

PRACTICAL EXPERIENCES OF VIBRATION CONDITION MONITORING

By A. R. FAIRCLOUGH and A. WIENESE

Sugar Milling Research Institute

Abstract

This paper evaluates the usefulness of measuring vibrations that are inherent in all machines and it shows how such measurements can be interpreted to indicate a machine's overall internal condition. Results from measurements on machinery employed at sugar factories are presented together with a survey of measuring equipment and methods currently employed by paper mills. The potential for introducing a predictive maintenance technique into the sugar industry as a cost saving tool is outlined.

Introduction

The South African sugar industry like many other industries is faced with ever increasing maintenance costs. Looking at the maintenance process it was felt that some rationalisation in this area could result in substantial savings in the maintenance budget.

A few words about maintenance management systems (MMS),⁵ both past and present, are necessary before progressing further. The first type of MMS was based on a "run-to-break" concept in which machines were allowed to operate until they failed, at which time they were replaced. This was the order of the day in the early decades of this century where machines tended to be over designed and were relatively simple by today's standards. At the same time industry was less capital intensive. These factors together with a lesser dependence on continuous operation of machinery, contributed to a more or less reliable operation. If things did go wrong they were relatively easy and simple to fix. This type of MMS served well until the second world war when a sudden demand for goods coupled with a reduction in manpower availability led to an increase in mechanisation. Industry became less tolerant of breakdowns and a calendar or scheduled type of maintenance came into being. The concept was based on the assumption that machines had a fixed "life-span", sometimes referred to as "hard-life", and to be able to achieve this predetermined "life-span" certain inspections and services would have to be undertaken periodically. This concept was the backbone of many MMS's and grouped together formed what we now understand as preventive maintenance. The idea worked well, for a time, when labour and replacement parts were cheap, but in today's world the system is proving to be uneconomic. It is manpower intensive and involves the use and replacement of costly spares and consumables many of which are replaced unnecessarily. In addition damage is sometimes inadvertently caused when machines are opened during the inspection process.

Although this type of MMS is still much in evidence today, as machines become more automated and their employment in industry increases an imbalance is created as they start to outnumber people. The consequence of this imbalance will mean that there are not enough trained personnel to service the number of machines employed resulting in missed schedules and inefficient maintenance and leading finally to breakdowns.

The alternative to this depressing scenario is the predictive approach which attempts to pre-empt a breakdown by the use of proven non-destructive monitoring techniques. One of these techniques is the measurement of vibration levels.^{5,6}

A machinery vibration condition monitoring (VCM) project was started at the SMRI during the 1986 crushing season to investigate a system of monitoring machinery condition by vibration measurements. The objectives of the project were (a) to become familiar with the concepts of VCM and (b) to gain sufficient experience in the methods and applications of such a system to be able to advise the sugar industry on the usefulness of the technique as a maintenance tool and where and how to apply it in a sugar factory. To meet these objectives a VCM system was developed and subsequently used in extensive field work. A sophisticated commercial package was also tried, and a survey conducted of VCM in other South African industries.

Vibration Monitoring Systems

The various hand held vibration meters commercially available range in price from R6 000,00 to well over R100 000,00. The basic functions of these meters are however similar in the collection of raw data, the handling and processing of data and the presentation of these data to the end user. The data handling and processing capabilities of such meters are limited and most systems are supplied with the option to interface to a computer. The computer software will then perform the more sophisticated system management and data presentation. The differences between the various vibration monitoring systems therefore, in terms of cost and capability, are dependent on the degree of sophistication of the vibration meter and associated software packages.

Bruel & Kjaer, (B & K),² suggest three degrees of sophistication when classifying instrumentation for vibration monitoring. The simplest system uses a pocket-sized vibration meter which measures the vibration level over a wide frequency range. Measurements are compared with general standards (ISO, VDI) according to the kW rating of the machine being measured, thus providing a rudimentary indication of a machine's condition.

First Level of Sophistication

B&K 2513 Vibration Meter

The B&K Type 2513 is classed as a General Purpose Vibration Meter and as such can be operated as a "stand-alone" instrument. Used in this manner the meter integrates raw data to obtain an overall vibration level quantified either in terms of acceleration or velocity. However, a prominent feature of the B&K meter is its ability to "average" data. When measurements are taken either as "Peak" or "RMS" energy values the meter is continuously "scanning" the raw data, and consequently the L.E.D. display fluctuates up and down the scale according to the energy level of the signal

under consideration. Trying to read a fluctuating meter is a familiar problem, and since one guess is as good as another the average value perceived will differ and therefore be inaccurate.

The problem of fluctuation has been solved by switching the meter into its "60s Leq", (60 second equivalent continuous level) mode. This means that the vibration level has the same energy as the fluctuating vibration level being scanned. The data are sampled over a 60 second period and then "frozen" on the display, thus displaying a more accurate reading. Unfortunately this "more accurate reading" is subject to human error; it has to be read off a logarithmic scale, (one guess is as good as another!), and finally recorded, manually, to a "Machine Status Report". The B&K 2513 has an A.C. output designed for interfacing with other B&K equipment such as tape recorders and frequency analysers. It is this facility that the SMRI Project used fully.

Second Level of Sophistication

The second level of sophistication comprises a hand held vibration meter which is capable of performing a Fast Fourier Transform (FFT), necessary to be able to carry out frequency analysis. One is now able to transform data from the time domain (first level of sophistication) into the frequency domain where vibration levels can be interpreted in terms of their position within the frequency spectrum. By viewing the spectrum one is now able to define the different frequency components present in the spectrum and analyze faults according to the position of the frequency component.

SMRI System

The SMRI system uses the B&K 2513 vibration meter interfaced to a personal computer via a fast analogue to digital converter board. Software was written to read the raw data from the meter, display these data on the screen (see Figure 1), perform the FFT, display the frequency spectrum (see Figure 2) and finally store both forms of data on disk for future analysis.

Although originally developed as a research tool, the SMRI system, developed to its present state, compares favourably with some commercial systems, particularly because of its low cost, and can in its present form be used with confidence in the factory environment not only to measure vibration levels but also to produce frequency spectra necessary for vibration analysis. Its value as a maintenance tool has been proved by the highly successful field work which has been carried out in sugar factories recently. The system does have limitations, the main one being that the vibration meter does not have a storage capacity, which necessitates the operator transporting a portable computer around the factory. Another factor is a restricted frequency range. The maximum frequency that can be recorded is 1000 Hz which is sufficient for most applications but too low for some gear meshing, roller bearing and blade pass frequencies.

The Rion VM-61 System

The Rion model VM-61 vibration meter¹ is an analogue meter similar to the B&K 2513 but, unlike the B&K, has a memory for storing the simple vibration level readings from

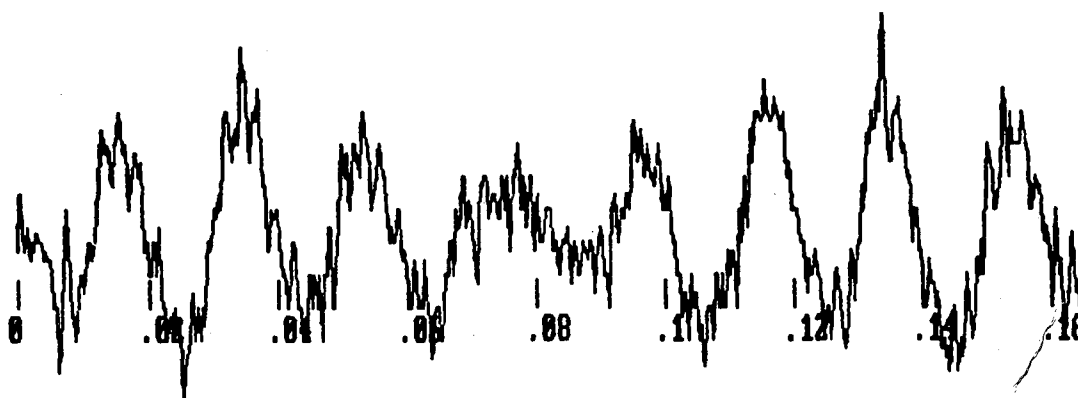


FIGURE 1 Typical waveform data measured on a turbine at Gledhow.

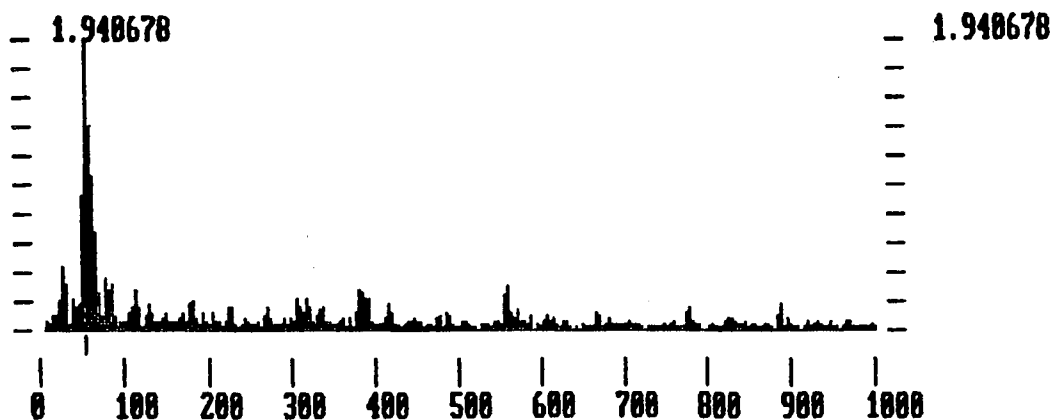


FIGURE 2 Frequency spectrum of the waveform in Figure 1.

250 test points. This makes the meter portable and through a compatible interface the raw data can be down loaded to a computer and analysed by using the SMRI software programme. There is a narrow band tunable filter available which plugs into the bottom of the meter at additional cost. By tuning the filter one is able to define whether the magnitudes of vibration occur at shaft rpm or 1st, 2nd and 3rd harmonics. The unit was tested at GH & ME and, although fulfilling the function for which it was designed, it was found to be much slower than the B&K in attaining an overall vibration level, and generally the B&K meter was preferred.

The above systems are adequate providing the number of measurement points are limited. As the number of points increases the data handling becomes unwieldy and justifies the use of a computer based system. These systems form the third level of sophistication.

Third Level of Sophistication

This is a software driven, computer based system which must be able to handle the following important functions:

- (a) Set up of a data base in order to define sections of plant, identify the type of machines in the sections and identify the positions on the machines where measurements will be taken. There must be no ambiguity in the set-up ie the code allocated to a measurement point on a machine must be specific to that point and machine and no other.
- (b) Set up a geographical route using the information outlined in (a) above.
- (c) Interpret at least one recognised standard for machinery permissible vibration levels, for example VDI 2056, DIN 45665 or BS 4675.
- (d) Set up alarm levels for different kW rated machines.
- (e) Perform multiple frequency spectral plots to allow "trending" and in so doing calculate lead time before repair.
- (f) Perform cross-machine spectral plots so that like machines can be compared.
- (g) Produce machine status reports including historical data.

The vibration meters are data collectors and are similar in concept. Most have a data storage facility and carry out an on board FFT alleviating the problem of carrying large pieces of equipment around the factory, whether they be portable computers or frequency analysers. They vary in the size of memory and operating frequency range. Some vibration meters can be interfaced directly to a printer for dumping spectral data and some are able to operate on user written programmes. The minimum requirements of these vibration meters are the ability to store raw data and to perform an FFT so that frequency spectra can be produced. The amount of data that can be stored will depend on the complexity of the route and how accessible the machines are. With this type of vibration meter the actual time taken to collect and analyse one data test point is a few seconds, and naturally time must be allowed in getting to and from the test points. On average an operator should be able to collect 600–800 data samples during a normal shift, which would represent approximately 140 machines. Other claims are made of 1500 samples per shift, which could be achieved with a well laid out plant, in close proximity and on one level. This type of system is highly portable and fast in operation. The vibration meter will most likely have other features such as a note pad facility or the ability to be used

as a straightforward data logger for collecting process measurements.

The software packages used with these vibration meters are large databases, capable of managing the entire machine condition monitoring procedure from data sampling through the analysis and diagnostic stage, setting alert and alarm levels scanning data files for trend analysis, comparing machines and producing reports on machine status and prediction to breakdown. A computer fitted with a hard disc is required since the software takes up approximately 3 mB of memory.

The C.S.I. System

This system has been used by the SMRI and can be considered typical of a third level system. The C.S.I. data collector⁴ can be used as a "stand-alone" instrument or operated together with a software package. As a stand-alone device the instrument is highly portable, measuring approximately 260 mm long, 160 mm wide and 40 mm deep. It is able to measure raw data, perform an FFT and store data in both the time and frequency domains. The instrument has a small L.C.D., upon which spectra can be generated. This operation can be performed at the test point under consideration. Facilities are also available to scan these spectra and expand them both in terms of band width and amplitude. (The SMRI system is able to compete at this level of sophistication but is slower and less portable).

Field Trials

All the work undertaken in the field was carried out using the SMRI vibration condition monitoring system. Different factories were visited and various items of plant were monitored over a period. The work concentrated mainly on turbo-alternator generating sets for the purpose of establishing a 'trend' on relatively stable machinery. At the same time plant such as boiler feed water pumps, gearboxes, shredder drives & rotors, induced draft fans and cyclodrives received attention. This work is reported in detail elsewhere⁴ and will be mentioned here only briefly.

Umfoloji

UF employed the services of a company specialising in the measurement of vibration to monitor their AEG/KANIS 5 mW alternator. The equipment used was a system called 'Vibrotest' by Schenk and the last vibration levels were recorded by them in August 1987. The following month the measurements were repeated by staff from the SMRI using the same measuring points but using the SMRI system. The machine was under the same load conditions and the results obtained from the SMRI system compared favourably.

Gledhow

The three turbo alternator sets at GH were monitored continuously during the 1987 season. A series of measurements taken at points on No. 1 Allen T/A set is shown in Figure 3. From this information it would be possible to set alert and alarm levels for all the points shown.

During the 1986/87 off-crop GH installed a stand-by boiler feed water pump set. The pump is a 5 stage unit manufactured by Sulzer, directly coupled to a 3 000 rpm motor and is identical to an existing set which has been in service for some years. When the pump was commissioned it was noticed that its vibration was much worse than that of the existing set. The SMRI was asked to measure the vibration levels on both pumps, and levels on the new pump were indeed higher. The first priority was to check alignment, and since the unit was still under guarantee the problem was

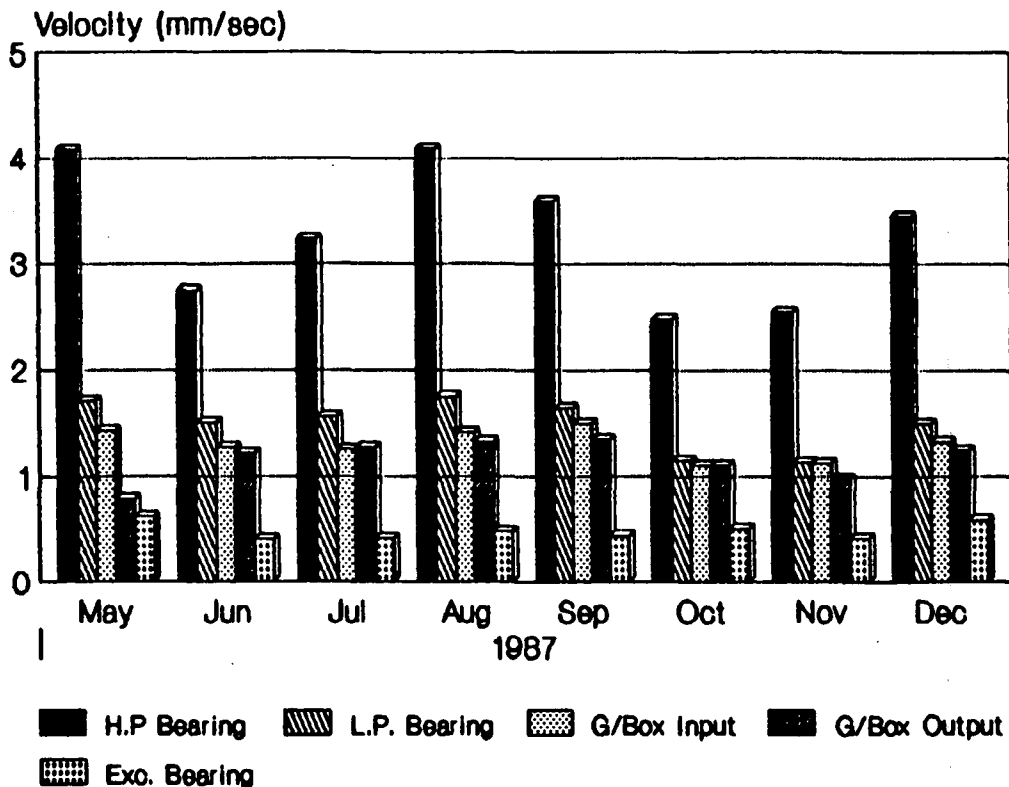


FIGURE 3 Trending data at Gledhow for turbo-alternator set No. 1 at full load (115 Hz).

brought to the attention of the manufacturer, who received a copy of the frequency spectrum submitted by the SMRI (Figure 2). The pump and motor were found to be misaligned which was subsequently corrected. Measurements were taken after alignment and it was found that the axial vibration levels had diminished as was to be expected. The radial readings however remained high and since they were present at shaft r.p.m. a defective journal bearing and/or bent shaft was suspected. It was decided to investigate the problem further by internal inspection in the 1987/88 off-crop. It was found that the pump did in fact have a bent shaft, the drive end bearing housing had picked up metal and the drive end oil ring was found to be non standard. This exercise illustrates the benefits of VCM. A “feel” that something was wrong was verified quickly by scientific method which enabled simple deductions to be made which proved to be accurate. In addition it is an example of how vibration measurement can be used to ‘prompt’ some response from a supplier and how useful information can be gained by comparing similar machines.

Maidstone

The 3 mW Metro-Vickers turbo alternator developed a high vibration during the season. The vibration was noticeable to MS staff standing in the vicinity of the machine, and a governor problem was suspected. Again using the SMRI system measurements were taken and a vibration level of 45 mm/sec was detected on the low pressure turbine bearing. The machine was shut down and the turbine opened. The major damage was found to be on the high pressure bearing which showed cracks and chipping on the journal. The rotor was 82 g out of balance with excessive ovality of the journals. It is difficult to explain why the high vibration level was detected on the L.P. side of the turbine when all the damage occurred on the H.P. side. Possibly the coupling between the rotor and gearbox was acting as a fulcrum causing the low pressure bearing to absorb the imbalance caused by the ‘floating’ shaft. In any event vibration measurement directed

the maintenance team to the component at fault, saving materials and man hours in unnecessary dismantling of ancillary equipment.

Mount Edgecombe

The levels of vibration emanating from the 4 B&M T/A sets at ME are high in relation to other installations. They emanate from various points in the drive trains of all four T/A's. Since the foundations of these machines are tied together in a concrete and steel structure, the vibrations are transmitted throughout the building and are most noticeable at certain points on the operating floor. The vibrations have been present to some degree for some years but have steadily increased recently and are now a cause for concern. Vibration measurements taken by the SMRI identified the problem areas which are receiving attention at the time of writing. Figure 4 shows the vibration levels of the four machines. The test points span the machine from the H.P. bearing (Test Point No. 1) to the exciter bearing (Test Point No. 5).

Vibration Condition Monitoring as Applied in some Paper Mills

Sappi Fine Paper and Sappi Kraft introduced a VCM system some years ago with the objective of reducing lost time resulting from mechanical breakdown, and more specifically to reduce breakdowns occurring outside normal working hours and thereby to reduce labour costs. The system involves the measurement of broadband vibration levels using hand held vibration meters. All machines in the plant are monitored with the exception of certain bearings on the felt rolls of the drying machines. These bearings are difficult to access due to hazardous environmental conditions, but plans are being made to include them in the programme by installing local transducers.

The system is managed by a foreman and one or two vibration testers. Data collected are recorded manually at the time of measurement and entered onto machinery log

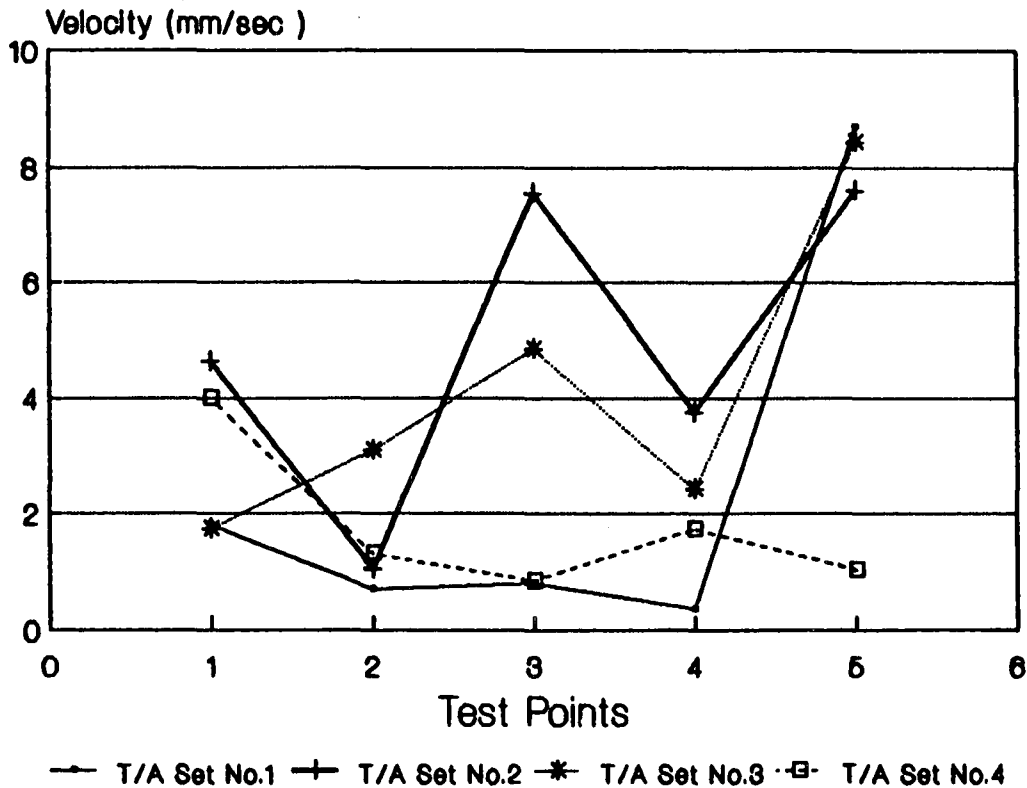


FIGURE 4 High vibration levels at Mount Edgecombe (see text for locations of test points).

sheets. In this way experience has been gained on the behaviour of machines at the plant from the enormous amount of information collected over the years. Since 1984, mechanical downtime has been reduced from an average of 9 hours per month to 0,6 hours per month in 1987. Cost saving figures were obtainable but from information received from a similar facility, downtime on a large paper making machine costs approximately R9 000 per hour in lost production. Since the mills operate on a 24 hour basis, all year round with no stop days for maintenance and little or no standby-by plant, simple arithmetic shows that losses have been reduced from approximately R972 000 to 70 000 per annum. This achievement is attributable solely to VCM.

Call-outs during silent hours are almost non-existent, and faults detected in the predictive maintenance process are slotted into planned machine stops. In conjunction with the vibration monitoring programme Sappi conducts a monthly check of all oils for water contamination. The equipment for this is supplied free by Mobil. When water content exceeds 0,5% the oil is purified on site. Simple viscosity checks are also undertaken at the plant. To back up these simple analyses oil samples are sent to Mobil every three months for a qualitative analysis. By employing these techniques Sappi has been able to reduce oil costs by approximately R200 000 per annum for the 1986 and 1987 seasons compared with 1985. The oil budget for 1988 is less than that for 1985. VCM has played a major part in these savings by pre-empting breakdowns and thereby preventing contamination of oil. An example of the role played by VCM is in the oil savings on the large paper machines which were using 2 100 litres of hydraulic oil per month in 1985. This has reduced to 420 litres per month in both 1986 and 1987, representing a saving of 80%.

Other Industries

Escom, Iscor, Sasol, Mobil, RTZ (Palabora) and Mondi, were approached to try to evaluate monetary savings attributable to their respective VCM systems. Unfortunately

this information was not available, but all concerned expressed their satisfaction with the technique and would not revert to preventive maintenance schemes.

Installation of a Third Level VCM System at a Sugar Mill

In this scenario the sequence of events required to set up a typical VCM system from the decision taken to introduce the technique through to commissioning and application is described. Questions which should be asked will be considered. As an example, assume that the objective is to improve overall time efficiency. Consider a mill crushing 1 200 000 tons of cane per annum based on a 36 week season with a 15 hour stop period per week. The overall time efficiency for the mill is 80%, no cane-stops 4%, scheduled stops 9% and other stops 7%. The objective is to improve OTE by improving the maintenance procedure. Generally scheduled stops are governed by evaporator cleaning and could possibly be reduced by looking at more efficient methods, and since less preventive style maintenance will take place the mill should look at reducing the stop day from 15 hours to say 12 hours, representing a saving of 20%. Assume that other stops are attributable to:

- (a) chokes — 1%
- (b) operational — 2%
- (c) breakdowns — 4%

Assuming little or nothing can be done, initially, about items (a) and (b) the mill should look to reducing its breakdowns by at least 70%. (Other industries have achieved better than this).

Therefore savings made on scheduled stops and breakdowns are 1,8% and 2,8% respectively. The total of 4,6% represents an improvement in time efficiency and, related to tons of cane, equates to 65714 tons. This tonnage in turn represents 2 weeks crushing for the mill in this model. The implication of this is obvious since the mill will be able to

reduce the crushing season by 2 weeks benefitting from higher pol, less fibre and ash through the mills, savings on coal and reduced labour costs etc.

The decision to install a VCM system will most likely have been based on a positive response from most if not all the following questions:

- (a) Do the benefits justify the cost and will the benefits be more cost effective than the present system, for example in terms of an overall decrease in the maintenance budget, plant availability or longer periods between overhauls?
- (b) Will the adoption of a condition monitoring system provide a more efficient planning function with a resultant decrease in expensive stock items?
- (c) Can the system be implemented with existing manpower, who should they be, what skill levels are required and is additional training needed?
- (d) Can present oil consumption be reduced significantly or at least to a realistic level?

Some of these points have been answered by the improvements made in the paper industry already discussed.

To install a computerised vibration condition monitoring system will require an investment of approximately R50 000. From the experiences of others one can expect improvements in the following areas:

- (a) Better plant availability since plant will not be taken off line for routine procedures.
- (b) Less frequent overhauls since these will only take place when the vibration signature of the machine does not conform to its normal operating level.
- (c) A reduction in call-outs and therefore a saving in the labour budget.

There will also be a reduction in oil consumption directly attributable to the VCM system since by pre-empting breakdowns there will be less oil contamination. The implementation of the VCM system will mean that the Planning Office will become more efficient since less paperwork will be generated. The only schedules to be compiled and processed will be for those items of plant which are not suitable for VCM, for example slat carriers and spiller tables. The available time thus produced will become available to the planning function for the management of VCM. Once sufficient data have been collected to implement trending of machines this information can be channelled to the buying department who will be able to make full use of the lead times for organising realistic stock levels. This will eliminate "thumb-suck" stock levels, generated in the past by the maintenance department, resulting in less capital tied up in unnecessary stock items.

A suggested procedure for the management of a VCM programme is outlined in Appendix A.

Conclusion

It is evident that modern systems of maintenance, based on vibration analysis, have a role to play in the sugar in-

dustry. Maintenance costs are escalating and equipment is ageing and expensive to replace. To reduce maintenance costs it is recommended that proven scientific non-destructive testing technology should be introduced into the industry thereby removing the "guesswork" from the maintenance procedure. VCM has proved its value for use as a cost saving method in the recent field trials. The concept is simple to use and the results relatively easy to interpret. In terms of cost VCM systems are inexpensive when considered in context with the enormous savings which can be achieved by their implementation, savings which are already being enjoyed by other industries.

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APPENDIX A

It is suggested that the management of the VCM programme becomes the responsibility of the planning officer. His function will be to manage the data base. His training will take place on site over a period of 5 to 6 days and will involve complete familiarization with the system. He will not be trained in diagnostic techniques since this function is handled by the software. A plus factor here is that the system will not be reliant upon one man. The planning officer after training and shortly after the system comes on line should start to train a subordinate who can deputize for him whilst on leave etc. For the same reason two people should be trained as vibration testers. Ideally they should be artisans and if this is not possible a minimum of standard 8 level education is required. The vibration tester should report to the planning officer. The planning officer will be responsible for loading routes, machines and measurement points into the vibration meter once they have been defined by, or in consultation with, factory management. He will direct the vibration tester along these routes and download the information collected into the host computer at the end of the day. At this point the software will take over the responsibility of processing reports. Hard copy reports should only be produced when the information contained therein has significance. For example it is pointless to produce paper stating that a machine is behaving within its design parameters. Should any abnormal information be present the necessary reports for further evaluation or action will be produced automatically and if a diagnostic program is installed the most likely causes of the anomaly will be stated. This system provides a simple self managed approach to vibration condition monitoring and as is the case at the paper mills the engineer rarely becomes involved with the procedure.

Once the ground work has been done and the system installed commissioning will take place in conjunction with the equipment suppliers. It is suggested that one section of plant be introduced at a time, and as soon as it is fully integrated into the VCM system further sections be added until the whole facility is being monitored. For example the power house will most likely be the first section to come on line followed by cane preparation plant, boiler feed water pumps, service and injection water etc.