PUMP CHARACTERISTICS FOR A COMPUTERIZED PUMP TRANSIENT ANALYSIS

by

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ABSTRACT

A method is presented for approximating a centrifugal pump's characteristic by an interpolation procedure when its true characteristic is not known. The characteristic is then represented by 12 sixth degree polynomials for use in a transient analysis computer program. Data used for approximating a centrifugal pump's characteristic is shown in tabular form in Tables 1 through 12. The data was obtained from the known characteristics of 7 different specific speed pumps.

The transient analysis of a water conveyance system containing centrifugal pumps requires knowledge of each pump's characteristic and because a pump's characteristic is not generally known ,it must be approximated. The characteristic can be critical in the transient analysis because changing the characteristic used to analyze the system will change the resulting head and discharge history of the system during a transient. The characteristic used may thus play a major role in determining such things as pipe thickness, surge tank size, air chamber size and valve closure times. Choosing a characteristic which approximated that of each pump in the system as closely as possible can be critical in determining the most economical design of the system.

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INTRODUCTION

The design of water conveyance systems whose main components are pipelines and centrifugal pumps and whose size and discharge can vary over a wide range requires knowledge of all the systems' components. The design of a water conveyance system must be analyzed for both steady and transient flow. In analyzing a system that contains a centrifugal pump, one of the difficulties is defining the characteristic to describe the pump's operation. Each pump has a unique characteristic which, when known along with the head across the pump (h), the speed of the pump (α) and the torque on the pump impeller (β), will enable the calculation of the discharge (q). A pump characteristic thus relates the four variables involved in pump operation (h, α, β, q). The characteristic of a pump is determined by testing the actual pump, or approximated by testing a model of the pump.

This thesis presents a method for approximating a given pump's characteristic when it is not known. Also, a procedure for storing the characteristic (known or approximated) in the form of 12 sixth degree polynomial equations is suggested. The 12 equations can then be used in a computer program to determine transient conditions in a water conveyance system containing a known pump. A pump's characteristic is broken down into the following 3 areas of pump operation for ease of representation.

1. The normal pumping zone, where speed and pump discharge are both positive.

2. The energy dissipation zone, where discharge has reversed (negative), but the pump is still rotating in a normal direction.
3. The turbine zone, where the discharge is negative, and the pump is rotating in the reverse direction.

When power failure of a pumping plant is a possibility, the consequences must be analyzed. To do so requires knowledge of the pump's WR^2 (rotating weight or inertia) and the characteristics of the pump. In the event of a power failure, there is no more energy supplied to keep the water moving, and the downstream head is higher than the upstream head. This situation is just the opposite of when power is being supplied to the pump. Such a condition causes the water in the pipeline to slow down and finally reverse. The reverse flow will continue in the line and in the pump until a valve is shut, stopping the flow. The slowing down and reversing of the water in the pipeline is of interest because there is an immediate downsurge in the line followed by an upsurge or headrise. The magnitude of these changes depends on the pump's characteristics and WR^2. In general, the larger the value WR^2 is of a given pump, the smaller the downsurge and subsequent upsurge, because the increased inertia of the pump supplies the water flowing in the pipeline with energy so that changes in velocity are slower, resulting in less variation in head (pressure). If the transient analysis of a pumping system is not done properly, the result can vary from the extreme of broken lines and damaged pumping plants to the extreme of a highly overdesigned and expensive system. Although this thesis is directed to closed water conveyance systems containing centrifugal pumps, the design of oil and gas pipelines containing pumps may be dependent on the pump characteristic used in their transient analysis.

A PRESENT METHOD OF ANALYSIS

When a pump has not been tested, its characteristic has not been defined, and it is usually approximated by using the known characteristic of another pump. The known characteristic can be chosen from one of the 7 for which data is tabulated in Tables 1 through 12. The method of picking which of the 7 known characteristics to use is usually based on the assumption that any two geometrically similar pumps of the same specific speed (Ns, a type number derived from the rated head, discharge and speed of a pump) will have similar performance characteristics.

Thus, when analyzing a conveyance system containing a centrifugal pump whose characteristic is not known, its specific speed is determined, and a known characteristic from a pump of similar specific speed is used in the analysis. A problem with this procedure is that there are not enough known pump characteristics to adequately cover the range of specific speeds encountered in centrifugal pumps. Thus a known characteristic from a pump which has a specific speed closest to that of the actual pump in the system is used in the transient analysis for the system. When using a computer to analyze a pump power failure, the known characteristic is usually represented by tabulated values of h, q, α, and β taken from the actual test of the pump. The computer program will use the tabulated values as a basis for interpolating specific values to be used during each time increment of the analysis.

PROPOSED METHOD

If the additional assumption that specific speed varies uniformly and continuously with pump geometry is made(Ref. 1), there is a uniformly continuous relation between specific speed and the corresponding pump's characteristic. Using the 7 known characteristics of varying specific speed shown in this paper, and fitting a 2nd or 3rd degree polynomial to them using the method of least squares, the characteristic for any specific speed pump can be approximated. The use of a 2nd or 3rd degree polynomial is arbitrary, and the one chosen for each case was done after observing a plot of the portion of the characteristic in question against specific speed. A function other than a 2nd or 3rd degree polynomial could be used if it represented the plotted data. This procedure thus uses a relation determined by using all 7 characteristics to approximate that of the pump in the system instead of picking the one known characteristic that has its specific speed closest to the specific speed of the pump actually in the system.

Once data representing the approximate characteristic is determined, it can be put in the form of 12 sixth degree polynomials which are then used in a pump transient analysis computer program to represent the pump operation.

PUMP TRANSIENT ANALYSIS

The method commonly used in the computerized analysis of pipeline transients incorporates the method of characteristics to represent the pipeline and a table containing values of the pump's characteristics (Ref. 2). The table of the pump's characteristics contains values of h, q, α, and β which represent the actual pump operation. In the transient analysis, values for all pump conditions are interpolated from the table so that at each instant of time during the transient, the head and discharge anywhere in the system are known, as well as the pump speed and torque.

Actual pump characteristic data can be put in the form of curves (Ref. 3 and 10) using the following homologous relations:

h/q^2 vs α/q $\qquad$ h/α^2 vs q/α

β/q^2 vs α/q $\qquad$ β/α^2 vs q/α

The four relations above can be graphed to represent each of the three pump zones: normal, energy dissipation, and turbine. The result is 12 curves. A sixth degree polynomial equation was chosen to represent each of the curves by taking 7 points from each curve and solving for the coefficients of the equations.

Data points representing the pump characteristic for any given specific speed are first found by a least squares fit procedure on data from 7 known characteristics of different specific speed pumps. The data from the 7 known characteristics and the 2nd or 3rd degree polynomial resulting from the least squares fitting procedure are shown in Tables 1 through 12. The portion of the pump characteristic in each table is shown on the next page.

Table 1	Normal pump zone, ($0\le\alpha/q\le1$), h/q^2 vs α/q
Table 2	Normal pump zone, ($0\le\alpha/q\le1$), B/q^2 vs α/q
Table 3	Normal pump zone, ($0\le q/\alpha\le1$), h/α^2 vs q/α
Table 4	Normal pump zone, ($0\le q/\alpha\le1$), B/α^2 vs q/α
Table 5	Energy dissipation zone, ($-1\le\alpha/q\le0$), h/q^2 vs α/q
Table 6	Energy dissipation zone, ($-1\le\alpha/q\le0$), B/q^2vs α/q
Table 7	Energy dissipation zone, ($-1\le q/\alpha\le0$), h/α^2vs q/α
Table 8	Energy dissipation zone, ($-1\le q/\alpha\le0$), B/α^2vs q/α
Table 9	Turbine zone, ($0\le\alpha/q\le1$), h/q^2vs α/q
Table 10	Turbine zone, ($0\le\alpha/q\le1$), B/q^2vs α/q
Table 11	Turbine zone, ($0\le q/\alpha\le1$), h/α^2vs q/α
Table 12	Turbine zone, ($0\le q/\alpha\le1$), B/α^2vs q/α

Data was taken from the following 7 known characteristics:

Pump Specific Speed	Reference
1276	3
1700	4
1940	5
3700	6
4600	7
7600	3
13,500	3

Some data is missing from the tables because the original tests were incomplete. The sixth degree polynomial, when used to approximate an actual characteristic, has the value of the ordinate within 0.01 of the actual curve representing the test of a pump. This is an adequate representation, because actual testing does not give accuracy with magnitude 0.01.

To determine the characteristic of any specific speed pump, a relation is derived using a least squares fitting procedure for each of h/α^2, h/q^2, β/α^2, versus Ns at the seven values of α/q and q/α. For instance, the data from Table 3 at $q/\alpha = 0$ are plotted in Figure 1, and a second degree polynomial is fit through the points. One point on a characteristic is defined in Figure 1 (i.e., $q/\alpha = 0$, $h/\alpha^2 = f(Ns)$. The point in this instance is determined by identifying the specific speed of the actual pump in the system. The use of a 2nd degree polynomial as the function to describe the variation of h/α^2 is arbitrary, and could be any type of function which will adequately represent the relation. Second or third degree polynomials were used here, and the choice was made on the basis of observation and experience. There are 7 equations for each table. Each equation along with the corresponding value of q/α or α/q represents a point on the characteristic whose specific speed is Ns. As other known characteristics are added to the data, these relations should be reviewed.

To approximate the unknown characteristic of a centrifugal pump whose specific speed is known, one must first solve the 7 equations under each table. This gives 7 points for each of the 12 areas into which the characteristic is subdivided. Because intermediate values are required during a pump transient analysis, a 6th degree polynomial is derived from the 7 points in each table. These 12 sixth degree polynomials then describe an approximate characteristic of a pump given the specific speed. They are stored in the computer program in the following form:

Pump zone $(0 \leq \alpha/q \leq 1)$

$$h/q^2 = A_1(\alpha/q)^6 + B_1(\alpha/q)^5 + C_1(\alpha/q)^4 + D_1(\alpha/q)^3 + E_1(\alpha/q)^2 + F_1(\alpha/q) + G_1$$

$$B/q^2 = A_2(\alpha/q)^6 + B_2(\alpha/q)^5 + C_2(\alpha/q)^4 + D_2(\alpha/q)^3 + E_2(\alpha/q)^2 + F_2(\alpha/q) + G_2$$

$(0 \leq q/\alpha \leq 1)$

$$h/\alpha^2 = A_3(q/\alpha)^6 + B_3(q/\alpha)^5 + C_3(q/\alpha)^4 + D_3(q/\alpha)^3 + E_3(q/\alpha)^2 + F_3(q/\alpha) + G_3$$

$$B/\alpha^2 = A_4(q/\alpha)^6 + B_4(q/\alpha)^5 + C_4(q/\alpha)^4 + D_4(q/\alpha)^3 + E_4(q/\alpha)^2 + F_4(q/\alpha) + G_4$$

Energy dissipation zone $(-1 \leq \alpha/q \leq 0)$

$$h/q^2 = A_5(\alpha/q)^6 + B_5(\alpha/q)^5 + C_5(\alpha/q)^4 + D_5(\alpha/q)^3 + E_5(\alpha/q)^2 + F_5(\alpha/q) + G_5$$

$$B/q^2 = A_6(\alpha/q)^6 + B_6(\alpha/q)^5 + C_6(\alpha/q)^4 + D_6(\alpha/q)^3 + E_6(\alpha/q)^2 + F_6(\alpha/q) + G_6$$

$(-1 \leq q/\alpha \leq 0)$

$$h/\alpha^2 = A_7(q/\alpha)^6 + B_7(q/\alpha)^5 + C_7(q/\alpha)^4 + D_7(q/\alpha)^3 + E_7(q/\alpha)^2 + F_7(q/\alpha) + G_7$$

$$B/\alpha^2 = A_8(q/\alpha)^6 + B_8(q/\alpha)^5 + C_8(q/\alpha)^4 + D_8(q/\alpha)^3 + E_8(q/\alpha)^2 + F_8(q/\alpha) + G_8$$

Turbine zone $(0 \leq \alpha/q \leq 1)$

$$h/q^2 = A_9(\alpha/q)^6 + B_9(\alpha/q)^5 + C_9(\alpha/q)^4 + D_9(\alpha/q)^3 + E_9(\alpha/q)^2 + F_9(\alpha/q) + G_9$$

$$B/q^2 = A_{10}(\alpha/q)^6 + B_{10}(\alpha/q)^5 + C_{10}(\alpha/q)^4 + D_{10}(\alpha/q)^3 + E_{10}(\alpha/q)2 + F_{10}(\alpha/q) + G_{10}$$

$(0 \leq q/\alpha \leq 1)$

$$h/\alpha^2 = A_{11}(q/\alpha)^6 + B_{11}(q/\alpha)^5 + C_{11}(q/\alpha)^4 + D_{11}(q/\alpha)^3 + E_{11}(q/\alpha)^2 + F_{11}(q/\alpha) + G_{11}$$

$$B/\alpha^2 = A_{12}(q/\alpha)^6 + B_{12}(q/\alpha)^5 + C_{12}(q/\alpha)^4 + D_{12}(q/\alpha)^3 + E_{12}(q/\alpha)^2 + F_{12}(q/\alpha) + G_{12}$$

The coefficients for each 6th degree equation can be determined in the program by solving seven equations in seven unknowns.

EXAMPLE

For purposes of illustration, consider the pump zone, $(0 \le q/\alpha \le 1)$ and the relation $h/\alpha^2 = f(q/\alpha)$. Assume a pump in the system has a rated head, discharge, and speed such that its Ns = 6000. The value of Ns would be determined in the computer program from the input of the pump's rated head, discharge, and speed. The seven equations in Table 3 would then be solved with Ns = 6000 and would result in the following seven points: (Ref. Table 3)

q/α	h/α^2
0	1.768
0.17	1.598
0.33	1.375
0.50	1.190
0.67	1.104
0.83	1.052
1.00	1.000

A sixth degree polynomial is then fit through these seven points, resulting in the following equation:

$$h/\alpha^2 = 11.886(q/\alpha)^6 - 32.051(q/\alpha)^5 + 28.001(q/\alpha)^4 - 6.466(q/\alpha)^3$$
$$- 1.461(q/\alpha)^2 - 0.677(q/\alpha) + 1.768$$

The other 11 equations representing the rest of the pump's characteristics are developed in a similar way.

SUMMARY OF METHOD

The computer program for pump transients will contain 7 equations for each of the 12 areas of pump operation. The equations are shown under each of the 12 tables. For the pump being analyzed, the data read into the program allows the calculation of specific speed $Ns = f(Q_R, H_R, N_R)$. Specific speed is the independent variable of the 7 equations shown under each table. When the equations are solved in the program, 7 points for each of the 12 areas of pump operation are determined. A 6th degree polynomial is then determined for each of these 12 areas using the 7 points from each area, and these equations are used in the transient analysis of the system containing the pump.

RESULTS AND CONCLUSIONS

As more characteristics become available the equations under each table should be re-evaluated to incorporate the additional data points. A least squares procedure was used to fit an equation to the points because there was some scatter (Fig. 1). The scatter arises because given a specific speed, a limited range of pumps can be designed (Ref. 8). If, however, when designing a pump, the criteria were used that given the Ns, the most efficient pump be designed, the relation between the pump's characteristic and Ns as shown in Figure 1 would have no scatter of points (Ref. 9). Because criteria other than designing the most efficient pump must be taken into consideration, there will be scatter. The method proposed here, as well as any other method of approximating a pump's characteristic, should be used only when the actual or model characteristics are not available.

ACKNOWLEDGEMENTS

This paper is based on Reference 10 with additional data added to make it more usable for the engineer involved in determining pump transients.

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Table 1

Normal Pump Zone

$q \geq 0, \alpha \geq 0 \quad (0 \leq \alpha/q \leq 1)$

		α/q						
	Ns	0	0.17	0.33	0.50	0.67	0.83	1.00
h/q^2	1276	-0.53	-0.42	-0.22	-0.04	0.23	0.56	1.00
	1700	-	-	-	-0.05	0.26	0.63	1.00
	1940	-	-	-	-	0.27	0.60	1.00
	3700	-	-	-	-	0.09	0.57	1.00
	4600	-	-	-	-	0.19	0.60	1.00
	7600	-1.56	-1.13	-0.69	-0.35	0.05	0.52	1.00
	13500	-1.00	-0.90	-0.76	-0.50	-0.11	0.37	1.00

α/q	Equation, $h/q^2 = f(Ns)$
0	$h/q^2 = 2.1089 \times 10^{-8} Ns^2 - 3.5005 \times 10^{-4} Ns - 0.1177$
0.17	$h/q^2 = 1.2374 \times 10^{-8} Ns^2 - 2.2210 \times 10^{-4} Ns - 0.1567$
0.33	$h/q^2 = 0.5109 \times 10^{-8} Ns^2 - 1.1967 \times 10^{-4} Ns - 0.0756$
0.50	$h/q^2 = 0.1995 \times 10^{-8} Ns^2 - 0.6776 \times 10^{-4} Ns + 0.0590$
0.67	$h/q^2 = 0.0532 \times 10^{-8} Ns^2 - 0.3772 \times 10^{-4} Ns + 0.3034$
0.83	$h/q^2 = -0.1492 \times 10^{-8} Ns^2 + 0.0338 \times 10^{-4} Ns + 0.5938$
1.00	$h/q^2 = 1.0000$

Table 2

Normal Pump Zone

$q \geq 0, \alpha \geq 0 \quad (0 \leq \alpha/q \leq 1)$

		α/q						
	Ns	0	0.17	0.33	0.50	0.67	0.83	1.00
β/q^2	1276	-0.30	-0.16	0.01	0.20	0.43	0.70	1.00
	1700	-	-	-	-	0.60	0.77	1.00
	1940	-	-	-	-	-	-	1.00
	3700	-	-	-	-	0.36	0.70	1.00
	4600	-	-	-	-	0.32	0.72	1.00
	7600	-1.56	-0.93	-0.47	-0.11	0.29	0.67	1.00
	13500	-0.56	-0.62	-0.60	-0.39	0.03	0.51	1.00

α/q	Equation, $\beta/q^2 = f(Ns)$
0	$B/q^2 = 3.0165\text{x}10^{-8}Ns^2 - 4.6698\text{x}10^{-4}Ns + 0.2468$
0.17	$B/q^2 = 1.4259\text{x}10^{-8}Ns^2 - 2.4832\text{x}10^{-4}Ns + 0.1336$
0.33	$B/q^2 = 0.4407\text{x}10^{-8}Ns^2 - 1.1502\text{x}10^{-4}Ns + 0.1496$
0.50	$B/q^2 = 0.0128\text{x}10^{-8}Ns^2 - 0.5015\text{x}10^{-4}Ns + 0.2638$
0.67	$B/q^2 = 0.0395\text{x}10^{-8}Ns^2 - 0.4378\text{x}10^{-4}Ns + 0.5562$
0.83	$B/q^2 = -0.1422\text{x}10^{-8}Ns^2 + 0.0304\text{x}10^{-4}Ns + 0.7281$
1.00	$B/q^2 = 1.0000$

Table 3

Normal Pump Zone

$q \geq 0, \alpha \geq 0 \quad (0 \leq q/\alpha \leq 1)$

		q/α						
	Ns	0	0.17	0.33	0.50	0.67	0.83	1.00
h/α^2	1276	1.29	1.29	1.27	1.23	1.18	1.10	1.00
	1700	1.08	1.08	1.09	1.09	1.10	1.06	1.00
	1940	1.41	1.35	1.30	1.25	1.19	1.11	1.00
	3700	1.40	1.36	1.26	1.09	1.04	1.05	1.00
	4600	1.68	1.56	1.42	1.27	1.17	1.07	1.00
	7600	1.96	1.71	1.40	1.21	1.12	1.06	1.00
	13500	2.73	2.33	2.02	1.76	1.57	1.36	1.00

q/α	Equation, $h/\alpha^2 = f(Ns)$
0	$h/\alpha^2 = 0.0870\text{x}10^{-8}Ns^2 + 1.1138\text{x}10^{-4}Ns + 1.0688$
0.17	$h/\alpha^2 = 0.1324\text{x}10^{-8}Ns^2 + 0.7126\text{x}10^{-4}Ns + 1.1229$
0.33	$h/\alpha^2 = 0.4333\text{x}10^{-8}Ns^2 + 0.0001\text{x}10^{-4}Ns + 1.2190$
0.50	$h/\alpha^2 = 0.6344\text{x}10^{-8}Ns^2 - 0.4847\text{x}10^{-4}Ns + 1.2524$
0.67	$h/\alpha^2 = 0.6186\text{x}10^{-8}Ns^2 - 0.5887\text{x}10^{-4}Ns + 1.2341$
0.83	$h/\alpha^2 = 0.4189\text{x}10^{-8}Ns^2 - 0.4103\text{x}10^{-4}Ns + 1.1474$
1.00	$h/\alpha^2 = 1.0000$

Table 4

Normal Pump Zone

$q \geq 0, \ \alpha \geq 0 \quad (0 \leq q/\alpha \leq 1)$

		q/α						
	Ns	0	0.17	0.33	0.50	0.67	0.83	1.00
β/α^2	1276	0.44	0.54	0.66	0.77	0.86	0.94	1.00
	1700	0.48	0.53	0.61	0.69	0.79	0.90	1.00
	1940	-	-	-	-	-	-	1.00
	3700	0.79	0.81	0.82	0.78	0.82	0.92	1.00
	4600	1.07	0.97	0.91	0.88	0.89	0.94	1.00
	7600	1.48	1.18	0.98	0.91	0.94	0.98	1.00
	13500	1.95	1.67	1.35	1.13	1.07	1.05	1.00

q/α	Equation, $B/\alpha^2 = f(Ns)$
0	$B/\alpha^2 = -0.6799 \times 10^{-8} Ns^2 + 2.2739 \times 10^{-4} Ns + 0.1246$
0.17	$B/\alpha^2 = -0.2820 \times 10^{-8} Ns^2 + 1.3533 \times 10^{-4} Ns + 0.3510$
0.33	$B/\alpha^2 = -0.0789 \times 10^{-8} Ns^2 + 0.6909 \times 10^{-4} Ns + 0.5523$
0.50	$B/\alpha^2 = 0.0218 \times 10^{-8} Ns^2 + 0.2942 \times 10^{-4} Ns + 0.6911$
0.67	$B/\alpha^2 = 0.0581 \times 10^{-8} Ns^2 + 0.1225 \times 10^{-4} Ns + 0.8019$
0.83	$B/\alpha^2 = 0.0463 \times 10^{-8} Ns^2 + 0.0425 \times 10^{-4} Ns + 0.9105$
1.00	$B/\alpha^2 = 1.0000$

Table 5

Energy Dissipation Zone

$q \leq 0, \alpha \geq 0 \quad (-1 \leq \alpha/q \leq 0)$

		α/q						
	Ns	0	-0.17	-0.33	-0.50	-0.67	-0.83	-1.00
h/q^2	1276	0.69	0.79	0.90	1.08	1.30	1.62	1.99
	1700	0.77	0.87	0.99	1.14	1.35	1.58	1.89
	1940	-	-	-	-	-	-	-
	3700	1.09	1.27	1.48	1.66	1.94	2.26	2.68
	4600	-	-	-	-	-	-	-
	7600	2.17	2.70	3.20	3.72	4.20	4.73	5.27
	13,500	1.08	1.48	2.02	2.70	3.60	4.82	6.29

/q	Equation, $h/q^2 = f(Ns)$
0	$h/q^2 = -5.3028 \times 10^{-12} Ns^3 + 8.4756 \times 10^{-8} Ns^2 - 1.5591 \times 10^{-4} Ns + 0.7851$
-0.17	$h/q^2 = -6.9699 \times 10^{-12} Ns^3 + 11.4708 \times 10^{-8} Ns^2 - 2.3874 \times 10^{-4} Ns + 0.9463$
-0.33	$h/q^2 = -7.9623 \times 10^{-12} Ns^3 + 13.2437 \times 10^{-8} Ns^2 - 2.6603 \times 10^{-4} Ns + 1.0652$
-0.50	$h/q^2 = -9.5911 \times 10^{-12} Ns^3 + 16.6633 \times 10^{-8} Ns^2 - 4.0247 \times 10^{-4} Ns + 1.3625$
-0.67	$h/q^2 = -9.7667 \times 10^{-12} Ns^3 + 17.2933 \times 10^{-8} Ns^2 - 4.0384 \times 10^{-4} Ns + 1.5671$
-0.83	$h/q^2 = -9.9354 \times 10^{-12} Ns^3 + 18.2964 \times 10^{-8} Ns^2 - 4.4174 \times 10^{-4} Ns + 1.8828$
-1.00	$h/q^2 = -9.0057 \times 10^{-12} Ns^3 + 17.2356 \times 10^{-8} Ns^2 - 3.7935 \times 10^{-4} Ns + 2.1562$

Table 6

Energy Dissipation Zone

$q \leq 0, \alpha \geq 0 \quad (-1 \leq \alpha/q \leq 0)$

		α/q						
	Ns	0	-0.17	-0.33	-0.50	-0.67	-0.83	-1.00
B/q^2	1276	0.86	0.91	0.95	0.98	1.00	1.02	1.04
	1700	1.13	1.18	1.25	1.32	1.37	1.41	1.44
	1940	-	-	-	-	-	-	-
	3700	1.20	1.38	1.55	1.72	1.96	2.19	2.42
	4600	-	-	-	-	-	-	-
	7600	2.10	2.57	3.05	3.40	3.68	3.95	4.22
	13.500	0.67	1.07	1.60	2.25	3.16	4.30	5.52

β/q	Equation, $B/q^2 = f(Ns)$
0	$B/q^2 = -5.1269\text{x}10^{-12}Ns^3 + 8.0581\text{x}10^{-8}Ns^2 - 1.8418\text{x}10^{-4}Ns + 1.0857$
-0.17	$B/q^2 = -6.1144\text{x}10^{-12}Ns^3 + 9.6169\text{x}10^{-8}Ns^2 - 1.8674\text{x}10^{-4}Ns + 1.1089$
-0.33	$B/q^2 = -7.0421\text{x}10^{-12}Ns^3 + 11.2035\text{x}10^{-8}Ns^2 - 1.9509\text{x}10^{-4}Ns + 1.1426$
-0.50	$B/q^2 = -6.8531\text{x}10^{-12}Ns^3 + 10.7919\text{x}10^{-8}Ns^2 - 1.2201\text{x}10^{-4}Ns + 1.0914$
-0.67	$B/q^2 = -5.0053\text{x}10^{-12}Ns^3 + 7.1744\text{x}10^{-8}Ns^2 + 1.1473\text{x}10^{-4}Ns + 0.8516$
-0.83	$B/q^2 = -2.8710\text{x}10^{-12}Ns^3 + 3.2554\text{x}10^{-8}Ns^2 + 3.5758\text{x}10^{-4}Ns + 0.6043$
-1.00	$B/q^2 = -0.6232\text{x}10^{-12}Ns^3 - 0.8140\text{x}10^{-8}Ns^2 + 6.0675\text{x}10^{-4}Ns + 0.3463$

Table 7

Energy Dissipation Zone

$q \leq 0, \quad \alpha \geq 0 \quad (-1 \leq q/\alpha \leq 0)$

		q/α						
	Ns	0	-0.17	-0.33	-0.50	-0.67	-0.83	-1.00
	1276	1.29	1.31	1.35	1.43	1.56	1.73	1.99
	1700	1.08	1.09	1.12	1.21	1.40	1.64	1.89
	1940	1.41	-	-	-	-	-	-
h/q^2	3700	1.40	1.45	1.55	1.66	1.86	2.20	2.68
	4600	1.68	-	-	-	-	-	-
	7600	1.96	2.16	2.43	2.83	3.41	4.19	5.27
	13,500	2.73	3.27	3.86	4.47	5.07	5.81	6.29

q/α	Equation, $h/\alpha^2 = f(Ns)$
0	$h/\alpha^2 = 0.0870 x 10^{-8} Ns^2 + 1.1138 x 10^{-4} Ns + 1.0688$
-0.17	$h/\alpha^2 = 0.3941 x 10^{-8} Ns^2 + 1.1449 x 10^{-4} Ns + 1.0164$
-0.33	$h/\alpha^2 = 0.5391 x 10^{-8} Ns^2 + 1.3913 x 10^{-4} Ns + 1.0107$
-0.50	$h/\alpha^2 = 0.5076 x 10^{-8} Ns^2 + 1.8965 x 10^{-4} Ns + 1.0043$
-0.67	$h/\alpha^2 = 0.1151 x 10^{-8} Ns^2 + 2.8847 x 10^{-4} Ns + 0.9981$
-0.83	$h/\alpha^2 = -0.5840 x 10^{-8} Ns^2 + 4.4086 x 10^{-4} Ns + 0.9666$
-1.00	$h/\alpha^2 = -9.0057 x 10^{-12} Ns^3 + 17.2356 x 10^{-8} Ns^2 - 3.7935 x 10^{-4} Ns + 2.1562$

Table 8

Energy Dissipation Zone

$q \leq 0,\ \alpha \geq 0\ (-1 \leq q/\alpha \leq 0)$

		q/α						
	Ns	0	-0.17	-0.33	-0.50	-0.67	-0.83	-1.00
B/α^2	1276	0.44	0.38	0.38	0.43	0.53	0.74	1.04
	1700	0.48	0.44	0.43	0.49	0.72	1.03	1.44
	1940	-	-	-	-	-	-	-
	3700	0.79	0.83	0.96	1.11	1.35	1.88	2.42
	4600	1.07	-	-	-	-	-	-
	7600	1.48	1.58	1.72	2.03	2.47	3.23	4.22
	13,500	1.95	2.37	2.94	3.67	4.38	4.99	5.52

q/α	Equation, $B/\alpha^2 = f(Ns)$
0	$B/\alpha^2 = -0.6799\text{x}10^{-8}Ns^2 + 2.2739\text{x}10^{-4}Ns + 0.1246$
-0.17	$B/\alpha^2 = -0.4275\text{x}10^{-8}Ns^2 + 2.2813\text{x}10^{-4}Ns + 0.0735$
-0.33	$B/\alpha^2 = -0.1311\text{x}10^{-8}Ns^2 + 2.2909\text{x}10^{-4}Ns + 0.0811$
-0.50	$B/\alpha^2 = 0.0910\text{x}10^{-8}Ns^2 + 2.5149\text{x}10^{-4}Ns + 0.1019$
-0.67	$B/\alpha^2 = 0.0959\text{x}10^{-8}Ns^2 + 2.9678\text{x}10^{-4}Ns + 0.1918$
-0.83	$B/\alpha^2 = -0.8172\text{x}10^{-8}Ns^2 + 4.6254\text{x}10^{-4}Ns + 0.2265$
-1.00	$B/\alpha^2 = -0.6232\text{x}10^{-12}Ns^3 - 0.8140\text{x}10^{-8}Ns^2 + 6.0675\text{x}10^{-4}Ns + 0.3463$

Table 9

Turbine Zone

$q/\leq 0,\ \alpha \leq 0\ (0 \leq \alpha/q \leq 1)$

		α/q						
	Ns	0	0.17	0.33	0.50	0.67	0.83	1.00
h/q^2	1276	0.69	0.64	0.63	0.66	0.73	0.85	1.01
	1700	0.77	0.71	0.70	0.70	0.73	0.83	0.94
	1940	-	-	-	-	-	0.72	0.83
	3700	1.09	1.01	0.92	0.87	0.81	0.79	0.79
	4600	-	-	-	-	-	-	-
	7600	2.17	1.60	1.10	0.77	0.60	0.47	0.38
	13,500	1.08	0.81	0.78	0.77	0.67	0.44	0.13

α/q	Equation, $h/q^2 = f(Ns)$
0	$h/q^2 = -5.3028\text{x}10^{-12} Ns^3 + 8.4756\text{x}10^{-8} Ns^2 - 1.5591\text{x}10^{-4} Ns + 0.7851$
0.17	$h/q^2 = -2.3634\text{x}10^{-12} Ns^3 + 2.9630\text{x}10^{-8} Ns^2 + 0.5078\text{x}10^{-4} Ns + 0.5395$
0.33	$h/q^2 = -1.0533\text{x}10^{-8}\ Ns^2 + 1.6727\text{x}10^{-4} Ns + 0.4408$
0.50	$h/q^2 = -0.2722\text{x}10^{-8}\ Ns^2 + 0.4523\text{x}10^{-4} Ns + 0.6433$
0.67	$h/q^2 = 0.1252\text{x}10^{-8}\ Ns^2 - 0.2692\text{x}10^{-4} Ns + 0.7929$
0.83	$h/q^2 = 0.3005\text{x}10^{-8}\ Ns^2 - 0.7827\text{x}10^{-4} Ns + 0.9398$
1.00	$h/q^2 = 0.3575\text{x}10^{-8}\ Ns^2 - 1.2284\text{x}10^{-4} Ns + 1.1323$

Table 10

Turbine Zone

$q \leq 0, \alpha \leq 0 \ (0 \leq \alpha/q \leq 1)$

		α/q						
	Ns	0	0.17	0.33	0.50	0.67	0.83	1.00
B/q^2	1276	0.86	0.81	0.76	0.69	0.62	0.54	0.46
	1700	1.13	1.03	0.95	0.88	0.83	0.79	0.73
	1940	-	-	-	-	-	-	-
	3700	1.20	1.09	0.96	0.84	0.70	0.56	0.45
	4600	-	-	-	-	-	-	-
	7600	2.10	1.57	1.15	0.83	0.56	0.31	0
	13,500	0.67	0.43	0.46	0.63	0.54	0.18	-0.15

α/q	Equation, $B/q^2 = f(Ns)$
0	$B/q^2 = -5.1269 \times 10^{-12} Ns^3 + 8.0581 \times 10^{-8} Ns^2 - 1.8418 \times 10^{-4} Ns + 1.0857$
0.17	$B/q^2 = -2.7431 \times 10^{-12} Ns^3 + 3.7035 \times 10^{-8} Ns^2 - 0.3342 \times 10^{-4} Ns + 0.8813$
0.33	$B/q^2 = -1.2870 \times 10^{-8} Ns^2 + 1.6269 \times 10^{-4} Ns + 0.6169$
0.50	$B/q^2 = -0.3919 \times 10^{-8} Ns^2 + 0.4585 \times 10^{-4} Ns + 0.7216$
0.67	$B/q^2 = -0.0954 \times 10^{-8} Ns^2 - 0.3050 \times 10^{-4} Ns + 0.7701$
0.83	$B/q^2 = 0.1887 \times 10^{-8} Ns^2 - 0.6932 \times 10^{-4} Ns + 0.7637$
1.00	$B/q^2 = 0.4065 \times 10^{-8} Ns^2 - 1.2508 \times 10^{-4} Ns + 0.7829$

Table 11

Turbine Zone

$q \leq 0, \alpha \leq 0$ ($0 \leq q/\alpha \leq 1$)

		q/α						
	Ns	0	0.17	0.33	0.50	0.67	0.83	1.00
h/α^2	1276	0.63	0.66	0.69	0.73	0.79	0.88	1.01
	1700	-	-	0.63	0.67	0.73	0.82	0.94
	1940	-	-	-	0.65	0.68	0.73	0.83
	3700	-	-	-	-	0.56	0.67	0.79
	4600	-	-	-	-	-	-	-
	7600	-0.67	-0.46	-0.28	-0.04	0.06	0.19	0.38
	13,500	-2.20	-1.55	-1.14	-0.86	-0.60	-0.28	0.13

q/α	Equation, $h/\alpha^2 = f(Ns)$
0	$h/\alpha^2 = -0.4398 \times 10^{-8} Ns^2 - 1.6653 \times 10^{-4} Ns + 0.8497$
0.17	$h/\alpha^2 = -0.0625 \times 10^{-8} Ns^2 - 1.7155 \times 10^{-4} Ns + 0.8799$
0.33	$h/\alpha^2 = 0.0651 \times 10^{-8} Ns^2 - 1.5960 \times 10^{-4} Ns + 0.8958$
0.50	$h/\alpha^2 = -0.1458 \times 10^{-8} Ns^2 - 1.0806 \times 10^{-4} Ns + 0.8646$
0.67	$h/\alpha^2 = -0.0427 \times 10^{-8} Ns^2 - 1.0702 \times 10^{-4} Ns + 0.9187$
0.83	$h/\alpha^2 = 0.1323 \times 10^{-8} Ns^2 - 1.1355 \times 10^{-4} Ns + 1.0063$
1.00	$h/\alpha^2 = 0.3575 \times 10^{-8} Ns^2 - 1.2284 \times 10^{-4} Ns + 1.1323$

Table 12

Turbine Zone

$q \leq 0, \alpha \leq 0 \quad (0 \leq q/\alpha \leq 1)$

		q/α						
	Ns	0	0.17	0.33	0.50	0.67	0.83	1.00
B/α^2	1276	-0.67	-0.37	-0.16	-0.03	0.10	0.24	0.46
	1700	-	-	-0.10	0.05	0.23	0.48	0.73
	1940	-	-	-	-	-	-	-
	3700	-	-	-	-	-0.10	0.18	0.45
	4600	-	-	-	-	-	-	-
	7600	-1.50	-1.09	-0.79	-0.63	-0.46	-0.29	0
	13,500	-2.33	-1.58	-1.30	-1.10	-0.84	-0.55	-0.15

q/α	Equation, $B/\alpha^2 = f(Ns)$
0	$B/\alpha^2 = -0.0772 \times 10^{-8} Ns^2 - 1.2440 \times 10^{-4} Ns - 0.5100$
0.17	$B/\alpha^2 = 0.2520 \times 10^{-8} Ns^2 - 1.3622 \times 10^{-4} Ns - 0.2003$
0.33	$B/\alpha^2 = 0.1513 \times 10^{-8} Ns^2 - 1.1999 \times 10^{-4} Ns + 0.0423$
0.50	$B/\alpha^2 = 0.1755 \times 10^{-8} Ns^2 - 1.1862 \times 10^{-4} Ns + 0.1792$
0.67	$B/\alpha^2 = 0.2856 \times 10^{-8} Ns^2 - 1.2598 \times 10^{-4} Ns + 0.3384$
0.83	$B/\alpha^2 = 0.3540 \times 10^{-8} Ns^2 - 1.3053 \times 10^{-4} Ns + 0.5543$
1.00	$B/\alpha^2 = 0.4065 \times 10^{-8} Ns^2 - 1.2508 \times 10^{-4} Ns + 0.7829$

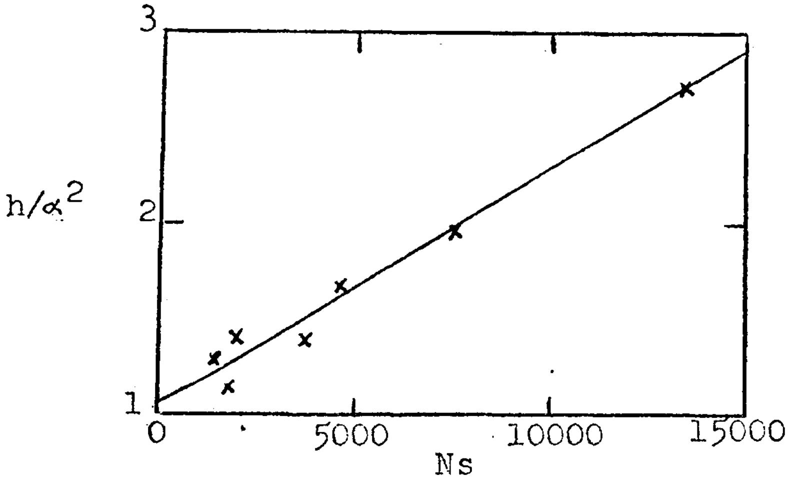

FIGURE 1

Data from TABLE 3 at $q/\alpha = 0$

Ns	1276	1700	1940	3700	4600	7600	13500
h/α^2	1.29	1.08	1.41	1.40	1.68	1.96	2.73

has a 2nd degree polynomial fit through it resulting in the following equation:

$$h/\alpha^2 = 0.0870\text{X}10^{-8}\text{Ns}^2 + 1.1138\text{X}10^{-4}\text{Ns} + 1.0688$$

APPENDIX

Nomenclature

H	Pressure head
H_R	Rated pressure head of a pump
h	Dimensionless pressure head H/H_R
N	Rotational speed of a pump
N_R	Rated rotational speed of a pump
N_S	Specific pump speed $\frac{N_R \sqrt{Q_R}}{(H_R)^{3/4}}$
Q	Discharge
Q_R	Rated discharge of a pump
q	Dimensionless discharge Q/Q_R
T	Torque on a pump
T_R	Rated torque of a pump
α	Dimensionless speed ratio N/N_R
β	Dimensionless torque ratio T/T_R
A_n	Constant coefficients in the 6th degree polynomial equations representing a pump's characteristics
B_n	
C_n	
D_n	
E_n	
F_n	
G_n	

Note: "Rated" refers to the point of best efficiency at normal speed.

DESCRIPTION OF PROGRAM

The main program uses the method of characteristics as described in Reference 2 to compute the transients in the pipes. This involves using two equations; one from the downstream direction and the other from the upstream direction, as well as a continuity equation for head, and another equation for discharge. These four equations are solved simultaneously for head and discharge at the point of interest. When a pipe boundary is a pump, the head and discharge at the pump are a function of the head and discharge from the upstream and downstream pipes, the α, β relation (function of WR^2), and the pump's characteristic relation. Thus four relations are used to solve for α, β, q, and h of the pump at any specific time. At each time increment the pump characteristic relation uses two of the twelve equations determined by the method shown in this thesis. The two equations to be used at any given time are determined by the zone of operation in which the pump happens to be.

Two subroutines in the program use the results of this thesis. They are the PUMPSB subroutine and the COEFP subroutine. Following is a description and listing of each.

PUMPSB

The pump subroutine (PUMPSB(I), I representing the pump in question) has two main functions; (1) to determine the initial operating condition of the pump, and (2) to determine the operating condition at any time after a power failure. The discussion here will be concerned with determining the operating condition of the pump after power failure. The upstream pipe characteristic has the form:

$$QP(K,J) + CF2 \times HP(K,J) = CF1.$$

The downstream pipe characteristic has the form:

$QP(K,J) + CB2 \times HP(K,J) = CB1$, where (K) represents the pipe of interest and (J) represents the segment in pipe (k) that is closest to the pump. At statement 20100 the pump speed is estimated using the speed at the previous time increment (ALPHAP(I), I is the pump under consideration) and an estimated change in speed (DALPP(I)). The discharge is then estimated (QPPI) using a similar procedure. This determines the value of α/q used in the thesis so that the zone of operation and the appropriate 6th degree polynomial coefficients can be stored in A1, B1, C1, D1, E1, F1, and G1. U and D are then substituted for α and q (ALI and QPPI).

Statement 20300 computes the head across the pump (HPP(I)), and the next statement computes the torque on the pump (BETAI) (the h and β used in the paper).

The downstream pipe head (HP(JDPN,(1)) and discharge (QP(JDPN, 1)) are then calculated using an equation derived from the characteristic equations and the continuity equations. This head and discharge are compared with the discharge and speed assumed at the beginning of the subroutine. If the error is too large, the procedure is repeated, and continues iterating until the error is acceptable. Values of α, β, q, and h for the pump, and the head and discharge of the downstream and upstream pipe are then established for the specified time (TIME). The subroutine is used once each time increment so a history of the transient is known.

COEFP

The subroutine (COEFP(I) I represents the pump in question) computes the coefficients of the 12 sixth degree equations which represent a pump's characteristics. The specific speed (SNS(I)) of the pump is determined in the main program from the values read in representing the pump, i.e., rated head, discharge, and speed. X1, X2, ... X6 are the values of the absissa in the paper, and the Y0, Y1, ... Y6 are determined from the appropriate equation for each table. From statement 19200 on, the Gaussian elimination method is used to determine the coefficients of a 6th degree polynomial which will go through the 7 points (X,Y) of the characteristic. The coefficients have the form AHQP(I,J), BHQP(I,J), CHQP(I,J), DHQP(I,J), and so forth. These are common variables to the program so they can be used in the subroutine that computes the pump transient.

The variable NSNS(I) can have values of 0, 1276, 7600, or 13,500. If the value of 0 is stored, the subroutine will produce characteristics as outlined in the paper. If any one of the other three are stored, the corresponding original characteristic is reproduced. Thus the program has the option of using a specific known characteristic or determining a characteristic using the procedure outlined in the thesis.

15.4I

```
      SUBROUTINE PUMPSB(I,JDPN,JUPN,JUPNN)
C
C                         SUBROUTINE TO COMPUTE H [ Q AT A PUMP
C
      COMMON/GSUB1/  Q(20,200), H(20,200), QP(20,200), HP(20,200)
         COMMON/GSUB2/ PIPDIA(20), PFRICT(20), NSEG(20), DT, TIME
         COMMON/CDT/ PLENGH(20), PCELET(20), NPIPES
         COMMON/CPP/QRATEP(10),HRATEP(10),SRATEP(10),
     1              WR2RP(10),AK1P(10),ALPHAP(10),BETAP(10),
     2              QPP(10),HPP(10),DALPP(10),DQPP(10),
     3               IDPNP(10), IUPNP(10)
C
         COMMON/CPPC/AHQP(10,3),BHQP(10,3),CHQP(10,3),
     1               DHQP(10,3),EHQP(10,3),FHQP(10,3),GHQP(10,3),
     2               AHAP(10,3),BHAP(10,3),CHAP(10,3),
     3               DHAP(10,3),EHAP(10,3),FHAP(10,3),GHAP(10,3),
     4               ABQP(10,3),BBQP(10,3),CBQP(10,3),
     5               DBQP(10,3),EBQP(10,3),FBQP(10,3),GBQP(10,3),
     6               ABAP(10,3),BBAP(10,3),CBAP(10,3),
     7               DBAP(10,3),EBAP(10,3),FBAP(10,3),GBAP(10,3),
     8               SNS(10), NSNS(10)
C
C
C  AT T=0 ASSUME ALPHA=1- GET STEADY STATE PUMPING
C
        CF2=.7854*PIPDIA(JUPN)**2*32.2/PCELET(JUPN)
        CF1=Q(JUPN,JUPNN-1)+CF2*H(JUPN,JUPNN-1)
     1     -DT*PFRICT(JUPN)*ABS(Q(JUPN,JUPNN-1))*Q(JUPN,JUPNN-1)
     2     /(2.*PIPDIA(JUPN)**3*.7854)
       CB2=-.7854*PIPDIA(JDPN)**2*32.2/PCELET(JDPN)
        CB1=Q(JDPN,2)+CB2*H(JDPN,2)
     1     -DT*PFRICT(JDPN)*ABS(Q(JDPN,2))*Q(JDPN,2)
     2     /(2.*PIPDIA(JDPN)**3*.7854)
      IF(TIME-.0001)20010,20010,20100
20010   QPP1=Q(JDPN,1)/QRATEP(I)
20040 IF(QPP1-1)20060,20050,20050
20050   A1=AHQP(I,1)
        B1=BHQP(I,1)
        C1=CHQP(I,1)
        D1=DHQP(I,1)
        E1=EHQP(I,1)
        F1=FHQP(I,1)
        G1=GHQP(I,1)
        A2=ABQP(I,1)
        B2=BBQP(I,1)
        C2=CBQP(I,1)
        D2=DBQP(I,1)
        E2=EBQP(I,1)
        F2=FBQP(I,1)
        G2=GBQP(I,1)
        QA=QPP1
      GO TO 20070
20060   A1=AHAP(I,1)
        B1=BHAP(I,1)
        C1=CHAP(I,1)
```

```
             D1=DHAP(I,1)
             E1=EHAP(I,1)
             F1=FHAP(I,1)
             G1=GHAP(I,1)
             A2=ABAP(I,1)
             B2=BBAP(I,1)
             C2=CBAP(I,1)
             D2=DBAP(I,1)
             E2=EBAP(I,1)
             F2=FBAP(I,1)
             G2=GBAP(I,1)
             QA=1./QPP1
       GO TO 20071
20070        HPP(I)=A1/   QA**4+B1/   QA**3+C1/   QA**2+D1/   QA+
     1              E1        +F1*QA      +G1*QA**2
       GO TO 20072
20071        HPP(I)=A1/QA**6+B1/QA**5+C1/QA**4+D1/QA**3+E1/QA**2
     1              +F1/QA+G1
20072        HP(JDPN,1)=((CF1-CB1)/CF2+HRATEP(I)*HPP(I))/(1.-CB2/CF2)
            QPP2=(CB1-CB2*HP(JDPN,1))/QRATEP(I)
        WRITE(61,20075)QPP1,QPP2,HPP(I),HP(JDPN,1)
20075   FORMAT(4E12.5)
         IF(ABS(QPP1-QPP2)-.0004)20090,20090,20080
20080        QPP1=QPP2
         GO TO 20040
20090        HP(JUPN,JUPNN)=(CF1-QPP2*QRATEP(I))/CF2
             QP(JUPN,JUPNN)=QPP2*QRATEP(I)
             ALPHAP(I)=1.
      IF(QPP1-1.)20095,20095,20097
20095        BETAP(I)=A2/QA**6+B2/QA**5+C2/QA**4+D2/QA**3+E2/QA**2
     1                +F2/QA+G2
       GO TO 20098
20097        BETAP(I)=A2/QA**4+B2/QA**3+C2/QA**2+D2/QA+
     1                E2+F2*QA+G2*QA**2
20098        DALPP(I)=-.003
             DQPP(I)=-.002
             QP(JDPN,1)    =QPP2*QRATEP(I)
             QPP(I)=QPP2
           RETURN
C
C
C   DO TRANSIENT PUMP CALCULATIONS
C
20100        AL1=ALPHAP(I)+DALPP(I)
             QPP1=QPP(I)+DQPP(I)
20110    IF(AL1/QPP1)20160,20120,20120
20120    IF(AL1)20190,20130,20130
20130    IF(AL1/QPP1-1.)20140,20140,20150
20140        A1=AHQP(I,1)
             B1=BHQP(I,1)
             C1=CHQP(I,1)
             D1=DHQP(I,1)
             E1=EHQP(I,1)
             F1=FHQP(I,1)
             G1=GHQP(I,1)
```

```
15.41        PUMPSB
                    A2=ABQP(I,1)
                    B2=BBQP(I,1)
                    C2=CBQP(I,1)
                    D2=DBQP(I,1)
                    E2=EBQP(I,1)
                    F2=FBQP(I,1)
                    G2=GBQP(I,1)
                    U=AL1
                    D=QPP1
                GO TO 20300
    C
    C      PUMP ZONE Q/A LESS 1
    C
    20150           A1=AHAP(I,1)
                    B1=BHAP(I,1)
                    C1=CHAP(I,1)
                    D1=DHAP(I,1)
                    E1=EHAP(I,1)
                    F1=FHAP(I,1)
                    G1=GHAP(I,1)
                    A2=ABAP(I,1)
                    B2=BBAP(I,1)
                    C2=CBAP(I,1)
                    D2=DBAP(I,1)
                    E2=EBAP(I,1)
                    F2=FBAP(I,1)
                    G2=GBAP(I,1)
                    U=QPP1
                    D=AL1
                GO TO 20300
    C
    C      ENERGY DISS ZONE A/Q LESS 1
    C
    20160       IF(AL1/QPP1+1.)20180,20180,20170
    20170           A1=AHQP(I,2)
                    B1=BHQP(I,2)
                    C1=CHQP(I,2)
                    D1=DHQP(I,2)
                    E1=EHQP(I,2)
                    F1=FHQP(I,2)
                    G1=GHQP(I,2)
                    A2=ABQP(I,2)
                    B2=BBQP(I,2)
                    C2=CBQP(I,2)
                    D2=DBQP(I,2)
                    E2=EBQP(I,2)
                    F2=FBQP(I,2)
                    G2=GBQP(I,2)
                    U=AL1
                    D=QPP1
                GO TO 20300
    C
    C      ENERGY DISS ZONE Q/A LESS 1
    C
    20180           A1=AHAP(I,2)
```

```
15.4I        PJMPSB

                  B1=BHAP(I,2)
                  C1=CHAP(I,2)
                  D1=DHAP(I,2)
                  E1=EHAP(I,2)
                  F1=FHAP(I,2)
                  G1=GHAP(I,2)
                  A2=ABAP(I,2)
                  B2=BBAP(I,2)
                  C2=CBAP(I,2)
                  D2=DBAP(I,2)
                  E2=EBAP(I,2)
                  F2=FBAP(I,2)
                  G2=GBAP(I,2)
                  U=QPP1
                  D=AL1
              GO TO 20300
     C
     C      TURBINE ZONE A/Q LESS 1
     C
     20190    IF(AL1/QPP1-1.)20200,20200,20210
     20200        A1=AHQP(I,3)
                  B1=BHQP(I,3)
                  C1=CHQP(I,3)
                  D1=DHQP(I,3)
                  E1=EHQP(I,3)
                  F1=FHQP(I,3)
                  G1=GHQP(I,3)
                  A2=ABQP(I,3)
                  B2=BBQP(I,3)
                  C2=CBQP(I,3)
                  D2=DBQP(I,3)
                  E2=EBQP(I,3)
                  F2=FBQP(I,3)
                  U=AL1
                  D=QPP1
              GO TO 20300
     C
     C      TURBINE ZONE Q/A LESS 1
     C
     20210        A1=AHAP(I,3)
                  B1=BHAP(I,3)
                  C1=CHAP(I,3)
                  D1=DHAP(I,3)
                  E1=EHAP(I,3)
                  F1=FHAP(I,3)
                  G1=GHAP(I,3)
                  A2=ABAP(I,3)
                  B2=BBAP(I,3)
                  C2=CBAP(I,3)
                  D2=DBAP(I,3)
                  E2=EBAP(I,3)
                  F2=FBAP(I,3)
                  G2=GBAP(I,3)
                  U=QPP1
                  D=AL1
```

15.4I PUMPSB

```
 C
 C     CALC. HEAD ACROSS PUMP
 C
 20300        HPP(I)=A1*U**6/D**4 +B1*U**5/D**3 + C1*U**4/D**2
     1              +D1*U**3/D +E1*U*U +F1*U*D +G1*D*D
              BETA1= A2*U**6/D**4 +B2*U**5/D**3 + C2*U**4/D**2
     1              +D2*U**3/D +E2*U*U +F2*U*D +G2*D*D
              HP(JDPN,1)=((CF1-CB1)/CF2+HRATEP(I)*HPP(I))/(1.-CB2/CF2)
              QP(JDPN,1)=CB1-CB2*HP(JDPN,1)
          IF(ABS(QP(JDPN,1)-QPP1*QRATEP(I))-.0060)20320,20320,20310
 20310        QPP1=QP(JDPN,1)/QRATEP(I)
             AL1=-AK1P(I)*(BETA1+BETAP(I))*DT+ALPHAP(I)
          GO TO 20110
 20320        QP(JUPN,JUPNN)=QP(JDPN,1)
              HP(JUPN,JUPNN)=HP(JDPN,1)-HPP(I)*HRATEP(I)
              DALPP(I)=AL1-ALPHAP(I)
              ALPHAP(I)=AL1
              BETAP(I)=BETA1
              DQPP(I)=QPP1-QPP(I)
              QPP(I)=QP(JDPN,1)/QRATEP(I)
            RETURN
            END

  MULTI-BANK COMPILATION.
```

```
4I

      SUBROUTINE COEFP(I)
C
C                        SUBROUTINE TO COMPUTE PUMP CHARACTERISTICS
C
         COMMON/CPPC/AHQP(10,3),BHQP(10,3),CHQP(10,3),
     1                  DHQP(10,3),EHQP(10,3),FHQP(10,3),GHQP(10,3),
     2                  AHAP(10,3),BHAP(10,3),CHAP(10,3),
     3                  DHAP(10,3),EHAP(10,3),FHAP(10,3),GHAP(10,3),
     4                  ABQP(10,3),BBQP(10,3),CBQP(10,3),
     5                  DBQP(10,3),EBQP(10,3),FBQP(10,3),GBQP(10,3),
     6                  ABAP(10,3),BBAP(10,3),CBAP(10,3),
     7                  DBAP(10,3),EBAP(10,3),FBAP(10,3),GBAP(10,3),
     8                   SNS(10), NSNS(10)
C
C    J=1(PUMP)  J=2(ENERGY DISS)  J=3(TURBINE)
C
C    K=1(HQ)  K=2(HA)  K=3(BQ)  K=4(BA)
C
C
C
C  DO PUMP ZONE
C                     H/Q2 PUMP A/Q    F 1
            X1=.17
            X2=.33
            X3=.50
            X4=.67
            X5=.83
            X6=1.00
        IF(NSNS(I))19005,19005,19001
19001   IF(NSNS(I)-7600)19002,19003,19004
C
19002       Y0=-0.53
            Y1=-0.42
            Y2=-0.22
            Y3=-0.04
            Y4= 0.23
            Y5= 0.56
            Y6= 1.00
        GOTO 19006
19003       Y0=-1.56
            Y1=-1.13
            Y2=-0.69
            Y3=-0.35
            Y4= 0.05
            Y5= 0.52
            Y6= 1.00
        GOTO 19006
19004       Y0=-1.00
            Y1=-0.90
            Y2=-0.76
            Y3=-0.50
            Y4=-0.11
            Y5= 0.37
            Y6= 1.00
        GOTO 19006
```

T-1566

```
4I       COEFP

19005 Y0=0.000E-12*SNS(I)**3+2.109E-8*SNS(I)**2-3.501E-4*SNS(I)-0.118
      Y1=0.000E-12*SNS(I)**3+1.237E-8*SNS(I)**2-2.221E-4*SNS(I)-0.157
      Y2=0.000E-12*SNS(I)**3+0.511E-8*SNS(I)**2-1.197E-4*SNS(I)-0.076
      Y3=0.000E-12*SNS(I)**3+0.200E-8*SNS(I)**2-0.678E-4*SNS(I)+0.059
      Y4=0.000E-12*SNS(I)**3+0.053E-8*SNS(I)**2-0.377E-4*SNS(I)+0.303
      Y5=0.000E-12*SNS(I)**3-0.149E-8*SNS(I)**2+0.034E-4*SNS(I)+0.594
      Y6=0.000E-12*SNS(I)**3+0.000E-8*SNS(I)**2+0.000E-4*SNS(I)+1.000
19006          J=1
               K=1
        GO TO 19200
C
C                         H/A2 PUMP Q/A    F 3
C
19010   IF(NSNS(I))19015,19015,19011
19011   IF(NSNS(I)-7600)19012,19013,19014
C
19012          Y0=1.29
               Y1=1.29
               Y2=1.27
               Y3=1.23
               Y4=1.18
               Y5=1.10
               Y6=1.00
        GOTO 19016
19013          Y0=1.96
               Y1=1.71
               Y2=1.40
               Y3=1.21
               Y4=1.12
               Y5=1.06
               Y6=1.00
        GOTO 19016
19014          Y0=2.73
               Y1=2.33
               Y2=2.02
               Y3=1.76
               Y4=1.57
               Y5=1.36
               Y6=1.00
        GOTO 19016
19015 Y0=0.000E-12*SNS(I)**3+0.087E-8*SNS(I)**2+1.114E-4*SNS(I)+1.069
      Y1=0.000E-12*SNS(I)**3+0.132E-8*SNS(I)**2+0.713E-4*SNS(I)+1.123
      Y2=0.000E-12*SNS(I)**3+0.433E-8*SNS(I)**2+0.000E-4*SNS(I)+1.219
      Y3=0.000E-12*SNS(I)**3+0.634E-8*SNS(I)**2-0.485E-4*SNS(I)+1.252
      Y4=0.000E-12*SNS(I)**3+0.619E-8*SNS(I)**2-0.589E-4*SNS(I)+1.234
      Y5=0.000E-12*SNS(I)**3+0.419E-8*SNS(I)**2-0.410E-4*SNS(I)+1.147
      Y6=0.000E-12*SNS(I)**3+0.000E-8*SNS(I)**2+0.000E-4*SNS(I)+1.000
19016          J=1
               K=2
        GO TO 19200
C
C                         B/Q2   PUMP   A/Q   F 2
C
19020   IF(NSNS(I))19025,19025,19021
19021   IF(NSNS(I))19022,19023,19024
```

```
4I         COEFP

 C
 19022             Y0=-0.30
                   Y1=-0.16
                   Y2= 0.01
                   Y3= 0.20
                   Y4= 0.43
                   Y5= 0.70
                   Y6= 1.00
               GOTO 19026
 19023             Y0=-1.55
                   Y1=-0.93
                   Y2=-0.47
                   Y3=-0.11
                   Y4= 0.29
                   Y5= 0.67
                   Y6= 1.00
               GOTO 19026
 19024             Y0=-0.56
                   Y1=-0.62
                   Y2=-0.60
                   Y3=-0.39
                   Y4= 0.03
                   Y5= 0.51
                   Y6= 1.00
               GOTO 19026
 19025  Y0=0.000E-12*SNS(I)**3+3.017E-8*SNS(I)**2-4.670E-4*SNS(I)+0.247
        Y1=0.000E-12*SNS(I)**3+1.426E-8*SNS(I)**2-2.483E-4*SNS(I)+0.134
        Y2=0.000E-12*SNS(I)**3+0.441E-8*SNS(I)**2-1.150E-4*SNS(I)+0.150
        Y3=0.000E-12*SNS(I)**3+0.013E-8*SNS(I)**2-0.502E-4*SNS(I)+0.264
        Y4=0.000E-12*SNS(I)**3+0.040E-8*SNS(I)**2-0.438E-4*SNS(I)+0.556
        Y5=0.000E-12*SNS(I)**3-0.142E-8*SNS(I)**2+0.030E-4*SNS(I)+0.728
        Y6=0.000E-12*SNS(I)**3+0.000E-8*SNS(I)**2+0.000E-4*SNS(I)+1.000
 19026             J=1
                   K=3
               GO TO 19200
 C
 C                            B/A2  PUMP   Q/A  F 4
 C
 19030         IF(NSNS(I))19035,19035,19031
 19031         IF(NSNS(I)-7600)19032,19033,19034
 C
 19032             Y0=0.44
                   Y1=0.54
                   Y2=0.66
                   Y3=0.77
                   Y4=0.86
                   Y5=0.94
                   Y6=1.00
               GOTO 19035
 19033             Y0=1.48
                   Y1=1.18
                   Y2=0.98
                   Y3=0.91
                   Y4=0.94
                   Y5=0.98
```

```
                Y6=1.00
            GOTO 19036
  19034         Y0=1.95
                Y1=1.67
                Y2=1.35
                Y3=1.13
                Y4=1.07
                Y5=1.05
                Y6=1.00
            GOTO 19035
  19035 Y0=0.000E-12*SNS(I)**3-0.680E-8*SNS(I)**2+2.274E-4*SNS(I)+0.125
        Y1=0.000E-12*SNS(I)**3-0.282E-8*SNS(I)**2+1.353E-4*SNS(I)+0.351
        Y2=0.000E-12*SNS(I)**3-0.079E-8*SNS(I)**2+0.691E-4*SNS(I)+0.552
        Y3=0.000E-12*SNS(I)**3+0.022E-8*SNS(I)**2+0.294E-4*SNS(I)+0.691
        Y4=0.000E-12*SNS(I)**3+0.058E-8*SNS(I)**2+0.123E-4*SNS(I)+0.802
        Y5=0.000E-12*SNS(I)**3+0.046E-8*SNS(I)**2+0.043E-4*SNS(I)+0.911
        Y6=0.000E-12*SNS(I)**3+0.000E-8*SNS(I)**2+0.000E-4*SNS(I)+1.000
  19036         J=1
                K=4
            GO TO 19200
  C
  C
  C  DO ENERGY DISSIPATION ZONE
  C
  C                           H/Q2 ENERGY DISS A/Q       F 5
  C
  19040         X1=-.17
                X2=-.33
                X3=-.50
                X4=-.67
                X5=-.83
                X6=-1.00
            IF(NSNS(I))19045,19045,19041
  19041     IF(NSNS(I)-7600)19042,19043,19044
  C
  19042         Y0=0.69
                Y1=0.79
                Y2=0.90
                Y3=1.08
                Y4=1.30
                Y5=1.52
                Y6=1.99
            GOTO 19046
  19043         Y0=2.17
                Y1=2.70
                Y2=3.20
                Y3=3.72
                Y4=4.20
                Y5=4.73
                Y6=5.27
            GOTO 19045
  19044         Y0=1.08
                Y1=1.48
                Y2=2.02
                Y3=2.70
```

```
                Y4=3.60
                Y5=4.82
                Y6=6.29
          GOTO 19046
  19045 Y0=-5.303E-12*SNS(I)**3+08.476E-8*SNS(I)**2-1.560E-4*SNS(I)+0.785
        Y1=-6.970E-12*SNS(I)**3+11.471E-8*SNS(I)**2-2.387E-4*SNS(I)+0.946
        Y2=-7.962E-12*SNS(I)**3+13.244E-8*SNS(I)**2-2.660E-4*SNS(I)+1.065
        Y3=-9.591E-12*SNS(I)**3+16.663E-8*SNS(I)**2-4.025E-4*SNS(I)+1.363
        Y4=-9.767E-12*SNS(I)**3+17.293E-8*SNS(I)**2-4.038E-4*SNS(I)+1.567
        Y5=-9.935E-12*SNS(I)**3+18.296E-8*SNS(I)**2-4.417E-4*SNS(I)+1.883
        Y6=-9.006E-12*SNS(I)**3+17.236E-8*SNS(I)**2-3.794E-4*SNS(I)+2.156
  19046         J=2
                K=1
          GO TO 19200
  C
  C                           H/A2 ENERGY DISS Q/A       F7
  C
  19050     IF(NSNS(I))19055,19055,19051
  19051     IF(NSNS(I)-7600)19052,19053,19054
  C
  19052         Y0=1.29
                Y1=1.31
                Y2=1.35
                Y3=1.43
                Y4=1.56
                Y5=1.73
                Y6=1.99
          GOTO 19055
  19053         Y0=1.96
                Y1=2.16
                Y2=2.43
                Y3=2.83
                Y4=3.41
                Y5=4.19
                Y6=5.27
          GOTO 19056
  19054         Y0=2.73
                Y1=3.27
                Y2=3.86
                Y3=4.47
                Y4=5.07
                Y5=5.81
                Y6=6.29
          GOTO 19056
  19055 Y0=+0.000E-12*SNS(I)**3+00.087E-8*SNS(I)**2+1.114E-4*SNS(I)+1.069
        Y1=+0.000E-12*SNS(I)**3+00.394E-8*SNS(I)**2+1.145E-4*SNS(I)+1.016
        Y2=+0.000E-12*SNS(I)**3+00.539E-8*SNS(I)**2+1.391E-4*SNS(I)+1.011
        Y3=+0.000E-12*SNS(I)**3+00.508E-8*SNS(I)**2+1.897E-4*SNS(I)+1.004
        Y4=+0.000E-12*SNS(I)**3+00.115E-8*SNS(I)**2+2.885E-4*SNS(I)+0.998
        Y5=+0.000E-12*SNS(I)**3-00.584E-8*SNS(I)**2+4.409E-4*SNS(I)+0.967
        Y6=-9.006E-12*SNS(I)**3+17.236E-8*SNS(I)**2-3.794E-4*SNS(I)+2.156
  19056         J=2
                K=2
          GO TO 19200
  C
```

```
,4I        COEFP

  C                             B/Q2 ENERGY DISS A/Q        F 6
  C
  19060     IF(NSNS(I))19065,19065,19061
  19061     IF(NSNS(I)-7600)19062,19063,19064
  C
  19062          Y0=0.86
                 Y1=0.91
                 Y2=0.95
                 Y3=0.98
                 Y4=1.00
                 Y5=1.02
                 Y6=1.04
            GOTO 19066
  19063          Y0=2.10
                 Y1=2.57
                 Y2=3.05
                 Y3=3.40
                 Y4=3.68
                 Y5=3.95
                 Y6=4.22
            GOTO 19066
  19064          Y0=0.57
                 Y1=1.07
                 Y2=1.60
                 Y3=2.25
                 Y4=3.16
                 Y5=4.30
                 Y6=5.52
            GOTO 19066
  19065 Y0=-5.127E-12*SNS(I)**3+08.058E-8*SNS(I)**2-1.842E-4*SNS(I)+1.086
        Y1=-6.114E-12*SNS(I)**3+09.617E-8*SNS(I)**2-1.867E-4*SNS(I)+1.109
        Y2=-7.042E-12*SNS(I)**3+11.204E-8*SNS(I)**2-1.951E-4*SNS(I)+1.143
        Y3=-6.853E-12*SNS(I)**3+10.792E-8*SNS(I)**2-1.220E-4*SNS(I)+1.091
        Y4=-5.005E-12*SNS(I)**3+07.174E-8*SNS(I)**2+1.147E-4*SNS(I)+0.852
        Y5=-2.871E-12*SNS(I)**3+03.255E-8*SNS(I)**2+3.576E-4*SNS(I)+0.604
        Y6=-0.623E-12*SNS(I)**3-00.814E-8*SNS(I)**2+6.068E-4*SNS(I)+0.346
  19066          J=2
                 K=3
            GO TO 19200
  C
  C                             B/A2 ENERGY DISS Q/A        F8
  C
  19070     IF(NSNS(I))19075,19075,19071
  19071     IF(NSNS(I)-7600)19072,19073,19074
  C
  19072          Y0=0.44
                 Y1=0.38
                 Y2=0.38
                 Y3=0.43
                 Y4=0.53
                 Y5=0.74
                 Y6=1.04
            GOTO 19075
  19073          Y0=1.48
                 Y1=1.58
```

```
                Y2=1.72
                Y3=2.03
                Y4=2.47
                Y5=3.23
                Y6=4.22
            GOTO 19075
 19074          Y0=1.95
                Y1=2.37
                Y2=2.94
                Y3=3.67
                Y4=4.38
                Y5=4.99
                Y6=5.52
            GOTO 19075
 19075 Y0=+0.000E-12*SNS(I)**3-00.680E-8*SNS(I)**2+2.274E-4*SNS(I)+0.125
       Y1=+0.000E-12*SNS(I)**3-00.428E-8*SNS(I)**2+2.281E-4*SNS(I)+0.074
       Y2=+0.000E-12*SNS(I)**3-00.131E-8*SNS(I)**2+2.291E-4*SNS(I)+0.081
       Y3=+0.000E-12*SNS(I)**3+00.091E-8*SNS(I)**2+2.515E-4*SNS(I)+0.102
       Y4=+0.000E-12*SNS(I)**3+00.096E-8*SNS(I)**2+2.968E-4*SNS(I)+0.192
       Y5=+0.000E-12*SNS(I)**3-00.817E-8*SNS(I)**2+4.625E-4*SNS(I)+0.227
       Y6=-0.623E-12*SNS(I)**3-00.814E-8*SNS(I)**2+6.068E-4*SNS(I)+0.346
 19076          J=2
                K=4
            GO TO 19200
 C
 C
 C  DO TURBINE ZONE
 C
 C                           H/Q2 TURB A/Q   F9
 C
 19080          X1=.17
                X2=.33
                X3=.50
                X4=.67
                X5=.83
                X6=1.00
            IF(NSNS(I))19085,19085,19081
 19081      IF(NSNS(I)-7600)19082,19083,19084
 C
 19082          Y0=0.59
                Y1=0.64
                Y2=0.63
                Y3=0.66
                Y4=0.73
                Y5=0.85
                Y6=1.01
            GOTO 19085
 19083          Y0=2.17
                Y1=1.60
                Y2=1.10
                Y3=0.77
                Y4=0.60
                Y5=0.47
                Y6=0.38
            GOTO 19086
```

```
.4I       COEFP

  19084           Y0=1.08
                  Y1=0.81
                  Y2=0.78
                  Y3=0.77
                  Y4=0.57
                  Y5=0.44
                  Y6=0.13
              GOTO 19085
  19085 Y0=-5.303E-12*SNS(I)**3+08.476E-8*SNS(I)**2-1.560E-4*SNS(I)+0.785
        Y1=-2.363E-12*SNS(I)**3+02.963E-8*SNS(I)**2+0.508E-4*SNS(I)+0.540
        Y2=+0.000E-12*SNS(I)**3-01.053E-8*SNS(I)**2+1.673E-4*SNS(I)+0.441
        Y3=+0.000E-12*SNS(I)**3-00.272E-8*SNS(I)**2+0.452E-4*SNS(I)+0.643
        Y4=+0.000E-12*SNS(I)**3+00.125E-8*SNS(I)**2-0.269E-4*SNS(I)+0.793
        Y5=+0.000E-12*SNS(I)**3+00.301E-8*SNS(I)**2-0.783E-4*SNS(I)+0.940
        Y6=+0.000E-12*SNS(I)**3+00.358E-8*SNS(I)**2-1.228E-4*SNS(I)+1.132
  19086           J=3
                  K=1
              GO TO 19200
  C
  C                             H/A2 TURB Q/A    F 11
  C
  19090       IF(NSNS(I))19095,19095,19091
  19091       IF(NSNS(I)-7600)19092,19093,19094
  C
  19092           Y0=0.63
                  Y1=0.66
                  Y2=0.69
                  Y3=0.73
                  Y4=0.79
                  Y5=0.88
                  Y6=1.01
              GOTO 19096
  19093           Y0=-0.67
                  Y1=-0.46
                  Y2=-0.28
                  Y3=-0.04
                  Y4= 0.06
                  Y5= 0.19
                  Y6= 0.38
              GOTO 19096
  19094           Y0=-2.20
                  Y1=-1.55
                  Y2=-1.14
                  Y3=-0.86
                  Y4=-0.60
                  Y5=-0.28
                  Y6= 0.13
              GOTO 19096
  19095 Y0=+0.000E-12*SNS(I)**3-00.440E-8*SNS(I)**2-1.665E-4*SNS(I)+0.850
        Y1=+0.000E-12*SNS(I)**3-00.063E-8*SNS(I)**2-1.716E-4*SNS(I)+0.880
        Y2=+0.000E-12*SNS(I)**3+00.065E-8*SNS(I)**2-1.596E-4*SNS(I)+0.896
        Y3=+0.000E-12*SNS(I)**3-00.146E-8*SNS(I)**2-1.081E-4*SNS(I)+0.865
        Y4=+0.000E-12*SNS(I)**3-00.043E-8*SNS(I)**2-1.070E-4*SNS(I)+0.919
        Y5=+0.000E-12*SNS(I)**3+00.132E-8*SNS(I)**2-1.136E-4*SNS(I)+1.006
        Y6=+0.000E-12*SNS(I)**3+00.358E-8*SNS(I)**2-1.228E-4*SNS(I)+1.132
```

```
.4I        COEFP

  19096         J=3
                K=2
           GO TO 19200
  C
  C                        B/Q2 TURB A/Q    F 10
  C
  19100    IF(NSNS(I))19105,19105,19101
  19101    IF(NSNS(I)-7600)19102,19103,19104
  C
  19102         Y0=0.86
                Y1=0.81
                Y2=0.76
                Y3=0.59
                Y4=0.62
                Y5=0.54
                Y6=0.46
           GOTO 19106
  19103         Y0=2.10
                Y1=1.57
                Y2=1.15
                Y3=0.83
                Y4=0.56
                Y5=0.31
                Y6=0.00
           GOTO 19106
  19104         Y0=0.67
                Y1=0.43
                Y2=0.46
                Y3=0.63
                Y4=0.54
                Y5=0.18
                Y6=-0.15
           GOTO 19106
  19105 Y0=-5.127E-12*SNS(I)**3+08.058E-8*SNS(I)**2-1.842E-4*SNS(I)+1.086
        Y1=-2.743E-12*SNS(I)**3+03.704E-8*SNS(I)**2-0.334E-4*SNS(I)+0.881
        Y2=+0.000E-12*SNS(I)**3-01.287E-8*SNS(I)**2+1.627E-4*SNS(I)+0.617
        Y3=+0.000E-12*SNS(I)**3-00.392E-8*SNS(I)**2+0.459E-4*SNS(I)+0.722
        Y4=+0.000E-12*SNS(I)**3-00.095E-8*SNS(I)**2-0.305E-4*SNS(I)+0.770
        Y5=+0.000E-12*SNS(I)**3+00.189E-8*SNS(I)**2-0.693E-4*SNS(I)+0.764
        Y6=+0.000E-12*SNS(I)**3+00.407E-8*SNS(I)**2-1.251E-4*SNS(I)+0.783
  19106         J=3
                K=3
           GO TO 19200
  C
  C                        B/A2 TURB Q/A    F 12
  C
  19110    IF(NSNS(I))19115,19115,19111
  19111    IF(NSNS(I)-7600)19112,19113,19114
  C
  19112         Y0=-0.67
                Y1=-0.37
                Y2=-0.16
                Y3=-0.03
                Y4= 0.10
                Y5= 0.24
```

```
                 Y6= 0.45
             GOTO 19116
  19113          Y0=-1.50
                 Y1=-1.09
                 Y2=-0.79
                 Y3=-0.63
                 Y4=-0.46
                 Y5=-0.29
                 Y6= 0.00
             GOTO 19116
  19114          Y0=-2.33
                 Y1=-1.58
                 Y2=-1.30
                 Y3=-1.10
                 Y4=-0.84
                 Y5=-0.55
                 Y6=-0.15
             GOTO 19116
  19115 Y0=+0.000E-12*SNS(I)**3-00.077E-8*SNS(I)**2-1.244E-4*SNS(I)-0.510
        Y1=+0.000E-12*SNS(I)**3+00.252E-8*SNS(I)**2-1.362E-4*SNS(I)-0.200
        Y2=+0.000E-12*SNS(I)**3+00.151E-8*SNS(I)**2-1.200E-4*SNS(I)+0.042
        Y3=+0.000E-12*SNS(I)**3+00.176E-8*SNS(I)**2-1.186E-4*SNS(I)+0.179
        Y4=+0.000E-12*SNS(I)**3+00.286E-8*SNS(I)**2-1.260E-4*SNS(I)+0.338
        Y5=+0.000E-12*SNS(I)**3+00.354E-8*SNS(I)**2-1.305E-4*SNS(I)+0.554
        Y6=+0.000E-12*SNS(I)**3+00.407E-8*SNS(I)**2-1.251E-4*SNS(I)+0.783
  19116          J=3
                 K=4
  C
  C
  C  USE MATRIX TO CALCULATE COEF
  C
  C
  19200          RS6  =(Y5-Y0)/(X6**6)
                 RS5  =(Y5-Y0)/(X5**6)
                 RS4  =(Y4-Y0)/(X4**6)
                 RS3  =(Y3-Y0)/(X3**6)
                 RS2  =(Y2-Y0)/(X2**6)
                 RS1  =(Y1-Y0)/(X1**6)
  C
                  Q1  =1./X1
                  Q2  =1./X2
                  Q3  =1./X3
                  Q4  =1./X4
                  Q5  =1./X5
                  Q6  =1./X6
  C
                  R1  =Q1*Q1
                  R2  =Q2*Q2
                  R3  =Q3*Q3
                  R4  =Q4*Q4
                  R5  =Q5*Q5
                  R6  =Q6*Q6
  C
                  S1  =Q1*R1
                  S2  =Q2*R2
```

5.4I COEFP

```
      S3  =Q3*R3
      S4  =Q4*R4
      S5  =Q5*R5
      S6  =Q6*R6
C
      T1  =Q1*S1
      T2  =Q2*S2
      T3  =Q3*S3
      T4  =Q4*S4
      T5  =Q5*S5
      T6  =Q6*S6
C
      U1  =Q1*T1
      U2  =Q2*T2
      U3  =Q3*T3
      U4  =Q4*T4
      U5  =Q5*T5
      U6  =Q6*T6
C
C
     RS36=(RS6-RS1)/(Q6-Q1)
     RS35=(RS5-RS1)/(Q5-Q1)
     RS34=(RS4-RS1)/(Q4-Q1)
     RS33=(RS3-RS1)/(Q3-Q1)
     RS32=(RS2-RS1)/(Q2-Q1)
C
     R61  =(R6-R1)/(Q6-Q1)
     R51  =(R5-R1)/(Q5-Q1)
     R41  =(R4-R1)/(Q4-Q1)
     R31  =(R3-R1)/(Q3-Q1)
     R21  =(R2-R1)/(Q2-Q1)
C
     S61  =(S6-S1)/(Q6-Q1)
     S51  =(S5-S1)/(Q5-Q1)
     S41  =(S4-S1)/(Q4-Q1)
     S31  =(S3-S1)/(Q3-Q1)
     S21  =(S2-S1)/(Q2-Q1)
C
     T61  =(T6-T1)/(Q6-Q1)
     T51  =(T5-T1)/(Q5-Q1)
     T41  =(T4-T1)/(Q4-Q1)
     T31  =(T3-T1)/(Q3-Q1)
     T21  =(T2-T1)/(Q2-Q1)
C
     U61  =(U6-U1)/(Q6-Q1)
     U51  =(U5-U1)/(Q5-Q1)
     U41  =(U4-U1)/(Q4-Q1)
     U31  =(U3-U1)/(Q3-Q1)
     U21  =(U2-U1)/(Q2-Q1)
C
C
     RS46  =(RS36-RS32)/(R61-R21)
     RS45  =(RS35-RS32)/(R51-R21)
     RS44  =(RS34-RS32)/(R41-R21)
     RS43  =(RS33-RS32)/(R31-R21)
```

T-1566

```
5.4I          COEFP

    C
                        S52  =(S61-S21)/(R61-R21)
                        S52  =(S51-S21)/(R51-R21)
                        S42  =(S41-S21)/(R41-R21)
                        S32  =(S31-S21)/(R31-R21)
    C
                        T62  =(T61-T21)/(R61-R21)
                        T52  =(T51-T21)/(R51-R21)
                        T42  =(T41-T21)/(R41-R21)
                        T32  =(T31-T21)/(R31-R21)
    C
                        U62  =(U61-U21)/(R61-R21)
                        U52  =(U51-U21)/(R51-R21)
                        U42  =(U41-U21)/(R41-R21)
                        U32  =(U31-U21)/(R31-R21)
    C
    C
                      RS56  =(RS46-RS43)/(S62-S32)
                      RS55  =(RS45-RS43)/(S52-S32)
                      RS54  =(RS44-RS43)/(S42-S32)
    C
                        T53  =(T62-T32)/(S62-S32)
                        T53  =(T52-T32)/(S52-S32)
                        T43  =(T42-T32)/(S42-S32)
    C
                        U63  =(U62-U32)/(S62-S32)
                        U53  =(U52-U32)/(S52-S32)
                        U43  =(U42-U32)/(S42-S32)
    C
    C
                      RS66  =(RS56-RS54)/(T63-T43)
                      RS65  =(RS55-RS54)/(T53-T43)
    C
                        U64  =(U63-U43)/(T63-T43)
                        U54  =(U53-U43)/(T53-T43)
    C
    C
    C     CALC COEF
    C
                      G=Y0
    C
                      F  =  (RS66-RS65)/(U64-U54)
    C
                      E  =  RS65-F*U54
    C
                      D  =  RS54-F*U43-E*T43
    C
                      C  =  RS43-F*U32-E*T32-D*S32
    C
                      B  =  RS32-F*U21-E*T21-D*S21-C*R21
    C
                      A  =  RS1  -F*U1  -E*T1  -D*S1  -C*R1  -B*Q1
                 IF(J-1)19300,19300,19330
   19300         IF(K-1)19500,19500,19310
   19310         IF(K-2)19300,19520,19320
```

5.4I COEFP

```
 19320   IF(K-3)19310,19540,19560
 C
 19330   IF(J-2)19300,19340,19370
 19340   IF(K-1)19500,19500,19350
 19350   IF(K-2)19500,19520,19360
 19360   IF(K-3)19350,19540,19560
 C
 19370   IF(K-1)19500,19500,19380
 19380   IF(K-2)19370,19520,19390
 19390   IF(K-3)19380,19540,19560
 19500        AHQP(I,J)=A
              BHQP(I,J)=B
              CHQP(I,J)=C
              DHQP(I,J)=D
              EHQP(I,J)=E
              FHQP(I,J)=F
              GHQP(I,J)=G
         IF(J-1)19010,19010,19510
 19510   IF(J-2)19010,19050,19090
 C
 19520        AHAP(I,J)=A
              BHAP(I,J)=B
              CHAP(I,J)=C
              DHAP(I,J)=D
              EHAP(I,J)=E
              FHAP(I,J)=F
              GHAP(I,J)=G
         IF(J-1)19020,19020,19530
 19530   IF(J-2)19020,19060,19100
 C
 19540        ABQP(I,J)=A
              BBQP(I,J)=B
              CBQP(I,J)=C
              DBQP(I,J)=D
              EBQP(I,J)=E
              FBQP(I,J)=F
              GBQP(I,J)=G
         IF(J-1)19030,19030,19550
 19550   IF(J-2)19030,19070,19110
 C
 19560        ABAP(I,J)=A
              BBAP(I,J)=B
              CBAP(I,J)=C
              DBAP(I,J)=D
              EBAP(I,J)=E
              FBAP(I,J)=F
              GBAP(I,J)=G
         IF(J-1)19040,19040,19570
 19570   IF(J-2)19040,19080,19580
 19580  CONTINUE
        DO 19589 J=1,3
        WRITE(61,19582)AHQP(I,J),BHQP(I,J),CHQP(I,J),DHQP(I,J),
      1                EHQP(I,J),FHQP(I,J),GHQP(I,J)
        WRITE(61,19583)AHAP(I,J),BHAP(I,J),CHAP(I,J),DHAP(I,J),
      1                EHAP(I,J),FHAP(I,J),GHAP(I,J)
```

```
5.4I         COEFP
             WRITE(61,19583)ABQP(I,J),BBQP(I,J),CBQP(I,J),DBQP(I,J),
        1                   EBQP(I,J),FBQP(I,J),GBQP(I,J)
             WRITE(61,19583)ABAP(I,J),BBAP(I,J),CBAP(I,J),DBAP(I,J),
        1                   EBAP(I,J),FBAP(I,J),GBAP(I,J)
   19582     FORMAT(/7E12.5)
   19583     FORMAT(7E12.5)
   19589    CONTINUE
                     RETURN
            END

      MULTI-BANK COMPILATION.
```