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)(Sin(Hs))^3(Sinα)

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

Sinα = angle of repose of material in each sub-mill. Sinα 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.

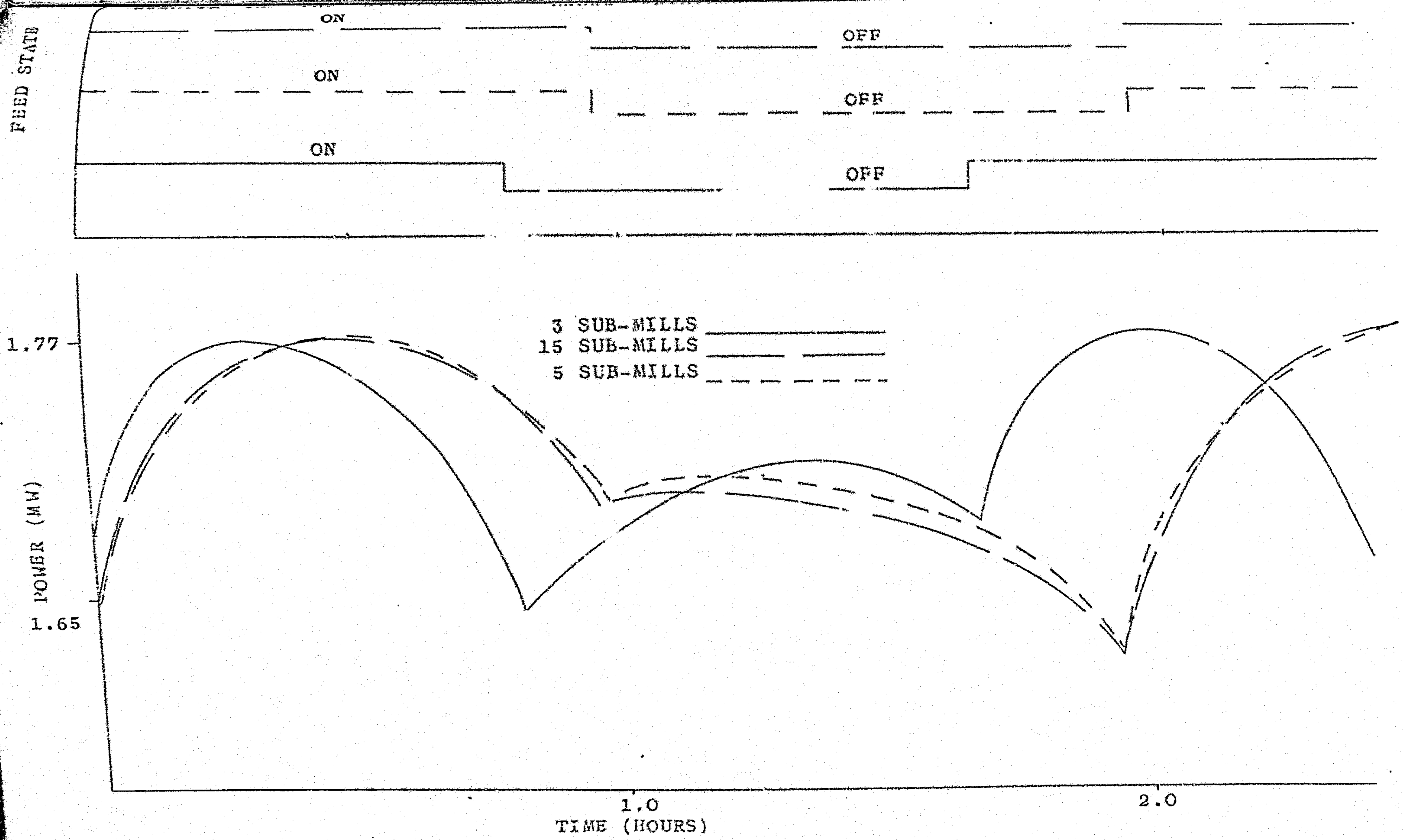
(2) The power curves in the 5 and 15 sub-mills simulations are remarkably similar, while the power curve for the 3 sub-mills simulation is significantly different. Clearly the 15 sub-mills simulation is the closest to reality. The 5 sub-mills model, however, would appear to represent an excellent compromise 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 <u>The Incorporation of Noise</u>

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:

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



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

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.

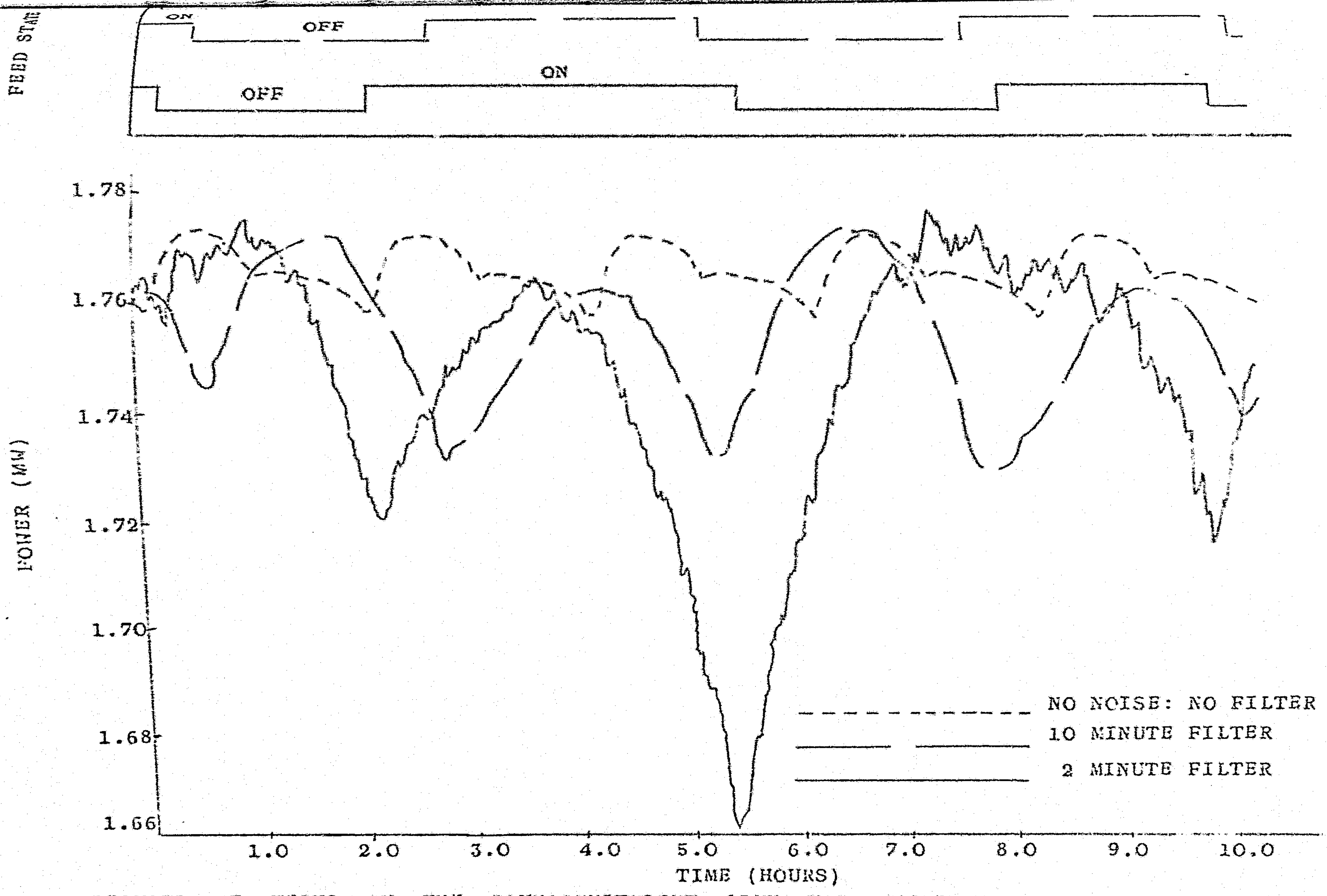
The power spectrum of the coloured Gaussian noise is:

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

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

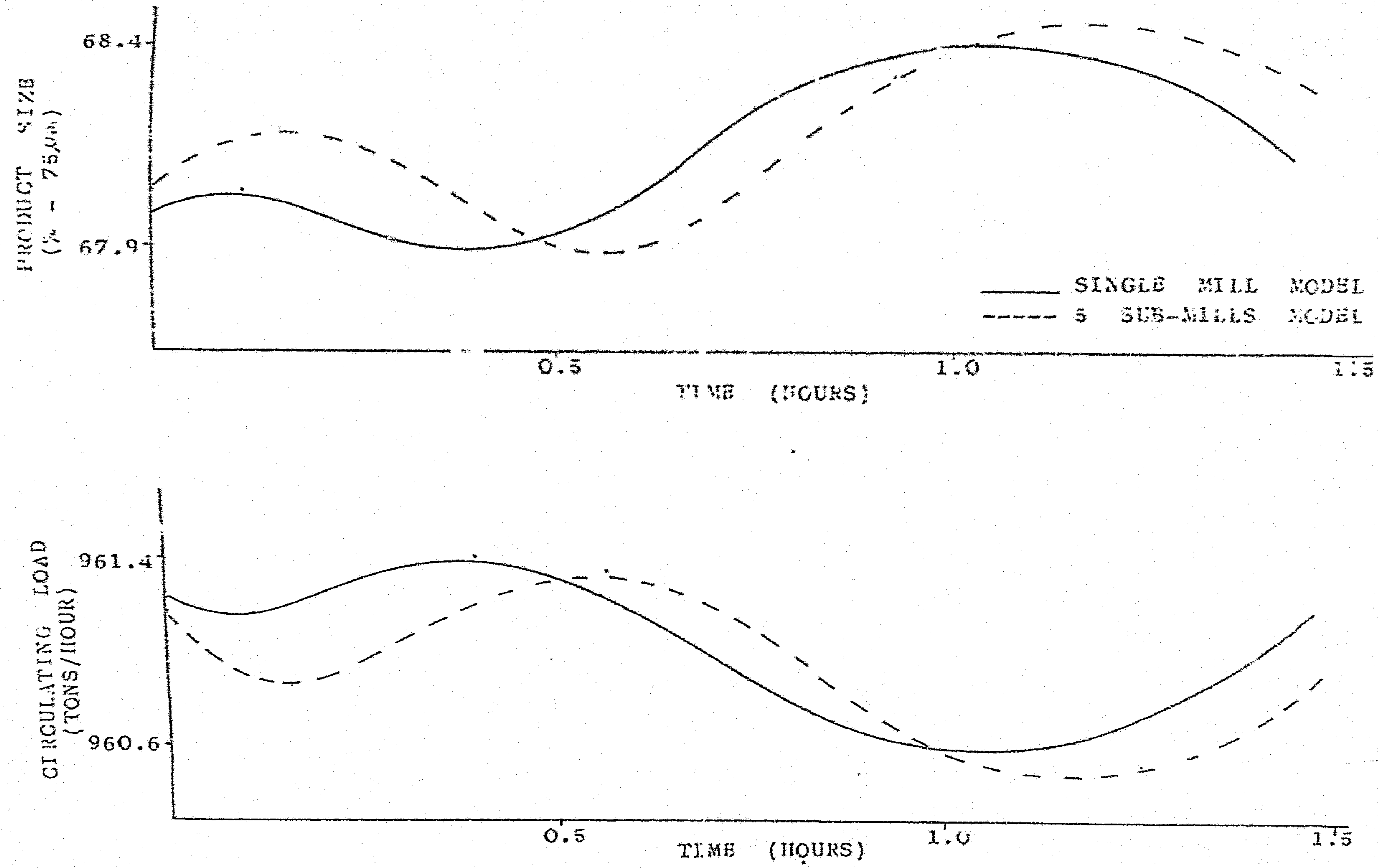


Fig. 11

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

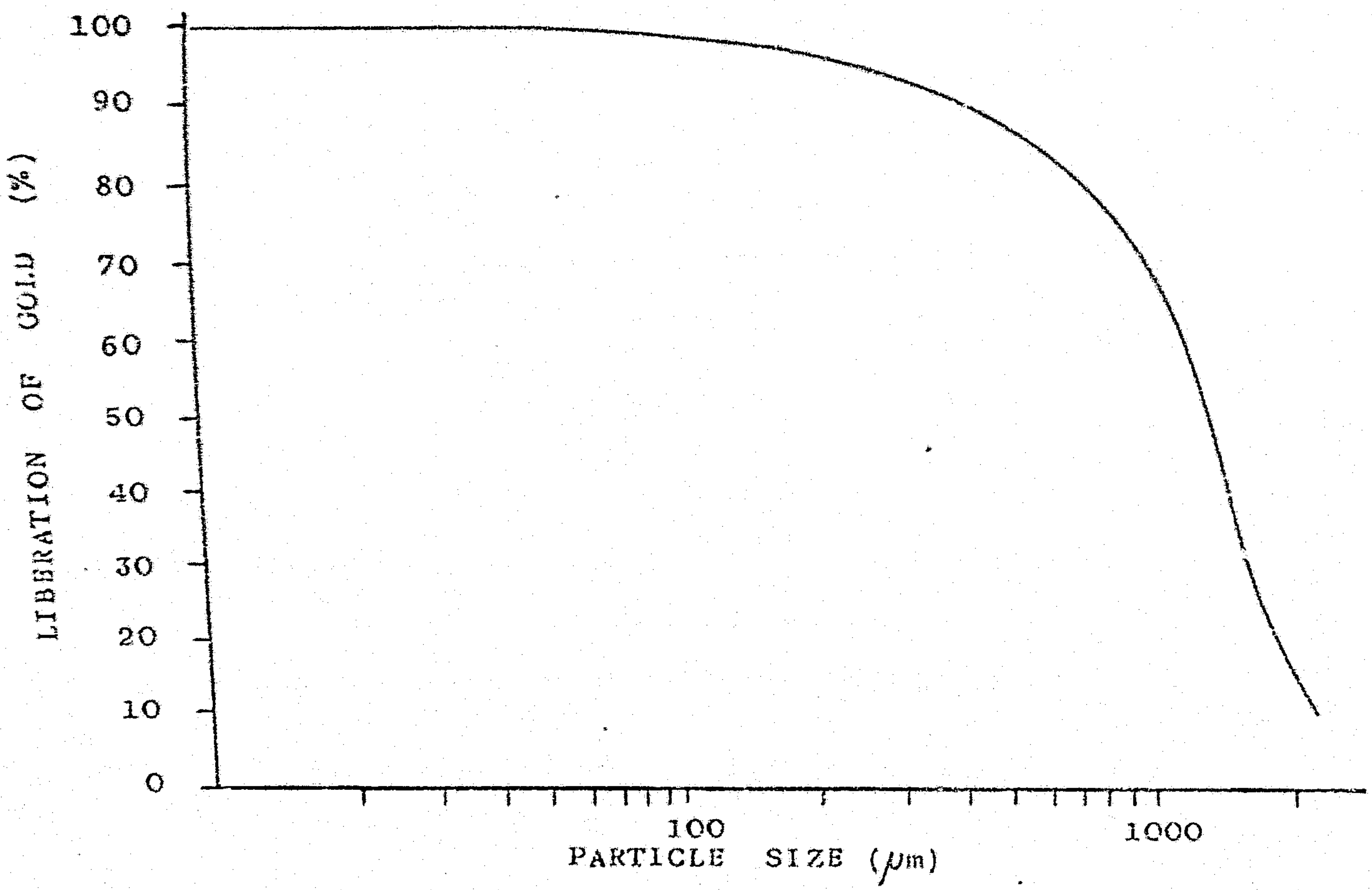


Fig. 12

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

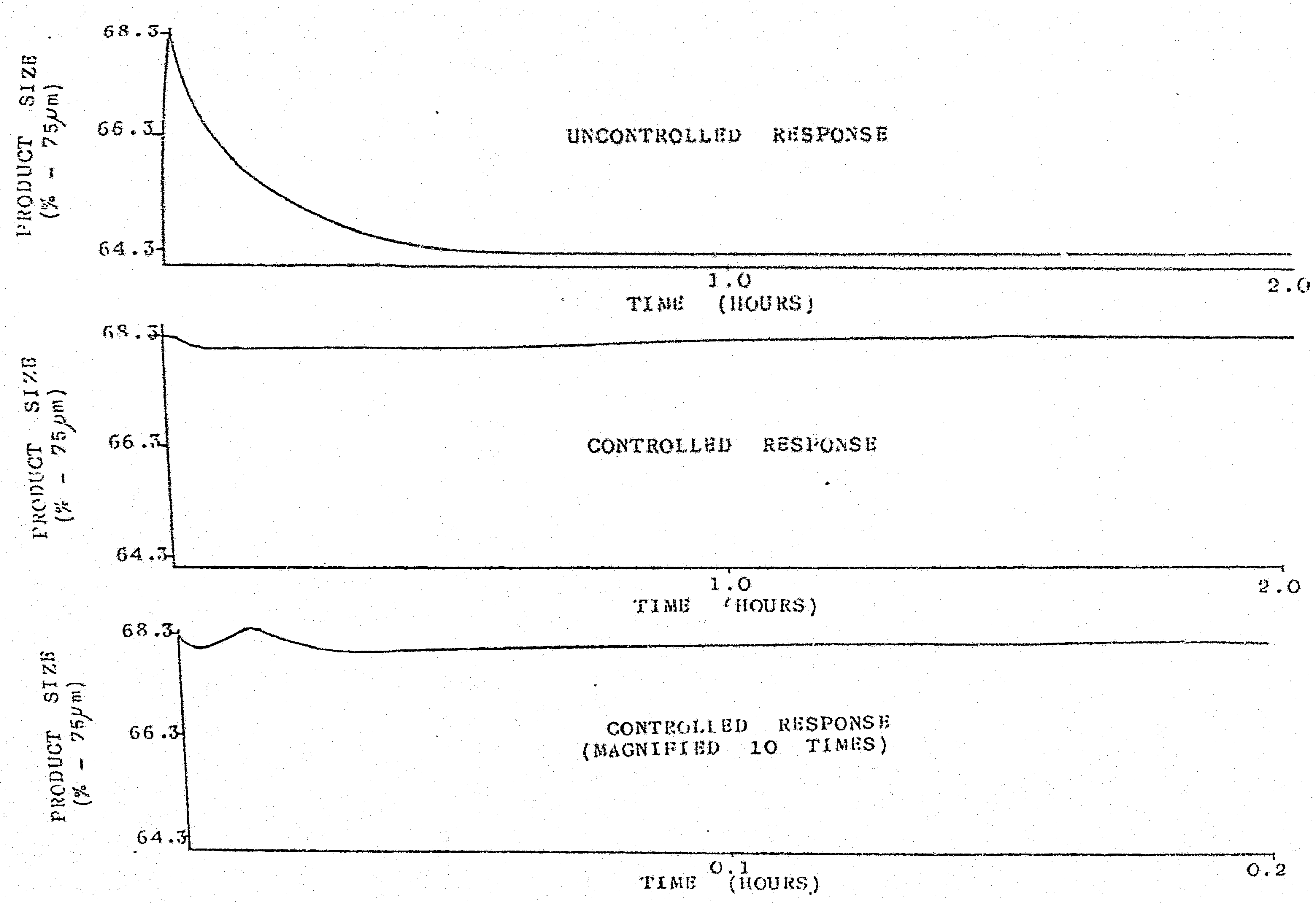


Fig. 13

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

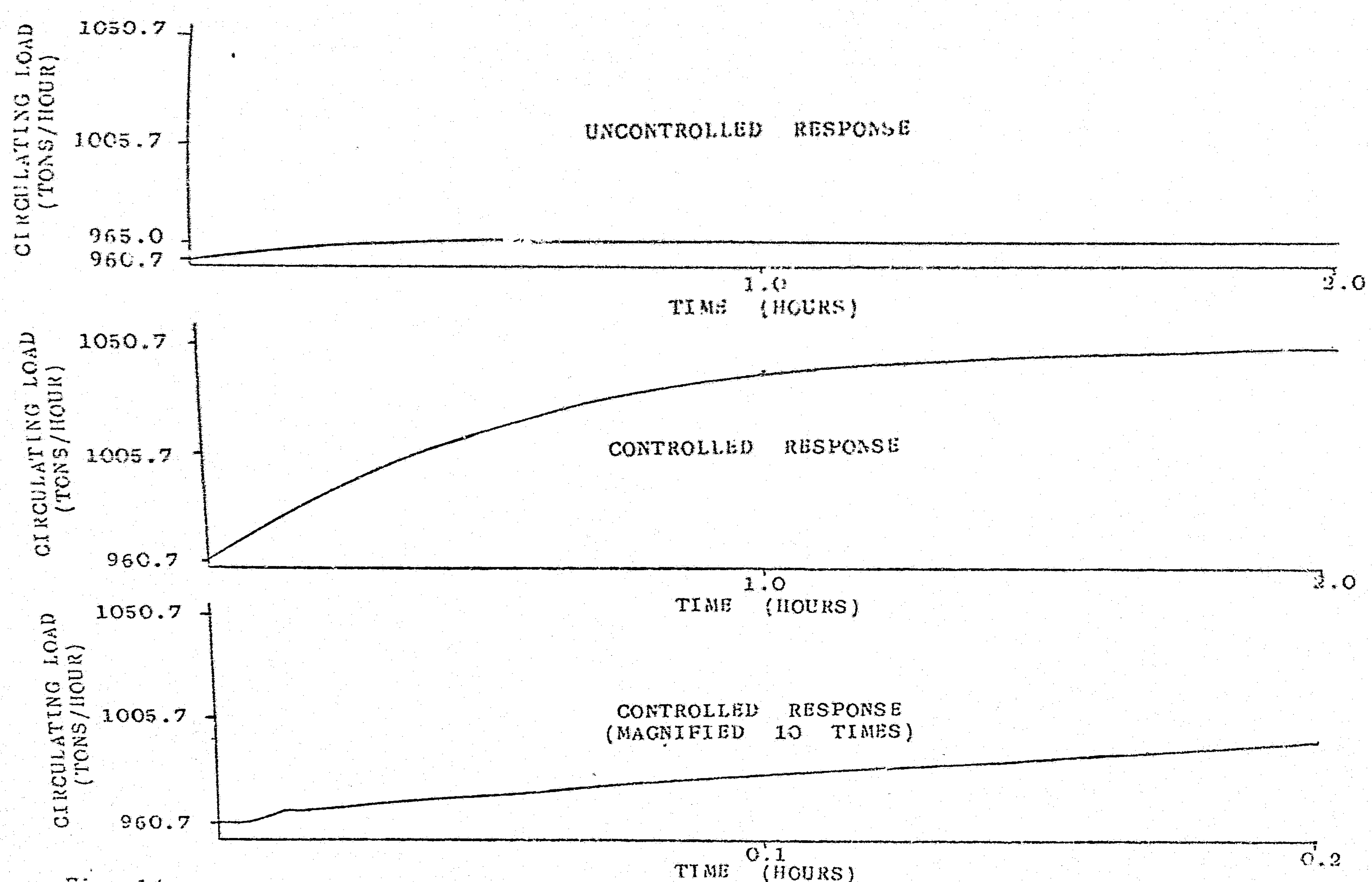


Fig. 14

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

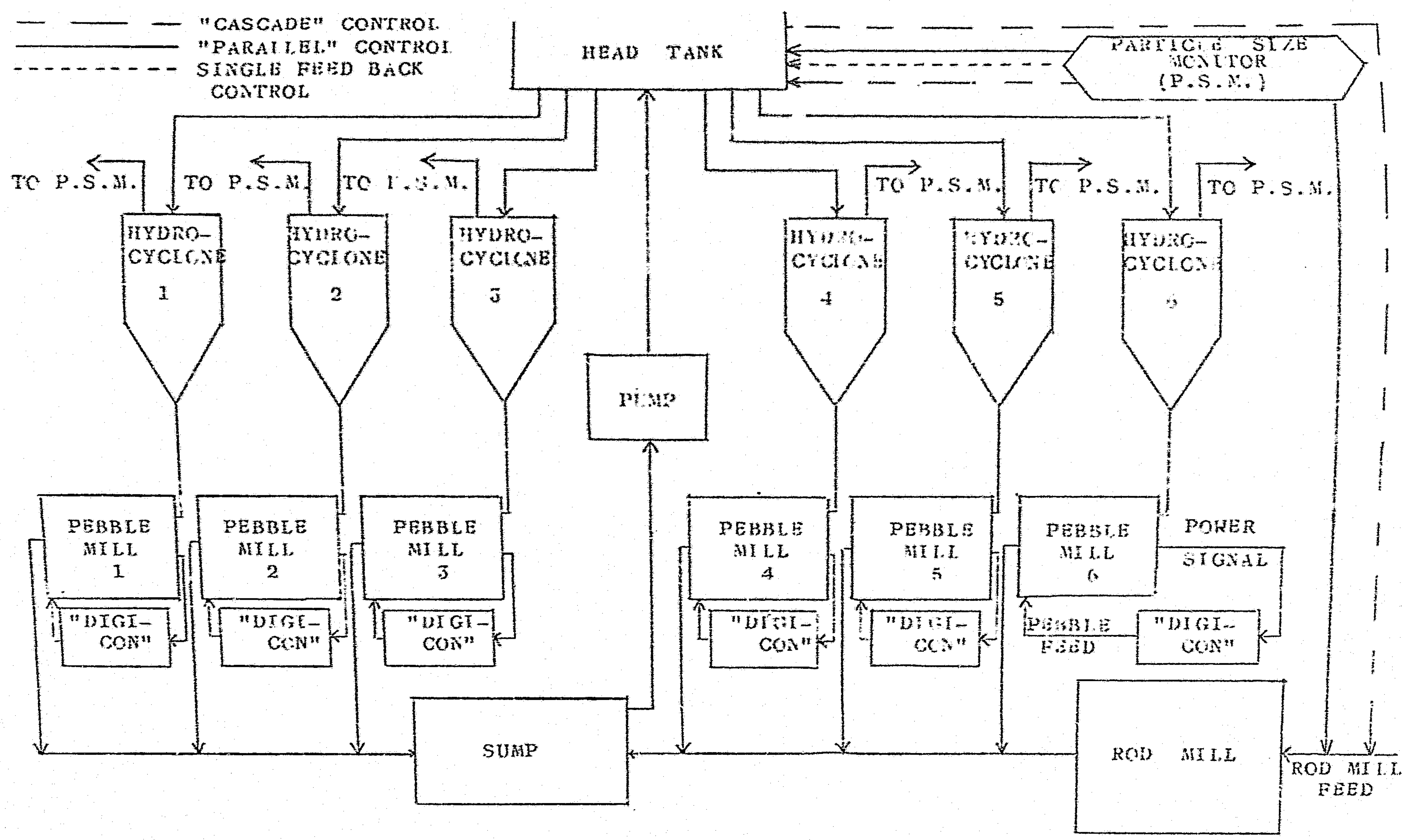


Fig. 15

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

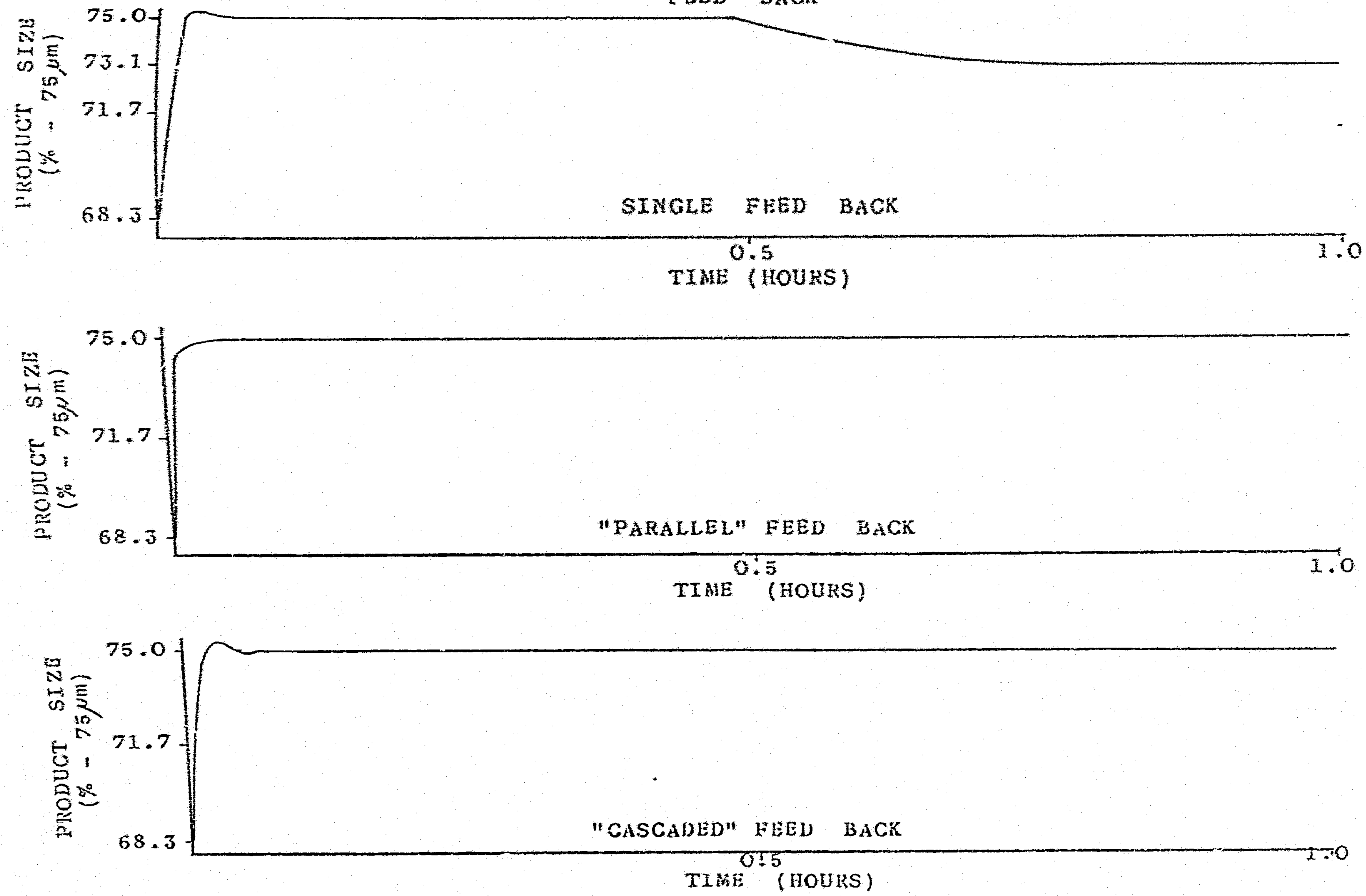


Fig. 16

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

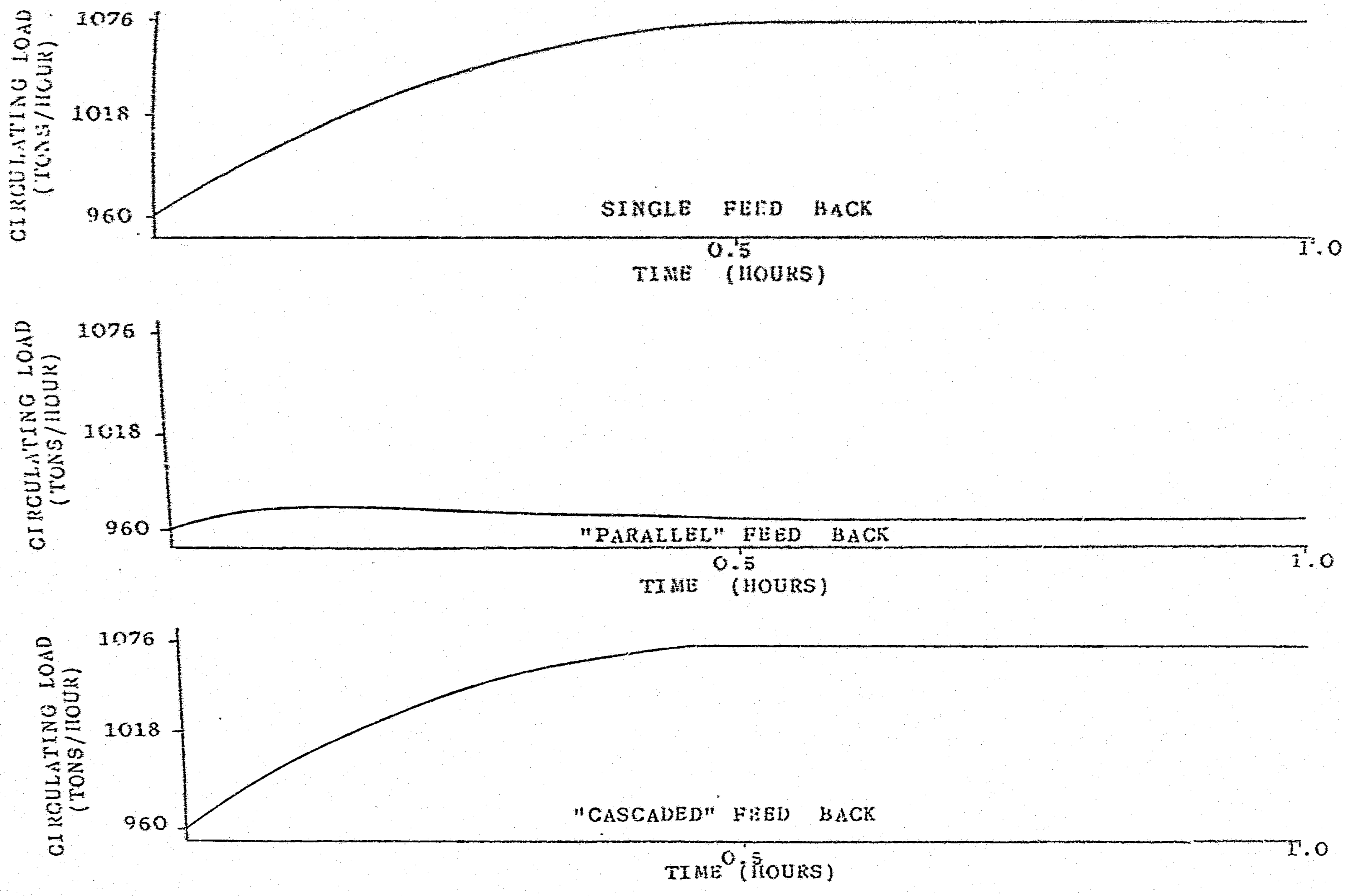


Fig. 17

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

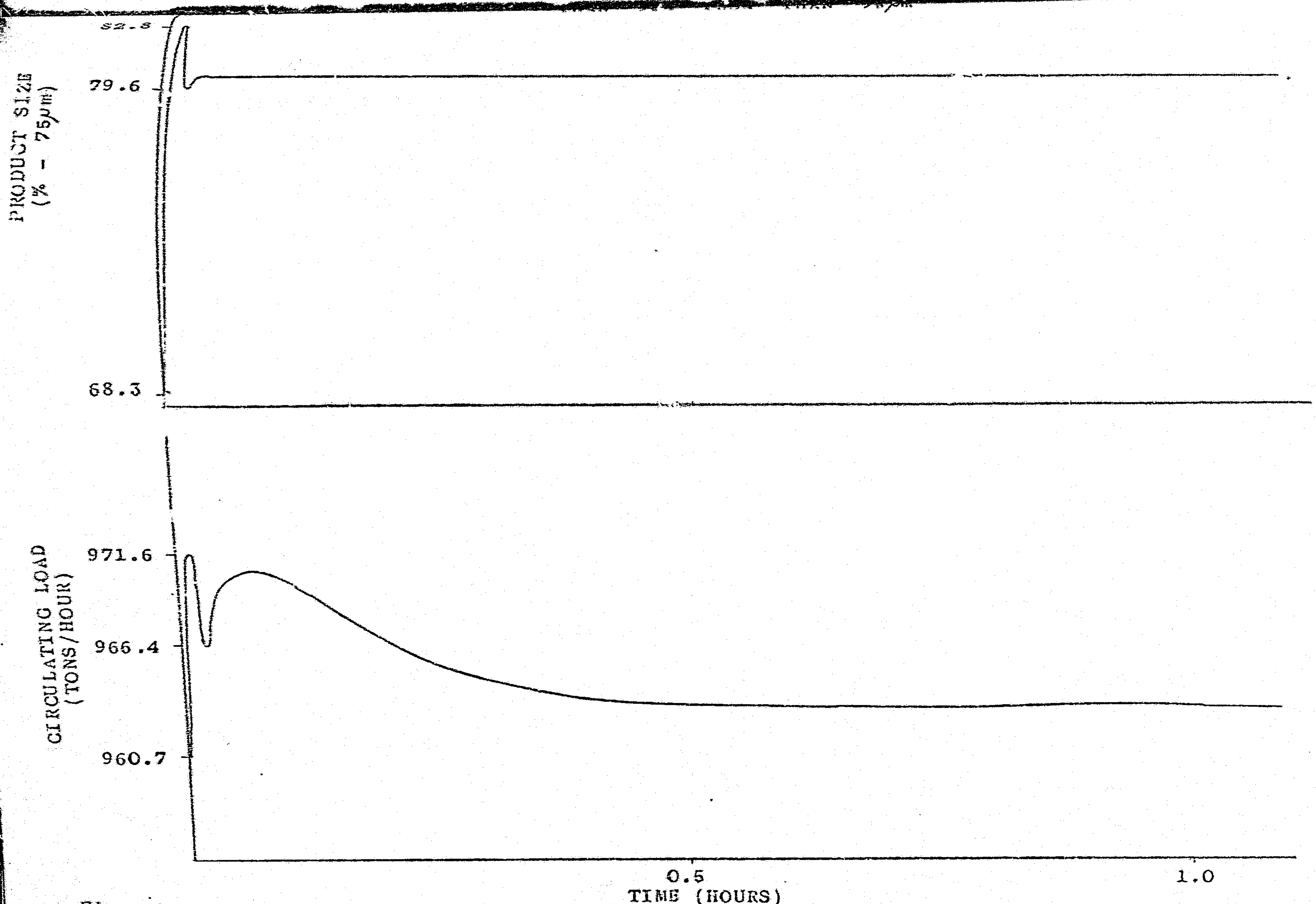
In further sets of simulations, it was demonstrated that product sizes finer than 75% less than 75μm can be achieved with the second and third control strategies if one is prepared to tolerate further drops in rod mill feed. Fig. 18 shows the response of the Buffelsfontein simulator to product size set 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
68.3
PRODUCT SIZE
(% - 75μm)
971.6
966.4
960.7
CIRCULATING LOAD
(TONS/HOUR)
0.5
1.0
TIME (HOURS)

Fig. 18

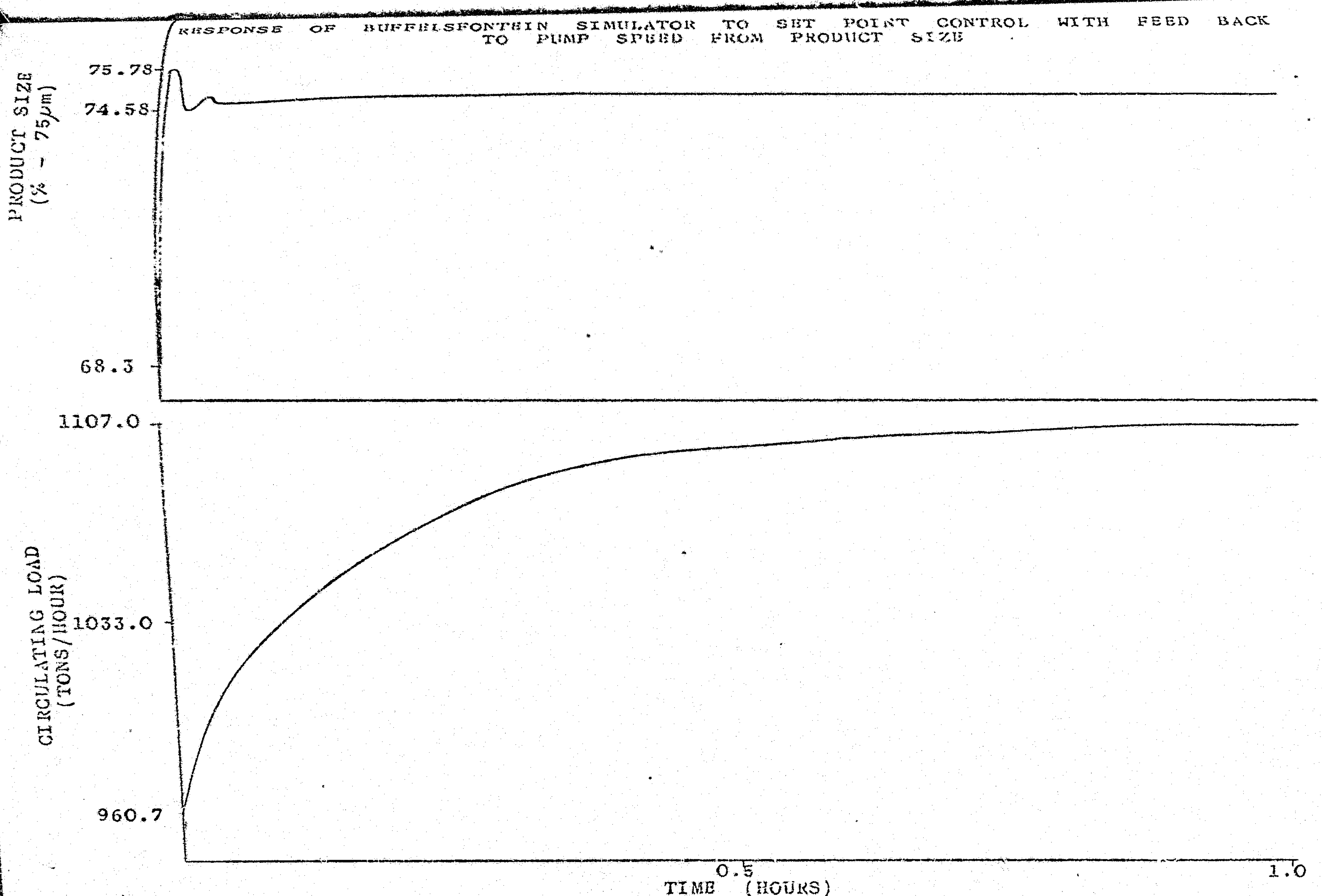

RESPONSE OF BUFFELSFONTEIN SIMULATOR TO SET POINT CONTROL WITH FEED BACK TO PUMP SPEED FROM PRODUCT SIZE
PRODUCT SIZE (% - 75μm)
75.78
74.58
68.3
CIRCULATING LOAD (TONS/HOUR)
1107.0
1033.0
960.7
0.5
1.0
TIME (HOURS)

Fig. 19

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

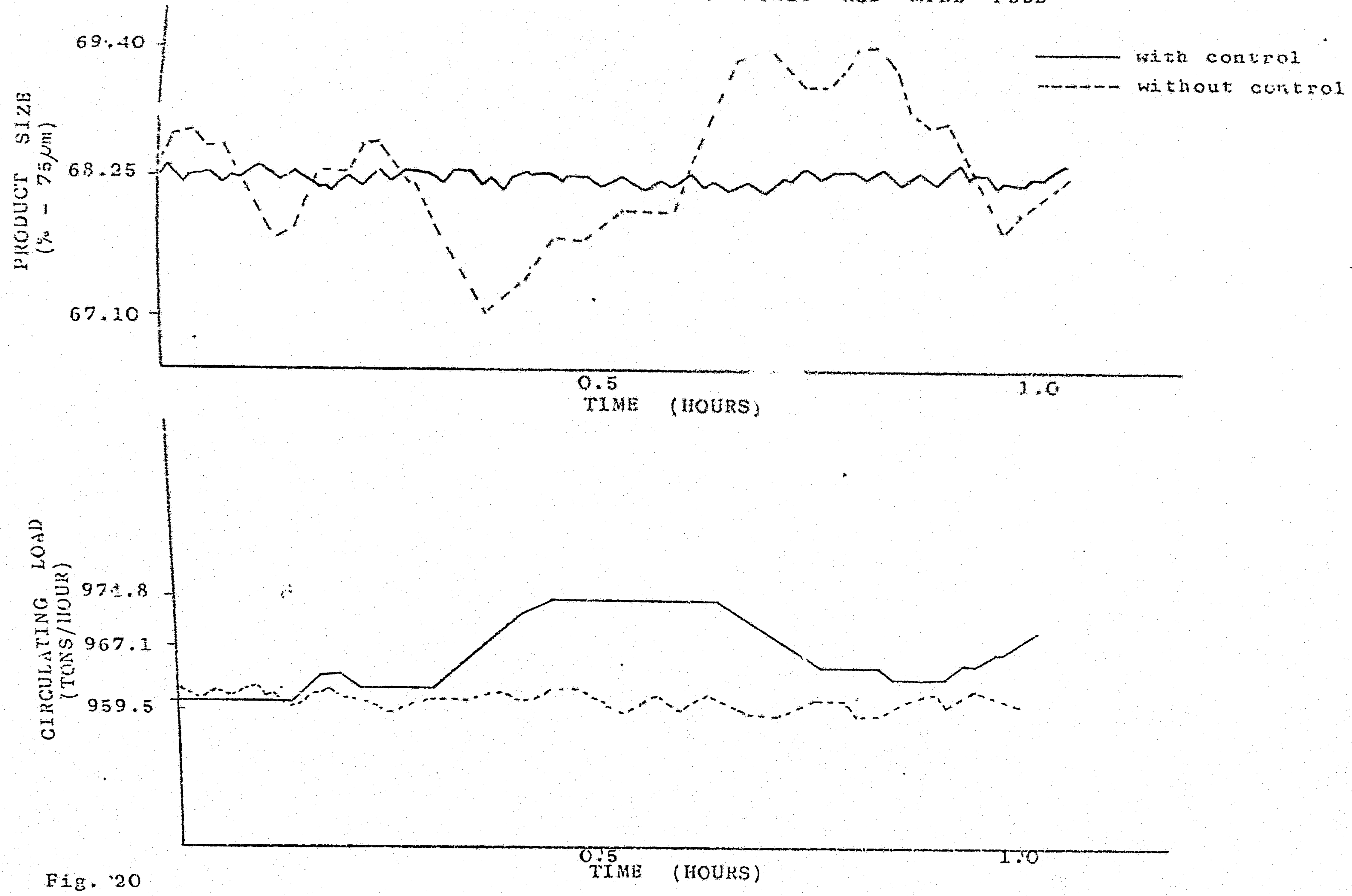


Fig. 20

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

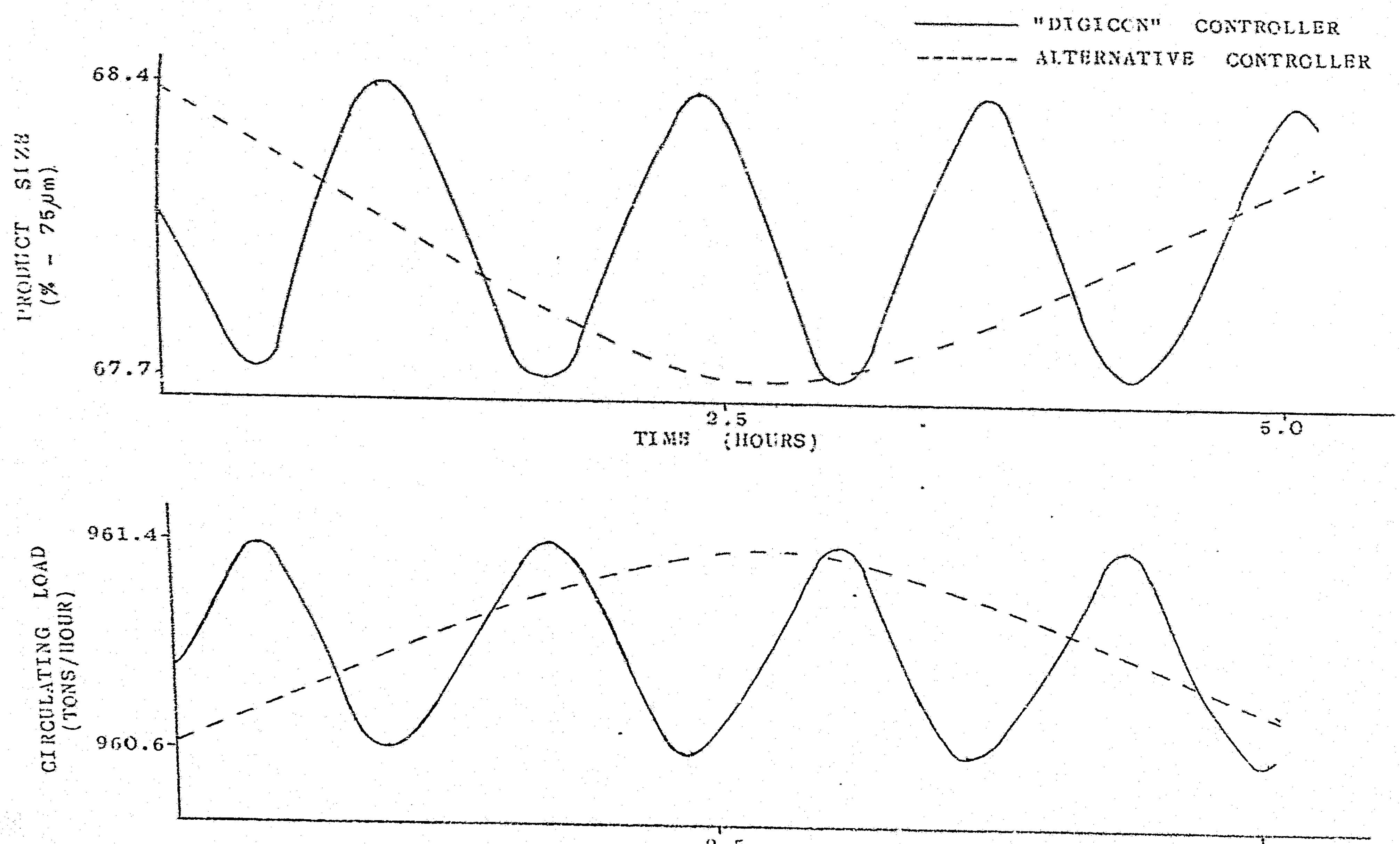


Fig. 21

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

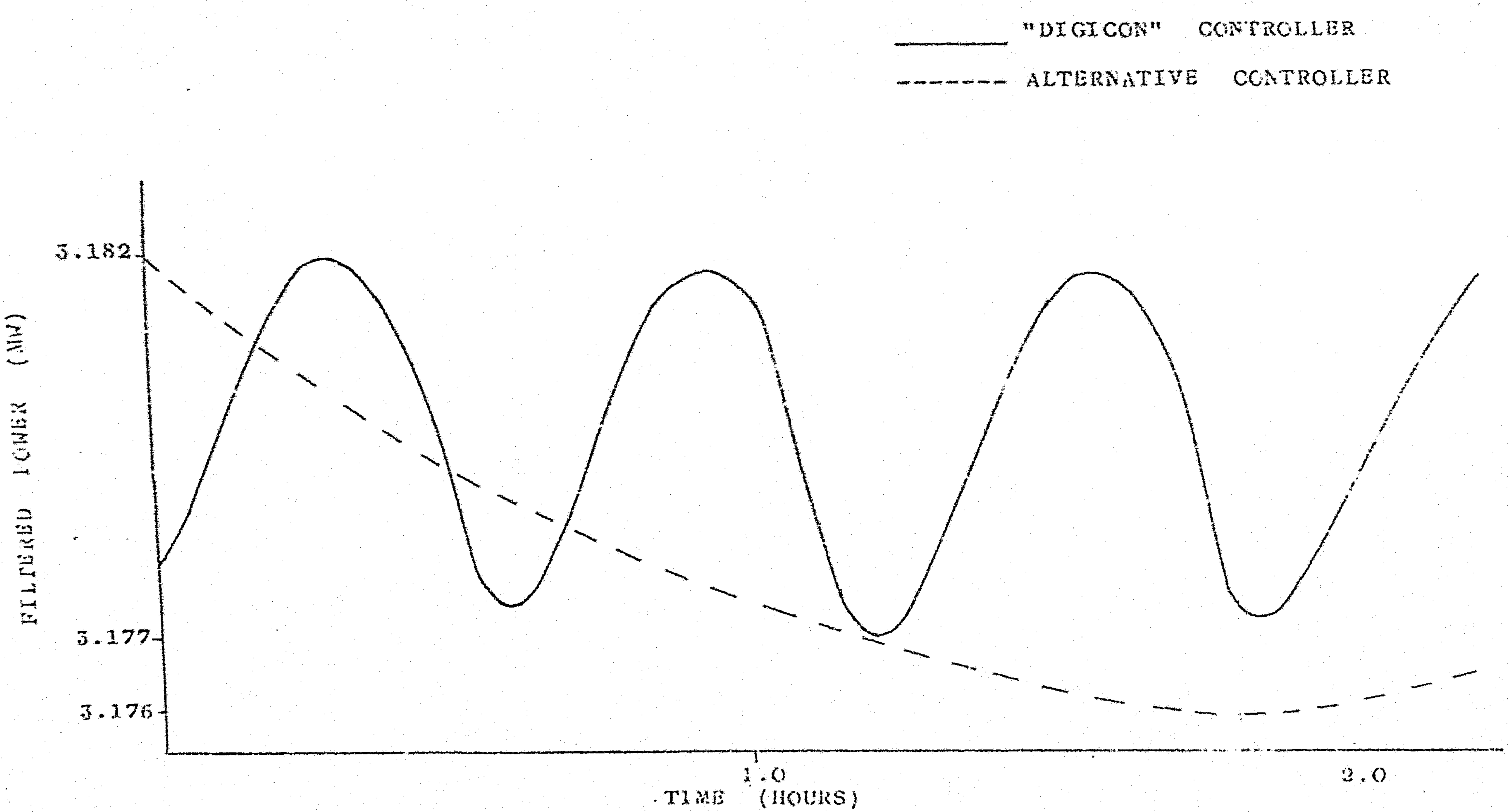


Fig. 22

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

```
AECDEFGH
//HTHTRI JOB C07,CLASS=E
/*JOBPARM  FORMS=9999,L=9999
// EXEC CSMP360
//GO.SYSIN DD *
INCON X1I=6.8183
INCON X2I=14.564
INCON X3I=0.1639
INCON X4I=0.1999
INCON X5I=2.8522
INCON X6I=0.1936
INCON X7I=0.9541
INCON X8I=2.8143
INCON X9I=0.1791
INCON X10I=0.8386
X11I=0
X1=INTGRL(X1I,C1)
C1=109-X1*4.582*((X1+X2/2.72)**0.5)
X2=INTGRL(X2I,C2)
C2=A-4.582*X2*((X1+X2/2.72)**0.5)
ZI1=4.582*X1*((X1+X2/2.72)**0.5)
ZI2=4.582*X3*X2*((X1+X2/2.72)**0.5)
ZI3=4.582*(1-X3)*X2*((X1+X2/2.72)**0.5)
A=7+(ZI14*ZI17)+(ZI15*ZI17)+ZI19*(1-EXP(-0.6931*((8.66/ZI24)**2)))+R
R=ZI21*(1-EXP(-0.6931*((166/ZI24)**2)))
ZI14=ZI11*2.72/2
ZI11=(266.6*(X8+X9+X10)/3.398+446.36)*X5/(X8+X9+X10)
ZI17=ZI16/ZI13
ZI16=109
ZI13=ZI10/2
ZI10=(266.6*(X8+X9+X10)/3.398+446.36)*X8/(X8+X9+X10)
ZI19=ZI14-ZI14*ZI17
ZI24=10**(1*ZI22-0.0005*ZI23+1.6624)
ZI23=ZI13+(ZI14+ZI15)/2.72
ZI15=ZI12*2.72/2
ZI12=(266.6*(X8+X9+X10)/3.398+446.36)*X10/(X8+X9+X10)
ZI22=(ZI14+ZI15)/(ZI13+ZI14+ZI15)
ZI21=ZI15-ZI15*ZI17
B=ZI26/A
ZI26=ZI18+ZI25
ZI18=ZI14*ZI17
ZI25=ZI19*(1-EXP(-0.6931*((8.66/ZI24)**2)))
X3=INTGRL(X3I,C3)
C3=(A*(B-X3)/X2+(1-X3)*1.65)
X4=INTGRL(X4I,C4)
C4=(70.0*(0.03-X4)/6.03+(1-X4)*2.4668)
X5=INTGRL(X5I,C5)
C5=( 2*4.582*X1*((X1+X2/2.72)**0.5)+0.3*70.0-(X5/(X5+X6+X7))*686.3)+D
D=250.3676+500*((4-X5-X6-X7)+(20*X11))
X6=INTGRL(X6I,C6)
C6=2*4.582*X3*X2*((X1+X2/2.72)**0.5)/2.72+(70./2.72)*X4-C
C=(X6/(X5+X6+X7))*686.3
X7=INTGRL(X7I,C7)
C7=2*4.582*(1-X3)*X2*((X1+X2/2.72)**0.5)/2.72+(70.0/2.72)*(1-X4)-Q
Q=(X7/(X5+X6+X7))*686.3
```

Listing 1

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

```
C8=(X5/(X5+X6+X7))*686.3-ZI10
X9=INTGRL(X9I,C9)
C9=(X6/(X5+X6+X7))*686.3-ZI11
X10=INTGRL(X10I,C10)
C10=(X7/(X5+X6+X7))*686.3-ZI12
X11=INTGRL(X11I,C11)
C11=(4-X5-X6-X7)
CLOAD=(ZI29+ZI27+ZI18+ZI25)*2
ZI20=ZI15*ZI17
PRODS=ZI30/(ZI30+ZI31)
ZI30=ZI14-ZI26
ZI31=ZI15-ZI28
ZI26=ZI18+ZI25
ZI28=ZI20+ZI27
ZI27=ZI21*(1-EXP(-0.6931*((166/ZI24)**2)))
U=X5+X6+X7
HDTVOL=X8+X9+X10
TIMER FINTIM=1.0,OUTDEL=0.02
PRTPLT PRODS(ZI1,ZI2,ZI3)
PRTPLT CLOAD(ZI10,ZI11,ZI12)
PRTPLT U(ZI13)
PRTPLT HDTVOL
END
STOP
ENDJOB
/*
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN SIMULATOR OPERATING IN STEADY STATE

```
********************************************************************************************
//HTHRDSTI JOE CC7.CLASS=A
/*JOBPARM   R=87.L=9999
// EXEC CSMP360.TIME.GO=10
//GO.SYSIN DD *
INCON X1AI=2.0543
INCON X1BI=2.0543.X1CI=2.0543
INCON X1DI=2.0543.X1EI=2.0543.X1FI=2.0543
INCON X2AI=7.11990.X2BI=7.11990
INCON X2CI=7.11990.X2DI=7.11990
INCON X2FI=7.11990.X2FI=7.11990
INCON X3AI=0.20881.X3BI=0.20881
INCON X3CI=0.20881.X3DI=0.20881
INCON X3FI=0.20881.X3FI=0.20881
INCON X4I=0.1556
INCON X5I=10.846
INCON X6I=0.64755
INCON X7I=3.3063
INCON X8I=10.843
INCON X9I=0.76701
INCON X10I=2.9921
INCON X11I=0
INCON X12I=0.
PARAMETER RODFI=120.
PARAMETER RUMPCA=1480.
HYCWU1=INSW(TST,48.8,0.0)
TST=TIME-1.5
HYCWU2=INSW(TST,48.8,0.0)
HYCWU3=48.8
HYCWU4=48.8
HYCWU5=48.8
HYCWU6=48.8
SGOVF1=(OVFL1L+OVFL1G+OVFL1W)/(OVFL1W+(OVFL1L+OVFL1G)/2.72)
SGOVF3=(OVFL3L+OVFL3G+OVFL3W)/(OVFL3W+(OVFL3L+OVFL3G)/2.72)
SGRODD=(RODWO+(RODLO+RODGO)*2.72)/(RODWO+RODLO+RODGO)
SGHYCU=(FLO1GU+FLO1LU+HYCWU1)/(HYCWU1+(FLO1GU+FLO1LU)/2.72)
SGHYCI=(HYCLI1+HYCGI1+HYCWI1)/(HYCWI1+(HYCGI1+HYCLI1)/2.72)
SGPEB1=(PEBW1O+(PEB1LO+PEB1GO)*2.72)/(PEBW1O+PEB1LO+PEB1GO)
SGPEB3=(PEBW3O+(PEB3LO+PEB3GO)*2.72)/(PEBW3O+PEB3LO+PEB3GO)
SGRAVH=(X8+2.72*(X9+X10))/(X8+X9+X10)
WADDHT =112.0
PARAMETER PEBFD1=9,PEBFD2=9,PEBFD3=9,PEBFD4=9
PARAMETER PEBFD5=9,PEBFD6=9
G1=INSW(TST,6.,999999.)
G2=INSW(TST,6.,999999.)
G3=INSW(TST,6.,4.)
G4=INSW(TST,6.,4.)
G5=INSW(TST,6.,4.)
G6=INSW(TST,6.,4.)
RODWO=0.25*RODFI
RODLO=((RODFI/2.72))*X4
RODGO=((RODFI/2.72))*(1-X4)
PEBW1O=10.99*X1A*((X1A+X2A/2.72)**0.5)
PEBW2O=10.99*X1B*((X1B+X2B/2.72)**0.5)
PEBW3O=10.99*X1C*((X1C+X2C/2.72)**0.5)
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN SIMULATOR OPERATING IN STEADY STATE

(cont'd.)

```
      PEBW5O=10.99*X1F*((X1F+X2F/2.72)**0.5)
      PEBW6O=10.99*X3A*X2A*((X1A+X2A/2.72)**0.5)/2.72
      PEB1LO=10.99*X3B*X2B*((X1B+X2B/2.72)**0.5)/2.72
      PEB2LO=10.99*X3B*X2B*((X1B+X2B/2.72)**0.5)/2.72
      PEB3LO=10.99*X3C*X2C*((X1C+X2C/2.72)**0.5)/2.72
      PEB4LO=10.99*X3D*X2D*((X1D+X2D/2.72)**0.5)/2.72
      PEB5LO=10.99*X3E*X2E*((X1E+X2E/2.72)**0.5)/2.72
      PEB6LO=10.99*X3F*X2F*((X1F+X2F/2.72)**0.5)/2.72
      PEB1GO=10.99*(1-X3A)*X2A*((X1A+X2A/2.72)**0.5)/2.72
      PEB2GO=10.99*(1-X3B)*X2B*((X1B+X2B/2.72)**0.5)/2.72
      PEB3GO=10.99*(1-X3C)*X2C*((X1C+X2C/2.72)**0.5)/2.72
      PEB4GO=10.99*(1-X3D)*X2D*((X1D+X2D/2.72)**0.5)/2.72
      PEB5GO=10.99*(1-X3E)*X2E*((X1F+X2E/2.72)**0.5)/2.72
      PEB6GO=10.99*(1-X3F)*X2F*((X1F+X2F/2.72)**0.5)/2.72
      SUMPWO=(X5/(X5+X6+X7))*PUMPCA
      SUMPLO=(X6/(X5+X6+X7))*PUMPCA
      SUMPGO=(X7/(X5+X6+X7))*PUMPCA
      HDTWO=(266.6*(X8+X9+X10)/3.398+446.36)*X8/(X8+X9+X10)
      HDTLO=(266.6*(X8+X9+X10)/3.398+446.36)*X9/(X8+X9+X10)
      HDTGO=(266.6*(X8+X9+X10)/3.398+446.36)*X10/(X8+X9+X10)
      HYCWI1=HDTWO/G1
      HYCWI2=HDTWO/G2
      HYCWI3=HDTWO/G3
      HYCWI4=HDTWO/G4
      HYCWI5=HDTWO/G5
      HYCWI6=HDTWO/G6
      HYCLI1=HDTLO*2.72/G1
      HYCLI2=HDTLO*2.72/G2
      HYCLI3=HDTLO*2.72/G3
      HYCLI4=HDTLO*2.72/G4
      HYCLI5=HDTLO*2.72/G5
      HYCLI6=HDTLO*2.72/G6
      HYCGI1=HDTGO*2.72/G1
      HYCGI2=HDTGO*2.72/G2
      HYCGI3=HDTGO*2.72/G3
      HYCGI4=HDTGO*2.72/G4
      HYCGI5=HDTGO*2.72/G5
      HYCGI6=HDTGO*2.72/G6
      MPWU1=HYCWU1/HYCWI1
      MPWU2=HYCWU2/HYCWI2
      MPWU3=HYCWU3/HYCWI3
      MPWU4=HYCWU4/HYCWI4
      MPWU5=HYCWU5/HYCWI5
      MPWU6=HYCWU6/HYCWI6
      SCTLU1=MPWU1*HYCLI1
      SCTLU2=MPWU2*HYCLI2
      SCTLU3=MPWU3*HYCLI3
      SCTLU4=MPWU4*HYCLI4
      SCTLU5=MPWU5*HYCLI5
      SCTLU6=MPWU6*HYCLI6
      RL1CLA=HYCLI1-SCTLU1
      RL2CLA=HYCLI2-SCTLU2
      RL3CLA=HYCLI3-SCTLU3
      RL4CLA=HYCLI4-SCTLU4
      RL5CLA=HYCLI5-SCTLU5
      RL6CLA=HYCLI6-SCTLU6
      SCTGU1=MPWU1*HYCGI1
      SCTGU2=MPWU2*HYCGI2
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN SIMULATOR OPERATING IN STEADY STATE

(cont'd.)

```
SCTGU5=MPWU5*HYCGI5
SCTGU6=MPWU6*HYCGI6
RG1CLA=HYCGI1-SCTGU1
RG2CLA=HYCGI2-SCTGU2
RG3CLA=HYCGI3-SCTGU3
RG4CLA=HYCGI4-SCTGU4
RG5CLA=HYCGI5-SCTGU5
RG6CLA=HYCGI6-SCTGU6
SP1CYI=(HYCLI1+HYCGI1)/(HYCLI1+HYCGI1+HYCWI1)
SP2CYI=(HYCLI2+HYCGI2)/(HYCLI2+HYCGI2+HYCWI2)
SP3CYI=(HYCLI3+HYCGI3)/(HYCLI3+HYCGI3+HYCWI3)
SP4CYI=(HYCLI4+HYCGI4)/(HYCLI4+HYCGI4+HYCWI4)
SP5CYI=(HYCLI5+HYCGI5)/(HYCLI5+HYCGI5+HYCWI5)
SP6CYI=(HYCLI6+HYCGI6)/(HYCLI6+HYCGI6+HYCWI6)
SLHY1I=HYCWI1+(HYCLI1+HYCGI1)/2.72
SLHY2I=HYCWI2+(HYCLI2+HYCGI2)/2.72
SLHY3I=HYCWI3+(HYCLI3+HYCGI3)/2.72
SLHY4I=HYCWI4+(HYCLI4+HYCGI4)/2.72
SLHY5I=HYCWI5+(HYCLI5+HYCGI5)/2.72
SLHY6I=HYCWI6+(HYCLI6+HYCGI6)/2.72
D50C1=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP1CYI-BIT1)
BIT1=0.0001*(16.67*HYCWI1+HYCLI1*16.67/2.72+HYCGI1*16.67/2.72)
D50C2=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP2CYI-BIT2)
BIT2=0.0001*(16.67*HYCWI2+HYCLI2*16.67/2.72+HYCGI2*16.67/2.72)
D50C3=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP3CYI-BIT3)
BIT3=0.0001*(16.67*HYCWI3+HYCLI3*16.67/2.72+HYCGI3*16.67/2.72)
D50C4=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP4CYI-BIT4)
BIT4=0.0001*(16.67*HYCWI4+HYCLI4*16.67/2.72+HYCGI4*16.67/2.72)
D50C5=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP5CYI-BIT5)
BIT5=0.0001*(16.67*HYCWI5+HYCLI5*16.67/2.72+HYCGI5*16.67/2.72)
D50C6=10**(0.040*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP6CYI-BIT6)
BIT6=0.0001*(16.67*HYCWI6+HYCLI6*16.67/2.72+HYCGI6*16.67/2.72)
CLALU1=RL1CLA*(1-EXP(-0.6931*((71.66/D50C1)**2)))
CLALU2=RL2CLA*(1-EXP(-0.6931*((71.66/D50C2)**2)))
CLALU3=RL3CLA*(1-EXP(-0.6931*((71.66/D50C3)**2)))
CLALU4=RL4CLA*(1-EXP(-0.6931*((71.66/D50C4)**2)))
CLALU5=RL5CLA*(1-EXP(-0.6931*((71.66/D50C5)**2)))
CLALU6=RL6CLA*(1-EXP(-0.6931*((71.66/D50C6)**2)))
FLO1LU=CLALU1+SCTLU1
FLO2LU=CLALU2+SCTLU2
FLO3LU=CLALU3+SCTLU3
FLO4LU=CLALU4+SCTLU4
FLO5LU=CLALU5+SCTLU5
FLO6LU=CLALU6+SCTLU6
CLAGU1=RG1CLA*(1-EXP(-0.6931*((166./D50C1)**2)))
CLAGU2=RG2CLA*(1-EXP(-0.6931*((166./D50C2)**2)))
CLAGU3=RG3CLA*(1-EXP(-0.6931*((166./D50C3)**2)))
CLAGU4=RG4CLA*(1-EXP(-0.6931*((166./D50C4)**2)))
CLAGU5=RG5CLA*(1-EXP(-0.6931*((166./D50C5)**2)))
CLAGU6=RG6CLA*(1-EXP(-0.6931*((166./D50C6)**2)))
FLO1GU=CLAGU1+SCTGU1
FLO2GU=CLAGU2+SCTGU2
FLO3GU=CLAGU3+SCTGU3
FLO4GU=CLAGU4+SCTGU4
FLO5GU=CLAGU5+SCTGU5
FLO6GU=CLAGU6+SCTGU6
OVFL1W=HYCWI1-HYCWU1
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN SIMULATOR OPERATING IN STEADY STATE

(cont'd.)

```
OVFL3W=HYCWI3-HYCWU3
OVFL4W=HYCWI4-HYCWU4
OVFL5W=HYCWI5-HYCWU5
OVFL6W=HYCWI6-HYCWU6
OVFL1L=HYCLI1-FLO1LU
OVFL2L=HYCLI2-FLO2LU
OVFL3L=HYCLI3-FLO3LU
OVFL4L=HYCLI4-FLO4LU
OVFL5L=HYCLI5-FLO5LU
OVFL6L=HYCLI6-FLO6LU
OVFL1G=HYCGI1-FLO1GU
OVFL2G=HYCGI2-FLO2GU
OVFL3G=HYCGI3-FLO3GU
OVFL4G=HYCGI4-FLO4GU
OVFL5G=HYCGI5-FLO5GU
OVFL6G=HYCGI6-FLO6GU
CIRCLD=(FLO1LU+FLO1GU)+(FLO2LU+FLO2GU)+(FLO3LU+FLO3GU)+ZZ
ZZ=(FLO4LU+FLO4GU)+(FLO5LU+FLO5GU)+(FLO6LU+FLO6GU)
SUMPV=X5+X6+X7
HDTVOL=X8+X9+X10
PRODS=(OVFL3L+OVFL4L+OVFL5L+OVFL6L)/SSSS
SSSS=(OVFL3L+OVFL4L+OVFL5L+OVFL6L+EE)
EE=OVFL3G+OVFL4G+OVFL5G+OVFL6G
X1A=INTGRL(X1AI,C1A)
C1A=(HYCWU1-PEBW10)
X1B=INTGRL(X1BI,C1B)
C1B=(HYCWU2-PEBW20)
X1C=INTGRL(X1CI,C1C)
C1C=(HYCWU3-PEBW30)
X1D=INTGRL(X1DI,C1D)
C1D=(HYCWU4-PEBW40)
X1E=INTGRL(X1EI,C1E)
C1E=(HYCWU5-PEBW50)
X1F=INTGRL(X1FI,C1F)
C1F=(HYCWU6-PEBW60)
UNFL1S=(FLO1LU)/(FLO1LU+FLO1GU)
UNFL3S=(FLO3LU)/(FLO3LU+FLO3GU)
AA=FLO1LU+FLO1GU+PEBFD1
AB=FLO2LU+FLO2GU+PEBFD2
AC=FLO3LU+FLO3GU+PEBFD3
AD=FLO4LU+FLO4GU+PEBFD4
AE=FLO5LU+FLO5GU+PEBFD5
AF=FLO6LU+FLO6GU+PEBFD6
BA=FLO1LU/AA
BB=FLO2LU/AB
BC=FLO3LU/AC
BD=FLO4LU/AD
BE=FLO5LU/AE
BF=FLO6LU/AF
X2A=INTGRL(X2AI,C2A)
C2A=AA-10.99*X2A*((X1A+X2A/2.72)**0.5)
X2B=INTGRL(X2BI,C2B)
C2B=AB-10.99*X2B*((X1B+X2B/2.72)**0.5)
X2C=INTGRL(X2CI,C2C)
C2C=AC-10.99*X2C*((X1C+X2C/2.72)**0.5)
X2D=INTGRL(X2DI,C2D)
C2D=AD-10.99*X2D*((X1D+X2D/2.72)**0.5)
X2E=INTGRL(X2EI,C2E)
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN SIMULATOR OPERATING IN STEADY STATE

(cont'd.)

```
[illegible]
X2F=INTGRL(X2FI,C2F)
C2F=AF-10.90*X2F*((X1F+X2F/2.72)**0.5)
X3A=INTGRL(X3AI,C3A)
C3A=(AA*(BA-X3A)/X2A+(1-X3A)*2.650)
X3B=INTGRL(X3BI,C3B)
C3B=(AB*(BB-X3B)/X2B+(1-X3B)*2.650)
X3C=INTGRL(X3CI,C3C)
C3C=(AC*(BC-X3C)/X2C+(1-X3C)*2.650)
X3D=INTGRL(X3DI,C3D)
C3D=(AD*(BD-X3D)/X2D+(1-X3D)*2.650)
X3E=INTGRL(X3EI,C3E)
C3E=(AE*(BE-X3E)/X2E+(1-X3E)*2.650)
X3F=INTGRL(X3FI,C3F)
C3F=(AF*(BF-X3F)/X2F+(1-X3F)*2.650)
X4=INTGRL(X4I,C4)
C4=RODFI*(0.03-X4)/6.03+(1-X4)*2.4668
X5=INTGRL(X5I,C5)
C5=RODWO+PEBW10+PEBW20+PEBW3C+PEBW40+PEBW50+PEBW60+R
R=172.+1700*((15.-SUMPV)+200*X11)-SUMFWO
SMPWAD=172.+1700*((15.-SUMPV)+200*X11)
X6=INTGRL(X6I,C6)
C6=PEB1LO+PEB2LO+PEB3LO+PEB4LC+PEB5LO+PEB6LO+RR
RR=RODLO-SUMPLO
X7=INTGRL(X7I,C7)
C7=PEB1GO+PEB2GO+PEB3GO+PEB4GO+PEB5GO+PEB6GO+TT
               TT=RODGO-SUMPGO
               X8=INTGRL(X8I,C8)
               C8=SUMFWO-HDTWC+WADDHT
               X9=INTGRL(X9I,C9)
               C9=SUMPLO-HDTLO
               X10=INTGRL(X10I,C10)
               C10=SUMPGO-HDTGO
               X11=INTGRL(X11I,C11)
               C11=(15.-SUMPV)
               TIMER FINTIM=1.0,OUTDEL=0.02
PRTPLT X1C(X2C,X3C,X4)
PRTPLT X5(X6,X7,X8)
PRTPLT X9(X10,HYCWU3,HYCWI3)
               PRTPLT PRODS(CIRCLD,SGRAVH,SUMPV)
PRTPLT PEBW30(PEB3LO,PEB3GO,HDTWO)
PRTPLT HDTLO(HDTGO,RODWO,RODGO)
PRTPLT HDTVOL(SUMPWO,SUMPLO,SUMPGC)
PRTPLT FLO3LU(FLO3GU,HYCLI3,HYCGI3)
PRTPLT SGRODO(SGHYCU,SGHYCI,SGPEB3)
PRTPLT SMPWAD(UNFL3S,SGOVF3,WADDHT)
               END
               STOP
ENDJOB
/*
```

Listing 3

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

```
//HTHOER JOE C07,CLASS=A                                    AECDEFGH
/*JOBPARM  R=87,L=9999
// EXEC CSMP360,TIME.GO=7
//GO.SYSIN DD *
             PARAMETER  MSIZE=40
PARAMETER MNOM=20.W=2.72
PARAMETER GRAD=340.
             INCON X1I=6.8183.X2I=14.564.X3I=0.1639
             INCON X4I=0.1999.X5I=2.8522.X6I=0.1936
             INCON X7I=0.9541.X8I=2.8143.X9I=0.1701
             INCON X10I=0.8386.X11I=0.0.S=0.99.TIMPLU=0.0
             INCON MSTI=20.1,ICFOWD=0.009.YESNO=1.
INCON MST2=20.05
INCON MST3=20
INCON MST4=20.MST5=20
             X1=INTGRL(X1I.C1)
             C1=109-X1*4.582*((X1+X2/2.72)**0.5)
             X2=INTGRL(X2I.C2)
             C2=A-4.582*X2*((X1+X2/2.72)**0.5)
A=P+(ZI14*ZI17)+(ZI15*ZI17)+ZI19*(1-EXP(-0.6931*((8.66/ZI24)**2)))+R
             R=ZI21*(1-EXP(-0.6931*((166/ZI24)**2)))
             ZI14=ZI11*2.72/2
             ZI11=(266*()8+X9+X10)/3.398+446.36)*X9/(X8+X9+X10)
             ZI17=ZI16/ZI13
             ZI16=105
             ZI13=ZI10/2
             ZI10=(266.6*(X8+X9+X10)/3.358+446.36)*X8/(X8+X9+X10)
             ZI19=ZI14-ZI14*ZI17
             ZI24=10**(1*ZI22-0.0005*ZI23+1.6624)
             ZI23=ZI13+(ZI14+ZI15)/2.72
             ZI15=ZI12*2.72/2
             ZI12=(266.6*(X8+X9+X10)/3.358+446.36)*X10/(X8+X9+X10)
             ZI22=(ZI14+ZI15)/(ZI13+ZI14+ZI15)
             ZI21=ZI15-ZI15*ZI17
             B=ZI26/A
             ZI26=ZI18+ZI25
             ZI18=ZI14*ZI17
             ZI25=ZI19*(1-EXP(-0.6931*((8.66/ZI24)**2)))
             X3=INTGRL(X3I.C3)
             C3=(A*(E-X3)/X2+(1-X3)*1.65)*S
             X4=INTGRL(X4I.C4)
             C4=(70.0*(0.03-X4)/6.03+(1-X4)*2.4668)
             X5=INTGRL(X5I.C5)
C5=( 2*4.582*X1*((X1+X2/2.72)**0.5)+0.3*70.0-(X5/(X5+X6+X7))*686.3)+D
             D=250.3676+500*((4-X5-X6-X7)+(20*X11))
             X6=INTGRL(X6I.C6)
             C6=2*4.582*X3*X2*((X1+X2/2.72)**0.5)/2.72+(70./2.72)*X4-C
             C=(X6/(X5+X6+X7))*686.3
             X7=INTGRL(X7I.C7)
C7=2*4.582*(1-X3)*X2*((X1+X2/2.72)**0.5)/2.72+(70.0/2.72)*(1-X4)-QS
             QS=(X7/(X5+X6+X7))*686.3
             X8=INTGRL(X8I.C8)
             C8=    (X5/(X5+X6+X7))*686.3-ZI10+60
             X9=INTGRL(X9I.C9)
```

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

(cont/d.)

```
      C10=(X7/(X5+X6+X7))*686.3-ZI12
      X11=INTGRL(X11I,C11)
      C11=(4-X5-X6-X7)
      CLOAD=(ZI29+ZI27+ZI18+ZI25)*2
      ZI20=ZI15*ZI17
      PRODS=ZI30/(ZI30+ZI31)
      ZI30=ZI14-ZI26
      ZI31=ZI15-ZI28
      ZI28=ZI20+ZI27
      ZI27=ZI21*(1-EXP(-0.6931*((166/ZI24)**2)))
      U=X5+X6+X7
      HDTVOL=X8+X9+X10
MMAS1=INTGRL(MST1,MMCH1)
BULD1=W/1.4+(X1+X2)*W/(MMAS1*1.4*5)
SMFL1=MMAS1/MSIZE
MPWR1=150*BULD1*((SIN(3.1415*SMFL1))**3.0)
MFED1=14*YFSND
MLOS1=7./5.
MOUT1=GRAD*FCN1*(SMFL1-SMFL2)
FCN1=FCNSW(SMFC1,ZERO,ZERO,ONE)
SMFC1=SMFL1-SMFL2
MMCH1=MFED1-MLOS1-MOUT1
S1=1-ABS((MNOM-MMAS1)/MNOM)
MMASS2=INTGRL(MST2,MMCH2)
BULDN2=W/1.4+(X1+X2)*W/(MMASS2*1.4*5)
SMFL2=MMASS2/MSIZE
MPOWR2=150*BULDN2*((SIN(3.1415*SMFL2))**3.0)
MFEED2=MOUT1
MLOSS2=7./5.
MOUT2=GRAD*FCN2*(SMFL2-SMFL3)
FCN2=FCNSW(SMFC2,ZERO,ZERO,ONE)
SMFC2=SMFL2-SMFL3
MMCH2=MFEED2-MLOSS2-MOUT2
S2=1-ABS((MNOM-MMASS2)/MNOM)
MMASS3=INTGRL(MST3,MMCH3)
MMASS4=INTGRL(MST4,MMCH4)
MMASS5=INTGRL(MST5,MMCH5)
BULDN3=W/1.4+(X1+X2)*W/(MMASS3*1.4*5)
BULDN4=W/1.4+(X1+X2)*W/(MMASS4*1.4*5)
BULDN5=W/1.4+(X1+X2)*W/(MMASS5*1.4*5)
SMFL3=MMASS3/MSIZE
SMFL4=MMASS4/MSIZE
SMFL5=MMASS5/MSIZE
MPOWR3=150*BULDN3*((SIN(3.1415*SMFL3))**3.0)
MPOWR4=150*BULDN4*((SIN(3.1415*SMFL4))**3.0)
MPOWR5=150*BULDN5*((SIN(3.1415*SMFL5))**3.0)
MOUT5=0
MFEED3=MOUT2
MOUT3=GRAD*FCN3*(SMFL3-SMFL4)
MFEED4=MOUT3
MFEED5=MOUT4
MLOSS3=7./5.
MLOSS4=7./5.
MLOSS5=7./5.
MMCH3=MFEED3-MLOSS3-MOUT3
MMCH4=MFEED4-MLOSS4-MOUT4
MMCH5=MFEED5-MLOSS5-MOUT5
```

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

(cont'd).

```
ZERO=0.0
ONE=1.0
SMFC3=SMFL3-SMFL4
SMFC4=SMFL4-SMFL5
S3=1-ABS((MNOM-MMASS3)/MNOM)
S4=1-ABS((MNOM-MMASS4)/MNOM)
S5=1-ABS((MNOM-MMASS5)/MNOM)
S=(S1+S2+S3+S4+S5)/5
MLOSS=MLOS1+MLOSS2+MLOSS3+MLOSS4+MLOSS5
MLSS=MLOSS9+MLOS10
P=MLOSS
MPOWER=MPOWR2+MPOWR3+MPOWR4+MPOWR5+MPWR1
        POWD=DERIV(ICPOWD,MPOWER)
        PMAX=ZHCLD(POWD,MPOWER)
NOSORT
        IF(POWD.LT.0.0)GO TO 2
        Q=1.0
        GO TO 5
2      CONTINUE
        Q=MPOWER/PMAX
5       PDROP=1.0-Q
IF(TIME.LT.TIMPLU)GO TO 9
        IF(PDROP.GT.0.005)GO TO 1
        9 YESNO=YFSNO
        GO TO 4
1 TIM=TIME
TIMPLU=TIM+0.9
        IF(YFSNO.LT.1.1.AND.YESNO.GT.0.9)GO TO 3
        YESNO=1.0
        GO TO 4
3       YESNO=0.0
4       CONTINUE
        SORT
        TIMER FINTIM=10.0,OUTDEL=0.02
PRTPLT  MPOWER(SMFL1,YESNO,PMAX)
PRTPLT  MMAS1(MMASS2,MMASS3,MMASS4),
PRTPLT  PRODS(CLOAD)
PRTPLT  MFEED2(MFED1,MFEED3,MFEED4)
        END
        STOP
ENDJOB
```

Listing 4

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

```
HTH        ACCT 7 D DEPT OF ELEC ENG                         FILE   BUFDG1                 MON 18/7/77 (77-19
****************************************************************************************************************
//HTHENG JOB CC7,CLASS=A                                                        CHANGE
/*JOBPARM  FORMS=9999,L=9999
// EXEC CSMP360,TIME.GO=7
//GO.SYSIN DD *
INCON NOISE=0.0
PARAMETER BETA=0.1
PARAMETER ALPHA=0.0025
INCON X1AI=2.0543
INCON X1BI=2.0543,X1CI=2.0543
INCON X1DI=2.0543,X1EI=2.0543,X1FI=2.0543
INCON X2AI=7.1199,X2BI=7.1199
INCON X2CI=7.1199,X2DI=7.1199
INCON X2EI=7.1199,X2FI=7.1199
INCON X3AI=0.20881,X3BI=0.20881
INCON X3CI=0.20881,X3DI=0.20881
INCON X3EI=0.20881,X3FI=0.20881
INCON X4I=0.1556
INCON X5I=10.646
INCON X6I=0.6475
INCON X7I=3.2063
INCON X8I=10.643
INCON X9I=0.76721
INCON X10I=2.9921
INCON X11I=0
INCON S1=0.99,S2=0.99,S3=0.99
INCON S4=0.99,S5=0.99,S6=0.99
INCON TIMPL1=0.0,TIMPL2=0.0,TIMPL3=0.0
INCON TIMPL4=0.0,TIMPL5=0.0,TIMPL6=0.0
INCON MST1=99.,MST2=99.,MST3=99.,MST4=99.
INCON MST5=99.,MST6=99.
INCON ICPOWD=0.009
INCON YFSNO3=0.0
INCON YFSNO2=0.0
INCON YFSNO1=0.0
INCON YFSNO4=0.0,YFSNO5=0.0,YFSNO6=0.0
PARAMETER MNOM=190.0
PARAMETER W=2.72
PARAMETER RODFI=100.
PARAMETER PUMPCA=1480.
NOSORT
R1=GAUSS(1.0,0.5)
NOISE=NOISE-BETA*NOISE*DELT+R1*(ALPHA*DELT)**0.5
SORT
HYCWU=48.8.
PARAMETER WADCHT=112.
PARAMETER MSIZE=200.0
PARAMETER G1=6,G2=6,G3=6,G4=6,G5=6,G6=6
MPWER1=150.*BULD1*((SIN(3.1415*(MMAS1/MSIZE)))**3.0)
MPWER2=150.*BULD2*((SIN(3.1415*(MMAS2/MSIZE)))**3.0)
MPWER3=150.*BULD3*((SIN(3.1415*(MMAS3/MSIZE)))**3.0)
MPWER4=150.*BULD4*((SIN(3.1415*(MMAS4/MSIZE)))**3.0)
MPWER5=150.*BULD5*((SIN(3.1415*(MMAS5/MSIZE)))**3.0)
MPWER6=150.*BULD6*((SIN(3.1415*(MMAS6/MSIZE)))**3.0)
BULD1=W/1.4+(X1A+X2A)*W/(MMAS1*1.4)
```

Listing 4

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

```
RULO5=W/1.4+(X1E+X2E)*W/(MMAS5*1.4)
RULO6=W/1.4+(X1F+X2F)*W/(MMAS6*1.4)
MMAS1=INTGRL(NST1,MMCH1)
MMAS2=INTGRL(NST2,MMCH2)
MMAS3=INTGRL(NST3,MMCH3)
MMAS4=INTGRL(NST4,MMCH4)
MMAS5=INTGRL(NST5,MMCH5)
MMAS6=INTGRL(NST6,MMCH6)
MMCH1=YESNO1-MLOS1
MMCH2=YESNO2-MLOS2
MMCH3=YESNO3-MLOS3
MMCH4=YESNO4-MLOS4
MMCH5=YESNO5-MLOS5
MMCH6=YESNO6-MLOS6
MLOS1=(9.)*((MNOM/MMAS1)**0.71)
MLOS2=(9.)*((MNOM/MMAS2)**0.71)
MLOS3=(9.)*((MNOM/MMAS3)**0.71)
MLOS4=(9.)*((MNOM/MMAS4)**0.71)
MLOS5=(9.)*((MNOM/MMAS5)**0.71)
MLOS6=(9.)*((MNOM/MMAS6)**0.71)
S1=1-ABS((MNOM-MMAS1)/MNOM)
S2=1-ABS((MNOM-MMAS2)/MNOM)
S3=1-ABS((MNOM-MMAS3)/MNOM)
S4=1-ABS((MNOM-MMAS4)/MNOM)
S5=1-ABS((MNOM-MMAS5)/MNOM)
S6=1-ABS((MNOM-MMAS6)/MNOM)
POWD1=DERIV(ICPOWD,MPWER1)
PMAX1=ZHOLD(POWD1,MPWER1)
POWD2=DERIV(ICPOWD,MPWER2)
PMAX2=ZHOLD(POWD2,MPWER2)
POWD3=DERIV(ICPOWD,MPWER3)
PMAX3=ZHOLD(POWD3,MPWER3)
POWD4=DERIV(ICPOWD,MPWER4)
PMAX4=ZHOLD(POWD4,MPWER4)
POWD5=DERIV(ICPOWD,MPWER5)
PMAX5=ZHOLD(POWD5,MPWER5)
POWD6=DERIV(ICPOWD,MPWER6)
PMAX6=ZHOLD(POWD6,MPWER6)
RODWO=0.25*RODFI
RODLO=((RODFI/2.72))*X4
RODGO=((RODFI/2.72))*(1-X4)
PEBW1O=10.99*X1A*((X1A+X2A/2.72)**0.5)
PEBW2O=10.99*X1B*((X1B+X2B/2.72)**0.5)
PEBW3O=10.99*X1C*((X1C+X2C/2.72)**0.5)
PEBW4O=10.99*X1D*((X1D+X2D/2.72)**0.5)
PEBW5O=10.99*X1E*((X1E+X2E/2.72)**0.5)
PEBW6O=10.99*X1F*((X1F+X2F/2.72)**0.5)
PEB1LO=10.99*X3A*X2A*((X1A+X2A/2.72)**0.5)/2.72
PEB2LO=10.99*X3B*X2B*((X1B+X2B/2.72)**0.5)/2.72
PEB3LO=10.99*X3C*X2C*((X1C+X2C/2.72)**0.5)/2.72
PEB4LO=10.99*X3D*X2D*((X1D+X2D/2.72)**0.5)/2.72
PEB5LO=10.99*X3E*X2E*((X1E+X2E/2.72)**0.5)/2.72
PEB6LO=10.99*X3F*X2F*((X1F+X2F/2.72)**0.5)/2.72
PEB1GO=10.99*(1-X3A)*X2A*((X1A+X2A/2.72)**0.5)/2.72
PEB2GO=10.99*(1-X3B)*X2B*((X1B+X2B/2.72)**0.5)/2.72
PEB3GO=10.99*(1-X3C)*X2C*((X1C+X2C/2.72)**0.5)/2.72
```

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

```
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
```

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

```
SLHYGI=HYCWI6+(HYCLI6+HYCGI6)/2.72
D50C1=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP1CYI-BIT1)
BIT1=0.0001*(16.67*HYCWI1+HYCLI1*16.67/2.72+HYCGI1*16.67/2.72)
D50C2=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP2CYI-BIT2)
BIT2=0.0001*(16.67*HYCWI2+HYCLI2*16.67/2.72+HYCGI2*16.67/2.72)
D50C3=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP3CYI-BIT3)
BIT3=0.0001*(16.67*HYCWI3+HYCLI3*16.67/2.72+HYCGI3*16.67/2.72)
D50C4=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP4CYI-BIT4)
BIT4=0.0001*(16.67*HYCWI4+HYCLI4*16.67/2.72+HYCGI4*16.67/2.72)
D50C5=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP5CYI-BIT5)
BIT5=0.0001*(16.67*HYCWI5+HYCLI5*16.67/2.72+HYCGI5*16.67/2.72)
D50C6=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP6CYI-BIT6)
BIT6=0.0001*(16.67*HYCWI6+HYCLI6*16.67/2.72+HYCGI6*16.67/2.72)
CLALU1=RL1CLA*(1-EXP(-0.6931*((71.66/D50C1)**2)))
CLALU2=RL2CLA*(1-EXP(-0.6931*((71.66/D50C2)**2)))
CLALU3=RL3CLA*(1-EXP(-0.6931*((71.66/D50C3)**2)))
CLALU4=RL4CLA*(1-EXP(-0.6931*((71.66/D50C4)**2)))
CLALU5=RL5CLA*(1-EXP(-0.6931*((71.66/D50C5)**2)))
CLALU6=RL6CLA*(1-EXP(-0.6931*((71.66/D50C6)**2)))
FL01LU=CLALU1+SCTLU1
FL02LU=CLALU2+SCTLU2
FL03LU=CLALU3+SCTLU3
FL04LU=CLALU4+SCTLU4
FL05LU=CLALU5+SCTLU5
FL06LU=CLALU6+SCTLU6
CLAGU1=RG1CLA*(1-EXP(-0.6931*((166/D50C1)**2)))
CLAGU2=RG2CLA*(1-EXP(-0.6931*((166/D50C2)**2)))
CLAGU3=RG3CLA*(1-EXP(-0.6931*((166/D50C3)**2)))
CLAGU4=RG4CLA*(1-EXP(-0.6931*((166/D50C4)**2)))
CLAGU5=RG5CLA*(1-EXP(-0.6931*((166/D50C5)**2)))
CLAGU6=RG6CLA*(1-EXP(-0.6931*((166/D50C6)**2)))
FL01GU=CLAGU1+MPWU1*HYCGI1
FL02GU=CLAGU2+MPWU2*HYCGI2
FL03GU=CLAGU3+MPWU3*HYCGI3
FL04GU=CLAGU4+MPWU4*HYCGI4
FL05GU=CLAGU5+MPWU5*HYCGI5
FL06GU=CLAGU6+MPWU6*HYCGI6
QVFL1W=HYCWI1-HYCWU
QVFL2W=HYCWI2-HYCWU
QVFL3W=HYCWI3-HYCWU
QVFL4W=HYCWI4-HYCWU
QVFL5W=HYCWI5-HYCWU
QVFL6W=HYCWI6-HYCWU
QVFL1L=HYCLI1-FL01LU
QVFL2L=HYCLI2-FL02LU
QVFL3L=HYCLI3-FL03LU
QVFL4L=HYCLI4-FL04LU
QVFL5L=HYCLI5-FL05LU
QVFL6L=HYCLI6-FL06LU
QVFL1G=HYCGI1-FL01GU
QVFL2G=HYCGI2-FL02GU
QVFL3G=HYCGI3-FL03GU
QVFL4G=HYCGI4-FL04GU
QVFL5G=HYCGI5-FL05GU
QVFL6G=HYCGI6-FL06GU
CIRCLD=(FL01LU+FL01GU)+(FL02LU+FL02GU)+(FL03LU+FL03GU)+ZZ
```

Listing 4

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

(cont'd.)

```
L.0234  HOTVOL=X8+X9+X10
L.0235  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-PEBW10)
L.0240  X1B=INTGRL(X1BI,C1B)
L.0241  C1B=(HYCWU-PEBW20)
L.0242  X1C=INTGRL(X1CI,C1C)
L.0243  C1C=(HYCWU-PEBW30)
L.0244  X1D=INTGRL(X1DI,C1D)
L.0245  C1D=(HYCWU-PEBW40)
L.0246  X1E=INTGRL(X1EI,C1E)
L.0247  C1E=(HYCWU-PEBW50)
L.0248  X1F=INTGRL(X1FI,C1F)
L.0249  C1F=(HYCWU-PEBW60)
L.0250  AA=FL01LU+FL01GU+MLOS1
L.0251  AB=FL02LU+FL02GU+MLOS2
L.0252  AC=FL03LU+FL03GU+MLOS3
L.0253  AD=FL04LU+FL04GU+MLOS4
L.0254  AE=FL05LU+FL05GU+MLOS5
L.0255  AF=FL06LU+FL06GU+MLOS6
L.0256  BA=FL01LU/AA
L.0257  BB=FL02LU/AB
L.0258  BC=FL03LU/AC
L.0259  BD=FL04LU/AD
L.0260  BE=FL05LU/AE
L.0261  BF=FL06LU/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(X5I,C5)
L.0289  C5=RODW0+PEBW10+PEBW20+PEBW30+PEBW40+PEBW50+PEBW60+R
L.0290  R=250.3676+1700*((15-SUMFV)+200*X11)-SUMPW0+0.0*NOISE
```

Listing 4

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

```
L.0293 [illegible]
L.0294 X7=INTGRL(X7I,C7)
L.0295 C7=PER1GO+PER2GO+PER3GO+PER4GO+PER5GO+PER6GO+TT
L.0296                 TT=RODGO-SUMPGO
L.0297                 X8=INTGRL(X8I,C8)
L.0298                 C8=SUMFWO-HDTWO+WAGDHT
L.0299                 X9=INTGRL(X9I,C9)
L.0300                 C9=SUMFLO-HDTLO
L.0301                 X10=INTGRL(X10I,C10)
L.0302                 C10=SUMPGO-HDTGO
L.0303                 X11=INTGRL(X11I,C11)
L.0304                 C11=(15-SUMPV)
L.0305 NOSORT
L.0306 IF(POWD1.LT.0.0)GO TO 21
L.0307 Q1=1.0
L.0308 GO TO 51
L.0309 21 CONTINUE
L.0310 Q1=MPWER1/PMAX1
L.0311 51 PDROP1=1.0-Q1
L.0312 IF(TIME.LT.TIMPL1)GO TO 91
L.0313 IF(PDROP1.GT.0.00125)GO TO 11
L.0314 91 YESNO1=YESNO1
L.0315 GO TO 41
L.0316 11 TIM1=TIME
L.0317 TIMPL1=TIM1+0.5
L.0318 IF(YESNO1.LT.18.9.AND.YESNO1.GT.17.1)GO TO 31
L.0319 YESNO1=18.0
L.0320 GO TO 41
L.0321 31 YESNO1=0.0
L.0322 41 CONTINUE
L.0323 IF(POWD2.LT.0.0)GO TO 2
L.0324 Q2=1.0
L.0325 GO TO 5
L.0326 2 CONTINUE
L.0327 Q2=MPWER2/PMAX2
L.0328 5 PDROP2=1.0-Q2
L.0329 IF(TIME.LT.TIMPL2)GO TO 9
L.0330 IF(PDROP2.GT.0.00125)GO TO 1
L.0331 9 YESNO2=YESNO2
L.0332 GO TO 4
L.0333 1 TIM2=TIME
L.0334 TIMPL2=TIM2+0.5
L.0335 IF(YESNO2.LT.18.9.AND.YESNO2.GT.17.1)GO TO 3
L.0336 YESNO2=18.0
L.0337 GO TO 4
L.0338 3 YESNO2=0.0
L.0339 4 CONTINUE
L.0340 IF(POWD3.LT.0.0)GO TO 23
L.0341 Q3=1.0
L.0342 GO TO 53
L.0343 23 CONTINUE
L.0344 Q3=MPWER3/PMAX3
L.0345 53 PDROP3=1.0-Q3
L.0346 IF(TIME.LT.TIMPL3)GO TO 93
L.0347 IF(PDROP3.GT.0.00125)GO TO 13
L.0348 93 YESNO3=YESNO3
L.0349 GO TO 43
```

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

```
L.0352 IF(YESNO3.LT.18.9.AND.YESNO3.GT.17.1)GO TO 33
L.0353 YESNO3=18.0
L.0354 GO TO 43
L.0355 33 YESNO3=0.0
L.0356 43 CONTINUE
L.0357 IF(POWD4.LT.0.0)GO TO 24
L.0358 Q4=4.0
L.0359 GO TO 54
L.0360 24 CONTINUE
L.0361 Q4=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 YESNO4=YESNO4
L.0366 GO TO 44
L.0367 14 TIM4=TIME
L.0368 TIMPL4=TIM4+0.5
L.0369 IF(YESNO4.LT.18.9.AND.YESNO4.GT.17.1)GO TO 34
L.0370 YESNO4=18.0
L.0371 GO TO 44
L.0372 34 YESNO4=0.0
L.0373 44 CONTINUE
L.0374 IF(POWD5.LT.0.0)GO TO 25
L.0375 Q5=1.0
L.0376 GO TO 55
L.0377 25 CONTINUE
L.0378 Q5=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 YESNO5=YESNO5
L.0383 GO TO 45
L.0384 15 TIM5=TIME
L.0385 TIMPL5=TIM5+0.5
L.0386 IF(YESNO5.LT.18.9.AND.YESNO5.GT.17.1)GO TO 35
L.0387 YESNO5=18.0
L.0388 GO TO 45
L.0389 35 YESNO5=0.0
L.0390 45 CONTINUE
L.0391 IF(POWD6.LT.0.0)GO TO 26
L.0392 Q6=1.0
L.0393 GO TO 56
L.0394 26 CONTINUE
L.0395 Q6=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 YESNO6=YESNO6
L.0400 GO TO 46
L.0401 16 TIM6=TIME
L.0402 TIMPL6=TIM6+0.5
L.0403 IF(YESNO6.LT.18.9.AND.YESNO6.GT.17.1)GO TO 36
L.0404 YESNO6=18.0
L.0405 GO TO 46
L.0406 36 YESNO6=0.0
L.0407 46 CONTINUE
L.0408 SORT
```

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

```
                PRTPLT PRODS(X1A,X2A,X3A)
                PRTPLT CIRCLD(X4,X5,X6)
                PRTPLT SUMPV(X7,X8,X9)
PRTPLT MPWER1(YESNG1,MPWER2,MPWER3)
PRTPLT MPWER4(X12)
PRTPLT S1(S2,S3,S4)
PRTPLT MPWER1(YESNC1,MMAS1,MMAS2)
PRTPLT NOISE
                END
                STOP
ENDJOB
/*
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN CIRCUIT INCORPORATING A 5 SUB-MILLS PEBBLE MILL POWER MODEL

```
**************************************************************************************************************
                                                                                    CHANGE
//HTHFRI JOB C07,CLASS=C
/*JOBPARM   FORMS=9999,L=9999
// EXEC CSMP360,TIME,GO=7
//GO.SYSIN DD *
PARAMETER GRAD=4000.
INCON X1AI=5.4249
INCON X1BI=5.4249,X1CI=5.4249
INCON X1DI=5.4249,X1EI=5.4249,X1FI=5.4249
INCON X2AI=10.005,X2BI=10.005
INCON X2CI=10.005,X2DI=10.005
INCON X2EI=10.005,X2FI=10.005
INCON X3AI=0.1727,X3BI=0.1727
INCON X3CI=0.1727,X3DI=0.1727
INCON X3EI=0.1727,X3FI=0.1727
INCON X4I=0.1556
INCON X5I=3.0583
INCON X6I=0.15582
INCON X7I=0.75589
INCON X8I=10.570
INCON X9I=0.5256
INCON X10I=2.5500
INCON X11I=0
INCON S1=0.99,S2=0.99,S3=0.99
INCON S4=0.99,S5=0.99,S6=0.99
INCON TIMPL1=0.0,TIMPL2=0.0,TIMPL3=0.0
INCON TIMPL4=0.0,TIMPL5=0.0,TIMPL6=0.0
INCON MSTA1=20.1,MSTB1=20.05,MSTC1=20.,MSTD1=20.,MSTE1=20.
INCON MSTA2=20.1,MSTB2=20.05,MSTC2=20.,MSTD2=20.,MSTE2=20.
INCON MSTA3=20.1,MSTB3=20.05,MSTC3=20.,MSTD3=20.,MSTE3=20.
INCON MSTA4=20.1,MSTB4=20.05,MSTC4=20.,MSTD4=20.,MSTE4=20.
INCON MSTA5=2C.1,MSTB5=20.05,MSTC5=20.,MSTD5=20.,MSTE5=20.
INCON MSTA6=20.1,MSTB6=20.05,MSTC6=20.,MSTD6=20.,MSTE6=20.
INCON ICPOWD=0.009
INCON YESNO3=0.0
INCON YESNO2=0.0
INCON YESNO1=0.0
INCON YESNO4=0.0,YESNO5=0.0,YESNO6=0.0
PARAMETER MNCW=20.0
PARAMETER W=2.72
PARAMETER RODFI=100.
PARAMETER PUMPCA=1480.
HYCWU=48.8
PARAMETER WADCHT=112.
PARAMETER MSIZE=40.0
PARAMETER G1=6,G2=6,G3=6,G4=6,G5=6,G6=6
MPWRA1=150.*BULDA1*((SIN(3.1415*(MMASA1/MSIZE)))**3.0)
MPWRB1=150.*BULDB1*((SIN(3.1415*(MMASB1/MSIZE)))**3.0)
MPWRC1=150.*BULDC1*((SIN(3.1415*(MMASC1/MSIZE)))**3.0)
MPWRD1=150.*BULDD1*((SIN(3.1415*(MMASD1/MSIZE)))**3.0)
MPWRE1=150.*BULDE1*((SIN(3.1415*(MMASE1/MSIZE)))**3.0)
MPWRA2=150.*BULDA2*((SIN(3.1415*(MMASA2/MSIZE)))**3.0)
MPWRB2=150.*BULDB2*((SIN(3.1415*(MMASB2/MSIZE)))**3.0)
MPWRC2=150.*BULDC2*((SIN(3.1415*(MMASC2/MSIZE)))**3.0)
MPWRD2=150.*BULDD2*((SIN(3.1415*(MMASD2/MSIZE)))**3.0)
```

Listing 5

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

```
L.0058 MPWRC3=150.*BULDC3*((SIN(3.1415*(MMASC3/MSIZE)))**3.0)
L.0059 MPWRD3=150.*BULDD3*((SIN(3.1415*(MMASD3/MSIZE)))**3.0)
L.0060 MPWRE3=150.*BULDE3*((SIN(3.1415*(MMASE3/MSIZE)))**3.0)
L.0061 MPWRA4=150.*BULDA4*((SIN(3.1415*(MMASA4/MSIZE)))**3.0)
L.0062 MPWRB4=150.*BULDB4*((SIN(3.1415*(MMASB4/MSIZE)))**3.0)
L.0063 MPWRC4=150.*BULDC4*((SIN(3.1415*(MMASC4/MSIZE)))**3.0)
L.0064 MPWRD4=150.*BULDD4*((SIN(3.1415*(MMASD4/MSIZE)))**3.0)
L.0065 MPWRE4=150.*BULDE4*((SIN(3.1415*(MMASE4/MSIZE)))**3.0)
L.0066 MPWRA5=150.*BULDA5*((SIN(3.1415*(MMASA5/MSIZE)))**3.0)
L.0067 MPWRB5=150.*BULDB5*((SIN(3.1415*(MMASB5/MSIZE)))**3.0)
L.0068 MPWRC5=150.*BULDC5*((SIN(3.1415*(MMASC5/MSIZE)))**3.0)
L.0069 MPWRD5=150.*BULDD5*((SIN(3.1415*(MMASD5/MSIZE)))**3.0)
L.0070 MPWRE5=150.*BULDE5*((SIN(3.1415*(MMASE5/MSIZE)))**3.0)
L.0071 MPWRA6=150.*BULDA6*((SIN(3.1415*(MMASA6/MSIZE)))**3.0)
L.0072 MPWRB6=150.*BULDB6*((SIN(3.1415*(MMASB6/MSIZE)))**3.0)
L.0073 MPWRC6=150.*BULDC6*((SIN(3.1415*(MMASC6/MSIZE)))**3.0)
L.0074 MPWRD6=150.*BULDD6*((SIN(3.1415*(MMASD6/MSIZE)))**3.0)
L.0075 MPWRE6=150.*BULDE6*((SIN(3.1415*(MMASE6/MSIZE)))**3.0)
L.0076 BULDA1=W/1.4+(X1A+X2A)*W/(MMASA1*1.4*5)
L.0077 BULDB1=W/1.4+(X1A+X2A)*W/(MMASB1*1.4*5)
L.0078 BULDC1=W/1.4+(X1A+X2A)*W/(MMASC1*1.4*5)
L.0079 BULDD1=W/1.4+(X1A+X2A)*W/(MMASD1*1.4*5)
L.0080 BULDE1=W/1.4+(X1A+X2A)*W/(MMASE1*1.4*5)
L.0081 BULDA2=W/1.4+(X1B+X2B)*W/(MMASA2*1.4*5)
L.0082 BULDB2=W/1.4+(X1B+X2B)*W/(MMASB2*1.4*5)
L.0083 BULDC2=W/1.4+(X1B+X2B)*W/(MMASC2*1.4*5)
L.0084 BULDD2=W/1.4+(X1B+X2B)*W/(MMASD2*1.4*5)
L.0085 BULDE2=W/1.4+(X1B+X2B)*W/(MMASE2*1.4*5)
L.0086 BULDA3=W/1.4+(X1C+X2C)*W/(MMASA3*1.4*5)
L.0087 BULDB3=W/1.4+(X1C+X2C)*W/(MMASB3*1.4*5)
L.0088 BULDC3=W/1.4+(X1C+X2C)*W/(MMASC3*1.4*5)
L.0089 BULDD3=W/1.4+(X1C+X2C)*W/(MMASD3*1.4*5)
L.0090 BULDE3=W/1.4+(X1C+X2C)*W/(MMASE3*1.4*5)
L.0091 BULDA4=W/1.4+(X1D+X2D)*W/(MMASA4*1.4*5)
L.0092 BULDB4=W/1.4+(X1D+X2D)*W/(MMASB4*1.4*5)
L.0093 BULDC4=W/1.4+(X1D+X2D)*W/(MMASC4*1.4*5)
L.0094 BULDD4=W/1.4+(X1D+X2D)*W/(MMASD4*1.4*5)
L.0095 BULDE4=W/1.4+(X1D+X2D)*W/(MMASE4*1.4*5)
L.0096 BULDA5=W/1.4+(X1E+X2E)*W/(MMASA5*1.4*5)
L.0097 BULDB5=W/1.4+(X1E+X2E)*W/(MMASB5*1.4*5)
L.0098 BULDC5=W/1.4+(X1E+X2E)*W/(MMASC5*1.4*5)
L.0099 BULDD5=W/1.4+(X1E+X2E)*W/(MMASD5*1.4*5)
L.0100 BULDE5=W/1.4+(X1E+X2E)*W/(MMASE5*1.4*5)
L.0101 BULDA6=W/1.4+(X1F+X2F)*W/(MMASA6*1.4*5)
L.0102 BULDB6=W/1.4+(X1F+X2F)*W/(MMASB6*1.4*5)
L.0103 BULDC6=W/1.4+(X1F+X2F)*W/(MMASC6*1.4*5)
L.0104 BULDD6=W/1.4+(X1F+X2F)*W/(MMASD6*1.4*5)
L.0105 BULDE6=W/1.4+(X1F+X2F)*W/(MMASE6*1.4*5)
L.0106 MMASA1=INTGRL(MSTA1,MMCHA1)
L.0107 MMASB1=INTGRL(MSTB1,MMCHB1)
L.0108 MMASC1=INTGRL(MSTC1,MMCHC1)
L.0109 MMASD1=INTGRL(MSTD1,MMCHD1)
L.0110 MMASE1=INTGRL(MSTE1,MMCHE1)
L.0111 MMASA2=INTGRL(MSTA2,MMCHA2)
L.0112 MMASB2=INTGRL(MSTB2,MMCHB2)
L.0113 MMASC2=INTGRL(MSTC2,MMCHC2)
```

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

```
L.0117 MMASB3=INTGRL(MSTB3,MMCHB3)
L.0118 MMASC3=INTGRL(MSTC3,MMCHC3)
L.0119 MMASD3=INTGRL(MSTD3,MMCHD3)
L.0120 MMASE3=INTGRL(MSTE3,MMCHE3)
L.0121 MMASA4=INTGRL(MSTA4,MMCHA4)
L.0122 MMASB4=INTGRL(MSTB4,MMCHB4)
L.0123 MMASC4=INTGRL(MSTC4,MMCHC4)
L.0124 MMASD4=INTGRL(MSTD4,MMCHD4)
L.0125 MMASE4=INTGRL(MSTE4,MMCHE4)
L.0126 MMASA5=INTGRL(MSTA5,MMCHA5)
L.0127 MMASB5=INTGRL(MSTB5,MMCHB5)
L.0128 MMASC5=INTGRL(MSTC5,MMCHC5)
L.0129 MMASD5=INTGRL(MSTD5,MMCHD5)
L.0130 MMASE5=INTGRL(MSTE5,MMCHE5)
L.0131 MMASA6=INTGRL(MSTA6,MMCHA6)
L.0132 MMASB6=INTGRL(MSTB6,MMCHB6)
L.0133 MMASC6=INTGRL(MSTC6,MMCHC6)
L.0134 MMASD6=INTGRL(MSTD6,MMCHD6)
L.0135 MMASE6=INTGRL(MSTE6,MMCHE6)
L.0136 MOUTA1=GRAD*(MMASA1/MSIZE-MMASB1/MSIZE)
L.0137 MOUTB1=GRAD*(MMASB1/MSIZE-MMASC1/MSIZE)
L.0138 MOUTC1=GRAD*(MMASC1/MSIZE-MMASD1/MSIZE)
L.0139 MOUTD1=GRAD*(MMASD1/MSIZE-MMASE1/MSIZE)
L.0140 MOUTA2=GRAD*(MMASA2/MSIZE-MMASB2/MSIZE)
L.0141 MOUTB2=GRAD*(MMASB2/MSIZE-MMASC2/MSIZE)
L.0142 MOUTC2=GRAD*(MMASC2/MSIZE-MMASD2/MSIZE)
L.0143 MOUTD2=GRAD*(MMASD2/MSIZE-MMASE2/MSIZE)
L.0144 MOUTA3=GRAD*(MMASA3/MSIZE-MMASB3/MSIZE)
L.0145 MOUTB3=GRAD*(MMASB3/MSIZE-MMASC3/MSIZE)
L.0146 MOUTC3=GRAD*(MMASC3/MSIZE-MMASD3/MSIZE)
L.0147 MOUTD3=GRAD*(MMASD3/MSIZE-MMASE3/MSIZE)
L.0148 MOUTA4=GRAD*(MMASA4/MSIZE-MMASB4/MSIZE)
L.0149 MOUTB4=GRAD*(MMASB4/MSIZE-MMASC4/MSIZE)
L.0150 MOUTC4=GRAD*(MMASC4/MSIZE-MMASD4/MSIZE)
L.0151 MOUTD4=GRAD*(MMASD4/MSIZE-MMASE4/MSIZE)
L.0152 MOUTA5=GRAD*(MMASA5/MSIZE-MMASB5/MSIZE)
L.0153 MOUTB5=GRAD*(MMASB5/MSIZE-MMASC5/MSIZE)
L.0154 MOUTC5=GRAD*(MMASC5/MSIZE-MMASD5/MSIZE)
L.0155 MOUTD5=GRAD*(MMASD5/MSIZE-MMASE5/MSIZE)
L.0156 MOUTA6=GRAD*(MMASA6/MSIZE-MMASB6/MSIZE)
L.0157 MOUTB6=GRAD*(MMASB6/MSIZE-MMASC6/MSIZE)
L.0158 MOUTC6=GRAD*(MMASC6/MSIZE-MMASD6/MSIZE)
L.0159 MOUTD6=GRAD*(MMASD6/MSIZE-MMASE6/MSIZE)
L.0160 MMCHA1=YESNO1-MLOSA1-MOUTA1
L.0161 MMCHB1=MOUTA1-MLOSB1-MOUTB1
L.0162 MMCHC1=MOUTB1-MLOSC1-MOUTC1
L.0163 MMCHD1=MOUTC1-MLOSD1-MOUTD1
L.0164 MMCHE1=MOUTD1-MLOSE1-0.0
L.0165 MMCHA2=YESNO2-MLOSA2-MOUTA2
L.0166 MMCHB2=MOUTA2-MLOSB2-MOUTB2
L.0167 MMCHC2=MOUTB2-MLOSC2-MOUTC2
L.0168 MMCHD2=MOUTC2-MLOSD2-MOUTD2
L.0169 MMCHE2=MOUTD2-MLOSE2-0.0
L.0170 MMCHA3=YESNO3-MLOSA3-MOUTA3
L.0171 MMCHB3=MOUTA3-MLOSB3-MOUTB3
L.0172 MMCHC3=MOUTB3-MLOSC3-MOUTC3
```

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

```
L.0176  MMCHB4=MOUTA4-MLOSB4-MOUTB4
L.0177  MMCHC4=MOUTB4-MLOSC4-MOUTC4
L.0178  MMCHD4=MOUTC4-MLOSD4-MOUTD4
L.0179  MMCHE4=MOUTD4-MLOSE4-0.0
L.0180  MMCHA5=YESNO5-MLOSA5-MOUTA5
L.0181  MMCHB5=MOUTA5-MLOSB5-MOUTB5
L.0182  MMCHC5=MOUTB5-MLOSC5-MOUTC5
L.0183  MMCHD5=MOUTC5-MLOSD5-MOUTD5
L.0184  MMCHE5=MOUTD5-MLOSE5-0.0
L.0185  MMCHA6=YESNO6-MLOSA6-MOUTA6
L.0186  MMCHB6=MOUTA6-MLOSB6-MOUTB6
L.0187  MMCHC6=MOUTB6-MLOSC6-MOUTC6
L.0188  MMCHD6=MOUTC6-MLOSD6-MOUTD6
L.0189  MMCHE6=MOUTD6-MLOSE6-0.0
L.0190  MLOSA1=(9./5.)*((MNOM/MMASA1)**0.71)
L.0191  MLOSB1=(9./5.)*((MNOM/MMASB1)**0.71)
L.0192  MLOSC1=(9./5.)*((MNOM/MMASC1)**0.71)
L.0193  MLOSD1=(9./5.)*((MNOM/MMASD1)**0.71)
L.0194  MLOSE1=(9./5.)*((MNOM/MMASE1)**0.71)
L.0195  MLOSA2=(9./5.)*((MNOM/MMASA2)**0.71)
L.0196  MLOSB2=(9./5.)*((MNOM/MMASB2)**0.71)
L.0197  MLOSC2=(9./5.)*((MNOM/MMASC2)**0.71)
L.0198  MLOSD2=(9./5.)*((MNOM/MMASD2)**0.71)
L.0199  MLOSE2=(9./5.)*((MNOM/MMASE2)**0.71)
L.0200  MLOSA3=(9./5.)*((MNOM/MMASA3)**0.71)
L.0201  MLOSB3=(9./5.)*((MNOM/MMASB3)**0.71)
L.0202  MLOSC3=(9./5.)*((MNOM/MMASC3)**0.71)
L.0203  MLOSD3=(9./5.)*((MNOM/MMASD3)**0.71)
L.0204  MLOSE3=(9./5.)*((MNOM/MMASE3)**0.71)
L.0205  MLOSA4=(9./5.)*((MNOM/MMASA4)**0.71)
L.0206  MLOSB4=(9./5.)*((MNOM/MMASB4)**0.71)
L.0207  MLOSC4=(9./5.)*((MNOM/MMASC4)**0.71)
L.0208  MLOSD4=(9./5.)*((MNOM/MMASD4)**0.71)
L.0209  MLOSE4=(9./5.)*((MNOM/MMASE4)**0.71)
L.0210  MLOSA5=(9./5.)*((MNOM/MMASA5)**0.71)
L.0211  MLOSB5=(9./5.)*((MNOM/MMASB5)**0.71)
L.0212  MLOSC5=(9./5.)*((MNOM/MMASC5)**0.71)
L.0213  MLOSD5=(9./5.)*((MNOM/MMASD5)**0.71)
L.0214  MLOSE5=(9./5.)*((MNOM/MMASE5)**0.71)
L.0215  MLOSA6=(9./5.)*((MNOM/MMASA6)**0.71)
L.0216  MLOSB6=(9./5.)*((MNOM/MMASB6)**0.71)
L.0217  MLOSC6=(9./5.)*((MNOM/MMASC6)**0.71)
L.0218  MLOSD6=(9./5.)*((MNOM/MMASD6)**0.71)
L.0219  MLOSE6=(9./5.)*((MNOM/MMASE6)**0.71)
L.0220  MPWER1=MPWRA1+MPWRB1+MPWRC1+MPWRD1+MPWRE1
L.0221  MPWER2=MPWRA2+MPWRB2+MPWRC2+MPWRD2+MPWRE2
L.0222  MPWER3=MPWRA3+MPWRB3+MPWRC3+MPWRD3+MPWRE3
L.0223  MPWER4=MPWRA4+MPWRB4+MPWRC4+MPWRD4+MPWRE4
L.0224  MPWER5=MPWRA5+MPWRB5+MPWRC5+MPWRD5+MPWRE5
L.0225  MPWER6=MPWRA6+MPWRB6+MPWRC6+MPWRD6+MPWRE6
L.0226  SA1=1-ABS((MNOM-MMASA1)/MNOM)
L.0227  SB1=1-ABS((MNOM-MMASB1)/MNOM)
L.0228  SC1=1-ABS((MNOM-MMASC1)/MNOM)
L.0229  SD1=1-ABS((MNOM-MMASD1)/MNOM)
L.0230  SE1=1-ABS((MNOM-MMASE1)/MNOM)
L.0231  SA2=1-ABS((MNOM-MMASA2)/MNOM)
```

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

```
SD2=1-ABS((MNCM-MMASD2)/MNOM)
SF2=1-ABS((MNCM-MMASF2)/MNOM)
SA3=1-ABS((MNCM-MMASA3)/MNOM)
SB3=1-ABS((MNCM-MMASB3)/MNOM)
SC3=1-ABS((MNCM-MMASC3)/MNOM)
SD3=1-ABS((MNCM-MMASD3)/MNOM)
SF3=1-ABS((MNCM-MMASF3)/MNOM)
SA4=1-ABS((MNCM-MMASA4)/MNOM)
SB4=1-ABS((MNCM-MMASB4)/MNOM)
SC4=1-ABS((MNCM-MMASC4)/MNOM)
SD4=1-ABS((MNCM-MMASD4)/MNOM)
SF4=1-ABS((MNCM-MMASF4)/MNOM)
SA5=1-ABS((MNCM-MMASA5)/MNOM)
SB5=1-ABS((MNCM-MMASB5)/MNOM)
SC5=1-ABS((MNCM-MMASC5)/MNOM)
SD5=1-ABS((MNCM-MMASD5)/MNOM)
SF5=1-ABS((MNCM-MMASF5)/MNOM)
SA6=1-ABS((MNCM-MMASA6)/MNOM)
SB6=1-ABS((MNCM-MMASB6)/MNOM)
SC6=1-ABS((MNCM-MMASC6)/MNOM)
SD6=1-ABS((MNCM-MMASD6)/MNOM)
SF6=1-ABS((MNCM-MMASF6)/MNOM)
S1=(SA1+SB1+SC1+SD1+SF1)/5.
S2=(SA2+SB2+SC2+SD2+SF2)/5.
S3=(SA3+SB3+SC3+SD3+SF3)/5.
S4=(SA4+SB4+SC4+SD4+SF4)/5.
S5=(SA5+SB5+SC5+SD5+SF5)/5.
S6=(SA6+SB6+SC6+SD6+SF6)/5.
MLOS1=MLOSA1+MLOSB1+MLOSC1+MLOSD1+MLOSF1
MLOS2=MLOSA2+MLOSB2+MLOSC2+MLOSD2+MLOSF2
MLOS3=MLOSA3+MLOSB3+MLOSC3+MLOSD3+MLOSF3
MLOS4=MLOSA4+MLOSB4+MLOSC4+MLOSD4+MLOSF4
MLOS5=MLOSA5+MLOSB5+MLOSC5+MLOSD5+MLOSF5
MLOS6=MLOSA6+MLOSB6+MLOSC6+MLOSD6+MLOSF6
POWD1=DERIV(ICPOWD,MPWER1)
PMAX1=ZHOLD(POWD1,MPWER1)
POWD2=DERIV(ICPOWD,MPWER2)
PMAX2=ZHOLD(POWD2,MPWER2)
POWD3=DERIV(ICPOWD,MPWER3)
PMAX3=ZHOLD(POWD3,MPWER3)
POWD4=DERIV(ICPOWD,MPWER4)
PMAX4=ZHOLD(POWD4,MPWER4)
POWD5=DERIV(ICPOWD,MPWER5)
PMAX5=ZHOLD(POWD5,MPWER5)
POWD6=DERIV(ICPOWD,MPWER6)
PMAX6=ZHOLD(POWD6,MPWER6)
RODWO=0.25*RODFI
RODLO=((RODFI/2.72))*X4
RODGO=((RODFI/2.72))*(1-X4)
PEBW1O=10.99*X1A*((X1A+X2A/2.72)**0.5)
PEBW2O=10.99*X1B*((X1B+X2B/2.72)**0.5)
PEBW3O=10.99*X1C*((X1C+X2C/2.72)**0.5)
PEBW4O=10.99*X1D*((X1D+X2D/2.72)**0.5)
PEBW5O=10.99*X1E*((X1E+X2E/2.72)**0.5)
PEBW6O=10.99*X1F*((X1F+X2F/2.72)**0.5)
PEB1LO=10.99*X3A*X2A*((X1A+X2A/2.72)**0.5)/2.72
PEB2LO=10.99*X3B*X2B*((X1B+X2B/2.72)**0.5)/2.72
```

COMPUTER PROGRAM LISTING FOR THE BUFFELSFONTEIN CIRCUIT INCORPORATING A 5 SUB-MILLS PEBBLE MILL POWER MODEL

(cont'd.)


```
[illegible]
PEB6LO=10.99*X3F*X2F*((X1F+X2F/2.72)**0.5)/2.72
PEB1GO=10.99*(1-X3A)*X2A*((X1A+X2A/2.72)**0.5)/2.72
PEB2GO=10.99*(1-X3B)*X2B*((X1B+X2B/2.72)**0.5)/2.72
PEB3GO=10.99*(1-X3C)*X2C*((X1C+X2C/2.72)**0.5)/2.72
PEB4GO=10.99*(1-X3D)*X2D*((X1D+X2D/2.72)**0.5)/2.72
PEB5GO=10.99*(1-X3E)*X2E*((X1E+X2E/2.72)**0.5)/2.72
PEB6GO=10.99*(1-X3F)*X2F*((X1F+X2F/2.72)**0.5)/2.72
SUMPWO=(X5/(X5+X6+X7))*PUMPCA
SUMPLO=(X6/(X5+X6+X7))*PUMPCA
SUMPGO=(X7/(X5+X6+X7))*PUMPCA
HDTWO=(266.6*(X8+X9+X10)/3.398+446.36)*X8/(X8+X9+X10)
HDTLO=(266.6*(X8+X9+X10)/3.398+446.36)*X9/(X8+X9+X10)
HDTGO=(266.6*(X8+X9+X10)/3.398+446.36)*X10/(X8+X9+X10)
HYCWI1=HDTWO/G1
HYCWI2=HDTWO/G2
HYCWI3=HDTWO/G3
HYCWI4=HDTWO/G4
HYCWI5=HDTWO/G5
HYCWI6=HDTWO/G6
HYCLI1=HDTLO*2.72/G1
HYCLI2=HDTLO*2.72/G2
HYCLI3=HDTLO*2.72/G3
HYCLI4=HDTLO*2.72/G4
HYCLI5=HDTLO*2.72/G5
HYCLI6=HDTLO*2.72/G6
HYCGI1=HDTGO*2.72/G1
HYCGI2=HDTGO*2.72/G2
HYCGI3=HDTGO*2.72/G3
HYCGI4=HDTGO*2.72/G4
HYCGI5=HDTGO*2.72/G5
HYCGI6=HDTGO*2.72/G6
MPWU1=HYCWU/HYCWI1
MPWU2=HYCWU/HYCWI2
MPWU3=HYCWU/HYCWI3
MPWU4=HYCWU/HYCWI4
MPWU5=HYCWU/HYCWI5
MPWU6=HYCWU/HYCWI6
SCTLU1=MPWU1*HYCLI1
SCTLU2=MPWU2*HYCLI2
SCTLU3=MPWU3*HYCLI3
SCTLU4=MPWU4*HYCLI4
SCTLU5=MPWU5*HYCLI5
SCTLU6=MPWU6*HYCLI6
RL1CLA=HYCLI1-SCTLU1
RL2CLA=HYCLI2-SCTLU2
RL3CLA=HYCLI3-SCTLU3
RL4CLA=HYCLI4-SCTLU4
RL5CLA=HYCLI5-SCTLU5
RL6CLA=HYCLI6-SCTLU6
RG1CLA=HYCGI1-MPWU1*HYCGI1
RG2CLA=HYCGI2-MPWU2*HYCGI2
RG3CLA=HYCGI3-MPWU3*HYCGI3
RG4CLA=HYCGI4-MPWU4*HYCGI4
RG5CLA=HYCGI5-MPWU5*HYCGI5
RG6CLA=HYCGI6-MPWU6*HYCGI6
SPICYI=(HYCLI1+HYCGI1)/(HYCLI1+HYCGI1+HYCWI1)
```

Listing 5

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

```
SP5CYI=(HYCLI5+HYCGI5)/(HYCLI5+HYCGI5+HYCWI5)
SP6CYI=(HYCLI6+HYCGI6)/(HYCLI6+HYCGI6+HYCWI6)
SLHY1I=HYCWI1+(HYCLI1+HYCGI1)/2.72
SLHY2I=HYCWI2+(HYCLI2+HYCGI2)/2.72
SLHY3I=HYCWI3+(HYCLI3+HYCGI3)/2.72
SLHY4I=HYCWI4+(HYCLI4+HYCGI4)/2.72
SLHY5I=HYCWI5+(HYCLI5+HYCGI5)/2.72
SLHY6I=HYCWI6+(HYCLI6+HYCGI6)/2.72
D50C1=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP1CYI-BIT1)
BIT1=0.0001*(16.67*HYCWI1+HYCLI1*16.67/2.72+HYCGI1*16.67/2.72)
D50C2=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP2CYI-BIT2)
BIT2=0.0001*(16.67*HYCWI2+HYCLI2*16.67/2.72+HYCGI2*16.67/2.72)
D50C3=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP3CYI-BIT3)
BIT3=0.0001*(16.67*HYCWI3+HYCLI3*16.67/2.72+HYCGI3*16.67/2.72)
D50C4=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP4CYI-BIT4)
BIT4=0.0001*(16.67*HYCWI4+HYCLI4*16.67/2.72+HYCGI4*16.67/2.72)
D50C5=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP5CYI-BIT5)
BIT5=0.0001*(16.67*HYCWI5+HYCLI5*16.67/2.72+HYCGI5*16.67/2.72)
D50C6=10**(0.04*20.32-0.0576*10.16+0.0366*19.+0.0299*100*SP6CYI-BIT6)
BIT6=0.0001*(16.67*HYCWI6+HYCLI6*16.67/2.72+HYCGI6*16.67/2.72)
CLALU1=RL1CLA*(1-EXP(-0.6931*((71.66/D50C1)**2)))
CLALU2=RL2CLA*(1-EXP(-0.6931*((71.66/D50C2)**2)))
CLALU3=RL3CLA*(1-EXP(-0.6931*((71.66/D50C3)**2)))
CLALU4=RL4CLA*(1-EXP(-0.6931*((71.66/D50C4)**2)))
CLALU5=RL5CLA*(1-EXP(-0.6931*((71.66/D50C5)**2)))
CLALU6=RL6CLA*(1-EXP(-0.6931*((71.66/D50C6)**2)))
FLO1LU=CLALU1+SCTLU1
FLO2LU=CLALU2+SCTLU2
FLO3LU=CLALU3+SCTLU3
FLO4LU=CLALU4+SCTLU4
FLO5LU=CLALU5+SCTLU5
FLO6LU=CLALU6+SCTLU6
CLAGU1=RG1CLA*(1-EXP(-0.6931*((166/D50C1)**2)))
CLAGU2=RG2CLA*(1-EXP(-0.6931*((166/D50C2)**2)))
CLAGU3=RG3CLA*(1-EXP(-0.6931*((166/D50C3)**2)))
CLAGU4=RG4CLA*(1-EXP(-0.6931*((166/D50C4)**2)))
CLAGU5=RG5CLA*(1-EXP(-0.6931*((166/D50C5)**2)))
CLAGU6=RG6CLA*(1-EXP(-0.6931*((166/D50C6)**2)))
FLO1GU=CLAGU1+MP%U1*HYCGI1
FLO2GU=CLAGU2+MP%U2*HYCGI2
FLO3GU=CLAGU3+MP%U3*HYCGI3
FLO4GU=CLAGU4+MP%U4*HYCGI4
FLO5GU=CLAGU5+MP%U5*HYCGI5
FLO6GU=CLAGU6+MP%U6*HYCGI6
OVFL1W=HYCWI1-HYCWU
OVFL2W=HYCWI2-HYCWU
OVFL3W=HYCWI3-HYCWU
OVFL4W=HYCWI4-HYCWU
OVFL5W=HYCWI5-HYCWU
OVFL6W=HYCWI6-HYCWU
OVFL1L=HYCLI1-FLO1LU
OVFL2L=HYCLI2-FLO2LU
OVFL3L=HYCLI3-FLO3LU
OVFL4L=HYCLI4-FLO4LU
OVFL5L=HYCLI5-FLO5LU
OVFL6L=HYCLI6-FLO6LU
```

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

```
[illegible]
L.0413 OVFL5G=HYCGI5-FLO5GU
L.0414 OVFL6G=HYCGI6-FLO6GU
L.0415 CIRCLD=(FLO1LU+FLO1GU)+(FLO2LU+FLO2GU)+(FLO3LU+FLO3GU)+ZZ
L.0416 ZZ=(FLO4LU+FLO4GU)+(FLO5LU+FLO5GU)+(FLO6LU+FLO6GU)
L.0417 SUMPV=X5+X6+X7
L.0418 HOTVOL=X8+X9+X10
L.0419 PRODS=(OVFL1L+OVFL2L+OVFL3L+OVFL4L+OVFL5L+OVFL6L)/SSSS
L.0420 SSSS=(OVFL1L+OVFL2L+OVFL3L+OVFL4L+OVFL5L+OVFL6L+EE)
L.0421 EE=OVFL1G+OVFL2G+OVFL3G+OVFL4G+OVFL5G+OVFL6G
L.0422 X1A=INTGRL(X1AI,C1A)
L.0423 C1A=(HYCWU-PERW1C)
L.0424 X1B=INTGRL(X1BI,C1B)
L.0425 C1B=(HYCWU-PERW2C)
L.0426 X1C=INTGRL(X1CI,C1C)
L.0427 C1C=(HYCWU-PERW3C)
L.0428 X1D=INTGRL(X1DI,C1D)
L.0429 C1D=(HYCWU-PERW4C)
L.0430 X1E=INTGRL(X1EI,C1E)
L.0431 C1E=(HYCWU-PERW5C)
L.0432 X1F=INTGRL(X1FI,C1F)
L.0433 C1F=(HYCWU-PERW6C)
L.0434 AA=FLO1LU+FLO1GU+MLOS1
L.0435 AB=FLO2LU+FLO2GU+MLOS2
L.0436 AC=FLO3LU+FLO3GU+MLOS3
L.0437 AD=FLO4LU+FLO4GU+MLOS4
L.0438 AE=FLO5LU+FLO5GU+MLOS5
L.0439 AF=FLO6LU+FLO6GU+MLOS6
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
```

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

```
C4=RODFT*(0.07-X4)/0.07+(1-X4)*2.4658
X5=INTGRL(X5I,C5)
C5=RODWO+PEBW1O+PEBW2O+PEBW3O+PEBW4O+FEBW5O+PEBW6O+R
R=252.3676+1700*((15-SUMPV)+200*X11)-SUMPWO
X6=INTGRL(X6I,C6)
C6=PEB1LO+PEB2LO+PEB3LO+PEB4LO+PEB5LO+PEB6LO+RR
RR=RODLO-SUMPLO
X7=INTGPL(X7I,C7)
C7=PEB1GO+PEB2GO+PEB3GO+PEB4GO+PEB5GO+PEB6GO+TT
              TT=RODGO-SUMPGO
              X8=INTGRL(X8I,C8)
              C8=SUMFWO-HDTWO+WADDHT
              X9=INTGPL(X9I,C9)
              C9=SUMFLO-HDTLO
              X10=INTGPL(X10I,C10)
              C10=SUMPGO-HDTGO
              X11=INTGRL(X11I,C11)
              C11=(15-SUMPV)
NOSORT
IF(POWD1.LT.0.0)GO TO 21
Q1=1.0
GO TO 51
21 CONTINUE
Q1=MPWER1/PMAX1
51 PDROP1=1.0-Q1
IF(TIME.LT.TIMPL1)GO TO 91
IF(PDROP1.GT.0.00125)GO TO 11
91 YESNO1=YESNO1
GO TO 41
11 TIM1=TIME
TIMPL1=TIM1+0.5
IF(YESNO1.LT.18.9.AND.YESNO1.GT.17.1)GO TO 31
YESNO1=18.0
GO TO 41
31 YESNO1=0.0
41 CONTINUE
IF(POWD2.LT.0.0)GO TO 2
Q2=1.0
GO TO 5
2 CONTINUE
Q2=MPWER2/PMAX2
5 PDROP2=1.0-Q2
IF(TIME.LT.TIMPL2)GO TO 9
IF(PDROP2.GT.0.00125)GO TO 1
9 YESNO2=YESNO2
GO TO 4
1 TIM2=TIME
TIMPL2=TIM2+0.5
IF(YESNO2.LT.18.9.AND.YESNO2.GT.17.1)GO TO 3
YESNO2=18.0
GO TO 4
3 YESNO2=0.0
4 CONTINUE
IF(POWD3.LT.0.0)GO TO 23
Q3=1.0
GO TO 53
```

Listing 5

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

```
      PDROP3=1.0-03
      IF(TIME.LT.TIMPL3)GO TO 93
      IF(PDROP3.GT.0.00125)GO TO 13
   93 YESNO3=YESNO3
      GO TO 43
   13 TIM3=TIME
      TIMPL3=TIM3+0.5
      IF(YESNO3.LT.18.9.AND.YESNO3.GT.17.1)GO TO 33
      YESNO3=18.0
      GO TO 43
   33 YESNO3=0.0
   43 CONTINUE
      IF(POWD4.LT.0.0)GO TO 24
      Q4=4.0
      GO TO 54
   24 CONTINUE
      Q4=MPWER4/PMAX4
   54 PDROP4=1.0-Q4
      IF(TIME.LT.TIMPL4)GO TO 94
      IF(PDROP4.GT.0.00125)GO TO 14
   94 YESNO4=YESNO4
      GO TO 44
   14 TIM4=TIME
      TIMPL4=TIM4+0.5
      IF(YESNO4.LT.18.9.AND.YESNO4.GT.17.1)GO TO 34
      YESNO4=18.0
      GO TO 44
   34 YESNO4=0.0
   44 CONTINUE
      IF(POWD5.LT.0.0)GO TO 25
      Q5=1.0
      GO TO 55
   25 CONTINUE
      Q5=MPWER5/PMAX5
   55 PDROP5=1.0-Q5
      IF(TIME.LT.TIMPL5)GO TO 95
      IF(PDROP5.GT.0.00125)GO TO 15
   95 YESNO5=YESNO5
      GO TO 45
   15 TIM5=TIME
      TIMPL5=TIM5+0.5
      IF(YESNO5.LT.18.9.AND.YESNO5.GT.17.1)GO TO 35
      YESNO5=18.0
      GO TO 45
   35 YESNO5=0.0
   45 CONTINUE
      IF(POWD6.LT.0.0)GO TO 26
      Q6=1.0
      GO TO 56
   26 CONTINUE
      Q6=MPWER6/PMAX6
   56 PDROP6=1.0-Q6
      IF(TIME.LT.TIMPL6)GO TO 96
      IF(PDROP6.GT.0.00125)GO TO 16
   96 YESNO6=YESNO6
      GO TO 46
   16 TIM6=TIME
```