A COMPUTER DATA ACQUISITION SYSTEM FOR A SUGAR MILLING TRAIN

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Abstract

As part of joint research project with the Noodsberg Sugar Company Limited, the National Electrical Engineering Research Institute installed a minicomputer system in the Jaagbaan mill of the company to collect data on the milling train during the 1972 milling season.

The on-line data included cane input rate, imbibition rate, mixed juice outflow, roller speed and lift, and provision was made to enter laboratory data, i.e. analyses of cane, expressed juice, mixed juice and bagasse by hand at regular intervals.

The paper describes the computer system hardware and software, the transducers used, and some of the engineering problems encountered. Operational experience with the system is discussed.

1. Introduction

As part of a project to develop a mathematical model of a three-roller sugar mill, a data acquisition system based on a minicomputer was installed at the Jaagbaan mill of the Noodsberg Sugar Co. Ltd., and operated during the 1972 milling season. Such a system for acquiring on-line data on the cane knives, the shredder and the six three-roller mills was chosen for the sake of accuracy and reliability, it being to a large extent independent of operator prejudice. A further advantage was that the data were immediately available in computer-accessible form.

The variables measured included cane rate, top roller lift and speed, drive motor power input, and imbibition rate and mixed juice rate. The analyses of the cane, bagasse, mixed juice and last expressed juice were typed in on a teletype connected to the computer. The current into the first mill was monitored to determine a mill stoppage.

This paper includes a description of the transducers which were used to measure cane input rate, top roller lift, motor current and top roller speed. The computer hardware and software are discussed, also operator-typed commands and reports printed on the teletype. The paper concludes with a discussion of the operational problems encountered.

2. Hardware

The data acquisition system, illustrated schematically in Figure 1, is based on a Varian Data 620/f computer with 8192 words of core storage. The peripheral equipment consists of a teletype, a cassette recorder, and sub-systems for analog and digital input. Figure 2 shows the hardware configuration in block diagram form.

The computer word length is 16 bits and the cycle time 750 nanoseconds. A direct memory access channel, an interrupt module and a real time clock are included.

The direct memory access channel allows data to be transferred direct to or from the computer memory

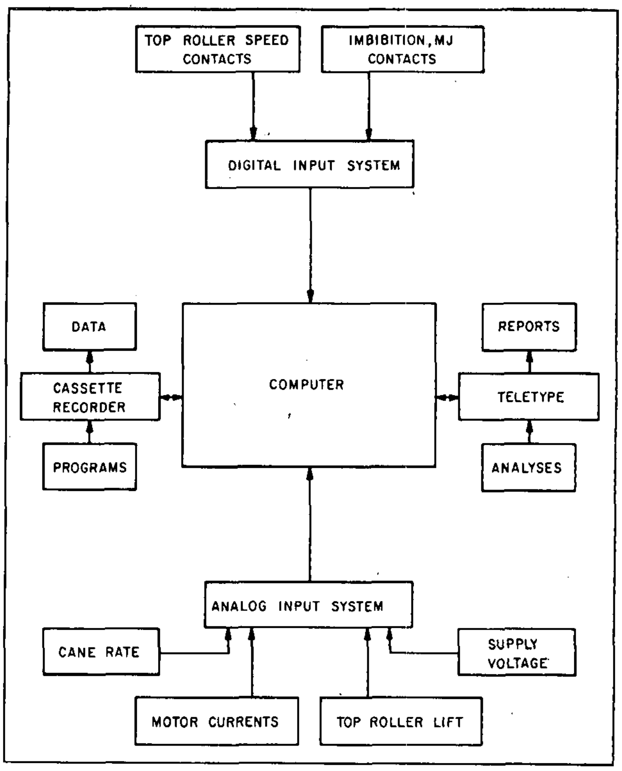

FIGURE 1: Block diagram of the data acquisition system.

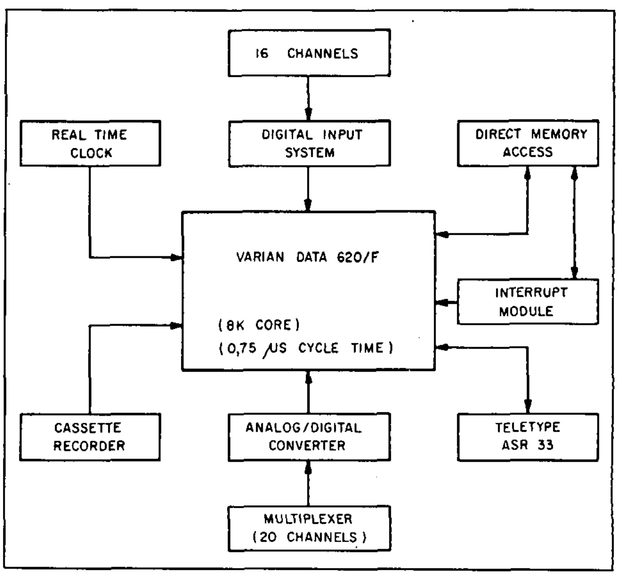

FIGURE 2: Block diagram of the computer and its associated peripherals.

without passing it through the operational registers of the central processing unit. The interrupt module and real time clock operate via the direct memory access unit. The interrupt module has 8 levels of priority interrupts which can be used by external devices to interrupt the central processing unit (CPU). The real-time clock is used under program control to keep the time of day. The basic time reference used by this module is the supply voltage frequency. Time derived from the clock has the same accuracy as the power frequency.

A hardware multiply-and-divide unit was included to enable 16-bit fixed-point numbers to be multiplied and divided in approximately 5,5 μs.

The teletype consists of a keyboard, a page printer, a paper tape reader and punch, all operating at a data transfer rate of 10 characters per second.

The cassette recorder uses standard ¼" type magnetic tape cassettes. The data transfer rate is 500 characters per second and the packing density 4 000 characters per metre. The length of the tape is 90 metres allowing data for 1 week to be recorded on one cassette. The digital input system accepts digital data asynchronously and stores this information temporarily until the data are read into computer memory. Up to 16 input lines are allowed. The digital input system is capable of transferring data at a rate of 1200 000 words per second, where one word is equivalent to the data on 16 input lines.

The analog input sub-system consists of an analog-to-digital converter, a sample-and-hold module and a 20-channel multiplexer. The input range of the converter is ± 10 volts. The analog signal is converted to a digital signal, containing 11 bits plus sign bit. This is equivalent to a resolution of 5 millivolts.

A direct memory access channel and an interrupt module provided in the system allow the real-time clock, the cassette recorder and the teletype to be run with interrupts, i.e. they can interrupt the computer when they are ready for a data transfer operation. This facility simplifies data input-output operations significantly.

3. Transducers and Interfaces

The following primary quantities were measured on-line under computer control: mass of cane input per unit time (cane rate); currents for the motors driving the cane knives, the shredder and the mills; top roller lift and speed; imbibition inflow and mixed juice outflow. A special weighbridge had to be constructed to measure the cane rate; other quantities were determined by suitably interfacing to an existing transducer, or by installing simple devices such as mechanically coupled potentiometers and microswitches.

Information such as the results of analyses of bagasse and juice streams was entered by hand via the teletype unit since no direct transducers for brix and sucrose content were available.

3.1 Cane rate

A system for measuring cane rate is indicated in Figure 3. The weighbridge, carrying approximately 2 meters of the conveyer belt feeding the shredder, is suspended on knife edges and the dead mass is balanced out. A load cell is attached to the structure in such a way as to measure the mass of the cane on the belt. The output from the load cell is preamplified before being transmitted to the multiplier box.

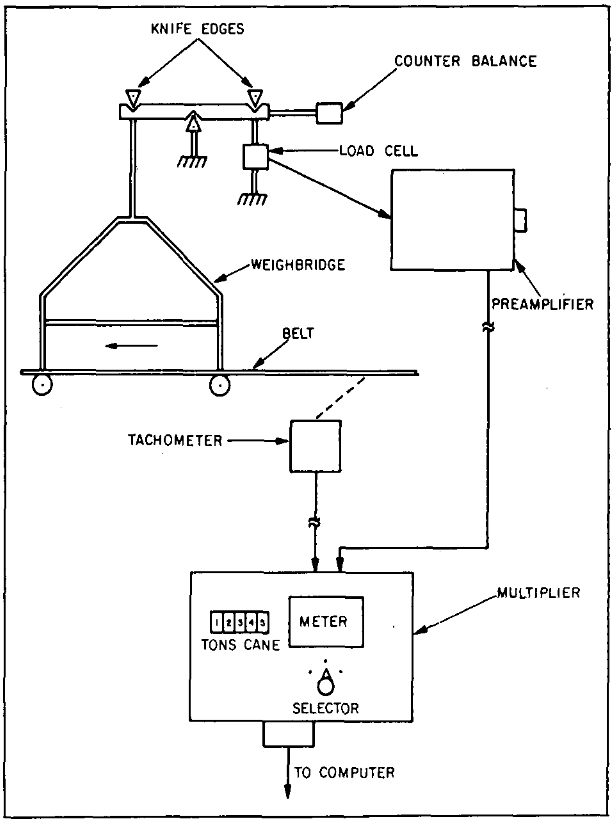

FIGURE 3: Schematic diagram of the cane rate measurement system.

The speed and mass signals are multiplied to obtain a signal, proportional to the cane rate in tons per hour, which is transmitted to the computer.

To simplify checking the operation of the bridge, a counter to count tons of cane is also included in the multiplier box. The cane rate is integrated until the output of the integrator reaches a voltage which is equivalent to one ton of cane. The counter is then incremented and the integrator reset.

The system operated successfully during the milling season and the error between the indicated tonnage milled over a week and the value supplied by the factory was of the order of 3%. This degree of accuracy was sufficient for the purpose of computer modelling.

3.2 Motor currents

The currents of the motors driving the cane knives, the shredder, and the mills were determined by using already available current transformers on one phase of each motor. Since the current transformers were connected to other control circuitry it was necessary to isolate them electrically from the computer, as shown in Figure 4 and described below.

A 0,2 ohm resistor was connected in series with the secondary of the current transformer. The voltage across this resistor was then stepped up in a voltage

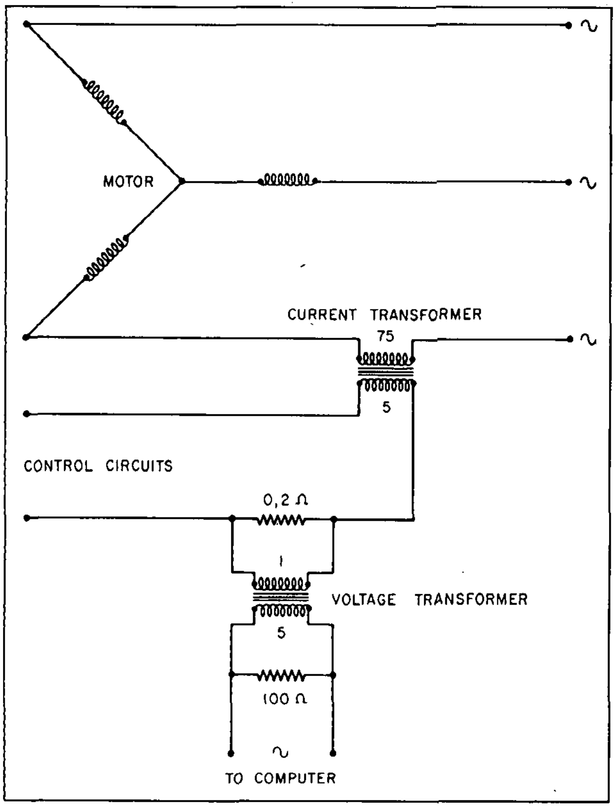

FIGURE 4: Circuit used to measure a mill motor current.

transformer to a level suitable for the analog-to-digital converter. The voltage transformer also provided the required isolation; it was loaded with a 100 ohm resistor to minimise harmonic distortion due to the non-linear characteristics of the core material of the transformer. Accuracy of measurement was of the order of 2%, and the phase error about 5 degrees.

3.3 Top roller lift

The top roller lift is taken as the average of the lift at the two end bearings, as shown in Figure 5.

To determine this average lift, both the front and rear yokes carrying the bearing were mechanically coupled to the shafts of potentiometers so that these shafts rotated as the yokes moved up or down. The wipers of the potentiometers were connected to an averaging operational amplifier, the capacitor in the feedback of which filters out unwanted noise signals.

Measurements on this system indicated that the amplifier output voltage tracks the lift to within 5%.

3.4 Top roller speed

The speed of the top roller was measured as indicated in Figure 6.

A microswitch, mounted near the shaft driving the top roller, is activated by 15 striker plates mounted at regular intervals on the circumference of the shaft. The output of a pair of normally open contacts of the microswitch is transmitted to the computer, which counts the number of contact closures per minute and divides this number by 15, the result being the required speed in revolutions per minute.

4. Software

The software was developed in assembler language. All program development was done at NEERI on a similar computer with faster input-output devices.

The software is divided into 3 sub-systems: an executive program, an input and output control program and a suite of functional programs as indicated in Figure 7.

4.1 Executive program

The executive program delegates control of the central processing unit to the various functional programs according to the time of day and the relative priorities of the calling program.

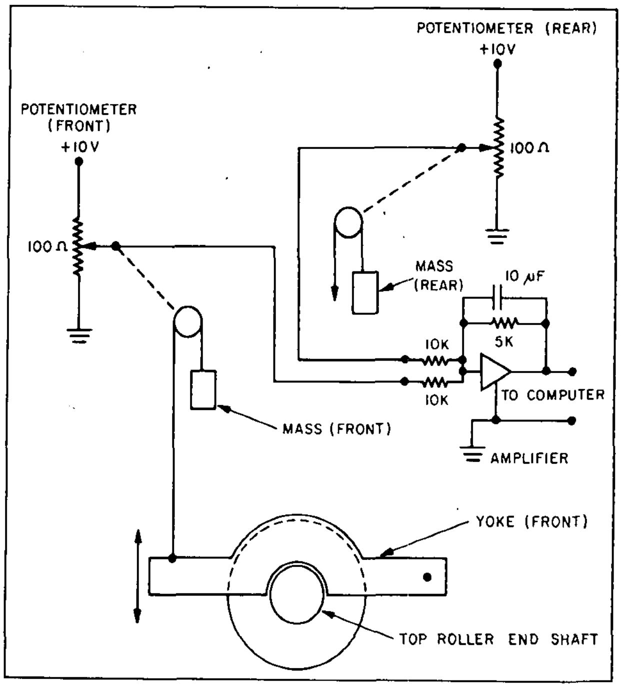

FIGURE 5: Schematic diagram of the top roller lift measurement.

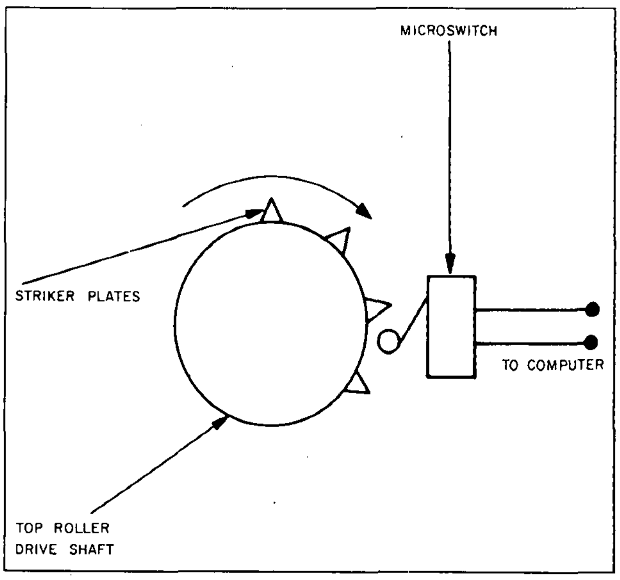

FIGURE 6: Schematic diagram of the top roller revolutions measurement.

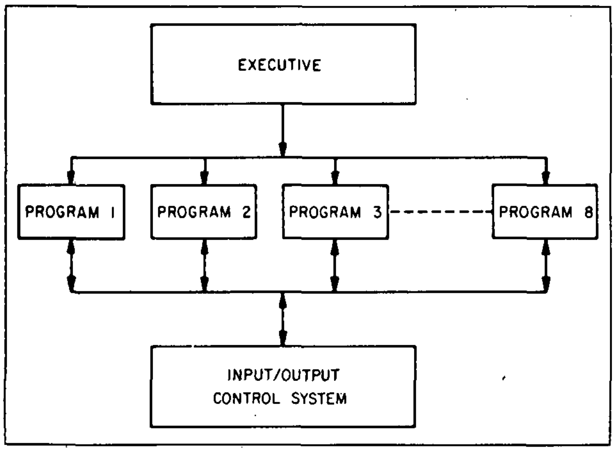

FIGURE 7: Block diagram of software system.

A number of subroutines contained in the executive are used by the functional programs to delay and schedule events via the executive. A functional program can request that it be delayed or turned off, or that another program be turned on at a specific time.

4.2 INPUT AND OUTPUT CONTROL SYSTEM

The input and output system controls the operation of the teletype and the cassette recorder. The operation of the analog-to-digital converter and the digital input system are controlled via simple subroutines contained in the particular functional program that requires analog or digital information.

A functional program initiates input or output by making an appropriate call to the input and output system. This call supplies the identification number of the unit to be used, the number of data words to be transmitted and the area in core where the data resides.

4.3 FUNCTIONAL PROGRAMS

Altogether there are eight functional programs. Four of these acquire data from the various transducers, one outputs hourly scan information on the cassette, two output four-hourly reports on the teletype and the last communicates with the operator. Table 1 lists the various quantities either measured direct by the computer, computed by it, or typed in via the teletype.

TABLE 1
Variables measured

Variable	Sample period
Top roller revs	60 sec.
Top roller lift	60 sec.
Last expressed juice analysis	Hourly
Power consumption in mill motors (Kwh)	60 sec.
Bagasse analysis	Hourly
Bagasse volume	60 sec.
Mill stop time	6 sec.
Cane weight	1 sec.
Mixed juice mass	Hourly
Mixed juice analysis	Hourly
Imbibition mass	Hourly
Cane rate	1 sec.
AC supply volts	—
Cane knives power (Kwh)	60 sec.
Shredder power (Kwh)	60 sec.
Mill motor current	60 sec.
Cane knives motor current	60 sec.
Shredder motor current	60 sec.

Programs 1 *and* 4

The microswitches on the top rollers are scanned every half-second. If a strike has occurred, a corresponding software counter is incremented. Simultaneously the contacts on the mixed juice and imbibition scales are checked for closure, whereupon the corresponding variables are incremented if necessary.

The top roller lift of each mill is sampled 120 times a minute and the lift value is taken as the average of these samples over a minute.

The power consumption of each mill motor is determined once every minute by integrating the product of mill current and voltage in one phase of the motor. The result is then added to a running total kept for each mill separately.

Program 1 runs at half-second intervals and program 4 at one-minute intervals.

Program 2

Program 2 is turned on every second. It determines the cane rate and digitally integrates it by adding the measured value to a running total, thus providing a measure of the mass of cane milled in an hour.

Program 3

This program monitors the current used by the motor driving the first mill. If the current drops below a preset level no cane is being milled andth is state of affairs is defined as a mill stop. The time when such a mill stop begins and ends is typed on the teletype (see Figure 9), and the total downtime is accumulated in a special software counter.

Program 5

The data accumulated during an hour are output by Program 5 on the cassette at the end of that hour. The variables in question are listed in Table 2.

TABLE 2
Variables recorded on cassette

Variable	Comments
Top roller revolutions per minute	Average of hour
Top roller lift	Average of hour
Last expressed juice analysis	Typed in per mill
Mill motor Kwh	Total for hour
Bagasse analysis	Typed in per mill
Bagasse volume	Computed
Top roller diameter	Constant for a week
Cane knives motor Kwh	Total for hour
Shredder motor Kwh	Total for hour
Stop time for first mill	Total for hour
Cane mass	Total for hour
Mixed juice mass	Total for hour
Mixed juice analysis	Typed in
Imbibition mass	Total for hour
Mill width	Constant

15/10/72 10 : 01 4 HOURLY REPORT NO. 3
CANE = 464,799 T / HR = 202,361
MJ = 582,777 T / HR = 253,726 SUC% = 8,279 BRIX = 9,584
IMB = 249,408 T / HR = 108,585
BAG = 131,430 T / HR = 57,193
1 KWH = 246,345 SUC% = 10,299 MOIS = 59,099 BRIX = 19,609
2 KWH = 187,045 SUC% = 8,299 MOIS = 57,799 BRIX = 12,309
3 KWH = 195,875 SUC% = 5,899 MOIS = 54,000 BRIX = 6,289
4 KWH = 204,109 SUC% = 3,599 MOIS = 56,899 BRIX = 3,179
5 KWH = 168,988 SUC% = 2,899 MOIS = 56,000 BRIX = 2,419
6 KWH = 210,803 SUC% = 1,674 MOIS = 53,149 BRIX = 2,812

TYPICAL FOUR HOURLY REPORT

FIGURE 8: Typical four-hourly report indicating the variables listed.

15/12/72 14 : 42 READY ? BA4, 3.5, 3.11, 55.9
15/12/72 14 : 43 READY ? EJ4, 2.39, 3.11
15/12/72 14 : 43 READY ? MJ11.91, 13.74
15/12/72 15 : 00 MILL STOPPED
15/12/72 15 : 03 MILL STARTED, DOWN MINUTES = 3.100
15/12/72 15 : 41 READY ? BA5, 2.3, 2.20, 53.9
15/12/72 15 : 41 READY ? EJ5, 1.6, 2.2
15/12/72 15 : 42 READY ? MJ12.5, 14.27

ANALYSES INPUT & MILL STOP ALARM

FIGURE 9: Typical typewriter listing indicating quanities typed into the computer and a mill stop alarm.

Programs 6 and 7

A selected set of data, a typical example of which is given in Figure 8, is printed four-hourly on the teletype. Such records are used by factory personnel to monitor the operation of the computer system. The four-hourly report is designed to coincide with the four-hourly analyses produced by the chemical laboratory.

A daily report similar to the four-hourly report is produced at 18 h 00 on each day, also a weekly report in similar format, typed on Sundays. These reports provide a quick reference for the factory personnel.

TABLE 3

Operator commands

Command	Description	Parameters
DT	Set date and time of day	—
CC	Change cassette	—
RD	Read data	Variable identification supplied
CD	Change data	Number, new value supplied
SR	Type special report	—
AD	Read analog channel	Channel number supplied
MJ	Mixed juice analysis	Brix and sucrose
BA	Bagasse analysis	Moisture, brix, sucrose
EJ	Expressed juice analysis	Brix and sucrose
PS	Change program status	Program no. and status
LC	Change / display core location	Location (and contents)

Program 8

Program 8 enables the operator to communicate with the system via the teletype. The various commands used are listed in Table 3. They provide for starting up the system, reading and/or changing data, and typing in the various results of analyses to determine the percentage moisture, brix and sucrose in the bagasse. On mill 6, bagasse analyses are determined hourly, while on the first 5 mills this is done once every five hours, these mills being taken in turn when an analysis is performed every hour.

The last expressed juice is analyzed every 6 hours for each mill, these being taken in turn as an analysis is carried out every hour. As soon as a result is known it is typed into the computer under supervision of the operator communications program. The mixed juice is analyzed for the percentage brix and sucrose it contains, the result being input in a manner similar to that used for the last expressed juice. Typical examples are given in Figure 9.

Determination of rms current and power

The current used by an electric motor is determined by taking the average of the square of 260 samples taken at a rate of 1 000 Hz. This method yields the rms current within an error of less than 1 %.

The power consumed by a motor is determined by sampling a phase voltage and the corresponding phase current consecutively. This double sampling is also done at a rate of 1 000 Hz. The following formula is then used to obtain the power used by the motor:

$P = 3\ \Sigma(I_i V_i)/N$

where: I_i and V_i = current and voltage samples respectively;

and N = number of samples = 260.

It is found that as long as the voltages representing I and V in the analog-to-digital converter do not differ by more than a factor of 10, the power is computed accurately to within less than 2%. The method also turns out to be relatively insensitive to line frequency variations, a change of $\pm$ 2 Hz in line frequency causing an error of less than 3% in the calculated power consumption.

5. Operation of the system

The practice at the sugar mill is to start milling at 12 noon on Mondays and to shut down again at midnight on Sundays for scheduled maintenance. The computer was started and turned off at the same times as the mill by factory personnel, but otherwise it operated unattended, and in this way ran almost continuously for six months. During this time data covering 12 full weeks were obtained, various teething troubles and malfunctions having caused loss of data during the remainder of the six-month period.

Since the computer was not situated in an air-conditioned room the environment was not ideal. An especially troublesome effect was the occurrence of random errors owing to overheating of the computer memory. The difficulty was overcome by blowing cool air from the roof of the factory into the computer room. The accumulation of dirt on the electronic circuits also caused occasional malfunctioning. This was overcome by cleaning the circuits with compressed air on Mondays, while the mill had stopped.

The fans that cool the CPU of the computer were contaminated by the particles of sugar and bagasse always present in the air at the sugar mill, and had to be cleaned regularly. It is recommended, however, that the computer be placed in a fully air-conditioned room in future.

Although the analyses typed into the computer were checked against high and low limits for validity, small errors in the typed values could not be detected. Spot checks on the data recorded on the cassette revealed very few errors.

On one occasion the load cell installed on the weighbridge was damaged by being overloaded by an unexpectedly large bundle of cane on the conveyer belt, and it had to be replaced with a unit having double the load specification.

The data obtained are currently being analyzed and the mathematical model of the mills fitted to them. The results are promising and it is hoped that a satisfactory model of the mills will emerge.

6. Acknowledgements

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