Experience on Paper Machine Condition Monitoring-A Case Study Highlighting Drying Cylinder Bearing Failures

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ABSTRACT

Unscheduled machine breakdowns have a direct effect on company's profits. Determining machine condition before breakdown occurs, puts control of downtime firmly in the hands of Maintenance Engineer. The Condition Monitoring of rotating elements has becoming increasingly a part of regular maintenance activity. This paper discusses some of the experience on condition monitoring of paper machines at APPM, detailing how multiparameter monitoring approach is important in tracing the defects. The paper follows the development of condition monitoring activities in APPM and resultant benefits and then a few experience reveal that the some serious defects were not apparent with simple shock pulse and vibration velocity measurements, specially in the case of Drying Cylinder bearings which run at slow rpm. Normal condition monitoring failed to predict the defects of dryer bearings and spectrum analysis is resorted to arrive at the result. Importance of software available for analyzing data and personal skills of the analyzing engineer is brought out through actual examples.

INTRODUCTION

Condition monitoring is the process of measuring the physical characteristics of a machine e.g. vibration, bearing condition, temperature, wear debris etc., while it is operating in order to predict the performance of the machine. Proper condition monitoring of rotating machinery not only helps plant engineers to reduce the possibility of catastrophic failures, but allow them to order replacement of parts in advance, schedule manpower, reduce spares inventory, plan multiple repairs during scheduled shuts and improve machinery availability to an optimum level (1, 2).

Machine problems and bearing defects manifest themselves differently during different stages of machine failure. A multi-parameter approach includes measuring a variety of parameters using multiple processing methods for a comprehensive view of machine condition. This article deals with practical experience of authors in the monitoring of vibration and bearing condition to predict the failure of rotating parts.

Overview of condition monitoring in APPM beginning

A regular vibration and shock pulse based condition monitoring system was inroduced in 1995 with a Shock Pulse Analyzer. This instrument measures shock pulses caused by bearing damages and also RMS Velocity readings of overall vibration levels. The monitoring technique was initially adopted for breakdown prone equipment like dryer felt rolls to establish credibility of the system. The following table shows the Dryer Felt Roll failure and corresponding downtime and production loss on a paper machine.

Table 1 : PM-5 Dryer Felt Rolls

Year	No of rolls failed	Down time hrs.	Production loss in tonnes
1993-1994	7	16	80
1994-1995	8	18	90
1995-1996	7	14	70
1996-1997	2	5	25
1997-1998	2	5	25
1998-1999	2	7	35
1999-2000	3	12	60
2000-2001	2	4	20
2001-2002	0	0	0
2002-2003	1	4	20
2003-2004	0	0	0

There were about 300 measuring points monitored every month. Slowly the system started yielding results and the breakdowns were minimized.

1st Instrument upgradation

This instrument was upgraded to Data logger version in the year 1998 to work with computer on a condition monitoring software.

Advantages over previous instrument

1. Manual data entry on field data sheets was avoided.
2. Enabled to monitor more bearings. (About 600 per month).
3. Time interval of subsequent monitoring schedules was reduced.

Predictions made & break downs prevented

1. Failure of Calender gear box bearing and gear damage
2. Failure of PCC pump bearing.
3. Failure of Jessop group drive pinion bearing
4. Failure of Pick up roll gear box bearing
5. Failure of OM Dryer pinion bearing

Installation of shock pulse transducers

Subsequently permanent mounting transducers were installed on critical bearings which are not accessible to monitor by hand held instruments, located in very hot and unsafe surroundings. They are connected to junctions boxes situated at a safe distance through coaxial cables.

2nd Instrument Upgradation

In 2001, this instrument was again upgraded to Machine Condition Analyzer and the software was also upgraded.

Advantages over previous version

1. Vibration frequency analysis
2. Lubmaster software
3. Long time recording (48 Hrs. Memory)
4. Temperature monitoring
5. Vibration Evaluation and Analysis Method EVAM
6. Transducer Line Test (TLT)

Vibration transducers were installed on critical bearings like drying cylinder drive end bearing of paper machine which are capable of capturing the vibration spectrum. Regular maintenance of the off line monitoring points. transducers and cables is being done by the APPM Engineers and technicians

We are slowly incorporating the vibration frequency analysis to most of the measuring points and the system is working well.

Some of the prediction made

1. Failure of Bottom press roll motor DE bearing
2. Failure of Dryer Pinion bearing
3. Foreign material entrapped in PCC Pump Impeller
4. Failure of an indrive shaft bearing

The above predictions were made basing on the vibration spectrum data captured along with shock pulse readings during regular measuring rounds

Condition monitoring of drying cylinders of paper machines

The drying cylinders of a typical paper machine are massive cast iron shells fitted with end journals, steam and condensate removal systems having 1.5 m shell diameter, 2-10 in number grouped together for drying the paper web. They are driven by electrical direct current motors via reduction gear boxes directly connected with gears and pinions through indrive shafts and couplings.

PM-5 Paper machine drying cylinders are mounted on SKF 23144 C/C/W33 spherical roller bearings at both ends, driven by a 60 teeth gear wheel meshing with another pinion having 40 teeth and the speed range varies from 40 to 120 rpm. Servosytem 150 oil supply comes to the bearings and the gear mesh through COL system with a pressure 2.6 kg/cm^2. Normally the operating temperature measured on the surface of the bearing housing would be around 70°C and the surface temperature of the drying cylinder would be around 90-110°C with an inlet steam pressure of 3.5 kg/cm^2.

Some of common problems encountered during maintenance of the drying cylinders in a paper machine are listed below:

1. Motor problems
2. Gear box failures
3. Indrive shaft/couplings damage
4. Gear and pinion wear/damage
4. Bearing deterioration/damage
5. Steam and condensate system leakages/ accumulation/damage
6. Overload
7. Draw variations
8. Drying cylinder shell /journal wear

As the rotating speed of the drying cylinder is low (40-120 rpm), the development of bearing damage often shows only at a deteriorated stage, thus, sometimes, calling for an emergency shut and leaving the maintenance Engineer with empty hands. To avoid such type of machine failures, it is essential to monitor the equipment for parameters like vibration, shock pulse, bearing temperature etc., and the trending provides display of changes in machine condition. The vibration spectrum analysis reveals development of machine condition deterioration at an early stage so as to plan for a shut to accomplish necessary repairs.

The following case studies show prediction of a drying cylinder bearing failure, a severely damaged outer race of a drying cylinder bearing, calendars gear box input shaft free end bearing failure and gear damage and lastly a pump fluid induced instability to show how simple vibration and shock pulse measurement do not depict defects and vibration frequency analysis reveals majority of the troubles.

Case Study 1

Cracked and slipping of inner race on its sleeve of a drying cylinder bearing in a paper machine (Fig. 1).

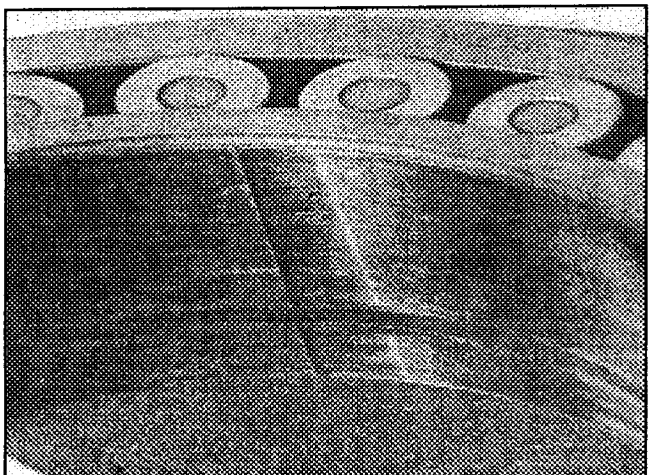


Fig. 1 : PM-5 Dryer No 8 NDE

The shock pulse and vibration data collected on the bearing in the routine manner is mentioned in Table 2.

The shock pulse and vibration overall readings appears to be allright and does not show any significant change and the load was also normal (50 Amps). The vibration spectrum captured shows (Fig. 2) high peaks at bearing symptoms, misalignment and looseness. This bearing was kept in the alarm list for inspection basing

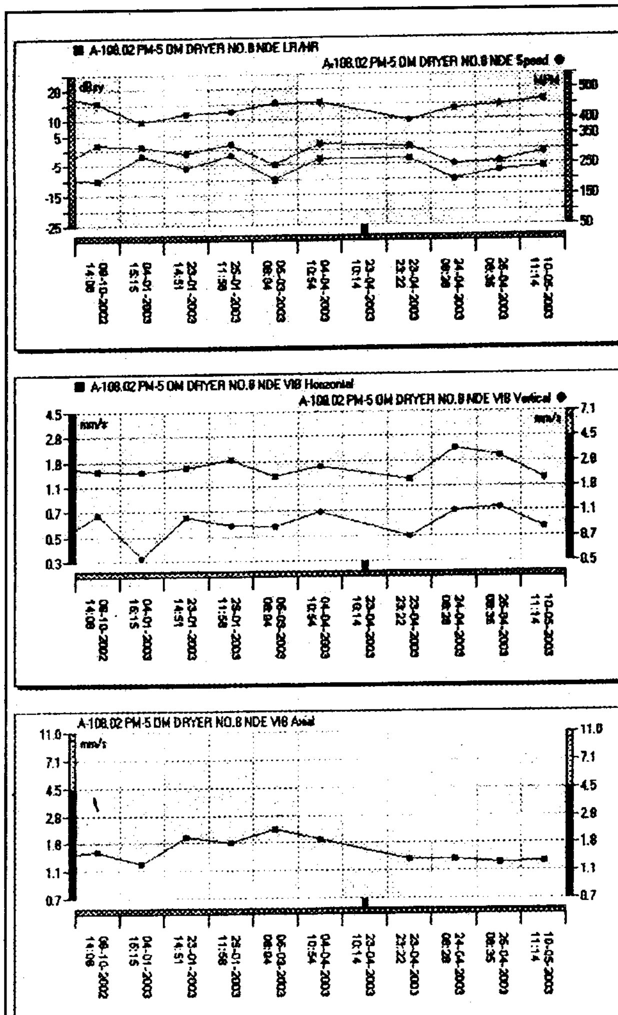


Fig. 2 Treno graphs of PM-5 Dryer No. 8 NDE

Table 2 : PM-5 Om dryer No. 8 NDE

Date	LR	HR	LUB	COND	CODE	MPM	VibH	VibV	VibA
10-05-2003	-1	6	5		A	463	1.32	0.83	1.32
25-04-2003	-4	-7	4		A	444	1.99	1.20	1.29
24-04-2003	-5	-10	6		A	434	2.33	1.12	1.40
23-04-2003	1	-3	3		A	396	1.30	0.70	1.40
04-04-2003	2	-3	4		A	458	1.65	1.09	1.94
05-03-2003	-5	-10	7		A	453	1.37	0.86	2.28
25-01-2003	2	-2	3		A	425	1.86	0.88	1.81
23-01-2003	-1	-6	4		A	420	1.62	1.01	2.00
04-01-2003	1	-2	2		A	392	1.51	0.53	1.26
09-10-2003	2	-10	7		A	458	1.54	1.05	1.58

on the vibration spectrum data. During a planned shut this bearing was inspected and found a full length crack right across the inner race of the bearing.

The vibration spectrum captured before replacement of the bearing is showing in Fig. 3.

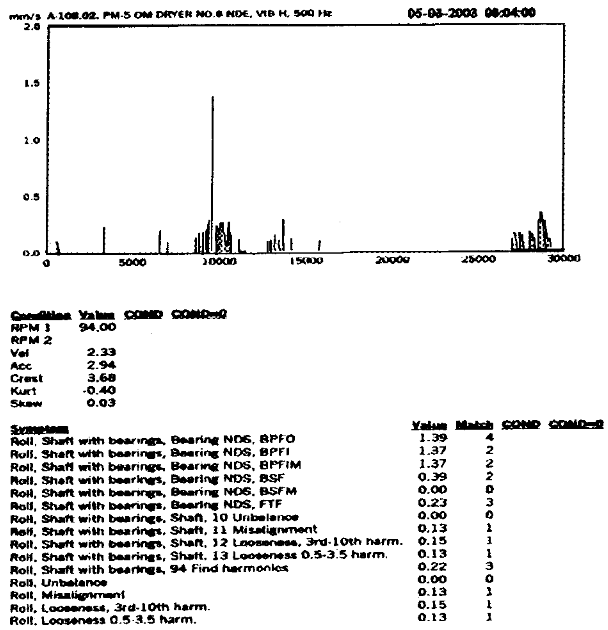


Fig. 3 PM-5 OM Dryer No. 8 NDE

The vibration frequency spectrum reveals a change in the operating condition of the bearing with increased peaks of misalignment, looseness, BPFO, BPFI and BPFIM. All high peaks disappeared after replacement of the bearing in the spectrum.

This case study is an example in which measuring results of simple vibration/shock pulse readings, sometimes, does not clearly indicate the machine condition on slow speed machines. The one indication we had is intermittent low LUB readings which indicate a low oil film (Fig.4). The periodicity of monitoring is

Fig. 4 PM-5 OM Dryer No. 14 NDE

Table 3 PM-5 OM Dryer No. 14 ND

Date	LR	HR	LUB	COND	CODE	MPM	VibH	VibV	VibA
10-05-2003	-1	6	5		A	463	1.32	0.83	1.32
25-04-2003	-4	-7	4		A	444	1.99	1.20	1.29
24-04-2003	-5	-10	6		A	434	2.33	1.12	1.40
23-04-2003	1	-3	3		A	396	1.30	0.70	1.40
04-04-2003	2	-3	4		A	458	1.65	1.09	1.94
05-03-2003	-5	-10	7		A	453	1.37	0.86	2.28
25-01-2003	2	-2	3		A	425	1.86	0.88	1.81
23-01-2003	-1	-6	4		A	420	1.62	1.01	2.00
04-01-2003	1	-2	2		A	392	1.51	0.53	1.26
09-10-2002	2	-10	7		A	458	1.54	1.05	1.58
08-06-2002	-6	-9	6		A	482	1.67	0.64	1.47
02-03-2002	1	-4	4		A	467	1.50	0.88	1.63
30-01-2002	0	-9	6		A	482	1.54	0.66	1.65
26-11-2001	-1	-10	5		A	406	1.52	0.72	1.87
10-09-2001	-9	-15			E3	491	1.86	0.70	2.33
16-05-2001	2	-1	3		A	453	1.95	0.74	1.69
08-01-2001	0	-7	3		A	339	1.20	0.60	1.50

also an important factor as the measuring results less in number leads to false alarms or no alarms at all. When normal condition monitoring failed to produce results, vibration frequency analysis may be resorted to on all slow speed equipment . The vibration spectrum measurements are being made on all drying cylinder bearings following the above incident.

Case Study 2

Heavy pitting and severe surface damage on outer race of a nondrive end bearing of a drying cylinder in Fig. 4.

Table 3 shows the shock pulse and vibration readings of the above bearing (Fig. 5).

The trend graphs of shock pulse LR and HR values, speed and vibration RMS velocity in mm/sec taken in three directions of a drying cylinder NDE bearing (Fig. 5).

The data collected on 9.10.2002 shows that the bearing is healthy and the next reading took on 4.1.2003 is showing low LUB No. Again on 21.1.2003, during a routine physical check, some abnormal sound is noticed from the bearing. Immediately one set of vibration and shock pulse readings were taken. The following is the

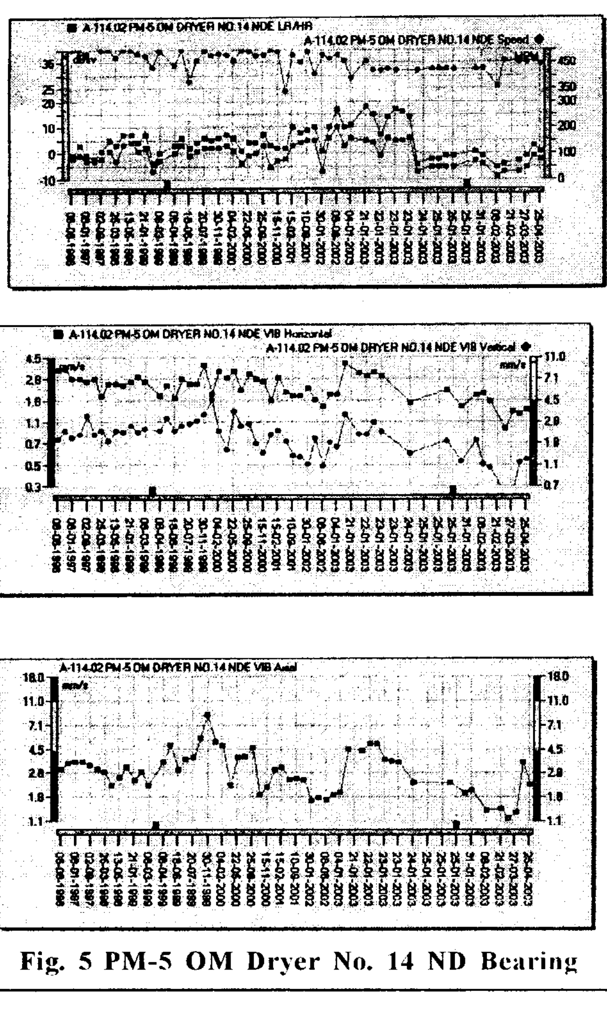
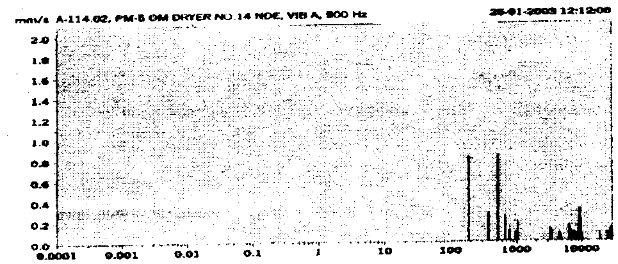


Fig. 5 PM-5 OM Dryer No. 14 ND Bearing



Condition	Value	COND	COND=0
RPM 1	90.00		
RPM 2			
Vel	5.02		
Acc	3.10		
Crest	4.12		
Kurt	1.06		
Skew	0.31		

Symptom	Value	Match	COND	COND=0
Roll, Shaft with bearings, Bearing NDS, BPFO	2.18	5		
Roll, Shaft with bearings, Bearing NDS, BPFI	1.22	6		
Roll, Shaft with bearings, Bearing NDS, BPFIM	1.22	6		
Roll, Shaft with bearings, Bearing NDS, BSF	1.07	6		
Roll, Shaft with bearings, Bearing NDS, BSFM	0.00	0		
Roll, Shaft with bearings, Bearing NDS, FTF	1.68	4		
Roll, Shaft with bearings, Shaft, 10 Unbalance	1.42	1		
Roll, Shaft with bearings, Shaft, 11 Misalignment	0.00	0		
Roll, Shaft with bearings, Shaft, 12 Looseness, 3rd-10th harm.	1.74	4		
Roll, Shaft with bearings, Shaft, 13 Looseness 0.5-3.5 harm.	1.49	2		
Roll, Shaft with bearings, 94 Find harmonics	2.68	10		
Roll, Unbalance	1.42	1		
Roll, Misalignment	0.00	0		
Roll, Looseness, 3rd-10th harm.	1.74	4		
Roll, Looseness 0.5-3.5 harm.	1.49	2		

Fig. 6 Vibration spectrum of PM-5 OM Dryer No. 14 NDE Bearing

vibration spectrum taken before replacement of the bearing is given in Fig. 6.

The frequency spectrum reveals bearing symptoms like BPFO, BPFI, FTF & BSF are present in the signature. The instrument was hooked up with the bearing for long time recording and the data so collected also depict the symptoms clearly indicating the failure of the bearing.

- It is recommended that critical equipment like drying cylinder bearing should be monitored on line or at least once in a week otherwise there is imminent danger of failures such as above.
- The time interval for data collection should be as close as possible.
- Consistent low oil film readings should not be ignored.
- Vibration frequency analysis should be carried out on slow speed machines.

Case Study 3

Prediction of failure of a paper machine Calendar gear box input shaft free end bearing, severe damage to gear and pinion. This is a single reduction gear box having 26 teeth on the pinion and 82 teeth on the gear driven by a DC motor and connected to the calendars stack. The vibration levels are consistently high on input shaft free end bearing and the shock pulse level is erratic. The trend graphs of shock pulse and vibration readings are presented in Fig. 7.

The maintenance engineers were alerted many times

Table 4 PM-5 Calendar Gearbox 1/Shaft free end.

Date	Time	LR	HR	LUB	COND	CODE	MPM	VibH	VibV	VibA
15-06-2001	10:53	24	18	2		A	405	1.63	2.1	1.76
09-06-2001	10:33	25	20	2		A	470	2.4	2.5	1.8
06-06-2001	09:57	21	17	4		A	481	1.4	2	1.3
31-05-2001	20:30	14	7	3		A	260	0.8	1	0.9
31-05-2001	10:02	14	0		35	C	162	3.41	3.34	5.82
22-04-2001	17:50	16	8			E3	480	5.2	5.9	6
20-03-2001	17:47	18	9	9		A	475	5.5	6	6.2
16-02-2001	15:19	11	7			E3	484	2.9	4.8	5.5
27-12-2000	11:22	15	8			E3	490	4.7	4.4	6.7
30-10-2000	10:18	19	11	7		A	490	4.5	5.7	4.8
22-08-2000	16:00	18	11	7		A	482	4.1	4.5	4.4
20-06-2000	15:43	21	14	5		A	500	5.6	8.7	5.6
14-02-2000	14:46	29	14	6		A	507	6.9	6.8	4.4
28-12-1999	11:49	20	11	2		A	318	6.4	6.5	6.2

before replacement of internals of this gear box. On inspection, no abnormality was noticed every time and only gear box oil was replenished. Only few days before a shutdown, loud noise started from the gear box. The vibration spectrum captured after hearing noise from the gear box is shown in Fig. 8.

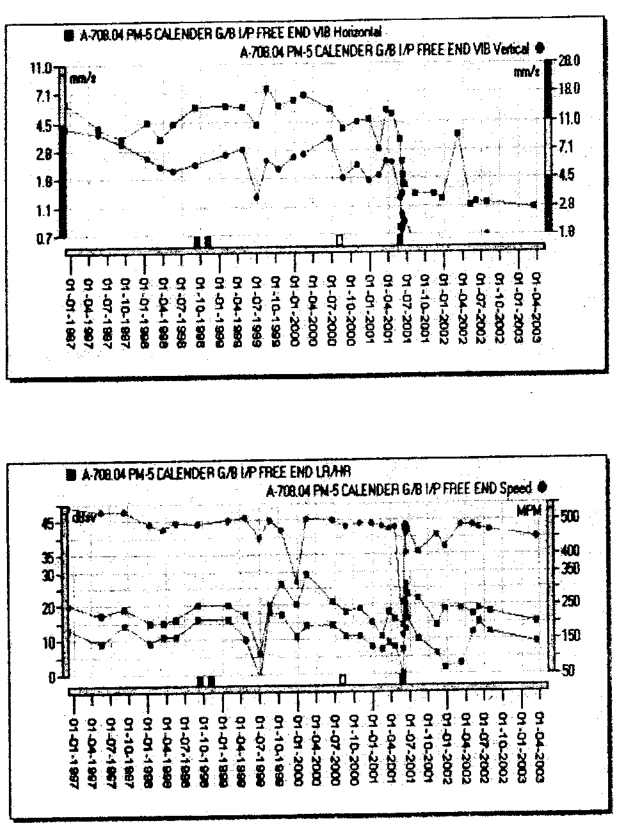


Fig. 7 PM-5 Calendar Gearbox Input Shaft free end.

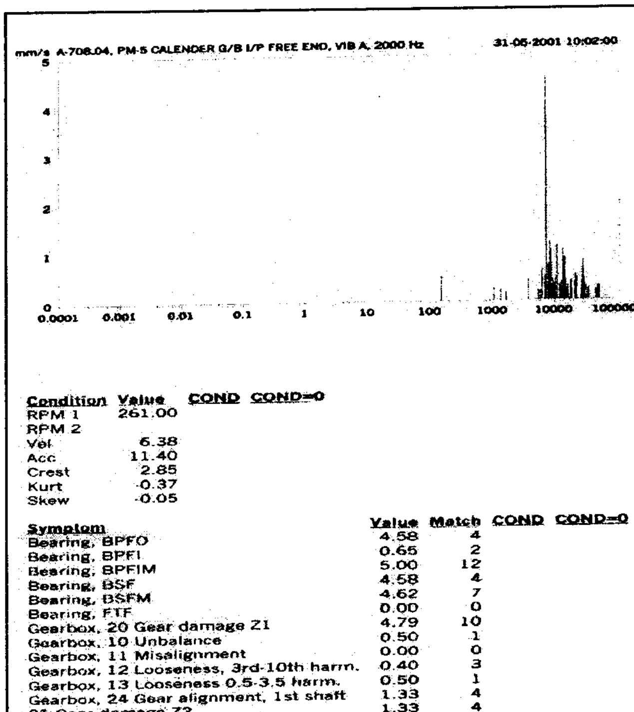


Fig. 8 Vibration spectrum of PM-5 Calendar gear

The vibration spectrum shows high amplitude peaks at bearing and gear mesh frequencies indicating bearing and gear damage. On opening the gear box, it is evident that the bearing, the gear and the pinion were worn out badly.

Table 5 : PM-3 PCC pump drive end

Date	LR	HR	LUB	COND	CODE	VibH	VibV	VibA
18-06-2001	32	26	3		A	3.62	2.60	1.72
06-06-2001	30	26	3		A	3.80	2.50	2.00
30-05-2001	48	40		56	D	72.00	59.60	47.08
28-05-2001	40	35	0	32	B	68.92	20.39	15.51
12-04-2001	35	28	2		A	2.90	1.60	2.30
20-03-2001	36	30	2		A	2.80	1.70	2.50
19-02-2001	35	31	2		A	2.60	1.60	2.50
09-01-2001	32	28	2		A	2.40	1.60	1.60

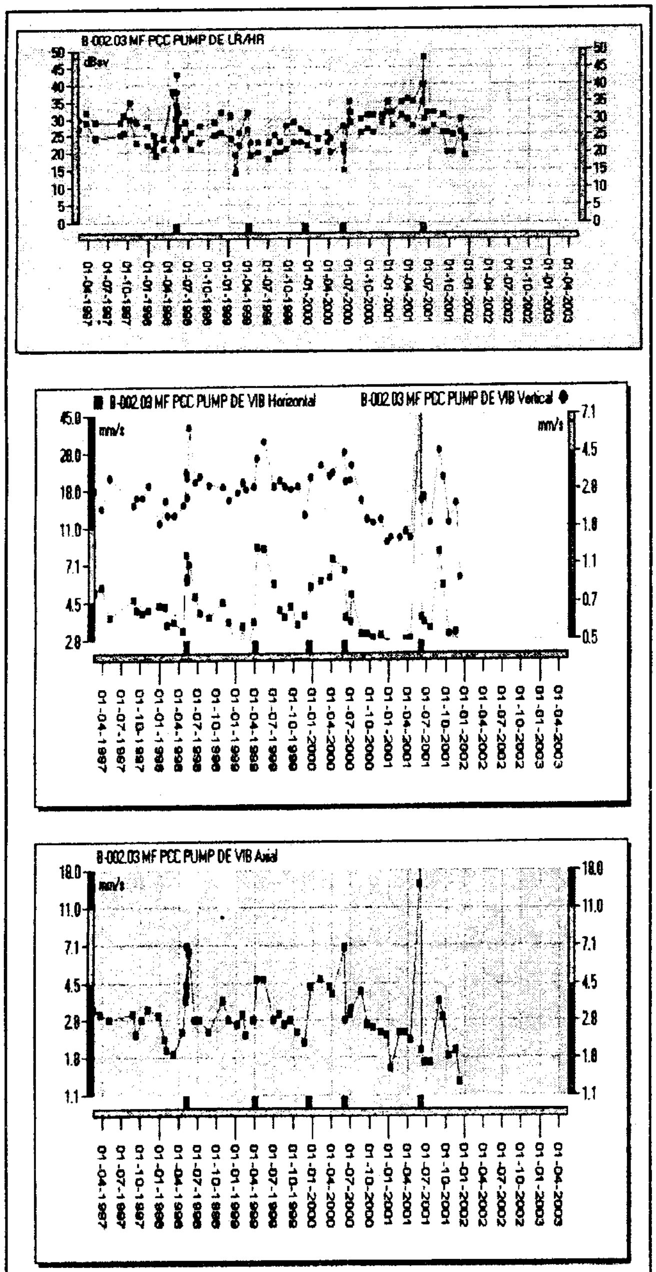


Fig. 9 Trend graphs of PM-3 PCC Pump bearing

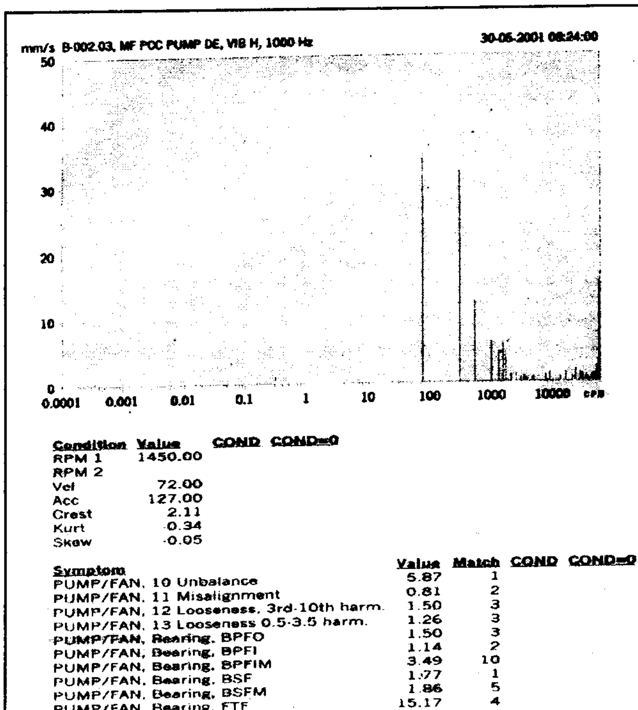


Fig. 10 Vibration spectrum of PM-3 PCC Pump drive end.

It may be concluded here that consistent high vibration level may lead to failures and bearing operating with increased clearances leads to failures.

Case Study 4

Foreign material entrapped in the impeller of a pump causing fluid induced instability raising vibrations to unexpected levels. This pump is mounted with a double suction impeller and driven by a 1450 rpm, 150 hp induction motor. The trend graphs showing rapid increase in vibration and shock pulse levels can be seen in Fig. 9. Vibration spectrums were taken on drive end bearing of the pump to suspect the culprit.

It is noticed that the dominant frequencies are at 75 cpm, 300 and 525 cpm spaced 225 cpm apart which produced high amplitude peak in additon to riase in acceleration level (127 m/s^2) due to foreign material entrapped in the impeller. It is also seen that bearing frequencies are present in the spectrum indicating damage to the bearings too. On opening the casing, it is found that a long iron angle was entrapped in the impeller.

Benefits arrived by the condition monitoring system

1. Reduced machine down time
2. Optimization of lubrication schedules
3. Inventory control
4. Better utilization of manpower
5. Access for multiple repairs

Limitations or constraints of the system

1. The time consumed for each vibration spectrum measurement is high.
2. Severe physical exertion of monitoring engineers takes place in hot and humid surroundings.

CONCLUSION

For any good condition monitoring programme, it is necessary to have measuring data at regular intervals backed up by proper lubrication and maintenance schedules. Proper care and maintenance of instruments and online/off line installations is also a key factor for quality of services and the analyzing engineers should be aware of the machine and its history too. Consistent high vibration levels sometimes lead to misinterpretation of the data which in turn causes failures. Lubrication also plays a vital role in maintenance of the equipment as consistent low lubrication levels may lead to failures. On slow speed machines such as drying cylinders, apart from shock pulse and vibration overall readings, regular vibration frequency analysis may be conducted to predict impending failures. Thus condition monitoring is one of the host of products and services designed to reduced unscheduled downtime, to achieve maximum service life of equipment while helping to improve overall plant efficiency.

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