Progressing Towards Proactive Maintenance

K. Thangaraju, A. Balakumar, S. Nandagopal and B. Mahesh

Tamil Nadu Newsprint and Papers Ltd., Kagithapuram-639136, (T.N.)

ABSTRACT

TNPL, since commissioning of its first paper machine in Sep'84 has tuned its maintenance practices with new strategies that evolved during its long successful operations.TNPL started its maintenance programme with preventive maintenance scheduling without entering into the phase of "run to failure" maintenance. Contrary to the fully automated Condition monitoring maintenance system followed in most of the mills abroad, TNPL followed maintenance with involvement of human interface. Besides low investment on maintenance resources, this practice helped to understand the maintenance techniques better and paved way for smooth entry into the proactive phase. The different phases in TNPL's maintenance history with preventive,predictive and current system of proactive maintenance practices with emphasis on reliability based maintenance are discussed with case studies.

INTRODUCTION

Over the years the maintenance has evolved from a necessary evil to a way for mills to enhance profits. New maintenance philosophies are developed with advancement of science and improved precision of measuring equipments.

Preventive and predictive maintenance

Preventive maintenance, which is nothing but a scheduled maintenance, allows for scheduled repair and replacement of parts that are failing. Scheduled maintenance tasks can be completed within the predetermined downtime with proper planning. The cost involved in this type of maintenance is on the higher side due to the fact that the machine is opened too early and replacement of certain parts is done even though there is no significant damage. However, this practice would bring down the overall maintenance cost lesser than that of breakdown maintenance.

Preventive and predictive maintenance modes are easily illustrated on the traditional bathtub curve (Fig. 1). The period when the failure rate begins to slope upward is often selected as the recommended intervention point for preventive maintenance.

Predictive maintenance typically allows the average machine to run past its preventive maintenance point. Maintenance, therefore, is scheduled and performed when a deterioration of performance or condition is identified. By lengthening the interval between repairs, the costs of maintenance are reduced. Also, machines that fail earlier than anticipated can be identified and repaired at a lower cost than if they were allowed to run longer. A slight reduction in failure rate can be realized when predictive maintenance is carried out.

The team, identified to lead the predictive effort, should be extremely interested in doing this kind of jobs, highly self-motivated and should not leave the company half ways around. Many successful predictive starts have later failed due to loss of the initiator. This should be his full time job and not one of many duties or else the effort will probably be doomed from the start. The recognition is important for it provides motivation and shows appreciation for the efforts and results of the people performing work and increases the credibility of these people. Here lies the role of the management in making the team result-oriented.

Evolution of proactive maintenance

Does the maintenance stop with the predictive technique? The saying goes "if you always do what you always have done. you will always get what you always had." In today's competitive market, this is just not good enough and we always try to get more than what we had. This evolved the modern programme of Proactive maintenance to give us more than what we had.

One missing aspect in breakdown or preventive or predictive maintenance is what should be done to improve the way the machine runs. Even a fully functioning predictive maintenance programme has room for significant improvement. Finding bearing degradation on critical machinery before failure is considered a great success. There is a limit to this success when the same problems are found repeatedly.

A truly proactive approach looks beyond the "save" from condition monitoring to the "source" of the failure and its correction. Ultimately, true fault determination and statistical information analysis on the categories of failure will determine the areas of focus for proactive maintenance.

The normal maintenance practice is to focus only on making availability of equipment for operation but it forgets about meeting the safety, environmental, insurance or other regulatory compliance. When proactive maintenance methods are applied to a machine, it is placed back in service at or as close to 100% as possible i.e., as good as new.

Ultimately the efficiency of maintenance team will be gauged on being able to go home at close of office hours with less calls in the middle of night to come in when compared to breakdown mode where you never know when you are to go home.

EXPERIMENTAL

How it started in TNPL ?

TNPL after start up in Sep'84 adhered to Preventive maintenance techniques, as "run-to-maintenance" was an old philosophy during that time also. Between 1985 and 1988, Preventive maintenance technique proved to be a reasonably good way of maintenance, as the equipments were new and failure rates were on the lower side. Most of the preventive maintenance activities like planning, scheduling, spares planning etc., were carried out by senior engineers and as usual regular shift activities were confined to attending to the immediate needs of operating crew.

The predictive maintenance technique was initiated in TNPL during 1988 with the introduction of a simple manual mode of measurement for shock pulse (SPM) and vibration. Simple schedules were drawn and SPM readings taken. Within 3 months, initial efforts showed quick enormous returns. This prompted the maintenance team to train the technicians and introduce shift wise schedules for measuring and monitoring shock pulse and vibration.

Way back in 1989, TNPL developed its own software based on the actual data that simplified and brought down the time required for data measurements. This facilitated the inclusion of more equipments under SPM monitoring and generation of more data for effective analysis.

Initially 100 points in the dryer area that were difficult to access due to high temperature and humidity, were provided with Permanently Mounted Transducers (PMT) in 1993 and later increased to 160 points in 1997. With PMT, the data measurement of an inaccessible point could be done from convenient place.

Based on the (Table 1) success of predictive maintenance practices in PM#1, PM#2 was provided with 324 PMT's in 1996-97 within a short span of one year of operation. It is pertinent to mention here that the specification for PM/c#2 included provision for mounting transducer in all bearing housings.

Having gained confidence in the predictive effort, the number of equipments covered under the condition

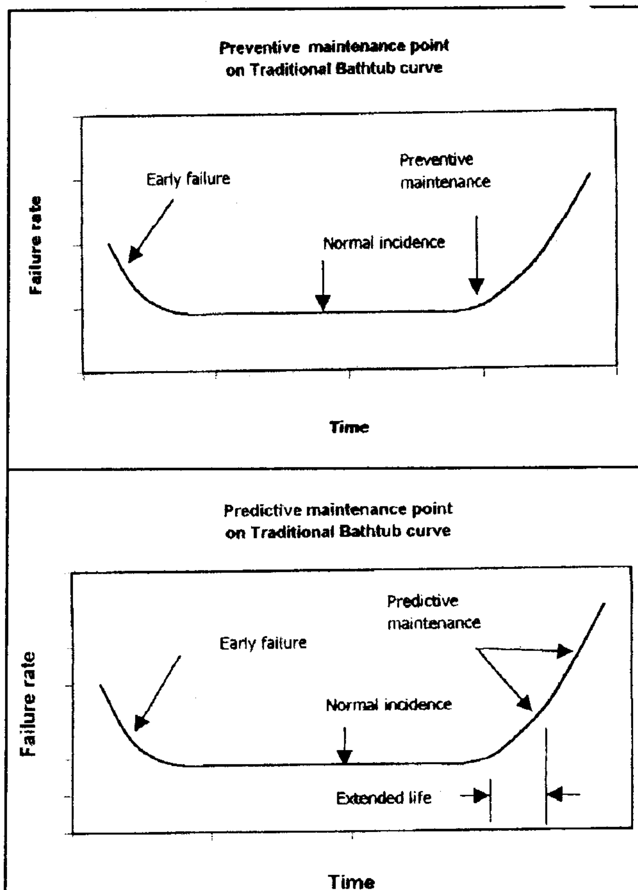

Fig. 1 Illustration of preventive and predictive modes on traditional bath tub curve

Table 1 : Downtime during Preventive and Predictive maintenance phases

Description	PM#1		PM#2	
	Mechanical downtime	Planned shutdown	Mechanical downtime	Planned shutdown
Preventive maintenance phase (1985-1988)	215 hrs/yr	430 hrs/yr	NA	NA
Predictive maintenance phase (1989-2002)	77 hrs/yr	470 hrs/yr	78 hrs/yr	400 hrs/yr

monitoring schedule has been gradually increased over the years and currently over 1413 points are covered with weekly schedule. This has now become a maintenance habit and basis for shutdown maintenance scheduling.

Till 1998 TNPL followed the regular predictive maintenance for identification of bad bearing and replacing it in the next scheduled shutdown. However a few unexpected failures between 1998 and 2001 on the dryer felt roll bearings and the dryer cylinder bearings which could not be identified by regular condition monitoring technique led to the conclusion that only condition monitoring is not adequate to reduce the break-down rate. This became an eye opener for introduction of Proactive maintenance by using root cause analysis techniques to improve system of condition monitoring and lubrication.

The chronological list of addition of condition monitoring tools (Table-2) would give an idea of how the maintenance practices in TNPL improved from the state of simple manual measurements to the present state of data logging and analysis.

RESULTS AND DISCUSSION

The impact of predictive maintenance is positively reflected on the machine downtime and manpower cost.

Analysis of downtime

Table-3 and Fig. 2 give the total downtime and trend of the mechanical breakdown hours and planned shutdown hours on PM/c#1 since its inception in 1985. Similar data are provided for PM/c#2 in Table 4 and Fig. 3 since its inception in 1995. As explained earlier, PM#1 was preventive maintenance system followed from 1985 to 1988 and switched over to predictive maintenance system while in PM#2 was predictive maintenance system started from the summarized data (Table 1) it can be inferred that the maintenance

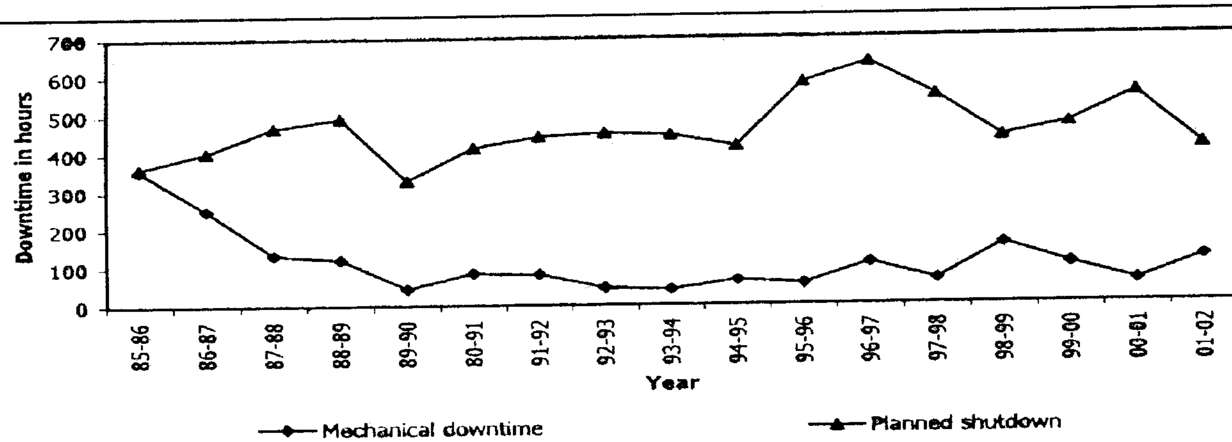

Fig. 2 Trend of mechanical downtime and planned shutdown in PM#1

Table 2 : Condition monitoring equipments

Sl. No.	Year of procurement	Description	Remarks
1	1988	Shock pulse meter SPM 43 A	To measure Shock pulse decibels
2	1988	Vibration meter IRD-811	To measure vibration (displacement and velocity)
3	1990	Stroboscope Porta-Strob ST2100	To check gear mesh, key looseness and condition of rotating components
4	1993	SPM T 2001 - 2 Nos	Shock pulse data logger
5	1993	Vibration analyser VA-10	Vibration analyser
6	1995	SPM A 2010	Shock pulse analyser
7	2000	Noncontact IR thermometer	To measure dryer sufrace temperature
8	2001	Thermopen SKF	To measure temperature of gear unit
9	2001	SEE pen shock pulse meter SKF	for instantaneous condition check

Table 3 Paper machine # 1 - Downtime (in hours)

Maintenance phase	Year	Mechanical downtime	Planned shut	Others	Total
Preventive	Apr 85-Mar 86	356.7	362.7	1919.3	2638.7
	Apr 86-Mar 87	251.3	403.3	1591.7	2246.3
	Apr 87-Mar 88	133.3	468.0	1194.3	1795.7
	Apr 88-Mar 89	120.7	492.0	1124.7	1737.3
Predictive	Apr 89-Mar 90	44.0	329.0	930.0	1303.0
	Apr 90-Mar 91	84	414	1042	1540
	Apr 91-Mar 92	80	443	825	1348
	Apr 92-Mar 93	44	452	1210	1706
	Apr 93-Mar 94	40	447	757	1244
	Apr 94-Mar 95	63	416	764	1243
	Apr 95-Mar 96	54	581	951	1586
	Apr 96-Mar 97	108	633	1208	1949
	Apr 97-Mar 98	63	547	1194	1804
	Apr 98-Mar 99	156	438	982	1576
	Apr 99-Mar 00	102	471	1164	1737
	Apr 00-Mar 01	56	549	849	1454
	Apr 01-Mar 02	118	412	748	1278

downtime hours reduced considerably with predictive maintenance while the planned shutdown hours increased marginally as expected.

Drop in overtime cost

The deployment of maintenance crew on overtime were analyzed in depth on various heads like absenteeism, planned shutdown, routine maintenance and breakdown maintenance from 1996-97. The overtime attributable to planned shutdown and breakdown maintenance are provided in Table 5. The trend (Fig. 4) shows appreciable decline of overtime on account of breakdown maintenance from 2.24% in 1998-99 to 0.66% in 2002-'03 when compared to overtime on planned shutdown remaining almost a straight line at around 9%.

Case studies on root cause failure analysis-Road to proactive maintenance

Case study-1) Reduction in press felt roll bearing failures in PM/c#1

Table 6 gives an analysis on the number of scheduled bearing changes with respect to the bearing failures on PM/c#1. The number of bearing failures was 7 during the preventive maintenance phase of four years when compared to only 4 failures in the 13 years of predictive maintenance period subsequently.

Failure rates are high in press felt rolls due to the fact that press felt rolls are subjected to heavy water spray, load and vibration (due to felt condition) when compared to the felt rolls in dryer section. Another

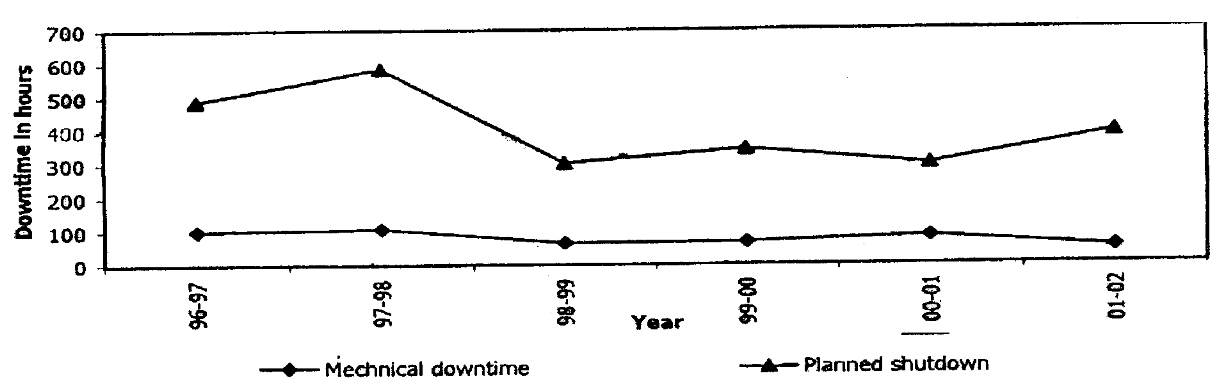

Fig. 3 Trend of Mechanical downtime and planned shutdown in PM#2

Table 4 Paper machine # 2- Downtime (in hours)

Maintenance phase	Year	Mechanical	Planned shut	Others	Total
Predictive	Apr 96-Mar 97	101	488	2387	2976
	Apr 97-Mar 98	107	584	1160	1851
	Apr 98-Mar 99	64	302	1122	1488
	Apr 99-Mar 00	67	344	1183	1594
	Apr 00-Mar 01	82	298	641	1021
	Apr 01-Mar 02	49	391	694	1134

Table 5 Data on overtime employed for mechanical maintenance (in hrs)

Year	Breakdown overtime	% Breakdown overtime	Planned shut overtime	% Planned shut overtime
Apr 98-Mar 99	2158.00	2.24%	9317.78	9.22%
Apr 99-Mar 00	994.50	1.01%	7939.15	8.11%
Apr 00-Mar 01	1069.50	1.33%	7058.00	8.81%
Apr 01-Mar 02	755.25	0.94%	6743.16	8.42%
Apr 02-Mar 03	564.50	0.66%	7974.75	9.37%

interesting finding is that the frequency of bearings failure in felt rolls of the basement felt circuits is exceptionally high due to heavy moist surroundings. This led to the following maintenance practices:

- Use of water repellant grease
- Increased frequency of greasing
- Dynamic balancing grade changed form G 6.3 to G 2.5
- Frequent moisture measurement across the felt

Case study-2) Comparison of oil and grease lubricated bearings in dryer felt roll

The analysis of failure rate (Table 7) on the dryer felt

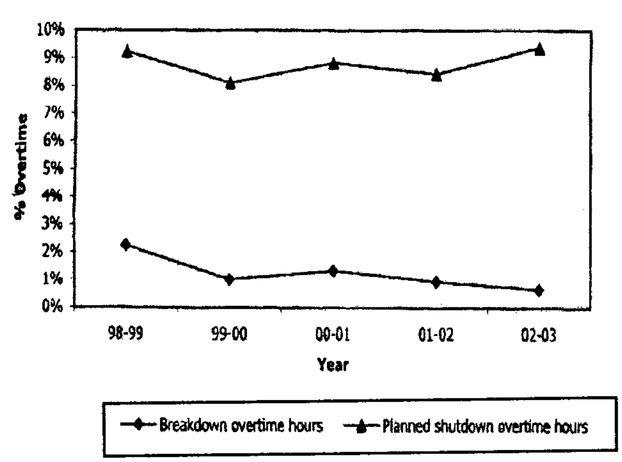

Fig. 4 Trend of overtime hours employed for mechanical maintenance

roll bearings shows that the failure rate is high with grease lubricated bearings compared to the oil lubricated bearings. The rate of bearing change per year bearing is 13.7% for grease lubricated bearings while it is only 3.35% for oil lubricated bearings. Based on this rate of bearing change, the assessed life for the grease lubricated bearings is 6-7 years while it is 25-30 years for oil lubricated bearings. However, sudden failure of oil lubricated dryer felt roll bearings on three occasions between 1998 and 2001 shot up the mechanical downtime considerably. These failures though damaged the roll journal could not be spotted through SPM which showed normal trend. On analysis, the following possible causes were identified :

- Failure due to fatigue (after 17 years of continuous operation)
- Restriction or block in lubricant flow due to contaminants

Using the opportunity of long shutdown in Nov'02 for its rebuild activities, TNPL converted all the 28 years grease lubricated bearings in dryer section to oil lubricated bearings and replaced all the 80 oil lubricated bearings that were in continuous operation since inception, to prevent failure in near future.

As a permanent measure to reduce bearing failures, following maintenance practices are since being followed :

- Predispatch inspection test certificates for all purchased bearings.
- Procurements of bearings only from authorized

Table 6 Press felt roll bearings replacement and failure analysis in PM/c#1

Period	Maintenance system	Description	Grease lubricated bearing
		Bearing Population (Nos.)	34
1985 to 1988	Preventive	Changed as per Schedule Breakdown Total brgs replaced % of change /yr /brg % of damage /yr. /brg	16 7 23 11.8 5.1
1989 to 2002	Predictive	Changed as per Schedule Breakdown Total brgs replaced % of change /yr /brg % of damage /yr /brg	97 4 101 21.9 0.9

Table 7 Dryer felt roll bearings replacements and failure analysis in PM/c#1

Period	Maintenance system	Description	Grease lubricated bearing		Oil lubricated bearing	
			Drive side	Tender side	Drive side	Tender side
1985 to 1988	Preventive	Bearing Population (Nos.)	14	14	68	68
		Changed as per Schedule	3	3	1	1
		Breakdown	2	1	0	0
		Total brgs replaced	5	3	1	1
		% of change /yr /brg	5.4	5.4	0.4	0.4
		% of damage /yr /brg	3.6	1.8	0	0
1989 to 2002	Predictive	Changed as per Schedule	27	23	32	27
		Breakdown	0	1	4	7
		Total brgs replaced	27	24	36	34
		% of change /yr /brg	14.8	12.6	3.6	3.1
		% of damage /yr /brg	0.0	0.5	0.5	0.8

sources of OEM's

- Mounting and dismounting of bearings only with bearings suppliers recommended tools like oil injection pump, hydraulic nuts, hydraulic pullers, bearing heaters etc.
- Cleanliness of lubrication oil improved using centrifuge, electrostatic cleaners, purifiers and filtration units.
- Measurement of moisture content and cleanliness level of oil at regular intervals.
- Addition of oil into tank through filtration units.
- Improved dynamic balancing class for all roll procurement and repair.

Case study-3) Dryer stretcher maintenance

Major breakdown in PM/c#1 dryer group in June'98 resulted in approximately 60 hrs of downtime. The IV group dryer top screen drive side stretcher chain link gave way leading to machine stoppage with the following consequential failures :

- 2 dryer felt rolls got bent and bearings broken.
- Front side vertical column, cross frame developed cracks.
- PV duct fallen down
- Both top and bottom screens damaged

Table 8 Number of suction roll changes in PM/c#1

Year	Suction rolls			Total
	Couch	Pick up	Press	
1987	1	4	2	7
1988	1	4	2	7
1989	1	5	3	9
1990	2	3	3	8
1991	2	5	4	11
1992	3	6	4	13
1993	4	5	5	14
1994	4	6	4	14
1995	5	5	5	15
1996	4	5	7	16
1997	3	8	5	16
1998	4	7	3	14
1999	5	4	3	12
2000	4	3	5	12
2001	3	3	3	9
2002	3	2	2	7
Total	**49**	**75**	**60**	**184**

After completing the maintenance work on war footing, the machine was put back into operation. This is the single longest mechanical downtime in the history of TNPL. Upon analysis of the failure, all the stretcher chains were changed in phases. Present practice is to check all the chains on a quarterly schedule for any crack, twist, tension etc.

Case study-4) Identification of condensate accumulation in dryer cylinder

Tender side bearing of dryer No.: 18 in PM/c#2 failed suddenly in Dec'98 without showing any deterioration in bearing condition. Spalling on the outer and inner race were noticed. Possible cause of failure was suspected to be heavy condensate accumulation resulting in excessive axial thrust load on the bearings. To eliminate repetition of such failures, the dryer surface temperature of all dryers is monitored before and after machine stoppage. The temperature values are compared with the reference temperature. The dryer cylinder with low temperature in operation and high temperature in stoppage is possibly filled with condensate. This dryer is then opened, condensate removed and siphon clearance checked. The cause of condensate accumulation was analyzed and corrective action taken. One of the causes identified was the blocking of siphon pipe by worn out Teflon particles from the Teflon filled carbon rings in the steam joint. This was corrected by replacing the Teflon-carbon rings with pure impregnated carbon rings. Incidentally, this practice also helped to maintain uniform load on the drives.

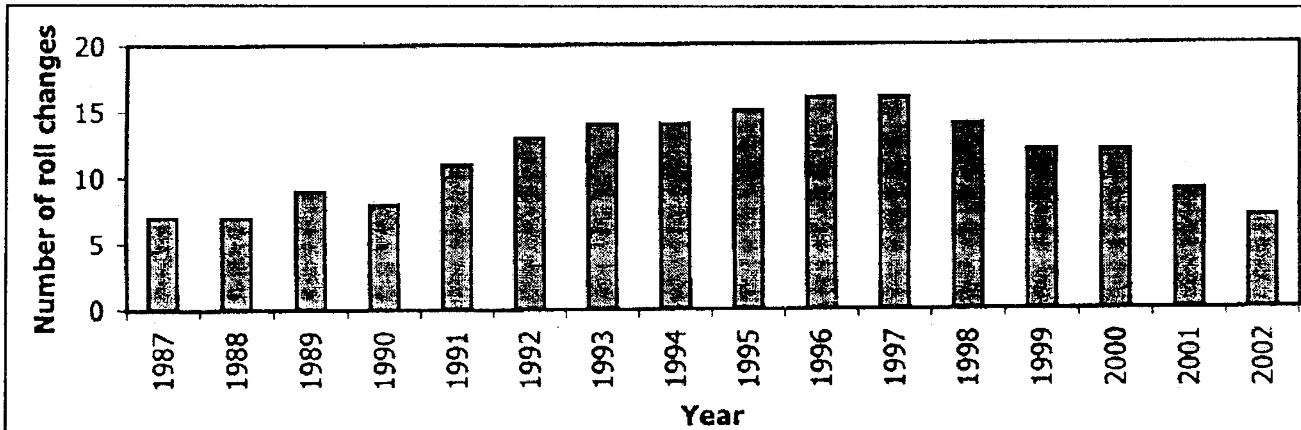

Fig. 5 Trend on number of suction roll changes

Table 9 Facilities added for Oil purification

Year of procurement	Description	Remarks
1990	Oil purifier (Alfa Laval MAB-103)	For 4 Nos. of lubrication/hydraulic tanks in PM/c#1
1996	Oil purifier (Alfa Laval MAB-205)	For dry end COL in PM/c#2
1999	Portable oil contamination	To measure the contamination levels analysis kit
2000	Portable oil filtration unit	For fresh oil filling and off-line filtration
2001	Water sensor	To measure the water content
2001	Electrostatic liquid cleaner-2 Nos.	For removal of insoluble particles in Press hydraulic tank in PM/c#1 and PM/c#2
2002	Oil purfier-2Nos (Alfa Laval 103 B)	Dedicated for individual hydraulic system to maintain water content within 0.06%-0.09%.

Case study-5) Improved maintenance on suction rolls

With commissioning of PM/c#2 (designed for Newsprint), TNPL dedicated PM#1 for making printing and writing papers. Fillers like China clay and talcum used in the pulp to obtain desired optical properties and more fines content in chemical bagasse pulp clog the roll perforations. The frequency of suction roll changes which was averaging 9 per years when more of newsprint was run from 1987-1992 increased to 15 per year with increase in rinting and writing paper from 1993-1998 (Table 8, Fig. 5).

With the following measures taken to overcome the problems of clogging, the number of suction roll change is brought down to 7 in 2002 :

- Dosing of alum in fog and lubrication showers. This

Table 10 History of pope reel primary arm failure in PM/c#1

Date	Description of failure	Breakdown time
04/03/1987	Tender side gear segment mounting bracket broken at collar. Welded with Xyron 223 electrode.	14 hrs
16/10/1997	0.9mm wear between the primary arm and drum brg housing on tender side and 0.17mm on drive side.	Regular inspection
09/10/1998	Bore machined and 6mm thick white metal liner provided. Reel drum housing outer dia machined to the new bore.	Planned shutdown
17/05/1999	Tenderside gear segment mounting bracket failed at collar due to arm movement beyond the stop position bracket welded.	7½ hrs
12/10/1999	On preventive maintenance replaced the tender side bracket.	Planned shutdown
10/12/2000	On preventive maintenance replaced the drive side bracket.	Planned shutdown
14/01/2002	Tenderside bracket failed at collar. Replaced with spare bracket. 5.5KW 1500 rpm motor replaced with 5.5KW 1000 rpm to slowdown the movement.	8 hrs
21/01/2002	0.2 to 0.35 mm wear between the primary arm and drum brg housing on tender side.	Regular inspection
30/01/2003	Both side gear segment mounting brackets failed. Fixed back after rectification on 11/2/03.	15 hrs

was discontinued as it caused corrosion on roll heads and scaling.

- External online high pressure cleaning showers operating at 30 bar were installed for continuous cleaning of the suction rolls.
- Damage to rubber cover due to high pressure shower was overcome by changing to polyurethane cover.
- Increase the shower pressure to 70 bar for couch and pick-up roll.

Case study-6) Improvement to hydraulic and lubrication system

With increasing automation and consequent usage of high number of servo valves, the hydraulic oil requires high degree of purity. 70%- 80% of the failures on hydraulic systems are known to be caused by oil contamination. After commissioning of PM/c#2 in 1995, the gradual build up of contaminants in the hydraulic system resulted in series of servo valve failures from 1997. As illustrated earlier, major cause of bearing failures were also traced to the oil cleanliness.

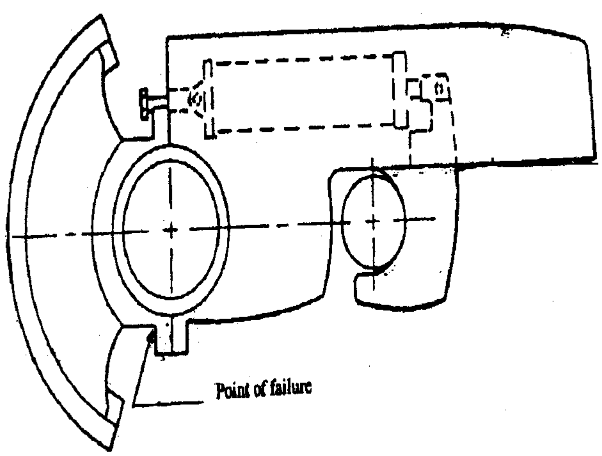

Fig. 6 Arrangement or primary arm

This led to specifying the oil cleanliness level in procurement stage and maintaining it in operation. The contamination control is done through high performance oil filtration systems. Table 9 gives the list of equipments. The cleanliness levels for hydraulic oil which was between NAS class 7-10 is now standardized to NAS class 6 (ISO 4406-class 15/12).

Case study-7) Analysis on primary arm failures

One of the frequent failures in paper machine is the primary arm (Fig. 6) gear segment mounting brackets in Pope reel (Table 10). The root cause of failure was traced to the followings :

- Fatigue due to spool loading shocks
- Impact loading due to change in limit switch position while lowering/raising the arm
- Galling effect due to wear out of bracket
- Stress concentration at the sharp radius of the collar
- Quality of material of construction.

The proactive measures taken for correction are :

- Changed the material of construction from Cast Iron GG 25 to EN 1563 (SG Iron)
- Cushioning pads provided over the mechanical stoppers.
- Bracket was redesigned and sharp corner at collar area was modified with additional ribs.
- Hard facing of bolts mounting area

Further, it is planned to change from electro-mechanical system of primary arm to hydraulic system for precise loading and reel spool magazine for spool loading.

CONCLUSION

TNPL, not content with the benefits of predictive maintenance, started the proactive techniques to improve the machine reliability and availability. Today maintenance is viewed as a profit center rather than a cost centre in TNPL. The improved maintenance practices, coupled with a proactive philosophy of maintenance and management support, TNPL achieved significant returns at lower costs through better utilization of resources. TNPL's maintenance teams not content to merely maintain the status quo, but seek continual improvements to meet the future goals of the mill. The fundamentals of proactive maintenance are not new and in reality any technically proficient organization should follow. Over a period, however proactive practices may suffer in favour of quick fix and production. The companies that recognizes the problem and act continuously to overcome and improve will produce better products at lower costs and provide greater job satisfaction to its employees.

ACKNOWLEDGEMENT

The authors wish to thank the TNPL Management for according the permission to publish this paper.