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Research Paper

RELIABILITY ANALYSIS OF WASHING UNIT OF PAPER MILL USING B. F. TECHNIQUE

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ABSTRACT:

In this paper, the performance of the washing unit of paper mill has been evaluated. For this Boolean function technique and algebra of logics are used. Reliability of the system under consideration is evaluated in two situations firstly when failures follow Weibull time distribution and second when failures follow Exponential time distribution. M.T.T.F. and failure rate of system under consideration are also calculated

KEYWORDS: Reliability, failure rate, M.T.T.F, Boolean Function Technique, Washing Unit of Paper Mill

I INTRODUCTION

The reliability of a system, equipment and a product is very important aspect of quality for its consistence performance over its expected life span. In fact, uninterrupted service and hazard free operation is an essential requirement of large complex systems like electric power generation and distribution plants or communication network systems such as railways, airways etc. In these cases, a sudden failure of even a single component, assembly or system results in health hazard, accident or interruption in continuity of service. Washing unit is a very important unit of paper mill. If any equipment in this unit does not work properly or get some fault introduced in it then the performance of whole plant will get affected and this will result in low productivity and loss in profit.

Since 1960, a lot of work has been done in the field of reliability engineering due to the importance of reliability engineering in different systems. There are several methods by which we can improve the system reliability. Four main components upon which reliability depends are: tolerance, operating conditions, time and probability. Komal, S.P. Sharma and Dinesh Kumar analysed the complex repairable industrial system using GABLT technique[1].Gupta PP, Agarwal SC, Kumar A, D R Prescott, R Remenyte-Prescott, S Reed, J D Andrews and C G Downes have also analysed the reliability using different methods[2 3 4].

The block diagram of washing unit of paper mill is shown in figure below:

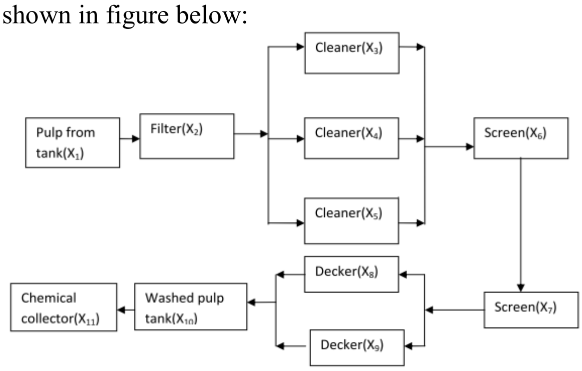

Fig. 1

II Reliability by Boolean Function Technique

To find out the reliability of washing unit of paper mill, a mathematical model is developed as shown in fig. 1. Assumptions made for applying Boolean Function Technique are:

1. At starting all components are good and operational.
2. The state of each component and of whole system is either good or fail.
3. The state of all components of the system is statistically independent.
4. The failure times of all components are arbitrary.
5. Supply between two components of system is hundred percent reliable.
6. There is no repair facility.
7. The reliability of each component is known in advance.

Notations

$X1$ = State of pulp from tank
$X2$ = State of filter
$X3, X4, X5$ = State of cleaners
$X6$ = State of 1^{st} screen
$X7$ = State of 2^{nd} screen
$X8, X9$ = State of both deckers
$X10$ = state of washed pump tank
$X11$ = State of chemical collector
X_i $(i = 1,2,\ldots 11) = 1$ in good state and 0 in bad state
X_i' = negation of X_i
$\wedge$ = Conjunction
$| \, |$ = Logical Matrix
R_i = Reliability of i^{th} part of the system
$Q_i = 1 - R_i$
R_s = Reliability of Whole System
$R_{SW}(t)/R_{SE}(t)$ = Reliability of the system as a whole when failures follows Weibull/ Exponential time distribution.

Now logical matrix representing all cases of working condition of washing unit of paper mill can be written as

$$F(X_1, X_2 \ldots\ldots X_{11}) = \begin{vmatrix} X_1 & X_2 & X_3 & X_6 & X_7 & X_8 & X_{10} & X_{11} \\ X_1 & X_2 & X_3 & X_6 & X_7 & X_9 & X_{10} & X_{11} \\ X_1 & X_2 & X_4 & X_6 & X_7 & X_8 & X_{10} & X_{11} \\ X_1 & X_2 & X_4 & X_6 & X_7 & X_9 & X_{10} & X_{11} \\ X_1 & X_2 & X_5 & X_6 & X_7 & X_8 & X_{10} & X_{11} \\ X_1 & X_2 & X_5 & X_6 & X_7 & X_9 & X_{10} & X_{11} \end{vmatrix}$$

……….(1)

$$F(X_1, X_2 \ldots\ldots X_{11}) = (X_1 X_2 X_6 X_7 X_{10} X_{11}) \wedge \begin{vmatrix} X_3 & X_8 \\ X_3 & X_9 \\ X_4 & X_8 \\ X_4 & X_9 \\ X_5 & X_8 \\ X_5 & X_9 \end{vmatrix}$$

$$= (X_1 X_2 X_6 X_7 X_{10} X_{11}) \wedge B$$

……….(2)

$$B = \begin{vmatrix} X_3 & X_8 \\ X_3 & X_9 \\ X_4 & X_8 \\ X_4 & X_9 \\ X_5 & X_8 \\ X_5 & X_9 \end{vmatrix} = \begin{vmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \\ M_6 \end{vmatrix}$$

……….(3)

Where $M1 = \left| X_3 \quad X_8 \right|$ ………..(4)

$M2 = \left| X_3 \quad X_9 \right|$ ………..(5)

$M3 = \left| X_4 \quad X_8 \right|$ ………..(6)

$M4 = \left| X_4 \quad X_9 \right|$ ………..(7)

$M5 = \left| X_5 \quad X_8 \right|$ ………..(8)

$M6 = \left| X_5 \quad X_8 \right|$ ………..(9)

The logical matrix in equation 3 represents cases of parallel units. M1 represents when X_3 and X_8 are working, M2 is the case when X_3 and X_9 are working and so on. By Orthogonalization algorithm, above equation can be written as

$$B = \left| \begin{array}{llllll} M_1 & & & & & \\ M_1' & M_2 & & & & \\ M_1' & M_2' & M_3 & & & \\ M_1' & M_2' & M_3' & M_4 & & \\ M_1' & M_2' & M_3' & M_4' & M_5 & \\ M_1' & M_2' & M_3' & M_4' & M_5' & M_6 \end{array} \right|$$ ………..(10)

Above logical matrix states that in row 2, M2 will be working and M1 will not be working. Row 3 in matrix represents that M1 and M2 are failed and M3 is in working condition and similar is the case with row 4. These rows can be expanded as shown in figure 3 by the application of Boolean algebra.

$Row2 = \left| M1' \, M2 \right|$

Row 2 states that units in M1 are not working and M2 are working where

$M1 = \left| X_3 \quad X_8 \right|$

$M2 = \left| X_3 \quad X_9 \right|$

Since M1 is not working that's why either X_3 or X_8 will not work and M2 is working so X3 and X_9 is in working condition. By analyzing both conditions it has been found that only unit X_8 will be under repair. So

$\left| M1' \, M2 \right| = \left| X3 \quad X8' \quad X9 \right|$ ………..(11)

Row 3 is $M_1' M_2' M_3$ which means M1 and M2 are not in working conditions. Since

$M1 = \left| X_3 \quad X_8 \right|$

$M2 = \left| X_3 \quad X_9 \right|$

$M3 = \left| X_4 \quad X_8 \right|$

$M_1' M_2' M_3 = X_3' \quad X_4 \quad X_8 \quad X_9'$ ………..(12)

Row 4 is $M_1' M_2' M_3' M_4$ which means M1, M2 and M3 are not in working conditions.

$M1 = \left| X_3 \quad X_8 \right|$

$M2 = \left| X_3 \quad X_9 \right|$

$M3 = \left| X_4 \quad X_8 \right|$

$M4 = \left| X_4 \quad X_9 \right|$

So $M1' \, M2' \, M3' \, M4 = \left| X3' \quad X4 \quad X8' \quad X9 \right|$ ..(13)

$M1' \, M2' \, M3' \, M4' M5 = \left| X3' \quad X4' \quad X5 \quad X8 \quad X9' \right|$ ………..(14)

$M1' \, M2' \, M3' \, M4' M5' M6 = \left| X3' \quad X4' \quad X5 \quad X8' \quad X9 \right|$ ………..(15)

Putting values of 11, 12, 13 into equation 10, we have

$$B = \left| \begin{array}{lllll} X_3 & X_8 & & & \\ X_3 & X_8' & X_9 & & \\ X_3' & X_4 & X_8 & X_9' & \\ X_3' & X_4 & X_8' & X_9 & \\ X_3' & X_4' & X_5 & X_8 & X_9' \\ X_3' & X_4' & X_5 & X_8' & X_9 \end{array} \right|$$ ………..(16)

Now by putting value of B into equation 2.

$$F(X_1, X_2 \ldots\ldots X_{11}) = \left| \begin{array}{lllllllllll} X_1 & X_2 & X_6 & X_7 & X_{10} & X_{11} & X_3 & X_8 & & & \\ X_1 & X_2 & X_6 & X_7 & X_{10} & X_{11} & X_3 & X_8' & X_9 & & \\ X_1 & X_2 & X_6 & X_7 & X_{10} & X_{11} & X_3' & X_4 & X_8 & X_9' & \\ X_1 & X_2 & X_6 & X_7 & X_{10} & X_{11} & X_3' & X_4 & X_8' & X_9 & \\ X_1 & X_2 & X_6 & X_7 & X_{10} & X_{11} & X_3' & X_4' & X_5 & X_8 & X_9' \\ X_1 & X_2 & X_6 & X_7 & X_{10} & X_{11} & X_3' & X_4' & X_5 & X_8' & X_9 \end{array} \right|$$ ………..(17)

Finally the probability of successful operation i.e. reliability of the system as a whole is given by

$R_s = P_r \{F(X_1, X_2 \ldots\ldots X_{11}) = 1\}$

$= R_1 R_2 R_6 R_7 R_{10} R_{11} [R_3 R_8 + R_3 R_9 (1-R_8) + R_4 (1-R_3) (1-R_8) (1-R_9) + R_4 R_9 (1-R_3) (1-R_8) + R_5 R_8 (1-R_3) (1-R_4) (1-R_9) + R_5 R_9 (1-R_3) (1-R_4) (1-R_8)]$ ………..(18)

A. Some Particular Cases

Case1: When all failures follow Weibull's Criteria

Let λ_i will be the failure rate of components corresponding to system state X_i and it follows weibull time distribution as discussed in previous chapter. Then reliability function of considered system at time 't' is given as:

$R = e^{-(\lambda_1+\lambda_2+\lambda_6+\lambda_7+\lambda_{10}+\lambda_{11})t^\alpha} [e^{-(\lambda_3+\lambda_8)t^\alpha} + e^{-(\lambda_3+\lambda_9)t^\alpha} (1-e^{-\lambda_8 t^\alpha}) + e^{-(\lambda_4)t^\alpha} (1-e^{-\lambda_3 t^\alpha}) (1-e^{-\lambda_8 t^\alpha}) (1-e^{-\lambda_9 t^\alpha}) + e^{-(\lambda_4+\lambda_9)t^\alpha} (1-e^{-\lambda_8 t^\alpha}) (1-e^{-\lambda_8 t^\alpha}) + e^{-(\lambda_5+\lambda_8)t^\alpha} (1-e^{-\lambda_3 t^\alpha}) (1-e^{-\lambda_4 t^\alpha}) (1-e^{-\lambda_9 t^\alpha}) + e^{-(\lambda_5+\lambda_9)t^\alpha} (1-e^{-\lambda_3 t^\alpha}) (1-e^{-\lambda_4 t^\alpha}) (1-e^{-\lambda_8 t^\alpha})]$ ……….(19)

When $\lambda_1 = \lambda_2 =$ -------------- $\lambda_{11} = \lambda$ then from above equation

$R_{sw}(t) = e^{-(6\lambda)t^\alpha}[\ 2e^{-(2\lambda)t^\alpha} - 4e^{-(4\lambda)t^\alpha} + 4\,e^{-(3\lambda)t^\alpha} - 2e^{-(5\lambda)t^\alpha} + e^{-(\lambda)t^\alpha}]$ ……..(20)

Case –II: When all failures follow Exponential time distribution

The continuous time distribution i.e. exponential distribution is a particular case of weibull distribution for $\alpha = 1$. Hence the reliability of a whole system at an instant't' is given by

$R_{se}(t) = e^{-(6\lambda)t}[\ 2e^{-(2\lambda)t} - 4e^{-(4\lambda)t} + 4\,e^{-(3\lambda)t} - 2e^{-(5\lambda)t} + e^{-(\lambda)t}]$ …. (21)

B. MTTF

If the failure time of the life test information of n items is $t_1, t_2, t_3 \ldots\ldots t_n$, then the mean time to failure (MTTF) is defined as:

$$MTTF = \frac{1}{n}\sum_{i=1}^{n} t_i$$

and the expression for M.T.T.F in this case is

$M.T.T.F = \int_0^\infty R_{se}(t)dt$

$= \frac{1}{4\lambda} + \frac{4}{10\lambda} + \frac{4}{9\lambda} - \frac{2}{11\lambda} + \frac{1}{7\lambda}$ ……. (22)

The exponential distribution curve in Boolean algebra reliability is the ideal curve of failure rate. By varying the value of failure rate i.e. lambda in above equations, the reliability of washing unit can be calculated.

A. Weibul Distribution and Exponential Distribution Grpah

By putting the value of failure rate in equation 18 and 19 reliability of weibul distribution curve and exponential curve is find out. Putting value of α=2, following table will show the value of reliability as per wiebul distribution curve and exponential distribution curve Setting $\lambda_i(i = 1,2,3\ldots.11) = 0.001$

Table 1: Reliability values showing for $R_{sw}(t)$, $R_{se}(t)$ with time

S. No.	t	$R_{sw}(t)$	$R_{se}(t)$
1	1	8.92332856514483	8.92332856514483
2	2	8.69721254655534	8.84731053693124
3	3	8.33301935612779	8.77194036519859
4	4	7.84864119721716	8.69721254655534
5	5	7.26704228779836	8.62312162399050
6	6	6.61446080447575	8.54966218648844
7	7	5.91846025831567	8.47682886864663
8	8	5.20602987674836	8.40461635029657

B. MTTF with Failure Rate

Mean time to failure is the mean of all failure rates. The table depicting the MTTF for λ_i =0.001 -0.008is shown below.

Table :2 M.T.T.F vs λ

S. No.	λ	M.T.T.F
1	0.001	255.483405483405
2	0.002	127.741702741703
3	0.003	85.1611351611352
4	0.004	63.8708513708514
5	0.005	51.0966810966811
6	0.006	42.5805675805676
7	0.007	36.4976293547722
8	0.008	31.9354256854257
9	0.009	28.3870450537117
10	0.0010	25.5483405483405
11	0.0011	23.2257641348550
12	0.0012	21.2902837902838

The resulting graph of above table is shown in fig 3. The graph shows that MTTF is decreasing with failure rate and at last it is becoming smooth. It depicts that MTTF should reached to a constant level with increase in the failure rate.

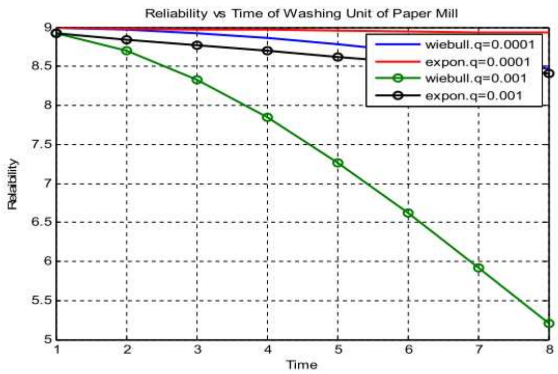

Fig.2 Graph showing weibull distribution and exponential distribution with time

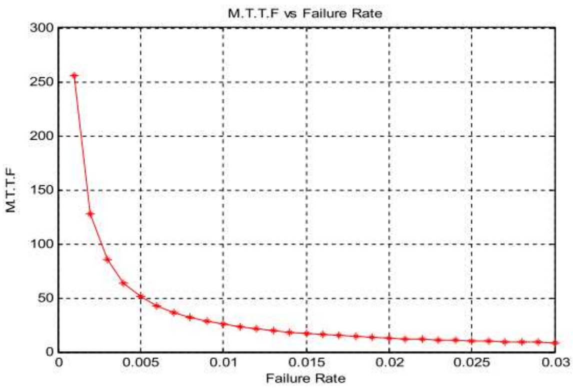

Fig. 3 Graph showing M.T.T.F. with failure rate

V CONCLUSION

In this paper, we considered washing unit of paper mill for analysis of various reliability parameters by employing the Boolean function technique and algebra of logics. Table 1 computes the reliability of the system with respect to time when failures rates follow exponential and weibull time distributions. An inspection of graph "reliability vs. time" (fig 2) reveals that the reliability of the complex system decreases approximately at a uniformly rate in case of exponential time distributions. Table 2 and graph "MTTF v/s Failure rate" (fig 3) yields that MTTF of the system decreases catastrophically in the beginning but later it decreases approximately at a uniform rate.

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