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A COMPARISON OF MANUAL AND AUTOMATIC CONTROL OF THE GRINDING CIRCUIT AT EAST MALARTIC MINES LIMITED, NORRIE, QUEBEC

F. J. KELLY AND W. A. GOW

EXTRACTION METALLURGY DIVISION

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A COMPARISON OF MANUAL AND AUTOMATIC CONTROL OF THE GRINDING CIRCUIT AT EAST MALARTIC MINES LIMITED, NORRIE, QUEBEC

by

F.J. Kelly* and W.A. Gow**

ABSTRACT

Surveys were made of the East Malartic Mines Limited grinding circuit while it was under manual control and when it was under automatic control. The automatic control system used involved the measurement of the intensity of a narrow frequency range of the sound emanating from the grinding units, and control of the feed rate so as to maintain the sound intensity at a pre-set value. Eighty per cent of the control signal came from the primary open-circuit rod mill, and the remaining twenty per cent from one of two secondary ball mills operating in parallel in closed circuit with hydraulic cyclones.

The surveys showed that the application of automatic control resulted in a significant reduction in the variability of the fineness of grind, and in the variability of the screen analyses, of all the products from the grinding circuit. For example, under manual control the 50% passing size of the rod mill discharge varied from 48 mesh to 150 mesh, while under automatic control the variation was within one Tyler screen size, i.e. from just less than 28 mesh to just less than 35 mesh.

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COMPARAISON ENTRE LA COMMANDE MANUELLE ET AUTOMATIQUE DU CIRCUIT DE BROYAGE À LA EAST MALARTIC MINES LIMITED, À NORRIE (QUÉBEC)

par

F. J. Kelly* et W. A. Gow**

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RÉSUMÉ

Les auteurs ont fait l'étude du circuit de broyage de l'East Malartic Mines Limited sous commande manuelle et sous commande automatique. Le système de commande automatique comportait la mesure de l'intensité d'une étroite bande de fréquence du son provenant des broyeurs, et le contrôle de la vitesse d'alimentation de façon à maintenir l'intensité du son à une hauteur réglée. Quatre-vingt pour cent du signal de commande provenait du concasseur à barres primaire à circuit ouvert, et 20 p. 100 venait de l'un des deux concasseurs secondaires à billes fonctionnant parallèlement en circuit fermé avec cyclones hydrauliques.

Les études ont démontré que l'emploi de la commande automatique donne une plus grande uniformité granulométrique tout au long du circuit. Ainsi, sous commande manuelle, les moyennes de granulométrie des particules des produits du concasseur à barres s'étageaient entre les treillis de 48 et de 150 mailles tandis que, sous commande automatique, elles se sont maintenues dans les limites d'un treillis Tyler, soit un peu moins de 28 mailles à un peu moins de 35.

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CONTENTS

FIGURES

TABLES

INTRODUCTION

Early in 1964, East Malartic Mines Limited, of Norrie, Quebec, contracted with Milltronics Limited,* of Peterborough, Ontario, for the installation of automatic controls in the mining company's grinding circuit. At the same time it was agreed that the Extraction Metallurgy Division of the Mines Branch at Ottawa would conduct independent surveys of the grinding operation, both before and after the automatic controls were used, to determine how the use of automatic control affected the over-all grinding operation. This report compares the results of these two surveys, which were done in June 1964 over a nine-day period when the circuit was under manual control, and in October 1965 over a ten-day period when the circuit was automatically controlled.

The grinding circuit at East Malartic Mines consists of one open-circuit rod mill as a primary grinding unit and two ball mills operating in parallel in closed circuit with hydraulic cyclones. The discharges from all three grinding units are combined for feeding to the cyclones. The grinding control varied the new feed rate to the rod mill in proportion to the intensity of certain sound frequencies emanating from the grinding units. The control system was adjusted so that the rod mill contributed 80% of the control signal and the No. 1 ball mill contributed the remaining 20%. Water to the rod mill was controlled automatically and was varied in proportion to the ore feed rate. In addition, water was added automatically to the cyclone feed as demanded by a pulp density sensor located in the cyclone overflow line. Both the grinding circuit and the control systems, shown in Figure 1, are described in detail elsewhere (1)(2).

In any hydrometallurgical operation, such as the gold cyanidation plant at East Malartic Mines, overgrinding usually results in increased reagent consumption and is wasteful of power and grinding media, while undergrinding results in lower extraction because of incomplete liberation of the minerals. Consequently, it is important, in such operations, to maintain an optimum and consistent grind. This is what the Milltronic control unit installed at East Malartic Mines is intended to do. This paper therefore deals mainly with a comparison of the consistency of size distributions of various products of the grinding circuit when the circuit was under manual and automatic control.

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* The authors believe that the data presented demonstrate that improved performance resulted from the application of automatic controls to the grinding units under discussion. However, nothing in this paper is to be considered as an endorsation by the Mines Branch of the particular controls used, nor of the work of any particular company.

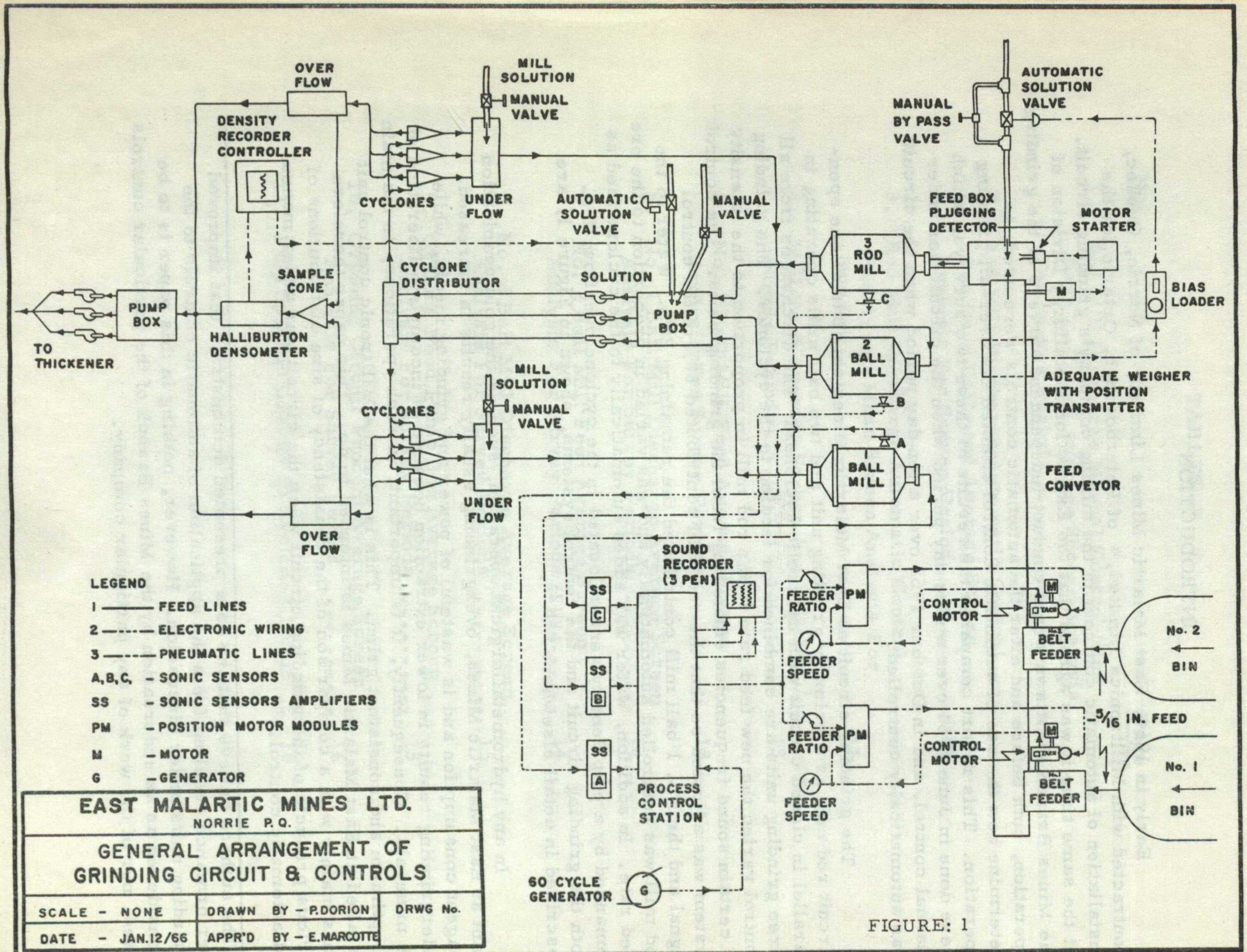
OVER FLOW
MILL SOLUTION
MANUAL VALVE
DENSITY RECORDER CONTROLLER
CYCLONES
UNDER FLOW
AUTOMATIC SOLUTION VALVE
MANUAL VALVE
CYCLONE DISTRIBUTOR
SOLUTION
SAMPLE CONE
PUMP BOX
TO THICKENER
HALLIBURTON DENSOMETER
PUMP BOX
3 ROD MILL
2 BALL MILL
1 BALL MILL
C
B
A
MILL SOLUTION
MANUAL VALVE
CYCLONES
UNDER FLOW
OVER FLOW
AUTOMATIC SOLUTION VALVE
MANUAL BY PASS VALVE
FEED BOX PLUGGING DETECTOR
MOTOR STARTER
M
BIAS LOADER
ADEQUATE WEIGHER WITH POSITION TRANSMITTER
FEED CONVEYOR
SOUND RECORDER (3 PEN)
SS C
SS B
SS A
PROCESS CONTROL STATION
FEEDER RATIO
PM
FEEDER SPEED
CONTROL MOTOR
M
TACH
No. 2 BELT FEEDER
No. 2
BIN
-5/16 IN. FEED
FEEDER RATIO
PM
FEEDER SPEED
CONTROL MOTOR
No. 1 BELT FEEDER
No. 1
BIN
60 CYCLE GENERATOR
G
LEGEND
1 FEED LINES
2 ELECTRONIC WIRING
3 PNEUMATIC LINES
A,B,C, - SONIC SENSORS
SS - SONIC SENSORS AMPLIFIERS
PM - POSITION MOTOR MODULES
M - MOTOR
G - GENERATOR
EAST MALARTIC MINES LTD.
NORRIE P.Q.
GENERAL ARRANGEMENT OF GRINDING CIRCUIT & CONTROLS
SCALE - NONE
DRAWN BY - P.DORION
DRWG No.
DATE - JAN.12/66
APPR'D BY - E.MARCOTTE

FIGURE: 1

PROCEDURE

Samples of rod mill feed and discharge, of both ball mill feeds and discharges, and of cyclone feed and cyclone overflow, were taken at hourly intervals. The samples taken during manual control were made into daily composites prior to analysis, while each hourly sample taken during automatic control was analysed separately. In order to compare screen analyses more conveniently, each analysis was reduced to two parameters: (a) the 50 weight per cent passing size or mean size: (b) the spread within which 68 per cent of the weight is distributed around the mean. These parameters could be calculated mathematically, since all the screen analyses under consideration approximated normal or Gaussian distributions (3). The 68 per cent spread represents the weight contained within one standard deviation on either side of the mean.

Figure 2 shows how these two parameters are used to compare screen analyses. Figure 2 (A) shows two size distributions having the same mean but different spreads, while 2 (B) shows two size distributions having different means but the same spreads. It should be noted that the logarithm of the size is used in these plots.

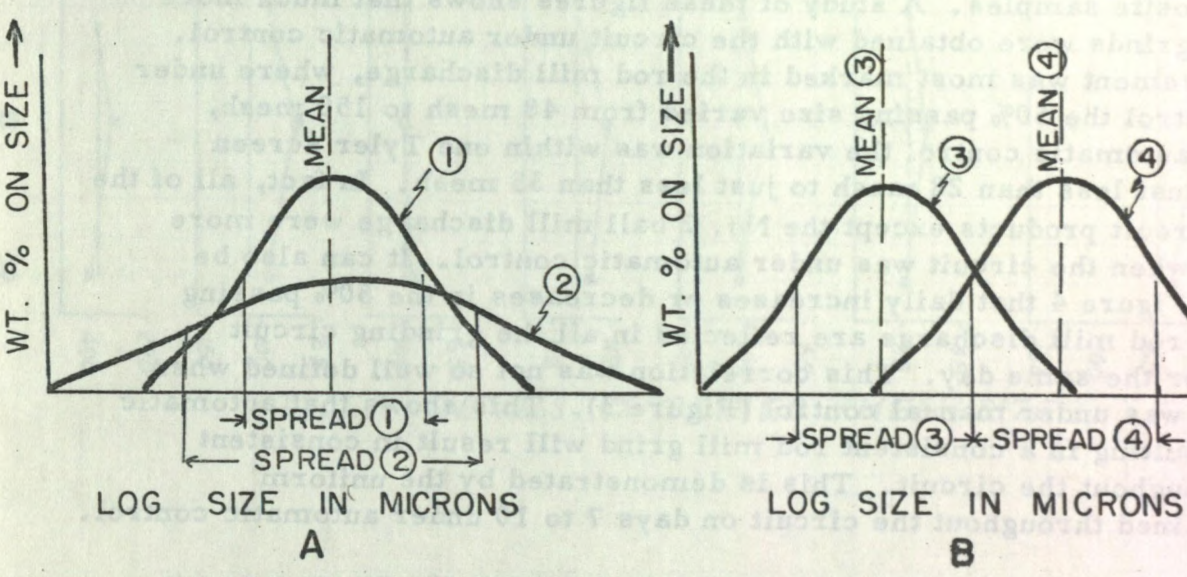

Figure 2. Typical size distributions.

In this report the mean size is expressed in either microns or Tyler screen size, and the spread in terms of the number of Tyler screen sizes required to bridge the spread. For example, if, in a particular screen analysis with a mean of 200μ (-65 + 100 mesh), 68 weight per cent was distributed around the mean in the size range -28 + 200 mesh, the spread would be 6 Tyler screen sizes.

In addition to comparing the means and spreads of the screen analyses of the various products under automatic and manual control, the degree of variation observed in the individual screen sizes of the various products from hour to hour or day to day was also studied.

RESULTS

The spreads observed for the eight grinding products studied in these surveys were 7 ± 1 Tyler screen sizes for the cyclone feed and overflow and both ball mill feeds and discharges, and 12 ± 1 for the rod mill feed and discharge. The application of automatic control had no effect on the spread of any of the products. It follows from this that in analysing the way in which the grind of any given product varies with time, it was only necessary to compare the mean or 50% passing sizes at different time intervals since the spread did not vary significantly either with time or with the type of control used.

Figures 3 and 4 show the variation in the 50% passing size of the daily composite samples. A study of these figures shows that much more consistent grinds were obtained with the circuit under automatic control. The improvement was most marked in the rod mill discharge, where under manual control the 50% passing size varied from 48 mesh to 150 mesh, while with automatic control the variation was within one Tyler screen size from just less than 28 mesh to just less than 35 mesh. In fact, all of the grinding circuit products except the No. 2 ball mill discharge were more consistent when the circuit was under automatic control. It can also be seen from Figure 4 that daily increases or decreases in the 50% passing size of the rod mill discharge are reflected in all the grinding circuit products for the same day. This correlation was not so well defined when the circuit was under manual control (Figure 3). This shows that automatic control resulting in a consistent rod mill grind will result in consistent grinds throughout the circuit. This is demonstrated by the uniform grinds obtained throughout the circuit on days 7 to 10 under automatic control.

To examine further the consistency of the grinds with the circuit under automatic control, Figure 5 was constructed showing the variation from hour to hour in the products' 50 per cent passing points. The data shown are for day 6 on Figure 4. Comparison of Figures 3, 4 and 5 shows

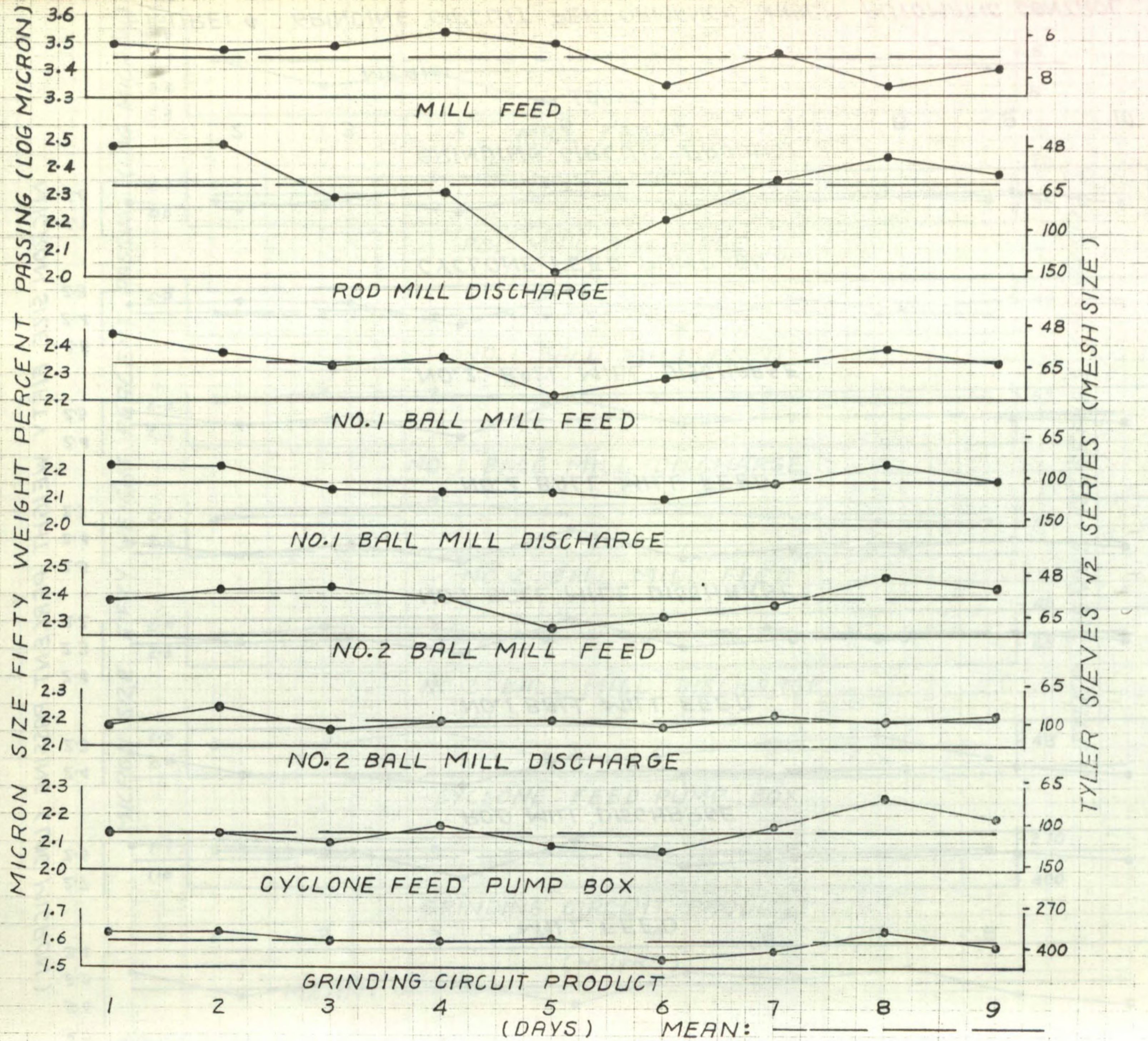

FIGURE: 3 GRINDING CIRCUIT PERFORMANCE UNDER MANUAL CONTROL

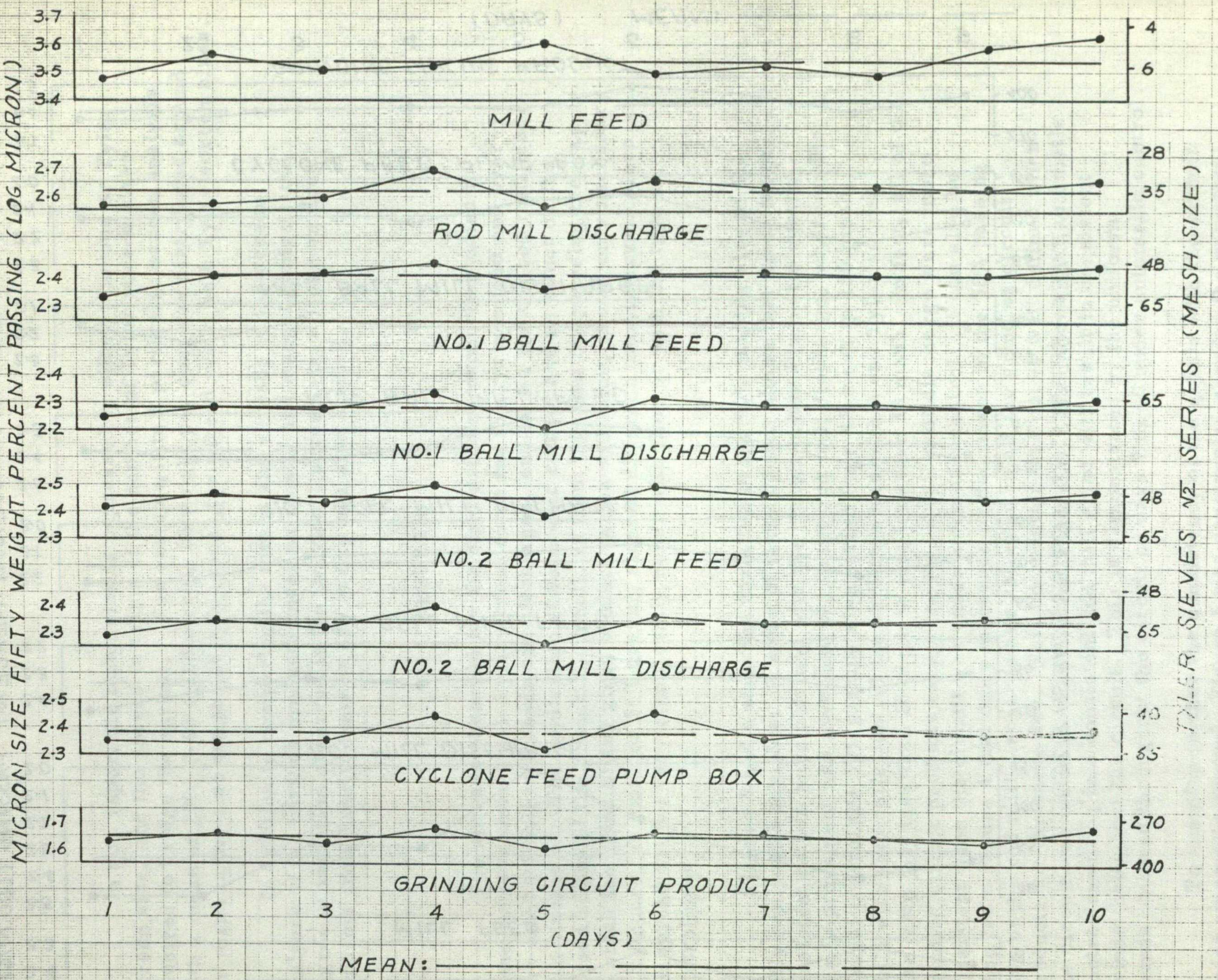

FIGURE: 4 GRINDING CIRCUIT PERFORMANCE UNDER AUTOMATIC CONTROL

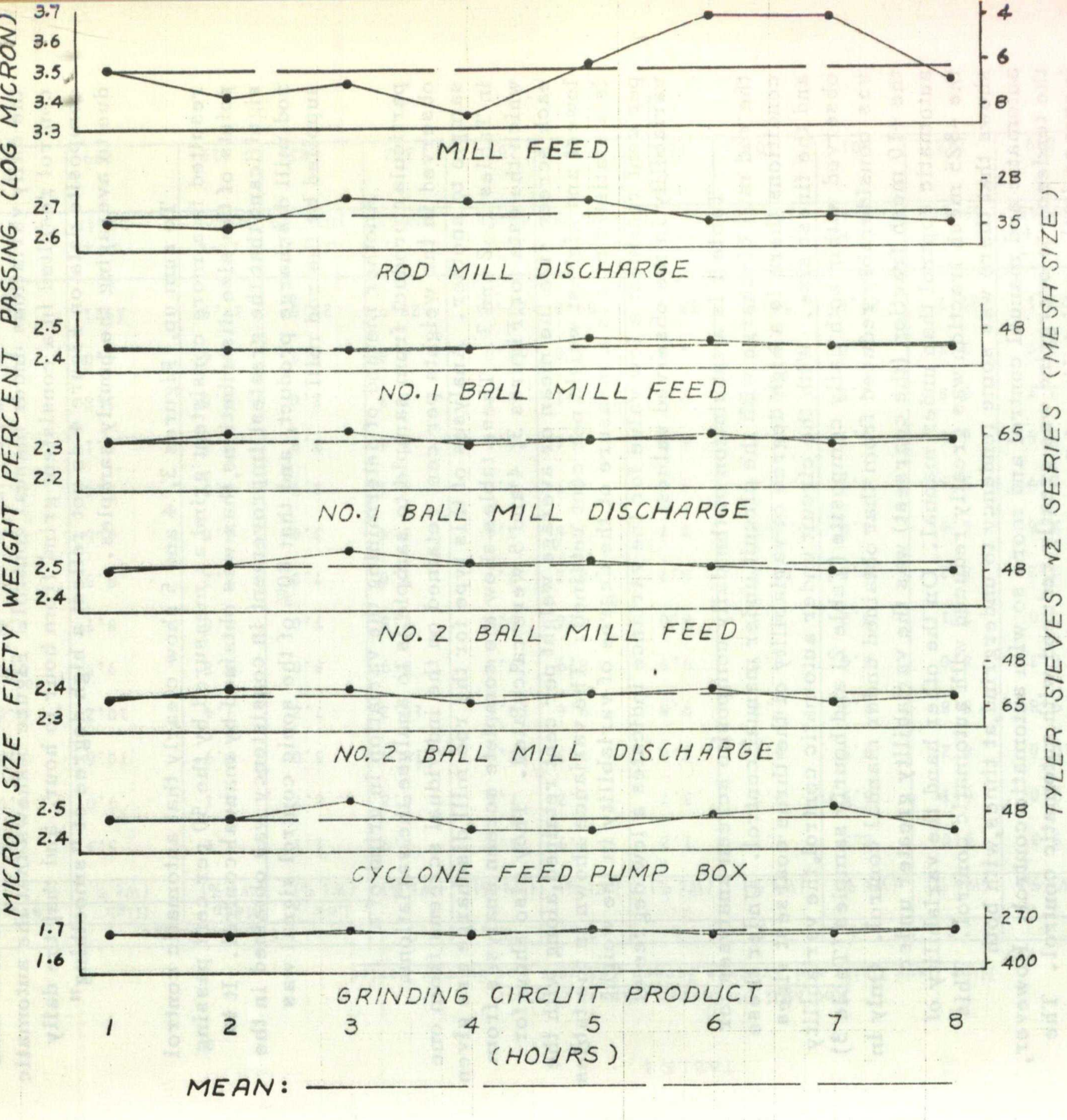

FIGURE: 5 GRINDING CIRCUIT PERFORMANCE UNDER AUTOMATIC CONTROL that the magnitudes of the hourly variation under automatic control were about the same as the daily variations under automatic control and less than the daily variations under manual control. Figure 5 shows that the automatic control resulted in a consistent grind from hour to hour, and that the daily composite data on Figure 4 do not reflect a high degree of "smoothing" due to averaging the hourly samples.

To sum up, Figures 3, 4 and 5 show clearly that automatic control resulted in a more consistent grind, as measured by the 50 per cent passing points of the size distributions, than was obtained by manual control. It is significant that the greatest improvement in consistency was obtained in the rod mill discharge product, and that 80% of the sonic control signal was supplied by the rod mill.

Another method of determining the variation in grind of a particular product from sample to sample is to analyse the variations observed in the weights per cent retained on the individual screens from one sample to another. Analyses of this type for the rod mill discharge are given in Tables 1, 2 and 3. These tables show the complete screen analyses from which the data for Figures 3, 4 and 5 were calculated. They also show for each screen size the mean or average weight per cent retained, along with the lowest and highest weight per cent retained. The variance shown in the tables is a statistic that is a measure of the degree of variability in the weight per cent retained: a low value for the variance indicates a low degree of variability in the observed values.

Table 1 is a tabulation of the daily composite screen analyses for the rod mill discharge with the circuit under manual control. Under these conditions there is a high degree of variability of the three coarsest sizes and the finest size. With the circuit under automatic control, the variability observed within both daily composite (Table 2) and hourly samples (Table 3) was considerably reduced from that obtained under manual control. Only in the +10 mesh fraction (the coarsest) was the variability greater under automatic control than under manual. On the other hand, the variability of the -325 mesh fraction was greatly reduced with automatic control. This shows that there was some tendency to undergrind, at times, with both automatic and manual control and more so with automatic control. However, the tendency to overgrind was greatly reduced with automatic control. The increase in the variability of the coarsest size with automatic control is not too significant, since undergrinding in the rod mill can be corrected in secondary grinding in the ball mills. On the other hand, the 90% improvement in the tendency to overgrind in the rod mill, resulting from the use of automatic control, is significant since overgrinding cannot be corrected in the

TABLE 1

Rod Mill Discharge Manual Control

Nine Days Daily and Average Screen Analysis For Survey Period

Days		1	2	3	4	5	6	7	8	9	Sample Range			
Particle Size											Low	Mean	High	Variance
(mesh)	(micron)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %,	
+ 10	+1651	4.2	5.3	4.0	2.3	1.1	1.2	2.9	4.0	2.9	1.1	3.1	5.3	2.00
14	1168	8.0	9.0	6.1	5.5	2.7	3.7	6.2	7.6	6.2	2.7	6.1	9.0	4.00
20	833	10.3	10.6	8.2	9.5	5.0	7.0	9.3	10.0	10.0	5.0	8.9	10.6	3.39
28	589	10.0	9.8	8.8	9.2	7.2	9.8	9.6	10.1	10.2	7.2	9.4	10.2	0.89
35	417	9.1	8.3	8.0	8.4	8.8	9.5	8.9	9.2	8.9	8.0	8.8	9.5	0.23
48	295	8.7	7.0	7.1	7.2	8.3	8.0	7.6	6.8	7.5	7.0	7.6	8.7	0.41
80	175	7.4	7.2	8.2	9.5	10.3	8.7	8.2	7.7	7.0	7.0	8.2	9.5	1.21
100	147	3.4	3.6	4.4	4.0	4.6	3.7	3.6	3.4	3.4	3.4	3.8	4.6	0.20
150	104	4.1	2.9	3.5	4.7	5.4	5.0	4.7	4.2	4.5	2.9	4.3	5.4	0.59
200	74	3.9	3.8	4.5	4.5	5.1	4.7	4.4	4.1	4.4	3.8	4.4	5.1	0.16
270	53	2.0	2.7	3.8	2.2	2.7	2.2	2.1	2.1	2.3	2.0	2.5	3.8	0.32
325	44	3.4	2.7	3.7	4.0	3.7	3.5	3.0	3.0	3.8	2.7	3.4	4.0	0.19
-325	-44	25.5	27.1	29.7	29.0	35.1	33.0	29.8	27.8	28.9	25.5	29.5	35.1	8.62
Mesh Range 50 Wt % Passing		- + 35-48	- + 35-48	- + 65-100	- + 48-65	- + 100-150	- + 65-100	- + 48-65	- + 48-65	- + 48-65	- + 100-150	- + 48-65	- + 35-48	
Micron Size 50 Wt % Passing		295	299	192	201	103	160	222	266	232	103	214	299	

TABLE 2

Rod Mill Discharge Automatic Control
Ten Days Daily and Average Screen Analysis For Survey Period

Days		1	2	3	4	5	6	7	8	9	10	Sample Range			
Particle Size												Low	Mean	High	Variance
(mesh)	(micron)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt%)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	
+ 10	+1651	7.6	8.2	9.0	15.3	7.9	12.0	10.2	10.7	12.5	11.9	7.6	10.5	15.3	6.01
14	1168	10.7	10.8	11.2	13.2	10.6	12.5	11.6	12.2	11.5	12.4	11.2	11.7	13.2	0.77
20	833	10.8	10.5	10.8	10.2	10.7	11.2	12.0	11.3	10.4	11.0	10.2	10.9	12.0	0.27
28	589	10.7	10.9	10.6	8.9	10.6	9.8	10.2	10.0	9.6	9.9	8.9	10.1	10.9	0.37
35	417	7.3	7.3	7.2	6.2	7.3	6.8	7.2	6.7	6.5	6.8	6.2	6.9	7.3	0.15
48	295	6.8	7.0	6.7	5.5	6.8	6.0	6.1	6.2	6.0	6.2	5.5	6.3	7.0	0.22
80	175	6.9	6.3	6.5	5.8	6.8	6.0	6.2	6.4	6.1	6.1	5.8	6.3	6.9	0.12
100	147	3.2	2.9	2.8	2.1	3.0	2.6	2.6	2.4	2.4	2.4	2.1	2.6	3.2	0.11
150	104	3.4	3.1	3.1	3.0	3.6	2.9	3.2	3.4	3.4	3.4	2.9	3.2	3.6	0.05
200	74	3.3	3.6	3.3	2.9	3.4	3.1	3.2	3.0	3.1	3.1	2.9	3.2	3.6	0.04
270	53	2.1	2.2	2.2	1.8	2.2	2.0	1.8	1.7	2.0	1.9	1.7	2.0	2.2	0.03
325	44	2.2	2.4	2.2	2.0	2.2	2.2	2.3	2.2	2.4	2.3	2.0	2.2	2.4	0.01
-325	-44	25.0	24.8	24.4	23.1	24.9	22.9	23.4	23.8	24.1	22.6	23.1	24.1	25.0	0.77
Mesh Range 50 Wt % Passing		- + 35-48	- + 35-48	- + 35-48	- + 28-35	- + 35-48	- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 35-48	- + 28-35	- + 28-35	
Micron Size 50 Wt % Passing		366	376	394	497	366	459	433	434	426	456	366	417	497	

TABLE 3

Rod Mill Discharge Automatic Control
Hourly and Mean Screen Analysis For One Day

Hours		1	2	3	4	5	6	7	8	Sample Range			
Particle Size										Low	Mean	High	Variance
(mesh)	(micron)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	(Wt %)	
+ 10	+1651	10.4	10.2	16.1	15.0	13.7	10.7	10.0	9.5	9.5	12.0	15.0	6.63
14	1168	12.0	12.2	13.2	13.0	13.0	12.2	12.2	12.1	12.0	12.5	13.0	0.24
20	833	12.0	10.6	10.0	11.2	12.0	10.6	12.3	10.8	10.0	11.2	12.3	0.69
28	589	10.0	10.1	9.3	8.9	9.4	10.3	10.1	10.7	9.3	9.8	10.7	0.35
35	417	7.0	7.0	6.0	6.3	6.8	7.0	7.0	7.1	6.0	6.8	7.1	0.16
48	295	5.6	6.5	6.0	5.2	5.4	6.5	6.1	7.0	5.2	6.0	7.0	0.38
80	175	6.0	6.2	6.0	5.8	6.0	6.0	6.2	6.0	5.8	6.0	6.2	0.02
100	147	2.8	2.8	2.5	2.2	2.2	3.0	2.8	2.8	2.2	2.6	3.0	0.09
150	104	2.4	3.0	2.5	3.2	3.2	2.8	3.0	3.0	2.4	2.9	3.2	0.09
200	74	3.5	3.0	3.2	2.5	2.5	3.8	3.1	3.0	2.5	3.1	3.8	0.20
270	53	1.8	2.2	1.6	2.2	1.8	1.5	2.1	2.5	1.6	2.0	2.5	0.12
325	44	2.8	2.1	2.0	2.5	2.0	2.9	1.5	2.0	1.5	2.2	2.9	0.22
-325	-44	23.7	24.1	21.6	22.0	22.0	22.7	23.6	23.5	21.6	22.9	24.1	0.90
Mesh Range 50 Wt % Passing		- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 28-35	- + 28-35	
Micron Size 50 Wt % Passing		432	419	525	505	511	431	442	423	423	459	525	

subsequent grinding stages. It is of note that the variabilities observed in the coarsest sizes in the rod mill discharge, both under manual and automatic control, may be reflections of the variability observed in the coarsest fraction of the rod mill feed (Table 4), and that the feed variability is outside of the grinding control whether it be manual or automatic.

Tables 1, 2 and 3 show in considerable detail the screen analyses obtained on the rod mill discharge. This detail is presented because most of the grinding control was on the rod mill. Space does not permit the presentation of as detailed results for the other grinding circuit products studied. However, Tables 4 to 10 show the variabilities from day to day observed for the rod mill feed, cyclone feed and overflow, and both ball mill feeds and discharges. The data in these tables are comparable to the data presented in the last 3 columns of Tables 1 and 2, covering the rod mill discharge. A study of Tables 4 to 10 shows that with the circuit under automatic control, the variabilities as indicated by the values of the variances are almost all less, and often considerably less, than those observed when the circuit was under manual control. These results confirm the observation, made from the data in Figures 3 to 5, that the appreciable reduction in variability effected in the rod mill discharge by automatic control is reflected throughout the grinding circuit.

It is apparent from the data that when the circuit was under automatic control the various products were all slightly coarser than the corresponding products obtained under manual control. The explanation for this is that, just prior to the survey of the automatically controlled circuit, a reduction in the mine's output forced the mill staff to reduce the capacities of the rod and ball mills by reducing the rod and ball loads. The amount by which the steel loads were reduced proved to be a little too great, and the capacities of the units were consequently a little too low, for the tonnage to be ground. Since the survey was completed, the steel loads have been adjusted so that at the present time the products are approximately as fine as those obtained when the circuit was manually controlled, while the improvement in variability observed with automatic control during the survey has been maintained. The capacity of the grinding circuit can be increased by further additions of steel, and it is believed that the automatic control system's effectiveness would be maintained at the higher capacities.

In comparing the results of the two surveys, it should be kept in mind that during the survey with the circuit under automatic control, the mill staff were still experimenting with the control loop. Consequently, some of the variability noted with the circuit under automatic control was due to manual disturbance of the control loop.

TABLE 4

Mill Feed
Average Screen Analysis For Survey Periods

Particle Size		Manual Control Sample Range				Automatic Control Sample Range			
(mesh)	(micron)	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance
+ 3	+6680	14.8	20.8	25.3	11.47	21.5	25.9	30.8	10.21
4	4699	14.7	16.2	18.5	1.71	14.5	15.5	17.2	0.84
6	3327	10.5	11.4	12.1	0.31	10.4	11.2	13.0	0.88
8	2362	6.2	7.2	8.2	0.34	7.1	7.8	8.6	0.26
10	1651	5.0	5.8	6.7	0.31	5.4	5.8	6.4	0.14
14	1168	4.5	5.2	5.9	0.25	4.5	5.1	5.6	0.15
20	833	3.2	3.8	4.7	0.21	3.1	3.7	4.1	0.15
28	589	2.5	2.9	3.5	0.10	2.6	3.1	3.5	0.11
35	417	2.0	2.4	3.0	0.09	1.9	2.2	2.4	0.04
48	295	1.8	2.3	3.3	0.22	1.7	2.0	2.3	0.05
80	175	1.3	2.2	2.7	0.18	1.9	2.2	2.4	0.04
100	147	1.0	1.2	1.6	0.03	0.6	0.9	1.0	0.01
150	104	1.3	1.5	1.8	0.02	1.1	1.3	1.5	0.02
200	74	1.5	1.7	2.0	0.02	1.2	1.3	1.4	0.01
270	53	0.8	1.2	2.0	0.16	0.7	0.9	1.0	0.01
325	44	1.4	1.6	2.0	0.05	0.9	1.0	1.2	0.01
-325	-44	11.2	12.6	15.4	1.79	9.1	10.1	10.9	0.38

TABLE 5

No. 1 Ball Mill Feed
Average Screen Analysis For Survey Periods

Particle Size		Manual Control Sample Range				Automatic Control Sample Range			
(mesh)	(micron)	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance
+ 10	+1651	0.1	1.3	2.3	0.50	1.8	3.0	4.5	0.80
14	1168	0.7	2.7	4.2	0.98	3.2	4.1	5.2	0.41
20	833	1.3	4.8	8.5	3.56	4.8	5.8	6.5	0.28
28	589	3.0	6.1	9.0	2.63	6.7	7.8	8.7	0.33
35	417	6.8	8.5	10.0	0.96	7.9	9.0	9.8	0.33
48	295	9.3	11.8	13.8	3.05	11.3	12.9	14.1	0.90
80	175	18.0	19.8	21.3	1.11	18.7	21.0	22.9	2.06
100	147	10.1	12.6	15.4	2.95	7.8	9.9	12.2	1.79
150	104	6.3	10.5	17.5	13.83	7.3	9.0	11.0	0.94
200	74	5.0	7.5	10.6	4.47	4.2	5.2	6.3	0.53
270	53	2.0	2.8	3.7	0.36	1.7	2.4	3.5	0.29
325	44	1.8	2.7	3.7	0.42	1.2	1.5	2.0	0.09
-325	-44	7.4	8.9	11.2	1.29	7.4	8.4	9.5	0.64

TABLE 6

No. 1 Ball Mill Discharge
Average Screen Analysis For Survey Periods

Particle Size		Manual Control Sample Range				Automatic Control Sample Range			
(mesh)	(micron)	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance
+ 10	+1651	0.0	0.1	0.5	0.30	0.5	1.4	2.4	0.37
14	1168	0.2	0.6	1.2	0.17	1.0	2.1	3.2	0.32
20	833	0.5	1.2	2.1	0.38	2.0	3.3	4.4	0.41
28	589	1.6	2.4	3.4	0.55	3.6	5.2	6.2	0.57
35	417	4.3	5.6	7.4	0.94	5.5	7.5	8.4	0.66
48	295	9.0	11.2	13.8	2.46	10.4	12.1	13.5	1.29
80	175	15.1	17.9	20.0	2.78	21.1	22.0	23.9	0.73
100	147	11.6	13.8	15.4	1.39	7.6	10.1	12.2	1.51
150	104	9.3	11.5	14.2	3.00	8.3	10.6	13.3	2.26
200	74	6.5	8.0	9.7	0.95	5.0	6.3	7.6	0.73
270	53	4.2	5.2	6.0	0.38	2.2	2.8	3.3	0.11
325	44	3.1	4.0	5.0	0.41	1.7	2.2	2.9	0.17
-325	-44	15.3	18.5	22.4	6.42	12.5	14.4	16.0	1.07

TABLE 7

No. 2 Ball Mill Feed
Average Screen Analysis For Survey Periods

Particle Size		Manual Control Sample Range				Automatic Control Sample Range			
(mesh)	(micron)	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance
+ 10	+1651	0.6	1.8	3.1	0.77	2.6	4.3	6.4	1.85
14	1168	1.3	3.5	5.5	1.47	4.0	5.0	6.3	0.54
20	833	2.5	5.7	7.8	3.22	5.5	6.3	7.2	0.31
28	589	4.4	6.8	8.5	1.70	7.3	8.2	8.8	0.22
35	417	8.4	9.1	9.6	0.19	8.0	9.2	9.8	0.31
48	295	10.0	13.0	18.6	6.13	10.3	13.1	14.8	1.52
80	175	18.1	20.0	22.5	3.70	19.3	20.6	22.3	0.84
100	147	8.5	11.3	16.2	4.80	6.4	9.0	11.1	1.94
150	104	6.2	9.3	13.0	5.26	6.6	8.2	10.8	1.40
200	74	4.6	6.1	8.8	1.80	3.7	4.6	5.8	0.47
270	53	1.5	2.5	4.3	0.66	1.6	2.0	2.6	0.11
325	44	2.0	2.5	3.1	0.24	1.0	1.4	2.1	0.14
-325	-44	5.9	8.4	9.3	1.06	6.3	8.1	9.1	0.93

TABLE 8

No. 2 Ball Mill Discharge
Average Screen Analysis For Survey Periods

Particle Size		Manual Control Sample Range				Automatic Control Sample Range			
(mesh)	(micron)	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance
+ 10	+1651	0.1	0.3	0.5	0.02	1.1	3.1	5.6	2.01
14	1168	0.2	1.0	1.7	0.28	2.0	3.2	4.6	0.66
20	833	1.0	1.8	3.5	0.78	3.0	4.2	5.0	0.43
28	589	2.0	3.0	4.5	1.02	4.6	6.1	7.2	0.50
35	417	4.8	6.1	8.2	0.94	6.3	7.9	8.9	0.48
48	295	10.7	13.4	16.1	4.46	9.2	11.9	13.0	1.52
80	175	16.3	17.2	18.3	0.37	19.4	21.1	22.9	1.13
100	147	11.5	13.4	14.8	1.53	7.7	9.6	11.2	1.63
150	104	9.3	11.3	12.7	1.88	7.5	9.7	13.1	2.24
200	74	6.4	7.2	8.1	0.76	4.4	5.5	7.0	0.53
270	53	4.2	5.8	10.6	3.63	2.0	2.6	3.2	0.18
325	44	3.0	3.7	4.0	0.10	1.3	1.9	2.7	0.17
-325	-44	12.1	15.8	19.8	6.46	11.6	13.2	14.6	0.85

TABLE 9

Cyclone Feed Pump Box
Average Screen Analysis For Survey Periods

Particle Size		Manual Control Sample Range				Automatic Control Sample Range			
(mesh)	(micron)	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance
+ 10	+1651	0.0	0.5	1.6	0.32	3.4	5.2	8.2	3.81
14	1168	0.1	1.3	3.3	1.10	3.8	4.8	6.4	0.70
20	833	0.7	2.3	4.5	1.86	5.0	5.6	6.3	0.16
28	589	1.8	3.5	5.5	1.81	6.2	7.0	7.4	0.16
35	417	4.0	5.6	6.7	0.91	6.9	7.8	8.4	0.23
48	295	6.9	8.9	10.3	1.51	8.3	10.6	11.7	1.39
80	175	13.7	16.8	19.3	3.30	16.6	18.2	20.8	1.62
100	147	9.1	10.4	11.8	0.73	6.5	8.4	10.2	1.22
150	104	9.4	11.5	13.5	1.91	6.8	8.7	12.4	2.37
200	74	6.7	8.2	10.0	1.06	4.2	5.3	6.5	0.60
270	53	2.6	3.2	3.8	0.14	1.9	2.4	3.1	0.10
325	44	3.5	4.5	5.2	0.25	1.5	1.9	2.7	0.16
-325	-44	18.5	23.3	27.9	8.34	12.9	14.1	15.0	0.52

TABLE 10

Grinding Circuit Product
Average Screen Analysis For Survey Period

Particle Size		Manual Control Sample Range				Automatic Control Sample Range			
(mesh)	(micron)	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance	Low (Wt %)	Mean (Wt %)	High (Wt %)	Variance
+ 48	+ 295	0.0	0.0	0.0	0.00	0.3	0.7	1.4	0.10
80	175	0.2	1.7	3.2	1.08	2.3	4.5	6.1	1.31
100	147	1.8	4.0	5.8	1.73	4.7	6.6	8.0	0.85
150	104	5.0	8.9	11.0	3.98	8.0	8.9	9.7	0.24
200	74	8.4	10.9	12.6	1.67	10.1	10.9	11.8	0.24
	56	6.2	11.1	17.1	10.03	4.0	5.7	6.8	0.63
	40	20.2	22.6	24.7	2.92	12.9	17.5	20.6	4.76
	28	12.6	13.5	14.1	0.21	16.3	17.3	18.3	0.55
	20	6.0	6.6	7.4	0.29	7.0	8.1	9.0	0.51
	14	4.9	5.6	6.8	0.55	7.2	7.8	9.1	0.42
	10	3.6	5.1	6.4	0.86	5.7	6.2	7.3	0.25
	-10	9.4	10.0	10.7	0.33	3.7	5.8	8.5	1.82

TABLE 11

Pulp Specific Gravity in Cyclone Circuit

Product	Pulp Specific Gravity (Manual)			Pulp Specific Gravity (Automatic)		
	Lowest	Mean	Highest	Lowest	Mean	Highest
Cyclone Feed	1.330	1.485	1.590	1.350	1.687	1.800
No. 1 Cyclone Bank Underflow (No. 1 Ball Mill Feed)	1.810	1.896	1.980	1.815	1.925	2.010
No. 2 Cyclone Bank Underflow (No. 2 Ball Mill Feed)	1.815	1.900	1.980	1.830	1.914	2.010
No. 1 Cyclone Bank Overflow (Grinding Circuit Product)	1.181	1.208	1.247	1.181	1.221	1.256
No. 2 Cyclone Bank Overflow (Grinding Circuit Product)	1.202	1.264	1.286	1.216	1.260	1.300

In addition to the grinding control based on the sound generated by the grinding mills, density control was applied to the cyclone overflow, using a Haliburton Densometer as the sensing device. This control loop varied the amount of water added to the cyclone feed, with the aim of maintaining a more consistent density in the cyclone overflow. As is shown in Figure 1, the grinding circuit contains two banks of cyclones operating in parallel. The underflows of these two banks were fed to the No. 1 and No. 2 ball mills. The overflows were combined before reaching the density controller. Table 11 shows range and average values of the specific gravities observed in the cyclone feed and in the underflow and overflow from each of the two banks with the circuit under manual or automatic control. This table shows that, except for the densities observed in the cyclone feed, there was no significant difference in the variabilities or means of the pulp specific gravities when the circuit was changed from manual to automatic control. Under automatic control the specific gravity of the cyclone feed varied more widely and had a higher mean than with manual control. Although the automatic control used on the cyclone circuit appeared to have only a limited effect on the pulp densities, it is a fact that the size distributions of the cyclone products exhibited much less variability with the circuit under automatic control. This means either that the density control of the cyclone overflow by adjustment of the cyclone feed density is advantageous in producing consistent size distributions in the products, or that close cyclone control of the cyclone operation is not necessary provided that the variability of the products, and particularly the rod mill discharge, is controlled within close limits. On the basis of the data available it is not possible to say which of these two factors is predominant.

CONCLUSIONS

1. The application of automatic control to the grinding circuit of East Malartic Mines Limited resulted in a significant reduction in the variability of the mean sizes, and of the screen analyses, of all the products from the three grinding mills.

2. This reduction in the variability of the products from the three grinding mills resulted in a reduction in the variability of the cyclone overflow product, even though the cyclone density control was not improved by the use of the automatic density controller installed.

3. The application of automatic control did not significantly affect the spreads of the products from the three grinding mills, nor the spread of the cyclone overflow product.

4. The data obtained provide no indication as to whether with improved cyclone density control a still greater reduction in the variability of the grinding mill product could have been obtained.

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REFERENCES

1. A. E. Gillis, "Circuitry and Equipment Installed for Control of the Grinding Circuit at East Malartic Mines Limited", Canadian Mining Journal, March 1966.

2. E. J. Marcotte, "Automatic Control of a Grinding Circuit as Experienced at East Malartic Mines", Canadian Mining Journal, March 1966.

3. G. Herdan, "Small Particle Statistics" (Butterworths, London, 1960), Chapters 6 and 7.

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