AN OVERVIEW OF FAULT TREE ANALYSIS (FTA) METHOD FOR RELIABILITY ANALYSIS

Article · March 2013

1 author:

Rajkumar Bhimgonda Patil
University of Maryland, College Park

Research Article

AN OVERVIEW OF FAULT TREE ANALYSIS (FTA) METHOD FOR RELIABILITY ANALYSIS

L. Y. Waghmode[1], Rajkumar B. Patil[2]

Address for Correspondence

[1,2]Department of Mechanical Engineering, Annasaheb Dange College of Engineering and Technology, Ashta, Shivaji University, Kolhapur, Maharashtra (India).

ABSTRACT

Reliability analysis plays crucial role in the design process. In order to increase reliability of a system, analysis of failure data is essential. Fault Tree Analysis (FTA) is a method that directly focuses on the modes of failures. FTA is a graphical representation of the major faults or critical failures associated with a product and the causes for the faults and potential countermeasures. This paper presents the FTA of Lathe Machine. Qualitative and quantitative analysis helps to identify critical design parameters, maintenance suggestions. It also includes how reliability analysis fruitful for Life cycle cost management.

KEYWORDS Fault Tree Analysis, FRACAS, Life Cycle Cost, MTBF, MTTF, Reliability Analysis.

I. INTRODUCTION

Reliability based design focuses on three terms as reliability, availability and maintainability. Reliability is defined to be the probability that the component or system will perform its intended functions for a specified period of time when used under stated operating conditions [1]. In simple words, reliability is nothing but the non-failure of the system over a given period of time. Reliability engineering is a sub-discipline within system engineering. Equipment and processes failures waste money on unreliability problem.

Reliability is a probability. This means that failure is regarded as a random phenomenon. We do not express any information on individual failures, the causes of failures, or relationships between failures, except that the likelihood for failures to occur varies over time according to the given probability function. Reliability engineering is concerned with meeting the specified probability of success, at a specified statistical confidence level.

Due to increased complexity of systems, reliability analysis is very essential for increasing the availability. Reliability analysis is useful for reducing Life Cycle Cost as well as increasing safety of human being. Fault Tree Analysis is one of the tools used for estimating reliability of a system. Due to its simplicity, focuses on possible modes of failures etc. it is widely used [3].

II. NEED OF RELIABILITY STUDY

Cranwell [4] presented a survey of reliability considerations. Over 90% of all reliability and quality costs in U.S. are being spend to correct product design inadequacies and defects after they have occurred while less than 10% are being spent to make products right in the first place. It is also suggested that the equipment purchase decision should be based on total life cycle costs, reliability and availability. Reliability and optimization in design help to reduce 15-20% of total life cycle costs.

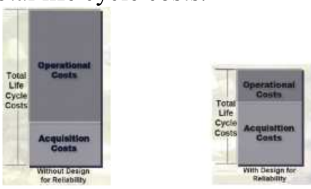

Figure 2. Results of implementation of Reliability prectices at design stage on LCC [4].

In order to implementation of reliability program successfully, following steps or basics are to be implemented.

- Good organized data collection program (failure recording & corrective action system) that accounts for uncertainty.
- Formalized reliability programs that are used throughout the lifecycle.
- Use of predictive modeling and simulation.
- Use of optimization techniques.

Waghmode [5] analyzed 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. Many organizations consider only the design and installation cost of a system and not whole LCC. But it is very essential to focus on source of cost savings, especially minimizing energy consumption and plant downtime.

Figure 3. Life Cycle Cost Analysis [5].

When we consider all the costs over the life cycle of any product, the initial purchase price is only a fraction of the total amount spent. Following equation gives the Life Cycle Cost (LCC) model.

LCC = Acquisition costs + Operating costs + Failure Costs + Support costs + Net Salvage Value.

$LCC=C_u*N+[F_o+P_A(i,t_d)*C_o*N]+[P_A(i,t_d)*C_f*t_o / MTTF*N]+[F_s+P_A(i,t_d)*C_s*N]-[P_F(i,t_d)*S*N]$

From the case study of reliability analysis of multi-stage centrifugal pump, it is found that proper pumping system design is the most important single element in minimizing the LCC. The maintenance cost is approximately 2.5 times the initial cost of the pump. Also it is found that the LCC is near about 12 to 13 times the initial costs. Hence it essential to record the data not only for LCC analysis but also it will also be useful as a base for analyzing the next generation products.

III. ACQUIRING RELIABILITY DATA

The world became more complicated in the late 1920s, and need of reliable system (such as helicopter, airplane etc.) arises during World War II. During the 1960s, '70s '80s applications of reliability principles were put to work. Performance improved and cost reduction programs occurred in mainframe computers, gas turbine engines, nuclear reactors, electronics, automobiles and consumer products using reliability engineering principles.

Accurate failure data is required for making good reliability decisions. Failures demonstrate evidence of lack of reliability. Reliability problems are failure, and failures cost money in an economic enterprise. Many factories, chemical plants and refineries have recorded and stored 10 to 20 years of failure data in maintenance information systems. Fresh data is acquired accurately analyzed rigorously when organization observe that failure data is actually used for decisions. Failure Reporting and Corrective Action Systems (FRACAS) are considered an early and important element for initiating improvements by acquiring reliability data correctly and using it in a closed loop system for improvements [3, 8].

Such complex failure data is converted into uncompleted, figure of merit, performance indices. Simple arithmetic concept is useful for 'getting a grip' on reliability by using mean times to/between failure derived from the summation of ages to failure divided by the number of failures. This is a simple, gross indicator of reliability.

Reliability is observed when mean time to failure (MTTF) for non-repairable systems or mean time between failure (MTBF) for repairable systems is long compared to the mission time. Reciprocal of MTBF or MTTF provide failure rates which are commonly displayed in tables for reliability data. Mean time indices are understandable by engineers but failure rates are usually better for making calculations.

IV. FAULT TREE ANALYSIS

FTA was originally developed **in1962 at Bell Laboratories by H.A Watson**, under a U.S Air Force Ballistics Systems Division contract to evaluate the Minuteman I Intercontinental Ballistic Missile (ICBM) Launch Control System. FTA is the most commonly used technique for causal analysis in risk and reliability studies. Fault tree analysis is a 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 field of safety engineering to quantitatively determine the probability of a safety hazard [6].

FTA is a graphical design technique that provides an alternative to reliability block diagrams. It is broader in scope than a reliability block diagram and differs from reliability block diagrams in several respects. It is top-down, deductive analysis structured in terms of events rather than components. An advantage of focusing on failures is that failures are usually easier to define than non-failures and there may be far fewer ways in which non-failures can occur. The focus is usually on a significant failure or a catastrophic event, which is referred to as the top event and appears at the top of the fault tree diagram.

The qualitative analysis consists of identifying the various combinations of events that will cause the top event to occur. This may followed by a quantitative analysis to estimate the probability of occurrence of the top event.

Fault Tree Analysis usually involves events from machine wear out, material failure or combinations of deterministic contributions to the event stemming from assigning hardware (machine)/system failure rate to branches or cut sets.

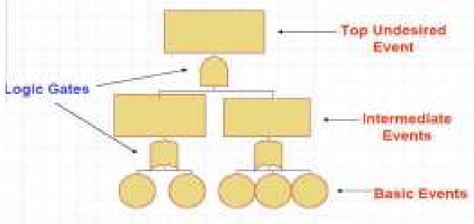

Figure 4. – Construction of Fault Tree Diagram.

Typically failure rates are carefully derived from substantiated historical data such as mean time between failure of the components, unit, subsystem or function. Predictor data may be assigned.

FTA can be used as a valuable design tool, can identify potential accidents, and can eliminate costly design changes. It can also be used as a diagnostic tool, predicting the most likely system failure in a system breakdown. FTA is used in safety engineering and in all major fields of engineering.

V. SYMBOLS USED IN FTA

The basic symbols used in FTA are grouped as events, gates, and transfer symbols.

TRANSFER SYMBOLS

Symbol	Meaning
	Transfer-In
	Transfer-out

GATE SYMBOL

Symbol	Meaning
	AND Gate
	OR Gate
	Exclusive OR Gate
	Priority AND Gate
	Inhibit Gate

EVENT SYMBOL

Symbol	Meaning
	Basic event
	Incomplete Event
	Conditional Event
	Normal Event
	Intermediate Event

VI. FTA OF LATHE MACHINE

A machine tool is power driven machine for making articles of a given shape, size and accuracy by removing metal from work piece in the form of chips. Machine tools are factory equipment for producing machines, instruments and tools of all kinds. So it can be said that the machine tool is mother of all machines. Hence the size of a country's stock of machine tool and their technical quality and condition largely characterize its industrial potential.

Most machine tool performs four functions as Hold the job, Hold the cutting tool, Move one or both of these, providing feeding motion to one of them. The lathe is one of the oldest and perhaps most important machine tool ever developed. The job to be machined to be rotated and cutting tool moved relative to the job. That is why the lathe is also called as "Turning Machines" if the tools move parallel to the axis of rotation of the work piece, cylindrical surface is produced, while if it moves perpendicular to this axis, it produces the flat surface.

In this case study the basic reasons for the failure of tool broken of the lathe machine have been studied. Fault Tree has been constructed on the basis of this study and qualitative and quantitative analysis has been done [9].

Qualitative Analysis

In this sub section using the sub fault tree's and Boolean algebra, the expressions for evaluating the probability of failure of tool broken has been obtained which are described below:

$F_1= V_3+V_4$; $F_2= F_1+V_7$; $F_2= V_3+V_4+V_7$; $F_3= F_2+V_5+V_6$; $F_3= V_3+V_4+V_7+V_5+V_6$; $F_4= V_8+V_9$; $F_5= V_{11}+V_{12}+V_{13}$;
$F_6= F_5+V_{14}$; $F_6=V_{11}+V_{12}+V_{13}+V_{14}$; $F_7=F_6+V_{15}$;
$F_7= V_{11}+V_{12}+V_{13}+V_{14}+V_{15}$; $F_8=F_7+V_{16}$;
$F_8= V_{11}+V_{12}+V_{13}+V_{14}+V_{15}+V_{16}$;
$F_9= F_8+V_{17}$; $F_9=V_{11}+V_{12}+V_{13}+V_{14}+V_{15}+V_{16}+V_{17}$;
$F= V_1+V_2+V_{10}+F_3+F_4+F_9$;
$F=V_1+V_2+V_3+V_4+V_5+V_6+V_7+V_8+V_9+V_{10}+V_{11}+V_{12}+V_{13}+V_{14}+V_{15}+V_{16}+V_{17}+V_{18}$

Quantitative Analysis

For the quantitative evaluation of fault tree of lathe machine the probability of failures of different components are collected and shown in Table (4).

Table 1. The description of the bottom events of Lathe Machine

CODE	FAULT	PROBABILITY OF FAILURE	CODE	FAULT	PROBABILITY OF FAILURE
V_1	Blunt tool	0.010	V_{10}	Selection of tool	0.015
V_2	Improper speed	0.015	V_{11}	Wrong choice	0.010
V_3	Lead screw fault	0.010	V_{12}	Using beyond shelf life	0.015
V_4	Wear and tear	0.010	V_{13}	Unclean media	0.010
V_5	Centre height	0.015	V_{14}	Improper coolant timing	0.015
V_6	Over hanging	0.010	V_{15}	No uniform hardness	0.010
V_7	Loose mounting	0.015	V_{16}	Improper alloying	0.010
V_8	Leakage	0.005	V_{17}	Blow holes	0.010
V_9	Dislocation of pipe	0.010	V_{18}	Feed not proper	0.010

Putting all the values of V_1 , … , V_{18} in equation given below,

The probability of failure P (F) of tool broken is

$P(F) = 1-[(1-V_1)(1-V_2)(1-V_3)(1-V_4)(1-V_5)(1-V_6)(1-V_7)(1-V_8)(1-V_9)(1-V_{10})(1-V_{11})(1-V_{12})(1-V_{13})(1-V_{14})(1-V_{15})(1-V_{16})(1-V_{17})(1-V_{18})]$

$= 0.18636878$

R = 1- Probability of failure

$= 1- 0.18636878$

R = 0.81363122

VII. SUMMARY

Fault Tree Analysis directly focuses on the modes of failure, which is more effective method than system reliability block diagram. Symbols used in FTA are easy to understand. The tool helps identify areas of concern for new product design or for improvement of existing products. It also helps identify corrective actions to correct or mitigate problems. Design optimization is possible with Life Cycle Cost (LCC) model. Failure data analysis helps to reduce considerable LCC. Reliable failure data is essential for analysis. It provides a clear and concise means of imparting reliability information to management.

REFERENCES

1. Charles E. Ebling, Introduction to Reliability and Maintainability Engineering, Tata McGraw Hill Publishing House, Edition 2000.
2. http://en.wikipedia.org/wiki/Reliability_%28engineering%29.
3. H. Paul Barringer, P. E. Barringer & Associates, An Overview of Reliability Engineering Principles, *Penn Well Conferences*, January 29 – February 2, 1996.
4. Robert M. Cranwell, Ground Vehicle Reliability – Design for Reliability, *2007 DoD Maintenance Symposium*, Orlando, Florida, November 13-16, 2007.
5. L. Y. Waghmode, *Some studies on Total life cycle costs of an industrial product or a system*, Dissertation of ME Design, Shivaji University, Kolhapur 2004.
6. Mohammad Sadegh Javadi, Azim Nobakht, Ali Meskarbashee, Fault Tree Analysis Approach in Reliability Assessment of Power System, *International Journal of Multidisciplinary Sciences and Engineering*, Vol. 2, No. 6, September 2011.
7. Masdi Muhammad, M. Amin Abd Majid, A Case Study of Reliability Assessment for Centrifugal Pumps in a Petrochemical Plant, *Fourth world congress on engineering asset management Athens*, Greece, 28-30 September 2009.
8. Ankush Kumar, *Fault Tree Analysis of different systems,* School of mathematics and computer applications. Thapar University, Patiala (Punjab). July 2009.

Appendix I – Fault Tree Diagram of Lathe Machine