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Simulation of multiple closed loop milling circuits

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circuit:

$WR = 7(100/MM)^{0.71}$

where 100 arises out of a 200 ton mill being one half full. Clearly, if the average value of MM is 100 tons, the average wear rate will still be 7 tons/hour.

4.4.3.2 Rate of Production of - 75μm Modification

In order to reflect that the mill is not grinding at optimum efficiency at any point other than one half filling point, it is necessary to incorporate a factor which will cause the rate of production of - 75μm material to drop when the mill is either underloaded or overloaded.

A linear equation of the following form has been used:

$$MF = 1 - \left|(Mnominal - MM)/Mnominal\right|$$

where:

MF = modifying factor with which the equation defining the rate of production of - 75μm material is multiplied

MM = mass of pebbles in the mill (tons)

Mnominal = a standard dry load to which the modifier is corrected (tons)
(100 tons for a 200 ton mill)

4.4.4 The Division of the Mill into Sub-Mills

In order to obtain a more realistic model relating mill power to mill charge, a tanks-in-series transport[18] concept was used to describe the mill. This involves splitting the whole pebble mill into a number of discrete sub-mills, each of which has its own power equation and each of which is series-connected to the next. The reason for this is that it has been proposed that, in large-scale

industrial mills, it takes a significant amount of time for the pebble feed to propagate down the length of the mill.

As a result of this, even though on average the mill may be one half full, this distribution is such that the first part of the mill will be overloaded while the second part of the mill will be underloaded resulting in less than maximum power being drawn.

4.4.4.1 Determination of Mass Flow Rate between Sub-Mills

In determining the flow rate at any point x along the length of the mill it has been assumed that flow rate is proportional to both the slope of the charge surface at point x and to the width of the charge surface at point x.

As a result of these assumptions the following equation is obtained:

$$\text{Flow} = (Z)(J)(dh/dx)$$

where:

Flow = flow rate of charge along the mill at point x

Z = a constant

J = width of charge surface at point x

dh/dx = slope of charge surface at point x

Adapting the above equation, which is a continuous equation, into a discrete equation, the following equation is obtained:

$$\text{Flow}_{pq} = (Z)(J)((hp - hq)/\Delta x))$$

where:

Flow_{pq} = flow rate of charge between sub-mills p and q

Z = a constant

J = width of charge surface at the interface between mills p and q

hp = height of charge in the pth sub-mill

hq = height of charge in the qth sub-mill

Δx = sub-mill width

When the mills are approximately half full,

$J(hp - hq) = Ap - Aq$ (an error analysis of this approximation is given in Appendix 3)

where:

Ap and Aq are the cross-sectional areas of the charge of the pth and qth sub-mills respectively.

It follows from the last equation that

$\Delta x \rho J(hp - hq) = \Delta x \rho Ap - \Delta x \rho Aq = Mp - Mq$

where:

ρ = density of mill charge

Mp = mass of charge in sub-mill p

Mq = mass of charge in sub-mill q

Re-arranging the discrete equation, it follows that:

$Flow_{pq} = Z^1(Mp - Mq)$

where:

$Z^1 = \frac{Z}{\rho \Delta x^2}$ = a constant

Thus the flow rate between sub-mills is directly proportional to the difference in the mass charge of the sub-mills, provided the sub-mills are approximately half full.

Appendix 2 considers the extension of the discrete sub-mills concept to an infinite number of sub-mills. From the work done in this Appendix, it is felt that due to the nature of the mathematics the inclusion of a continuously distributed model into C.S.M.P. simulators

would be extremely difficult.

In addition to this, work done by Herbst, Mika and Rajamani[19] indicates that the errors involved in using a lumped parameter model, as opposed to a distributed parameter model, for a mill are very small.

4.4.5 Simulations with Pebble Mill Power Models

The non-linear Blyvooruitzicht simulator was programmed to incorporate 3 different pebble mill power models controlled by "Digicon". The first simulation involved splitting the mill into 3 sub-mills, while the final two simulations involved splitting the mill into 5 and 15 sub-mills respectively.

To illustrate the procedure adopted for modelling the power in these simulations, consider the 5 sub-mills simulator. (See Listing 3 for a program listing).

The overall power of each pebble mill, to which the "Digicon" responds, is obtained by summing the power of each of the 5 sub-mills.

The equation used to obtain the power of each of the sub-mills is the equation given in section 4.4.2, namely:

$$P = C(BD)(\mathrm{Sin}(1.8s))^{3}(\mathrm{Sin}\alpha)$$

where:

P = power drawn by each sub-mill

BD = bulk density of material in each sub-mill

C = a constant

s = specific mill filling of each sub-mill

$\mathrm{Sin}\alpha$ = angle of repose of material in each sub-mill. $\mathrm{Sin}\alpha$ has been taken to be a constant in this investigation. (See section 4.4.2.2).

From the preceding equation, it is clear that it is necessary to know the pebble mass charge of each of the sub-mills. In order to get a dynamic measure of the contents of each of the sub-mills, equations representing the change of mass with respect to time in each of the sub-mills were used. These equations were then integrated with respect to time to get total pebble mass in each of the sub-mills.

The form of these equations is given below:

MMCH = MFEED - MLOSS - MOUT

where:

MMCH = mass change of pebbles in each of the sub-mills during the last integration interval (tons)

MFEED = input of pebbles to each of the sub-mills during the last integration period (tons)

MLOSS = loss of pebbles due to grinding from each of the sub-mills during the last integration period (tons)

MOUT = flow of pebbles from each of the sub-mills to the next sub-mill during the last integration period (tons); clearly the MOUT value for the second sub-mill must equal the MFEED value for the third sub-mill, etc., and the MFEED value for the first sub-mill must equal the overall pebble feed of the entire mill.

MLOSS for each of the sub-mills is calculated by means of the Stanley equation described in section 4.4.3.1. In the case of 5 sub-mills, the equation used is:

$$MLOSS = (7/5)((100/5)/MM)^{0.71}$$

where:

MM = mass of pebbles in each sub-mill (tons)

MFEED is determined by the equation developed in section 4.4.4.1, namely:

$$MFEED = Z^{1}(Mp - Mq)$$

i.e. the flow between sub-mills is directly proportional to

the pebble mass difference between sub-mills.

The results of these simulations can be summarised in Fig. 9. From the figure it is clear that the following objective, which was outlined in section 4.4.1, has been achieved, namely: the power curve is a-symmetric about power peaks and the power peak is different depending on whether the mill is coming out of an overloaded or under-loaded state.

In addition to this, the following can be observed:

(1) No delay is detectable between a change of feed state and an increase in power.

(2) The power curves in the 5 and 15 sub-mills simulations are remarkably similar, while the power curve for the 3 sub-mills simulation is significantly different. Clearly the 15 sub-mills simulation is the closest to reality. The 5 sub-mills model, however, would appear to represent an excellent compromise between accuracy and complexity. (The program for the 15 sub-mills case takes approximately twice as long to run as the program for the 5 sub-mills case).

4.4.5.1 The Incorporation of Noise

For a realistic test of the mill power model (incorporating 5 sub-mills), it is necessary to corrupt the power signal with noise and to look at the response of the "Digicon" to this noisy power signal. This noise occurs as a result of random disturbances in the circuit.

The noise added is of the following form:

$$dN(t) = - rN(t)dt + \text{Gauss}\sqrt{\sigma\, dt}$$

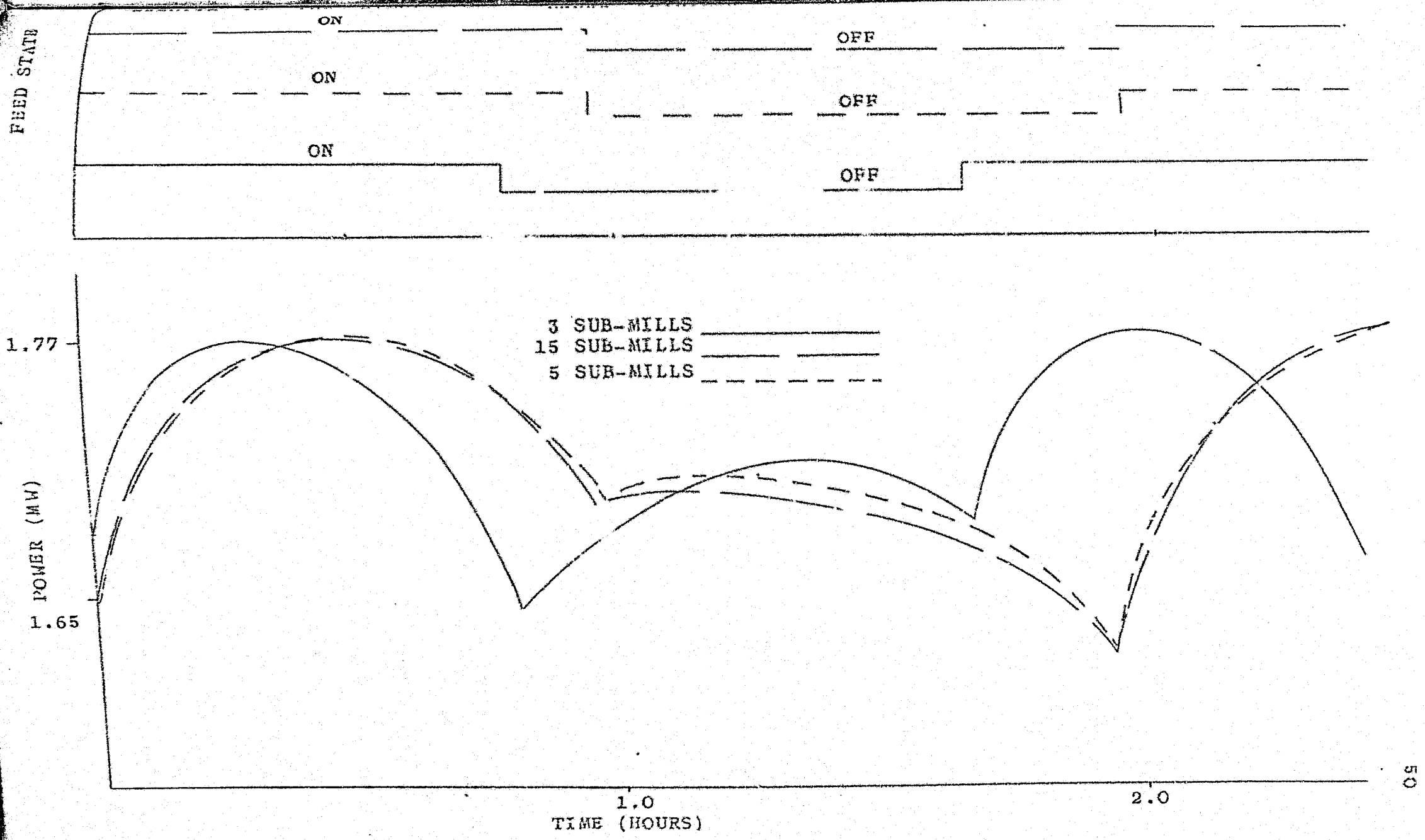

FEED STATE
ON
OFF
ON
OFF
ON
OFF
3 SUB-MILLS
15 SUB-MILLS
5 SUB-MILLS
1.77
1.65
POWER (MW)
1.0
2.0
TIME (HOURS)
50

Fig. 9

which is the equation describing coloured Gaussian noise. Gauss is a Gaussianly distributed random number.

In the discrete case (necessary for computer simulation), the noise has been generated in the following fashion:

$$N(t + \Delta t) = N(t) - rN(t)\Delta t + \text{Gauss}\sqrt{\nu dt}$$

where Gauss is a C.S.M.P. generated random number having a Gaussian distribution. This distribution has been chosen to have zero mean and a standard deviation of 0.5.

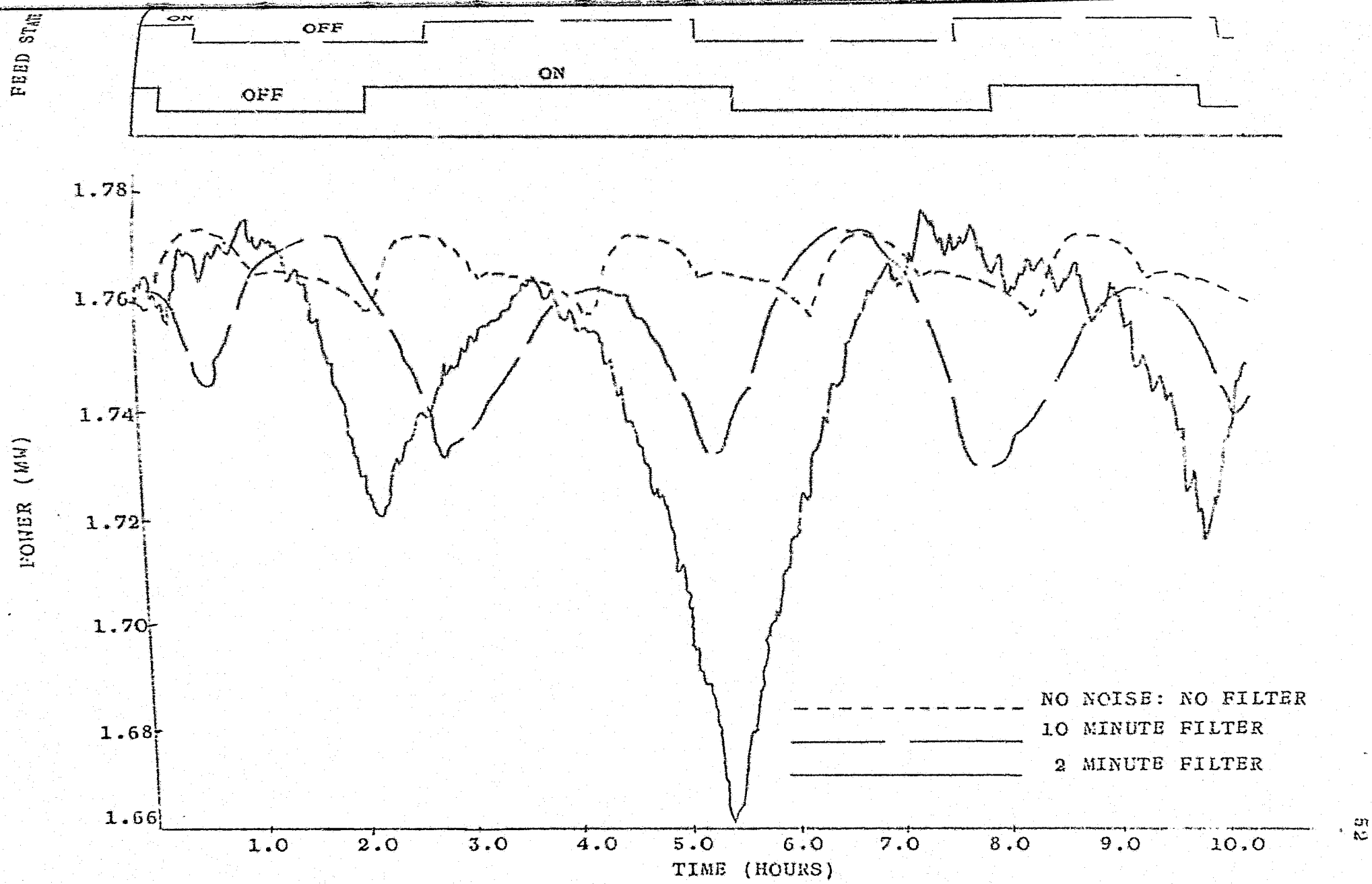
The power spectrum of the coloured Gaussian noise is:

$$\Phi(\omega) = \frac{\nu}{r^2 + \omega^2}$$

while its variance is given by

$$\frac{\nu}{2r}$$

Values of ν and r, which generated noise similar to noise found in practice, were used. This noise was introduced and simulations were run (using the 2 and 10-minute filters). Spurious switching of the "Digicon" was observed and the mill either choked up or ran empty. Noise of a lower level was then introduced and the simulations were repeated. The results can be best summarised in Fig. 10. From this figure it can be seen that for the 10-minute filter, a delay of approximately 10 minutes exists between change of feed state and power rise, and that for a 2-minute filter a delay of approximately 2 minutes exists. These delays have been observed in practice, and they are caused purely by the averaging period of the filter and not related to the time taken for the fresh pebble feed to propagate along the mill. This is



RESULTS OF TESTS ON THE BLYVOORUITZICHT SIMULATOR WHERE NOISE HAS BEEN ADDED TO THE POWER SIGNAL. (THE 5 SUB-MILLS PEBBLE MILL POWER MODEL HAS BEEN USED.)

Fig. 10

corroborated by the fact that when the filter was eliminated from the simulations no delay existed.

In addition to this, Fig. 10 shows quite clearly the deterioration of performance of the "Digicon" under noisy conditions as a function of filter time constant. Note that in the case of the 2-minute filter the power drops significantly lower than in the case of the 10-minute filter. The reason for this is that more noise can get through the 2-minute filter than through the 10-minute filter, resulting in the "Digicon" locking on to spurious noise peaks and thereby delaying switching when the power falls. This observation is in agreement with the fact that, in practice, the "Digicon" has worked best when the 10-minute filter has been selected.

4.4.6 A Review of the Pebble Mill Power Model

In section 4.4.1 the power characteristics of a pebble mill under "Digicon" control have been described. Sections 4.4.2 to 4.4.5 have described the development and testing of a model to reflect these characteristics on the Blyvooruitzicht circuit. The model appears to be very realistic since it reflects the power characteristics found in practice and the spurious switching of the "Digicon" in the presence of noise.

In addition to this, the model has advanced an explanation for the time delay present between the change of pebble feed state and an increase in the apparent power drawn by the pebble mill. It has also been demonstrated that the splitting of the pebble mill into five sections does not result in an unwieldy simulation program for the

Blyvooruitzicht circuit. (See Listing 3). Thus it would appear that there is justification for using the 5 sub-mills power model as opposed to the single mill power model in a "small" milling circuit. As a result of the good correlation between the mill power model and practice, it is felt that this model could be used as the basis for the design of more advanced pebble feed controllers.

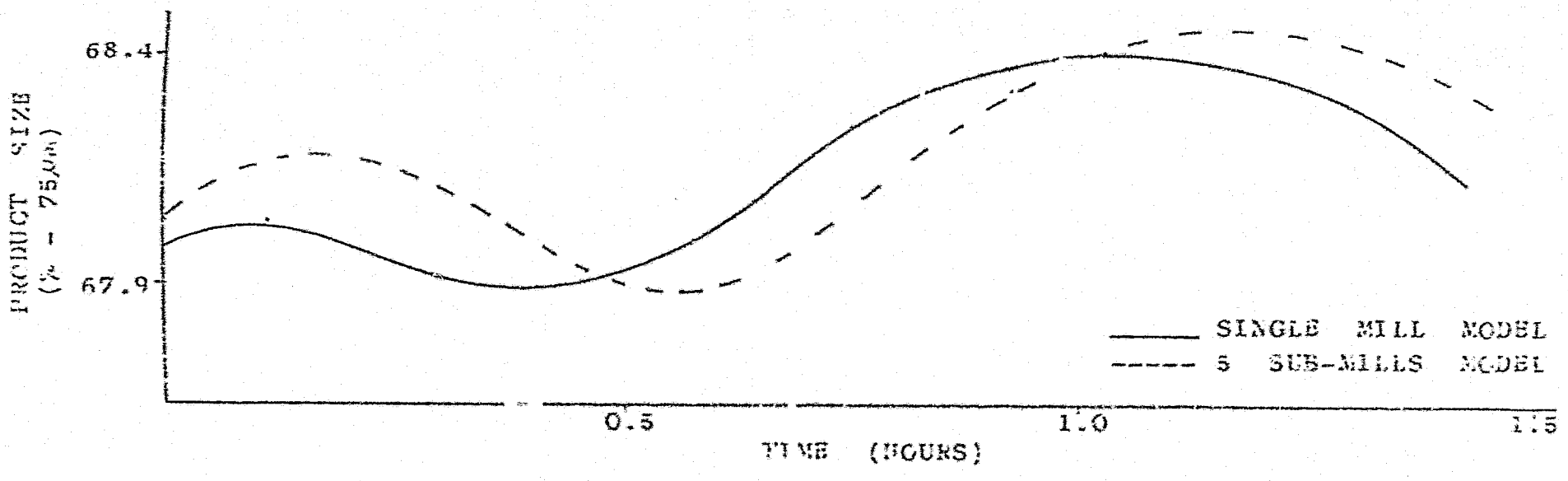
4.5 The Use of the Pebble Mill Power Model in a "Large" Milling Circuit

In section 4.4 an advanced power model (incorporating 5 sub-mills) has been developed, and it has been decided that in the case of a "small" milling circuit the extra computer effort is justified in terms of the superior definition which this model provides. It is now appropriate to consider whether this conclusion holds for a "large" milling circuit.

4.5.1 Simulations of a "large" Milling Circuit with the Pebble Mill Power Model

Simulations were run wherein pebble mill power models were included in the Buffelsfontein simulator. In the first instance, the power model used was the single mill model, while, in the second instance, the 5 sub-mills model was used. In both cases "Digicon" power control was used. Listing 4 gives a listing of the program for the first simulation, while Listing 5 gives a listing of the program for the second simulation. Fig. 11 compares a portion of one cycle of the simulated product size and circulating load, resulting from the single mill

COMPARISON OF ONE CYCLE OF RESPONSES OF BUFFELSFONTEIN SIMULATOR, UNDER "DIGICON" CONTROL, WITH A SINGLE MILL MODEL AND A 5 SUB-MILLS MODEL



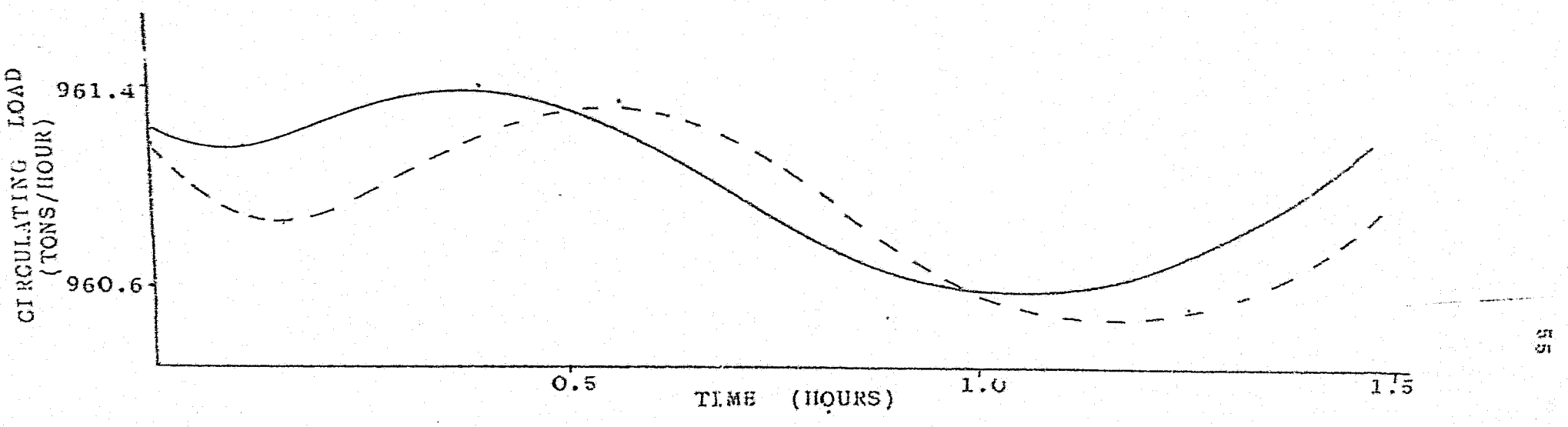


Fig. 11

simulation, with a portion of one cycle of the simulated product size and circulating load resulting from the 5 sub-mills simulation.

From this comparison it is seen that the overall shape of the curves is similar while small differences in detail do exist. The magnitude of the variation is of the same order in both cases.

Bearing in mind the enormous complexity of the 5 sub-mills simulation (56 state variables are required) as opposed to the relative simplicity of the single mill simulation (32 state variables are required), it is fair to conclude that the extra computer effort required by the 5 sub-mills model can only be justified in a simulation of a "large" milling circuit requiring a very high degree of definition.

4.6 Summarising Remarks

This chapter has dealt with certain aspects of the modelling described in Chapters 2 and 3 with the intention of determining what minimum level of complexity is required in the modelling to ensure that the resultant simulators have enough definition and accuracy to be able to yield a better understanding of milling circuits.

CHAPTER 5

THE VALIDITY OF THE SIMULATORS

5.1 General

After simulators have been built, it is necessary to check the outputs of these simulators against the outputs of the real-life systems which the simulators are modelling. This is done by a process of tests in which added confidence in the simulators is gained as each stage in the testing is passed. Ultimately one hopes to be able to express confidence in the simulators that they will reflect reality within the error bounds to which the simulators were originally built.

5.2 The Validity of the Blyvooruitzicht Simulator

Tests done by Hinde[3] have indicated that there exists a strong degree of correlation between the simulated dynamic response of the Blyvooruitzicht circuit to a step change in its rod feed (Fig. 3) and to a step change in its water addition (Fig. 2), and the actual dynamic response of the circuit to these steps. This has contributed to a degree of confidence in the simulator sufficient to warrant the use of the simulator for the development of improved control strategies for the circuit.

5.3 The Validity of the Buffelsfontein Simulator

5.3.1 Level of Accuracy intended

The Buffelsfontein simulator which has been developed in this dissertation was primarily intended to model the

overall trends which exist in the Buffelsfontein circuit operating under dynamic conditions. It was of secondary importance to model the circuit in such a manner that the outputs of the simulator would agree exactly with the actual outputs of the real-life system.

5.3.2 Factors influencing the Accuracy of the Simulator

One of the major factors influencing the accuracy of the simulator was the fact that the models describing the circuit were arrived at largely through simulation. This was necessary because opportunities to do modelling tests on the Buffelsfontein circuit were limited.

Other factors influencing the accuracy of the simulator are:

(1) The fact that the accuracy of all the measurements taken on, and used in the development of the simulator, are limited by the accuracy of the measurement technique used. As examples of this, the magnetic flow meter and the particle size monitor are both complex instruments that are subject to calibration problems.

(2) The fact that the milling circuit in general is a system which is subject to random fluctuations. This could result in the average value for a certain measured parameter to be different from, say, one one-hour period to another.

5.3.3 Analysis of the Outputs of the Simulator

5.3.3.1 Outputs of the Steady State Simulator

The testing of the simulator under steady state conditions

has been described in Chapter 3, and it has been said that there is a good degree of correlation with the actual circuit in steady state.

5.3.3.2 Outputs of the Dynamic Simulator

Two standard tests were run to check the dynamic response of the simulator. The first test, shown in Fig. 5, is a step in the water addition to the head tank (distributor), while the second test, shown in Fig. 6, is a step in the feed to the rod mill.

The response of the actual circuit to these tests was not available; however, the response of the simulator to these tests can be evaluated by considering that:

(1) The response of the Buffelsfontein simulator to the step in rod mill feed was similar in form to the response of the Blyvooruitzicht circuit to a similar step. (Compare Fig. 6 with Fig. 3).

(2) The response of the Buffelsfontein simulator to the step in water addition to the head tank was similar in form to the response of the Blyvooruitzicht circuit to a similar step. (Compare Fig. 5 with Fig. 2).

(3) The Buffelsfontein simulator's response to the step change in head tank water addition has the same characteristic as observed in the response of the Brenda Mine[20] and Rustenburg Platinum Mine[21] to similar steps, namely that they all exhibit the inverse response reported by Lees[22].

On considering the above points, it is felt that the

simulator which has been developed to model the Buffelsfontein circuit can be regarded as a simulator which will, at the least, indicate the trend which the Buffelsfontein circuit will follow when in a dynamic state.

5.3.4 Future Work

As was stated in section 5.3.1, it was not a primary intention of the Buffelsfontein simulator to model the circuit in such a manner that simulated outputs would agree exactly with actual outputs.

In future studies, it would be desirable to gain direct access to the circuit to do the following:

(1) Run dynamic tests on the circuit to compare the simulated outputs with actual outputs.

(2) Account for and rectify any discrepancies which may occur between the simulated system and the real system. This could be done by running "modelling" tests on various elements in the circuit with the aim of updating those models whose outputs do not match reality within small error bounds.

(3) Account in the simulator for the differential transport time of material from the head tank to each hydrocyclone.

Thus, as a result of what has been outlined above, it can be said that there exists a well-defined route by which the present dynamic simulator, which follows trends, can be [illegible] to track the actual outputs with small errors.

CHAPTER 6

THE USE OF THE BUFFELSFONTEIN SIMULATOR FOR THE INVESTIGATION OF CONTROL STRATEGIES

6.1 General

The improved control of milling circuits is a subject which, in recent years, has received a considerable amount of attention[23, 24, 25, 20].

It is not the intention of this dissertation to recommend definite control strategies for the Buffelsfontein circuit, but rather to consider various control strategies with the aim of determining whether improved control is a realistic possibility for the Buffelsfontein circuit.

The Buffelsfontein simulator, incorporating a single mill power model with "Digicon" control, has been used throughout this chapter to investigate:

(1) The ability of a controller to maintain the steady state product size when the system is subjected to a step.

(2) The ability of a controller to track a set point in product size which is finer than the steady state product size.

(3) The ability of a controller to reduce variations in product size when the system is subject to a noisy feed input.

(4) The advantages (or lack thereof) of "Digicon" pebble mill control as opposed to a different mill control strategy.

6.2 Control Objectives

An important aspect of grinding circuit control is the objective which one sets for the controller. Two broad classes are outlined below:

(i) It is desired to increase the fineness of grind of the product. This is consistent with an ore where the finer the ground product is the greater the yield of mineral will be.

(ii) It is desired to minimise fluctuations in the product size. This is consistent with an ore that has a knee[4] (see Fig. 12) in its mineral yield/product size characteristic, i.e. for an ore where the mineral yield will be a constant for all product sizes finer than a certain size. It is then desirable to keep the product size at the knee.

Both objectives have been dealt with in this investigation.

6.3 Control of the System when subjected to a Step

The Buffelsfontein simulator was subjected to a step change in rod feed (100 tons/hour to 110 tons/hour) and the control objective was the maintenance of the steady state product size. The form of the controller was proportional integral feed back from the Particle Size Monitor (P.S.M.) to head tank water addition. (See single feed back control in Fig. 15). Figs. 13 and 14 show the controlled and uncontrolled responses of the system to the step. The steady value of water addition to the head tank under this control is 220 tons/hour. (Water addition to the head

PERCENTAGE LIBERATION OF GOLD IN DISCRETELY SIZED CRUSHED ORE

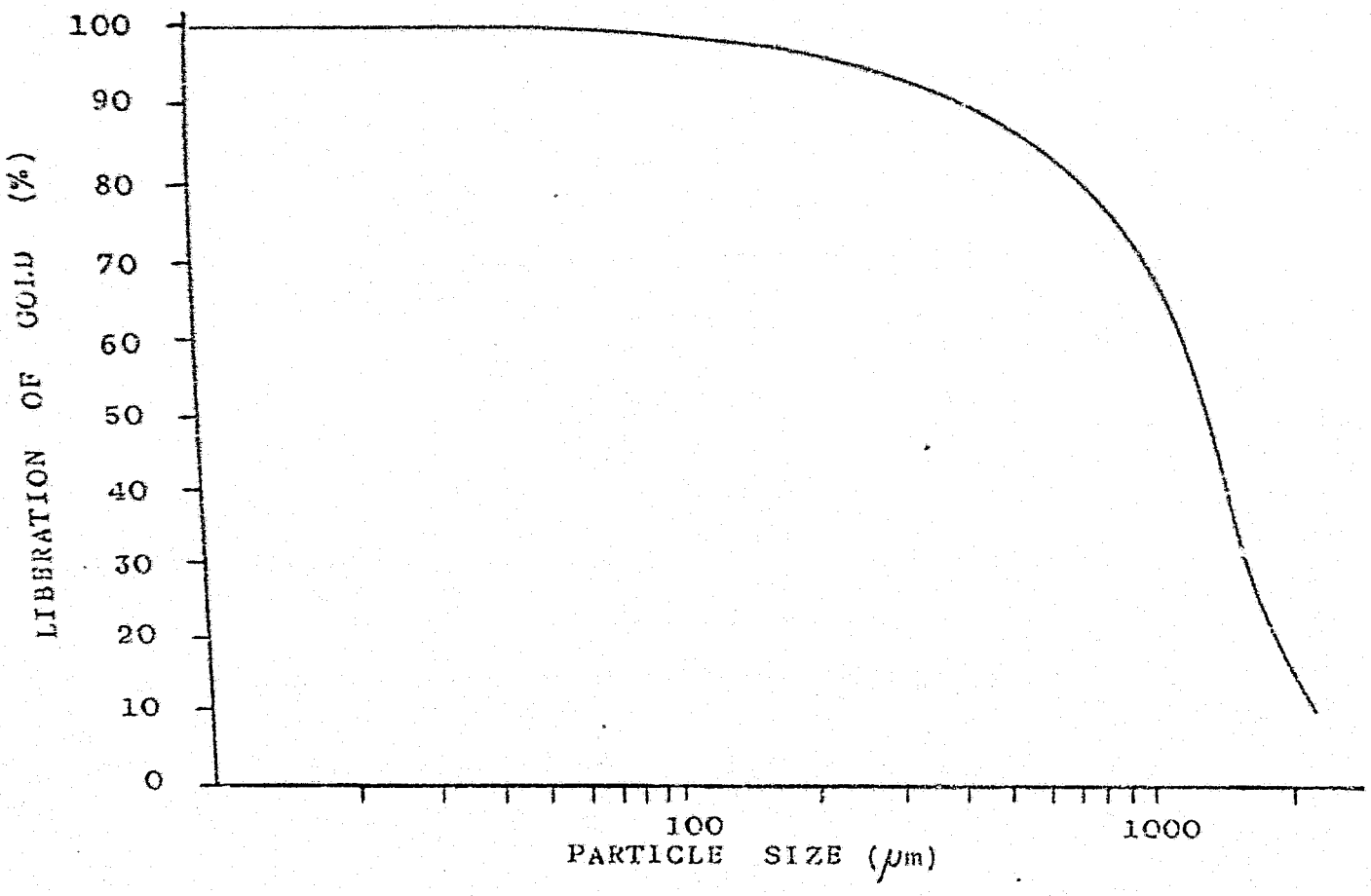


Fig. 12

CONTROLLED AND UNCONTROLLED RESPONSES OF BUFFELSFONTEIN CIRCUIT TO A STEP CHANGE IN ROD MILL FEED (100 TONS/HOUR TO 110 TONS/HOUR)

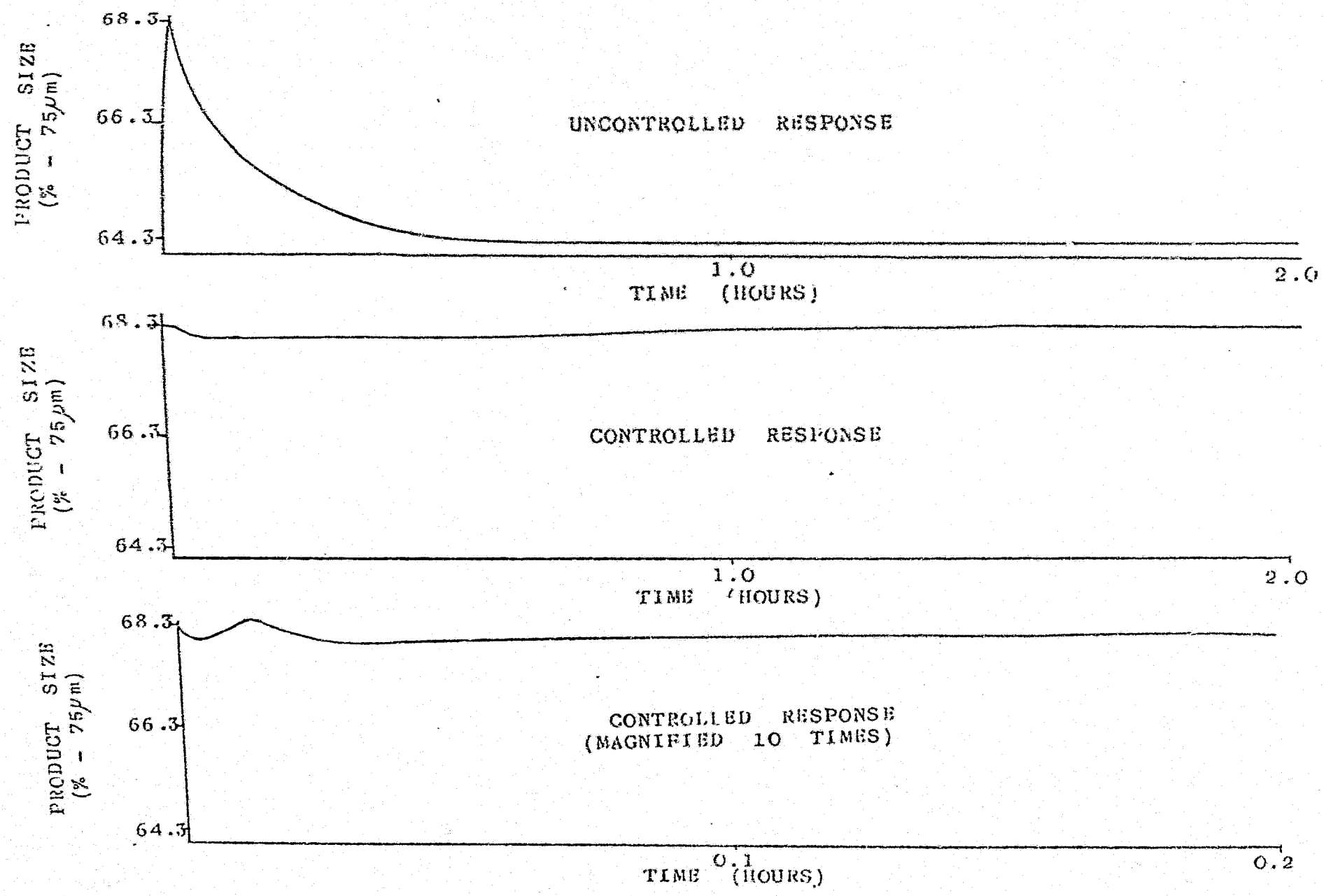


Fig. 13

CONTROLLED AND UNCONTROLLED RESPONSES OF BUFFELSFONTEIN CIRCUIT TO A STEP CHANGE IN ROD MILL FEED (100 TONS/HOUR TO 110 TONS/HOUR)

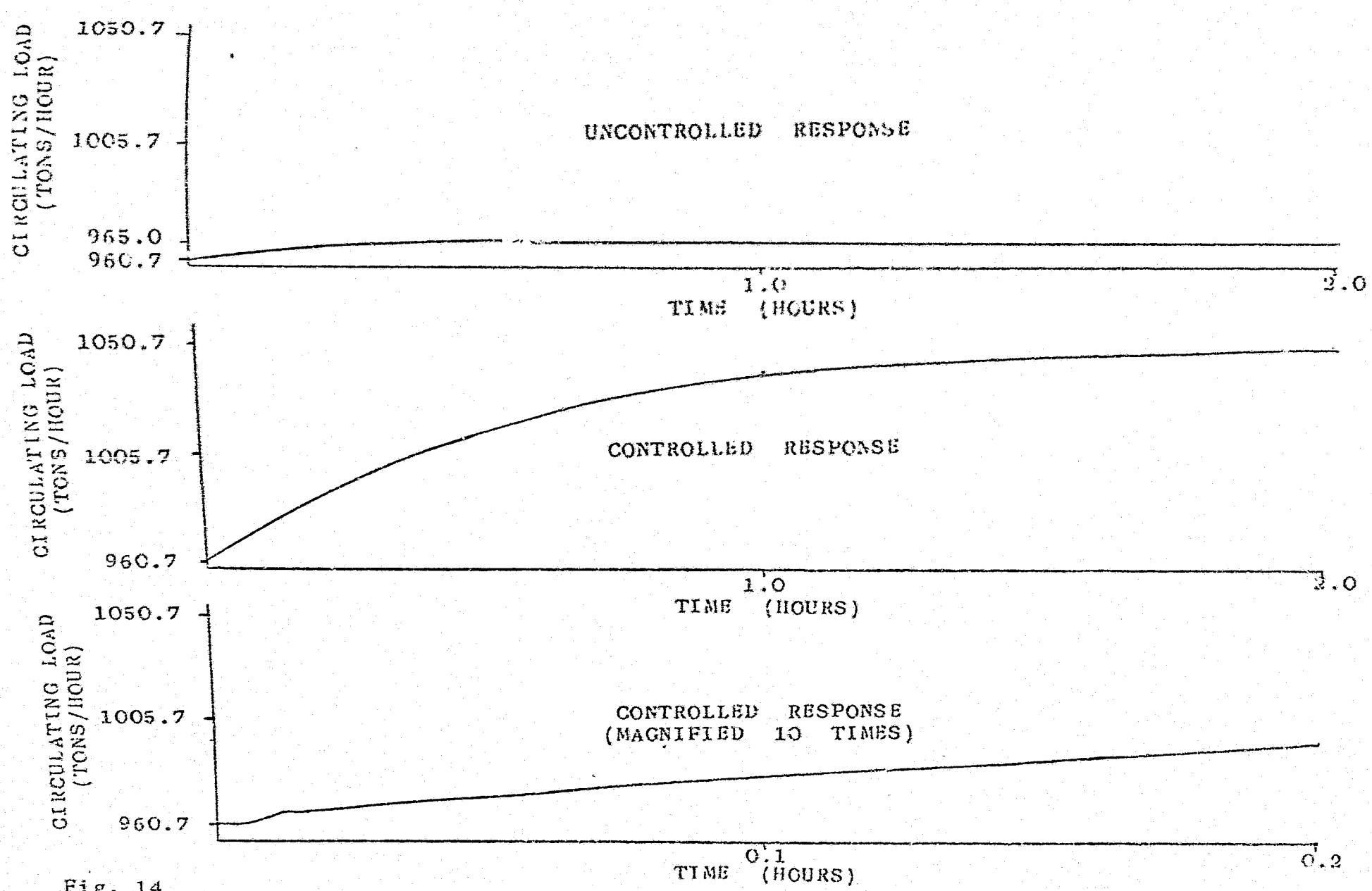


Fig. 14

tank under normal operating conditions is 112 tons/hour). From these figures it is clear that, in principle, control of the Buffelsfontein circuit under dynamic conditions is possible. It must be pointed out that a study aimed at determining the best control strategy under these circumstances must account for the inherent delay between head tank water addition and product size.

6.4 Finer Product Size Control

As outlined in section 6.2, under certain circumstances it is desirable to increase the fineness of grind of the product. Simulations were, therefore, run in which a set point in product size finer than the normal product size was specified. In order to achieve this, three different control strategies were used. (See Fig. 15).

In the first case, feed back from the product size to head tank water addition was used. In the second case, ("parallel" control), feed back from product size to head tank water addition and feed back from product size to rod mill feed were used, while, in the third case, ("cascade" control), the product size was fed back to head tank water addition, and this, in turn, was fed back to rod mill feed.

In all cases, the feed back was via a proportional integral controller and the water which could be added to the head tank was limited to an arbitrary value of 250 tons/hour. (This was done in order to reflect that in practice there is a limit to the amount of water which can be added to the head tank). In the third case, the control loop from the head tank to the rod mill was only

SCHEMATIC DIAGRAM OF BUFFELSFONTEIN CIRCUIT WITH CONTROL CONFIGURATIONS INCLUDED

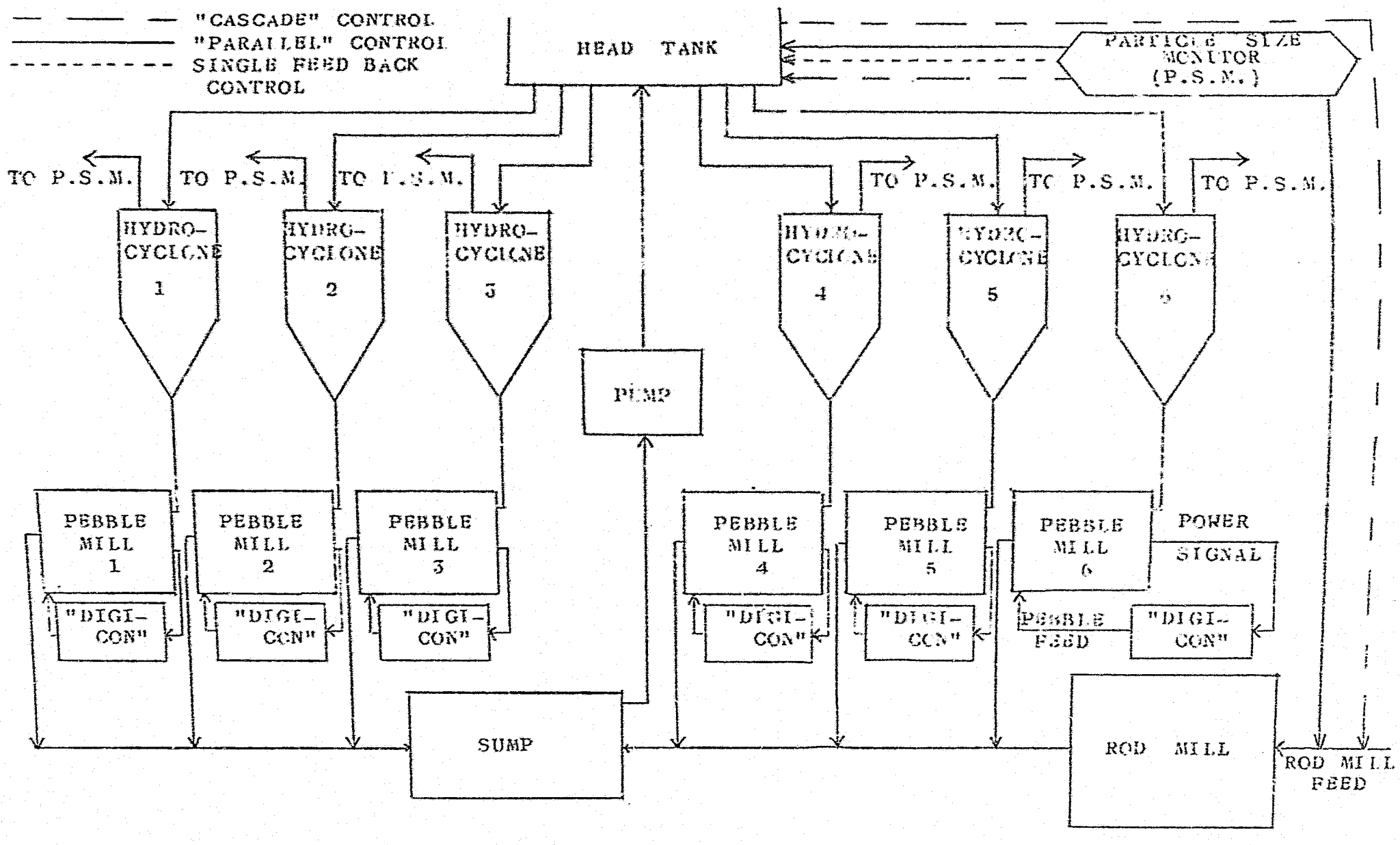


Fig. 15

activated when the water addition to the head tank had saturated.

In the first set of simulations, a product size of 75% less than 75μm was specified. Figs. 16 and 17 give the responses of the circuit to the three different controllers.

From these figures, it is clear that the first type of controller cannot maintain a product size of 75% less than 75μm. The reason for this is that the water addition to the head tank has saturated. In addition to this, it can be seen that, with the first type of controller and with a saturation level of 250 tons/hour, the best product size which one can aim for is 73.1% less than 75μm.

Figs. 16 and 17 also demonstrate that it is possible to maintain a product size of 75% less than 75μm with the second type of controller. In order to achieve this, however, the rod mill feed must drop to 83.4 tons/hour while the water addition to the head tank must rise to 128.7 tons/hour.

In addition to the above, Figs. 16 and 17 demonstrate that it is possible to maintain a product size of 75% less than 75μm with the third type of controller. In this case, the rod mill feed need only drop to 93.7 tons/hour, while the water addition to the head tank must rise to 250 tons/hour. The underlying reason which explains why the third control strategy can effect its control at a higher rod mill feed than the second control strategy is that the second type of controller shares the control "load", while the third type of controller uses the rod

COMPARISON OF RESPONSES OF BUFFELSFONTEIN SIMULATOR TO SET POINT CONTROL WITH SINGLE FEED BACK, "PARALLEL" FEED BACK AND "CASCADED" FEED BACK

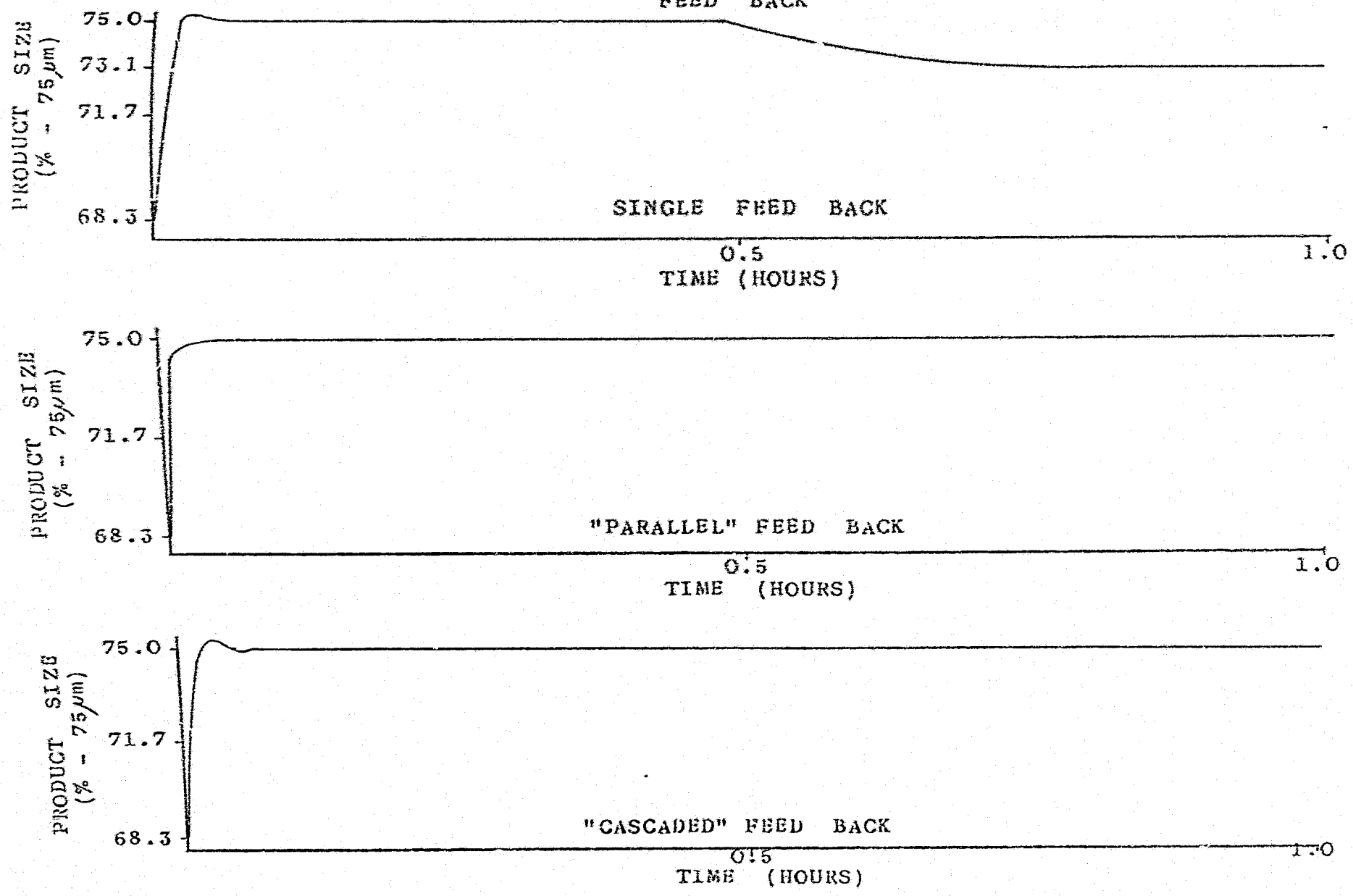


Fig. 16

COMPARISON OF RESPONSES OF BUFFELSFONTEIN SIMULATOR TO SET POINT CONTROL WITH SINGLE FEED BACK, "PARALLEL" FEED BACK AND "CASCADED" FEED BACK

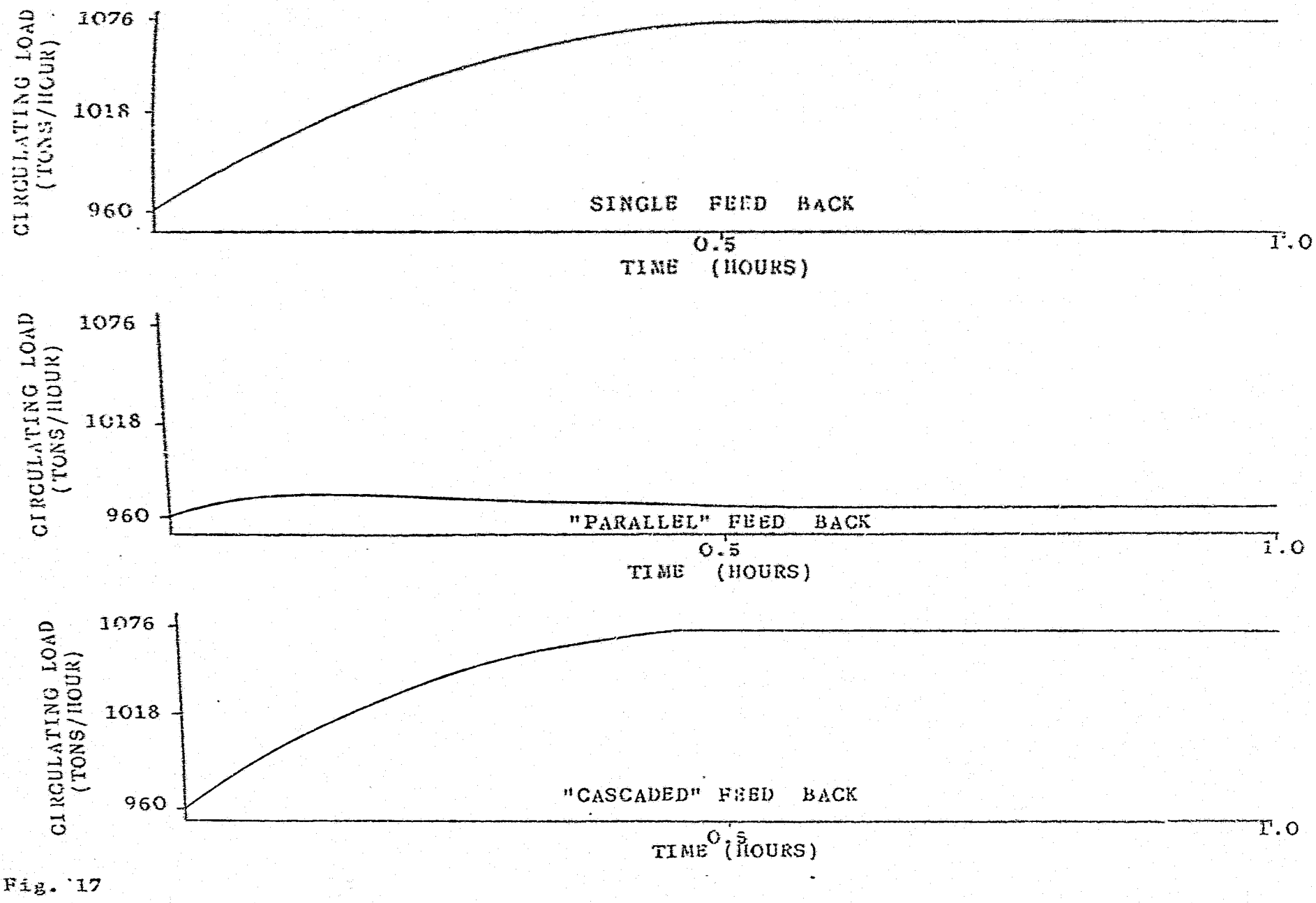


Fig. 17

mill feed as a control variable only when no additional water can be added to the head tank.

In further sets of simulations, it was demonstrated that product sizes finer than 75% less than 75μm can be achieved with the second and third control strategies if one is prepared to tolerate further drops in rod mill feed. Fig. 18 shows the response of the Buffelsfontein simulator to product size set point control of 80% less than 75μm with the second controller.

In addition to the above sets of simulations, a simulation was run (see Fig. 19) wherein the Buffelsfontein circuit's product size was controlled to 75% less than 75μm through proportional integral feed back from the product size to the pump speed. This simulation demonstrates that control strategies need not necessarily incorporate control over water addition to the head tank.

In conclusion, it can be said that, in principle, fine product size control of the Buffelsfontein circuit is possible.

6.5 Control of Product Size Variance

Random variations which exist in a milling circuit will affect the product size, resulting in a randomly varying product size. For the reasons outlined in section 6.2, it is desirable to reduce these variations. In order to test whether product size variance could be reduced on the Buffelsfontein circuit, noise of a similar nature to that described in Chapter 4 was added to the rod mill feed. Fig. 20 compares the uncontrolled response of the

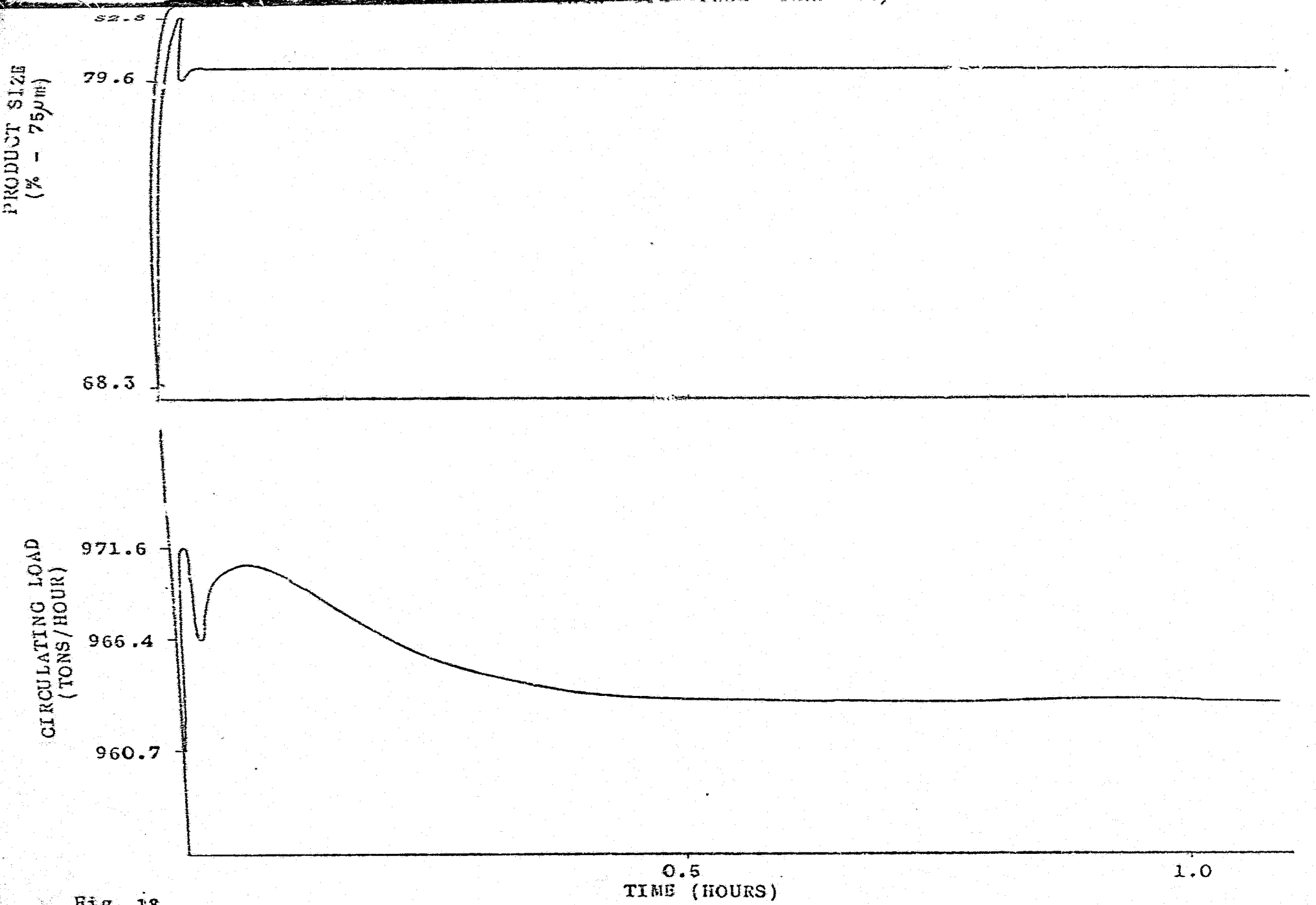

82.8
79.6
PRODUCT SIZE
(% - 75μm)
68.3
971.6
966.4
960.7
CIRCULATING LOAD
(TONS/HOUR)
0.5
1.0
TIME (HOURS)

Fig. 18

RESPONSE OF BUFFELSFONTEIN SIMULATOR TO SET POINT CONTROL WITH FEED BACK TO PUMP SPEED FROM PRODUCT SIZE

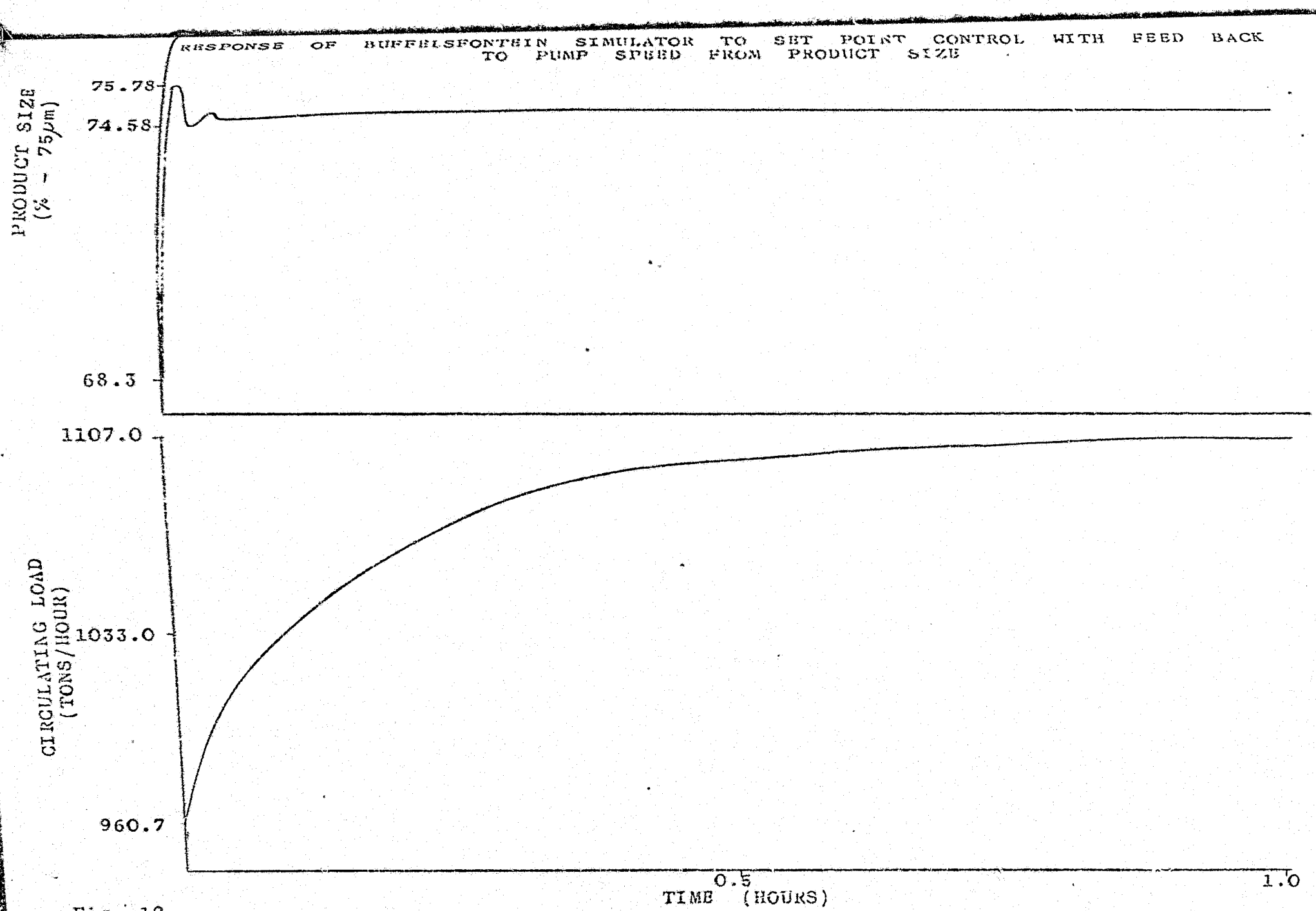


Fig. 19

COMPARISON OF CONTROLLED AND UNCONTROLLED RESPONSES OF BUFFELSFONTEIN SIMULATOR TO NOISY ROD MILL FEED

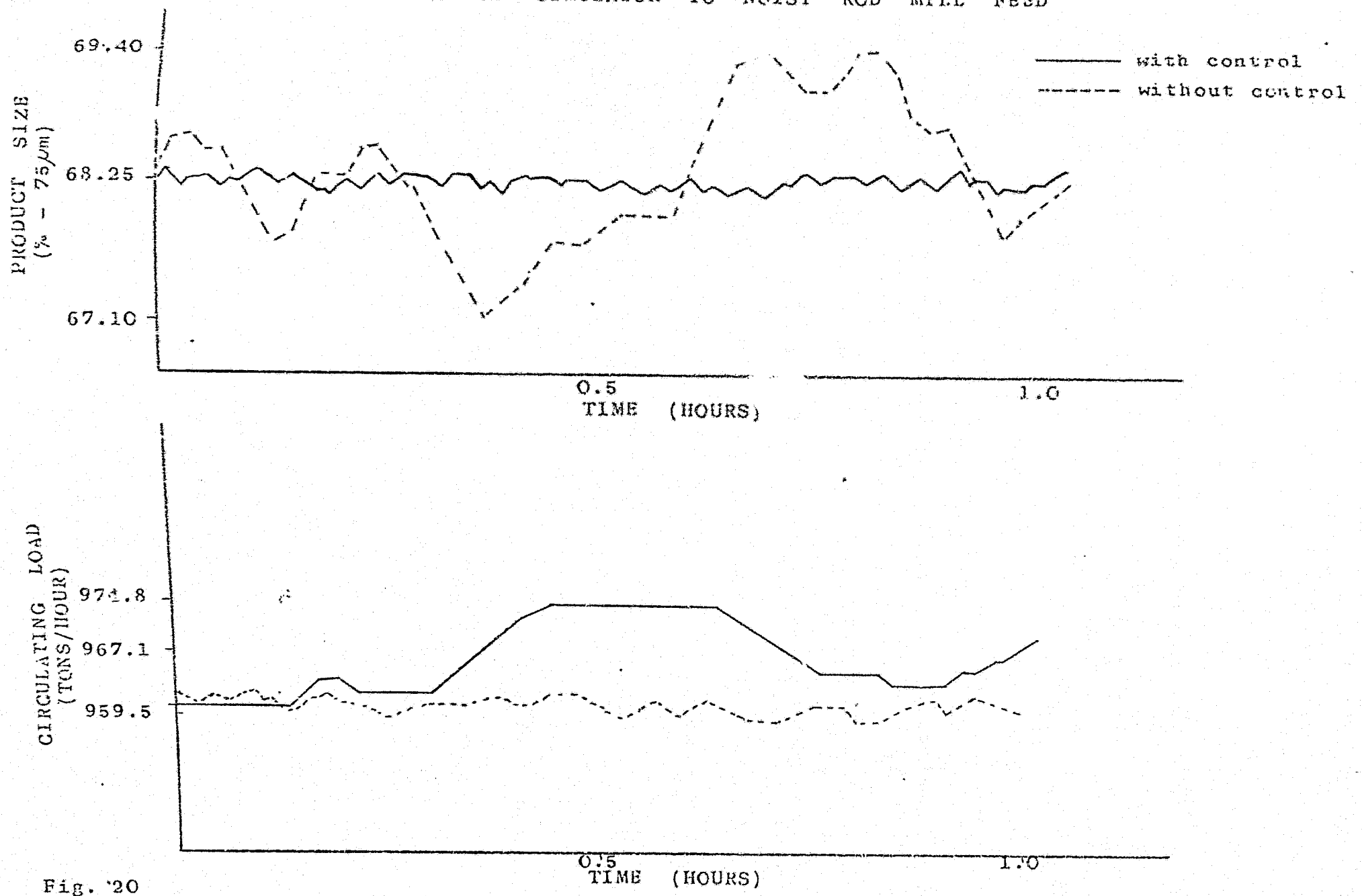


Fig. 20

system to this noisy input with the controlled response of the system to a similar input. Single feed back control of the same form as the control described in section 6.3 has been used.

As a result of these tests, it is felt that control of product size variance is a realistic objective for the Buffelsfontein circuit.

6.6 Pebble Feed Control

The Buffelsfontein simulator was used to compare the effectiveness of "Digicon" pebble mill control with an alternative pebble mill control strategy. The alternative controller operates in the same way as the "Digicon", excepting that the pebble feed is not switched between full on and off as in the "Digicon" but rather between a value just above the average feed value and a value just below the average feed value.

In the Buffelsfontein circuit, the "Digicon" switches between 18 tons/hour and 0 tons/hour, while the alternative controller switches between 10 tons/hour and 8 tons/hour.

Simulations were run with the system operating in steady state under both types of control. In order to compare the two different controllers, three performance indices were devised.

Firstly, the product size was integrated to obtain a measure of the fineness of the product. The second performance index was the integral of the difference between actual product size and steady state product size. This was intended to serve as a measure of the variation of

product size. The final performance index was integrated mill power. This was intended to measure the total amount of power drawn by each mill.

Fig. 21 contrasts the product size and circulating load of the Buffelsfontein circuit under "Digicon" control with the product size and circulating load of the Buffelsfontein circuit under the control of the alternative controller. Fig. 22 contrasts the mill power characteristics of the "Digicon" controller with the power characteristics of the alternative controller.

No significant difference between the two different strategies was indicated by the performance indices. (The order of difference was 0.10%).

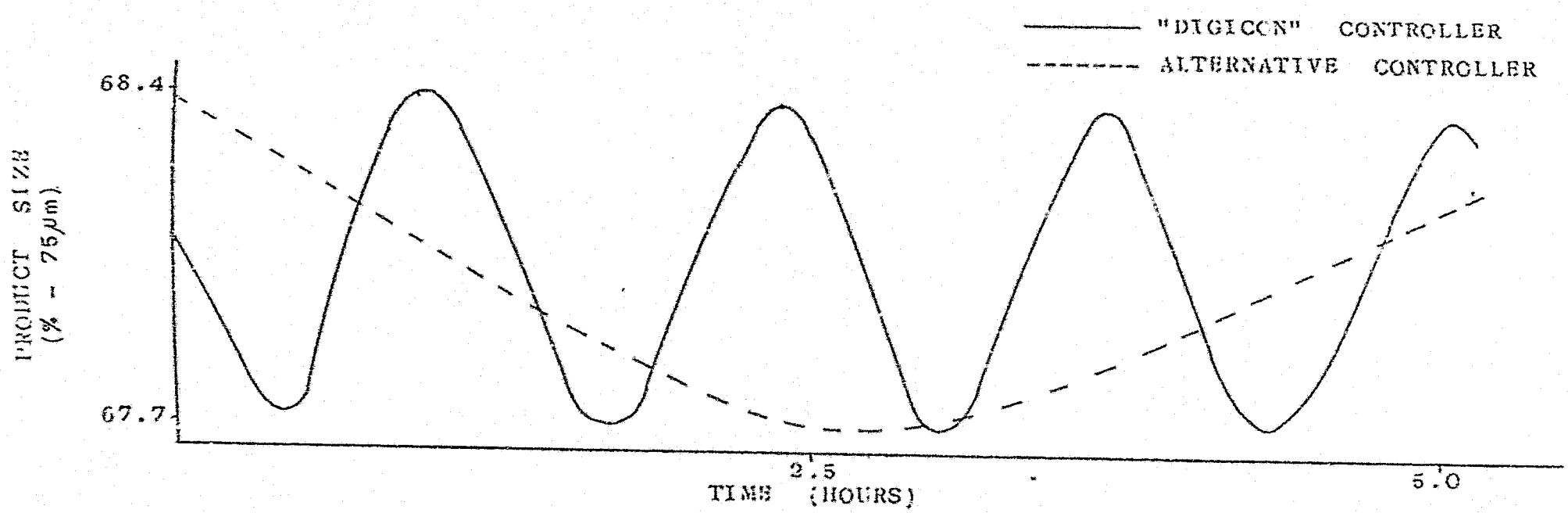
Simulations were then run with the system subjected to step changes in the inputs of the system, and again the performance indices showed no significant difference between the two control strategies. It can therefore be concluded that there is no significant difference between the two controllers.

Bearing the above simulations in mind, it can be said that facilities do exist in the Buffelsfontein simulator for the comparison of different mill control strategies.

6.7 Concluding Remarks

This chapter has demonstrated the feasibility of improved control of the Buffelsfontein milling circuit. As pointed out in section 6.1, it was not the intention of this study to recommend optimum controllers, thus the controllers which have been used were chosen for their simplicity.

COMPARISON OF PRODUCT SIZE AND CIRCULATING LOAD OF BUFFELSFONTEIN CIRCUIT UNDER "DIGICON" CONTROL WITH PRODUCT SIZE AND CIRCULATING LOAD OF BUFFELSFONTEIN CIRCUIT UNDER CONTROL OF ALTERNATIVE CONTROLLER



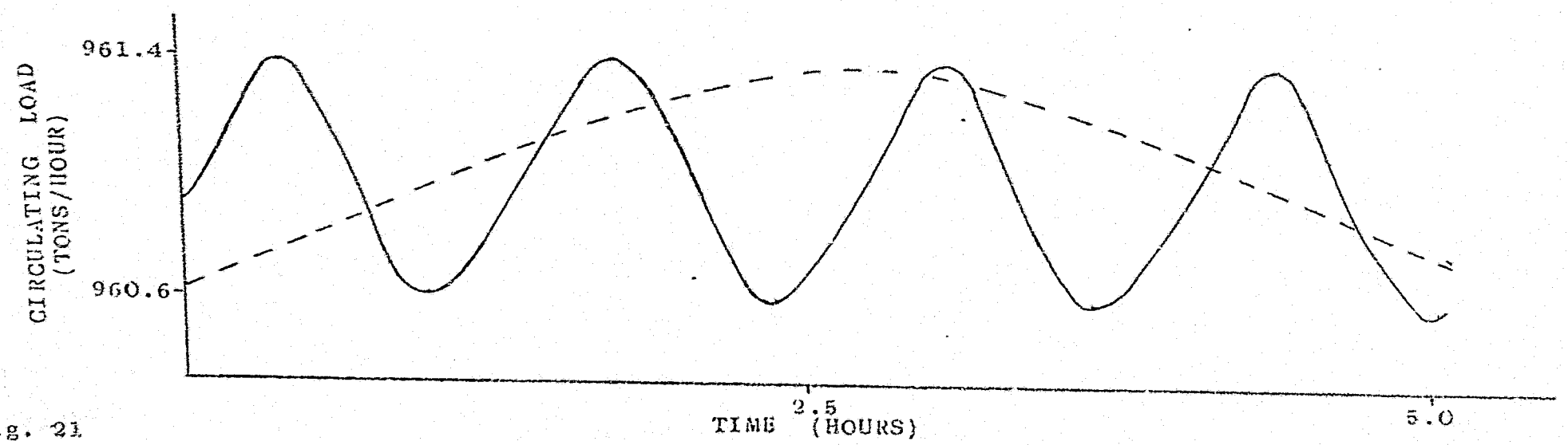


Fig. 21

COMPARISON OF MILL POWER CHARACTERISTICS OF "DIGICON" CONTROLLER
WITH MILL POWER CHARACTERISTICS OF ALTERNATIVE CONTROLLER

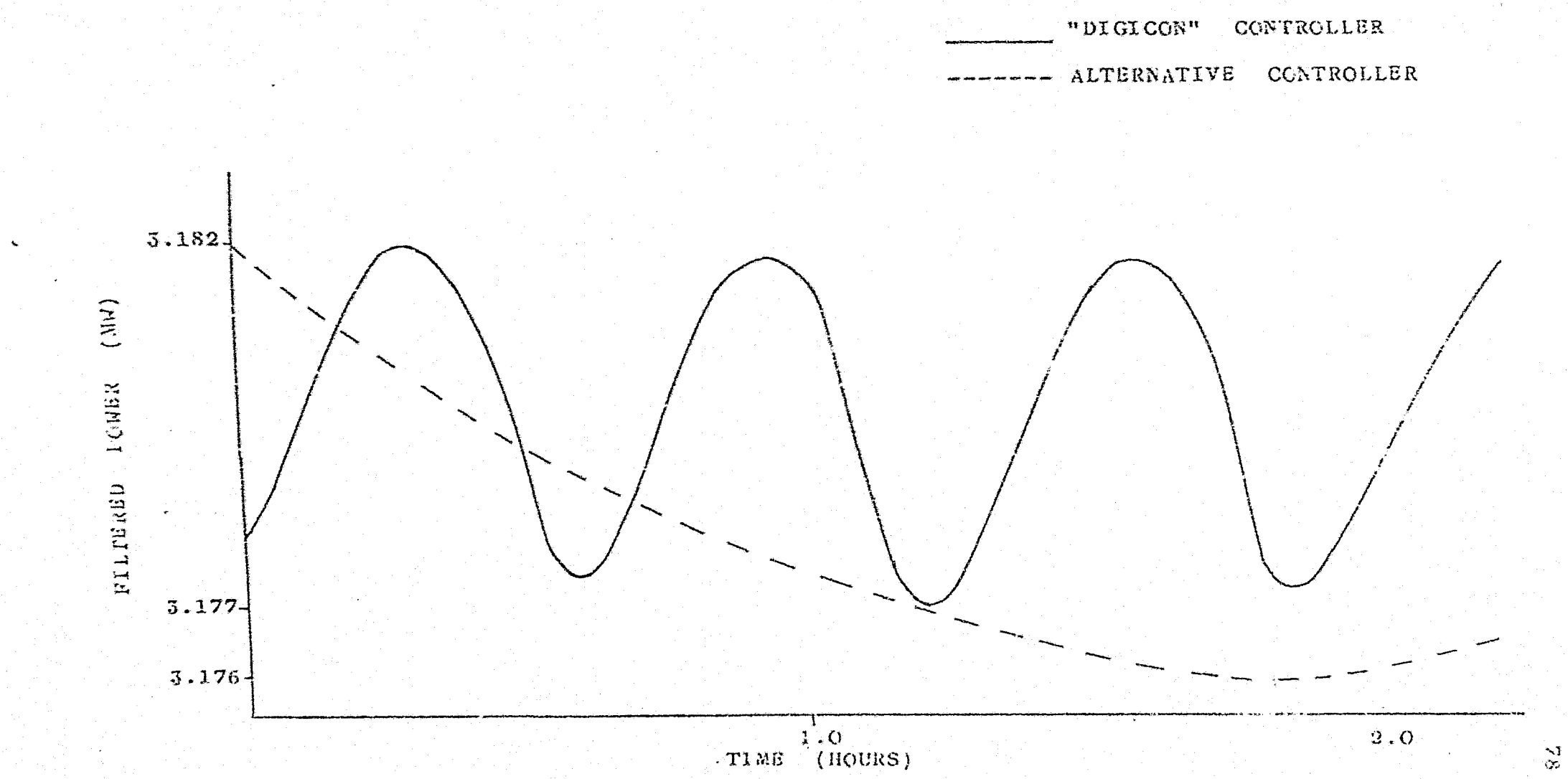


Fig. 22

APPENDIX 1

COMPUTER PROGRAM LISTINGS

1. Listing of non-linear Blyvooruitzicht Simulator.

2. Listing for Buffelsfontein Simulator operating in Steady State.

3. Listing of non-linear Blyvooruitzicht Simulator incorporating a 5 Sub-Mills Pebble Mill Power Model.

4. Listing for Buffelsfontein Circuit incorporating a Single Mill Pebble Mill Power Model.

5. Listing for Buffelsfontein Circuit incorporating a 5 Sub-Mills Pebble Mill Power Model.

COMPUTER PROGRAM LISTING OF THE NON-LINEAR
BLYVOORUITZICHT SIMULATOR

```
L.0001 //HTHTRI JOB C07,CLASS=E                                                AECDEFGH
L.0002 /*JOBPARM  FORMS=9999,L=9999
L.0003 // EXEC CSMP360
L.0004 //GO.SYSIN DD *
L.0005 INCON X1I=6.8183
L.0006 INCON X2I=14.564
L.0007 INCON X3I=0.1639
L.0008 INCON X4I=0.1999
L.0009 INCON X5I=2.8522
L.0010 INCON X6I=0.1936
L.0011 INCON X7I=0.9541
L.0012 INCON X8I=2.8143
L.0013 INCON X9I=0.1701
L.0014 INCON X10I=0.8386
L.0015 X11I=0
L.0016 X1=INTGRL(X1I,C1)
L.0017 C1=109-X1*4.582*((X1+X2/2.72)**0.5)
L.0018 X2=INTGRL(X2I,C2)
L.0019 C2=A-4.582*X2*((X1+X2/2.72)**0.5)
L.0020 ZI1=4.582*X1*((X1+X2/2.72)**0.5)
L.0021 ZI2=4.582*X3*X2*((X1+X2/2.72)**0.5)
L.0022 ZI3=4.582*(1-X3)*X2*((X1+X2/2.72)**0.5)
L.0023 A=7+(ZI14*ZI17)+(ZI15*ZI17)+7I19*(1-EXP(-0.6931*((8.66/ZI24)**2)))+R
L.0024 R=ZI21*(1-EXP(-0.6931*((166/ZI24)**2)))
L.0025 ZI14=ZI11*2.72/2
L.0026 ZI11=(266.6*(X8+X9+X10)/3.398+446.36)*X9/(X8+X9+X10)
L.0027 ZI17=ZI16/ZI13
L.0028 ZI16=109
L.0029 ZI13=ZI10/2
L.0030 ZI10=(266.6*(X8+X9+X10)/3.398+446.36)*X8/(X8+X9+X10)
L.0031 ZI19=ZI14-ZI14*7I17
L.0032 ZI24=10**(1*ZI22-0.0005*ZI23+1.6624)
L.0033 ZI23=ZI13+(ZI14+ZI15)/2.72
L.0034 ZI15=ZI12*2.72/2
L.0035 ZI12=(266.6*(X8+X9+X10)/3.398+446.36)*X10/(X8+X9+X10)
L.0036 ZI22=(ZI14+ZI15)/(ZI13+ZI14+ZI15)
L.0037 ZI21=7I15-ZI15*ZI17
L.0038 B=ZI26/A
L.0039 ZI26=ZI18+ZI25
L.0040 ZI18=ZI14*7I17
L.0041 ZI25=ZI19*(1-EXP(-0.6931*((8.66/ZI24)**2)))
L.0042 X3=INTGRL(X3I,C3)
L.0043 C3=(A*(B-X3)/X2+(1-X3)*1.65)
L.0044 X4=INTGRL(X4I,C4)
L.0045 C4=(70.0*(0.03-X4)/6.03+(1-X4)*2.4668)
L.0046 X5=INTGRL(X5I,C5)
L.0047 C5=( 2*4.582*X1*((X1+X2/2.72)**0.5)+0.3*70.0-(X5/(X5+X6+X7))*686.3)+D
L.0048 D=250.3676+500*((4-X5-X6-X7)+(20*X11))
L.0049 X6=INTGRL(X6I,C6)
L.0050 C6=2*4.582*X3*X2*((X1+X2/2.72)**0.5)/2.72+(70./2.72)*X4-C
L.0051 C=(X6/(X5+X6+X7))*686.3
L.0052 X7=INTGRL(X7I,C7)
L.0053 C7=2*4.582*(1-X3)*X2*((X1+X2/2.72)**0.5)/2.72+(70.0/2.72)*(1-X4)-Q
L.0054 Q=(X7/(X5+X6+X7))*686.3
```

COMPUTER PROGRAM LISTING OF THE NON-LINEAR
BLYVOORUITZICHT SIMULATOR (cont'd).

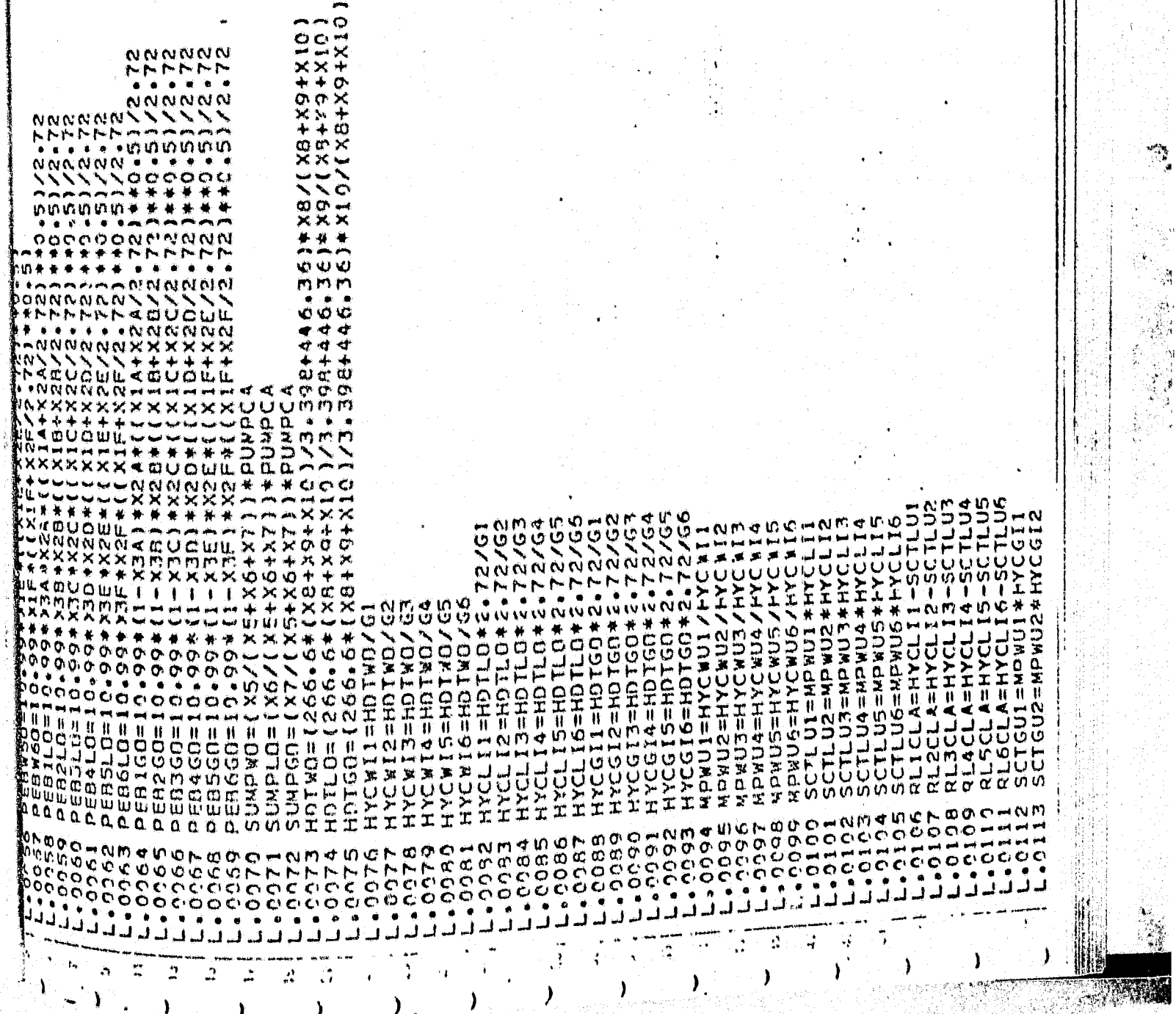
```
L.0056 C8=
L.0057 X9=INTGRL(X9I,C9)
L.0058 C9=(X6/(X5+X6+X7))*686.3-ZI11
L.0059 X10=INTGRL(X10I,C10)
L.0060 C10=(X7/(X5+X6+X7))*686.3-ZI12
L.0061 X11=INTGRL(X11I,C11)
L.0062 C11=(4-X5-X6-X7)
L.0063 CLOAD=(ZI20+ZI27+ZI18+ZI25)*2
L.0064 ZI20=ZI15*ZI17
L.0065 PRODS=ZI30/(ZI30+ZI31)
L.0066 ZI30=ZI14-ZI26
L.0067 ZI31=ZI15-ZI28
L.0068 ZI26=ZI18+ZI25
L.0069 ZI28=ZI20+ZI27
L.0070 ZI27=ZI21*(1-EXP(-0.6931*((166/ZI24)**2)))
L.0071 U=X5+X6+X7
L.0072 HDTVOL=X8+X9+X10
L.0073 TIMER FINTIM=1.0,OUTDEL=0.02
L.0074 PRTPLT PRODS(ZI1,ZI2,ZI3)
L.0075 PRTPLT CLOAD(ZI10,ZI11,ZI12)
L.0076 PRTPLT U(ZI13)
L.0077 PRTPLT HDTVOL
L.0078 END
L.0079 STOP
L.0080 ENDJOB
L.0081 /*
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN
SIMULATOR OPERATING IN STEADY STATE

```
L.0001 //HTHRDST1 JOB CC7,CLASS=A
L.0002 /*JOBPARM  R=87,L=9999
L.0003 // EXEC CSMP360,TIME.GO=10
L.0004 //GO.SYSIN DD *
L.0005 INCON X1AI=2.0543
L.0006 INCON X1BI=2.0543,X1CI=2.0543
L.0007 INCON X1DI=2.0543,X1EI=2.0543,X1FI=2.0543
L.0008 INCON X2AI=7.11990,X2BI=7.11990
L.0009 INCON X2CI=7.11990,X2DI=7.11990
L.0010 INCON X2EI=7.11990,X2FI=7.11990
L.0011 INCON X3AI=0.20881,X3BI=0.20881
L.0012 INCON X3CI=0.20881,X3DI=0.20881
L.0013 INCON X3EI=0.20881,X3FI=0.20881
L.0014 INCON X4I=0.1556
L.0015 INCON X5I=10.846
L.0016 INCON X6I=0.84755
L.0017 INCON X7I=3.3063
L.0018 INCON X8I=10.843
L.0019 INCON X9I=0.76701
L.0020 INCON X10I=2.9921
L.0021 INCON X11I=0
L.0022 INCON X12I=0.
L.0023 PARAMETER RODFI=120.
L.0024 PARAMETER BUMPCA=1480.
L.0025 HYC%U1=INSW(TST,48.8,0.0)
L.0026 TST=TIME-1.5
L.0027 HYC%U2=INSW(TST,48.8,0.0)
L.0028 HYCWU3=48.8
L.0029 HYCWU4=48.8
L.0030 HYC%U5=48.8
L.0031 HYC%U6=48.8
L.0032 SGOVF1=(OVFL1L+OVFL1G+OVFL1W)/(OVFL1W+(OVFL1L+OVFL1G)/2.72)
L.0033 SGOVF3=(OVFL3L+OVFL3G+OVFL3W)/(OVFL3W+(OVFL3L+OVFL3G)/2.72)
L.0034 SGRODO=(RODWO+(RODLO+RODGO)*2.72)/(RODWO+RODLO+RODGO)
L.0035 SGHYCU=(FLO1GU+FLO1LU+HYCWU1)/(HYCWU1+(FLO1GU+FLO1LU)/2.72)
L.0036 SGHYCI=(HYCLI1+HYCGI1+HYCWI1)/(HYCWI1+(HYCGI1+HYCLI1)/2.72)
L.0037 SGPFB1=(PEBW1C+(PEB1LO+PEB1GO)*2.72)/(PEBW1O+PEB1LO+PEB1GO)
L.0038 SGPFB3=(PEBW3O+(PEB3LO+PEB3GO)*2.72)/(PEBW3O+PFB3LO+PEB3GO)
L.0039 SGRAVH=(X8+2.72*(X9+X10))/(X8+X9+X10)
L.0040 WADDHT =112.0
L.0041 PARAMETER PEBFD1=9,PEBFD2=9,PEBFD3=9,PEBFO4=9
L.0042 PARAMETER PEBFD5=9,PEBFD6=9
L.0043 G1=INSW(TST,6.,999999.)
L.0044 G2=INSW(TST,6.,999999.)
L.0045 G3=INSW(TST,6.,4.)
L.0046 G4=INSW(TST,6.,4.)
L.0047 G5=INSW(TST,6.,4.)
L.0048 G6=INSW(TST,6.,4.)
L.0049 RODWO=0.25*RODFI
L.0050 RODLO=((RODFI/2.72))*X4
L.0051 RODGO=((RODFI/2.72))*(1-X4)
L.0052 PEBW1O=10.99*X1A*((X1A+X2A/2.72)**0.5)
L.0053 PEBW2O=10.99*X1B*((X1B+X2B/2.72)**0.5)
L.0054 PEBW3O=10.99*X1C*((X1C+X2C/2.72)**0.5)
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN SIMULATOR OPERATING IN STEADY STATE

(cont'd.)



COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN
SIMULATOR OPERATING IN STEADY STATE
(cont'd.)

```
L.0116 SCTGU5=MPWU5*HYCGI5
L.0117 SCTGU6=MPWU6*HYCGI6
L.0118 RG1CLA=HYCGI1-SCTGU1
L.0119 RG2CLA=HYCGI2-SCTGU2
L.0120 RG3CLA=HYCGI3-SCTGU3
L.0121 RG4CLA=HYCGI4-SCTGU4
L.0122 RG5CLA=HYCGI5-SCTGU5
L.0123 RG6CLA=HYCGI6-SCTGU6
L.0124 SP1CYI=(HYCLI1+HYCGI1)/(HYCLI1+HYCGI1+HYCWI1)
L.0125 SP2CYI=(HYCLI2+HYCGI2)/(HYCLI2+HYCGI2+HYCWI2)
L.0126 SP3CYI=(HYCLI3+HYCGI3)/(HYCLI3+HYCGI3+HYCWI3)
L.0127 SP4CYI=(HYCLI4+HYCGI4)/(HYCLI4+HYCGI4+HYCWI4)
L.0128 SP5CYI=(HYCLI5+HYCGI5)/(HYCLI5+HYCGI5+HYCWI5)
L.0129 SP6CYI=(HYCLI6+HYCGI6)/(HYCLI6+HYCGI6+HYCWI6)
L.0130 SLHY1I=HYCWI1+(HYCLI1+HYCGI1)/2.72
L.0131 SLHY2I=HYCWI2+(HYCLI2+HYCGI2)/2.72
L.0132 SLHY3I=HYCWI3+(HYCLI3+HYCGI3)/2.72
L.0133 SLHY4I=HYCWI4+(HYCLI4+HYCGI4)/2.72
L.0134 SLHY5I=HYCWI5+(HYCLI5+HYCGI5)/2.72
L.0135 SLHY6I=HYCWI6+(HYCLI6+HYCGI6)/2.72
L.0136 D50C1=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP1CYI-BIT1)
L.0137 BIT1=0.0001*(16.67*HYCWI1+HYCLI1*16.67/2.72+HYCGI1*16.67/2.72)
L.0138 D50C2=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP2CYI-BIT2)
L.0139 BIT2=0.0001*(16.67*HYCWI2+HYCLI2*16.67/2.72+HYCGI2*16.67/2.72)
L.0140 D50C3=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP3CYI-BIT3)
L.0141 BIT3=0.0001*(16.67*HYCWI3+HYCLI3*16.67/2.72+HYCGI3*16.67/2.72)
L.0142 D50C4=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP4CYI-BIT4)
L.0143 BIT4=0.0001*(16.67*HYCWI4+HYCLI4*16.67/2.72+HYCGI4*16.67/2.72)
L.0144 D50C5=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP5CYI-BIT5)
L.0145 BIT5=0.0001*(16.67*HYCWI5+HYCLI5*16.67/2.72+HYCGI5*16.67/2.72)
L.0146 D50C6=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP6CYI-BIT6)
L.0147 BIT6=0.0001*(16.67*HYCWI6+HYCLI6*16.67/2.72+HYCGI6*16.67/2.72)
L.0148 CLALU1=RL1CLA*(1-EXP(-0.6931*((71.66/D50C1)**2)))
L.0149 CLALU2=RL2CLA*(1-EXP(-0.6931*((71.66/D50C2)**2)))
L.0150 CLALU3=RL3CLA*(1-EXP(-0.6931*((71.66/D50C3)**2)))
L.0151 CLALU4=RL4CLA*(1-EXP(-0.6931*((71.66/D50C4)**2)))
L.0152 CLALU5=RL5CLA*(1-EXP(-0.6931*((71.66/D50C5)**2)))
L.0153 CLALU6=RL6CLA*(1-EXP(-0.6931*((71.66/D50C6)**2)))
L.0154 FLO1LU=CLALU1+SCTLU1
L.0155 FLO2LU=CLALU2+SCTLU2
L.0156 FLO3LU=CLALU3+SCTLU3
L.0157 FLO4LU=CLALU4+SCTLU4
L.0158 FLO5LU=CLALU5+SCTLU5
L.0159 FLO6LU=CLALU6+SCTLU6
L.0160 CLAGU1=RG1CLA*(1-EXP(-0.6931*((166./D50C1)**2)))
L.0161 CLAGU2=RG2CLA*(1-EXP(-0.6931*((166./D50C2)**2)))
L.0162 CLAGU3=RG3CLA*(1-EXP(-0.6931*((166./D50C3)**2)))
L.0163 CLAGU4=RG4CLA*(1-EXP(-0.6931*((166./D50C4)**2)))
L.0164 CLAGU5=RG5CLA*(1-EXP(-0.6931*((166./D50C5)**2)))
L.0165 CLAGU6=RG6CLA*(1-EXP(-0.6931*((166./D50C6)**2)))
L.0166 FLO1GU=CLAGU1+SCTGU1
L.0167 FLO2GU=CLAGU2+SCTGU2
L.0168 FLO3GU=CLAGU3+SCTGU3
L.0169 FLO4GU=CLAGU4+SCTGU4
L.0170 FLO5GU=CLAGU5+SCTGU5
L.0171 FLO6GU=CLAGU6+SCTGU6
L.0172 OVFL1W=HYCWI1-HYCWU1
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN
SIMULATOR OPERATING IN STEADY STATE
(cont'd.)

```
L.0175 OVFL3W=HYCWI3-HYCWU3
L.0176 OVFL4W=HYCWI4-HYCWU4
L.0177 OVFL5W=HYCWI5-HYCWU5
L.0178 OVFL6W=HYCWI6-HYCWU6
L.0179 OVFL1L=HYCLI1-FLO1LU
L.0180 OVFL2L=HYCLI2-FLO2LU
L.0181 OVFL3L=HYCLI3-FLO3LU
L.0182 OVFL4L=HYCLI4-FLO4LU
L.0183 OVFL5L=HYCLI5-FLO5LU
L.0184 OVFL6L=HYCLI6-FLO6LU
L.0185 OVFL1G=HYCGI1-FLO1GU
L.0186 OVFL2G=HYCGI2-FLO2GU
L.0187 OVFL3G=HYCGI3-FLO3GU
L.0188 OVFL4G=HYCGI4-FLO4GU
L.0189 OVFL5G=HYCGI5-FLO5GU
L.0190 OVFL6G=HYCGI6-FLO6GU
L.0191 CIRCLD=(FLO1LU+FLO1GU)+(FLO2LU+FLO2GU)+(FLO3LU+FLO3GU)+ZZ
L.0192 ZZ=(FLO4LU+FLO4GU)+(FLO5LU+FLO5GU)+(FLO6LU+FLO6GU)
L.0193 SUMPV=X5+X6+X7
L.0194 HOTVOL=X8+X9+X10
L.0195 PRODS=(OVFL3L+OVFL4L+OVFL5L+OVFL6L)/SSSS
L.0196 SSSS=(OVFL3L+OVFL4L+OVFL5L+OVFL6L+EE)
L.0197 EE=OVFL3G+OVFL4G+OVFL5G+OVFL6G
L.0198 X1A=INTGRL(X1AI,C1A)
L.0199 C1A=(HYCWU1-PEBW10)
L.0200 X1B=INTGRL(X1BI,C1B)
L.0201 C1B=(HYCWU2-PEBW20)
L.0202 X1C=INTGRL(X1CI,C1C)
L.0203 C1C=(HYCWU3-PEBW30)
L.0204 X1D=INTGRL(X1DI,C1D)
L.0205 C1D=(HYCWU4-PEBW40)
L.0206 X1E=INTGRL(X1EI,C1E)
L.0207 C1E=(HYCWU5-PEBW50)
L.0208 X1F=INTGRL(X1FI,C1F)
L.0209 C1F=(HYCWU6-PEBW60)
L.0210 UNFL1S=(FLO1LU)/(FLO1LU+FLO1GU)
L.0211 UNFL3S=(FLO3LU)/(FLO3LU+FLO3GU)
L.0212 AA=FLO1LU+FLO1GU+PEBFD1
L.0213 AB=FLO2LU+FLO2GU+PEBFD2
L.0214 AC=FLO3LU+FLO3GU+PEBFD3
L.0215 AD=FLO4LU+FLO4GU+PEBFD4
L.0216 AE=FLO5LU+FLO5GU+PEBFD5
L.0217 AF=FLO6LU+FLO6GU+PEBFD6
L.0218 BA=FLO1LU/AA
L.0219 BB=FLO2LU/AB
L.0220 BC=FLO3LU/AC
L.0221 BD=FLO4LU/AD
L.0222 BE=FLO5LU/AE
L.0223 BF=FLO6LU/AF
L.0224 X2A=INTGRL(X2AI,C2A)
L.0225 C2A=AA-10.99*X2A*((X1A+X2A/2.72)**0.5)
L.0226 X2B=INTGRL(X2BI,C2B)
L.0227 C2B=AB-10.99*X2B*((X1B+X2B/2.72)**0.5)
L.0228 X2C=INTGRL(X2CI,C2C)
L.0229 C2C=AC-10.99*X2C*((X1C+X2C/2.72)**0.5)
L.0230 X2D=INTGRL(X2DI,C2D)
L.0231 C2D=AD-10.99*X2D*((X1D+X2D/2.72)**0.5)
L.0232 X2E=INTGRL(X2EI,C2E)
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN
SIMULATOR OPERATING IN STEADY STATE
(cont'd.)

```
L.0234 C3F=AF-10.00*X2F*((X1F+X2F/2.72)**0.5)
L.0235 X3A=INTGRL(X3AI,C3A)
L.0236 C3A=(AA*(BA-X3A)/X2A+(1-X3A)*2.650)
L.0237 X3B=INTGRL(X3BI,C3B)
L.0238 C3B=(AB*(BB-X3B)/X2B+(1-X3B)*2.650)
L.0239 X3C=INTGRL(X3CI,C3C)
L.0240 C3C=(AC*(BC-X3C)/X2C+(1-X3C)*2.650)
L.0241 X3D=INTGRL(X3DI,C3D)
L.0242 C3D=(AD*(BD-X3D)/X2D+(1-X3D)*2.650)
L.0243 X3E=INTGRL(X3EI,C3E)
L.0244 C3E=(AE*(BE-X3E)/X2E+(1-X3E)*2.650)
L.0245 X3F=INTGRL(X3FI,C3F)
L.0246 C3F=(AF*(BF-X3F)/X2F+(1-X3F)*2.650)
L.0247 X4=INTGRL(X4I,C4)
L.0248 C4=RODFI*(0.03-X4)/6.03+(1-X4)*2.4668
L.0249 X5=INTGRL(X5I,C5)
L.0250 C5=RODWO+PEBW10+PEBW20+PEBW3C+PEBW40+PEBW50+PEBW6O+R
L.0251 R=172.+1700*((15.-SUMPV)+200*X11)-SUMPWO
L.0252 SMPWAD=172.+1700*((15.-SUMPV)+200*X11)
L.0253 X6=INTGRL(X6I,C6)
L.0254 C6=PEB1LO+PEB2LO+PEB3LO+PEB4LO+PEB5LO+PEB6LO+RR
L.0255 RR=RODLO-SUMPLO
L.0256 X7=INTGRL(X7I,C7)
L.0257 C7=PEB1GO+PEB2GO+PEB3GO+PEB4GO+PEB5GO+PEB6GO+TT
L.0258              TT=RODGO-SUMPGO
L.0259              X8=INTGRL(X8I,C8)
L.0260              C8=SUMPWO-HDTWC+WADDHT
L.0261              X9=INTGRL(X9I,C9)
L.0262              C9=SUMPLO-HDTLO
L.0263              X10=INTGRL(X10I,C10)
L.0264              C10=SUMPGO-HDTGO
L.0265              X11=INTGRL(X11I,C11)
L.0266              C11=(15.-SUMPV)
L.0267              TIMER FINTIM=1.0,OUTDEL=0.02
L.0268 PRTPLT X1C(X2C,X3C,X4)
L.0269 PRTPLT X5(X6,X7,X8)
L.0270 PRTPLT X9(X10,HYCWU3,HYCWI3)
L.0271              PRTPLT PRODS(CIRCLD,SGRAVH,SUMPV)
L.0272 PRTPLT PEBW30(PEB3LO,PEB3GO,HDTWO)
L.0273 PRTPLT HDTLO(HDTGO,RODWO,RODGO)
L.0274 PRTPLT HDTVOL(SUMPWO,SUMPLO,SUMPGO)
L.0275 PRTPLT FLO3LU(FLO3GU,HYCLI3,HYCGI3)
L.0276 PRTPLT SGRODO(SGHYCU,SGHYCI,SGPEB3)
L.0277 PRTPLT SMPWAD(UNFL3S,SGOVF3,WADDHT)
L.0278              END
L.0279              STOP
L.0280 ENDJOB
L.0281 /*
```

COMPUTER PROGRAM LISTING OF THE NON-LINEAR BLYVOORUITZICHT
SIMULATOR INCORPORATING A 5 SUB-MILLS PEBBLE MILL POWER
MODEL


```
L.0001 //NTHOER JOB 007,CLASS=A                                          AECDEFGH
L.0002 /*JOBPARM  R=87,L=9999
L.0003 // EXEC CSMP360,TIME.GO=7
L.0004 //GO.SYSIN DD *
L.0005          PARAMETER  MSIZE=40
L.0006 PARAMETER MNOM=20,W=2.72
L.0007 PARAMETER GRAD=340.
L.0008         INCON X1I=6.8183,X2I=14.564,X3I=0.1639
L.0009         INCON X4I=0.1999,X5I=2.8522,X6I=0.1936
L.0010         INCON X7I=0.9541,X8I=2.8143,X9I=0.1701
L.0011         INCON X10I=0.8386,X11I=0.0,S=0.99,TIMPLU=0.0
L.0012         INCON MSTI=20.1,ICFOWD=0.009,YESNO=1.
L.0013 INCON MST2=20.05
L.0014 INCON MST3=20
L.0015 INCON MST4=20,MST5=20
L.0016         X1=INTGRL(X1I,C1)
L.0017         C1=109-X1*4.582*((X1+X2/2.72)**0.5)
L.0018         X2=INTGRL(X2I,C2)
L.0019         C2=A-4.582*X2*((X1+X2/2.72)**0.5)
L.0020 A=P+(ZI14*ZI17)+(ZI15*ZI17)+ZI19*(1-EXP(-0.6931*((8.66/ZI24)**2)))+R
L.0021         R=ZI21*(1-EXP(-0.6931*((166/ZI24)**2)))
L.0022         ZI14=ZI11*2.72/2
L.0023         ZI11=(266*(>8+X9+X10)/3.398+446.36)*X9/(X8+X9+X10)
L.0024         ZI17=ZI16/ZI13
L.0025         ZI16=109
L.0026         ZI13=ZI10/2
L.0027         ZI10=(266.6*(X8+X9+X10)/3.398+446.36)*X8/(X8+X9+X10)
L.0028         ZI19=ZI14-ZI14*ZI17
L.0029         ZI24=10**(1*ZI22-0.0005*ZI23+1.6624)
L.0030         ZI23=ZI13+(ZI14+ZI15)/2.72
L.0031         ZI15=ZI12*2.72/2
L.0032         ZI12=(266.6*(X8+X9+X10)/3.398+446.36)*X10/(X8+X9+X10)
L.0033         ZI22=(ZI14+ZI15)/(ZI13+ZI14+ZI15)
L.0034         ZI21=ZI15-ZI15*ZI17
L.0035         B=ZI26/A
L.0036         ZI26=ZI18+ZI25
L.0037         ZI18=ZI14*ZI17
L.0038         ZI25=ZI19*(1-EXP(-0.6931*((8.66/ZI24)**2)))
L.0039         X3=INTGRL(X3I,C3)
L.0040         C3=(A*(E-X3)/X2+(1-X3)*1.65)*S
L.0041         X4=INTGRL(X4I,C4)
L.0042         C4=(70.0*(0.03-X4)/6.03+(1-X4)*2.4668)
L.0043         X5=INTGRL(X5I,C5)
L.0044 C5=( 2*4.582*)1*((X1+X2/2.72)**0.5)+0.3*70.0-(X5/(X5+X6+X7))*686.3)+D
L.0045         D=250.3676+500*((4-X5-X6-X7)+(20*X11))
L.0046         X6=INTGRL(X6I,C6)
L.0047         C6=2*4.582*X3*X2*((X1+X2/2.72)**0.5)/2.72+(70./2.72)*X4-C
L.0048         C=(X6/(X5+X6+X7))*686.3
L.0049         X7=INTGRL(X7I,C7)
L.0050 C7=2*4.582*(1-X3)*X2*((X1+X2/2.72)**0.5)/2.72+(70.0/2.72)*(1-X4)-QS
L.0051         QS=(X7/(X5+X6+X7))*686.3
L.0052         X8=INTGRL(X8I,C8)
L.0053         C8=    (X5/(X5+X6+X7))*686.3-ZI1C+60
L.0054         X9=INTGRL(X9I,C9)
```

COMPUTER PROGRAM LISTING OF THE NON-LINEAR BLYVOORUITZICHT
SIMULATOR INCORPORATING A 5 SUB-MILLS PEBBLE MILL POWER
MODEL (cont/d.)

```
L.0057          C10=(X7/(X5+X6+X7))*686.3-ZI12
L.0058          X11=INTGRL(X11I,C11)
L.0059          C11=(4-X5-X6-X7)
L.0060          CLOAD=(ZI20+ZI27+ZI18+ZI25)*2
L.0061          ZI20=ZI15*ZI17
L.0062          PROOS=ZI30/(ZI30+ZI31)
L.0063          ZI30=ZI14-ZI26
L.0064          ZI31=ZI15-ZI28
L.0065          ZI28=ZI20+ZI27
L.0066          ZI27=ZI21*(1-EXP(-0.6931*((166/ZI24)**2)))
L.0067          U=X5+X6+X7
L.0068          HDTVOL=X8+X9+X10
L.0069  MMAS1=INTGRL(MST1,MMCH1)
L.0070  BULD1=W/1.4+(X1+X2)*W/(MMAS1*1.4*5)
L.0071  SMFL1=MMAS1/MSIZE
L.0072  MPWR1=150*BULD1*((SIN(3.1415*SMFL1))**3.0)
L.0073  MFED1=14*YFSNO
L.0074  MLOS1=7./5.
L.0075  MOUT1=GRAD*FCN1*(SMFL1-SMFL2)
L.0076  FCN1=FCNSW(SMFC1,ZERO,ZERO,ONE)
L.0077  SMFC1=SMFL1-SMFL2
L.0078  MMCH1=MFED1-MLOS1-MOUT1
L.0079  S1=1-ABS((MNOM-MMAS1)/MNOM)
L.0080  MMASS2=INTGRL(MST2,MMCH2)
L.0081  BULDN2=W/1.4+(X1+X2)*W/(MMASS2*1.4*5)
L.0082  SMFL2=MMASS2/MSIZE
L.0083  MPOWR2=150*BULDN2*((SIN(3.1415*SMFL2))**3.0)
L.0084  MFEED2=MOUT1
L.0085  MLOSS2=7./5.
L.0086  MOUT2=GRAD*FCN2*(SMFL2-SMFL3)
L.0087  FCN2=FCNSW(SMFC2,ZERO,ZERO,ONE)
L.0088  SMFC2=SMFL2-SMFL3
L.0089  MMCH2=MFEED2-MLOSS2-MOUT2
L.0090  S2=1-ABS((MNOM-MMASS2)/MNOM)
L.0091  MMASS3=INTGRL(MST3,MMCH3)
L.0092  MMASS4=INTGRL(MST4,MMCH4)
L.0093  MMASS5=INTGRL(MST5,MMCH5)
L.0094  BULDN3=W/1.4+(X1+X2)*W/(MMASS3*1.4*5)
L.0095  BULDN4=W/1.4+(X1+X2)*W/(MMASS4*1.4*5)
L.0096  BULDN5=W/1.4+(X1+X2)*W/(MMASS5*1.4*5)
L.0097  SMFL3=MMASS3/MSIZE
L.0098  SMFL4=MMASS4/MSIZE
L.0099  SMFL5=MMASS5/MSIZE
L.0100  MPOWR3=150*BULDN3*((SIN(3.1415*SMFL3))**3.0)
L.0101  MPOWR4=150*BULDN4*((SIN(3.1415*SMFL4))**3.0)
L.0102  MPOWR5=150*BULDN5*((SIN(3.1415*SMFL5))**3.0)
L.0103  MOUT5=0
L.0104  MFEED3=MOUT2
L.0105  MOUT3=GRAD*FCN3*(SMFL3-SMFL4)
L.0106  MFEED4=MOUT3
L.0107  MFEED5=MOUT4
L.0108  MLOSS3=7./5.
L.0109  MLOSS4=7./5.
L.0110  MLOSS5=7./5.
L.0111  MMCH3=MFEED3-MLOSS3-MOUT3
L.0112  MMCH4=MFEED4-MLOSS4-MOUT4
L.0113  MMCH5=MFEED5-MLOSS5-MOUT5
```

COMPUTER PROGRAM LISTING OF THE NON-LINEAR HLYVOORUITZICHT
SIMULATOR INCORPORATING A 6 SUB-MILLS PEBBLE MILL POWER
MODEL (cont'd).

```
L.0117 ZERO=0.0
L.0118 ONE=1.0
L.0119 SMFC3=SMFL3-SMFL4
L.0120 SMFC4=SMFL4-SMFL5
L.0121 S3=1-ABS((MNOM-MMASS3)/MNOM)
L.0122 S4=1-ABS((MNOM-MMASS4)/MNOM)
L.0123 S5=1-ABS((MNOM-MMASS5)/MNOM)
L.0124 S=(S1+S2+S3+S4+S5)/5
L.0125 MLOSS=MLOS1+MLOSS2+MLOSS3+MLOSS4+MLOSS5
L.0126 MLSS=MLOSS9+MLOS10
L.0127 P=MLOSS
L.0128 MPOWER=MPOWR2+MPOWR3+MPOWR4+MPOWR5+MPWR1
L.0129       POWD=DERIV(1CPOWD,MPOWER)
L.0130       PMAX=ZHOLD(POWD,MPOWER)
L.0131 NOSORT
L.0132       IF(POWD.LT.0.0)GO TO 2
L.0133       Q=1.0
L.0134       GO TO 5
L.0135 2     CONTINUE
L.0136       Q=MPOWER/PMAX
L.0137 5     PDROP=1.0-Q
L.0138 IF(TIME.LT.TIMPLU)GO TO 9
L.0139       IF(PDROP.GT.0.005)GO TO 1
L.0140       9 YESNO=YESNO
L.0141       GO TO 4
L.0142 1 TIM=TIME
L.0143 TIMPLU=TIM+0.8
L.0144       IF(YESNO.LT.1.1.AND.YESNO.GT.0.9)GO TO 3
L.0145       YESNO=1.0
L.0146       GO TO 4
L.0147 3     YESNO=0.0
L.0148 4     CONTINUE
L.0149       SORT
L.0150       TIMER FINTIM=10.0,OUTDEL=0.02
L.0151 PRTPLT MPOWER(SMFL1,YESNO,PMAX)
L.0152 PRTPLT MMAS1(MMASS2,MMASS3,MMASS4).
L.0153 PRTPLT PRODS(CLOAD)
L.0154 PRTPLT MFEED2(MFED1,MFEED3,MFEED4)
L.0155       END
L.0156       STOP
L.0157 ENDJOB
```

```
L.0001 //HTHSNG JOB CC7,CLASS=A                                    CHANGE
L.0002 /*JOBPARM  FORMS=9999,L=9999
L.0003 // EXEC CSMP360,TIME.GO=7
L.0004 //GO.SYSIN DD *
L.0005 INCON NOISE=0.0
L.0006 PARAMETER BETA=0.1
L.0007 PARAMETER ALPHA=0.0025
L.0008 INCON X1AI=2.0543
L.0009 INCON X1BI=2.0543,X1CI=2.0543
L.0010 INCON X1DI=2.0543,X1EI=2.0543,X1FI=2.0543
L.0011 INCON X2AI=7.1199,X2BI=7.1199
L.0012 INCON X2CI=7.1199,X2DI=7.1199
L.0013 INCON X2EI=7.1199,X2FI=7.1199
L.0014 INCON X3AI=0.20881,X3BI=0.20881
L.0015 INCON X3CI=0.20881,X3DI=0.20881
L.0016 INCON X3EI=0.20881,X3FI=0.20881
L.0017 INCON X4I=0.1556
L.0018 INCON X5I=10.846
L.0019 INCON X6I=0.84756
L.0020 INCON X7I=3.3063
L.0021 INCON X8I=10.843
L.0022 INCON X9I=0.76721
L.0023 INCON X10I=2.5921
L.0024 INCON X11I=0
L.0025 INCON S1=0.99,S2=0.99,S3=0.99
L.0026 INCON S4=0.99,S5=0.99,S6=0.99
L.0027 INCON TIMPL1=0.0,TIMPL2=0.0,TIMPL3=0.0
L.0028 INCON TIMPL4=0.0,TIMPL5=0.0,TIMPL6=0.0
L.0029 INCON MST1=99.,MST2=99.,MST3=99.,MST4=99.
L.0030 INCON MST5=99.,MST6=99.
L.0031 INCON ICPOWD=0.009
L.0032 INCON YESN03=0.0
L.0033 INCON YESN02=0.0
L.0034 INCON YESN01=0.0
L.0035 INCON YESN04=0.0,YESN05=0.0,YESN06=0.0
L.0036 PARAMETER MNOM=100.0
L.0037 PARAMETER W=2.72
L.0038 PARAMETER RODEI=100.
L.0039 PARAMETER PUMPCA=1480.
L.0040 NOSORT
L.0041 R1=GAUSS(1.0,0.5)
L.0042 NOISE=NOISE-BETA*NOISE*DELT+R1*(ALPHA*DELT)**0.5
L.0043 SORT
L.0044 HYCYU=48.8.
L.0045 PARAMETER WADCHT=112.
L.0046 PARAMETER MSIZE=200.0
L.0047 PARAMETER G1=6.G2=6,G3=6,G4=6,G5=6,G6=6
L.0048 MPWER1=150.*BULD1*((SIN(3.1415*(MMAS1/MSIZE)))**3.0)
L.0049 MPWER2=150.*BULD2*((SIN(3.1415*(MMAS2/MSIZE)))**3.0)
L.0050 MPWER3=150.*BULD3*((SIN(3.1415*(MMAS3/MSIZE)))**3.0)
L.0051 MPWER4=150.*BULD4*((SIN(3.1415*(MMAS4/MSIZE)))**3.0)
L.0052 MPWER5=150.*BULD5*((SIN(3.1415*(MMAS5/MSIZE)))**3.0)
L.0053 MPWER6=150.*BULD6*((SIN(3.1415*(MMAS6/MSIZE)))**3.0)
L.0054 BULD1=W/1.4+(X1A+X2A)*W/(MMAS1*1.4)
```

LISTING 4

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COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN CIRCUIT
INCORPORATING A SINGLE MILL PEBBLE MILL POWER MODEL

```
L.0058 BULO5=W/1.4+(X1E+X2E)*W/(MMAS5*1.4)
L.0059 BULO6=W/1.4+(X1F+X2F)*W/(MMAS6*1.4)
L.0060 MMAS1=INTGRL(MST1,MMCH1)
L.0061 MMAS2=INTGRL(MST2,MMCH2)
L.0062 MMAS3=INTGRL(MST3,MMCH3)
L.0063 MMAS4=INTGRL(MST4,MMCH4)
L.0064 MMAS5=INTGRL(MST5,MMCH5)
L.0065 MMAS6=INTGRL(MST6,MMCH6)
L.0066 MMCH1=YESNO1-MLOS1
L.0067 MMCH2=YESNO2-MLOS2
L.0068 MMCH3=YESNO3-MLOS3
L.0069 MMCH4=YESNO4-MLOS4
L.0070 MMCH5=YESNO5-MLOS5
L.0071 MMCH6=YESNO6-MLOS6
L.0072 MLOS1=(9.)*((MNCM/MMAS1)**3.71)
L.0073 MLOS2=(9.)*((MNCM/MMAS2)**3.71)
L.0074 MLOS3=(9.)*((MNCM/MMAS3)**3.71)
L.0075 MLOS4=(9.)*((MNCM/MMAS4)**3.71)
L.0076 MLOS5=(9.)*((MNCM/MMAS5)**3.71)
L.0077 MLOS6=(9.)*((MNCM/MMAS6)**3.71)
L.0078 S1=1-ABS((MNCM-MMAS1)/MNCM)
L.0079 S2=1-ABS((MNCM-MMAS2)/MNCM)
L.0080 S3=1-ABS((MNCM-MMAS3)/MNCM)
L.0081 S4=1-ABS((MNCM-MMAS4)/MNCM)
L.0082 S5=1-ABS((MNCM-MMAS5)/MNCM)
L.0083 S6=1-ABS((MNCM-MMAS6)/MNCM)
L.0084 POWD1=DERIV(ICPOWD,MPWER1)
L.0085 PMAX1=ZHOLD(POWD1,MPWER1)
L.0086 POWD2=DERIV(ICPOWD,MPWER2)
L.0087 PMAX2=ZHOLD(POWD2,MPWER2)
L.0088 POWD3=DERIV(ICPOWD,MPWER3)
L.0089 PMAX3=ZHOLD(POWD3,MPWER3)
L.0090 POWD4=DERIV(ICPOWD,MPWER4)
L.0091 PMAX4=ZHOLD(POWD4,MPWER4)
L.0092 POWD5=DERIV(ICPOWD,MPWER5)
L.0093 PMAX5=ZHOLD(POWD5,MPWER5)
L.0094 POWD6=DERIV(ICPOWD,MPWER6)
L.0095 PMAX6=ZHOLD(POWD6,MPWER6)
L.0096 RODWO=0.25*RODFI
L.0097 RODLO=((RODFI/2.72))*X4
L.0098 RODGO=((RODFI/2.72))*(1-X4)
L.0099 PEBW10=10.99*X1A*((X1A+X2A/2.72)**0.5)
L.0100 PEBW20=10.99*X1B*((X1B+X2B/2.72)**0.5)
L.0101 PEBW30=10.99*X1C*((X1C+X2C/2.72)**0.5)
L.0102 PEBW40=10.99*X1D*((X1D+X2D/2.72)**0.5)
L.0103 PEBW50=10.99*X1E*((X1E+X2E/2.72)**0.5)
L.0104 PEBW60=10.99*X1F*((X1F+X2F/2.72)**0.5)
L.0105 PEB1LO=10.99*X3A*X2A*((X1A+X2A/2.72)**0.5)/2.72
L.0106 PEB2LO=10.99*X3B*X2B*((X1B+X2B/2.72)**0.5)/2.72
L.0107 PEB3LO=10.99*X3C*X2C*((X1C+X2C/2.72)**0.5)/2.72
L.0108 PEB4LO=10.99*X3D*X2D*((X1D+X2D/2.72)**0.5)/2.72
L.0109 PEB5LO=10.99*X3E*X2E*((X1E+X2E/2.72)**0.5)/2.72
L.0110 PEB6LO=10.99*X3F*X2F*((X1F+X2F/2.72)**0.5)/2.72
L.0111 PEB1GO=10.99*(1-X3A)*X2A*((X1A+X2A/2.72)**0.5)/2.72
L.0112 PEB2GO=10.99*(1-X3B)*X2B*((X1B+X2B/2.72)**0.5)/2.72
L.0113 PEB3GO=10.99*(1-X3C)*X2C*((X1C+X2C/2.72)**0.5)/2.72
```

```
L.0116 PERAGO=10.99*(1-X3F)*X2F*((X1F+X2F/2.72)**0.5)/2.72
L.0117 SUMPWO=(X5/(X5+X6+X7))*PUMPCA
L.0118 SUMPLO=(X6/(X5+X6+X7))*PUMPCA
L.0119 SUMPGO=(X7/(X5+X6+X7))*PUMPCA
L.0120 HDTWO=(266.6*(X8+X9+X10)/3.398+446.36)*X8/(X8+X9+X10)
L.0121 HDTLO=(266.6*(X8+X9+X10)/3.398+446.36)*X9/(X8+X9+X10)
L.0122 HDTGO=(266.6*(X8+X9+X10)/3.398+446.36)*X10/(X8+X9+X10)
L.0123 HYCWI1=HDTWO/G1
L.0124 HYCWI2=HDTWO/G2
L.0125 HYCWI3=HDTWO/G3
L.0126 HYCWI4=HDTWO/G4
L.0127 HYCWI5=HDTWO/G5
L.0128 HYCWI6=HDTWO/G6
L.0129 HYCLI1=HDTLO*2.72/G1
L.0130 HYCLI2=HDTLO*2.72/G2
L.0131 HYCLI3=HDTLO*2.72/G3
L.0132 HYCLI4=HDTLO*2.72/G4
L.0133 HYCLI5=HDTLO*2.72/G5
L.0134 HYCLI6=HDTLO*2.72/G6
L.0135 HYCGI1=HDTGO*2.72/G1
L.0136 HYCGI2=HDTGO*2.72/G2
L.0137 HYCGI3=HDTGO*2.72/G3
L.0138 HYCGI4=HDTGO*2.72/G4
L.0139 HYCGI5=HDTGO*2.72/G5
L.0140 HYCGI6=HDTGO*2.72/G6
L.0141 MPWU1=HYCWU/HYCWI1
L.0142 MPWU2=HYCWU/HYCWI2
L.0143 MPWU3=HYCWU/HYCWI3
L.0144 MPWU4=HYCWU/HYCWI4
L.0145 MPWU5=HYCWU/HYCWI5
L.0146 MPWU6=HYCWU/HYCWI6
L.0147 SCTLU1=MPWU1*HYCLI1
L.0148 SCTLU2=MPWU2*HYCLI2
L.0149 SCTLU3=MPWU3*HYCLI3
L.0150 SCTLU4=MPWU4*HYCLI4
L.0151 SCTLU5=MPWU5*HYCLI5
L.0152 SCTLU6=MPWU6*HYCLI6
L.0153 RL1CLA=HYCLI1-SCTLU1
L.0154 RL2CLA=HYCLI2-SCTLU2
L.0155 RL3CLA=HYCLI3-SCTLU3
L.0156 RL4CLA=HYCLI4-SCTLU4
L.0157 RL5CLA=HYCLI5-SCTLU5
L.0158 RL6CLA=HYCLI6-SCTLU6
L.0159 RG1CLA=HYCGI1-MPWU1*HYCGI1
L.0160 RG2CLA=HYCGI2-MPWU2*HYCGI2
L.0161 RG3CLA=HYCGI3-MPWU3*HYCGI3
L.0162 RG4CLA=HYCGI4-MPWU4*HYCGI4
L.0163 RG5CLA=HYCGI5-MPWU5*HYCGI5
L.0164 RG6CLA=HYCGI6-MPWU6*HYCGI6
L.0165 SP1CYI=(HYCLI1+HYCGI1)/(HYCLI1+HYCGI1+HYCWI1)
L.0166 SP2CYI=(HYCLI2+HYCGI2)/(HYCLI2+HYCGI2+HYCWI2)
L.0167 SP3CYI=(HYCLI3+HYCGI3)/(HYCLI3+HYCGI3+HYCWI3)
L.0168 SP4CYI=(HYCLI4+HYCGI4)/(HYCLI4+HYCGI4+HYCWI4)
L.0169 SP5CYI=(HYCLI5+HYCGI5)/(HYCLI5+HYCGI5+HYCWI5)
L.0170 SP6CYI=(HYCLI6+HYCGI6)/(HYCLI6+HYCGI6+HYCWI6)
L.0171 SLHY1I=HYCWI1+(HYCLI1+HYCGI1)/2.72
L.0172 SLHY2I=HYCWI2+(HYCLI2+HYCGI2)/2.72
```

```
L.0176 SUHYEI=HYCWI6+(HYCLI6+HYCGI6)/2.72
L.0177 D50C1=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP1CYI-BIT1)
L.0178 BIT1=0.0001*(16.67*HYCWI1+HYCLI1*16.67/2.72+HYCGI1*16.67/2.72)
L.0179 D50C2=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP2CYI-BIT2)
L.0180 BIT2=0.0001*(16.67*HYCWI2+HYCLI2*16.67/2.72+HYCGI2*16.67/2.72)
L.0181 D50C3=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP3CYI-BIT3)
L.0182 BIT3=0.0001*(16.67*HYCWI3+HYCLI3*16.67/2.72+HYCGI3*16.67/2.72)
L.0183 D50C4=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP4CYI-BIT4)
L.0184 BIT4=0.0001*(16.67*HYCWI4+HYCLI4*16.67/2.72+HYCGI4*16.67/2.72)
L.0185 D50C5=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP5CYI-BIT5)
L.0186 BIT5=0.0001*(16.67*HYCWI5+HYCLI5*16.67/2.72+HYCGI5*16.67/2.72)
L.0187 D50C6=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP6CYI-BIT6)
L.0188 BIT6=0.0001*(16.67*HYCWI6+HYCLI6*16.67/2.72+HYCGI6*16.67/2.72)
L.0189 CLALU1=RL1CLA*(1-EXP(-0.6931*((71.66/D50C1)**2)))
L.0190 CLALU2=RL2CLA*(1-EXP(-0.6931*((71.66/D50C2)**2)))
L.0191 CLALU3=RL3CLA*(1-EXP(-0.6931*((71.66/D50C3)**2)))
L.0192 CLALU4=RL4CLA*(1-EXP(-0.6931*((71.66/D50C4)**2)))
L.0193 CLALU5=RL5CLA*(1-EXP(-0.6931*((71.66/D50C5)**2)))
L.0194 CLALU6=RL6CLA*(1-EXP(-0.6931*((71.66/D50C6)**2)))
L.0195 FLO1LU=CLALU1+SCTLU1
L.0196 FLO2LU=CLALU2+SCTLU2
L.0197 FLO3LU=CLALU3+SCTLU3
L.0198 FLO4LU=CLALU4+SCTLU4
L.0199 FLO5LU=CLALU5+SCTLU5
L.0200 FLO6LU=CLALU6+SCTLU6
L.0201 CLAGU1=RG1CLA*(1-EXP(-0.6931*((166/D50C1)**2)))
L.0202 CLAGU2=RG2CLA*(1-EXP(-0.6931*((166/D50C2)**2)))
L.0203 CLAGU3=RG3CLA*(1-EXP(-0.6931*((166/D50C3)**2)))
L.0204 CLAGU4=RG4CLA*(1-EXP(-0.6931*((166/D50C4)**2)))
L.0205 CLAGU5=RG5CLA*(1-EXP(-0.6931*((166/D50C5)**2)))
L.0206 CLAGU6=RG6CLA*(1-EXP(-0.6931*((166/D50C6)**2)))
L.0207 FLO1GU=CLAGU1+MPWU1*HYCGI1
L.0208 FLO2GU=CLAGU2+MPWU2*HYCGI2
L.0209 FLO3GU=CLAGU3+MPWU3*HYCGI3
L.0210 FLO4GU=CLAGU4+MPWU4*HYCGI4
L.0211 FLO5GU=CLAGU5+MPWU5*HYCGI5
L.0212 FLO6GU=CLAGU6+MPWU6*HYCGI6
L.0213 OVFL1W=HYCWI1-HYCWU
L.0214 OVFL2W=HYCWI2-HYCWU
L.0215 OVFL3W=HYCWI3-HYCWU
L.0216 OVFL4W=HYCWI4-HYCWU
L.0217 OVFL5W=HYCWI5-HYCWU
L.0218 OVFL6W=HYCWI6-HYCWU
L.0219 OVFL1L=HYCLI1-FLO1LU
L.0220 OVFL2L=HYCLI2-FLO2LU
L.0221 OVFL3L=HYCLI3-FLO3LU
L.0222 OVFL4L=HYCLI4-FLO4LU
L.0223 OVFL5L=HYCLI5-FLO5LU
L.0224 OVFL6L=HYCLI6-FLO6LU
L.0225 OVFL1G=HYCGI1-FLO1GU
L.0226 OVFL2G=HYCGI2-FLO2GU
L.0227 OVFL3G=HYCGI3-FLO3GU
L.0228 OVFL4G=HYCGI4-FLO4GU
L.0229 OVFL5G=HYCGI5-FLO5GU
L.0230 OVFL6G=HYCGI6-FLO6GU
L.0231 CIRCLO=(FLO1LU+FLO1GU)+(FLO2LU+FLO2GU)+(FLO3LU+FLO3GU)+ZZ
```

```
L.0235 PROVOL=AA+X5+X10
L.0236 PRODS=(OVFL1L+OVFL2L+OVFL3L+OVFL4L+OVFL5L+OVFL6L)/SSSS
L.0236 SSSS=(OVFL1L+OVFL2L+OVFL3L+OVFL4L+OVFL5L+OVFL6L+FF)
L.0237 FF=OVFL1G+OVFL2G+OVFL3G+OVFL4G+OVFL5G+OVFL6G
L.0238 X1A=INTGRL(X1AI,C1A)
L.0239 C1A=(HYCWU-PEBW1C)
L.0240 X1B=INTGRL(X1BI,C1B)
L.0241 C1B=(HYCWU-PEBW2C)
L.0242 X1C=INTGRL(X1CI,C1C)
L.0243 C1C=(HYCWU-PEBW3C)
L.0244 X1D=INTGRL(X1DI,C1D)
L.0245 C1D=(HYCWU-PEBW4C)
L.0246 X1E=INTGRL(X1EI,C1E)
L.0247 C1E=(HYCWU-PEBW5C)
L.0248 X1F=INTGRL(X1FI,C1F)
L.0249 C1F=(HYCWU-PEBW6C)
L.0250 AA=FLO1LU+FLO1GU+WLOS1
L.0251 AB=FLO2LU+FLO2GU+WLOS2
L.0252 AC=FLO3LU+FLO3GU+WLOS3
L.0253 AD=FLO4LU+FLO4GU+WLOS4
L.0254 AE=FLO5LU+FLO5GU+WLOS5
L.0255 AF=FLO6LU+FLO6GU+WLOS6
L.0256 BA=FLO1LU/AA
L.0257 BB=FLO2LU/AB
L.0258 BC=FLO3LU/AC
L.0259 BD=FLO4LU/AD
L.0260 BE=FLO5LU/AE
L.0261 BF=FLO6LU/AF
L.0262 X2A=INTGRL(X2AI,C2A)
L.0263 C2A=AA-10.99*X2A*((X1A+X2A/2.72)**0.5)
L.0264 X2B=INTGRL(X2BI,C2B)
L.0265 C2B=AB-10.99*X2B*((X1B+X2B/2.72)**0.5)
L.0266 X2C=INTGRL(X2CI,C2C)
L.0267 C2C=AC-10.99*X2C*((X1C+X2C/2.72)**0.5)
L.0268 X2D=INTGRL(X2DI,C2D)
L.0269 C2D=AD-10.99*X2D*((X1D+X2D/2.72)**0.5)
L.0270 X2E=INTGRL(X2EI,C2E)
L.0271 C2E=AE-10.99*X2E*((X1E+X2E/2.72)**0.5)
L.0272 X2F=INTGRL(X2FI,C2F)
L.0273 C2F=AF-10.99*X2F*((X1F+X2F/2.72)**0.5)
L.0274 X3A=INTGRL(X3AI,C3A)
L.0275 C3A=(AA*(BA-X3A)/X2A+(1-X3A)*2.650)*S1
L.0276 X3B=INTGRL(X3BI,C3B)
L.0277 C3B=(AB*(BB-X3B)/X2B+(1-X3B)*2.650)*S2
L.0278 X3C=INTGRL(X3CI,C3C)
L.0279 C3C=(AC*(BC-X3C)/X2C+(1-X3C)*2.650)*S3
L.0280 X3D=INTGRL(X3DI,C3D)
L.0281 C3D=(AD*(BD-X3D)/X2D+(1-X3D)*2.650)*S4
L.0282 X3E=INTGRL(X3EI,C3E)
L.0283 C3E=(AE*(BE-X3E)/X2E+(1-X3E)*2.650)*S5
L.0284 X3F=INTGRL(X3FI,C3F)
L.0285 C3F=(AF*(BF-X3F)/X2F+(1-X3F)*2.650)*S6
L.0286 X4=INTGRL(X4I,C4)
L.0287 C4=RODFI*(0.03-X4)/6.03+(1-X4)*2.4668
L.0288 X5=INTGRL(Y5I,C5)
L.0289 C5=RODW0+PEBW1D+PEBW2D+PEBW3D+PEBW4D+PEBW5D+PEBW6D+R
L.0290 R=250.3676+1700*((15-SUMPV)+200*X11)-SUMPW0+0.0*NOISE
```

COMPUTER PROGRAM LISTING
INCORPORATING A SINGLE MILL PEBBLE MILL FOR THE BUFFELSFONTEIN CIRCUIT
MODEL
(cont'd.)

```
L.0294 C*** END OF MODEL-SUBROUTINE
L.0295 X7=INTGRL(XI7,C7)
L.0296 C7=PER1GO+PER2GO+PER3GO+PER4GO+PER5GO+PER6GO+TT
L.0297                 TT=ROUGO-SUMPGO
L.0298                 X8=INTGRL(X8I,C8)
L.0299                 C8=SUMFWO-HDTWO+WADDHT
L.0300                 X9=INTGRL(X9I,C9)
L.0301                 C9=SUMFLO-HDTLO
L.0302                 X10=INTGRL(X10I,C10)
L.0303                 C10=SUMPGO-HDTGO
L.0304                 X11=INTGRL(X11I,C11)
L.0305                 C11=(15-SUMPV)
L.0306 NOSORT
L.0307 IF(POWD1.LT.0.0)GO TO 21
L.0308 Q1=1.0
L.0309 GO TO 51
L.0310 21 CONTINUE
L.0311 Q1=MPWER1/PMAX1
L.0312 51 PDPOP1=1.0-Q1
L.0313 IF(TIME.LT.TIMPL1)GO TO 91
L.0314 IF(PDPOP1.GT.0.00125)GO TO 11
L.0315 91 YESNO1=YESNO1
L.0316 GO TO 41
L.0317 11 TIM1=TIME
L.0318 TIMPL1=TIM1+0.5
L.0319 IF(YESNO1.LT.18.9.AND.YESNO1.GT.17.1)GO TO 31
L.0320 YESNO1=18.0
L.0321 GO TO 41
L.0322 31 YESNO1=0.0
L.0323 41 CONTINUE
L.0324 IF(POWD2.LT.0.0)GO TO 2
L.0325 Q2=1.0
L.0326 GO TO 5
L.0327 2 CONTINUE
L.0328 Q2=MPWER2/PMAX2
L.0329 5 PDPOP2=1.0-Q2
L.0330 IF(TIME.LT.TIMPL2)GO TO 9
L.0331 IF(PDPOP2.GT.0.00125)GO TO 1
L.0332 9 YESNO2=YESNO2
L.0333 GO TO 4
L.0334 1 TIM2=TIME
L.0335 TIMPL2=TIM2+0.5
L.0336 IF(YESNO2.LT.18.9.AND.YESNO2.GT.17.1)GO TO 3
L.0337 YESNO2=18.0
L.0338 GO TO 4
L.0339 3 YESNO2=0.0
L.0340 4 CONTINUE
L.0341 IF(POWD3.LT.0.0)GO TO 23
L.0342 Q3=1.0
L.0343 GO TO 53
L.0344 23 CONTINUE
L.0345 Q3=MPWER3/PMAX3
L.0346 53 PDPOP3=1.0-Q3
L.0347 IF(TIME.LT.TIMPL3)GO TO 93
L.0348 IF(PDPOP3.GT.0.00125)GO TO 13
L.0349 93 YESNO3=YESNO3
L.0350 GO TO 43
```

COMPUTER PROGRAM LISTING FOR THE BUBBLESNONTAIN CIRCUIT INCORPORATING A SINGLE MILL PEBBLE MILL LOWER MODEL (cont'd.)

Listing 4

```
L.0352 IF(YESN03.LT.18.9.AND.YESN03.GT.17.1)GO TO 33
L.0353 YESN03=18.0
L.0354 GO TO 43
L.0355 33 YESN03=0.0
L.0356 43 CONTINUE
L.0357 IF(POWD4.LT.0.0)GO TO 24
L.0358 04=4.0
L.0359 GO TO 54
L.0360 24 CONTINUE
L.0361 04=MPWER4/PMAX4
L.0362 54 PDROP4=1.0-04
L.0363 IF(TIME.LT.TIMPL4)GO TO 94
L.0364 IF(PDROP4.GT.0.00125)GO TO 14
L.0365 94 YESN04=YESN04
L.0366 GO TO 44
L.0367 14 TIM4=TIME
L.0368 TIMPL4=TIM4+0.5
L.0369 IF(YESN04.LT.18.9.AND.YESN04.GT.17.1)GO TO 34
L.0370 YESN04=18.0
L.0371 GO TO 44
L.0372 34 YESN04=0.0
L.0373 44 CONTINUE
L.0374 IF(POWD5.LT.0.0)GO TO 25
L.0375 05=1.0
L.0376 GO TO 55
L.0377 25 CONTINUE
L.0378 05=MPWER5/PMAX5
L.0379 55 PDROP5=1.0-05
L.0380 IF(TIME.LT.TIMPL5)GO TO 95
L.0381 IF(PDROP5.GT.0.00125)GO TO 15
L.0382 95 YESN05=YESN05
L.0383 GO TO 45
L.0384 15 TIM5=TIME
L.0385 TIMPL5=TIM5+0.5
L.0386 IF(YESN05.LT.18.9.AND.YESN05.GT.17.1)GO TO 35
L.0387 YESN05=18.0
L.0388 GO TO 45
L.0389 35 YESN05=0.0
L.0390 45 CONTINUE
L.0391 IF(POWD6.LT.0.0)GO TO 26
L.0392 06=1.0
L.0393 GO TO 56
L.0394 26 CONTINUE
L.0395 06=MPWER6/PMAX6
L.0396 56 PDROP6=1.0-06
L.0397 IF(TIME.LT.TIMPL6)GO TO 96
L.0398 IF(PDROP6.GT.0.00125)GO TO 16
L.0399 96 YESN06=YESN06
L.0400 GO TO 46
L.0401 16 TIM6=TIME
L.0402 TIMPL6=TIM6+0.5
L.0403 IF(YESN06.LT.18.9.AND.YESN06.GT.17.1)GO TO 36
L.0404 YESN06=18.0
L.0405 GO TO 46
L.0406 36 YESN06=0.0
L.0407 46 CONTINUE
L.0408 SORT
```

COMPUTER PROGRAM LISTING FOR THE BUBBELSPONTEIN CIRCUIT
INCORPORATING A SINGLE MILL FEEBLE MILL POWER MODEL
(cont'd.)

Listing 4

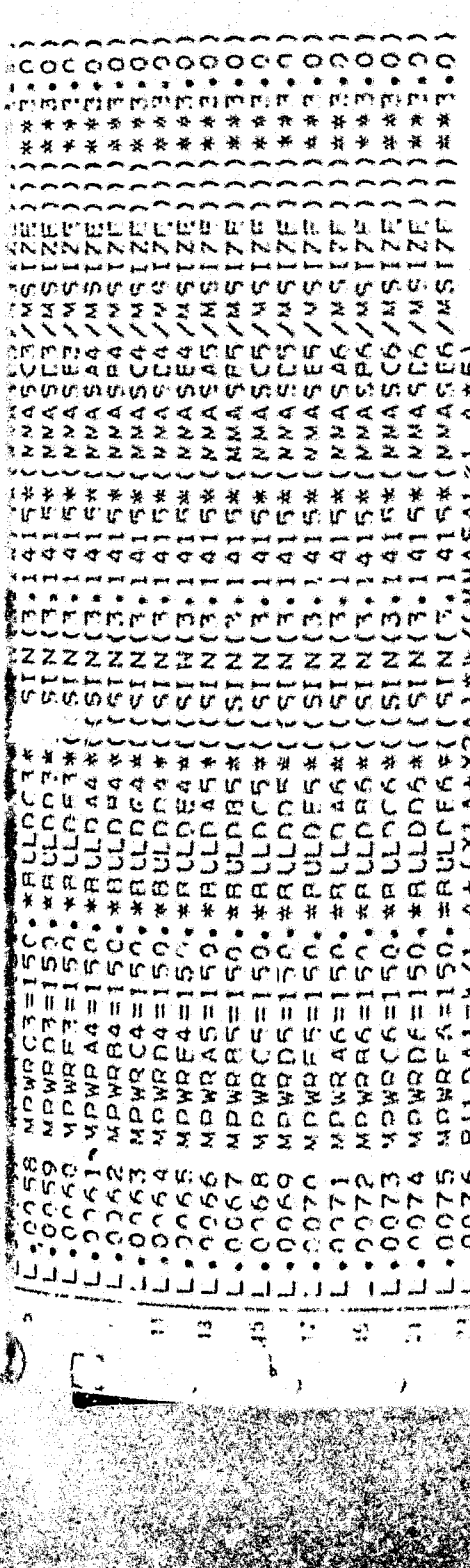

```
L.0410                PRTPLT PROD3(X1A,X2A,X3A)
L.0411                PRTPLT CIRCLD(X4,X5,X6)
L.0412                PRTPLT SUMPV(X7,X8,X9)
L.0413 PRTPLT MPWER1(YESNO1,MPWER2,MPWER3)
L.0414 PRTPLT MPWER4(X10)
L.0415 PRTPLT S1(S2,S3,S4)
L.0416 PRTPLT MPWER1(YESNO1,MMAS1,MMAS2)
L.0417 PRTPLT NOISE
L.0418                END
L.0419                STOP
L.0420 ENDJOB
L.0421 /*
```

CHANGE

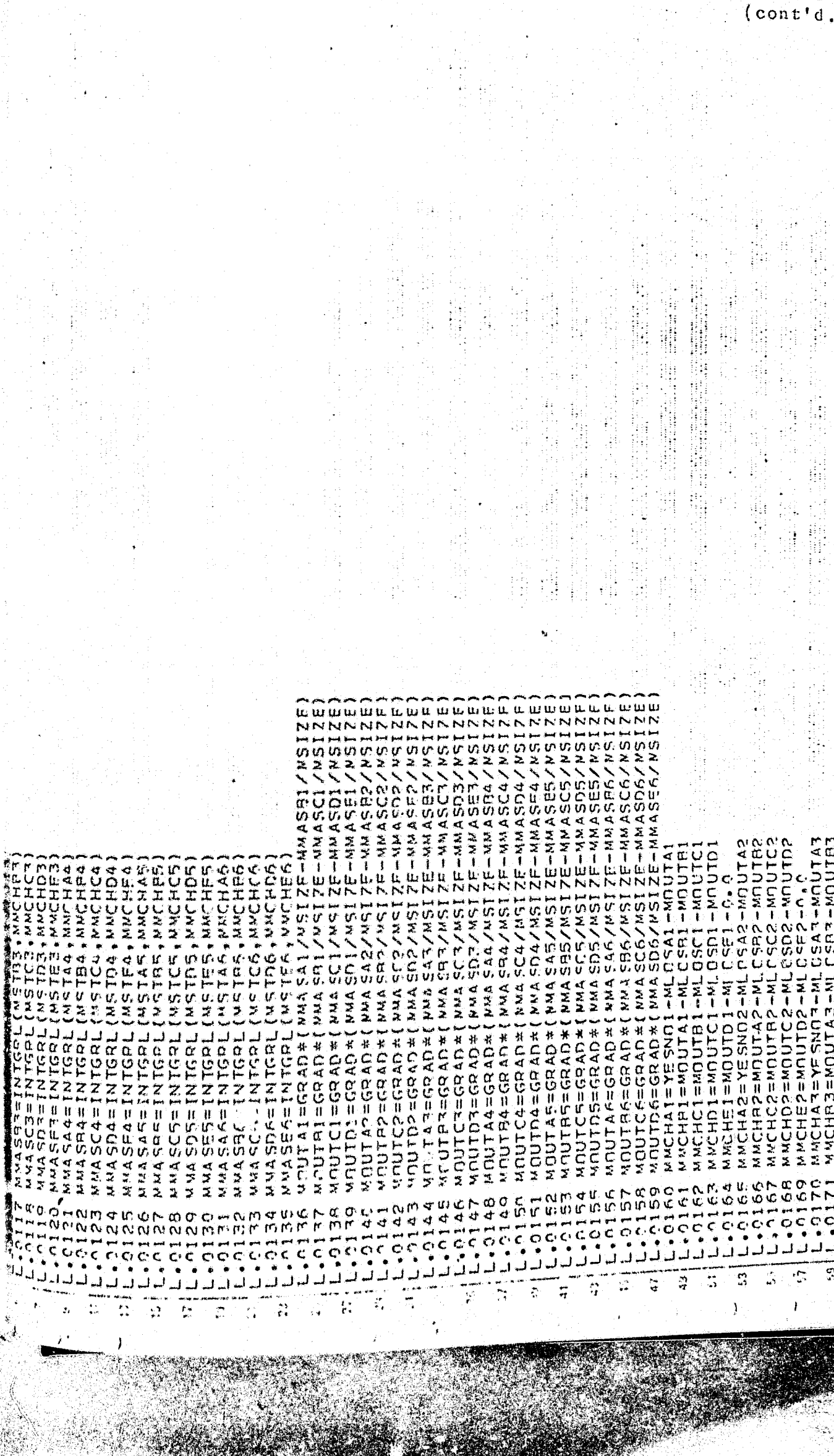
```
L.0001 //HTHFRT JOB C07,CLASS=C
L.0002 /*JOBPARM  FORMS=9999,L=9999
L.0003 // EXEC CSMP360,TIME,GO=7
L.0004 //GO.SYSIN DD *
L.0005 PARAMETER GRAD=4000.
L.0006 INCON X1AI=5.4249
L.0007 INCON X1BI=5.4249,X1CI=5.4249
L.0008 INCON X1DI=5.4249,X1EI=5.4249,X1FI=5.4249
L.0009 INCON X2AI=10.005,X2BI=10.005
L.0010 INCON X2CI=10.005,X2DI=10.005
L.0011 INCON X2EI=10.005,X2FI=10.005
L.0012 INCON X3AI=0.1727,X3BI=0.1727
L.0013 INCON X3CI=0.1727,X3DI=0.1727
L.0014 INCON X3EI=0.1727,X3FI=0.1727
L.0015 INCON X4I=0.1556
L.0016 INCON X5I=3.0883
L.0017 INCON X6I=0.15582
L.0018 INCON X7I=0.75589
L.0019 INCON X8I=10.570
L.0020 INCON X9I=0.5256
L.0021 INCON X10I=2.5500
L.0022 INCON X11I=0
L.0023 INCON S1=0.99,S2=0.99,S3=0.99
L.0024 INCON S4=0.99,S5=0.99,S6=0.99
L.0025 INCON TIMPL1=0.0,TIMPL2=0.0,TIMPL3=0.0
L.0026 INCON TIMPL4=0.0,TIMPL5=0.0,TIMPL6=0.0
L.0027 INCON MSTA1=20.1,MSTB1=20.05,MSTC1=20.,MSTD1=20.,MSTE1=20.
L.0028 INCON MSTA2=20.1,MSTB2=20.05,MSTC2=20.,MSTD2=20.,MSTE2=20.
L.0029 INCON MSTA3=20.1,MSTB3=20.05,MSTC3=20.,MSTD3=20.,MSTE3=20.
L.0030 INCON MSTA4=20.1,MSTB4=20.05,MSTC4=20.,MSTD4=20.,MSTE4=20.
L.0031 INCON MSTA5=20.1,MSTB5=20.05,MSTC5=20.,MSTD5=20.,MSTE5=20.
L.0032 INCON MSTA6=20.1,MSTB6=20.05,MSTC6=20.,MSTD6=20.,MSTE6=20.
L.0033 INCON TCPOWD=0.009
L.0034 INCON YESNO3=0.0
L.0035 INCON YESNO2=0.0
L.0036 INCON YESNO1=0.0
L.0037 INCON YESNO4=0.0,YESNO5=0.0,YESNO6=0.0
L.0038 PARAMETER MNCM=20.0
L.0039 PARAMETER W=2.72
L.0040 PARAMETER RODFT=100.
L.0041 PARAMETER PUMPCA=1480.
L.0042 HYCAU=48.8
L.0043 PARAMETER WADCHT=112.
L.0044 PARAMETER MSIZE=40.0
L.0045 PARAMETER G1=6,G2=6,G3=6,G4=6,G5=6,G6=6
L.0046 MPWRA1=150.*BULDA1*((SIN(3.1415*(MMASA1/MSIZE)))**3.0)
L.0047 MPWRB1=150.*BULDB1*((SIN(3.1415*(MMASB1/MSIZE)))**3.0)
L.0048 MPWRC1=150.*BULDC1*((SIN(3.1415*(MMASC1/MSIZE)))**3.0)
L.0049 MPWRD1=150.*BULDD1*((SIN(3.1415*(MMASD1/MSIZE)))**3.0)
L.0050 MPWRE1=150.*BULDE1*((SIN(3.1415*(MMASE1/MSIZE)))**3.0)
L.0051 MPWRA2=150.*BULDA2*((SIN(3.1415*(MMASA2/MSIZE)))**3.0)
L.0052 MPWRB2=150.*BULDB2*((SIN(3.1415*(MMASB2/MSIZE)))**3.0)
L.0053 MPWRC2=150.*BULDC2*((SIN(3.1415*(MMASC2/MSIZE)))**3.0)
L.0054 MPWRD2=150.*BULDD2*((SIN(3.1415*(MMASC2/MSIZE)))**3.0)
```

Listing 5

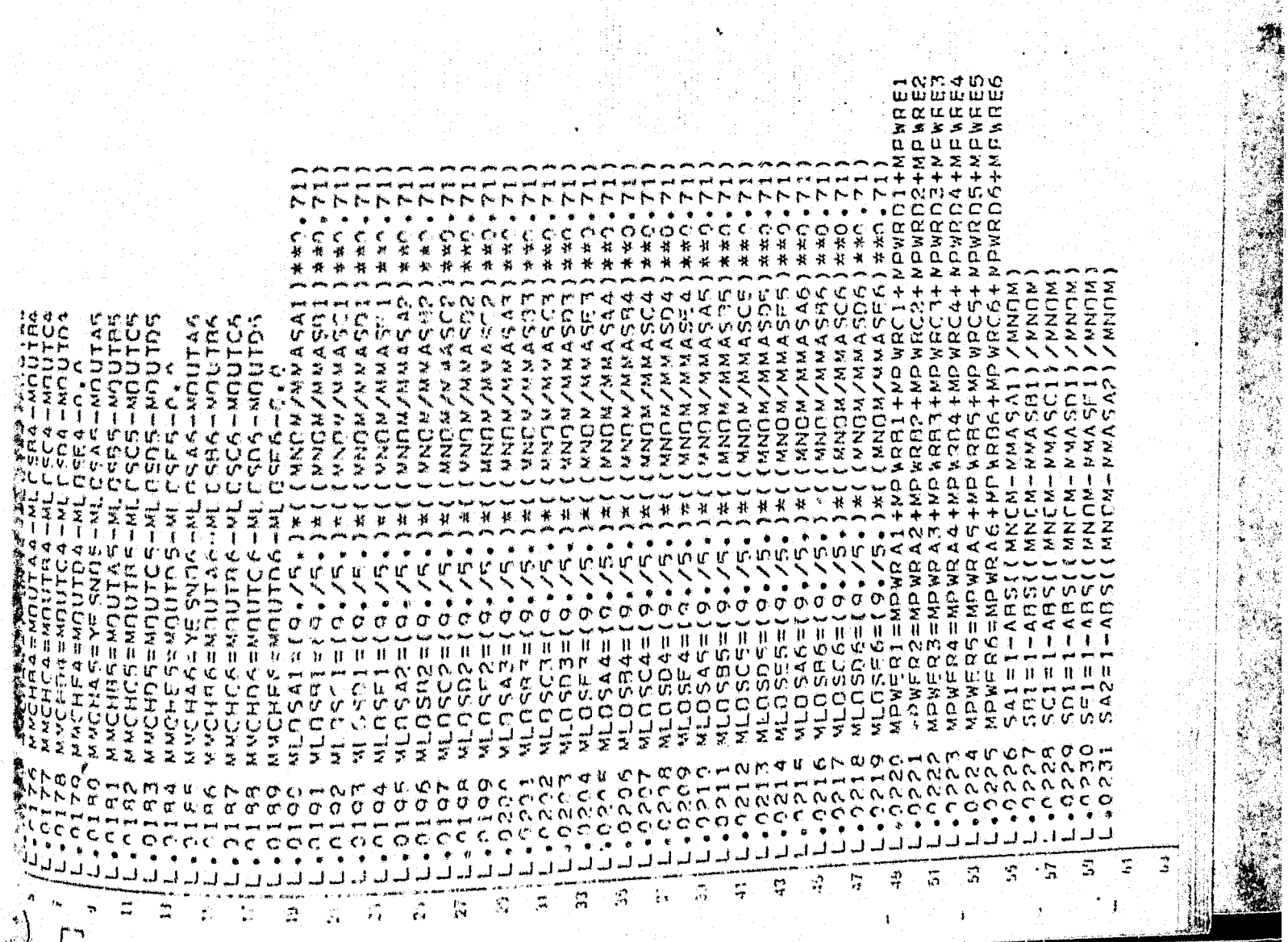
COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN CIRCUIT INCORPORATING A 5 SUB-MILLS PEBBLE MILL POWER MODEL (cont'd.)



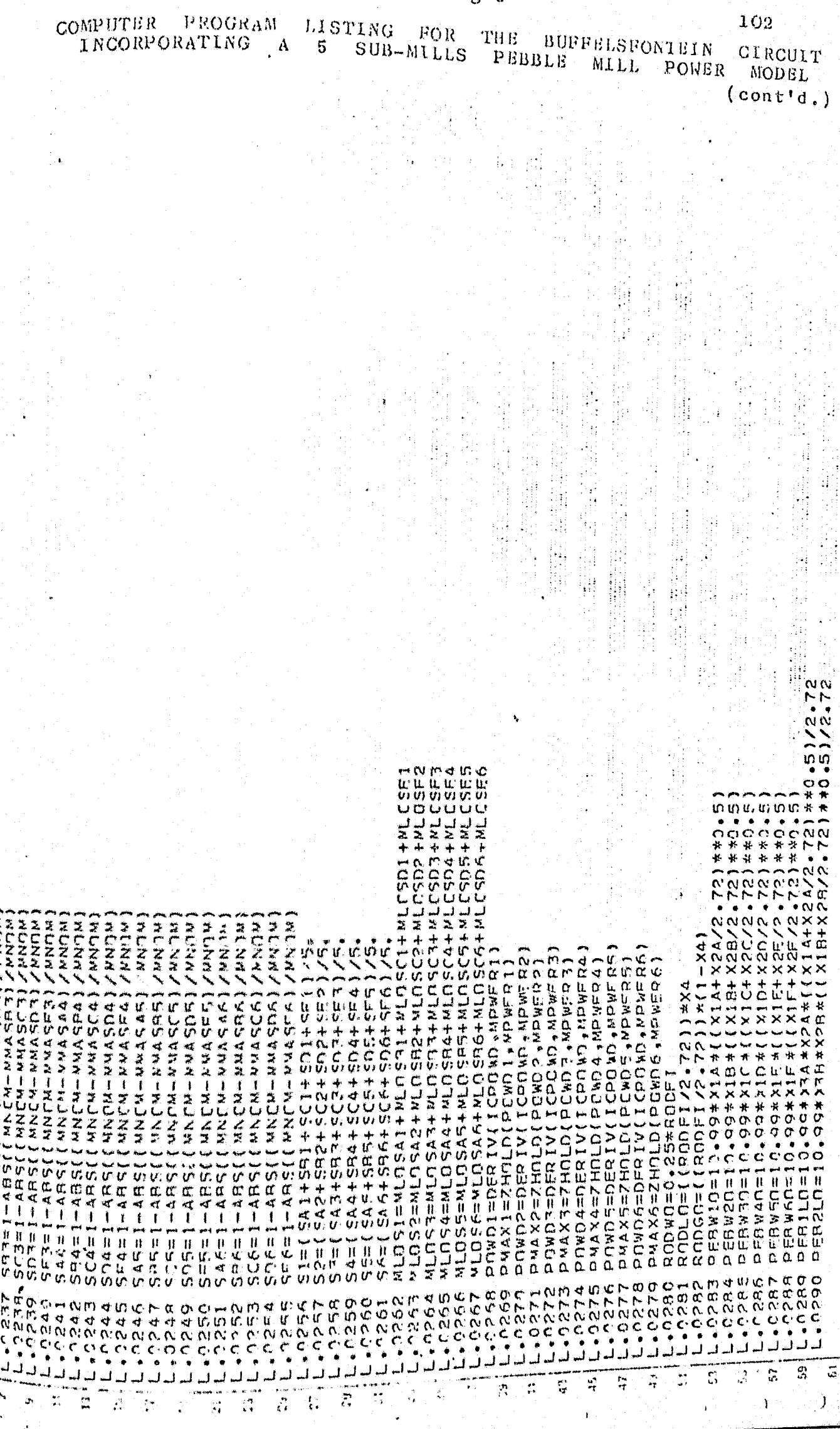
COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN CIRCUIT INCORPORATING A 5 SUB-MILLS PEBBLE MILL POWER MODEL (cont'd.)



COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN CIRCUIT INCORPORATING A 5 SUB-MILLS PEBBLE MILL POWER MODEL (cont'd.)



COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN CIRCUIT INCORPORATING A 5 SUB-MILLS PEBBLE MILL POWER MODEL (cont'd.)



Listing 5

```
L.0296 PERALO=10.99*X3F*X2F*((X1F+X2F/2.72)**0.5)/2.72
L.0297 PERA1GO=10.99*(1-X3A)*X2A*((X1A+X2A/2.72)**0.5)/2.72
L.0298 PERA2GO=10.99*(1-X3B)*X2B*((X1B+X2B/2.72)**0.5)/2.72
L.0299 PERA3GO=10.99*(1-X3C)*X2C*((X1C+X2C/2.72)**0.5)/2.72
L.0300 PERA4GO=10.99*(1-X3D)*X2D*((X1D+X2D/2.72)**0.5)/2.72
L.0301 PERA5GO=10.99*(1-X3E)*X2E*((X1E+X2E/2.72)**0.5)/2.72
L.0302 PERA6GO=10.99*(1-X3F)*X2F*((X1F+X2F/2.72)**0.5)/2.72
L.0303 SUMPWO=(X5/(X5+X6+X7))*PUMPCA
L.0304 SUMPLO=(X6/(X5+X6+X7))*PUMPCA
L.0305 SUMPGO=(X7/(X5+X6+X7))*PUMPCA
L.0306 HDTWO=(266.6*(X8+X9+X10)/3.398+446.36)*X8/(X8+X9+X10)
L.0307 HDTLO=(266.6*(X8+X9+X10)/3.398+446.36)*X9/(X8+X9+X10)
L.0308 HDTGO=(266.6*(X8+X9+X10)/3.398+446.36)*X10/(X8+X9+X10)
L.0309 HYCWI1=HDTWO/G1
L.0310 HYCWI2=HDTWO/G2
L.0311 HYCWI3=HDTWO/G3
L.0312 HYCWI4=HDTWO/G4
L.0313 HYCWI5=HDTWO/G5
L.0314 HYCWI6=HDTWO/G6
L.0315 HYCLI1=HDTLO*2.72/G1
L.0316 HYCLI2=HDTLO*2.72/G2
L.0317 HYCLI3=HDTLO*2.72/G3
L.0318 HYCLI4=HDTLO*2.72/G4
L.0319 HYCLI5=HDTLO*2.72/G5
L.0320 HYCLI6=HDTLO*2.72/G6
L.0321 HYCGI1=HDTGO*2.72/G1
L.0322 HYCGI2=HDTGO*2.72/G2
L.0323 HYCGI3=HDTGO*2.72/G3
L.0324 HYCGI4=HDTGO*2.72/G4
L.0325 HYCGI5=HDTGO*2.72/G5
L.0326 HYCGI6=HDTGO*2.72/G6
L.0327 MPWU1=HYCWU/HYCWI1
L.0328 MPWU2=HYCWU/HYCWI2
L.0329 MPWU3=HYCWU/HYCWI3
L.0330 MPWU4=HYCWU/HYCWI4
L.0331 MPWU5=HYCWU/HYCWI5
L.0332 MPWU6=HYCWU/HYCWI6
L.0333 SCTLU1=MPWU1*HYCLI1
L.0334 SCTLU2=MPWU2*HYCLI2
L.0335 SCTLU3=MPWU3*HYCLI3
L.0336 SCTLU4=MPWU4*HYCLI4
L.0337 SCTLU5=MPWU5*HYCLI5
L.0338 SCTLU6=MPWU6*HYCLI6
L.0339 RL1CLA=HYCLI1-SCTLU1
L.0340 RL2CLA=HYCLI2-SCTLU2
L.0341 RL3CLA=HYCLI3-SCTLU3
L.0342 RL4CLA=HYCLI4-SCTLU4
L.0343 RL5CLA=HYCLI5-SCTLU5
L.0344 RL6CLA=HYCLI6-SCTLU6
L.0345 RG1CLA=HYCGI1-MPWU1*HYCGI1
L.0346 RG2CLA=HYCGI2-MPWU2*HYCGI2
L.0347 RG3CLA=HYCGI3-MPWU3*HYCGI3
L.0348 RG4CLA=HYCGI4-MPWU4*HYCGI4
L.0349 RG5CLA=HYCGI5-MPWU5*HYCGI5
L.0350 RG6CLA=HYCGI6-MPWU6*HYCGI6
L.0351 SPICYI=(HYCLI1+HYCGI1)/(HYCLI1+HYCGI1+HYCWI1)
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L.0354 SP6CYI=(HYCLI6+HYCGI6)/(HYCLI6+HYCGI6+HYCWI6)
L.0355 SLHY1I=HYCWI1+(HYCLI1+HYCGI1)/2.72
L.0356 SLHY2I=HYCWI2+(HYCLI2+HYCGI2)/2.72
L.0357 SLHY3I=HYCWI3+(HYCLI3+HYCGI3)/2.72
L.0358 SLHY4I=HYCWI4+(HYCLI4+HYCGI4)/2.72
L.0359 SLHY5I=HYCWI5+(HYCLI5+HYCGI5)/2.72
L.0360 SLHY6I=HYCWI6+(HYCLI6+HYCGI6)/2.72
L.0361 D50C1=10**(2.04*2).32-0.0576*19.16+0.0366*19.+0.0299*100*SP1CYI-BIT1)
L.0362 BIT1=0.0001*(16.67*HYCWI1+HYCLI1*16.67/2.72+HYCGI1*16.67/2.72)
L.0363 D50C2=10**(2.04*2).32-0.0576*19.16+0.0366*19.+0.0299*100*SP2CYI-BIT2)
L.0364 BIT2=0.0001*(16.67*HYCWI2+HYCLI2*16.67/2.72+HYCGI2*16.67/2.72)
L.0365 D50C3=10**(2.04*2).32-0.0576*19.16+0.0366*19.+0.0299*100*SP3CYI-BIT3)
L.0366 BIT3=0.0001*(16.67*HYCWI3+HYCLI3*16.67/2.72+HYCGI3*16.67/2.72)
L.0367 D50C4=10**(2.04*2).32-0.0576*19.16+0.0366*19.+0.0299*100*SP4CYI-BIT4)
L.0368 BIT4=0.0001*(16.67*HYCWI4+HYCLI4*16.67/2.72+HYCGI4*16.67/2.72)
L.0369 D50C5=10**(2.04*2).32-0.0576*19.16+0.0366*19.+0.0299*100*SP5CYI-BIT5)
L.0370 BIT5=0.0001*(16.67*HYCWI5+HYCLI5*16.67/2.72+HYCGI5*16.67/2.72)
L.0371 D50C6=10**(2.04*2).32-0.0576*19.16+0.0366*19.+0.0299*100*SP6CYI-BIT6)
L.0372 BIT6=0.0001*(16.67*HYCWI6+HYCLI6*16.67/2.72+HYCGI6*16.67/2.72)
L.0373 CLALU1=RL1CLA*(1-EXP(-0.6931*((71.66/D50C1)**2)))
L.0374 CLALU2=RL2CLA*(1-EXP(-0.6931*((71.66/D50C2)**2)))
L.0375 CLALU3=RL3CLA*(1-EXP(-0.6931*((71.66/D50C3)**2)))
L.0376 CLALU4=RL4CLA*(1-EXP(-0.6931*((71.66/D50C4)**2)))
L.0377 CLALU5=RL5CLA*(1-EXP(-0.6931*((71.66/D50C5)**2)))
L.0378 CLALU6=RL6CLA*(1-EXP(-0.6931*((71.66/D50C6)**2)))
L.0379 FL01LU=CLALU1+SCTLU1
L.0380 FL02LU=CLALU2+SCTLU2
L.0381 FL03LU=CLALU3+SCTLU3
L.0382 FL04LU=CLALU4+SCTLU4
L.0383 FL05LU=CLALU5+SCTLU5
L.0384 FL06LU=CLALU6+SCTLU6
L.0385 CLAGU1=RG1CLA*(1-EXP(-0.6931*((166/D50C1)**2)))
L.0386 CLAGU2=RG2CLA*(1-EXP(-0.6931*((166/D50C2)**2)))
L.0387 CLAGU3=RG3CLA*(1-EXP(-0.6931*((166/D50C3)**2)))
L.0388 CLAGU4=RG4CLA*(1-EXP(-0.6931*((166/D50C4)**2)))
L.0389 CLAGU5=RG5CLA*(1-EXP(-0.6931*((166/D50C5)**2)))
L.0390 CLAGU6=RG6CLA*(1-EXP(-0.6931*((166/D50C6)**2)))
L.0391 FL01GU=CLAGU1+MPWU1*HYCGI1
L.0392 FL02GU=CLAGU2+MPWU2*HYCGI2
L.0393 FL03GU=CLAGU3+MPWU3*HYCGI3
L.0394 FL04GU=CLAGU4+MPWU4*HYCGI4
L.0395 FL05GU=CLAGU5+MPWU5*HYCGI5
L.0396 FL06GU=CLAGU6+MPWU6*HYCGI6
L.0397 OVFL1W=HYCWI1-HYCWU
L.0398 OVFL2W=HYCWI2-HYCWU
L.0399 OVFL3W=HYCWI3-HYCWU
L.0400 OVFL4W=HYCWI4-HYCWU
L.0401 OVFL5W=HYCWI5-HYCWU
L.0402 OVFL6W=HYCWI6-HYCWU
L.0403 OVFL1L=HYCLI1-FL01LU
L.0404 OVFL2L=HYCLI2-FL02LU
L.0405 OVFL3L=HYCLI3-FL03LU
L.0406 OVFL4L=HYCLI4-FL04LU
L.0407 OVFL5L=HYCLI5-FL05LU
L.0408 OVFL6L=HYCLI6-FL06LU
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L.0413 OVFL5G=HYCGIS-FLO5GU
L.0414 OVFL6G=HYCGI6-FLO6GU
L.0415 CIRCLD=(FLO1LU+FLO1GU)+(FLO2LU+FLO2GU)+(FLO3LU+FLO3GU)+ZZ
L.0416 ZZ=(FL 4LU+FLC4GU)+(FLO5LU+FLO5GU)+(FLC6LU+FLO6GU)
L.0417 SUMPV=X5+X6+X7
L.0418 HOTVOL=X8+X9+X1C
L.0419 PROOS=(OVFL1L+OVFL2L+OVFL3L+CVFL4L+OVFL5L+OVFL6L)/SSSS
L.0420 SSSS=(OVFL1L+CVFL2L+OVFL3L+OVFL4L+CVFL5L+OVFL6L+EE)
L.0421 EE=OVFL1G+OVFL2G+OVFL3G+CVFL4G+OVFL5G+CVFL6G
L.0422 X1A=INTGRL(X1AI,C1A)
L.0423 C1A=(HYCWU-PERW1C)
L.0424 X1B=INTGRL(X1BI,C1B)
L.0425 C1B=(HYCWU-PERW20)
L.0426 X1C=INTGRL(X1CI,C1C)
L.0427 C1C=(HYCWU-PERW30)
L.0428 X1D=INTGRL(X1DI,C1D)
L.0429 C1D=(HYCWU-PERW40)
L.0430 X1E=INTGRL(X1EI,C1E)
L.0431 C1E=(HYCWU-PERW50)
L.0432 X1E=INTGRL(X1EI,C1E)
L.0433 C1E=(HYCWU-PERW60)
L.0434 AA=FLO1LU+FLO1GU+VLOS1
L.0435 AB=FLO2LU+FLO2GU+VLOS2
L.0436 AC=FLO3LU+FLO3GU+VLOS3
L.0437 AD=FLO4LU+FLO4GU+VLOS4
L.0438 AE=FLO5LU+FLO5GU+VLOS5
L.0439 AF=FLO6LU+FLO6GU+VLOS6
L.0440 BA=FLO1LU/AA
L.0441 BB=FLO2LU/AB
L.0442 BC=FLO3LU/AC
L.0443 BD=FLO4LU/AD
L.0444 BE=FLO5LU/AE
L.0445 BF=FLO6LU/AF
L.0446 X2A=INTGRL(X2AI,C2A)
L.0447 C2A=AA-10.99*X2A*((X1A+X2A/2.72)**0.5)
L.0448 X2B=INTGRL(X2BI,C2B)
L.0449 C2B=AB-10.99*X2B*((X1B+X2B/2.72)**0.5)
L.0450 X2C=INTGRL(X2CI,C2C)
L.0451 C2C=AC-10.99*X2C*((X1C+X2C/2.72)**0.5)
L.0452 X2D=INTGRL(X2DI,C2D)
L.0453 C2D=AD-10.99*X2D*((X1D+X2D/2.72)**0.5)
L.0454 X2E=INTGRL(X2EI,C2E)
L.0455 C2E=AE-10.99*X2E*((X1E+X2E/2.72)**0.5)
L.0456 X2F=INTGRL(X2FI,C2F)
L.0457 C2F=AF-10.99*X2F*((X1F+X2F/2.72)**0.5)
L.0458 X3A=INTGRL(X3AI,C3A)
L.0459 C3A=(AA*(BA-X3A)/X2A+(1-X3A)*2.650)*S1
L.0460 X3B=INTGRL(X3BI,C3B)
L.0461 C3B=(AB*(BB-X3B)/X2B+(1-X3B)*2.650)*S2
L.0462 X3C=INTGRL(X3CI,C3C)
L.0463 C3C=(AC*(BC-X3C)/X2C+(1-X3C)*2.650)*S3
L.0464 X3D=INTGRL(X3DI,C3D)
L.0465 C3D=(AD*(BD-X3D)/X2D+(1-X3D)*2.650)*S4
L.0466 X3E=INTGRL(X3EI,C3E)
L.0467 C3E=(AE*(BE-X3E)/X2E+(1-X3E)*2.650)*S5
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L.0472 X5=INTGRL(X5I,C5)
L.0473 C5=RODWO+PEBW10+PEBW20+PEBW30+PEBW40+PEBW50+PEBW60+R
L.0474 R=250.3676+1700*((15-SUMPV)+200*X11)-SUMPWO
L.0475 X6=INTGRL(X6I,C6)
L.0476 C6=PEB1LO+PEB2LO+PEB3LO+PEB4LO+PEB5LO+PEB6LO+RR
L.0477 RR=RODLO-SUMPLO
L.0478 X7=INTGRL(X7I,C7)
L.0479 C7=PEB1GO+PEB2GO+PEB3GO+PEB4GO+PEB5GO+PEB6GO+TT
L.0480              TT=RODGO-SUMPGO
L.0481              X8=INTGRL(X8I,C8)
L.0482              C8=SUMPWO-RDTWO+WADDHT
L.0483              X9=INTGRL(X9I,C9)
L.0484              C9=SUMPLO-RDTLO
L.0485              X10=INTGRL(X10I,C10)
L.0486              C10=SUMPGO-RDTGO
L.0487              X11=INTGRL(X11I,C11)
L.0488              C11=(15-SUMPV)
L.0489 NOSORT
L.0490 IF(POWD1.LT.0.0)GO TO 21
L.0491 Q1=1.0
L.0492 GO TO 51
L.0493 21 CONTINUE
L.0494 Q1=MPWER1/PMAX1
L.0495 51 PDROP1=1.0-Q1
L.0496 IF(TIME.LT.TIMPL1)GO TO 91
L.0497 IF(PDROP1.GT.0.00125)GO TO 11
L.0498 91 YESNO1=YESNO1
L.0499 GO TO 41
L.0500 11 TIM1=TIME
L.0501 TIMPL1=TIM1+0.5
L.0502 IF(YESNO1.LT.18.9.AND.YESNO1.GT.17.1)GO TO 31
L.0503 YESNO1=18.0
L.0504 GO TO 41
L.0505 31 YESNO1=0.0
L.0506 41 CONTINUE
L.0507 IF(POWD2.LT.0.0)GO TO 2
L.0508 Q2=1.0
L.0509 GO TO 5
L.0510 2 CONTINUE
L.0511 Q2=MPWER2/PMAX2
L.0512 5 PDROP2=1.0-Q2
L.0513 IF(TIME.LT.TIMPL2)GO TO 9
L.0514 IF(PDROP2.GT.0.00125)GO TO 1
L.0515 9 YESNO2=YESNO2
L.0516 GO TO 4
L.0517 1 TIM2=TIME
L.0518 TIMPL2=TIM2+0.5
L.0519 IF(YESNO2.LT.18.9.AND.YESNO2.GT.17.1)GO TO 3
L.0520 YESNO2=18.0
L.0521 GO TO 4
L.0522 3 YESNO2=0.0
L.0523 4 CONTINUE
L.0524 IF(POWD3.LT.0.0)GO TO 23
L.0525 Q3=1.0
L.0526 GO TO 53
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L.0529 IF(PDROP3.LT.TIMPL3)GO TO 93
L.0530 IF(TIME.LT.TIMPL3)GO TO 93
L.0531 IF(PDROP3.GT.0.00125)GO TO 13
L.0532 93 YESNO3=YESNO3
L.0533 GO TO 43
L.0534 13 TIM3=TIME
L.0535 TIMPL3=TIM3+0.5
L.0536 IF(YESNO3.LT.18.5.AND.YESNO3.GT.17.1)GO TO 33
L.0537 YESNO3=18.0
L.0538 GO TO 43
L.0539 33 YESNO3=0.0
L.0540 43 CONTINUE
L.0541 IF(POWD4.LT.0.0)GO TO 24
L.0542 04=4.0
L.0543 GO TO 54
L.0544 24 CONTINUE
L.0545 04=MPWER4/PMAX4
L.0546 54 PDROP4=1.0-04
L.0547 IF(TIME.LT.TIMPL4)GO TO 94
L.0548 IF(PDROP4.GT.0.00125)GO TO 14
L.0549 94 YESNO4=YESNO4
L.0550 GO TO 44
L.0551 14 TIM4=TIME
L.0552 TIMPL4=TIM4+0.5
L.0553 IF(YESNO4.LT.18.5.AND.YESNO4.GT.17.1)GO TO 34
L.0554 YESNO4=18.0
L.0555 GO TO 44
L.0556 34 YESNO4=0.0
L.0557 44 CONTINUE
L.0558 IF(POWD5.LT.0.0)GO TO 25
L.0559 05=1.0
L.0560 GO TO 55
L.0561 25 CONTINUE
L.0562 05=MPWER5/PMAX5
L.0563 55 PDROP5=1.0-05
L.0564 IF(TIME.LT.TIMPL5)GO TO 95
L.0565 IF(PDROP5.GT.0.00125)GO TO 15
L.0566 95 YESNO5=YESNO5
L.0567 GO TO 45
L.0568 15 TIM5=TIME
L.0569 TIMPL5=TIM5+0.5
L.0570 IF(YESNO5.LT.18.5.AND.YESNO5.GT.17.1)GO TO 35
L.0571 YESNO5=18.0
L.0572 GO TO 45
L.0573 35 YESNO5=0.0
L.0574 45 CONTINUE
L.0575 IF(POWD6.LT.0.0)GO TO 26
L.0576 06=1.0
L.0577 GO TO 56
L.0578 26 CONTINUE
L.0579 06=MPWER6/PMAX6
L.0580 56 PDROP6=1.0-06
L.0581 IF(TIME.LT.TIMPL6)GO TO 96
L.0582 IF(PDROP6.GT.0.00125)GO TO 16
L.0583 96 YESNO6=YESNO6
L.0584 GO TO 46
L.0585 16 TIM6=TIME
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