Reliability Modelling of a Gravity Die Casting System Covering Seven Types of Failure Categories

Ramanpreet Kaur[1], Shakeel Ahmad[2], Upasana Sharma[3]
[1,3]*Department of Statistics, Punjabi University, Patiala-147002, Punjab, India*
[2]*Akbar Peerbhoy College of Commerce and Economics,Mumbai-8*

Abstract- This paper presents the reliability modelling of a Gravity Die casting system. The Gravity Die Casting system consists of seven main units namely; Hydraulic System, Electrical Part , Mechanical System , Die tools , Melt Shortage, Vacuum System and Robot. The whole system can fail due to failure of any of the unit. Operative unit has a constant failure rate but a general repair time distribution. The failure time of the unit is exponentially distributed. The Semi-Markov process and regenerative point technique have been used to derive the expressions for mean time to system failure and profit of the models. A particular case is considered to highlight the results graphically.
Keywords: Die casting, Semi-Markov process, regenerative point technique, mean time to system failure (MTSF).

I. INTRODUCTION

A System is a combination of various components and their is functional relationship between its components. The properties and behaviour of each component ultimately affects the properties of the system. Any system of components that passes through the different stages, which can be operational as well as failure. Failure or malfunction means the non-performance of some action that is due to expected. Failures are affected the performance of the system and the reliability. During the last 45 years, reliability concept have been applied in various manufacturing and technological fields. Earlier researcher Goel,L. et.al(1990),Singh,S.et.al(1991),Alidrisi,M.(1992),Gupta,R. et.al(1994), Srinivasan, S. K., and Subramanian, R. 2006) have analyzed the different approaches of standby system. Rizwan,S.(2010)dealt with Probabilistic analysis of a desalination unit with nine failure categories. For the same types of failure discussed by Sharma U and Kaur j (2013) in his paper "Availability of a Compressor Unit Covering Nine Types of Failure Categories". Reliability techniques have also been applied to a number of industrial and transportation problems including automobile industry. Sengar, S., and Singh, S. (2014) Discussed the reliability analysis of an engine assembly process of automobiles with inspection facility.

The present paper discusses reliability analysis of the manufacturing process of Gravity Die Casting. In piston foundry the Gravity die casting system plays an important role for producing the product of pistons. System operates with the help of robotics and two sub-units. The units fails due to any one of the seven types of failure as identified in the data i.e. failure of Hydraulic System, Electrical Parts, Mechanical System, Die tools, Melt Shortage, Vacuum System and Robot. The Semi-Markov processes and regenerative point technique are used to obtain following measures of system performance in steady state:

- Transition probabilities and mean sojourn times in different states.
- MTSF of the system.
- Steady state availability of the system.
- Busy period analysis of repairman.
- Expected number of visits of the repairman.
- The profit incurred to the system is evaluated and the graphical study is also made.

II. MODEL DESCRIPTION AND ASSUMPTIONS:

- The unit is initially operative at state 0 and transits probabilistically depending on the type of failure to any of the seven states 1 to 7 with probabilities p1,p2,p3,p4,p5,p6,p7 respectively as shown in Fig.1.

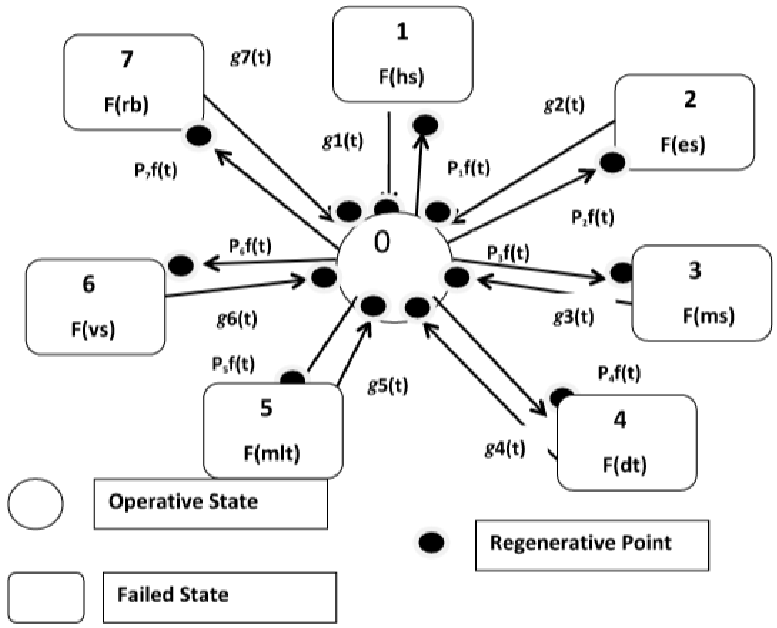

Fig.1: "Transition Diagram"

- All units are connected in series.
- The system has two states; operative state and failed state.
- All failure times are assumed to have exponential distribution with failure rate (λ) whereas the repair times have general distribution.
- After each repair at states 1 to 7, the unit works as good as new.
- The unit is brought into operation as soon as possible.

III. NOTATIONS:

O_I: Operative state.
λ: Constant failure rate of the unit.
p_1: Probability of failure of Hydraulic system.
p_2: Probability of failure of Electrical parts.
p_3: Probability of failure of Mechanical system.
p_4: Probability of failure of Die tools.
p_5: Probability of failure of Melt-Shortage.
p_6: Probability of failure of Vacuum system.
p_7: Probability of failure of Robot.
$F(hs)$: Failed state due to the failure of Hydraulic system.
$F(es)$: Failed state due to the failure of Electrical parts.
$F(ms)$: Failed state due to the failure of Mechanical system.
$F(dt)$: Failed state due to the failure of Die tools.
$F(mlt)$: Failed state due to the failure of Melt-Shortage.
$F(vs)$: Failed state due to the failure of Vacuum system.
$F(rb)$: Failed state due to the failure of Robot.
pij, Qij(t) probability density function(p.d.f),cumulative distribution (c.d.f) of first passage time from a regenerative state i to j or to a failed state j in (0,t] φ(t) c.d.f. of first passage time from regenerative state i to a failed state j Laplace Transforms (LT) i.e. for any f(t) and g(t)

f(t)∗g(t) = $\int_0^t f(t-u)\,g(u)\,du$

f(t): p.d.f. of failure time.
G1(t),g1(t): C.d.f. and p.d.f. of time to repair when failure occur due to failure of Hydraulic system.
G2(t),g2(t): C.d.f. and p.d.f. of time to repair when failure occur due to failure of Electrical parts.
G3(t),g3(t): C.d.f. and p.d.f. of time to repair when failure occur due to failure of Mechanical system.
G4(t),g4(t): C.d.f. and p.d.f. of time to repair when failure occur due to failure of Die tools.
G5(t),g5(t): C.d.f. and p.d.f. of time to repair when failure occur due to failure of Melt-Shortage.
G6(t),g6(t): C.d.f. and p.d.f. of time to repair when failure occur due to failure of Vacuum system.
G7(t),g7(t): C.d.f. and p.d.f. of time to repair when failure occur due to failure of Robot.

IV. TRANSITION PROBABILTIES:

A state transition diagram showing the possible states of transition of the system is shown in Fig.1. The time period of entry into states 0,1,2,3,4,5,6 and 7 are regenerative points and these states are regenerative states. The non-zero elements pij are given below:

$p_{01} = p_1, p_{02} = p_2, p_{03} = p_3, p_{04} = p_4, p_{05} = p_5, p_{06} = p_6, p_{07} = p_7$,

$p_{01} = p_{02} = p_{03} = p_{04} = p_{05} = p_{06} = p_{07} = 1$

By these transition probabilities it is also verified that

$p_{01} + p_{02} + p_{03} + p_{04} + p_{05} + p_{06} + p_{07} = 1$

$p_{i0} = 1$ for (1,2,....,7)

The unconditional mean time taken by the system to transit for any regenerative state 'j 'when it (time) is counted from the epoch of entrance into state 'i 'is mathematically state as:

$$m_{ij} = \int_0^{\infty} t\, dQ_{ij}(t) = -q_{ij}^{*\prime}(0)$$

$$m_{01} + m_{02} + m_{03} + m_{04} + m_{05} + m_{06} + m_{07} = \mu_0,$$

$$m_{10} = \mu_1, m_{20} = \mu_2, m_{30} = \mu_3, m_{40} = \mu_4, m_{50} = \mu_5, m_{60} = \mu_6, m_{70} = \mu_7.$$

V. MEAN TIME TO SYSTEM FAILURE:

Mean time to system failure (MTSF) of the system is determined by considering failed state as absorbing state when system starts from initial state S0 is

$$\text{MTSF} = T_0 = \lim_{s\to 0} \frac{1-\phi_0^{**}(s)}{s}$$

Using L' Hospital Rule & putting the value of $\phi_0^{**}(s)$, we have

$$T_0 = \frac{N}{D}$$

Where

$N = \mu_0$ & $D = 1$

VI. AVAILABILITY ANALYSIS:

Using the theory of regenerative processes, the availability A0 of the system is given by $A_0 = \lim_{s\to 0}(sA_0^*(s)) = \frac{N_1}{D_1}$

Where

$N_1 = \mu_0$

$$D_1 = \mu_0 + \sum_{i=1}^{7} p_i \mu_i$$

VII. BUSY PERIOD ANALYSIS OF A REPAIRMAN:

Busy period analysis of a repairman is given by

$$B_0 = \frac{N_2}{D_1}$$

Where

$N_2 = (W_1 p_{01} + W_2 p_{02} + W_3 p_{03} + W_4 p_{04} + W_5 p_{05} + W_6 p_{06} + W_7 p_{07})$
& D1 is already specified.

VIII. EXPECTED NUMBER OF VISITS OF REPAIRMAN:

Expected no. of visits of repairman is given by

$$V_0 = \frac{N_3}{D_1}$$

Where

$N_3 = (p_{01} + p_{02} + p_{03} + p_{04} + p_{05} + p_{06} + p_{07}) = 1$
& D1 is already specified.

IX. PROFIT ANALYSIS:

The expected total profit acquired to the system is given by

$P = C_0 A_0 - C_1 B_0 - C_2 V_0$

Where

$C_0 =$ Revenue per unit up time of the system.

$C_1 =$ Cost per unit up-time for which the repairman is busy.

$C_2 =$ Cost per visit of a repairman.

X. GRAPHICAL REPRESENTATION AND CONCLUSION:

The following particular cases are considered for graphical representation. Let us suppose that $g1(t) = \alpha 1 e^{-\alpha 1 t}$, $g2(t) = \alpha 2 e^{-\alpha 2 t}$, $g3(t) = \alpha 3 e^{-\alpha 3 t}$, $g4(t) = \alpha 4 e^{-\alpha 4 t}$, $g5(t) = \alpha 5 e^{-\alpha 5 t}$, $g6(t) = \alpha 6 e^{-\alpha 6 t}$, $g7(t) = \alpha 7 e^{-\alpha 7 t}$

Therefore, we have

$p_{01} = p_1$, $p_{02} = p_2$, $p_{03} = p_3$, $p_{04} = p_4$, $p_{05} = p_5$, $p_{06} = p_6$, $p_{07} = p_7$,

$p_{i0} = 1$ for (1,2,....,7)

$\mu_0 = 1/\lambda$, $\mu_1 = 1/\alpha 1$, $\mu_2 = 1/\alpha 2$, $\mu_3 = 1/\alpha 3$, $\mu_4 = 1/\alpha 4$, $\mu_5 = 1/\alpha 5$, $\mu_6 = 1/\alpha 6$,

$\mu_7 = 1/\alpha 7$,

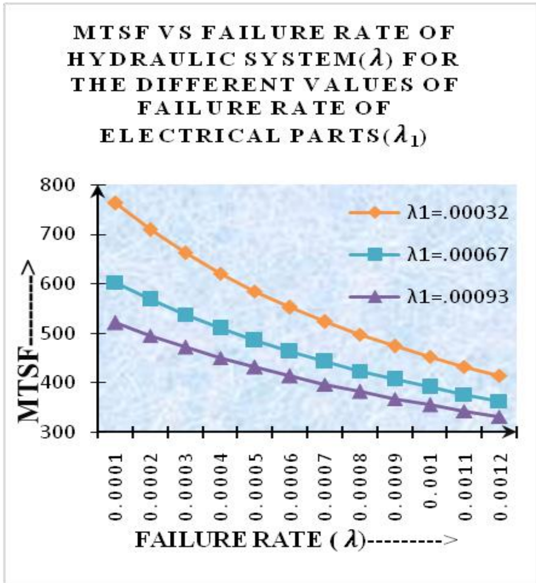

Fig. 2

As shown in fig. 2 the behaviour of MTSF w.r.t. rate of failure of Hydraulic System (λ) for the different values of the rate of failure of Electrical Parts (λ1). It clear from the figure that MTSF gets decreased with increase in values of rate of failure of Hydraulic System (λ). Also MTSF decreases as failure rate of Electrical Parts (λ1) increases.

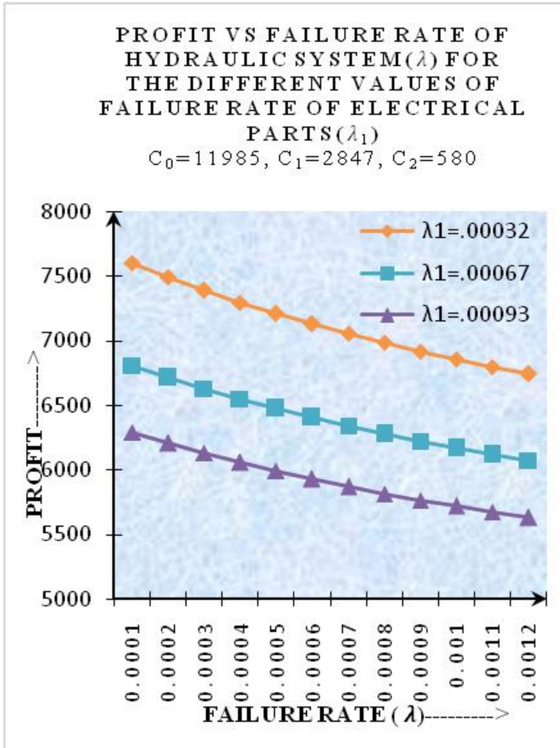

Fig. 3

As shown in fig. 3 nature of profit w.r.t to rate of failure of Hydraulic System (λ) for the different values of rate of failure of Electrical Parts (λ1). As the failure rate of Hydraulic System (λ) increases, the profit of the system decreases. Also, on the increase in the failure rate of Electrical Parts (λ1), profit decreases.

XI. REFERENCES

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