE SURGE.

THIS IS A SAMPLE PROBLEM OF AN ARTICULATED SWING TYPE CHECK VALVE FOR THE SLAM (M0188) CODE.

OUTPUT

TIME (SEC)	ANGLE OF DISC FROM VERT (DEGREES)	DISC ANGULAR VELOCITY (RAD/SEC)	DISC ANGULAR ACCELER. (RAD/SEC SQ)	WEIGHT MOMENT (IN-LBS)	FLOW MOMENT (IN-LBS)	SPRING MOMENT (IN-LBS)	INERTIA MOMENT (IN-LBS)	WATER VELOCITY (FT/SEC)
0.102	64.5147	-0.1053	-2.2222	-66.5399	50.9845	0.0000	-15.5554	25.5267
0.202	63.1115	-0.4078	-3.6264	-65.7431	40.3580	0.0000	-25.3851	21.1267
0.302	59.6870	-0.7916	-3.8965	-63.6342	36.3584	0.0000	-27.2757	16.7267
0.402	54.0733	-1.1577	-3.3115	-59.6893	36.5085	0.0000	-23.1808	12.3267
0.502	46.5746	-1.4458	-2.5041	-53.5342	36.0052	0.0000	-17.5289	7.9267
0.602	37.5839	-1.6976	-2.8628	-44.9578	24.9182	0.0000	-20.0395	3.5267
0.702	26.8519	-2.0827	-4.7641	-33.2939	-0.0550	0.0000	-33.3489	-0.8733
0.802	13.2864	-2.9200	-23.6930	-16.9400	-148.9109	0.0000	-165.8509	-5.2733

THE ARTICULATED VALVE HAS CHANGED PIVOTS AT THIS POINT.

SLAM CODE M0188 CHECK VALVE SLAM PRESSURE SURGE.

THIS IS A SAMPLE PROBLEM OF AN ARTICULATED SWING TYPE CHECK VALVE FOR THE SLAM (M0188) CODE.

OUTPUT

THE ARTICULATED VALVE REQUIRES A MUCH SMALLER FINITE DIFFERENCE INCREMENT BETWEEN THE CLOSED POSITION AND THE POSITION FOR ARTICULATION THAN AFTER ARTICULATION. THEREFORE, DURING THE FORMER INTERVAL, THE SPECIFIED INCREMENT IS REDUCED BY A FACTOR OF 10.

TIME (SEC)	ANGLE OF DISC FROM VERT (DEGREES)	DISC ANGULAR VELOCITY (RAD/SEC)	DISC ANGULAR ACCELER. (RAD/SEC SQ)	WEIGHT MOMENT (IN-LBS)	FLOW MOMENT (IN-LBS)	SPRING MOMENT (IN-LBS)	INERTIA MOMENT (IN-LBS)	WATER VELOCITY (FT/SEC)
0.830	28.0989	-3.6143	-88.7499	-41.6606	-579.5890	0.0000	-621.2496	-6.5053
0.840	25.7534	-4.6108	-111.7150	-38.4324	-743.5723	0.0000	-782.0047	-6.9453
0.850	22.7636	-5.8773	-143.1814	-34.2247	-968.0453	0.0000	-1002.2700	-7.3853
0.860	18.9479	-7.5120	-185.7485	-28.7211	-1271.5182	0.0000	-1300.2393	-7.8253
0.870	14.0620	-9.6322	-239.9842	-21.4913	-1658.3979	0.0000	-1679.8892	-8.2653
0.880	7.7983	-12.3299	-299.2986	-12.0018	-2083.0883	0.0000	-2095.0901	-8.7053
0.890	-0.1760	-15.5905	-351.7041	0.2718	-2462.2005	0.0000	-2461.9288	-9.1453
0.900	-10.1820	-19.4987	-457.5383	15.6361	-3218.4041	0.0000	-3202.7680	-9.5853
0.908	-20.1862	-25.1789	-1400.0815	30.5223	-9831.0927	0.0000	-9800.5704	-9.9373

THE INITIAL VALVE POSITION (INCHES)= 64.7000
THE EXTINGUISHED VELOCITY BASED ON THE EQUATIONS OF MOTION (FT/SEC) = -9.9373
THE DELTA P CORRESPONDING TO THIS EXTIGUISHED VELOCITY (PSI) = -668.6622
THE EXTINGUISHED VELOCITY BASED ON THE SWEPT OUT VOLUME THEORY (FT/SEC) = -8.2720
THE DELTA P CORRESPONDING TO THIS EXTIGUISHED VELOCITY (PSI) = -556.6045