

# Reliability Analysis of Vertical Broaching Machine by Fault Tree Analysis (FTA) Method

**Mr. S. B. Herwade**

*PG Student*

*Department of Mechanical Engineering*

*Dr.J.J.Magdum College of Engineering, Jaysingpur, Shivaji University, Kolhapur, India*

**Prof. A. M. Naniwadekar**

*Professor*

*Department of Mechanical Engineering*

*Dr.J.J.Magdum College of Engineering, Jaysingpur, Shivaji University, Kolhapur, India*

## Abstract

Reliability Analysis by Fault Tree Analysis (FTA) method plays crucial role in design process. FTA is a graphical representation of major failure occurs in a machine, their causes of failures and potential countermeasures. This paper deals with a reliability analysis of vertical broaching machine by FTA method. Qualitative and quantitative analysis helps to identify the critical design parameters and maintenance suggestions.

**Keywords:** Vertical Broaching Machine, Reliability Analysis, FTA Method, Qualitative Analysis

## I. INTRODUCTION

In today's competitive world, reliability analysis of equipment or machine is extremely important to maintain quality with delivery deadlines. This can achieve by using proper maintenance and design changes for unreliable subsystem and components of a complex system. It is significant to develop the strategy for maintenance, replacement and design changes related to those subsystems or components. An analysis of down time along with causes is essential to identify the unreliable components and subsystems. The growing awareness of reliability arises from the fact that there is a need for efficient, economic and continuous running of equipment or system in any organization for achieving the targeted production at a minimum cost to face the present competition. The word reliability is associated with the civilization of mankind to compare one item or person with another. Trustworthy, dependable and consistent are the words, which can be used to give an indication of why the characteristic of reliability is so much valued [1]. Reliability cannot be precisely measured with respect to human behavior but it can give an indication that a particular person is more reliable than the other. The characteristic of reliability is usually used to describe some function or in widest sense, it may be said to be a measure of performance.

The complexity of industrial systems as well as their products is increasing day-by-day. The improvement in effectiveness of complex systems has therefore acquired special importance in the recent years. The effectiveness of system is understood to mean the suitability of the system for the fulfillment of the intended tasks and the efficiency of utilizing the means put into it [2]. The suitability of performing definite tasks is primarily determined by reliability and quality of the system. Keeping this in view it was proposed to carry out reliability, maintainability and life cycle cost analysis of a Vertical Broaching Machine based on time to failure and time to repair data. This work is sponsored by G.S.Engineers, Ichalkaranji. The main objective was to study failure patterns of selected Vertical Broaching Machine and to develop a reliability model to estimate reliability.

### A. Vertical Broaching Machine

Vertical Broaching Machines are used in small scale as well as large scale industries for internal and external broaching of components to produce keyways in pulleys and gears, grooves and splines. These models are low as well as medium cost machines, ideally used for mass production. These machines are fully protected to give maximum safety and prevent accidents. The vertical Broaching Machine has a control panel conveniently placed within operator's reach. Almost any irregular cross section can be broached as long as all surfaces of the component remain parallel to the direction of broach travel. These machines are used for mass and batch production. For increasing salability, durability and compete their competitors, research, redesign and development work is carried out. The main objective of this research is to improve reliability and optimize the total life cycle cost in order to increase availability. As the competition is increasing, also the manufactures are trying to reduce the cost of the machine but at the same time, it is required to maintain the quality of the product. Quality, reliability, availability and less maintenance are the requirements. This work is sponsored by G.S.Engineers, Ichalkaranji. G.S.Engineers, Ichalkaranji are leading manufacturers of Special Purpose Machines, Vertical Broaching Machines etc. The fig.1 shows the Vertical Broaching Machine.



Fig. 1: Vertical Broaching Machine

Table – 1  
Specification of Vertical Broaching Machine

<i>Parameters</i>	<i>Specification</i>
<i>Pulling capacity</i>	6000 kg
<i>Cylinder Make</i>	Hydrotech
<i>Bore dia.</i>	63 mm
<i>Piston rod dia.</i>	45 mm
<i>Maximum stroke</i>	1200 mm
<i>Cutting speed ( variable )</i>	1.0 to 5 mtrs/min
<i>Return Speed</i>	6 mtrs/min
<i>Face plate dimensions</i>	325×680 mm
<i>Maximum shank dia. A or B as per DIN 1415/1417</i>	25 mm- 32mm
<i>Dia. of bore in false plate</i>	200H7 mm
<i>Power of electric motor</i>	7.5 HP /1500 rpm
<i>Power of coolant motor</i>	0.37 kw (0.5 H.P)
<i>Operating Pressure at full load</i>	90 kg /cm.sq
<i>Hydraulic capacity</i>	210 litres
<i>Coolant fluid reservoir capacity</i>	180 litres

### **B. Fault Tree Analysis Method**

Fault tree analysis (FTA) is the commonly used technique to analyze failure patterns of engineering and biological systems. 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. It is basically composed of logic diagrams that display the state of the system and is constructed using graphical techniques [3]. This analysis method is mainly used in the fields of safety engineering and reliability engineering to understand how systems can fail, to identify the ways to reduce risk or to determine event rates of a safety accident or a particular system level 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.













Fault Tree Analysis was originally developed in 1962 at Bell Laboratories by H.A.Watson, under a U.S Air Force Ballistics System Division. It was later adopted and extensively applied by Boeing Company. FTA is a top-down approach to failure analysis, starting with a undesirable event called TOP event, and then determining all the ways that TOP event can occur.

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 the 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 system.

### **C. Symbols used in FTA Method**

The selection of effective symbols and their implementation plays an important role in construction of fault tree diagram. The basic symbols used in FTA are grouped as gates, events and transfer symbols. Table 3.1 shows various symbols used in FTA.

Table – 2  
Symbols used in FTA

Gate symbol		Event symbol		Transfer symbol	
Symbol	Meaning	Symbol	Meaning	Symbol	Meaning
	AND Gate		Basic event		Transfer-In
	OR Gate		Incomplete Event		
	Exclusive OR Gate		Conditional Event		Transfer-out
	Priority AND Gate		Normal Event		
	Inhibit Gate		Intermediate Event		

#### D. Steps Involved in FTA Method

There are five major steps to a fault tree analysis [4]:

- 1) Define the system, its boundaries, and the top event.
- 2) Construct the fault tree, which symbolically represents the system and its relevant events.
- 3) Perform a qualitative evaluation by identifying those combinations of events that will cause the top event.
- 4) Perform a quantitative evaluation by assigning failure probabilities or unavailability to the basic events and computing the probability of the top event.
- 5) Interpret and present the results

## II. DESIGN AND CONSTRUCTION DETAILS OF VERTICAL BROACHING MACHINE

### A. Design Consideration

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 Vertical Broaching Machine. These design considerations for Vertical Broaching Machine are given below.

- A broach always moves forward and in straight line, so that all the elements of the broached surface must be parallel to the axis of the travel.
- The ideal hardness range for broaching is from 12 to 22 HRC.
- All machinable materials, metallic or nonmetallic, can be broached. Some of the newer materials like nickel base and heat-resisting alloys can also be broached with care.
- The pulling capacity of machine is 6000 kg and stroke length is 1200mm.
- The main frame consists of upper table (face plate), lower table and two columns. This frame is clamped on a fabricated structure.
- The two hydraulic cylinders are clamped to the upper table to pull the broach on upper side.
- Because of rigid construction the machine is firmly mounted on leveled floor and it is secure to the floor through the four holes of M16 provided in the machine.
- The maximum rapid return speed of broach is 6m/min.
- Machine should be installed in such a way as to isolate all the vibrations. Machine must be accurately leveled both in longitudinal and transverse direction by the use of precision level.
- The crosshead has two oil nipples. They must be filled with lubricating oil.
- The height of the main frame and other equipments is selected such that maintenance work will require less effort.
- Proper damping system should be there in order to damp shocks coming from cutting tools.
- Different components are designed in order to minimize cost of the system to compete with competitors.

### B. Construction Details

The important construction and operational features of the Vertical Broaching Machine are given below.

#### 1) Broach

The broaching tool has a series of teeth so arranged that they cut metal when the broach is given a linear movement and it cuts away the material since its teeth are progressively increasing inn height. Broaching can greatly increase productivity, hold tight tolerances and produce precision finishes. Broach tool is the heart of broaching; its construction is unique for it combines rough, semi-finish and finish teeth in one tool.

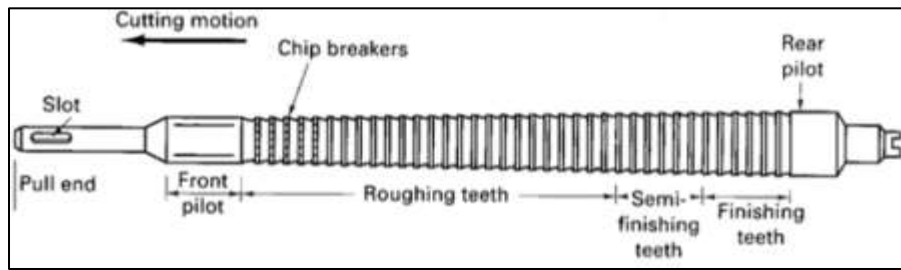


Fig. 2: Parts of a Broaching Tool

Feed is accomplished by the increased step between any two successive teeth on the broach. The total material removed in a single pass of broach is the cumulative result of all the teeth in the tool in action. The cutting speed of the broach is decided by the linear travel of the tool with respect to the work piece.

Common broach material is 18-4-1 stainless steel as its name indicates; it has 4% chromium, 1% vanadium, 18% tungsten. This is corrosion and wear resistant steel. Carbide is also recommended for broach making, these broaches are used for broaching brittle material like cast iron in automobile industry. Inserted bit type and cemented carbide type broaches are also preferred to reduce the cost of broaches.

### 2) Hydraulic Power Pack



Fig. 3: Hydraulic Power Pack Assembly

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 crosshead on vertical columns to pull the broach in forward stroke to complete the broaching operation on component. The speed of the broaching is variable by means of a flow control valve.

### 3) Electrical Control Panel



Fig. 4: Control Panel

It consists of no. of push buttons present on it, some of them are like hydraulic ON, Broach UP, Broach Down, Coolant ON/Off, Ram Stop, Power ON etc. The operation of individual is given below.

- Hydraulic ON- This is push button control. Coolant pump motor starts with switch 'ON', however, the coolant flow can be stopped with the control valve on the head.
- Broach UP/Down- The broach start and stops the operation depends upon control panel and solenoid valve operation which actuates the hydraulic cylinder.
- Coolant ON/Off- This switch is used to start coolant motor or stop the motor whenever necessary.

#### 4) Puller Jaw System

A broach pulling mechanism is provided for utilizing puller jaws which engage with a significantly larger circumferential groove at the end of the broach to pull the broach through the work piece without any vertical drop of the broach in the puller mechanism during any part of the broaching operation. To accomplish this, a piston assembly is mounted at the bottom of the broach pulling mechanism to allow the end of the broach to bottom thereon. The piston assembly is controllably pressurized to lock a wall of the groove of the broach end between the puller jaws and the piston assembly thereby preventing any movement or dropping of the broach due to a loose fit of the jaws with respect to the groove throughout the entire broaching operation.

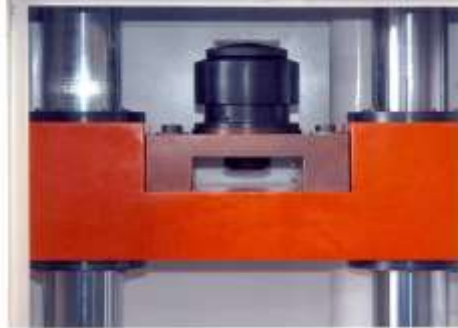


Fig. 5: Puller jaw system

### III. CONSTRUCTION OF FAULT TREE OF VERTICAL BROACHING MACHINE

The main objective of Vertical Broaching Machine is to machining of the job with high machining accuracy and high productivity. Therefore, failure to do machining is considered as top event. The failure of Vertical Broaching Machine is because of eleven reasons. First reason is failure of broach. There are number of factors affecting the failure of the broach which are considered as intermediate events. Second reason is failure of hydraulic system failure; it is also a dependent event so it is an intermediate event. Third reason is electrical control system failure; it is also a dependent event so it is also an intermediate event. Fourth reason is failure of column wiper. Fifth reason is failure of puller jaw. Sixth reason is improper coolant supply. Seventh reason is failure of broach guide bush. Eighth reason is failure of coolant pump. Ninth reason is failure of oil seal. Tenth reason is flow control valve failure. Eleventh reason is filter failure. Twelfth reason is connector failure. These are the twelve reasons to failure of Vertical Broaching Machine. There are total five main reasons (top sub events) of failure, which are given below,

- Failure of Broach
- Hydraulic System Failure
- Electrical Control System Failure
- Failure of Column Wiper
- Failure of Puller Jaw

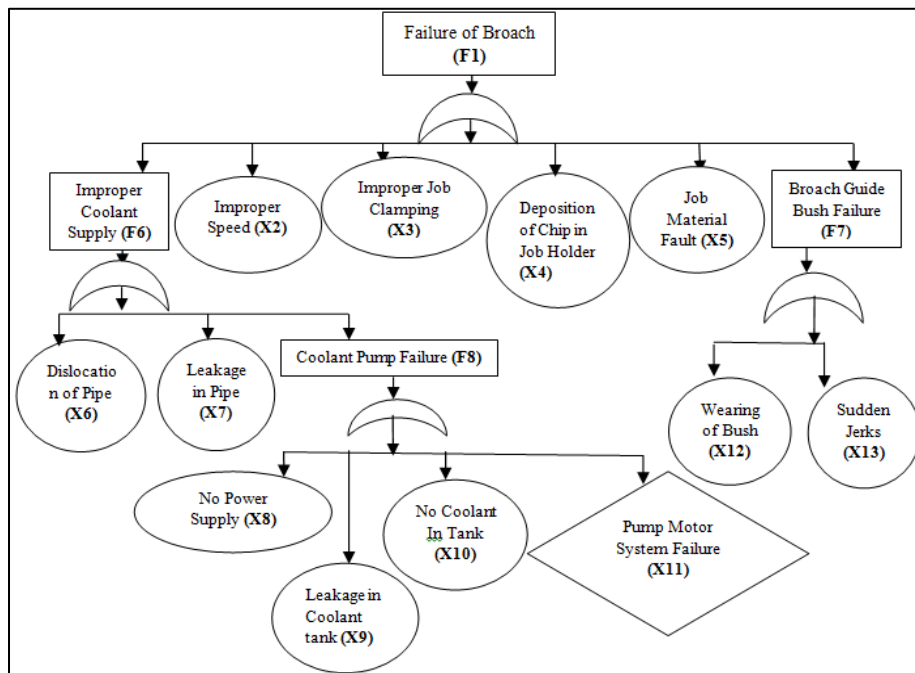


Fig. 6: Failure of Broach

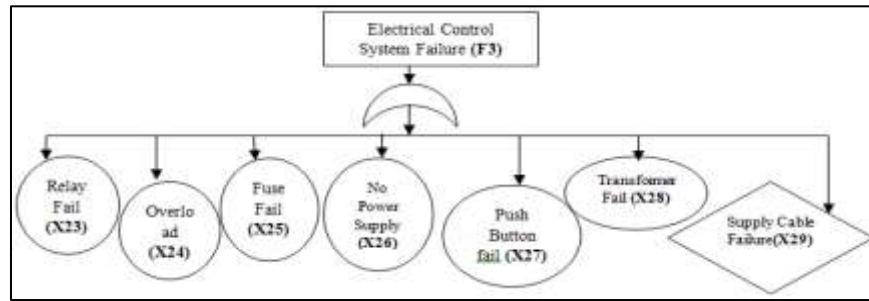


Fig. 7: Electrical Control System Failure

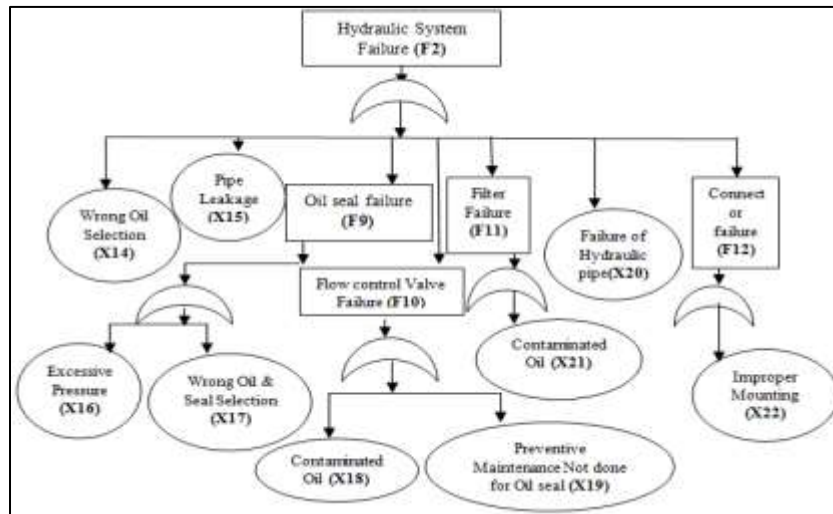


Fig. 8: Hydraulic System Failure

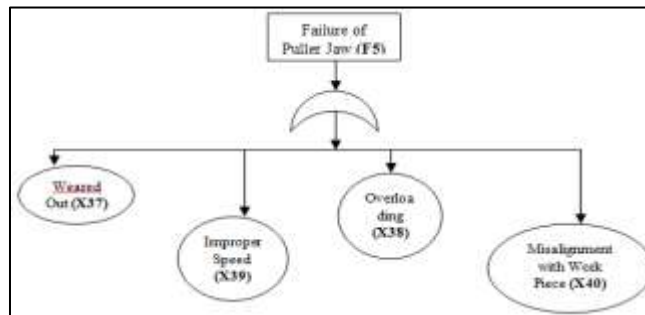


Fig. 9: Failure of Puller Jaw

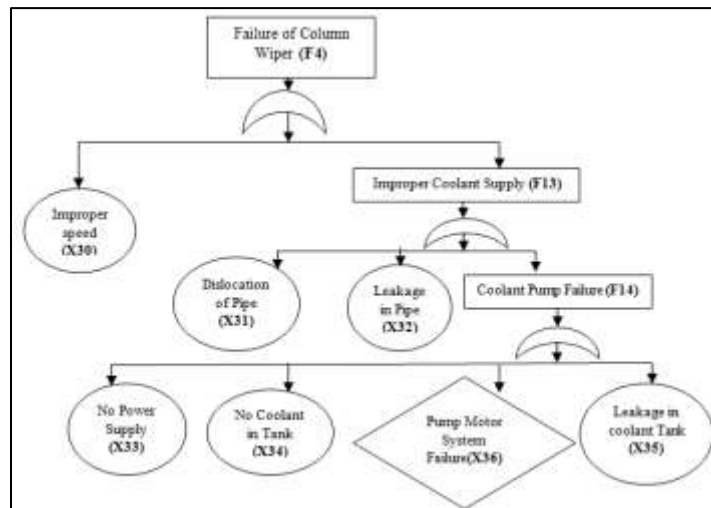


Fig. 10: Failure of Column Wiper

#### IV. QUALITATIVE ANALYSIS

Let  $X_1, X_2, X_3, \dots, X_{40}$  denotes 40 basic events and  $F_1, F_2, F_3, \dots, F_{14}$  denotes intermediate events and  $F$  denotes top event. For qualitative analysis, Boolean algebra method has been used. In this method, '+' sign denotes OR gate and '.' sign denotes AND gate.

$$F = F_1 + X_1 + F_2 + F_3 + F_4 + F_5, F_1 = F_6 + X_2 + X_3 + X_4 + X_5 + F_7$$

But,  $F_6 = X_6 + X_7 + F_8, F_7 = X_{12} + X_{13}, F_8 = X_8 + X_9 + X_{10} + X_{11}$ ; Therefore,

$$F_1 = X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13}$$

$$F_2 = X_{14} + X_{15} + F_9 + F_{10} + F_{11} + F_{12} + X_{20}$$

But,  $F_9 = X_{16} + X_{17}, F_{10} = X_{18} + X_{19}, F_{11} = X_{21}, F_{12} = X_{22}$ ; Therefore,

$$F_2 = X_{14} + X_{15} + X_{16} + X_{17} + X_{18} + X_{19} + X_{20} + X_{21} + X_{22}$$

$$F_3 = X_{23} + X_{24} + X_{25} + X_{26} + X_{27} + X_{28} + X_{29}$$

$F_4 = X_{30} + F_{13}$ , But,  $F_{13} = X_{31} + X_{32} + F_{14}, F_{14} = X_{33} + X_{34} + X_{35} + X_{36}$ , Therefore,

$$F_4 = X_{30} + X_{31} + X_{32} + X_{33} + X_{34} + X_{35} + X_{36}$$

$$F_5 = X_{37} + X_{38} + X_{39} + X_{40}$$

Putting values of  $F_1, F_2, F_3, F_4, F_5$ , in equation of  $F$ , we get,

$$F = X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + X_{17} + X_{18} + X_{19} + X_{20} + X_{21} + X_{22} + X_{23} + X_{24} + X_{25} + X_{26} + X_{27} + X_{28} + X_{29} + X_{30} + X_{31} + X_{32} + X_{33} + X_{34} + X_{35} + X_{36} + X_{37} + X_{38} + X_{39} + X_{40}$$

#### V. QUANTITATIVE ANALYSIS

For the given analysis, it is considered that power supply is constant and continuous. The components except  $X_1, X_{11}, X_{16}, X_{20}, X_{21}, X_{22}, X_{23}, X_{27}$  and  $X_{36}$  are suggested for preventive maintenance. Hence reliability of the system is the resultant of reliabilities of components  $X_1, X_{11}, X_{16}, X_{20}, X_{21}, X_{22}, X_{23}, X_{27}$  and  $X_{36}$ . Therefore final equation takes the following form and same is used to estimate system reliability.

$$R_s = R_1 \times R_{11} \times R_{16} \times R_{20} \times R_{21} \times R_{22} \times R_{23} \times R_{27} \times R_{36}$$

Here Hydraulic oil seal, Hydraulic pipe and Hydraulic power pack motor had very low reliability for a period of one year. Hence these are also kept for preventive maintenance.

Therefore above equation takes the following form and this equation is used to find the system reliability.

$$R_s = 0.9707 \times 0.8801 \times 0.8163 \times 0.9941 \times 0.9208 \times 0.8226$$

$$R_s = 0.53$$

Thus, the reliability of Vertical Broaching Machine by fault tree analysis method is 0.53.

#### VI. RESULT AND CONCLUSION

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

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