Fault Analysis for Reliability Centered Maintenance (RCM) in Machining

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Abstract - Serviceability, functionality, reliability and maintainability functions are useful in the engineering industry as functions that span the life cycle of engineered products. Reliability Centered Maintenance (RCM), in this case, is an element of equipment design, operation and installation that are expressed based on maintainability of the economy, product functionality, accuracy and safety in product performance and maintenance actions. This research uses plant examples (Balbina hydroelectric plant for FTA analysis and Flat Rock Assembly Plant) for RCM to discuss the functions. An evaluation of Fault Tree Analysis (FTA) is provided with an overview of its reliability and equipment effectiveness, which can be attained based on the implementation of wide-range initiatives and activities such as adoption of novel equipment, condition monitoring, root cause focus, standardization, design maintainability, long-term planning and general product upgradability.

Keywords - Fault Tree Analysis (FTA), Reliability Centered Maintenance (RCM), Serviceability, functionality, maintainability, upgradability

I. INTRODUCTION

The application of novel technologies in machining has facilitated significant transformation in working processes. Intense application and adoption of automatized models and state-of-the-art equipment has uplifted the maintenance segment to a strategic dimension focusing on fundamental operational availability for international automotive, electrical and aeronautical industries. One of the most contemporary maintenance initiatives is Reliability Centered Maintenance (RCM), which has significantly enhanced its application in various industrial activities whereby maintaining the physical functionality of processes and assets, which includes the identification of faults [1]. RCM is applied in various modern segments of the economy, incorporating tertiary services. RCM application has been considered fundamental and stimulated with the enhancement of guidelines imposed by the community of people, security groups and entities of environmental preservation. This has in turn facilitated the enhanced serviceability, functionality and maintainability in the mechanical industry.

In the electrical industry for example, companies face challenges while trying to adapt to newly imposed guidelines regarding the market relations: challenges of managerial and technological obsolescence. Nonetheless, because of the sophisticated electronic and electric equipment applied for consumers, reliability requirements of electrical energy and its supplies have enhanced significantly. To minimize frequency, time of failure occasions and probability of minimized effects, it is essential to considered undertaking financial investments towards the increment of system reliability and maintainability. Reliability and maintainability functions come with many obstacles compared to any management segments [2]. The technologies of conditional maintenance, which consider the monitoring of engineered products and equipment during its normal functioning and execution of the halts when faults and defects are identified has now become critical.

With FTA implementation in the Balbina's plant for example, it is projected that subsidizing functional decision-making approaches is fundamental in minimizing corrective faults of engineered products and equipment. The fault analysis strategies are applied in the consolidated maintainability of systems; enhance reliability, functionality and optimizing upgradability.

Fault Tree Analysis (FTA) is critical in making it necessary for analysts to evaluate a plant's components and their relations [3]. This allows them to identify and assess the process defects and recommend the enhancements as effective monitoring models and protection for redundancies. FTA incorporates the construction of fault tree, which is a logical diagram using a deductive procedure that from predefined undesired occasion to determine the potential causes of occasions [4]. The procedure pursues evaluations of successive amalgamations of component failures until attaining the basic failures i.e. FT major occasions, which incorporate the limit of evaluation resolution. The undesired occasion is typically known as 'tree top events'. Critical concepts of FTA incorporate the translation of physical models in structured logical diagram in Fig 1 and Fig 2, which particular failure causes affect the interest top occasions.

With RCM implementation in the American plant automotive engineering plant, the functions of serviceability, functionality, upgradability, reliability and maintainability are applied. Over the past few decades, there has been a downtime and engineered products have not posed significant obstacles in automotive industry. Targets for the general functionality of engineered products surpass 85%, which is more than the standardized percentage. This has therefore enhanced achievability in some instances. Uptimes close to 100% in considerably mission-crucial segment are considered. Serviceability attentions are the similarly concentrated on the future, present and past and reactive works comprise of about 5% of the general task load in some plants. The executives are a major advocate of fundamental plant maintainability for engineered products, which defines the present state of reliability in America.

The Flat Rock Assembly Plant was established in 1972 and constructed its manufacturing segment two years later. More than 1300 of the firm's high-end technologically enhanced and customized motors are manufactured every day. Within the plant, the concentration is done considering a stringent method to enhance reliability. Irrespective of the kind of operation being considered and the tracking being done, the focus is to attain 100% reliability and performance. Clients are paying for quality engineering services and do not project any form of breakdown on the plant's floor. To attain reliability and maintainability excellence, particular drivers in electronic systems have to be considered [5]. macro-level that considers the manner in which one can ensure the equipment follow its projected role in the firm; micro-level focusing on the maintenance aspect as scheduled and planned.

The reliability of the plant has a strategic relevance and there is a stringent focus on planning that is certainly one of the major factors to attain reliability. The executives of the American plant are expert planners for firm maintainability at the plant and strongly believe in its significance. This indicates that there is considerable support at top-level management group for issues on reliability. At the board level, there have always been individuals who connect to the executives and every individual at the superior management group and all these understand the profitability and performance of the engineering sector. Technicians and managers i.e. equipment service associates are obliged to functionally and structurally enhance maintainability according to the needs of the plant.

Since its establishment of the manufacturing sector in 1994, the firm has produce about 3.5 million motors, which produces about 1300 automobiles in a single business day. It also provides jobs for more than 8,000 individuals as is distributed by more than 250 North American distributors. The establishment of the plant, which also considers 4.6 km2 whereby more than 5Mft2, is under its roof hence making it unique. The plan has been divided into four different segments: Energy/facility, Paint shop, Assembly, and Body Shop. Every unit uses a different method to achieve maintenance. For example, the body shop considers an integrated method and has limited maintenance segment whereas the associates whose there focus is considerably on maintainability operate closely as a team with the quality and production associates who communicate with the supervisors of the shop.

More than 100 body shops and equipment service associates operate ten hours on shifts with more than an hour of obligatory overtime. In case the line is exceeding to the top form after the operational hours, punch-outs are executed earlier. Equipment service associates are not experts, but multi-craft professionals performing wide-range corrective, predictive and preventive obligations. Since the wide-range line incorporates automation equipment with about 1300 robots, a significant proposition of the base shifts is considered based on predictive maintenance that incorporates the application of current motor monitoring and infrared thermography, including scheduled corrective operations and project planning approaches.

Preventive maintainability on robots happens following the shifts or at scheduled timeframes when equipment does not operate swiftly, which explains why planning is fundamental in this case. Assembly works in a traditional manner. It is about seventy multi-craft reports for equipment service associates to install and assembly engineered products to facilitate maintainability. Shifts are the same as the body shops; however, preventive maintainability activities include the major share of in-shift operations. There are about nine robots and this explains why there is approximately 75% preventive maintainability operation completed while the line is in operation. Corrective works are planned for flexible durations and off shift. Outsourcing is fundamental for staffing in maintainability of the four different plant units in the American firm. It assures flexibility and permits the executives to concentrate on workforce core competencies.

Section I has introduced the concept of FTA and how it is relevant for RCM for mechanical engineering plants. FTA will be applied to assess the faults in machines and illustrate the functions of serviceability, functionality, reliability and maintainability in engineering firms. To address these functions, this paper uses examples and cases of two firms Balbina hydroelectric plant and Flat Rock Assembly Plant with a central focus on FTA and RCM respectively. The remaining part of the research is organized as follows: Section II presents the background analysis of the research. Section III is the literature review section. Section IV focusses of the main analysis of the paper. Section V concludes the paper and provides future directions.

II. BACKGROUND ANALYSIS

With RCM as a maintenance framework, which is projected to systemize and rationalize the identification of tasks, a maintenance plan can be draw. The framework focusses on assuring operational security, maintainability and reliability of engineered products, equipment, and installations that are affordable. With the application of different maintenance forms, RCM focusses on protecting equipment functions through the determination of maintenance requirements for equipment.

In this case, RCM has been structured with major guideline that stipulates that maintenance tasks have to be justified before execution has been completed. Justification approaches corresponds to the economy, functionality and security in preventing or delaying particular failure modes. This method captures critical features of RCM application, which also focusses on establishing critically adjusted maintenance tasks that assure plant operational performance from critical accurate assessment of functions that have been developed by every component of equipment or productive systems.

When mechanical industries use RCM to create maintenance models, it is fundamental to understand that these models or approaches should answer accurately and correctly the following questions: What functions have to be preserved? What are the relative functional failures? What are the relative failure effects? What are the relative failure modes? What are the consequences of failure? What are the effective and applicable tasks? What are the remainder alternatives? For answers to these questions to be provided, RCM applies numerous tools and methods from open set remedies, which include the traditional ones, current ones and modern ones according to their effectively documented patterns and structuralized sequences. In this paper, the tools utilized to develop the maintenance approach based on RCM specification is FTA.

FTA is a tool of processes and product analysis, which allow for a standardized and systematic assessment of failures, identifying consequences and facilitating the adoption of preventive and corrective actions. FTA, in this research has been used in the oil circulation model (cooling and lubrication) of interlinked bearing of hydraulic generating units using an example of Balbina hydroelectric plant.

Outsourcing gives the plant with the required flexibility to contract and expand where needed. This shows that when a reduction of the workload becomes essential, it can be attained through the cancellation of outsourced contracts other than removing the plant's individual associates. Planning is based on four different segments: Energy/facility, Paint shop, Assembly, and Body Shop. The energy/facility unit with its workers, about twenty, is dependent on contractors performing 30% of the entire unit workload. The engineering plant is run based on lean strategy. It focusses on core competencies and what has to be achieved. The direction is to shift into equipment management, which incorporates making engineered products to operate effectively as required.

There are commodity competencies, which can be bought from the external enterprise partners e.g. initiating changes on air filters, a technical competency on which the staff's timeframe has to be spent. Whereas the single units are not dependent on one another, some issues are considered to reflect in all the units. For instance, there no general managers for the maintainability of the plant, instead, the managerial representative from every unit create the steering committee for plant's maintainability.

The driver of maintainability is a non-traditional method, which is vital in ascending engineering plants into international standard with the best performance. Reliability and maintainability do not originate from the same department or with a single person. Each person plays a critical role in attaining reliability, maintainability, upgradability and general effectiveness of engineered products. This is a game played by the entire workforce and it is considered that the workforce mentality is a considerably decisive element in winning the game.

After the analysis of faults, the general Effectiveness of the Engineered Products (EEP), upgradability and other critical factors are considered at various levels, which means that key procedural indicators are considered in the various levels. EEP and uptime are directly connected to the number of motors, which can be manufactured for users. The EEP is expressed mathematically as:

EEP = Engineered Product Efficiency (EPE) x Engineered Product Availability (EPA) x Quality Rate (QR).

EPE represents the efficiency of engineered products. It is scheduled runtime deducting the engineered product downtime, which is divided by the scheduled runtime. QR represents the rate of quality based on the production of engineered products. If the pieces of engineered products cause motors to necessitate reworking, then this adds over EEP. This is the general unit deducting the defect unit, which is divided by the overall unit. Even though this is a standard process to utilize maximum velocity as a basis for mathematical expressions, it is not applicable to certain cases. Instead, velocity is reflected in the unit objective and the plant is staff for certain workload.

The engineered product and equipment are installed based on velocity dimension and adjusted according to the condition of the market. Two different of EPE are present: department dimension EPE evaluates the complete line over the main target, whereas product and equipment level EPE evaluates every part of the target. In another example of the Flat Rock Assembly Plant, assembly is obliged a departmental ambition for EPE at about 93%, which incorporates EPA and EPE sub-objectives of 99% and 98% respectively. For quality elements and productivity of EPE, targets signify 100%.

Energy/facilities have EPE targets of approximately 90%; however, it is based on the mean higher percentage. As for uptime charting, the shops are more than 90%, both as a department and a fundamental equipment piece. The general mark for regular assembly surpasses 94% and this has been as high as 95%. In warehouses, the uptime score of 98% and 99% have been attained on critical equipment such as systems, transfer motors and cranes. Minor maintenance percentage i.e. less than 5% represents reactive, unplanned works with approximately 88% of the works done based on planned schedule. Maintenance works are scheduled, tracked and planned based on how well-structured they are. The main target of maintenance is structured at 90%. It has to be noted that there are minimal equipment issues and engineered products cannot be considered an obstacle for the plants.

III. LITERATURE REVIEW

D. Setiawan, N. Jusolihun and W. Cahyo in [6] confirm that Reliability Centered Maintenance (RCM) is an enhancement approach within the maintenance management sector. Its foundational purpose is to enhance reliability of manufacturing machines. RCM has been considered to fundamental in preventing the failure of machines, which could amount to consequential damages. RCM is a maintenance approach to a global company level that is applied to optimize industrial maintenance systems.

P. Goel and N. Singh in [7] argue that cost effectiveness, product quality, uptime and reliability will be enhanced provided it is accomplished under the conditions and guidelines structured by environmental, safety regulations, and laws. RCM is applied for machines with high safety threat whenever there are high requirements concerning uptime, or during downtime of particular machines leading to significant funds. The main aim is to prevent the effects of machine failure.

F. Fathurohman and S. Triyono in [8] applied preventive maintenance using an expedition firm presenting RCM concentrating on various conditions in which availability and reliability of machines is for fundamental significance. The foundation of RCM is seen in the aeronautical industry. In the early 1960s, the manufacturers of Boeing investigated the costs of maintenance of the Boeing 747. At this dimension, this type of aircraft was larger and complex compared to the present Boeing had, and standardized preventive maintenance schedule proved insufficient. It was typically believed that failure chances enhanced as the aircraft parts aged.

O. Pialot and D. Millet in [9] attest that the chances of failure upgrades when parts age. Nonetheless, it was projected that some of these parts of Boeing 747 would possibly break frequently whenever they were new. This explained why they looked certainly at the failure consequences when forming novel maintenance plans that broken low-power warnings in the cockpit light, for example. The maintenance of the aircraft type was definitely developed by the Aviation Agency of America, with a plan of maintainability, which was based on the increment of equipment reliability. In the early 1970s, the approach was established by the armed forces in America and RCM approach was considered an official advancement approach. Later on, it was effectively applied in the nuclear power plants, chemical industries and railway lines.

D. Shalev and J. Tiran in [10] commented on Fault Tree Analysis (FTA) through deductive procedure from pre-defined undesired occasions to determine the potential causes of occasions. The procedure is based on the evaluation of successive combination of failure that incorporates limitation of analysis remedies. The undesired events are typically known as the treetop events. The critical FTA concept incorporates the translation of physical models in a structured logical presentation whereby particular causes let to the interest top occasions.

M. Kim, E. Jin and M. Park in [11] argue about the significant popularity of FTA from two aspects. Firstly because to wide-range flexibility or graphic representations of complex models proportionate through particular symbology and secondly because of wide-range computational easiness, card payment systems and in elements of less but significant numbers required for failure probabilities mathematical expressions when contrasted to significant ones for cases of normal values of successive probabilities.

S. Eisinger and U. Rakowsky in [12] confirm that RCM requires multi-disciplinary groups to systematically evaluate the various potential sources of failures, effects and malfunctions. The groups who identify exactly how machines operate and individuals who are skilled on production procedures in general participate in the development process. Every group can comment on the application of engineered products and equipment.

X. Jiang, F. Duan, H. Tian and X. Wei [13] comment that RCM concentrates on inventory and mitigating potential failure issues. Different group members can participate and apply their skills and experiences to consider in prior. RCM power is its assessment of critical model failures and the effects thereof down to minimal details. Next, a choice is made regarding suitable approaches that can be used maintainability of risks, which have been found. Every approach is chosen with reference to technical feasibility and the expenses that accompany the completion of industrial tasks.

IV. CRITICAL ANALYSIS

To attain optimum reliability, there should be maintenance of tools and activities, which necessitate analysis of faults.

A. RCM Based on Fault Analysis

1) General Productive Maintainability

General productive maintainability is fundamental helped to achieve and develop uptime and EEP by forming a group approach that evaluates the fault and enhance maintainability, serviceability and reliability [14]. General productive maintainability activities vary in units and areas of production. In an example of the Flat Rock Assembly Plant, the body shop have their engineered products and equipment shut down in many areas for 15 minutes in every shift to allow the production operators to perform adjustments and cleaning activities. In some other body shop segments, shutdowns can happen often in 15 minutes after two hours or infrequently (a single hour block in every week), whereas assembly have some production operators assigned full-time General productive maintainability duties.

The fluids fill cells and glazing cell each has two individuals in every shift to do these tasks. The production operators do not have general productive maintainability limits. For example, cooling and lubrication is a maintenance obligation, which has to be ensured by the responsible associates to maintain engineered production and equipment to limit any potential faults. This is different from the energy/facility, where advanced and basic general productive maintainability activities are outsourced the contractors of the plant. The general productive maintainability has been applied to enhance reliability through the enhancement of responsiveness, ownership and communication.

2) Long-Term Scheduling

The mechanical firm has drawn up critical documents, which evaluate maintenance needs of fundamental systems over a considerable duration that span several decades. Minor and major activities have been identified, which require to be performed to achieve long-term sustainability of assets. This is vital as an instrumental role than highlights maintainability faults for which critical resources are required. For instance, the plant has to regularly overhaul the gas turbines because of workhorse manner, which they utilized. It aids in the consideration of useful equipment life of engineered products and equipment when it has to be shifted to novel conditions.

3) Design Maintainability

The plant has substantially been extended and has transformed its assembly layout from two-line scheme to one-line scheme. All motors are assembled on a similar line. After the conversion and extension, the Flat Rock Assembly Plant was capable of following a fresh beginning to numerous things, including maintainability. Novel equipment was established and installed in a way that enhances maintainability and accessibility.

a) Partnering and Standardization for Maintainability

The engineering plant supports the standardization of engineered products and equipment. For instance, the site focused on a project meant to change its programmable logic controller to Siemens product. The company and plant has now been considered as a single plc. platform. For a wide-spread firm like this, standardization makes cross-plant and corporate partnering potential. Most equipment is the same in the entire firm. This makes it possible to receive remedies to potential faults from the plant around the global corporate production system.

This enhances EEP and uptime. Maintenance standards and equipment best practices are gathered on an international basis at firm's Core Competence at Munich, Germany. All the data collected and lessons learned are drawn to the center where it can be utilized and gathered by other engineering sites. Insight sharing from the experiences of various plants on company-wide platforms aid others to get things right and establish reliability into the processes and equipment. Considerable idea sharing and collaborating happens between the plant and among maintenance, operations and repair suppliers.

b) Condition Monitoring for Maintainability

The conversion and extension of the plant also presented an opportunity to install the sensors on various precarious equipment components. The initial model utilized the aspect of monitoring the complete factory and grouped it into different zones. However, it is now possible to locate the faults down to particular equipment. When potential fault or degradation has been noticed, actions should be taken with immediate effect and the fault addressed before incidents happen.

Sensors and plc interfaces with industrial computerized maintenance software can be used to submit the present status data. On a daily basis of this information and subsequent comparisons based on standardized deviations, SAP model can be used to determine the needs of the countermeasures. Dependent of various factors, it might produce work notifications and orders in computerized maintainability management scheme or send it through email, phone call or sending a page out. Condition monitoring tools and equipment is implemented on cost effective basis.

B. Fault Tree Analysis (FTA)

The maintainability firms and with example case of Balbina's plant, engineering firms are determined to identify the problem source and prevent any form of reoccurrence.

1) Case Analysis

FTA is discussed in this part using the case analysis of the cooling and lubrication model of interlinked bearing. The rotating mass of the turbine generator segment is based on axially on prop bearing and guide bearing, whereby all these bearings are incorporates into similar oil containers. The sets are known as interlinked bearing. The interlinked bearing is a sliding form comprising of dual major and distinct surfaces, being the mobile segment linked to an axle, and the fixed segment incorporated by sabots and skids. The mobile segment incorporates polishing steel discs, which are typically known as mirrors. There are no contacts between two surfaces because typically it incorporates the oil firms between them with a sole function to prevent direct contacts of metals to metals and to enhance cooling, wastes on heat produced by attrition between the surfaces.

Oil is removed from containers through the bomb before being cooled using the heat exchangers and led to the containers with active segments immersed. The exchanges of heat have a cooling fluid as water. In the segment, there are two exchangers, one being typically in operation and the other one as reserve. In suppressed tubing, after the cooling scheme, filters are installed with an ambition to complete oil cleanness after potentially returning to the main container.

Because of the weight of the entire rotating mass and hydraulic attraction, which is over to the prop bearing, it is fundamental that during the start of the machine and halt, oil is injected between prop and sabot bearing ring to effectively lubricate it. Prop bearing oil injection model creates an oil film between rotating and fixed parts, in the 0% brand and brands above 50%. Prop bearing is automatically lubricated. The injection of oil in prop bearing is realized by dual high-pressure bombs, which are identified as AH and AG. The cooling of oil is also realized using two bombs, which are identified bombs as AJ and AI.

Identification of failures is a common practice among professionals in assessing factors of system maintainability, reliability and risk management. In this paper, we use FTA to evaluate the factors. The scheme that will be evaluated comprises on the same FTA, which is, the cooling and lubrication scheme of interlinked bearing (Fig 1). The top occasion of FT was considered as being failure in cooling and lubrication scheme of interlinked bearing. The trees with their logical combinations of the basic occasion lead to the failures in the related schemes are displayed in Fig 2 (a, b, c and d).

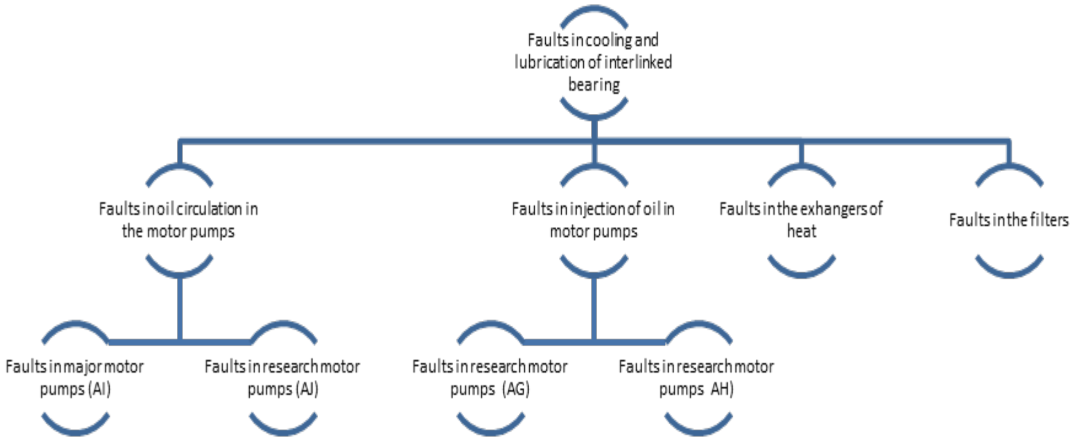
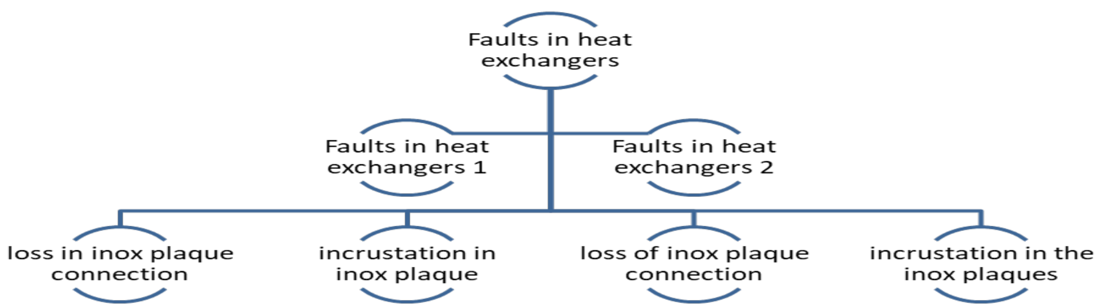
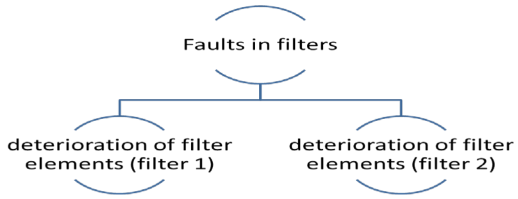


Fig 1: FTA showing the major faults in cooling and lubrication system of interlinked bearing



a)



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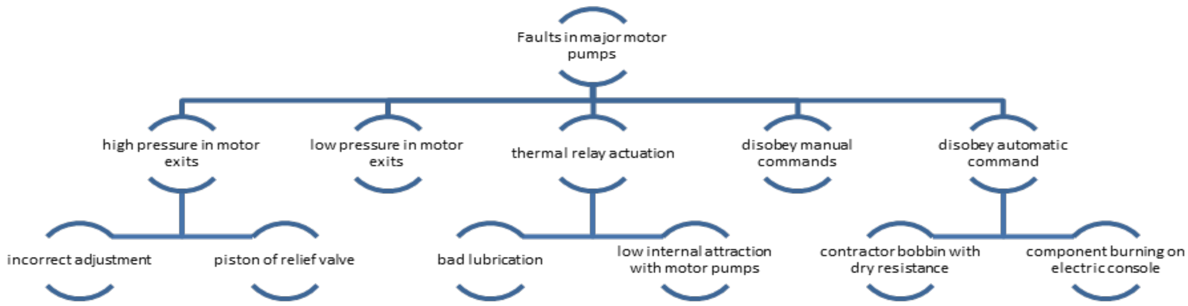

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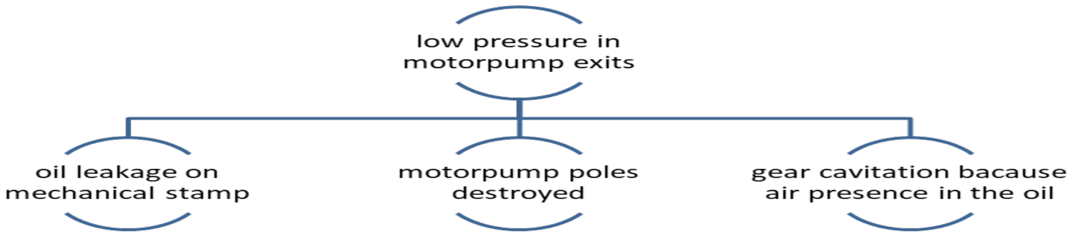
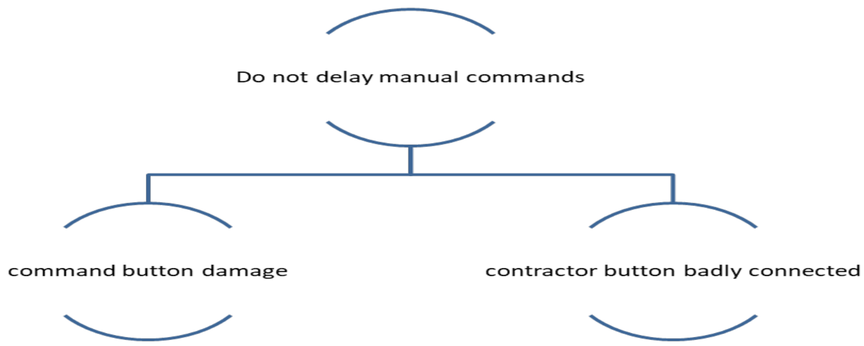


d)



d)

Fig 2: Fig 2: FTA showing the faults in various parts (a, b, c, d)

It is fundamental to focus that the basic risks and faults referring to the motor pumps i.e. AH, GAC, AJ and AI are fundamentally the same ones and basically had been indicated in the FT with the illustrations of the motor pumps. In that case, the tree has to be read considering that the logical gate that have the illustration of the motor pump signifies every motor pumps, AH, GAC, AJ and AI (Fig 1).

With the example, earlier mention, of the Flat Rock Assembly Plant, the body shop, for instance, in case the breakdown lie takes more than 15 minutes to mitigate the faults (whereas in assembly, the standard duration is 10 minute), the maintainability professionals perform FTA. The possibilities are utilized for correcting the faults and the associates stat focused until the fault is rectified. The application of FTA is not a quick action. It necessitates the application of professionalism and work force, including the planning group.

An effective course of action has to be structured for simple tasks considering the expenditure and efforts required. In such instances, the complete FTA is not essential. Moreover, when equipment is new and a malfunction happens, it will require the maintainers more time to mitigate the fault and rectify it since they are still mastering particular features. The identification of the faults and their remedies are transferrable to the same piece of equipment in the plants' group obliged to ensure that data achieved is shared with the executives.

2) Significance of FTA for RCM

With FTA, the executive and senior managers are continuously updated with information from the maintainability group including why it is relevant in ensuring that the production processes remains on the run. This means that constant spotlight is maintained regarding the performance of the equipment and its maintainability. The plant in general evaluate and removes the faults through Lean Six Sigma project. Presently, the master black belts, green belts play a vital role on the 5-7 person attack group. The lean six sigma is driven with data. The explains the variation between it and other fundamental issue-solving measures. Evaluating data will lead to the identification of effective remedies for the faults.

The functions of an engineering plan are based on intervals. In the case of Balbina hydroelectric plant, new motors are introduced with every line of motor coming with new equipment meant to produce vehicles. This assures EEP benefits. The equipment is normally the state-of-the-art technology. This shows that staff maintenance is constantly based on training and learning curves for particular pieces of equipment. Staff turnover and change in the firm shows that RCM should be assessed with faults rectified.

For instance, if machines undergo upgradability about seven times a year and present no faults, the yearly upgradability occasion could cut in half [15]. The purpose of this is to identify the correct balance, i.e. not to consider too much or too little but ensure the performance of the right thing. The frequency of upgradability is swiftly transforming from time-based to cycle-based or condition-based. Preventive maintainability in occasion of upgradability is based on the operation of the running equipment. The aspect and trend to enhance digitalization and demographic change will present new problems hence requiring the adoption of novel maintainability technologies.

With FTA, top occasions will incorporate the new problems that are considered critical by the system. These issues may demand posterior analysis. FTA allows joint analysis is various causes, which amounts to the occurrence of top events to provide analysts with enough understanding amount the operation and behavior of the system. It permits the identification of how constituent elements of the system are connected. This permits, for instance, the definition of equipment behavior in redundancy since it is a case of heat exchangers and filters or the standby instances of motor pumps.

With FTA, it is possible to enhance RCM, identify the set of occasions constituting the resolution limits, and stimulate the identification of basic occurrences probabilities of basic causes. After FTA, the determination of minimum cuts is done. FT cut is a collection of basic occasions whose occurrences implies in the occasion occurrences at the top of the tree. Minimum cut represent the basic events, which cannot be reduced without losing the condition of the cut or is the minimal connection of occasions, which occur and lead to faults in the system.

V. CONCLUSIONS AND FUTURE DIRECTIONS

In this research, FTA analysis has been used to identify the critical components of the cooling and lubrication system on the interlinked bearing, command circuit of motor pumps and heat exchangers with reference to the case the Balbina hydroelectric plant. However, exchangers do not present any faults that are considered severe, they present the failure to be frequent. It is considered that FTA does not consider any potential severity of faults, but only the occasion. In that case, when FTA is structured, the top occurrence has to be chosen critically, in a manner that all the other basic occasions can be considered, in a particular manner, severe. The second element more crucial, by FTA, corresponds to the element that shows that the fault in motor pumps is severe and significantly frequent. After FTA analysis, it can be seen that the plant equipment holds premier-level status since its reliability, style and performance are maintained.

This paper has also used the Flat Rock Assembly Plant case to discuss serviceability, functionality and maintainability functions. From the analysis, it can be seen that over the past few decades, there was not the same degree of utilization of computerized maintainability management scheme. With SAP, upgradability and preventive maintenance can be evaluated and its effectiveness evaluated. The average time between the repair of the faults and response to calls and the degree of preventive maintenance has incredibly enhanced.

Nonetheless, the objective of serviceability, functionality and maintainability is not yet complete if engineering firms are not undergoing the required transformations. FTA shows that firms are doing something wrong that has to be rectified. Future directions should base on a remedy for firms to limit the faults in machining. All aspects of the remedy, which also include inability to change, have significant effect on customer demand and customer satisfaction. Future digitalization trends and change in demography set bar higher and concept of RCM should adapt to novel challenges enhance the reliability and maintainability of machines.

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