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RELIABILITY ANALYSIS OF PISTON MANUFACTURING SYSTEM

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Abstract

Now days, internal combustion engines are used in most of the automobiles and mechanical machineries. The piston is a part without which no internal combustion engine can work i.e., piston plays a vital role in almost all types of vehicles. So, the reliability of piston manufacturing system is most essential for the proper functioning of vehicles. In this paper, fault tree method is used to analyze the reliability of piston manufacturing system. Also, risk reduction worth is adopted as a measure of importance for identifying the crucial element that has significant impact on the reliability.

Keywords: reliability, piston manufacturing system, fault tree analysis

1. Introduction

Several researchers have used fault tree analysis (FTA) method to analyze the vast majority of industrial system reliability problems. FTA is a deductive failure analysis which focuses on one particular undesired event and which provides a method for determining cause of this event [1]. Factors that contribute to the events are traced to the smallest sub-divisions termed as basic events. The cascading effects of several sub-systems may be linked together and multiple effects may be captured through logical AND and OR relationships. Head event probability is determined from basic events in the fault tree.

Tanaka and Fan [2] presented the approach based on a fuzzy fault tree model and determined the maximum possibility of system failure from the possibility of failure of each component within the system according to the extension principle. Hessian et al. [3] discussed FTA for system design, development, modification, and verification. Geymayr and Ebecken [4] discussed the application of knowledge-engineering and a methodology for the assessment and measurement of reliability, availability, maintainability, and safety of industrial systems using fault tree representation. Schweitzer et al. [5] discussed reliability analysis of transmission protection using fault tree methods. Chao and Sheng [6] discussed FTA of dust suppression mechanism in a spray system with wetting agent. Xing [7] investigated and compared a set of existing component importance measures and select the most informative and appropriate one for guiding the maintenance of the system. Cheng et al. [8] proposed a new approach by combining the FTA and FMECA and the reactor system's reliability was analyzed quantitatively. Hong et al. [9] studied the reliability assessment of protection system for switchyard using FTA. Choi and Cho [10] discussed a practical method for accurate quantification of large fault trees. Hsiao and Lu [11] studied risk informed design refinement of a power system protection scheme. Volkanovski et al. [12] discussed application of the fault tree analysis for assessment of power system reliability. Zhenjie et al. [13] studied reliability evaluation of flood releasing structures power supply of hydroelectric power station by FTA.

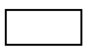
In this paper, fault tree method is used to analyze the reliability of piston manufacturing system. Also, risk reduction worth is adopted as a measure of importance for identifying the crucial element that has significant impact on the reliability.

This paper is organized as follows: In section 2, some basic concepts are described. In section 3, piston manufacturing system is discussed. In section 4, fault trees for piston manufacturing system are constructed. In section 5, quantitative analysis of piston manufacturing system is presented. The conclusion is discussed in section 6.

2. FTA Basic Concepts

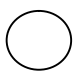
In this section, some basic concepts of FTA are presented [1,14].

2.1 Fault Tree Symbols [1].

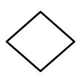


Top Event: An undesired state of a system caused by events occurring within the system or in the system environment. Top event is represented by rectangle.

Intermediate Event:
An intermediate event is a fault event which occurs from a combination of other events via logic gates. Intermediate event is also represented by rectangle.



Basic Event: The circle describes a basic initiating fault event that requires no further development. In other words, it signifies that the appropriate limit of resolution has been reached.



Undeveloped Event: An event which is not further developed either because it is of insufficient consequence or because information is unavailable.

OR Gate: Output fault occurs if at least one of the input faults occurs.

AND Gate: Output fault occurs if all of the input faults occur.

2.2 Minimal Cut Set

Minimal cut sets (MCS_s) constitute the simplified fault tree through the Boolean operation. To determine the MCS_s of a fault tree, the tree is first transformed to its equivalent Boolean equations and then either the "top-down" or "bottom-up" substitution method is used [1].

Any fault tree consists of a finite number of MCS_s, which are unique for the top event. The minimal cut set expression for the top event can be written in the general form,

$$Top = \sum_{i=1}^{k} MCS_i \qquad (1)$$

where Top is the top event and MCS_i is the i^{th} minimal cut set and k is the number of MCS_s. Each minimal cut set consists of combination of specific basic events and hence in general n - component minimal cut set can be expressed as

$$MCS_i = \prod_{i=1}^{n} X_i \tag{2}$$

where X_i is the i^{th} basic event and n is the number of basic events in a minimal cut set.

2.3 Risk Reduction Worth (RRW)

One significant quantity in the reliability assessment is the "measures of importance". One may obtain the importance of elements influencing reliability by RRW as well as know where the weakness of the system is. The RRW is the decrease in the probability of the top event that can be achieved given that one of the basic events is assured not to occur [14]. The RRW method is defined as follows:

$$I_i^{RRW} = \frac{U_S[U_{base}]}{U_S[U_{base} \mid U_i = 0]} \tag{3}$$

where

I_i^{RRW} = the index of RRW for element i

$U_S[U_{base}]$ = unavailability of system

U_i = unavailability of element i

3. Piston Manufacturing System

To make a piston as a complete product, twelve machining operations are required. The process chart of piston manufacturing is shown in Figure 1.

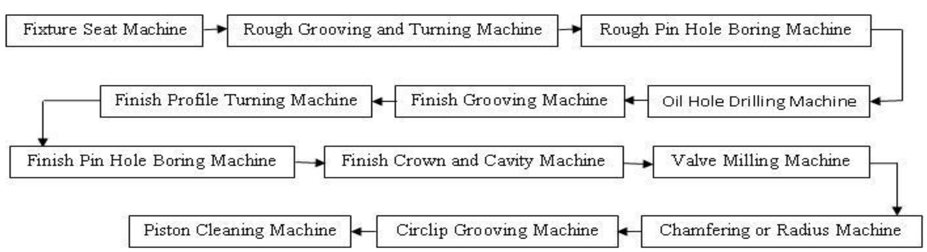


Figure 1: Process chart of piston manufacturing system

The operations that are performed on these machines or sub-systems are as follows:

Fixture Seat Machine: This machine is used to clamp the piston.

Rough Grooving and Turning Machine: On this machine, rough grooves are made on the piston.

Rough Pin Hole Boring Machine: Pin hole boring operation is performed using this machine.

Oil Hole Drilling Machine: On this machine, one hole is made on the piston to supply the oil.

Finish Grooving Machine: On this machine, finishing is given to the rough grooves which are prepared using rough grooving and turning machine.

Finish Profile Turning Machine: Ovality shape is given to the piston using this machine.
Finish Pin Hole Boring Machine: On this machine, finishing is given to the pin hole portion which are prepared using rough pin hole boring machine.
Finish Crown and Cavity Machine: Finishing is given to the crown of piston using this machine.
Valve Milling Machine: On this machine, valve recess is made on the piston.
Chamfering or Radius Machine: This machine rounds off the corners of the piston.
Circlip Grooving Machine: On this machine, circlip grooves are made on the piston.
Piston Cleaning Machine: This machine is used to clean the inside and outside portion of the piston.

The unstable operating status of piston manufacturing system is assumed as top event. Top event probability depends upon the probability of twelve intermediate events (defined as the sub-top events). Table 1 describes the top event. The sub-top events and intermediate events are shown in Tables 2 and Table 3 respectively. The basic events and their probabilities are shown in Table 4. These failure probabilities are evaluated using exponential distribution.

Table 1: Top Event

Event label	Name of top event
T	Unstable operating status of piston manufacturing system

Table 2: Sub-top Events

Event label	Name of the event
$R1$	Unstable operating status of fixture seat machine
$R2$	Unstable operating status of rough grooving and turning machine
$R3$	Unstable operating status of rough pin hole boring machine
$R4$	Unstable operating status of oil hole drilling machine
$R5$	Unstable operating status of finish grooving machine
$R6$	Unstable operating status of finish profile turning machine
$R7$	Unstable operating status of finish pin hole boring machine
$R8$	Unstable operating status of finish crown and cavity machine
$R9$	Unstable operating status of valve milling machine
$R10$	Unstable operating status of chamfering or radius machine
$R11$	Unstable operating status of circlip grooving machine
$R12$	Unstable operating status of piston cleaning machine

Table 3: Intermediate Events

Event label	Name of the event
$E1, F1, G1, H1, I1, J3, K1, L3, M3, N1, O1$	Spindle bearing failure
$E2, F5, I5$	Tool post slides wear out
$E3$	Centering cylinder failure
$G2, H2, J5, K3, L5, M5, N3$	Slides wear out
$E4, F4, G4, H7, I4, N5, O2, P6$	Motor failure
$E5, G6, H5, K2, N2$	Failure of clamping cylinder which holds piston

$E6, F6, G3, H3, I6, J7, K4, L7, M7, N4, O3, P5$	Electric switch gear failure
$E7, F7, G8, H8, I7, N6, O4, P7, G8, H8, I7$	Single phasing failure
$E8, F8, G9, H9, I8, N7, O5, P8, G9, H9$	Failure of functioning pulley
$F3, G5, H4, I3, J6, K5, L6, M6$	Improper coolant supply
$F2, I2, J4, L4, M4$	Tailstock failure
$G7$	Drill failure
$H6$	Indexing problem
$J1, L1, M1$	Ball screw failure
$J2, L2, M2$	Turret not working properly
$K6$	Gear box failure
$P1$	Chain not functioning
$P2$	Pneumatic cylinder failure
$P3$	Heater failure
$P4$	Ultrasonic vibrator failure

Table 4: Basic Events and Their Probabilities

Event label	**Probability**	**Name of the event**
$X1, X4, X20, X35, X41, X43, X62, X64, X84, X99, X112, X126, X129, X150, X185, X188, X200$	200×10^{-5}	Insufficient lubrication
$X105, X116, X141, X143, X154, X164, X171, X175$	100×10^{-5}	
$X211$	50×10^{-5}	
$X2, X14, X21$, X33, $X40, X53, X61, X83, X85, X97, X111, X125, X149, X170, X184, X198, X199, X206, X233$	100×10^{-5}	Life wear out
$X3, X34, X42, X63, X98, X115, X128, X153, X174, X187$	80×10^{-5}	Linear bearing failure
$X5$	80×10^{-5}	Seal leaked
$X6$	40×10^{-5}	No hydraulic pressure
$X7$	1×10^{-5}	Shaft broken
$X8$	100×10^{-5}	Bearing/ Bush failure
$X9, X28, X48, X78, X92, X193, X201, X228$	100×10^{-5}	Bearing failure
$X104$, $X142$, $X163$	70×10^{-5}	
$X107$, $X145$, $X166$	80×10^{-5}	
$X138$	50×10^{-5}	
$X10, X29, X49, X79, X93, X194, X202, X229$	200×10^{-5}	

$X16$, $X36$, $X44$, $X65$, $X100$, $X121$, $X130$, $X159$, $X180$, $X189$, $X207$, $X217$, $X224$	100×10^{-5}	Fuse blown
$X11$, $X30$, $X50$, $X80$, $X94$, $X195$, $X203$, $X230$	50×10^{-5}	Wire burnt
$X18$, $X37$, $X45$, $X66$, $X101$, $X122$, $X131$, $X160$,181, $X190$, $X208$, $X225$	10×10^{-5}	
$X220$	30×10^{-5}	
$X12$, $X31$, $X51$, $X81$, $X95$, $X196$, $X204$, $X231$	100×10^{-5}	Over loading
$X13$, $X32$, $X52$, $X74$, $X82$, $X96$, $X197$, $X205$, $X232$	50×10^{-5}	Belt failure
$X15$, $X58$, $X73$, $X127$, $X186$	200×10^{-5}	Less air pressure
$X215$	100×10^{-5}	
$X17$, $X38$, $X46$, $X67$, $X102$, $X123$, $X132$, $X161$, $X182$, $X191$, $X209$, $X226$	70×10^{-5}	Circuit breaker failure
$X19$, $X39$, $X47$, $X68$, $X103$, $X124$, $X133$, $X162$, $X183$, $X192$, $X210$, $X227$	80×10^{-5}	Limit switch failure
$X22$, $X86$, $X113$, X151, $X172$	200×10^{-5}	Tailstock bearing failure
$X23$, $X87$, $X114$, $X152$, $X173$	200×10^{-5}	Tailstock centre failure
$X24$, $X54$, $X69$, $X88$, $X117$, $X134$, $X155$, $X176$	200×10^{-5}	Pump failure
$X25$, $X55$, $X70$, $X89$, $X118$, $X135$, $X156$, $X177$	10×10^{-5}	Less coolant level in tank
$X26$, $X56$, $X71$, $X90$, $X119$, $X136$, $X157$, $X178$	30×10^{-5}	Pipe leaked
$X27$, $X57$, $X72$, $X91$, $X120$, $X137$, $X158$, $X179$	8×10^{-5}	Pipe chocked
$X59$	100×10^{-5}	Drill blunt
$X60$	100×10^{-5}	Drill broken
$X75$	100×10^{-5}	Pulley bearing failure
$X76$	50×10^{-5}	Loose pulley
$X77$	50×10^{-5}	Motor failure
$X106$, $X144$, $X165$	70×10^{-5}	Nut wear out
$X108$, $X146$, $X167$	80×10^{-5}	Less pressure
$X109$, $X147$, $X168$	50×10^{-5}	Gear not working
$X110$, $X148$, $X169$	50×10^{-5}	Miss alignment of turret
$X139$	30×10^{-5}	Blunt tool

$X140$	30×10^{-5}	Slide jam
$X212$	80×10^{-5}	Loose chain
$X213$	100×10^{-5}	Sprocket bearing failure
$X214$	30×10^{-5}	Seal of cylinder not working properly
$X216$	200×10^{-5}	Valve not working
$X218$	30×10^{-5}	Temperature controller failure
$X219$	30×10^{-5}	Short circuit
$X221$	50×10^{-5}	Heater failure
$X222$	100×10^{-5}	Electric circuit failure
$X223$	100×10^{-5}	Tranducer failure

4. Fault Tree Construction of Piston Manufacturing System

On the basis of causes of unstable operating status of piston manufacturing system, the fault trees for the top event and sub-top events are constructed and are shown in Figure 2 to Figure 14.

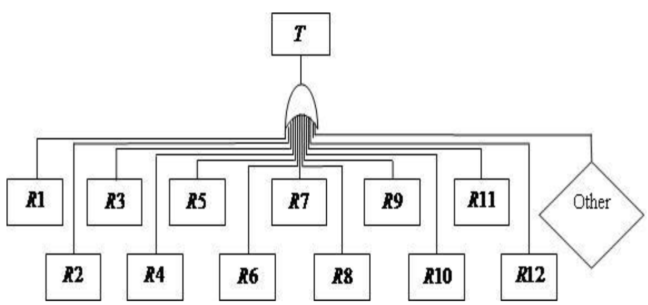


Figure 2: Fault tree of top event of piston manufacturing system

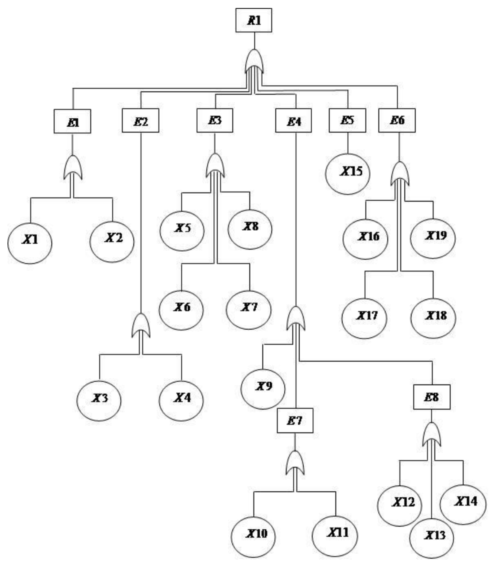


Figure 3: Fault tree of fixture seat machine

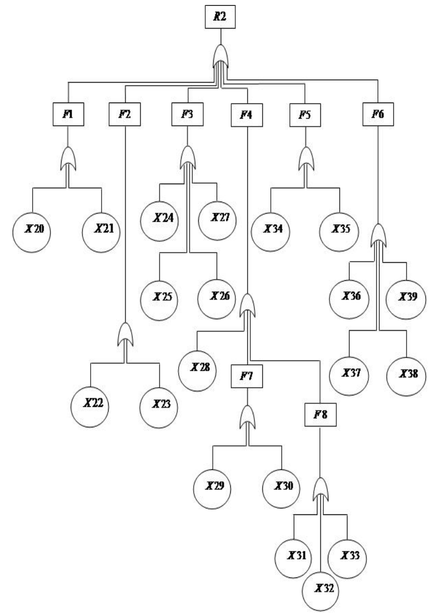


Figure 4: Fault tree of rough grooving and turning machine

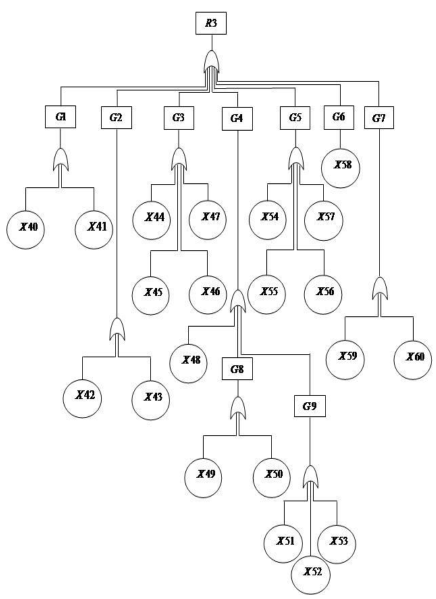


Figure 5: Fault tree of rough pin hole boring machine

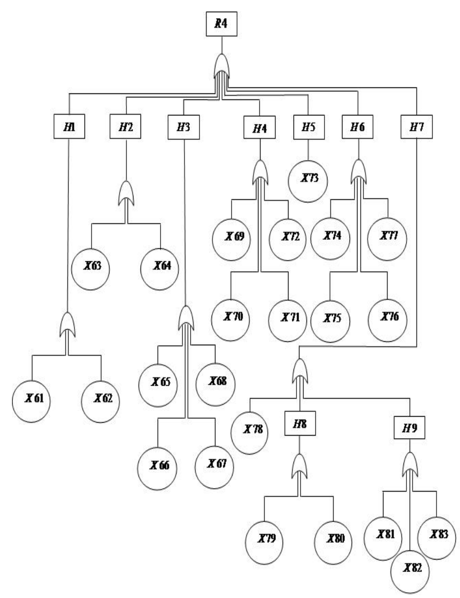


Figure 6: Fault tree of oil hole drilling machine

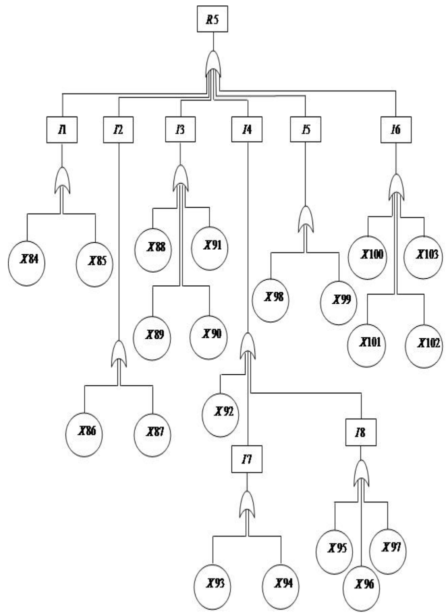


Figure 7: Fault tree of finish grooving machine

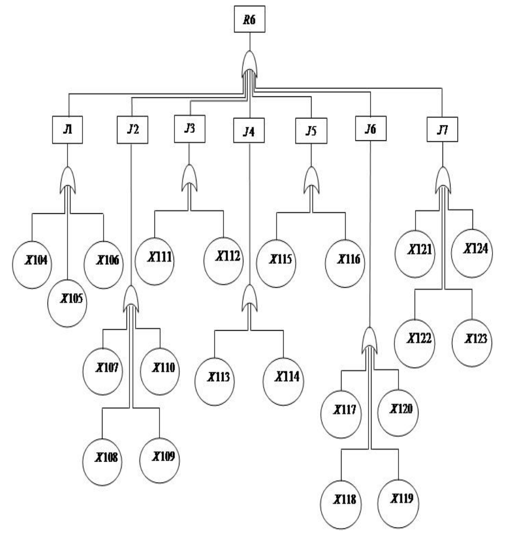


Figure 8: Fault tree of finish profile turning machine

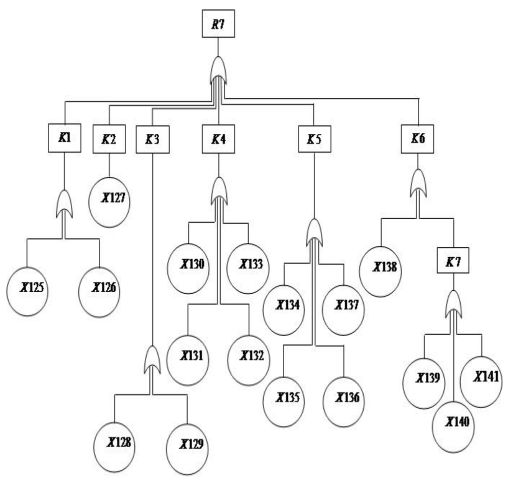


Figure 9: Fault tree of finish pin hole boring machine

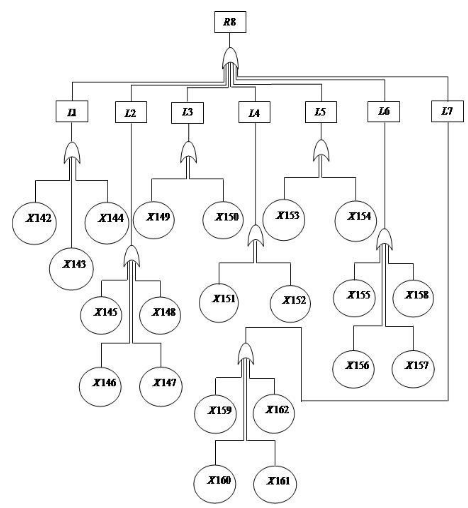


Figure 10: Fault tree of finish crown and cavity machine

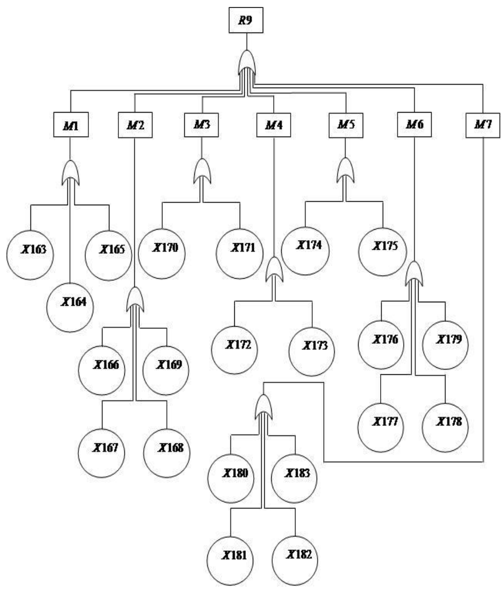


Figure 11: Fault tree of valve milling machine

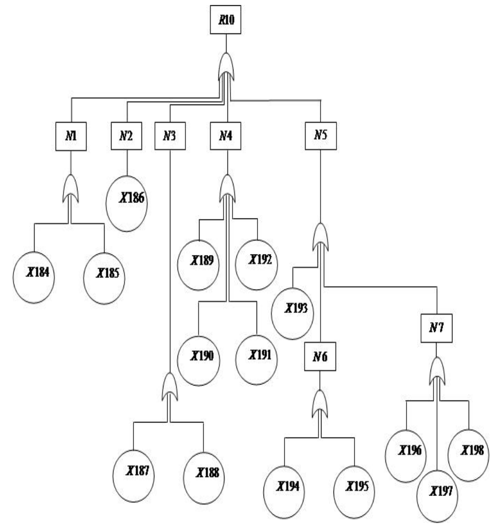


Figure 12: Fault tree of chamfering or radius machine

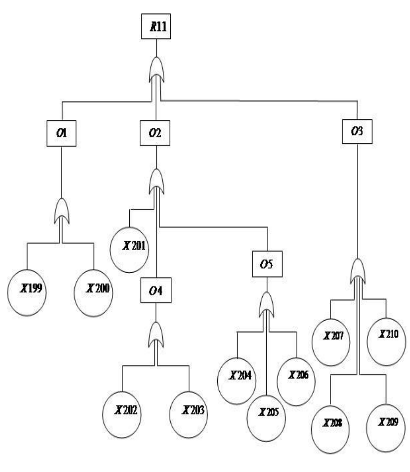


Figure 13: Fault tree of circlip grooving machine

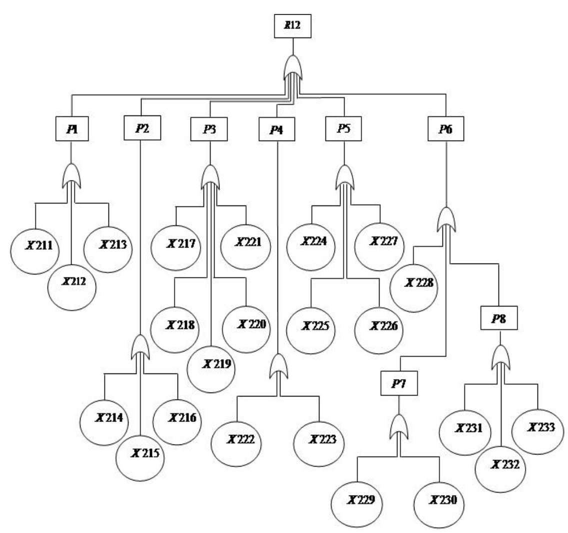


Figure 14: Fault tree of piston cleaning machine

5. Quantitative Analysis of Piston Manufacturing System

Using section 2.2, the top event probability is given by the probability of the union of the MCS_s . Let $P(T)$ be the probability of the top event T , then

$$P(T) = P(\bigcup_{i=1}^{50} MCS_i) = \sum_{i=1}^{50} P(MCS_i) = 4.011 \times 10^{-2}$$

So, reliability of piston manufacturing system = $1 - P(T) = 95.989 \times 10^{-2}$

The RRWs of piston manufacturing system is calculated by equation (3) and are shown in Table 5. This table shows the decrease in the probability of the occurrence of the top event when the probability of the given basic event is negligible i.e. there is no failure.

Table 5: RRWs of Piston Manufacturing System

Root Cause	RRWs	Root Cause	RRWs
Insufficient lubrication	1.095602	Less pressure	1.020351
Bearing failure	1.080841	Loose chain	1.020351
Fuse blown	1.080841	Circuit breaker failure	1.017762
Less air pressure	1.080841	Nut wear out	1.017762
Tailstock bearing failure	1.052479	Belt failure	1.012623
Tailstock centre failure	1.052479	Loose pulley	1.012623
Pump failure	1.052479	Motor failure	1.012623
Valve not working	1.052479	Gear not working	1.012623
Life wear out	1.025569	Miss alignment of turret	1.012623
Bearing/ Bush failure	1.025569	Heater failure	1.012623
Over loading	1.025569	No hydraulic pressure	1.010073
Drill blunt	1.025569	Pipe leaked	1.007536
Drill broken	1.025569	Blunt tool	1.007536
Pulley bearing failure	1.025569	Slide jam	1.007536
Sprocket bearing failure	1.025569	Seal of cylinder not working properly	1.007536
Electric circuit failure	1.025569	Temperature controller failure	1.007536
Tranducer failure	1.025569	Short circuit	1.007536
Wire burnt	1.022953	Pipe chocked	1.001998
Linear bearing failure	1.020351	Shaft broken	1.000249
Seal leaked	1.020351	Less coolant level in tank	1.000249
Limit switch failure	1.020351		

From the Table 5, it can be easily seen that the most critical basic event that influences the system reliability is insufficient lubrication.

6. Conclusion

Reliability of the piston manufacturing system is analyzed using the fault tree analysis. The measure of importance for the fault event is also identified using risk reduction worth. The most critical fault event that influences the system reliability is the insufficient lubrication. The conclusion drawn from the analysis of our results is consistent with the actual performance of the manufacturing system.

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References

1. Vesely, W. E., Goldberg, F. F., Roberts, N. H. and Haasl D. F. (1981). Fault tree handbook, technical report NUREG-0492, U.S. Nuclear Regulatory Commission, Washington, D.C.
2. Tanaka, H. and Fan, L. T. (1983). Fault tree analysis by fuzzy probability, IEEE Transactions on Reliability, R-32(5), p. 453-457.
3. Hessian, R. T., Salter, B. B. and Edwin F. Goodwin, E. F. (1990). Fault-tree analysis for system design, development, modification, and verification, IEEE Transactions on Reliability, 39(1), p. 87-91.
4. Geymayr, J. A. B. and Ebecken, N. F. F. (1995). Fault-tree analysis: A knowledge-engineering approach, IEEE Transactions on Reliability, 44(1), p. 37-45.
5. Schweitzer, E. O., Fleming, B., Lee, T. J. and Anderson, P. M. (1997). Reliability analysis of transmission protection using fault tree methods, Proceedings 24th Annual Western Protective Relay, p. 1-7.
6. Chao, W. and Sheng, G. D. (2000). Fault tree analysis of dust suppression mechanism in a spray system with wetting agent, Journal of Central South University of Technology, 7(3), p. 117-123.
7. Xing, L. (2004). Maintenance-oriented fault tree analysis of component importance, Reliability and Maintainability, Annual Symposium – RAMS, p. 534-539.
8. Cheng, G., Zhang, Y. and Liu, Y. (2005). Reliability analysis techniques based on FTA for reactor-regenerator system, Proceedings 18th International Conference on Structural Mechanics in Reactor Technology, p. 3843-3854.
9. Hong, Y. Y., Lee, L. H. and Cheng, H. H. (2006). Reliability assessment of protection system for switchyard using fault-tree analysis, Proceedings International Conference on Power System Technology, p. 1-8.
10. Choi, J. S., Cho, N. Z. (2007). A practical method for accurate quantification of large fault trees, Reliability Engineering and System Safety, 92(7), p. 971-982.
11. Hsiao, T. Y., and Lu, C. N. (2008). Risk informed design refinement of a power system protection scheme", IEEE Transactions on Reliability, R-57(2), p. 311-321.

12. Volkanovski, A., Cepin, M. and Mavko, B. (2009). Application of the fault tree analysis for assessment of power system reliability, Reliability Engineering and System Safety, 94(6), p. 1116-1127.
13. Zhenjie, L., Yue, Y. and Bowen, W. (2010). Reliability evaluation of flood releasing structures power supply of hydroelectric power station by fault tree analysis, Proceedings Power and Energy Engineering Conference, p. 1-5.
14. Stamatelatos, M., Vesely, W., Dugan, J., Fragola, J., Minarick, J., and Railsback, J. (2002). Fault tree handbook with aerospace application, NASA office of Safety and Mission Assurance, Washington.