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AVAILABILITY ANALYSIS OF A TWO-UNIT CENTRIFUGE SYSTEM CONSIDERING THE HALT STATE ON OCCURRENCE OF MINOR/MAJOR FAULT

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ABSTRACT
This paper deals with a centrifuge system consisting two identical unit cold standby considering major/minor fault. It is assumed that system leads to partial failed state on occurrence of a minor fault whereas on occurrence of a major fault it leads to complete failure. Some time the system is need to be brought at halt state for repair/ replacement (off-line) and repairs/ replacements of the system/ components is done. In general on complete failure of the system, the repairman first inspect whether the fault is repairable or non repairable and accordingly carry out the repair or replacement of the components involved. Various measures of system effectiveness are obtained by using Markov processes and regenerative point technique. The analysis of the system is carried out on the basis of the graphical studies and conclusions are drawn regarding the availability of the system.

KEYWORDS: Centrifuge System, MTSF, Expected Uptime, Markov Process, Regenerative Point Technique

INTRODUCTION
In the present scenario filtration and purification plays a very important role in the modern society pertaining to the health of the human being and the qualities of the products used by them. A large number of equipments or systems of equipments are involved in the industries to meet out the requirements of such products. One such system is a centrifuge system used for separation of two objects having different type of density. Centrifuge system is being used in Refineries for oil purification, in milk plants to extract the fats, in laboratories for blood fractionation and wine clarification etc. Thus the reliability and cost of the centrifuge system plays a very significant role in such type of industries and hence need to be analyzed.

In fact a large number of researchers in the field of reliability modeling including Gupta and Kumar (1983), Gopalan and Murlidhar (1991), Tuteja et al (2001), Taneja et al (2004), Taneja and Parashar (2007), Gupta et al (2008), Kumar et al (2010), etc. analyzed various one-unit/ two-unit systems. Kumar et al. (2001) investigated a two-unit redundant system with the degradation after first failure and replacement after second failure. Tuteja et.al (2001) studied reliability and profit analysis of two-unit cold standby system with partial failure and two types of repairman. Taneja and Nanda (2003) studied probabilistic analysis of a two-unit cold standby system with resume and repeat repair policies. Singh and Chander (2005) analyzed reliability of two systems each of which contains non-identical units-an electric transformer and a generator. Kumar and Bhatia (2011, 2012, 2013) discussed the behaviour of the single unit centrifuge system considering the concepts of inspections, halt of system, degradation, minor/major faults, neglected faults, online/offline maintenances, repairs of the faults etc.

Recently, Kumar V. et al. (2014) discussed the reliability and profit analysis of a two-unit cold standby centrifuge system considering repair and replacement with inspection.

As far as we concern with the research work on reliability modeling, none of the researchers have analyzed such a two-unit cold standby centrifuge system considering such a situation with occurrence of various faults. To fill up this gap, the present paper discussed an analysis of a stochastic model for two-unit centrifuge system considering halt of the system on occurrence of minor/major fault. On complete failure of the system, the repairman first inspect

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whether the fault is repairable or non repairable and accordingly carry out the repair or replacement of the components involved. In general all the inspections, repairs and replacements have done on-line as well as off-line during the unit operative/ inoperative, but sometimes in emergency the operative unit of the system may be brought to halt for the repair or replacement. Various measures of system effectiveness such as mean sojourn time, MTSF, expected up time and expected down time of the system are obtained using Markov processes and regenerative point technique. The conclusions regarding reliability and availability of the system are given on the basis of graphical studies.

SYSTEM DESCRIPTION AND OTHER ASSUMPTIONS AND METHODS

a. Faults are self- announcing on occurring in the system.
b. There is a single repairman facility with the system to repair the fault.
c. After each repair the system is as good as new.
d. Inspection is carried out only on the occurrence of major faults.
e. During online repair/waiting for repair there may be occurrence of major fault.
f. On occurrence of minor/major fault whether it is repairable or irreparable on-line, the system is need to be brought at halt state for repair/ replacement (off-line).
g. The failure time distributions are exponential while other time distributions are general.
h. Switching is perfectly done on occurrence of major fault.
i. All the random variables are mutually independent.

Notations

λ_1/λ_2 :Rate of occurrence of major/ minor failure

λ_3 :Rate of occurrence of failure due to delay in repair

a / b :Probability that a fault is repairable/ non-repairable

η_1/η_2 :Rate at which the system brought to be at halt state

$i_1(t)/I_1(t)$:p.d.f./ c.d.f. of time to inspection of the unit at failed state

$i_2(t)/I_2(t)$:p.d.f./ c.d.f. of time to inspection of the unit at halted state

$g_1(t)/G_1(t)$:p.d.f./ c.d.f. of times to repair of minor fault at down state

$g_2(t)/G_2(t)$:p.d.f./ c.d.f. of times to repair the unit at failed state

$h_1(t)/H_1(t)$:p.d.f./ c.d.f. of times to replacement of the unit at failed state

$O_r/O_w/O_{cs}$:Operative unit under repair/ waiting/ cold standby

$F_i/F_r/F_{rp}/F_w$:Failed unit under inspection/ repair/ replacement/ waiting

F_R/F_{RP}:Failed unit under repair/ replacement continue from the previous state

TRANSITION PROBABILITIES AND MEAN SOJOURN TIMES

A state-transition diagram in fig.1 shows various states of transition of the system. The epochs of entry into states 0, 1, 2, 3, 4, 5 and 7 are regeneration points and thus these are regenerative states. The state's 6 and 8 are failed state and 9 and 10 are halt state.

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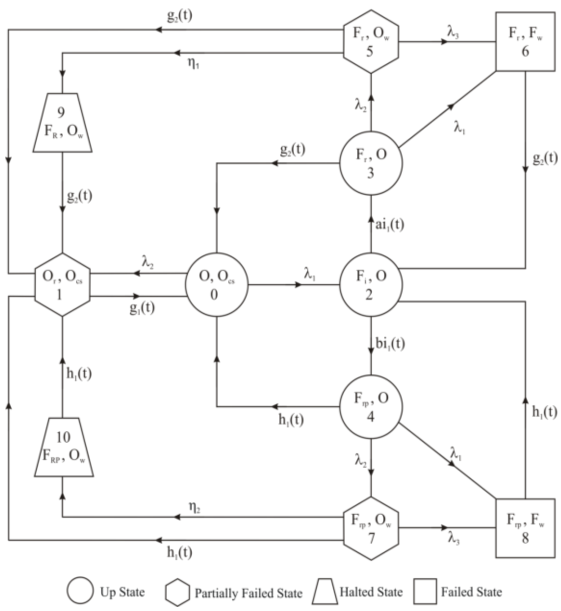
Figure:



State Transition Diagram

The transition probabilities are given by

$$dQ_{01}(t)=\lambda_2 e^{-(\lambda_1+\lambda_2)t}dt \quad dQ_{02}(t)=\lambda_1 e^{-(\lambda_1+\lambda_2)t}dt$$

$$dQ_{10}(t)=g_1(t)dt$$

$$dQ_{23}(t)=ai_1(t)dt$$

$$dQ_{24}(t)=bi_1(t)dt \quad dQ_{30}(t)=e^{-(\lambda_1+\lambda_2)t}g_2(t)dt$$

$$dQ_{31}^{5}(t)=\left(\lambda_2 e^{-(\lambda_1+\lambda_2)t}©1\right)g_2(t)dt \quad dQ_{32}^{6}(t)=\left(\lambda_1 e^{-(\lambda_1+\lambda_2)t}©1\right)g_2(t)dt$$

$$dQ_{35}(t)=\lambda_2 e^{-(\lambda_1+\lambda_2)t}\overline{G_2}(t)dt \quad dQ_{36}(t)=\lambda_1 e^{-(\lambda_1+\lambda_2)t}\overline{G_2}(t)dt$$

$$dQ_{40}(t)=e^{-(\lambda_1+\lambda_2)t}h_1(t)dt \quad dQ_{41}^{7}(t)=\left(\lambda_2 e^{-(\lambda_1+\lambda_2)t}©1\right)h_1(t)dt$$

$$dQ_{42}^{8}(t)=\left(\lambda_1 e^{-(\lambda_1+\lambda_2)t}©1\right)h_1(t)dt \quad dQ_{47}(t)=\lambda_2 e^{-(\lambda_1+\lambda_2)t}\overline{H_1}(t)dt$$

$$dQ_{48}(t)=\lambda_1 e^{-(\lambda_1+\lambda_2)t}\overline{H_1}(t)dt \quad dQ_{51}(t)=e^{-(\eta_1+\lambda_3)t}g_2(t)dt$$

$$dQ_{51}^{9}(t)=\eta_1\left(e^{-(\eta_1+\lambda_3)t}©1\right)g_2(t)dt \quad dQ_{52}^{6}(t)=\left(\lambda_3 e^{-(\eta_1+\lambda_3)t}©1\right)g_2(t)dt$$

$$dQ_{56}(t)=\lambda_3 e^{-(\eta_1+\lambda_3)t}\overline{G_2}(t)dt \quad dQ_{59}(t)=\eta_1 e^{-(\eta_1+\lambda_3)t}\overline{G_2}(t)dt$$

$$dQ_{62}(t)=g_2(t)dt \quad dQ_{71}(t)=e^{-(\eta_2+\lambda_3)t}h_1(t)dt$$

$$dQ_{71}^{10}(t)=\eta_2\left(e^{-(\eta_2+\lambda_3)t}©1\right)h_1(t)dt \quad dQ_{78}(t)=\lambda_3 e^{-(\eta_2+\lambda_3)t}\overline{H_1}(t)dt$$

$$dQ_{72}^{8}(t)=\left(\lambda_3 e^{-(\eta_2+\lambda_3)t}©1\right)h_1(t)dt \quad dQ_{7,10}(t)=\eta_2 e^{-(\eta_2+\lambda_3)t}\overline{H_1}(t)dt$$

$$dQ_{82}(t)=h_1(t)dt$$

$$dQ_{91}(t)=g_2(t)dt$$

$$dQ_{10,1}(t) = h_1(t)dt$$

Taking L.S.T $Q_{ij}^{**}(s)$ and $p_{ij} = \lim_{s\to 0} Q_{ij}^{**}(s)$, the non-zero elements $p_{ij,}$ are obtained as under:

$$p_{01} = \frac{\lambda_2}{\lambda_1+\lambda_2} \qquad p_{02} = \frac{\lambda_1}{\lambda_1+\lambda_2}$$

$$p_{10} = g_1^*(0) \qquad p_{23} = ai_1^*(0)$$

$$p_{24} = bi_1^*(0) \qquad p_{30} = g_2^*(\lambda_1+\lambda_2)$$

$$p_{31}^5 = \frac{\lambda_2\left[1-g_2^*(\lambda_1+\lambda_2)\right]}{\lambda_1+\lambda_2} = p_{35} \quad p_{32}^6 = \frac{\lambda_1\left[1-g_2^*(\lambda_1+\lambda_2)\right]}{\lambda_1+\lambda_2} = p_{36}$$

$$p_{40} = h_1^*(\lambda_1+\lambda_2) \quad p_{41}^7 = \frac{\lambda_2\left[1-h_1^*(\lambda_1+\lambda_2)\right]}{\lambda_1+\lambda_2} = p_{47}$$

$$p_{42}^8 = \frac{\lambda_1\left[1-h_1^*(\lambda_1+\lambda_2)\right]}{\lambda_1+\lambda_2} = p_{48} \quad p_{51} = g_2^*(\eta_1+\lambda_3)$$

$$p_{51}^9 = \frac{\eta_1\left[1-g_2^*(\eta_1+\lambda_3)\right]}{\eta_1+\lambda_3} \quad p_{52}^6 = \frac{\lambda_3\left[1-g_2^*(\eta_1+\lambda_3)\right]}{\eta_1+\lambda_3} = p_{56}$$

$$p_{59} = \frac{\eta_1\left[1-g_2^*(\eta_1+\lambda_3)\right]}{\eta_1+\lambda_3}$$

$$p_{62} = g_2^*(0)$$

$$p_{71} = h_1^*(\eta_2+\lambda_3)$$

$$p_{71}^{10} = \frac{\eta_2\left[1-h_1^*(\eta_2+\lambda_3)\right]}{\eta_2+\lambda_3}$$

$$p_{72}^8 = \frac{\lambda_3\left[1-h_1^*(\eta_2+\lambda_3)\right]}{\eta_2+\lambda_3} = p_{78} \quad p_{7,10} = \frac{\eta_2\left[1-h_1^*(\eta_2+\lambda_3)\right]}{\eta_2+\lambda_3}$$

$$p_{82} = h_1^*(0) \qquad p_{91} = g_2^*(0)$$

$$p_{10,1} = h_1^*(0)$$

By these transition probabilities, it can be verified that

$$p_{01} + p_{02} = 1 \qquad p_{23} + p_{24} = 1$$

$$p_{30} + p_{35} + p_{36} = 1 \qquad p_{30} + p_{32}^6 + p_{35} = 1$$

$$p_{40} + p_{47} + p_{48} = 1 \qquad p_{40} + p_{42}^8 + p_{47} = 1$$

$$p_{51} + p_{56} + p_{59} = 1 \qquad p_{51} + p_{51}^9 + p_{52}^6 = 1$$

$$p_{71} + p_{78} + p_{7,10} = 1 \qquad p_{71} + p_{71}^{10} + p_{72}^8 = 1$$

$$p_{10} = p_{62} = p_{82} = p_{91} = p_{10,1} = 1$$

The unconditional mean time taken by the system to transit for any regenerative state j, when it is counted from epoch of entrance into that state i, is mathematically stated as-

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

Thus-

$$m_{01} + m_{02} = \mu_0 \qquad m_{10} = \mu_1$$
$$m_{23} + m_{24} = \mu_2 \qquad m_{30} + m_{35} + m_{36} = \mu_3$$
$$m_{40} + m_{47} + m_{48} = \mu_4 \qquad m_{51} + m_{56} + m_{59} = \mu_5$$
$$m_{62} = \mu_6 \qquad m_{71} + m_{78} + m_{7,10} = \mu_7$$
$$m_{82} = \mu_8 \qquad m_{91} = \mu_9$$
$$m_{10,1} = \mu_{10} \qquad m_{30} + m_{32}^{6} + m_{35} = k_1$$
$$m_{40} + m_{42}^{8} + m_{47} = k_2 \qquad m_{51} + m_{51}^{9} + m_{52}^{6} = k_3$$
$$m_{71} + m_{71}^{10} + m_{72}^{8} = k_4$$

where

$$k_1 = -g_2^{*\prime}(0) = k_3 \qquad k_2 = -h_1^{*\prime}(0) = k_4$$

The mean sojourn time in the regenerative state i (μ_i) is defined as the time of stay in that state before transition to any other state then we have

$$\mu_0 = \frac{1}{\lambda_1 + \lambda_2} \qquad \mu_1 = -g_1^{*\prime}(0)$$
$$\mu_2 = -i_1^{*\prime}(0) \qquad \mu_3 = \frac{1 - g_2^{*}(\lambda_1 + \lambda_2)}{(\lambda_1 + \lambda_2)}$$
$$\mu_4 = \frac{1 - h_1^{*}(\lambda_1 + \lambda_2)}{(\lambda_1 + \lambda_2)} \qquad \mu_5 = \frac{1 - g_2^{*}(\lambda_3)}{\lambda_3}$$
$$\mu_6 = -g_2^{*\prime}(0) \qquad \mu_7 = \frac{1 - h_1^{*}(\lambda_3)}{\lambda_3}$$
$$\mu_8 = -h_1^{*\prime}(0) \qquad \mu_9 = -g_2^{*\prime}(0)$$
$$\mu_{10} = -h_1^{*\prime}(0)$$

MEASURES OF THE SYSTEM EFFECTIVENESS

Various measures of the system effectiveness obtained in steady state using the arguments of the theory of regenerative process are as under:

The Mean Time to System Failure (MTSF) = N/D
Expected Up-Time of the System with Full Capacity (AF_0) = N_1/D_1
Expected Up-Time of the System with Reduced Capacity (AR_0) = N_2/D_1

where

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$$N = \mu_0 + p_{01}\mu_1 + p_{02}\begin{bmatrix} \mu_2 + p_{23}\{\mu_3 + p_{35}(\mu_5 + p_{51}\mu_1)\} \\ +p_{24}\{\mu_4 + p_{47}(\mu_7 + p_{71}\mu_1)\} \end{bmatrix}$$

$$D = 1 - p_{01} - p_{02}\left[p_{23}(p_{30} + p_{35}p_{51}) + p_{24}(p_{40} + p_{47}p_{71})\right]$$

$$N_1 = \mu_0\left[1 - p_{23}\left(p_{32}^6 + p_{35}p_{52}^6\right) - p_{24}\left(p_{42}^8 + p_{47}p_{72}^8\right)\right] + p_{02}(\mu_2 + p_{23}\mu_3 + p_{24}\mu_4) + p_{02}\begin{bmatrix} \mu_2 + (p_{23}p_{35} + p_{24}p_{47})\mu_1 + p_{23}(k_1 + p_{35}k_3) \\ +p_{24}(k_2 + p_{47}k_4) \end{bmatrix} + p_{02}(p_{23}p_{35}\mu_5 + p_{24}p_{47}\mu_7)$$

$$D_1 = (\mu_0 + p_{01}\mu_1)\left[1 - p_{23}\left(p_{32}^6 + p_{35}p_{52}^6\right) - p_{24}\left(p_{42}^8 + p_{47}p_{72}^8\right)\right]$$

$$N_2 = p_{01}\mu_1\left[1 - p_{23}\left(p_{35} + p_{32}^6\right) - p_{24}\left(p_{47} + p_{42}^8\right)\right] + \mu_1\left[p_{23}\left(p_{35} - p_{52}^6\right) + p_{24}\left(p_{47} - p_{72}^8\right)\right]$$

GRAPHICAL INTERPRETATION AND CONCLUSION

For graphical analysis following particular cases are considered-

$g_1(t) = \beta_1 e^{-\beta_1 t}$ $\quad g_2(t) = \beta_2 e^{-\beta_2 t}$ $\quad i_1(t) = \alpha_1 e^{-\alpha_1 t}$ $\quad h_1(t) = \gamma_1 e^{-\gamma_1 t}$

Therefore, we have

$$p_{01} = \frac{\lambda_2}{\lambda_1 + \lambda_2} \qquad p_{02} = \frac{\lambda_1}{\lambda_1 + \lambda_2}$$

$$p_{10} = 1 \qquad p_{23} = a$$

$$p_{24} = b \qquad p_{30} = \frac{\beta_2}{\lambda_1 + \lambda_2 + \beta_2} \quad p_{31}^5 = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \beta_2} = p_{35} \quad p_{32}^6 = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \beta_2} = p_{36}$$

$$p_{40} = \frac{\gamma_1}{\lambda_1 + \lambda_2 + \gamma_1}$$

$$p_{41}^7 = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \gamma_1} = p_{47}$$

$$p_{42}^8 = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \gamma_1} = p_{48}$$

$$p_{51} = \frac{\beta_2}{\eta_1 + \lambda_3 + \beta_2}$$

$$p_{51}^9 = \frac{\eta_1}{\eta_1 + \lambda_3 + \beta_2} = p_{59}$$

$$p_{52}^6 = \frac{\lambda_3}{\eta_1 + \lambda_3 + \beta_2} = p_{56}$$

$$p_{62} = 1 \qquad p_{71} = \frac{\gamma_1}{\eta_2 + \lambda_3 + \gamma_1}$$

$$p_{71}^{10} = \frac{\eta_2}{\eta_2 + \lambda_3 + \gamma_1} = p_{7,10}$$

$$p_{72}^8 = \frac{\lambda_3}{\eta_2 + \lambda_3 + \gamma_1} = p_{78}$$

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$$\mu_0 = \frac{1}{\lambda_1 + \lambda_2} \qquad \mu_1 = \frac{1}{\beta_1}$$

$$\mu_2 = \frac{1}{\alpha_1} \qquad \mu_3 = \frac{1}{\lambda_1 + \lambda_2 + \beta_2}$$

$$\mu_4 = \frac{1}{\lambda_1 + \lambda_2 + \gamma_1} \qquad \mu_5 = \frac{1}{\eta_1 + \lambda_3 + \beta_2}$$

$$\mu_6 = \frac{1}{\beta_2} \qquad \mu_7 = \frac{1}{\eta_1 + \lambda_3 + \gamma_1}$$

$$\mu_8 = \frac{1}{\gamma_1} \qquad \mu_9 = \frac{1}{\beta_2}$$

$$\mu_{10} = \frac{1}{\gamma_1}$$

Various graphs are plotted for MTSF, Expected up time and Expected down time and Profit of the system by taking different values of failure rates (λ_1, λ_2 & λ_3), inspection rate (α_1), repair rates (β_1 & β_2), replacement rate (γ_1), halt rate (η_1 & η_2) and probabilities of repairable & non-repairable (a & b).

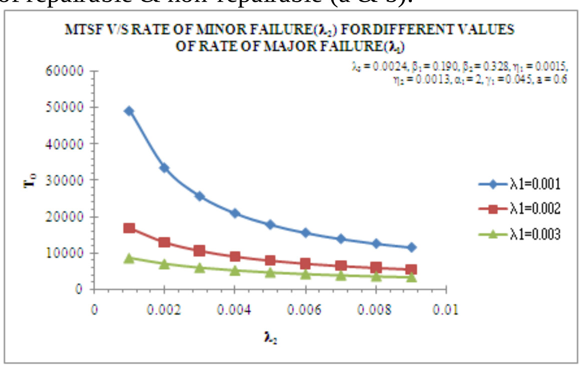

Fig. 2

Fig. 2 gives the graph between MTSF (T_0) and the rate of failure (λ_2) due to minor faults for different values of the rate of failure (λ_1) due to major faults. The graph reveals that the MTSF decreases with increase in the values of the failure rates.

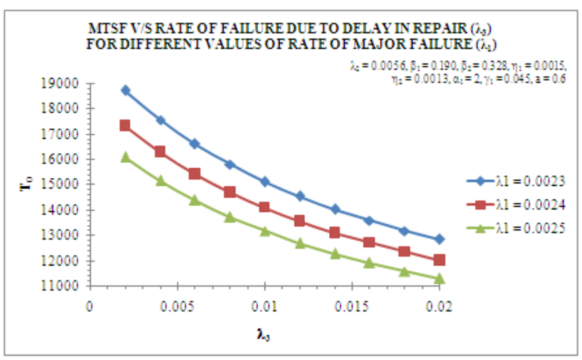

Fig. 3

The curves in Fig. 3 give the graph between MTSF (T_0) and rate of failure due to delay in repair (λ_3) for different values of rate of major failure (λ_1) of the system. The graph reveals that the MTSF decreases with increase in the values of the failure rates.

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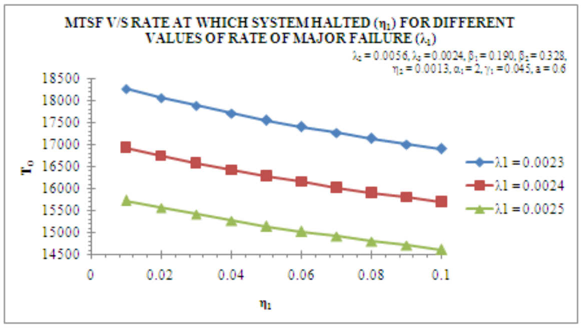

Fig. 4

The curves in Fig. 4 give the graph between MTSF (T_0) and rate at which system halted (η_1) for different values of rate of major failure (λ_1) of the system. The graph reveals that the MTSF decreases with increase in the values of the rate at which system halted as well as the failure rate.

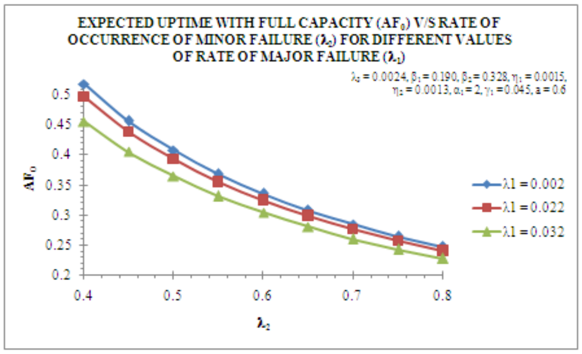

Fig. 5

Fig. 5 gives the graph between Expected uptime with full capacity (AF_0) and the rate of occurrence of minor faults (λ_2) for different values of rate of occurrence of major faults (λ_1). The graph reveals that the Expected uptime with full capacity decreases with increase in the values of the failure rates.

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