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RELIABILITY CENTERED MAINTENANCE IN INDUSTRIAL PLANNING - A CASE STUDY

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Abstract - Maintenance planning and scheduling is one of the most efficient investments an industry can make to improve productivity and availability, at the same time to ensure safe working environment at the minimum operating cost. This paper discusses a general approach to develop Reliability Centered Maintenance plan for any system, with the help of a case study of a drag chain conveyor system. RCM is a recently unfolded maintenance strategy with the basic goal of maximizing reliability and availability. This is achieved by incorporating all traditional maintenance strategies and implementing specific policy on each of the assets of the facility. The process involves identifying individual systems or functions and addressing any possible issues ahead of time, using methods like FMEA or FMECA. From the operating history and failure details of the system, approximate life and reliability at any time can be estimated using statistical methods. RPN is calculated from the assessment of risk of failure, and is used to identify critical equipment and prioritize failure modes. Careful analysis of all the results helps in identifying the best suitable maintenance strategy for individual components. The paper further discusses the method of deducing the optimum interval for preventive maintenance tasks, based on reliability data.

Keywords - Maintenance, RCM, RPN, FMEA, FMECA, Conveyor System

I. INTRODUCTION

Maintenance has been experiencing a slow but constant evolution across years, from the earlier concept of „necessary evil‟ up to being considered an integral function to an industry and a way of competitive advantage[1]. In this modern world, all industries are functioning with the solemn aim of increasing quality and productivity at the minimum possible cost. Maintenance planning is very crucial in this scenario not only to achieve maximum productivity, but also to ensure a safe working environment. Although maintenance activities require investment and skilled labour, it can prove to be cost efficient in the long run. The motive behind plant maintenance is to maintain plant and equipment at the maximum operating efficiency, reducing downtime and ensuring operational safety, safeguard investment by minimizing rate of deterioration and achieving this at optimum cost through budgeting and controls[2]. Many maintenance strategies have been practiced since the outburst of the industrial era, Reliability Centered Maintenance being the most advanced one.

One of the major challenges faced by maintenance department is deciding when and what kind of intervention must be taken for specific equipment[3]. Preventive maintenance involves maintenance tasks carried out before the failure occurs, thus preventing any breakdown of the equipment to happen. Although this strategy is considered to be highly beneficial, applying it on non critical equipment can prove to be a waste of resources and skilled labour. RCM was developed to optimize maintenance policy by a cost effective balance of breakdown, preventive, predictive and corrective maintenance activities[4]. It is a highly structured analysis formulated to decide on maintenance policy to be applied on each of the equipment, by collection and assessment of reliability data of every individual asset. RCM programs have existed since the 1960s, which were originally developed and proven in the aviation industry and then later adopted into other industries. RCM basically identifies the equipment or functions of the company that are most critical and optimize their maintenance strategies to minimize failure to ultimately improve equipment reliability and availability. The most critical equipment are those which tend to fail often and whose failure will affect the system‟s productivity and compromise the safety of the men and machines.

Traditionally, the maintenance planning utilizes the experience of the staff involved and also the original equipment manufacturer‟s manual provided[3]. But since the real operating conditions are not predictable, the actual equipment reliability and failure modes may vary significantly from that given in the operating manual. Since RCM utilizes real data to decide the maintenance type, the reliability of the equipment or system can be calculated with very good accuracy. This paper proposes a general method to develop a reliability centered maintenance plan for any system, with the help of a case study of a chain conveyor system. The main objective was to establish a maintenance plan for the system based on quantitative analysis in the context of RCM. Also to formulate a preventive maintenance tasks list and to calculate the optimum interval between the different tasks to be carried out.

II. LITERATURE REVIEW

RCM is a systematic consideration of system functions, the ways functions can fail, and a priority based consideration of safety and economics that identifies effective and applicable PM tasks[5]. Although RCM methodology has its origin in the

aircraft and aerospace industry, over the years it has found its application in various industries[6][7][8][9].
A general framework to carry out RCM is given in [10]. PM tasks are identified by careful analysis of design data, operational data and reliability data. The traditional approach of FMECA is described as method to identify the critical assets. Failures are classified into sudden, wear-out and gradual failures[5]. Identification of critical components and their prioritization is an crucial criteria in RCM. [11] concludes that functional dependencies cluster has the most precedence among all criteria clusters in decision making (cost, maintainability, complexity and safety impact being other criteria clusters). [12] proposes a conceptual framework that conciliates tactic and explicit information from the maintenance function, thus generating a new knowledge base used in analyzing and improving decisions in deploying a customized RCM. Process Mining techniques and Multi Criteria Design Making/Analysis are proposed to support the decisions in RCM implementations.
A quantitative analysis for establishing a maintenance plan in context of RCM is presented in [3]. Probability distributions of failure of different equipment and simulation of production and maintenance using Monte Carlo approach is used in a case study to identify new approaches to system maintenance and optimum interval for maintenance tasks.
In [4], RCM technique is presented in a systematic approach with the case study of a steam plant. The paper further goes on to suggest a maintenance labour program and also proposed a spare parts program for improving cost efficiency.

III. RELIABILITY CENTERED MAINTENANCE METHODOLOGY

Reliability Centered Maintenance is an innovative approach to maintenance in which the strengths of individual maintenance strategies are taken advantage of with the ultimate aim of improving system reliability with minimized life cycle costs.
The steps followed in this study for executing RCM is outlined in the figure. Steps 1-2 involves gathering of detailed knowledge of the system and its operational history. This information can be useful when it comes to deciding which failures will be most critical for the intended system application. The next steps involve identifying the system functions, both primary and secondary, and the functional failures. The failure modes are then considered and their effects are studied. All secondary equipment which might cause a functional failure in our main equipment are also included in FMEA analysis. The failure modes are then prioritized based on the severity and implications of the failure, occurrence and the the current ability to detect the failures. RPN or Risk Priority Number is the product of severity, occurrence and detection and is calculated to identify the critical failures and equipment. The failure data can be fit into a Weibull distribution to calculate the reliability of the equipment at any time. The Weibull parameter β gives us an insight on to which maintenance policy is to be adopted. β>1 implies the failure rate is increasing and hence preventive maintenance has to be carried out. Weibull analysis also helps us to decide on an optimum interval between PM tasks. The critical failure modes are then analyzed in the logic tree to determine the best course of actions to be taken to reduce the risks associated. An expert survey of maintenance and production should be carried out for this as this is one of the most influential step in RCM. In steps 8-9 RCM decision logic is applied to develop a task procedure and are implemented on the selected system. Although most of the companies give very less importance, post implementation analysis is very crucial to the successful accomplishment of any policy. The implemented plan should be evaluated precisely and updates should be included if necessary.

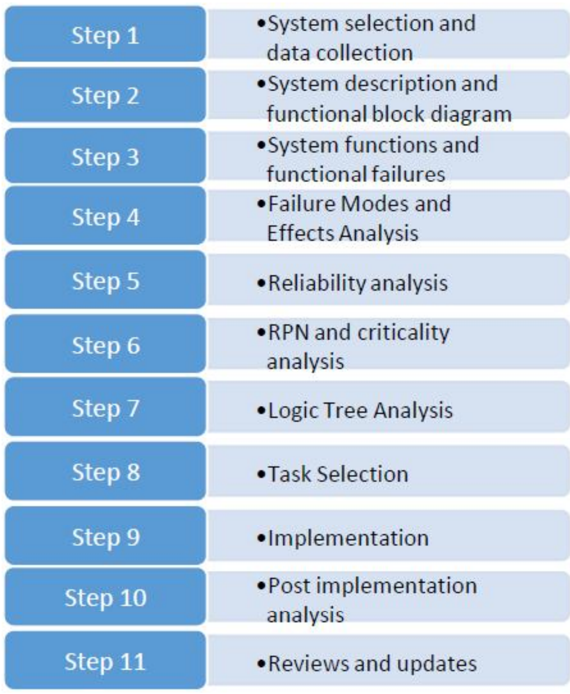

Fig.1. RCM Methodology

IV. CASE STUDY

An inclined drag chain conveyor in a production plant, which is required to transport very hot calcine from a drum cooler to a horizontal chain conveyor is selected as our system. There is a chute at the end of the conveyor through which calcine is discharged to the horizontal conveyor. The conveyor has an inclination of 25 degrees and there is also an outlet to a ball mill in the middle. The functional block diagram of the system is shown. The main components of the conveyor system are (1).Motor (2).Gearbox (3).Chain Drive (4).Bearings (5).Tensioning system (6).Drag Chain (7).Sprockets

(8).Guide rail and Liner. The failure of any of the component will affect the operation and performance of the conveyor system.

While performing the Failure Modes and Effects Analysis, apart from the chain conveyor, few secondary equipment are also included in the study. This is because even though they may not have any direct influence on the functioning of the chain conveyor, any malfunction of these may lead to the conveyor failure. Here, the secondary equipment selected are (1).Drum Cooler (2)Discharge Valve (3).Ball Mill (4).Discharge Chute (5).Discharge Valve Vibrator (6).Zero Speed Sensor. The functional failures of these equipment which can lead to a malfunction in chain conveyor are identified and how it will affect our system functions are carefully studied. The drum cooler is used to cool the very hot calcine delivered to it after hot processing. The ball mill reduces the size of the material entering through discharge valve, to the required size for further processing. A vibrator is attached to the discharge valve so as to ensure that the valve does not get chocked due to accumulation of material. The discharge chute discharges calcine into horizontal chain conveyor for further transportation. A zero speed sensor is attached to the system so as to give warning when the conveyor stops unexpectedly.

The most essential requirement for reliability analysis and maintenance planning is failure data. For the present analysis, the breakdown data for the past two years were collected from the records.

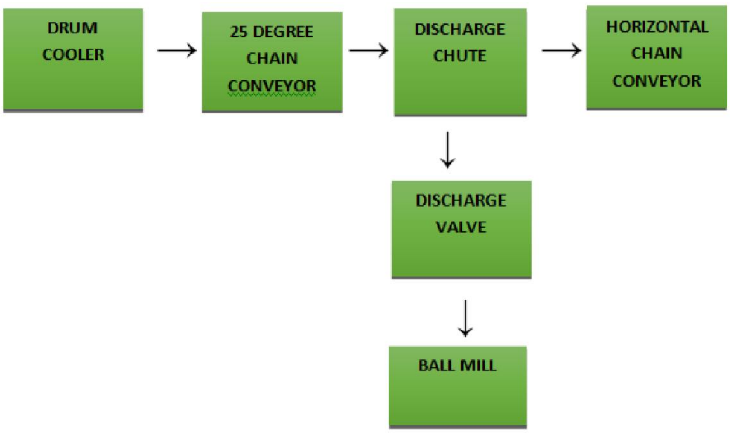

Fig.2. Functional Block Diagram of 25 Degree Chain Conveyor

Event	25 Degree CC Event Date	Cumulative Days	Cumulative Hrs	Reason for stoppage
-	01-01-2017	0	0	(Full replacement)
1	17-07-2017	197	4728	Liner damage
2	17-07-2017	197	4737	Link damage
3	30-12-2017	363	8712	Guide rail broken
4	28-01-2018	392	9408	Hub broken
5	18-03-2018	441	10584	Guide rail broken

Table.1. The breakdown data of 25 degree chain conveyor

FUNCTION	FUNCTIONAL FAILURE	FAILURE MODES	POSSIBLE CAUSES	Pattern	S	O	D	RPN	Maintenance plan	ACTIONS TO BE TAKEN
To convey calcine from drum cooler to ball mill/horizontal conveyor at a temp of approx 350 °C at a max rate of 60 TPH.	Not able to deliver upto capacity	Damaged parts - flights/links/guide rail	wear/corrosion/abrasion/loading issues	W	4	3	2	24	TBM	SOP to be followed correctly PM inspection for wear/ damage
		Casing damage(false air ingress to the conveyor)	corrosion/abrasion	W	4	2	1	8	TBM	-
		Material spillage or build up	casing damage/damaged parts	R	3	3	2	18	CBM	-
	Fail to deliver at the specified temp.	Temp of calcine high at conveyor inlet itself	drum cooler fault/any upstream equip fault	R	3	2	2	12	CBM	-
		Uncontrolled overflow/underflow running		R	3	2	2	12	CBM	-
	Chain conveyor not running	Power failure/ Electrical system failure	electrical	R	1	2	1	2	CBM	-
		Drive system failure/broken parts (motor,gearbox,coupling,bearing)	misalignment/loading/lubrication/fatigue/wear/contamination	R	3	3	2	18	CBM	-
		Jamming of conveyor chain	material packed in chain/guide rail damage/ discharge prob	W	4	5	2	40	CBM	PM inspection for any faults Chute vibrator to be installed
		Guide rail/ nose guide/liner damage	loading prob/ wear	R	4	3	2	24	TBM	PM inspection regularly Proper cleaning of system
		Discharge system issues	discharge chute/valve chocking	F	4	3	2	24	DOM	Chute vibrator and chute detector to be installed Proper cleaning of system
		Link damage(sideplate/inner link failure/flight /pin breakage)	wear/temp/loading/tensioning/ design issues	W	4	3	2	24	TBM	PM inspection regularly for wear/ damage, chain tension
		Chain slipping over sprocket	wear/loading/tensioning/lubrication issues	R	3	2	2	12	CBM	-

Table.2. Failure Modes, Effects and Criticality Analysis for 25 Degree Chain Conveyor

The failure modes and nature were identified to select the suitable maintenance strategy for each type.The failure patterns were classified as random, frequent or wear out models based on the actual failure frequency data available. The adopted strategies are Condition Based Maintenance(CBM), Time Based Maintenance(TBM) and Design Out Maintenance(DOM). Critical functions were selected on the basis of calculated RPN and actions to be taken were suggested.

The secondary equipment functions which are critical and will cause serious malfunctions in the chain conveyor were also identified and solutions were proposed.

EQUIPMENT	FUNCTION	FAILURE MODE	POSSIBLE CAUSES	Pattern	S	O	D	RPN	Maintenance plan	ACTIONS TO BE TAKEN
Drum Cooler	To reduce temp of calcine from 400°C to 200°C and deliver it to CC	Not delivering calcine to CC due to external jamming	water leakage from the drum cooler	R	4	4	2	32	CBM	Monitor load of drum cooler Check for any leakages regularly Cleaning on scheduled time
Ball Mill	To reduce the size of calcine to the required level	Not running	inlet/outlet jamming	R	4	3	2	24	CBM	Monitor load of ball mill Check for noise/vibration Scheduled cleaning
Discharge Chute	To discharge calcine from 25 Deg CC to horizontal CC	Chute chocking	material build up	F	4	4	2	32	DOM	Vibrator to be installed and run at regularly Chute detector to be installed Scheduled cleaning

Table.3. Failure Modes, Effects and Criticality Analysis of Secondary Equipment

SOD Criteria The criteria used for calculating RPN is summarized in the table given. If RPN is greater than 20, the equipment or function is considered to be critical.

Severity	
5	Damage SHE and equipment
4	Damage of equipment if not detected in time
3	Affect 3P (productivity , performance and profitability) if not detected in time
2	affect performance & quality if not detected in time
1	Doesn't cause any of the above even if not detected in time
Probability of occurrence	
5	< 1 month
4	< 6 month
3	< 1 year
2	< 2 year
1	> 2 year
Detection capability	
5	Impossible now
4	possible but unsafe
3	Possible but inaccessible
2	possible with instrumentation
1	possible , easily visible

Table.3. SOD Criteria Weibull Analysis

An important task in maintenance planning is to develop a PM checklist and also to deduce the optimum interval for PM tasks to be carried out. Weibull analysis can be used to calculate the reliability of the equipment at any time. Based on reliability data, the life of the system can be approximated. L10 life is a concept in bearing engineering which is defined as the number of hours (or number of million rotations) a bearing will last with 90% reliability. L50 and L90 can also be defined in the same manner. This concept is utilized in this study to calculate the life of our system. L90 is assumed to be the total system life, after which the drag chain is replaced. Reliability Analytics Toolkit was used to perform Weibull Analysis for the study. The failure data is taken as input and the Weibull probability plot is given as the output. L10, L50 and L90 can be calculated from Weibull probability plot. The software uses linear regression method to calculate the Weibull parameters β and θ. β value was calculated as 2.24,which indicates an increasing failure rate of the system. θ was estimated as 8813 hours, the point at which the system has a reliability of 36.2%. This parameter gives an approximate measure of the system‟s life and is useful in determining the interval between PM tasks. A cost assessment system was not available to evaluate the cost of the maintenance activities and deduce an optimum interval so as to minimize the cost involved. Hence from reliability point of view, a rough estimate of the interval between PM tasks was calculated using the formula L50/5. This formula doesn‟t give the exact interval between PM tasks, but is used as thumb rule to get an idea of the approximate range of interval. Based on the calculated results, and the original equipment manufacturer‟s manual the best suitable interval was adopted.

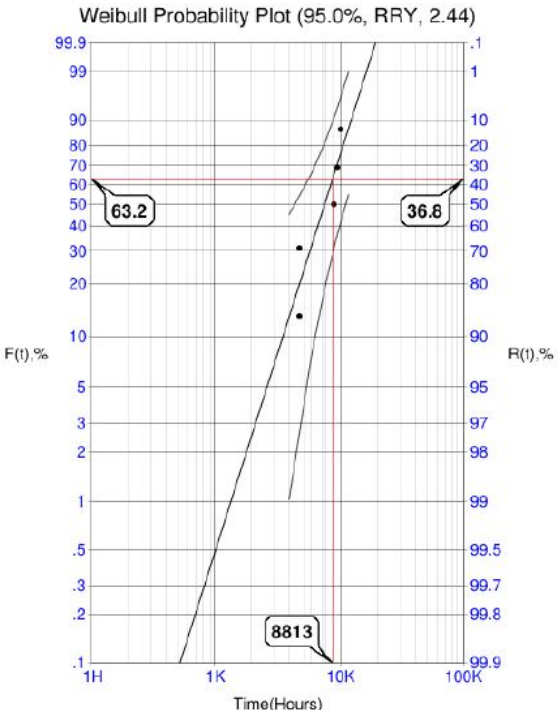

Fig.3. Weibull Probability Plot

Task	Frequency
Check the drive end for internal wear	15 Days
Check tension end for internal wear	15 Days
Gear Box Oil Level checking	15 Days
Lubricate the drive chain	15 Days
Check any Leakage	15 Days
Check any abnormal sound	15 Days
Check the condition of drag chain links	15 Days
Check all bolts (jack, foundation etc.)	15 Days
Check tension of chain at drive and tail	15 Days
Condition of Chain Link	6 Months
Thickness of chain link measure & record	6 Months
Vibration analysis of motor at non drive end	2 Months
Vibration analysis of motor at drive end	2 Months
Vibration analysis of gearbox input side	2 Months
Vibration analysis of gearbox output side	2 Months
Vibration analysis of sprocket drive end	2 Months
Vibration analysis of sprocket non drive end	2 Months

Table.4. PM Tasks List

CONCLUSION

The paper provides an outline to carry out Reliability Centered Maintenance in any system, with the example of a drag chain conveyor system. The process features identifying the critical functions and failure modes and suggestions to improve the the present situation. Another key feature of the work was finding the optimum interval to carry out preventive maintenance tasks. A new method was adopted to have a rough estimate of the interval. Accordingly a PM tasks list was developed with the interval specified for each task. The proposed method to calculate the interval between different tasks does not involve any cost considerations, and was calculated solely based on reliability considerations. The study can be further extended to develop a cost based maintenance plan which considers all the cost involved in deploying the required manpower and resources for the maintenance activities.

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