Application of Reliability Centered Maintenance on Horizontal Boring Machine - A Case Study

B. Devaraj Naik[1], Pradeep Kumar Soni[2]

[1]M. Tech. Scholar, Department of Mechanical Engineering, Maulana Azad National Institute of Technology, (MANIT), Bhopal, Madhya Pradesh, India
[2]Assistant Professor, Department of Mechanical Engineering, Maulana Azad National Institute of Technology, (MANIT), Bhopal, Madhya Pradesh, India

***Abstract*—*A case study has been developed by analyzing the RCM effectiveness on the balancing system of horizontal boring machine in private sector Madhya Pradesh , by using tools such as FMEA (Failure Modes and Effects Analysis), FTA (Fault Tree Analysis), MTBF (Mean time between failure) and MTTR (Mean time to repair). The failure characteristics of system components (cylinder, Direction control valve and pump) have been compared in terms of RPN, Criticality number, MTBF and MTTR. Fault tree analysis performed on the balancing system enabled to explore the root causes of component failure with help of hydraulic balancing circuit. FMEA analysis provided RPN (Risk priority number) and criticality numbers which indicated higher failure risk for Direction control valve, whereas MTBF and MTTR values suggested pump has higher failure chance. By preparing a logic diagram for each of the components, the contribution of each one for the implementation of a structured predictive maintenance planning has been determined.*

Keywords*—Reliability centred maintenance (RCM), Fault tree analysis (FTA), FMEA, MTBF, and MTTR, RPN (Risk priority number).

I. INTRODUCTION

Maintenance is an essential part of the hydraulic system today. A reliable hydraulic system is required to ensure progress in the horizontal boring machine operation. When the hydraulic system stops functioning, the industry has to declare downtime which increases the expenses further. This highlights the importance of a maintenance strategy to avoid break down. [5]

A good maintenance strategy is based on understanding the system and knowledge of maintenance concepts. The challenge is to choose the right maintenance concept for the specific equipment and operation conditions. The implementation of reliability centered maintenance (RCM) can help decide what equipment that needs different maintenance strategies to ensure a high reliability at a reasonable cost.

In this work, RCM has been applied on the hydraulic balancing system of a horizontal boring machine in industries. The main hazard analysis techniques used in this work are the Failure tree (FTA) and Failure Modes and Effects Analysis (FMEA). The FTA and FMEA are tools of product and processes analysis that allow to a systematic and standardized analysis of potential failures, establishing its consequences and guiding the adoption of corrective or preventive actions. [2]

II. RELIABILITY CENTRED MAINTENANCE

RCM is used as a maintenance tool that aims to rationalize and systemise the determination of adequate tasks, which can be adopted within the maintenance plan. Moreover, it aims to ensure the reliability and the operational security of equipments and installations to the lesser cost [2]. By exploiting totally different kinds of maintenance, the RCM intends to protect the functionality of the system or component by determining the maintenance needs of each equipment.

When it uses RCM to determine a maintenance technique, it is important to keep in mind that these maintenance strategies should answer correctly and accurately to the subsequent questions:

(i) What are the functions to preserve?
(ii) What are the functional failures?
(iii) What are the failure modes?
(iv) What are the failure effects?
(v) What are the failure consequences?
(vi) What are the applicable and effective tasks?
(vii) What are the remaining alternatives?

To answer every question, the RCM uses several strategies to establish a maintenance plan in a structuralized and documented sequence. [3]

Methodology

The objective of this work is to improve the reliability of the hydraulic system and perform a maintenance cost analysis of these tools. It is accomplished by using tools like FMEA, FTA, MTBF (Mean Time between Failures) and MTTR (Mean Time to Repair) on the system components such as cylinder, dc valve and pump.

1. Hydraulic circuit preparation of the balancing circuit.
2. Fault tree analysis of the system.
3. FMEA of cylinder, Direction valve valve and pump.
4. Calculation of MTBF and MTTR.
5. Preparation of Logic Tree diagram for each component
6. Proposing the optimized maintenance strategy.

III. HYDRAULIC BORING MACHINE

The boring machine is shown in the figure 1. Whose associated hydraulic balancing circuit is depicted in figure 2.

Fig.1: Hydraulic boring machine

The horizontal boring machine shown above is installed in steam turbine workshop of privet sector Madhya Pradesh. This horizontal boring machine is used in boring operation of steam turbines.

It consists of two beds, one of which is horizontal (300m) and other is vertical. The travel lengths of beds are 27m and 5m. The travel length of head is 1250mm and that of spindle is 1750mm.

3.1 Hydraulic Circuit of Balancing System

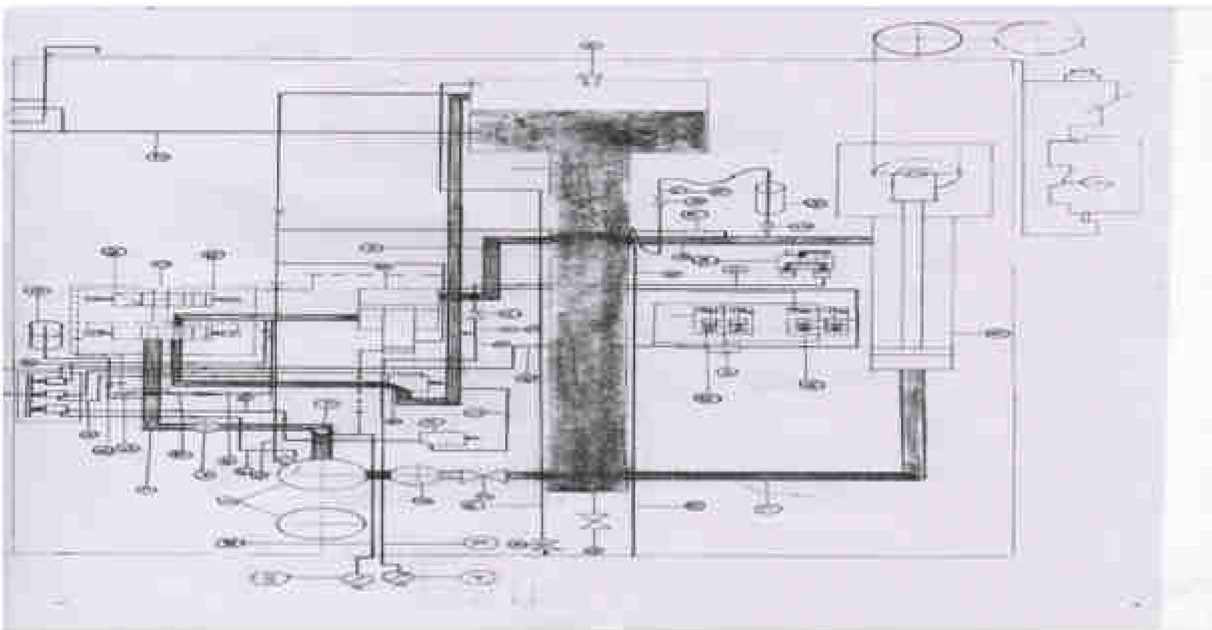

Fig.2: Hydraulic Circuit of Balancing System

IV. FAULT TREE ANALYSIS (FTA)

The Fault Tree Analysis (FTA) is one of the basic and the most used methods for analysis of technical system reliability and safety. FTA is a deductive method where at first is the top event, which represents a failure, and then the possible causes of this failure inside the system are analyzed. The basis of the fault tree represents a transformation of physical systems to structural logic diagram.

4.1 Fault Tree Diagram

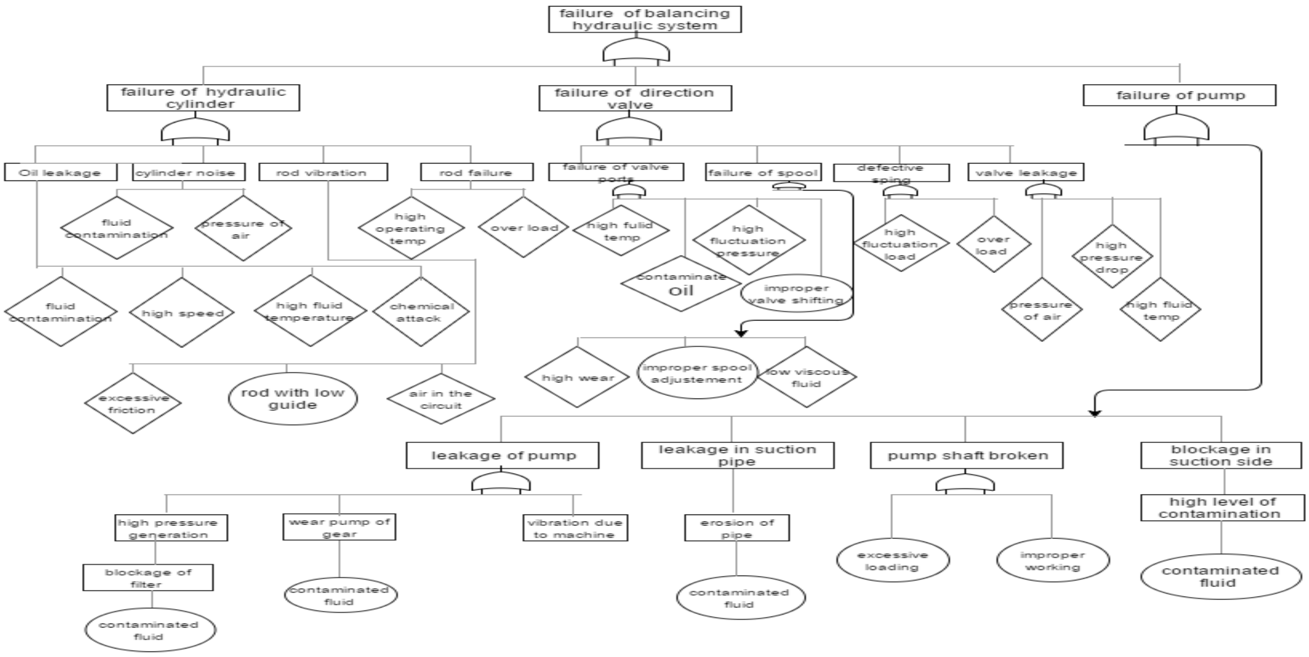

Fig.3: Fault Tree Analysis

It is important to emphasize that the basic failures referring to all major components (cylinder, pump, Direction Control valve) are essentially the same ones and generically had been shown in the fault tree with the description of hydraulic system.

Once the FTA has been prepared, it follows an analysis through FMEA so that an appropriate maintenance plan can be developed by the comparative study of these hydraulic components.

V. FAILURE MODE AND EFFECTIVE ANALYSIS

The failure modes and effects analysis (FMEA) is one of the most efficient low-risk tools for prevention of problems and for identification of more efficacious solutions, in cost terms, in order to prevent such problems. FMEA is a deductive technique that consists on failure identification in each component, its causes and consequences on the equipment and on the whole system. The FMEA Referring to the equipment failures. The phases of RCM (reliability centred maintenance) implementation depend on the answers to such questions.

5.1 FMEA

The failure mode and effect analysis uses various factors for failure evaluation and analysis and it include component function, failure mode, potential effects, and potential causes of failure and current controls.

No	Item/Function	Failure mode	Potential effects	S	Potential Causes	O	Current Controls	D	Risk Priority Number (RPN)	Critical number

These factors can be obtained from the detailed study of the system which is further used for evaluating the maintenance strategy to be adopted. The FMECA thus rank the maintenance activities according to priority which will optimize the maintenance activities. [5]

FMEA procedure-

- Reviewing design details, illustrating equipment block diagram and recognizing all potential failures, respectively. Following recognition, all possible causes and effects should be classified to the related failure modes.

After this practice, failures are prioritized according to ranking based on Risk Priority Number (RPN)

RPN=S*O*D

- **Severity(S)** refers to the immensity of the last effect of a system failure.
- **Occurrence (O)** refers to the probability of a failure to occur.
- **Detection (D)** refers to the likelihood of detecting a failure before it can occur.

5.2 Criteria for Failure Modes Evaluation.

Table.1: Criteria for Failure Modes Evaluation

Rank	**Severity**	Rank	**Occurrence**
1-2	Failure is of such minor nature that the operator will probably not detect the failure	1	An unlikely probability of occurrence: probability of occurrence < 0.001
3-5	Failure will result in slight deterioration of part or system Performance	2-3	A remote probability of occurrence: 0.001 < probability of occurrence < 0.01
6-7	Failure will result in operator dissatisfaction and/or deterioration of part or system performance.	4-6	An occasional probability of occurrence: 0.01 < probability of occurrence < 0.10
7-9	Failure will result in high degree of operator dissatisfaction and cause non-functionality of system.	7-9	An occasional probability of occurrence: 0.10 < probability of occurrence < 0.20
10	Failure will result in major operator dissatisfaction or major damage.	10	A high probability of occurrence: 0.20 < probability of occurrence.
Rank	**Detection**		
1-2	Very high probability that the defect will be detected.		
3-4	High probability that the defect will be detected.		
5-7	Moderate probability that the defect will be detected.		
8-9	Low probability that the defect will be detected.		
10	Very low (or zero) probability that the defect will be detected.		

It is important to note that the definitions, levels and numbers assigned to the different levels can vary depending on the system under evaluation. [1]

It has proven useful that nonconsecutive numbers (e.g. 1,3,5,7,10) are more useful than consecutive numbers e.g., 1,2,3,4,5, as the use of non-consecutive numbers allows more distinction between ratings and less debate amongst team member

5.3 FMEA Analysis of Major Components of Hydraulic Circuit

Table.2: FMEA Analysis of Major Components of Hydraulic Circuit

No	**Item/ function**	**Failure mode**	**Potential effect**	**S**	**Potential Causes**	**O**	**Current Control**	**D**	**RPN**	**Critical No**
1	cylinder	1. Rod failure 2.Oil Leakage 3.Cylinder noise 4. Rod vibration	1.Machine stops 2.System Pressure lowers 3.unpleasant working condition 4. Noise	5	1. High operating temperature ,over load 2.Erosion 3. High speed ,excessive friction 4. high speed,	5	1.Working under prescribed limit 2.Painting the surface 3.Improper lubrication 4.Proper alignment of components	5	125	25

					misalignment					
2	Direction Valve	1.Failure of valve ports 2. Failure of spool 3.Defective spring 4. Valve leakage	1.Flow stops 2. Improper oil flow 3.Improper shifting 4.Pressure lowers	6	1.High fluctuation pressure 2. High wear , improper spool adjustment 3 High fluctuation load, over load 4. High fluid temperature , erosion	10	1.Cleaning, Fitting and Tightening 2. Cleaning and fitting 3. Work under permissible 4.Periodically cheeking	6	360	60
3	pump	1. Leakage of pump 2. Leakage in suction Pipe 3. Pump shaft broken 4 blockage in suction side	1.System pressure lowers 2. System press lowers 3. System stops 4 Flow of oil stops	9	1.Contaminated high pressure of fluid 2. Erosion 3.Excessive loading 4.Contamination of oils	9	1.Proper fitting 2.Check hydraulic hoses and fitting 3. Check flow rate ,visual inspection 4.Visual inspection	4	324	81

The result of the FMEA analysis was identification of three failure mode that should be prioritized in the maintenance plan. The frequency of the high priority maintenance activities should be increased or new maintenance activities should be implemented.

Failure mode	Risk priority number (RPN)	Criticality number
Cylinder	125	25
D.C. Valve	360	60
Pump	324	81

FMEA analysis in this thesis ranks the valve as the highest priority. While the pump has the second highest priority and cylinder is the last highest RPN. The valve, pump and cylinder should be prioritized in the maintenance plan.

VI. ANALYSIS OF MTBF AND MTTR

Mean time to between to failure (MTBF):

MTBF is the time between two failures. When failure rate is constant, the mean time between failures is the reciprocal of the constant failure rate or the ratio of the test time to the number of failures [4]

$$MTBF = \frac{Total\ Available\ Hrs - Breakdown\ Hrs}{No.Breakdown}$$

Mean time to Repair (MTTR):

Mean Time to Repair" is the average time that it takes to repair something after a failure. [4]

$$MEAN\ TIME\ TO\ REPAIR(MTTR) = \frac{total\ breakdown\ Hrs}{NO.Breakdown}$$

Failure calculation:

Total available hrs in years = 365*44 = 16060hrs

Cylinder

Failure in 2 years = 1 time
Repair time = 1 day
No. Break down = 1 day

$$\text{MTBF} = \frac{16060-44}{1} = 16016 \text{ hrs};$$

$$\text{MTTR} = \frac{44}{1} = 44 \text{ days}$$

Direction Valve

Failure in 2 years = 4 times
Repair time= 1day
No. Break down = 4 days

$$MTBF = \frac{16060-176}{4} = 3971 \text{ hrs} ; \quad MTTR = \frac{176}{4} = 44 \text{ hrs}$$

Pump

Failure in 2 years = 3 times
Repair time = 2 days
No. Break down = 6 days

$$MTBF = \frac{16060-264}{3} = 5265 \text{ hrs} ;$$

$$MTTR = \frac{264}{3} = 88 \text{ hrs}$$

The comparison of MTF and MTTR for various components shows that shows that the pump has least values followed by Direction control valve and cylinder. It indicates that pump fails at comparatively higher frequency than other components and the working duration is also less. Thus, pump requires highest priority in maintenance plan.

Failure mode	MTBF	MTTR
Cylinder	16016	88
D.C.	5265	44
Valve		
Pump	3971	44

VII. RCM LOGIC DIAGRAM

Once the priorities have been decided, the necessary corrective actions should be determined to prevent the failure which is accomplished with the help of logic tree diagrams prepared for each component. As shown in fig 4, 5, 6. A logic tree diagram depicts the appropriate course of actions that needs to be implemented to address the particular component failure based on the effectiveness, cost and priority associated with the particular task. These actions include redesigning, replacement, run to failure, real-time monitoring task and PM task. The cost analysis performed on the replacement of cylinder, pump and valve obtained expenses as rupees 10700, 7800 and 4800 respectively with which the cost effectiveness of maintenance task adopted can be determined. Fig. shows the logic tree diagrams prepared for cylinder, pump and Direction control valve. [6]

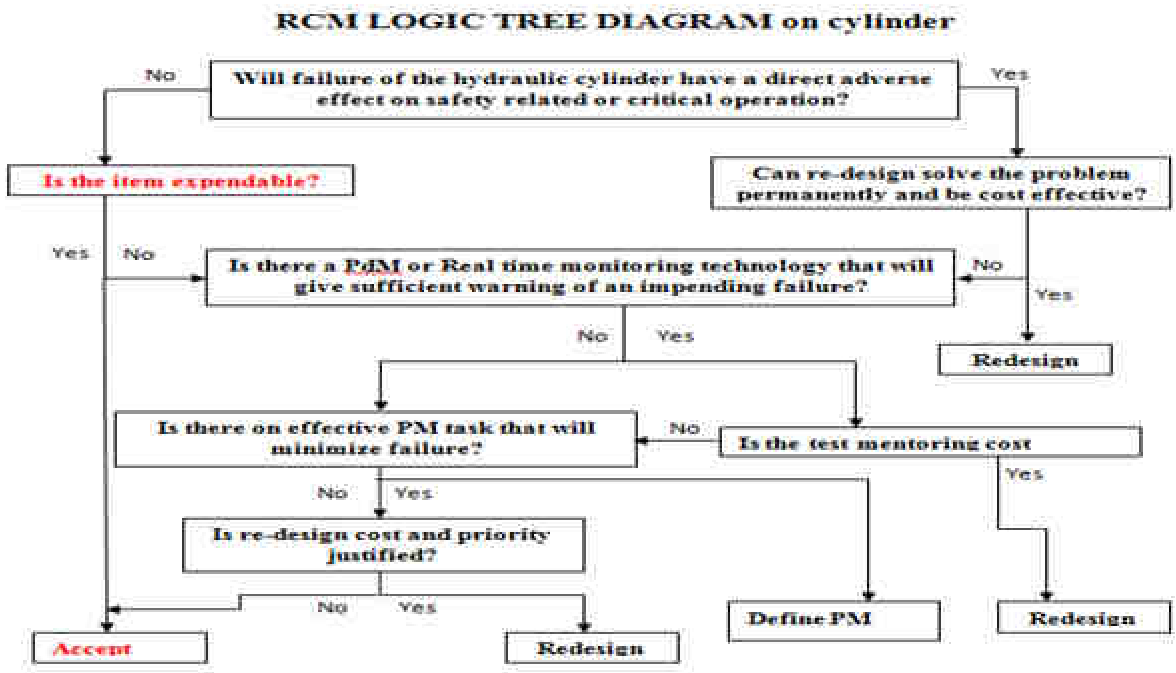

Fig.4: logic diagram for cylinder

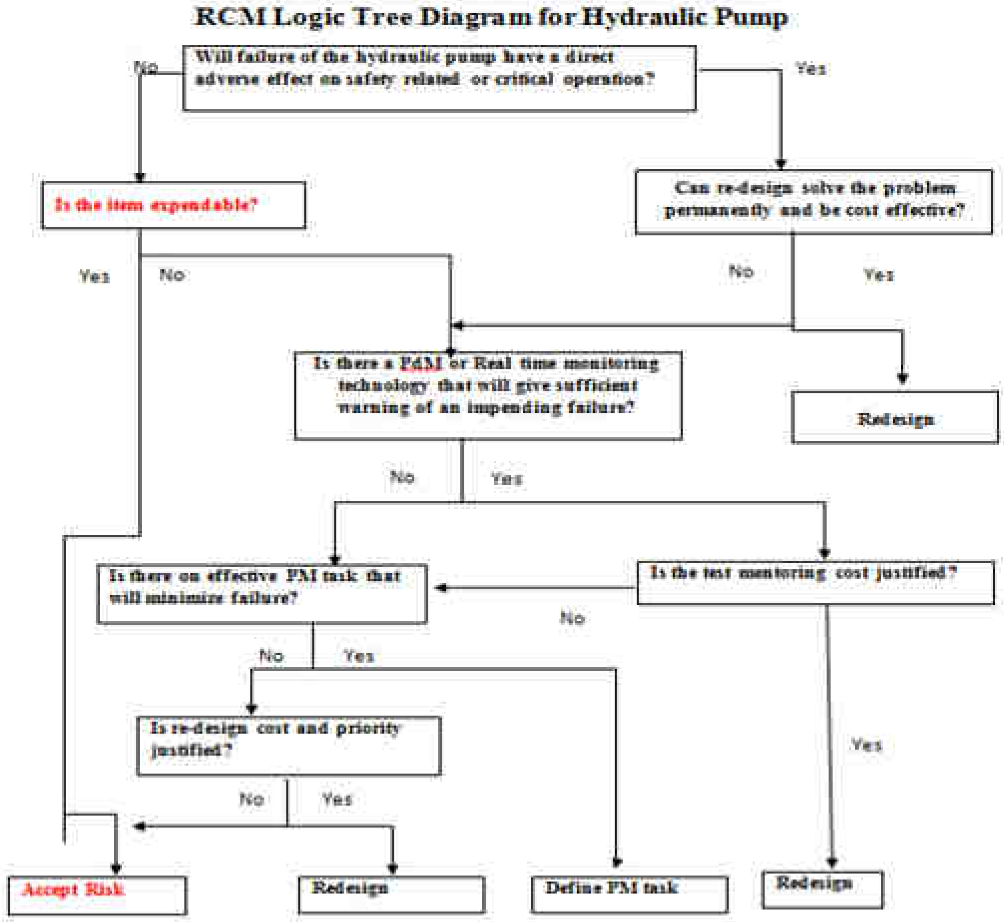

Fig.5: Logic Diagram for Pump

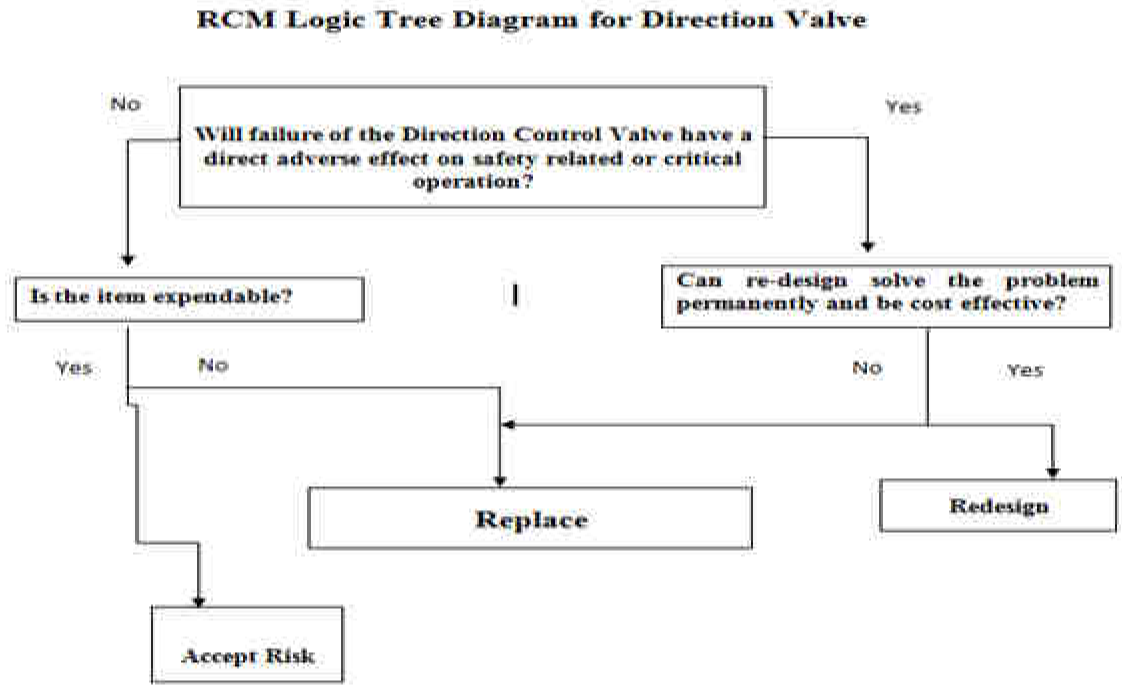

Fig.6: logic diagram for D.C. Valve

VIII. MAINTENANCE STRATEGY

With the help of logic tree diagrams, the required preventive maintenance activities need to be determined. Also, the existing maintenance strategy on the machine is given in table. This can be used to evaluate the proposed strategies. Most of the parts on the hydraulic machine need a periodic maintenance strategy. Activities like cylinder pump and direction valve fits into a periodic schedule. Some of the equipment needs to be tended more often than others. The maintenance activities should therefore be divided into groups.

- Group A of maintenance is done every 3 months
- Group B is done every 6 months
- Group C is done annual
- Group D is done every five years

The different types of preventive maintenance activities that are needed for the hydraulic system is listed.

IX. PROPOSED CHECK LIST

The proposed check list of preventive maintenance tasks for the hydraulic components check list is shown in table.3

Table.3: Proposed Preventive Maintenance Check List for Hydraulic System

Hydraulic Components	**Tick of**	**Remarks**
Hydraulic pump		
Check pump leakage		
Check noise		
Check mounting		
Check oil contamination		
Hydraulic cylinder		
Check leakage		
Check noise		
Check mounting		
Hydraulic direction control valve		
Check valve leakage		
Check noise		
Check mounting		

It is suggested that by the proper monitoring of the above mentioned PM tasks, the system functionality can be maintained efficiently at low cost and safety risk

X. CONCLUSIONS

Reliability Centered Maintenance strategy has been applied to the hydraulic balancing circuit of horizontal boring machine in industries. FMEA analysis has been performed on the hydraulic components such as actuating cylinder, pump and DC valve and comparison was made between them in terms of RPN and Critical Number. It was found that DC valve has a higher risk of failure with RPN 360 and Critical No. 60 compared to pump (RPN 324; Critical No. 81) and cylinder (RPN 125; Critical No. 25).

Another comparison was made between the components in terms of MTBF and MTTR, in which cylinder was found to be subjected to lesser risk of failure with MTBF 16016hrs and MTTR 88hrs. The corresponding values for DC valve and pump were obtained as 5265/44hrs and 3971/44hrs respectively.

With the help of RCM Logic Diagrams and cost analysis, appropriate maintenance task has been determined for each component failure that should be executed in a timely manner as decided. By ensuring the proper implementation of these tasks, the system reliability can be improved by minimizing the cost.

REFERENCES

[1] Feili, H. R., Akar, N., Lotfizadeh, H., Bairampour, M., & Nasiri, S. (2013).Risk analysis of geothermal power plants using Failure Modes and Effects Analysis (FMEA) technique. *Energy Conversion and Management*, *72*, 69-76.

[2] de Queiroz Souza, R., & Álvares, A. J. (2008). FMEA and FTA analysis for application of the reliability-centered maintenance methodology: case study on hydraulic turbines. In *ABCM Symposium Series in Mechatronics* (Vol. 3, pp. 803-812).

[3] B Devaraj naik., pardeep kumar soni.,(2016). Research review on reliability centred maintenance (Vol. 5, Issue 6, June).

[4] Kumar, P., & Rudramurthy, R. (2013). Analysis of Breakdowns and improvement of Preventive Maintenance on 1000 ton hydraulic press. *International Journal of Emerging Technology and advanced Engineering (IJETAE)*, *3*(8).

[5] Langlo, F. (2014). Application of a reliability centered maintenance on a drilling system

[6] Nowlan, F. S., & Heap, H. F. (1978). *Reliability-centered maintenance*. United Air Lines Inc San Francisco Ca.