EXPERIENCES WITH CONDITION BASED MONITORING AT PONGOLA

By T. ENDRES and H. COOMANS
CG Smith Sugar Ltd, Pongola

Abstract

A system of condition based monitoring is described involving the collection and manipulation of vibration data, oil analysis and various other performance data. Experience obtained with the system at Pongola is related whilst practical advice is provided for its implementation, administration and economic justification.

Introduction

When considering a maintenance system for the 1990s one needs to utilise fully all available technology, especially that which is PC based. The old philosophy of 'strip and replace' cannot be accepted in today's world for the following reasons:

- Research has proved that there is a more economic manner in which to do maintenance.
- 'Strip and replace' maintenance is costly in a climate where there is continual pressure on maintenance costs in order to maximise profits.
- The effects of endless overtime and high pressure offcrop maintenance on human resources is counter-productive.

Over a short space of time practical methods have been developed and implemented at Pongola to make up the condition based monitoring programme which makes use of the following parameters:

- Vibration analysis
- Oil condition analysis
- Vacuum pump performance testing
- Non destructive testing

Vibration analysis

All rotating equipment produces vibrations to some degree. These vibrations originate from numerous sources either within the machine or externally. The amplitude and frequency of these vibration signatures are captured and then analyzed to assist in determining the condition of the equipment. Interpreting the different components within the vibration signature or spectrum can sometimes be difficult in that dissimilar machine conditions sometimes lead to similar vibration signatures, e.g. misalignment and imbalance.

The following machine conditions were identified as the major causes of vibration within the plant at Pongola:

- Misalignment
- Structural defects
- V-Belt defects
- Bearing defects
- Imbalance
- Electrical motor defects
- Couplings
- Cavitation

Misalignment

The types encountered are angular, radial, bearing and pulley. Misalignment problems can cause early failure of bearings, couplings, vee-belts and pulleys. Furthermore case studies have shown that there is an increase in power consumed by misaligned equipment of between 7 and 12% (Anon, 1991).

Misalignment is identified by a high 2 × rpm vibration peak of the shaft in the radial direction in the case of radial misalignment and by a peak at 1 × rpm in the axial direction in the case of angular misalignment. Radial misalignment, however, also produces a high axial vibration at 1 × rpm of the shaft. Generally if a high axial vibration is detected in the signature, a misalignment problem can be expected. Figure 1 shows the vibration spectrum before and after the directly coupled motor and pump were aligned correctly.

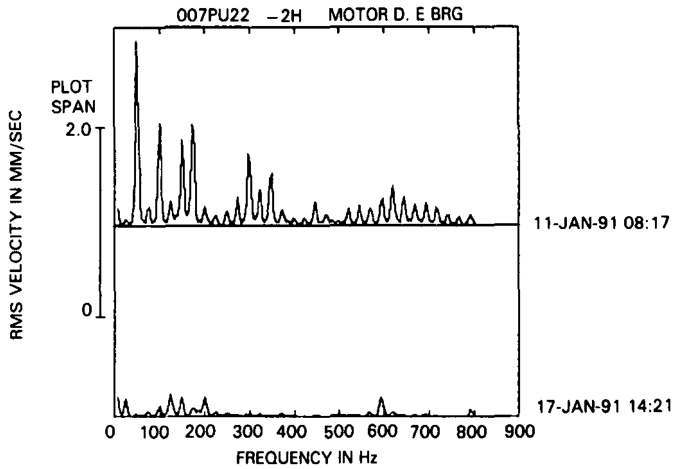

FIGURE 1 Pre and Post Alignment Correction

Structural

Many machine structures, e.g. bases, are nowadays designed for strength rather than rigidity due to cost implications. It is very rare that a base is designed to limit or minimise vibration. This leads to resonant vibration forces being set up in the machine structure. These vibrations can also be transmitted to adjacent machines in which they can cause unnecessary failure. 'In-house' manufactured bases need to be designed with an inherent degree of stiffness if the problem of structures resonating at the same frequency as the running speed of the equipment is to be eliminated. Base foot-plates need to be accurately packed to avoid 'Soft Foot' conditions in mounted equipment.

Structural resonance problems are indicated by a high 1 × rpm peak (Figure 2) with a change of phase close to running speed.

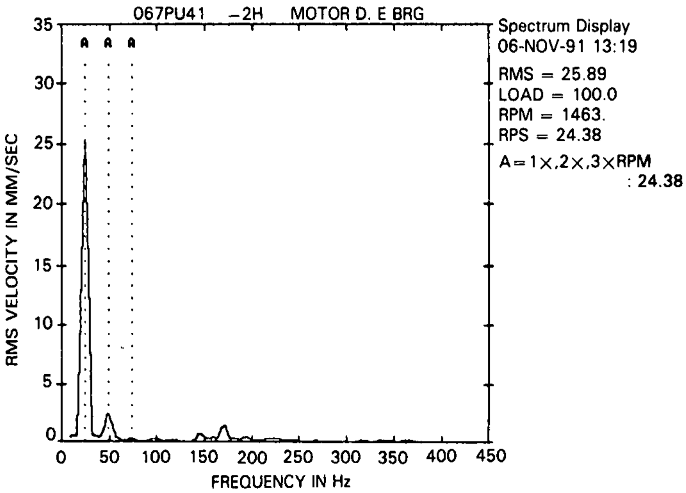

FIGURE 2 Resonating Structure

Belts

Three types of belt defects have been encountered at Pongola:

- Belt tension too tight which leads to excessive stresses being exerted on bearings, thus decreasing their life spans.
- Mismatched belt sets - high vibration readings are produced from individual belts having different tensions.
- Defective belts - bearings and pulleys are damaged by the continuous knocking action.

Belt defects are identified by a prominent 1 × belt speed frequency peak in the vibration signature. Figure 3 shows comparative spectra of a belt set damaged by slipping during startup and after the belts were changed.

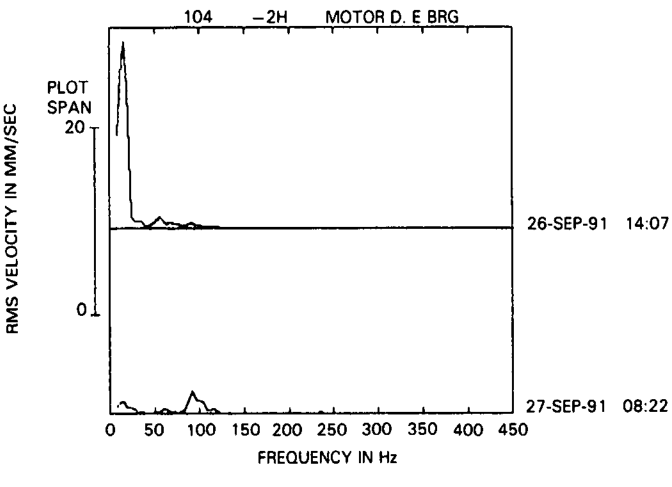

FIGURE 3 Poor and Good Condition Belts

Antifriction bearings

Complete bearing failure inevitably results in damage to other components within the running unit. The early detection of bearing defects is thus vital. Each component in the bearing develops a unique or characteristic vibration signature. By calculating the various frequencies for each component and relating this to the signature one can identify which component is defective. Other types of bearing defects include bearings which are loose on the shaft; bearings loose in the housing; misalignment of bearings (more prominent with plumber block configurations) and brinelling in stationary units. Bearing damage is initially indicated by peaks in the high frequency ranges (above 2 000 Hz) but as it degrades becomes more obvious in the 800–1 600 Hz range, and finally in the 400–800 Hz range.

Figure 4 shows signatures of a defective and a new bearing installation.

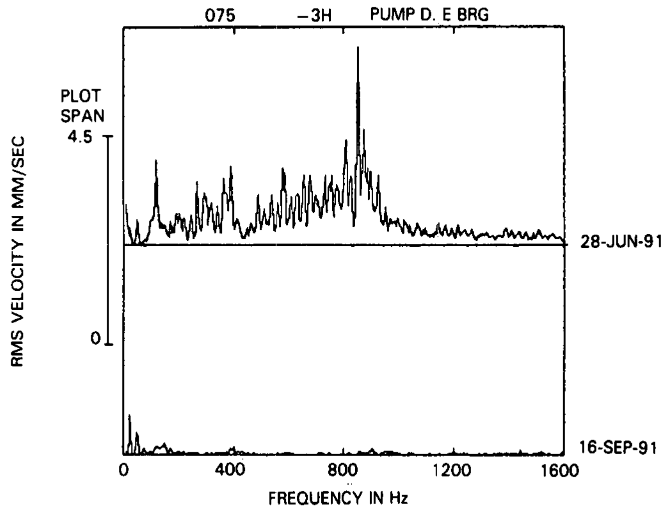

FIGURE 4 Typical Defective (above) and New (below) Bearings

Loose bearings in housings are indicated by a prominent 4 × rpm machine speed peak. Figure 5 shows comparative spectra of this defect.

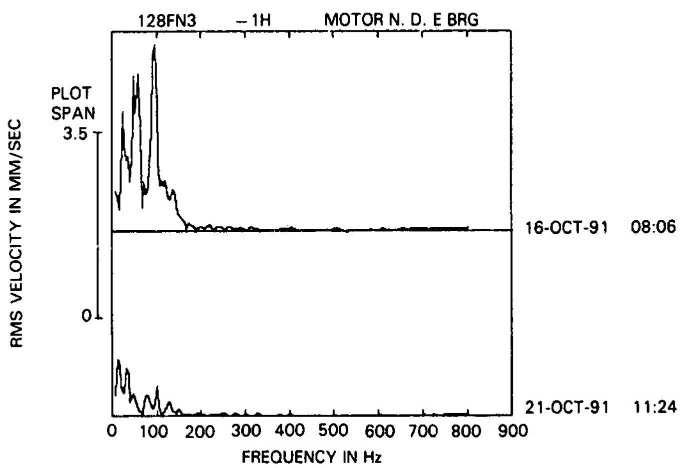

FIGURE 5 Pre and Post Signature of loose bearing in Casing

Bearings which are loose on shafts are indicated by a high 3 × rpm machine speed peak. Bearing brinelling has the same signature characteristics as a damaged bearing. It is caused by vibration transmitted from surrounding equipment while the bearing is stationary over an extended period. This is a very real problem where a standby machine philosophy is adopted. To avoid brinelling, standby plant must be alternated at regular intervals or isolated from the vibration source.

Imbalance

Out of balance conditions originate for various reasons:

- Maintenance - rebuilding of liners etc.
- Build up of foreign matter on blades.
- Broken blades, vanes or knives.
- Looseness on shaft.

Imbalance in equipment eventually leads to bearing damage and in extreme situations, bent shafts. A high 1 × rpm peak on the spectrum (Figure 6a) with a strongly sinusoidal waveform (Figure 6b) and very few harmonics indicate the presence of an imbalance.

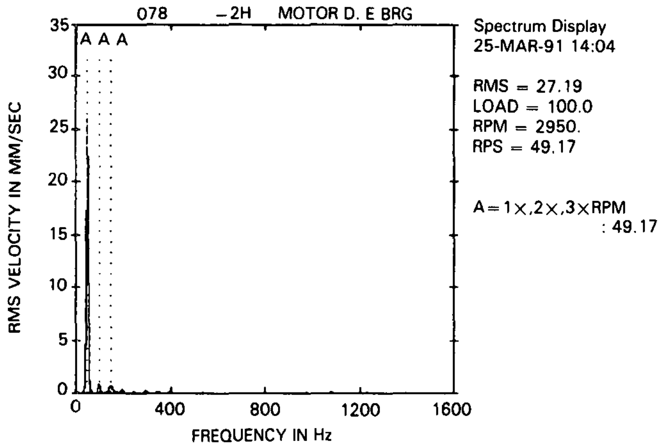

FIGURE 6a Typical Imbalance

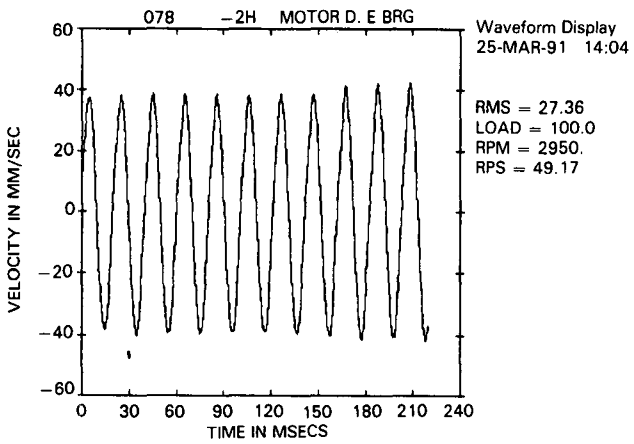

FIGURE 6b Waveform Signature

Imbalance in a vibration signature can sometimes be misinterpreted as misalignment as this is also indicated by a high 1 × rpm machine speed peak. To facilitate the balancing process trial weights have been made up which either clamp on or are bolted onto the equipment being balanced. All cane knives and shredder rotors, fans, motor rotors, shafts etc. are now balanced on site at Pongola using the vibration analyser and its associated software. Figure 7 shows the vibration signatures of a typical imbalance condition on a fan.

Electrical motor defects

Electric motor defects which lead to vibration changes can be classified in one of two categories:

(a) **Mechanical.** Bearing defects are indicated on the signature as per bearing related defects. Rotor looseness inevitably leads to shaft failure. As the rotor moves on

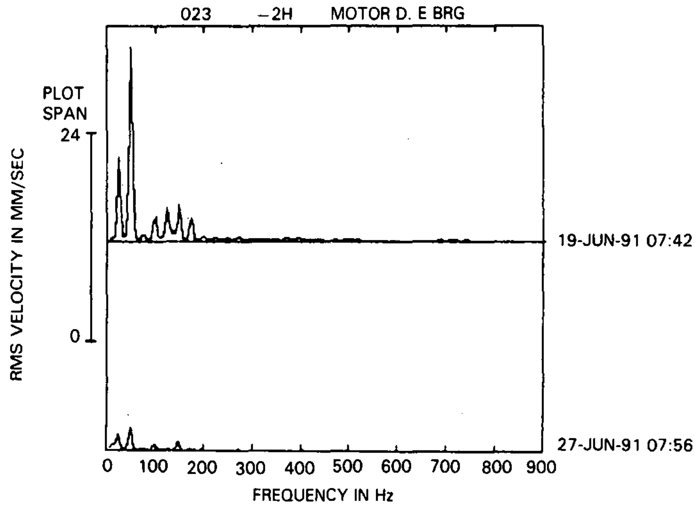

FIGURE 7 Case History of Fan

the shaft an electrical impedance is produced giving rise to a high 1 × line frequency peak, i.e. 50 Hz on the signature (Figure 8). Cooling fan loose on shaft is seen as a high 1,3 × rpm motor speed peak (Figure 9).

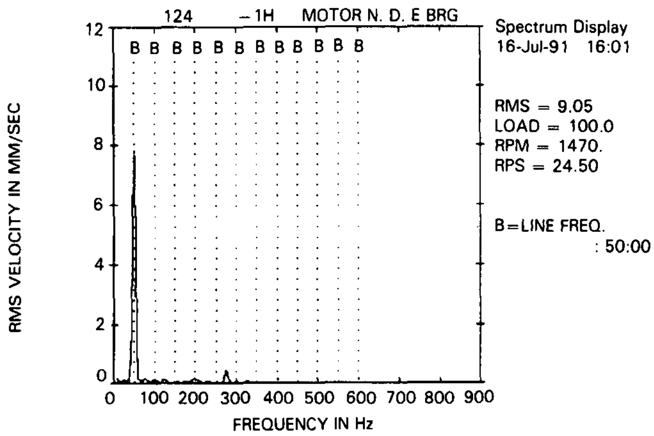

FIGURE 8 Electrical Disturbance - Loose Rotor

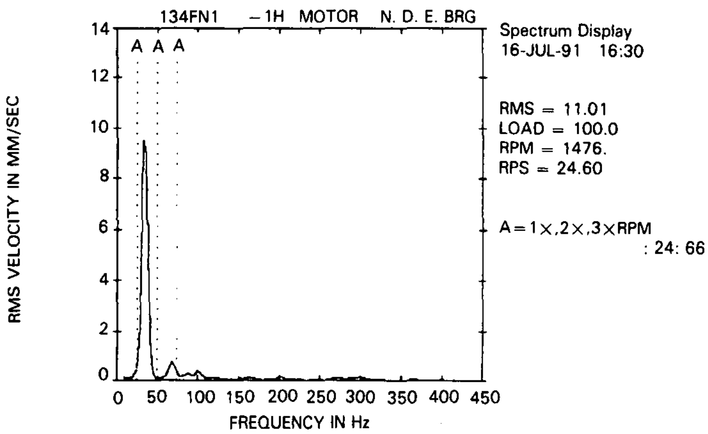

FIGURE 9 Motor Fan Loose

(b) **Electrical.** Electrically induced defects are indicated by high 1 × line frequency peaks. Further evidence of electrical problems are:
- Broken rotor bars indicated by a 'swinging' ammeter.
- An electrical defect indicated if the peak disappears the instant power is cut.
- Magnetic misalignment or a bent shaft indicated by high axial vibrations.

Couplings

Coupling defect identification can be difficult as the vibration signature characteristics are similar to those of defective bearings. It should however be noted that with a coupling defect the prominent peaks are low frequency and there are substantially more harmonics of running speed when looseness of the coupling is indicated. The highest peaks are associated with the number of bad pins or teeth in the coupling.

The case history in Figure 10 illustrates vibration signatures taken from a directly coupled motor and pump unit (the coupling is a pin type). Similar signatures are produced from defective or seized gear couplings. It has become standard practice at Pongola to record vibration levels of any newly aligned coupling in order that these defects may be identified and corrected if they occur.

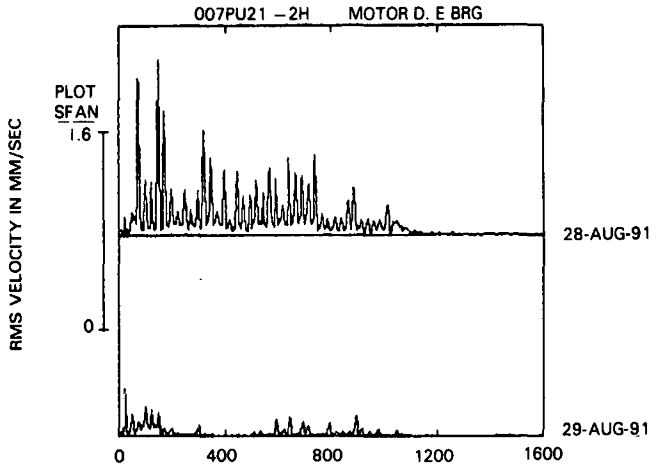

FIGURE 10 Faulty Coupling Comparison Signatures

Cavitation

Cavitation in pumps has a detrimental effect on casings, impellers, wear rings and bearings. Cavitation is very easily identified on a vibration spectrum by the harmonics present, peaking at the number of vanes × running speed, e.g. a pump with six vanes on the impeller will show a distinct peak at 6 × rpm (Figure 11).

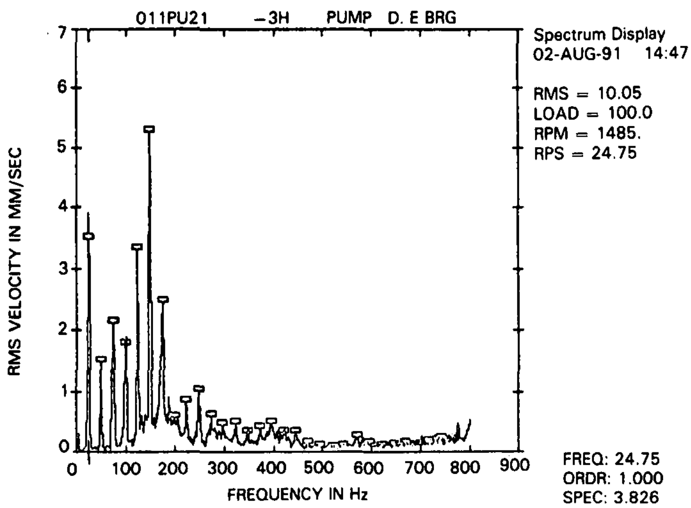

FIGURE 11 Typical Cavitation Spectra

Oil condition analysis

Regular oil condition analysis gives a very good indication of the condition of both the lubricant and the wear components within the unit. As with vibration analysis it gives an early warning of impending faults. Oil in critical equipment at Pongola is sampled on a monthly basis, but most of the sampling is done prior to the shutdown period. By utilizing both the vibration analysis and oil analysis results, the condition of the machine and scope of work required can be established. Water and silicon contamination of oil in equipment has been the major fault detected from samples taken at Pongola. The curve in Figure 12 indicates the cost saving effected in the oils and lubricant budget by condition based monitoring and oil analysis in particular.

LUBRICATION COSTS

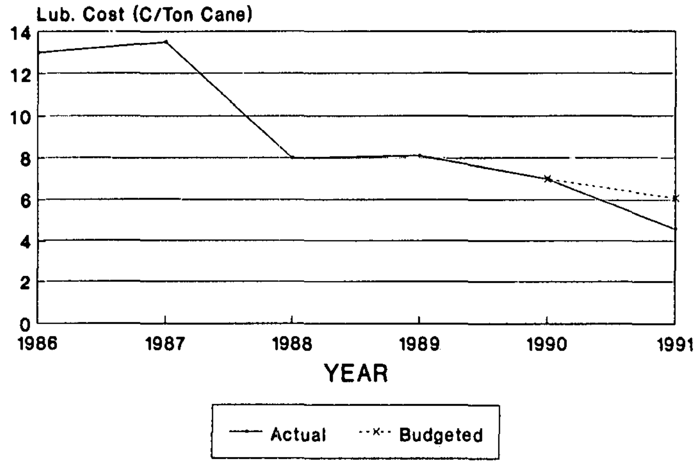

FIGURE 12 Lubrication Costs Curve (Actual Cost)

Vacuum pump performance testing

Efforts within this area have been directed at large vacuum pumps used at various locations within the plant. Bench tests, using different operating conditions are performed annually by an independent authority and full reports are submitted (Figure 13). Based on these reports and a bearing condition report, a decision is made upon the extend of work to be performed.

PERFORMANCE OF VACUUM PUMP

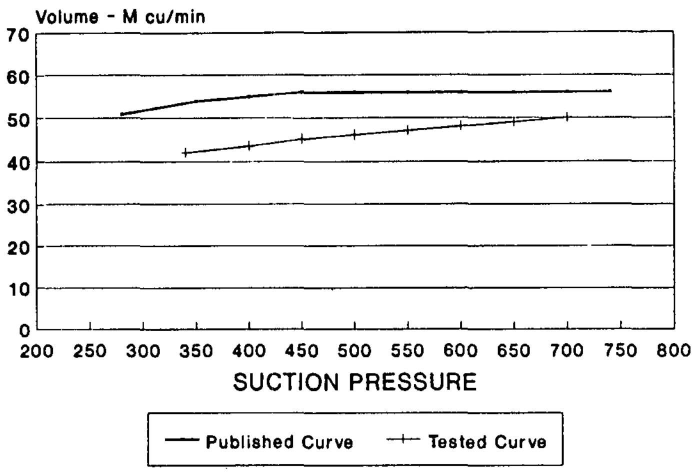

FIGURE 13 Performance Curve

Non destructive test methods

Although non-destructive testing (NDT) has always been practised in some form or other at Pongola its application is ever increasing. NDT methods such as thickness testing are being utilised in order to plan the replacement of boiler superheater elements as well as other items. NDT methods used at Pongola are:

- Boiler tube thickness testing
- Hydrogen impingement crack testing in deaerator
- Mill roll, pinion and flange bolt crack detection
- Carrier and conveyor head and tail shaft crack detection
- Fan shaft crack detection
- Centrifugal basket crack detection
- Steam trap effectiveness/operation
- Thermography

Notepad Observations Summary Report

Point	Date	Observation
070 1H	→ C Seed Receiver 21-Nov-01	Suggest both berarings are changed.
026CX6 1H	→ A Crystallizer No. 6 21-Nov-91	Motor Fan Loose on Shaft – Check.
009PU41 2H	→ A Vacuum Pan No. 7 Vacuum Pump 21-Nov-91	Coupling Alignment to be checked.
	*** End of Report***	

FIGURE 14 Vibration Analysis Exception Report

Oil Analysis Exception Report - 15/01/92

Unit	Date	Report Back
Effluent disposal gate gearbox	25/10/92	The period oil has been in use is unknown. Wear rates are normal. Debris analysis normal. 7.1% water present in the oil – check for point of entry. Water makes the oil unfit for futher use. Change the oil.
Wolff Crane Long Travel Gearbox 1	11/11/91	Debris Analysis revealed a light concentration of very small wear particles. Higher than normal silicon level in the oil – check for leaking seals and check breather. Recommend removing cover plate and checking for abnormal wear particles inside housing. Check for abnormal noise. Silicon and wear metal contamination makes the oil unfit for further use.

FIGURE 15 Oil Analysis Exception Report - 15/01/92

Administration of maintenance system

Condition based monitoring as a maintenance philosophy has taken off remarkably well within the plant, and accurate record keeping is important for history and future planning purposes. At Pongola the computerised planned maintenance system provides management with all data required. Both the condition based monitoring system and the planned maintenance system are controlled from the Planning Department, where cross referencing is readily available between 'what is planned and when' and the current condition of the machine in question. The need to maintain equipment on a time based programme has to a large extent fallen away.

To provide Management and Engineers with information, effective documentation needs to be provided. This can be in the form of reports, work orders, vibration signatures or oil analysis reports.

Figures 14 to 16 illustrate the various reports designed for combined use with preventative maintenance and condition based monitoring.

Vibration Analysis Feedback History Report

	Date	*Job Title and Comments*
C/K. Feeder Drum Electric Motor		
Job Number: 63236		
Primary Damage		Check/Replace bearings
Savings:	15/04/91	worn.
Secondary Damage	400.00	Replaced bearings – water
Saving:	1500.00	got into motor.
Sugar Dryer No. 1 - Exhaust Fan Motor		
Job Number: 71509		Check motor N. D. E Brg
Primary Damage		– loose. Stripped N. D. E.
Savings:	20/10/91	– Housing worn out, re-
Secondary Damage	400.00	sleeved housing and
Saving:	0.00	reassembled.

FIGURE 16 Feedback Report & Savings

Economic justification

The implementation of a condition based system has had a very substantial payback for Pongola. The reduction in workload as a result of using condition based monitoring in the Electrical Department alone has led to tremendous cost savings. Time gained in this department has been utilised in tackling capital projects thus avoiding contractor and overtime costs. Estimates to-date show that primary damage savings of R155 000 and secondary damage savings of R195 000 have been achieved since October 1990.

Primary damage is defined as 'immediate damage attributable to the defect', e.g. bearing failure and shaft build up and remachining. Secondary damage is 'secondary damage attributable to the defect', e.g. bearing failure causing first the bearings to collapse and then the rotor of the motor to rub on the stator.

The graph in Figure 17 indicates the tremendous impact of condition based monitoring upon the factory maintenance budget. Callouts have reduced considerably, and in 1991 were half the number than in 1989.

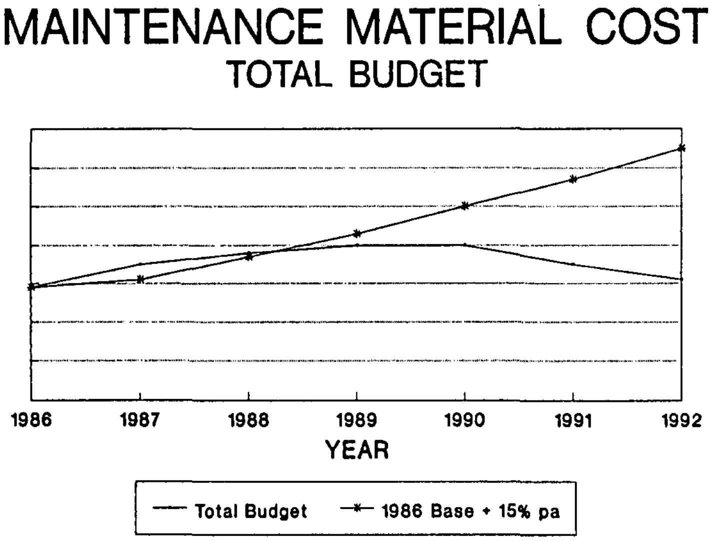

FIGURE 17 Actual Budget vs 1986 Projected Budget

Conclusions

A decision was taken a year and a half ago to implement a system of condition based monitoring prior to the following offcrop. The very low failure rate of equipment in the season has convinced personnel that this was the correct decision. When offcrop periods get shorter and production is increased as is expected at Pongola, the system will benefit all in that workload will be cut dramatically compared to continuing with scheduled maintenance.

Future plans include the 'in-house' testing of vacuum pumps, centrifugal pump efficiency testing, manufacture of a balancing machine and permanent monitoring of turbo alternator sets.

Acknowledgements

Sincere thanks are extended to the Management and Staff of Pongola for the opportunity of presenting this paper and the assistance of D Botha in particular in researching and implementing the system. Furthermore the co-operation and faith of Management, Engineers, Process staff, Foreman and artisans in providing the system with a "chance" is much appreciated.

REFERENCES

Anon. (1991). The hidden cost of misalignment. *Trendsetter Newsletter* 2 (5, Sept): 2.