IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

DEVELOPMENT AND FAILURE MODE ANALYSIS OF CENTERING AND PLUNGE MACHINE (500)

Shahane S.M.* , Y.R.Patil
Student, Dr.JJMCOE Jaysingpur
Asst. Professor, Dr.JJMCOE Jaysingpur

ABSTRACT

Newly developed machines has to undergo different tests to ensure the safety and reliability of machines. This paper deals with the failure mode analysis of the newly developed Centering and Plunge machine. Different possible modes of failure has been considered for this study and their potential to cause failure in machine has been studied. Failure of different subsystems like electrical and electronic subsystems has been studied in this work.

KEYWORDS: Failure mode analysis, Centering and Plunge Machine, Development.

INTRODUCTION

Engineering systems now a day are becoming more and more complex due to the application of automation, miniaturization, embedded technology, presence of software-hardware interfaces, and its interdisciplinary nature. Concern for environment, cost of failures and associated down times, safety of operation, and effectiveness of maintenance are also becoming important considerations. Failures of engineering systems such as aircraft, trains, nuclear power plants, chemical industries, satellites, thermal power plants, and process industries in the past have resulted in loss of human lives and irreparable damage to the property and the environment. How do we eliminate or at least minimize such unexpected failures and improve the system performance? How we design, install, operate, maintain, and dispose engineering system with better utilization and safety? The concept of reliability engineering helps us to find out ways to improve the performance and safety. Reliability engineering is an interdisciplinary branch that focuses on the systematic study of failures of engineering components and system.

This work is sponsored by FIE Group Company-SPM tools, Ichalkaranji. SPM Tools was established in1954. SPM TOOLS, Ichalkaranji are leading manufacturers of Centering & Plunge Facing Machine, CNC machine, VMC machine, Broaching machine, Band saw machine etc. Centering &Plunge Facing Machine are used in small scale as well as large scale industries for centering, plunge facing, chamfering and external turning of the two ends simultaneously of the bar stock, such as camshaft, crankshaft, motor-shaft, universal joint etc. These models are low as well as medium cost machines, ideally used for mass production.

Standard Features:

- including motor.Complete electrical equipment
- Complete hydraulic system.
- Hydraulic feed with automatic controls of cutting pressure and over load protection.
- Complete coolant system with pump & piping.
- Operating tools & spanners.

Therefore by considering importance of this machine in mass production, it is decided to carry out the reliability, maintainability, availability and life cycle cost optimization of centering and plunge facing machine-500.

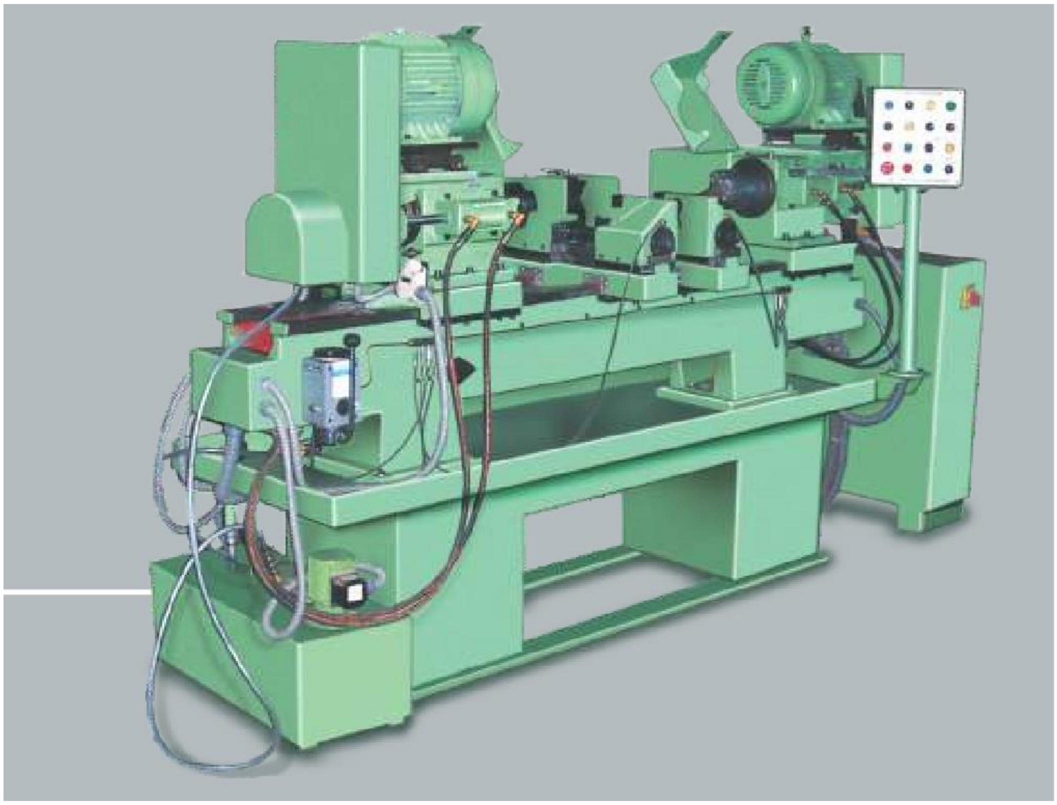

Figure 1- Centering &Plunge Facing Machine (CFAM-500).

Table 1- Specifications of Model CFAM-500

Model	CFAM - 500
Possible work piece length	500mm
Min. work piece diameter admitted in vice	12mm
Max. work piece diameter admitted in vice	125mm
Clamping System	Hydraulic motor
Spindle speed	350/500/750/1000
Max stoke of each quill	50mm
Quill feed	Hydraulic
Maximum plunge facing diameter	63mm
Center drill sizes	BS 3 to BS 6
Spindle Motor each	2.2/960 KW/RPM
Hydraulic Power Pack	3.37/1440 KW/RPM
Coolent Motor	0.1/2800
Total Power	7.87

LITERATURE SURVEY:

Yiquiang et al [3] in the design and development of CNC lathes, an effective reliability allocation method is needed to allocate system level reliability requirements into subsystem and components levels. During the allocation process, many factors have to be considered. Some of these factors can be measured quantitatively while others have to be assessed qualitatively. They had considered seven criteria for conducting reliability allocation and found its actual value. Frequency of failure, criticality of failure, maintainability, complexity, and manufacturing technology, working conditions, cost and machine is divided into 15 subsystems. He compared allocated MTBF and observed MTBF. It can be seen that the reliability indexes of most of the subsystems of existing CNC lathes observed do not meet the allocated reliability requirements. Action should be taken to improve the reliabilities of these subsystems, such as the turret, clamping accessory and so on. Finally he concluded, reliability allocation of CNC lathe should consider various factors such as the performance, design, manufacturing, use, maintenance, cost and reliability of the system.

Yiquiang et al [4] fields' failure data for CNC lathe was collected over a period of two years on approximately 80 CNC lathes. A coding system to code failure was devised and a failure analysis date bank of CNC lathe was established. The failure position and subsystem, failure mode and cause were analysed to indicate the weak system of CNC lathe. Finally he concluded that main failure subsystem for the mechanical system are the turret and chuck. The principle mode of failure is the damage of components includes electric and electronic components (69%), mechanical components (26%), hydraulic and pneumatic components (5%). Most of them are standard components and bought- in components. It is evidence that there were lack of reliability allocation and reliability screening when the CNC lathes were designed and manufactured.

Dai et al [5] Over a period of two years, they have investigated the failure data of 14 VMC and have found the distribution of failure mode and that of failure position, causes of failure and the way to enhance the reliability of the VMC. The majority of VMC failure solved by repairing the damaged parts carefully or substituting it with new one. The better way to reduce the failure frequency, adopt the grease lubricating style, use axial ball bearing under the piston which makes the slight turn possible, eliminate the belt and join the servomotor to the ball screw directly on condition that qualified coupler is chosen and careful assembly is done.

Keller et al. [6] described a reliability and maintainability study of CNC system. For this analysis field failure data was collected in a period of three year on 35 CNC machines during their warranty period were analysed. In order to apply quantitative reliability methods, a coding system was devised and failure data which were then collected into a data bank. The Lognormal and Weibull distribution was found to be applicable to describe time between failures and the repair times. The Duane reliability growth model arising from the introduction of modifications to improve machine tool performance gave a good fit to the observed reliability growth for a CNC system.

Barabady et al. [7] presented reliability and availability analysis of the crushing plant no-3 at Jajarm Bauxite Mine in Iran. In this case study, the crushing plant is divided into subsystems. The parameters of some probability distributions, such as Weibull, Exponential, and Lognormal distributions have been estimated by using Reliasoftsweibull ++6 software and from results, it was concluded that the conveyer subsystem and secondary screen subsystem are critical from a reliability point of view, and the secondary crusher subsystem and conveyer subsystem are critical from an availability point of view. It was further shown that the reliability analysis is very useful for deciding preventive maintenance intervals for different reliability levels.

Kumar et al. [8] concluded that reliability of equipment is extremely important to maintain quality. This is achieved by using proper maintenance and design changes for unreliable subsystems and components of a complex system. It is significant to develop a strategy for maintenance, replacement and design changes related to those subsystems and components. An analysis of down time along with causes is essential to identify the unreliable components and subsystems.

Waghmode et al. [9] used Fault Tree Analysis method to find out major faults or critical failures associated with product and the causes for the faults and potential countermeasures for lathe machine. Qualitative and quantitative analysis helps to identify critical design parameters. It is also shown that how reliability analysis fruitful for Life cycle cost management.

Waghmode et al. [10] analysed and concluded that the initial price is not the only criteria of the procurement. Most of the cost is associated with the hazard rate or failure rate of the product during the life cycle of the product.But it is very essential to focus onsource of cost savings, especially minimizing energy consumption and plant downtime. From the study on reliability analysis of a typical heavy usage multi-stage centrifugal pump, it is found that initial cost is a fraction of the total life cycle cost. Proper pumpingsystem design is the most important single element in minimizing the LCC. Themaintenance cost is approximately 0.6 to 2.5 times the initial cost of the pump. Also it isfound that the LCC is nearly 12 to 13 times the initial costs.

Barringer et al [11] emphasized the need of practical reliability details to define life cycle costs of the product. Life cycle cost comparisons help to decide the lowest long-term cost of ownership driven by a single estimator called net present value. The net present values require decisions about when and how much maintenance or replacement costs will be incurred which is driven by the time and modes for component failures found by using reliability technology.The first cost for procurement is not the last cost. Procurement cost may represent only a small fraction of the total cost during the life of an item, and in other cases, it may be a large portion of the total life cycle costs. For high-grade products, the seller must produce life cycle costs to overcome buyer resistance to the higher initial cost. It is not in the interest of most low-grade products seller's to show life cycle cost, as the best story they have is the non-resistance threshold of low first cost.

Jun et al [12] this paper conducts the reliability modelling of aircraft equipment and predicts its MTBF. The results shown that reliability analysis and the application of FMECA method prolong the lifespan of this equipment and improves the operational reliability greatly.

Volkanovski et al. [13] developed a new method for power system reliability analysis using the fault tree analysis approach. The method is based on fault trees generated for each load point of the power system. The fault trees are related to disruption of energy delivery from generators to the specific load points. Quantitative evaluation of the fault trees, which represents a standpoint for assessment of reliability of power delivery, enables identification of the most important elements in the power system. The power system reliability was assessed and the main contributors to power system reliability have been identified, both qualitatively and quantitatively.

Patil [15] found that reliability and life cycle cost analysis helps to improve performance, minimize costs of system. He discussed comparison of different reliability models in order to select model for analysis. He implemented fault tree analysis method for analysis of band saw cutting machine and life cycle cost has been optimized by reliability analysis.

Louit [26] emphasized on the procedure for the selection of time to failure models based on the assessment of trends in maintenance data. Reliability centered maintenance and total productive maintenance have played an important role in maintenance optimization. Nevertheless, data analysis and statistical modeling are very valuable, tools to optimize the maintenance. When insufficient data will be available, then model selection will be dependent on data censoring, possible trends in time between failures and graphical methods such as cumulative failure vs. time plots. The selection procedure has been applied for fleet of backhoes.

Yu Jie [27] analyzed the data of the CNC machine tools with two-parameter Weibull distribution and exponential distribution. He gets the results that the failure time of the CNC machine tools rules to Weibull distribution. He estimated the parameters. When they use three-parameter to estimate the parameters, they know that the results are close to the reality and the estimated life is more precise.

Enparantza et al. [28] discussed a life cycle cost calculation and management system for machine tools to provide life cycle cost data prediction at offer phase and to support the design phase decisions by managing real machine tool behavior data. The LCC model takes care of acquisition cost, operation cost, maintenance cost and turnover/scrap cost.

Barringer [11] emphasized the need of practical reliability details to define life cycle costs of the product. Life cycle cost comparisons help to decide the lowest long-term cost of ownership driven by a single estimator called net present value. The net present values require decisions about when and how much maintenance or replacement costs will be incurred which is driven by the time and modes for component failures found by using reliability technology.

The above review shows that reliability analysis technique has been applied to evaluate different types of systems. It is found that reliability and life cycle cost analysis helps to improve performance, minimize costs of system. In this work it is proposed to apply this technique to analyze the reliability of Centering & Plunge Facing Machine (500). The effect of reliability on the life cycle cost of the same machine will also be studied.

BASIC CONCEPT AND APPROACH FOR RELIABILITY ANALYSIS

When dealing with reliability field data, proper selection of models for time to failure data is quite essential as it affects the expected number failures. Hence, time to failure models form critical constituents of any reliability analysis. Many times conventional times to failure analysis techniques are adopted and the analyses rely on false premises, such as independent and identically distributed time between failures assumption which is, in fact, not appropriate for all systems. For many systems, there may be presence of trend in time between failure data of the system.

Under such circumstances, the successive failure times may neither be independent nor identically distributed and the above assumption may not hold good. This can lead to erroneous model selection for time to failure of a particular component or system leading to erroneous estimates of life cycle costs and in turn wrong conclusions and decisions. To overcome this, a methodology for estimation of repairable product/system is presented step by step in fig. 2.1. It shows a detailed flowchart for model identification and is used here as a framework for analysis of the failure data and repair data of the product/system.

There are many sources of data in the industries that are relevant to reliability modeling of product/equipment/system such as maintenance reports, operational and maintenance information. The first step in analyzing such data is to identify failure with significant consequence. For this purpose, it is appropriate to use the Pareto principle of the ‘‘significant few and the insignificant many’’. It is often found that a large proportion of failure in a product is due to the small number of causes. The next step after collection, sorting and classification of the data is validation of the assumption of independent and identically distributed (iid) nature of the TBF and TTR data of each component/subsystem.

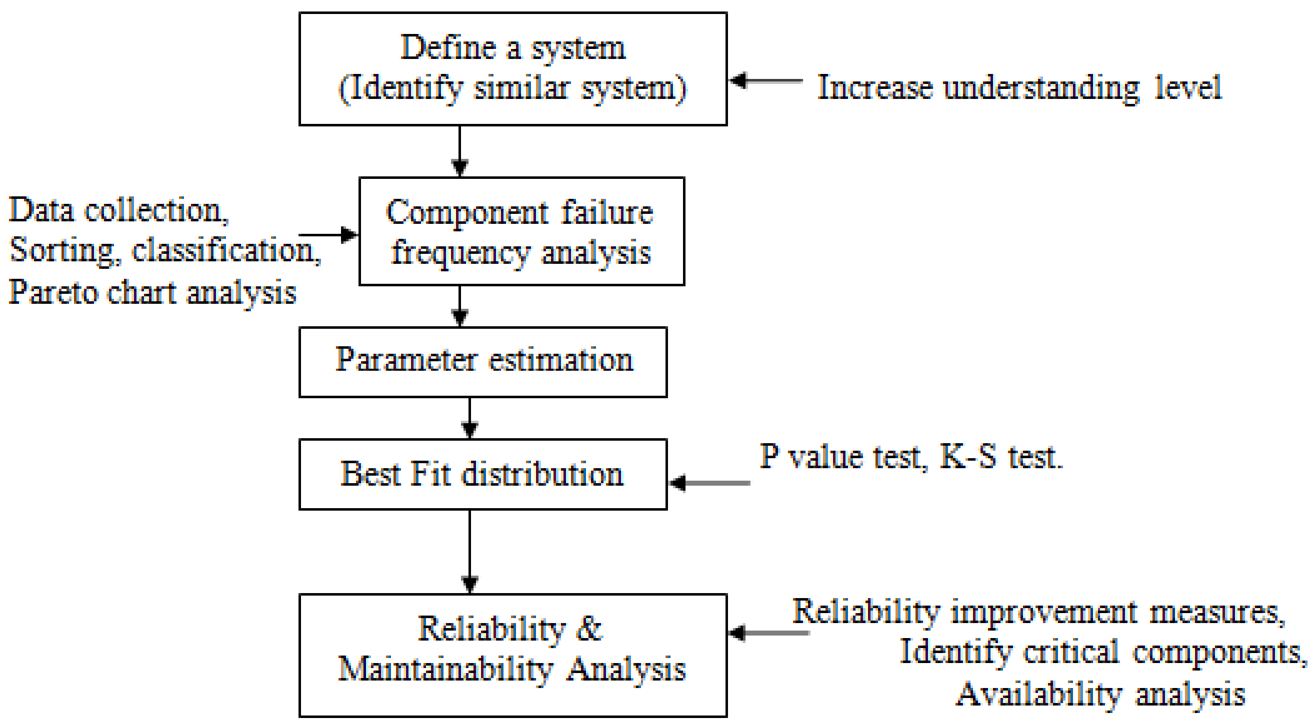

Figure 2: Selection of time to failure model

Two common methods used to validate the iid assumption are the trend test and the serial correlation test and is described by practical example in Refs. [17]. If the assumption that the data are identical is not valid, then classical statistical techniques for reliability analysis may not be appropriate; therefore, a non-stationary model such as non-homogeneous Poisson process (NHPP) must be fitted. The approach for fitting an NHPP to non-stationary data is very different from the techniques involved in fitting a distribution function to iid. A functional form that has been most commonly applied to repairable systems is the NHPP model based on the power law process. The χ^2 test and the Kolmogorov–Smirnov test are classically encountered for the validation of the best-fit distribution [10]

FAULT TREE ANALYSIS METHOD

Bell telephone laboratories developed the concept of fault tree analysis in 1962 for the U.S. air force for use with the Minuteman system. It was later adopted and extensively applied by the Boeing Company. Fault tree analysis (FTA) is a top down, deductive failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level events. This analysis method is mainly used in the fields of safety engineering and reliability engineering to understand how systems can fail, to identify the best ways to reduce risk or to determine event rates of a safety accident or a particular system level (functional) failure. FTA is used in the aerospace, nuclear power, chemical and process, pharmaceutical, petrochemical and other high-hazard industries; but is also used in fields as diverse as risk factor identification relating to social service system failure[29].

Fault tree analysis can help to prevent failures from occurring by providing with data showing how and under what circumstances the failure could occur, allowing for alternative measures to prevent (or design out) the catastrophic failures or hazards. The Boolean methodology and equations are used to construct and simplify the fault tree. As fault trees are constructed, the Boolean equations are used to evaluate the qualitative and quantitative characteristic of a critical system.

The qualitative analysis of the fault tree determines the:

a) Probability of system failure (top event) based on a single failure (basic event) cause,
b) Combination of component failures,
c) Importance ranking of contributors to system failure.

The quantitative analysis of the fault tree focuses on the probabilities of system and the occurrence of the top event based on the probabilities of failure of the basic events.

FTA can be used to:

a) Understand the logic leading to the top event / undesired state.
b) Show compliance with the (input) system safety / reliability requirements.
c) Prioritize the contributors leading to the top event - creating the critical equipment/parts/events lists for different importance measures.
d) Monitor and control the safety performance of the complex system.
e) Minimize and optimize resources.
f) Assist in designing a system. The FTA can be used as a design tool that helps to create (output / lower level) requirements.

DESIGN AND CONSTRUCTION DETAILS OF CFAM-500

Design considerations:

It is very essential to consider certain design parameters while designing any system. These considerations decide quality, capacity, performance and efficiency of the system. To achieve some of these objectives, certain design considerations have been made for Centering & Plunge Facing machine. These design considerations for Centering & Plunge Facing machine are given below.

1. Machining operation should be carried out automatically.
2. Size of the machine should be compact so that it will occupy less space, in order to cut a job of any length up to 500mm.
3. The combined centering and facing operation saves machining time, handling time and floor space. So, centering and facing operation should be combined.
4. The cutting cycle must be operated with push button on a fast approach, slow feed and rapid return basis.
5. The machine should have two hydraulic operated self centering work holding vices with push button control.
6. Total four speeds should be provided thro "V" change pulleys. This makes the machine suitable for machining different materials of different sizes.
7. Centering and facing operation at both ends is should be achieved simultaneously by plunge operation through hydraulically operated quills. The automatic quill feeding is achieved through two hydraulic cylinders mounted on either sides of head stock. Infinitely variable feed can be selected by flow control valve provided on the hydraulic power pack.
8. The machine is built on rugged graded cast iron bed. The box type design with integrated runways ensures high rigidity and favoring characteristics. The square runways are ground within close limits to machine the accuracy of centering at both ends on the same axis.
9. Coolant supply should be through the hallow spindle of tool heads and directs coolant on the tool effectively.

10. In order to increase aesthetic look and to get the feel of robust design machine is painted by green color.
11. The height of the control panel and other equipments is selected such that maintenance work will require less effort.
12. Proper damping system should be there in order to damp shocks coming from motors and cutting tools.
13. Different components are designed in order to minimize cost of the system to compete with competitors.
14. Total mass of the system is approximately thousand kilograms, which is minimized by optimization techniques.
15. Because of rigid construction this machine, it is imperative that the base be fully supported on all four mounting pads.

Construction and operation:

The important construction and operational features of the CFAM-500 are given below.

i. Head Stock and Tailstock :

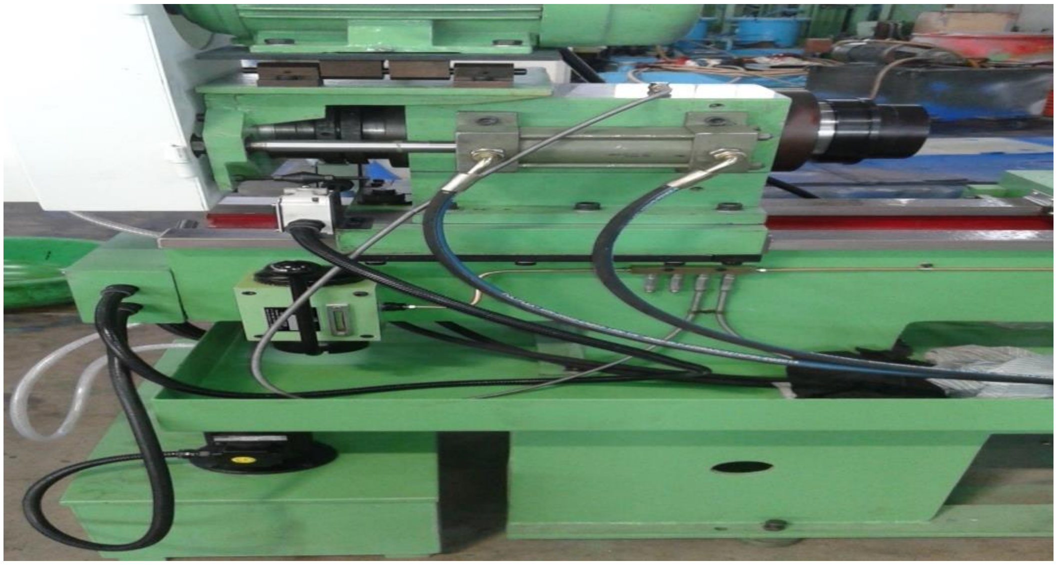

Figure 4 – Head stock and Tailstock Assembly.

Two Spindles are supported by two taper roller bearings at both sides. One head stock is permanently fixed & tailstock is adjustable to accommodate different job lengths. Feed is given to the spindle by hydraulic cylinder. Feed rate is adjusted by adjusting flow control valve. Rotational motion is given to the spindle by motor which is connected through belt and pulley arrangement. To adjust the depth of cut quills are provided. Four stepped pulley is provided to adjust different speed with respect to change in material and required surface finish. On these two spindles specially designed drill holder are mounted, which will hold drill beat as well as inserts.

ii. Hydraulic power pack.

It consists of electrical induction motor and gear pump which is connected to manifold and with help of pressure control valve as well as direction control valve, hydraulic oil is transferred to hydraulic cylinder and to hydraulic pump to move headstock, tailstock assembly and for clamping / decamping of work piece respectively.

iii. Coolant system:

It consists of electrical induction motor and pump. Coolant is supplied with high pressure to manifold through the pipe. Coolant are spread over point of cutting tool i.e. insert and job, then coolant can carry away heat and chips. Coolant is collected in tank after filter and reused.

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

Figure 5 – Coolant system assembly.

Figure 5 – Hydraulic power pack assembly.

iv. Lubrication system:

Figure 6 – Lubrication System.

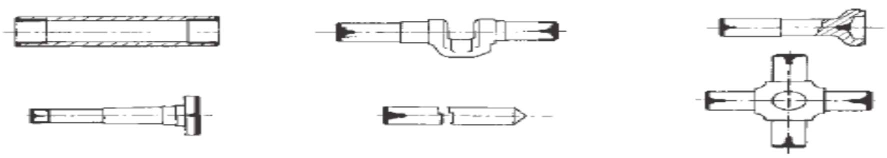

Figure 7 – Different work pieces which can be machined on machin

Figure 8 – Clamping System.

It consists of hand pump. Lubrication is provided to spindle of headstock, tailstock, quills and slides with help of copper tube. Oil level indicator is provided on oil tank. When lubricant level goes down below the mark, we have to fill it with oil.

CONSTRUCTION OF FAULT TREE OF CFAM-500

The main objective of CFAM-500 is to machining of the job with stable machining accuracy and high productivity. Therefore, failure to do machining is considered as top event. The failure of CFAM-500 is because of nine reasons. First reason is failure of cutting tool. There are number of factors affecting the failure of the cutting tool which are considered as intermediate events. Second reason is failure of electrical control system failure; it is also a dependent event so it is an intermediate event. Third reason is head stock/ tail stock failure. Fourth reason is failure of hydraulic system. Fifth reason is failure of clamping system failure. Sixth reason is failure of coolant system. Seventh reason is failure of coolant pump failure. Eighth reason is failure of bearing. Ninth reason is failure of hydraulic pump motor assembly failure. These are the nine reasons to failure of CFAM-500

Failure Of Cutting Tool

There are many reasons of failure of tool i.e. improper coolant supply, Improper cutting speed, feed, Depth of cut, Wrong tool Selection, Job Material is Faulty. Improper coolant supply is due to Dislocation of pipe, Leakage from pipe, Coolant pump failure. Coolant pump failure is due to No power supply, No coolant in tank, Pump & Motor subassembly failure, Leakage of coolant from tank. Figure shows the failure relationship fig 9

Electrical Control System Failure

Failure of electrical control system mostly occurs due to overload, relay fail, sensor fail, transformer fail, fuse fail, supply cable fail, no power supply. All are series elements, so connected by OR gate to the intermediate top event as shown in Figure 10

Headstock / Tailstock failure:

Failure of tailstock is due bearing failure, cylinder failure, motor failure, oil seal failure. Bearing will fail due to coolant entering in bearing, no grease to bearing, improper assembly or disassembly. FTA of this sub-system is shown in Figure 11

Hydraulic System failure:

The failures of hydraulic system are due to less oil level, valve failure, hoses failure, pump motor assembly failure etc. Pump and motor assembly fail due to lead screw jam, less oil level, improper resting, oil seal failure, wrong selection of oil etc. Figure 12 shows the failure relationship

Clamping System failure:

Clamping system will fail due to lead screw jam, less oil level and improper resting. Figure 13 shows the failure relationship.

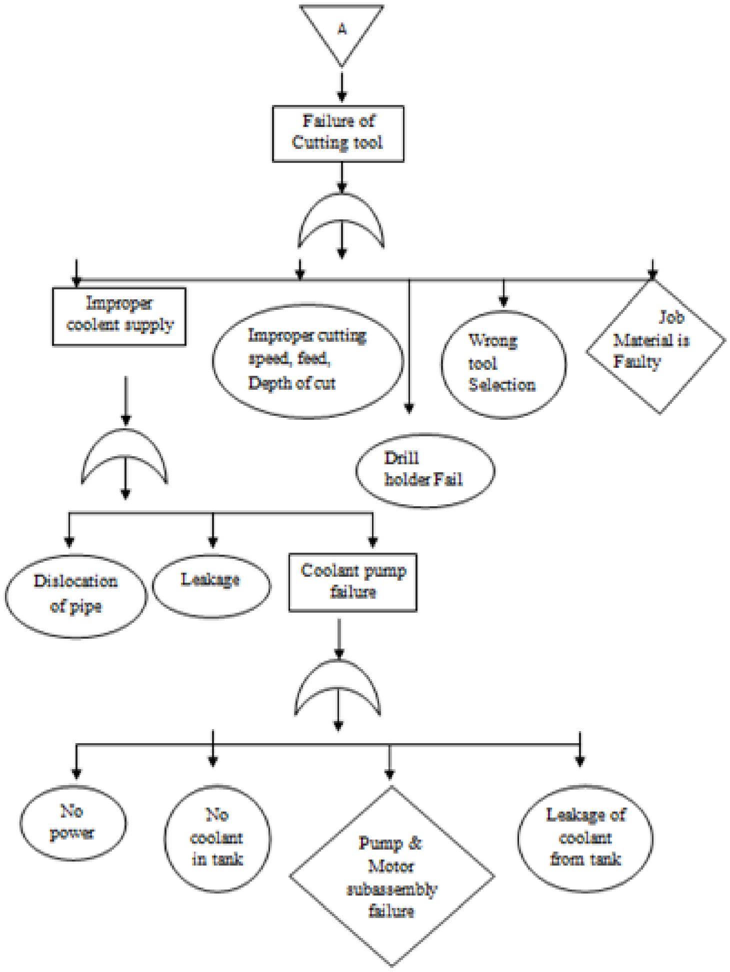

Figure 9 –Cutting Tool failure

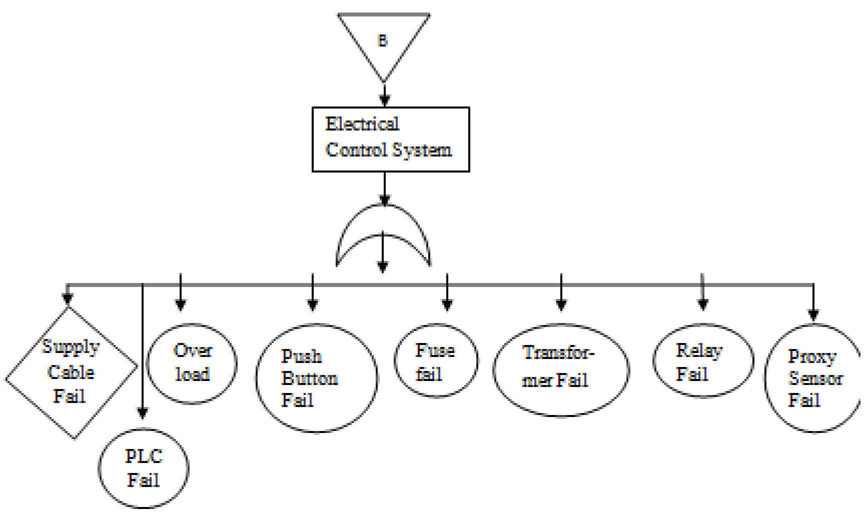

Figure 10 - Electrical control system failure

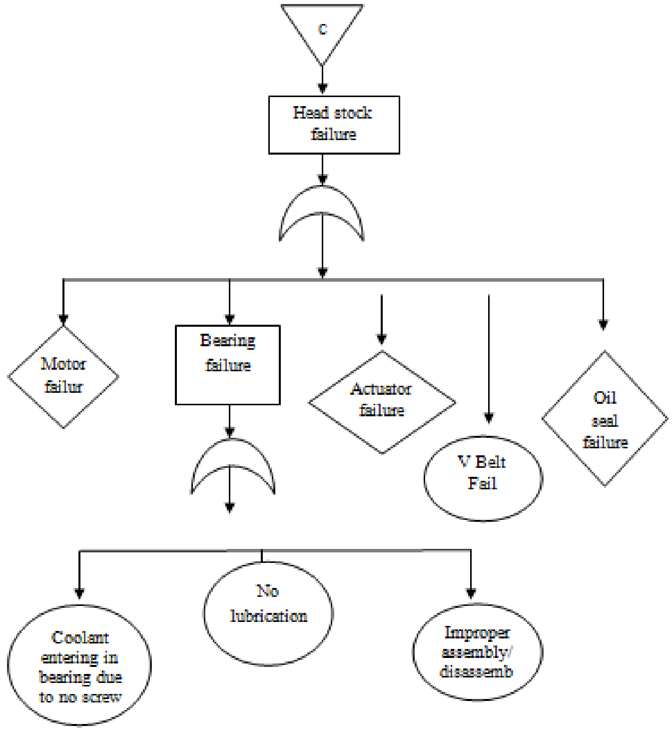

Figure 11 - Headstock / Tailstock failure

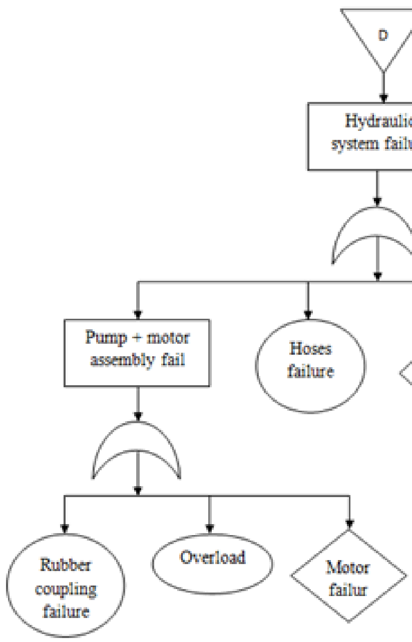

Figure 13 – Hydraulic System failure

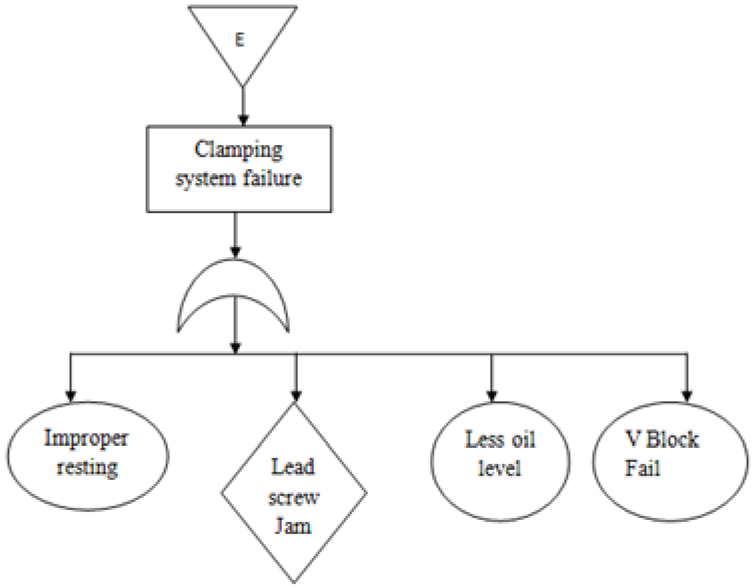

Figure 13 - Clamping failure

CONCLUSIONS

To improve the reliability of CFAM-500, the most important measure requiring immediate attention are to grasp and remove the factors causing problems in all steps of the life cycle, The following conclusions can be derived.

1. The weakest subsystem of cfam-500 is Electrical and Electronic subsystem whose failures required the longest repair time. It shows that the repairmen were not familiar with the Electrical and Electronic subsystem, so the company should conduct repair training for the repairmen.
2. The failures of Electrical and Electronic subsystem were mainly caused by the overloading and therefore the manufacture factory should try to avoid overloading.
3. The primary cause of failure CFAM-500 machine is the breakage of components, so the CFAM-500 manufacturer should strengthen the reliability management to the outsourcing components in the course of reliability improvement designing, the user should train the operation and maintenance personnel of CFAM-500 and try their best to reduce the harmful environment influence on CFAM-500 machine.

The objective was to reduce hazard rate of the system and minimizing life

REFERENCES

1. Charles E. Ebling, "Introduction to Reliability and Maintainability Engineering", TataMc-Graw Hill Publishing House, Edition 2000.
2. www.spmtools.co.in. SPM TOOLS, (Yadrav) Ichalkaranji.
3. Yiquiang Wang, Richard C.M. TYam, Ming J. Zuo, Peter Tse. "A comprehensive reliability allocation method for design of CNC lathes". Reliability Engineering and System Safety, Page no.247-252, February 7, 2001.
4. Yiqiang Wang, Yazhou Jia, Junyi Yu, Yuhua Zuhua Zheng, Shangfeng Yi. " Failure probabilistic model of CNC lathes". Reliability Engineering and System Safety, Volume 65, Page no.307-314, 1999.
5. Yi Dai, Yazhou jia, " Reliability of a VMC and its improvement", Reliability Engineering and System Safety, Volume 72, Page no.99-102, 2001.
6. A.Z.Keller, A.R.R Kamathi, "Reliability Analysis Of CNC Machine Tools." Journal of Reliability engineering, Volume 3, Page no. 449-473, 1982.
7. Javad Barabady, Uday Kumar, "Reliability Analysis of Mining Equipment: A Case Study of a Crushing Plant at Jajarm Bauxite Mine in Iran". Reliability Engineering and System Safety, Page no. 647-653, 2008.
8. Saurabh Kumar, Gopi Chattopadhyay, Uday Kumar, "Reliability Improvement through Alternative Designs-A Case Study." Reliability Engineering and System Safety, Page no.983-991, February 6, 2007.
9. L. Y. Waghmode, R. B. Patil, "An Overview of Fault Tree Analysis (FTA) Method for Reliability Analysis." Journal of

Engineering Research and Studies, Volume 4, Page no. 6-8, January 2013.
10. L. Y. Waghmode, A. Sahastrabhudhe, P. Kulkarni, "A Life Cycle Cost of Pump Using An Activity Based Costing Methodology." Journal of Mechanical Design, Volume 132, Page no.121006-1 to 121006-9, December 2010.
11. H. Paul Barringer, "Why you need practical reliability details to define life cycle costs for your products and competitors' products?"www.barringerl.com.
12. Li Jun, Xu Huibin, "Reliability Analysis of Aircraft Equipment Based on FMECA method." 2012 International Conference on Solid State Devices and Material Science, page no 1866-1822, march 3, 2012.
13. H. Paul Barringer, "An Overview of Reliability Engineering Principles" www.barringerl.com.
14. http://en.wikipedia.org/wiki/fault tree analysis.
15. Rajkumar B. Patil, "An Overview of Fault Tree Analysis (FTA) Method for Reliability Analysis and Life Cycle Cost (LCC) Management", IOSR Journal for Mechanical and Civil Engineering, ISSN 2278-1684, Page no.14-18.
16. Charles E. Ebling, "Introduction to Reliability and Maintainability Engineering", Tata Mc-Graw Hill Publishing House, Edition 2000.
17. V.N.A. Naikan, "Reliability Engineering and Life Testing", PHI Publication, Edition 2010.
18. H. Paul Barringer, P. E. Barringer & Associates, An Overview of Reliability Engineering Principles, Penn Well Conferences, January 29 – February 2, 1996.
19. http://en.wikipedia.org/wiki/Reliability_%28 engineering%29.
20. A. K. Gupta, "Reliability Engineering and Technology", Macmillan India Limited, Edition 1996, pp 409 – 419.
21. U. Dinesh Kumar, "Tutorials on Life Cycle Costing & Reliability Engineering Course Material", Indian Institute of Management, Bangalore.
22. Charles E. Ebling. "An introduction to Reliability and Maintainability Engineering" Tata McGraw-Hill, Edition 2000.