

TOTAL TIME ON TEST PLOT ANALYSIS FOR MECHANICAL COMPONENTS OF THE RSG-GAS REACTOR

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ABSTRACT

TOTAL TIME ON TEST PLOT ANALYSIS FOR MECHANICAL COMPONENTS OF THE RSG-GAS REACTOR. Total time on test plot analysis for primary and secondary pumps of the RSG-GAS reactor is reported. This method is for analyzing time between failure of the primary and secondary pumps at the RSG-GAS reactor to see whether the failure data of the component is in the IFR or DFR state. The primary and secondary pumps are the mechanical components in the RSG-GAS reactor cooling system which are used for routine operation. The method uses a total time on test plots for a nonhomogeneous Poisson process failure model based on Barlow and Bernard report. It is reported that the median failure rate of the RSG-GAS primary pumps and secondary pumps lies in the international data range. The calculation results show that the failure rate of the RSG-GAS reactor primary pumps and secondary pumps component has a distribution of fairly exponential characteristics, this means that the operation of primary and secondary pumps of the RSG-GAS reactor component is still within its useful life.

INTRODUCTION

The component failure rate data or λ collection reports are often intended to give Mean Time Between Failure (MTBF) estimates. The A value could be defined as the reciprocal value of the mean time between failure, a parameter that is obtained as the arithmetic mean of the lifetimes of the component observed. The failure function is commonly a function of t , $\lambda(t)$; practical experience shows that the function $\lambda(t)$ qualitatively behaves like a bath-tub curve. The component or system is usually chosen to operate within the region of constant failure rate.

The failure rate of any component type (Hauptmanns and Horpke)[1]

is determined by equation $\lambda = \frac{n}{mT}$ where n is the number of failure

occurring, m is the number of statistically identical components observed, and T is the period of observation (calendar time) or operation time in hrs.

The MTBF estimate is only generally valid if times between failures are exponentially distributed random variables. Since this is often not the case, especially for mechanical components like pumps, a graphical plot is more informative technique. To focus on the kind of problem to be solved, the failure data using total time on test plot will be first analyzed.

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The primary and secondary pumps of the RSG-GAS reactor are the selected components for analysis; and the data are taken from the operation log-book of the RSG-GAS reactor during 10 years of reactor operation since 1987.

The purpose of the analysis is to find the failure rate of the primary and secondary pumps at the RSG-GAS reactor in the median value, with λ 5% (5% percentile) and λ 95% (95% percentile) values using Blamni[3] code and to see whether the failure data of the component is in the IFR(increasing failure rate) or DFR(decreasing failure rate) state. The failure rate calculation is done using Blamni code based on the Log-Normal distribution approximation using Bayes estimation. The Blamni code is a Fortran language computer code based on the time interval observation and the number of failure during observation.

THEORETICAL BACKGROUND

The reliability $R(t)$ of a device is defined as the probability that it performs an assigned function under specified condition for a given period of time. The cumulative probability density function, $F(t)$, is the complement of $R(t)$. The reliability is the probability that the device will perform without failure for some time, T . This is equivalent to the time to failure exceeding T and is evaluated by integrating the probability density function from point t to infinity

$$R(t) = Pr(T > t) = \int_t^{\infty} f(u) du \quad (1)$$

The unreliability $F(t)$ is the CDF (cumulative probability density function) of the device for time less than t , is

$$F(t) = 1 - R(t) = Pr(T \leq t) = \int_0^t f(u) du \quad (2)$$

The probability density function $f(t)$ is defined as

$$f(t) = \frac{dF(t)}{dt} = -\frac{dR(t)}{dt} \quad (3)$$

The density function for the exponential distribution is : $f(t) = \lambda e^{-\lambda t}$ Therefore the reliability function is

$$R(t) = \int_t^{\infty} \lambda e^{-\lambda u} du = e^{-\lambda t}, \quad (4)$$

and the unreliability function is :

$$F(t) = 1 - e^{-\lambda t} \quad (5)$$

The next reliability measure to be discussed is the concept of failure rate $h(t)$. Where $h(t)dt$ is a conditional probability, the failure rate is defined as

$$h(t)dt = \Pr(\text{failure between } t \text{ and } t+dt | \text{survived to } t) = \frac{f(t)dt}{R(t)}. \quad (6)$$

If the dt in equation (6) is removed and if λ is constant, the failure rate is the density function divided by the reliability function

$$h(t) = \frac{\lambda e^{-\lambda t}}{e^{-\lambda t}} = \lambda \quad (7)$$

The failure function of a component is commonly a function of t , $A(t)$; practical experience shows that the function $\lambda(t)$ qualitatively behaves like a bath-tub curve. It is characterized by a relatively high early failure rate (the burn-in period) followed by a fairly constant, prime of life period where failures occur randomly, and then a final wearout or burn-out phase. Probability or life distribution of the component in the early state follows a Weibull distribution with $0 < \beta < 1$ and the life distribution of the component in the wearout state also follows a Weibull distribution with ($\beta > 1$). Ideally, the component or system in use behaves to have constant failure rate.

Four probability or life distributions can be used to assess failure rates. They are Exponential, Weibull, Normal and Log-Normal distributions. The other methods for testing the suitability with respect to the available data are nonparametric failure rate estimation, total-time-on-test plots, probability plotting, and goodness-of-fit tests.

The total-time-on-test plot is a graphical plot of the data as a tool for model identification [7]. The quantity $H(t)$ is called the total-time-on-test plot transform, where $0 < t < 1$ and F^{-1} is the inverse function of F , is defined by

$$h(t) = \int_0^{F^{-1}(t)} R(u) du \quad (8)$$

A scale transform is commonly used, where the CDF is divided by the time

to failure, resulting in

$$H^\infty(t) = \frac{1}{\theta} \int_0^{(t)} R(u) du \quad (9)$$

For the exponential case, where, $0 < t < 1$, the scaled time-on-test transform becomes

$$H(t) = t \quad (10)$$

Consider an example using observed failure times, t_1, t_2, \dots, t_n . These times are not chronological, but indicate the times from start-up to failure of the device; they have been sorted in increasing order. The number of survivors to time t is denoted by $N(t)$, where $N(t_1) = n$, $N(t_2) = n-1$ since one of them fails by time t_1 , and so on. An estimate of the reliability of the survival probability beyond time t , the number of survivors divided by the original number of devices, i.e.

$$R(t) = \frac{N(t)}{n} \quad (11)$$

To estimate the probability of surviving time t_i , the following expression is used for the inverse function

$$F(t_i) \cong \frac{i}{n} \Rightarrow F^{-1}\left(\frac{i}{n}\right) = t_i \quad (12)$$

This is approximately equal to i/n , since i of the devices have survived until time n . When both of the above expressions are substituted into the definitions of the total-time-on-test transform, the result is

$$H_{\frac{i}{n}}^{\infty} \cong \frac{\int_0^{ti} N(t)dt}{\int_0^m N(t)dt} \quad (13)$$

For convenience of calculation to evaluate the total time on test, the r

expression of equation $\int_0^{ti} N(t)dt$ can be written as

$$\int_0^{ti} N(t)dt = nt_1 + (n-1)(t_2 - t_1) + \dots + (n-i+1)(t_i - t_1) \quad (14)$$

The graphic representation of total-time-on-test is formed by plotting i/n on the horizontal axis and $H(i/n)$ on the vertical axis.

In general, the plot of the scaled time-on-test transform is within a unit square. The departure of the plot from the diagonal indicates the behavior of the failure rate. If the graph of H is concave, an IFR is indicated; if H is convex, a DFR is indicated; and if H is linear, an exponential failure is indicated. The analysis result for a component, whose characteristics of the plot indicates an exponential distribution or a constant failure rate, winds around the diagonal.

DATA ANALYSIS

There are three primary and three secondary pumps installed in RSG-GAS reactor[8], i.e. JEOI-APOI, JEOI-AP02 and JEOI-AP03 (primary pumps) and PAOI-APO1, PA02-AP02 and PA03-AP03 (secondary pumps). They are identical in type and duty. The primary pump is of centrifugal type, single stage and using mechanical seals. The design parameters of the primary pumps are : throughput per pump 1570 m³/hrs, motor power rating 160 kW and the total discharge head 27 meter. The design parameters of the secondary pumps are : throughput per pump 1950 m³/hrs, motor power rating 220 kW and the total discharge head 29 meter.

The observation of the primary pumps is taken from 24 March 1987 to 17 December 1996, then the total calendar time was 85272 hrs. The time interval

failure data during observation are

- a. Time interval failure data for JEOI-APO1 pump : $T = 2767$ hrs, 114 hrs, 2319 hrs, 9026 hrs, 3 hrs and 258 hrs respectively. The operation time was 16457 hrs.
- b. Time interval failure data for JEO1-AP02 pump : $T = 2805$ hrs, 8 hrs, 1132 hrs and 10136 hrs respectively. The operation time was 22058 hrs.
- c. Time interval failure data for JEO1-AP03 pump : $T = 54$ hrs, 595 hrs, 18 hrs and 9 hrs respectively. The operation time was 9885 hrs.

Time interval failure data for three pumps are : $T = 2767$ hrs, 114 hrs, 2319 hrs, 9026 hrs, 3 hrs, 258 hrs, 2805 hrs, 8 hrs, 1132 hrs, 10136 hrs, 54 hrs, 595 hrs, 18 hrs and 9 hrs respectively. The total operation time was 48400 hrs.

The observation of the secondary pumps is taken from 20 June 1987 to 16 September 1997 , then the total calendar time was 89784 hrs. The time interval failure data during observation are

- a. Time interval failure data for PAOI-APO I pump : $T = 2160$ hrs, 746 hrs, 402 hrs, 954 hrs, 491 hrs, 6560 hrs and 4992 hrs respectively. The operation time was 22289 hrs.
- b. Time interval failure data for PA02-AP02 pump : $T = 3474$ hrs, 150 hrs, 358 hrs, 101 hrs, 1359 hrs, 3465 hrs, 1060 hrs, 614 hrs, 1921 hrs, 4082 hrs and 199 hrs respectively. The operation time was 17446 hrs.
- c. Time interval failure data for PA03-AP03 pump : $T = 605$ hrs, 273 hrs, 70 hrs, 62 hrs and 5320 hrs respectively. The operation time was 11655 hrs.

Time interval failure data for three pumps are : $T = 2160$ hrs, 746 hrs, 402 hrs, 954 hrs, 491 hrs, 6560 hrs, 4992 hrs, 3474 hrs, 150 hrs, 358 hrs, 101 hrs, 1359 hrs, 3465 hrs, 1060 hrs, 614 hrs, 1921 hrs, 4082 hrs, 199 hrs, 605 hrs, 273 hrs, 70 hrs, 62 hrs and 5320 hrs respectively. The total operation time was 51391 hrs.

It will be assumed that the successive failure events of pumps can be described probabilistically by a non-homogeneous Poisson process. If $N(t)$ is the number of pump failures in $[0,t]$, then

$$P[N(t) = k] = \frac{[\Lambda(t)]^k}{k!} e^{-\Lambda(t)} \quad (15)$$

for $k = 0, 1, 2, 3, \dots$ where $\Lambda(t)$ is the mean number of pump failures in $[0, t]$. Since $\Lambda(t)$ is not known, it must be estimated from the data. The approach is to use an appropriate total time on test plot to make preliminary model identification. The superposition of n independent non-homogeneous Poisson processes each with mean function, $\Lambda(t)$, will again be a non-homogeneous Poisson process with mean function, $n\Lambda(t)$. Now let each process run for the same time interval $[0, T]$. Let

$$Z_{(1)} < Z_{(2)} < \dots < Z_{(N(T))} \quad (16)$$

be the ordered superposed event times on a common age axis, where $N(T)$ is the total number of events in $[0, T]$.

The scaled total time on test plot for the non-homogeneous Poisson process model is a plot of

$$\frac{\int_0^{Z_{(i)}} n(u) du}{\int_0^{Z_{(N(T))}} n(u) du} \text{ versus } \frac{i}{N(T)} \quad (17)$$

All data for the three pumps is analyzed. Table I and Table 2 are the examples to show the calculation results. Table I is the failure rate calculation results using Blamni[3] code based on the Log-Normal distribution approximation using operation and calendar observation time. Based on the time interval observation and the number of failure during observation data the value of failure rate could be calculated. Table 2 gives the matrix that was set up to aid in plotting results for primary pumps.

Data from Table 2 can be plotted as a graph of $1/n$ versus $\bar{H}(i/n)$ to show the total time on test plot for each data. Figure 1 and Figure 2 are the examples to show the total time on test plot using data in Table 2.

CONCLUSIONS

The value of the failure rate calculation results for the RSG-GAS reactor primary and secondary pumps (Table 1) shows that it is in the same order with the international failure data[5,6]. The λ median for the three pumps is still in the upper bound and lower bound values of their results. The result for the observation time based on the operation time is one order higher than the calculation based on the calendar time.

The total time on test plot analysis calculations shows that the RSG-GAS reactor primary and secondary pumps component is indicated in IFR although the calculation results exhibit a distribution with fairly exponential characteristics. Figure 2 is more realistic than Figure 1, this means that due to the ageing time the calculation is more realistic using calendar time than using operation time. This also means that increasing failure rate is indicated while the operation of the component is still in useful life. But due to the limited available data or limited time of observations the data analysis is still far from sufficient. It is recommended that routine maintenance and inspection be taken in order to reduce the characteristics of IFR. Nevertheless, method and application of the total time on test plot analysis for analyzing time between failures for any mechanical component of the RSG-GAS reactor seem to be feasible.

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Table 1. Failure rate data calculation results using Blamni code based on the Log-Normal distribution approximation

Calculation based on the operation time period in hr				
Primary pump Secondary pum	λ_{median} ($10^{-4}/hr$)	$\lambda_{5\%}$ ($10^{-4}/hr$)	$\lambda_{95\%}$ ($10^{-4}/hr$)	EF
	2,93	1,95	4,4	1,5
	4,51	3,26	6,23	1,4
Calculation based on the calendar tume in hr				
Primary pump Secondary pum	λ_{median} ($10^{-5}/hr$)	λ_{median} ($10^{-5}/hr$)	λ_{median} ($10^{-5}/hr$)	EF
	5,54	3,69	8,32	1,5
	8,6	5,99	1,19	1,4

Table 2. Data applied to total time on test plot for the three primary pumps based on operation time and calendar time.

Based on operation time (T=48400hrs)			Based on operation time (T=255816hrs)		
i/N	Z(i)	$\infty H(i/n)$	i/N	Z(i)	$\infty H(i/n)$
0,07	3	0,001	0,07	336	0,03
0,14	8	0,004	0,14	496	0,04
0,21	9	0,004	0,21	604	0,05
0,29	18	0,007	0,29	870	0,06
0,36	54	0,02	0,36	1561	0,1
0,43	114	0,04	0,43	7262	0,4
0,50	258	0,08	0,50	7322	0,41
0,57	595	0,16	0,57	8706	0,46
0,64	1132	0,27	0,64	10466	0,53
0,71	2319	0,47	0,71	13986	0,63
0,79	2767	0,53	0,79	19006	0,75
0,86	2805	0,54	0,86	19034	0,75
0,93	9026	0,96	0,93	39771	0,99
1	10136	1	1	41705	1

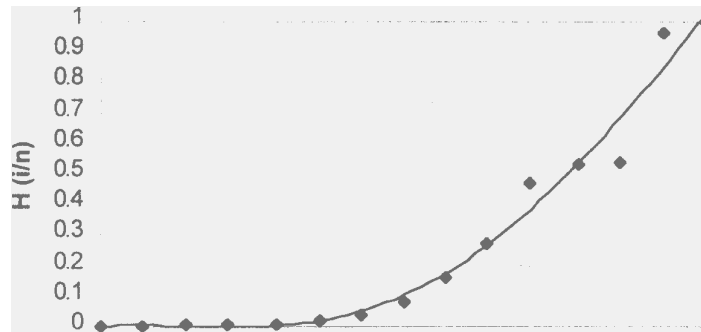


Figure 1. Total time test plot for three pumps based on operation time (data is taken from table 2)

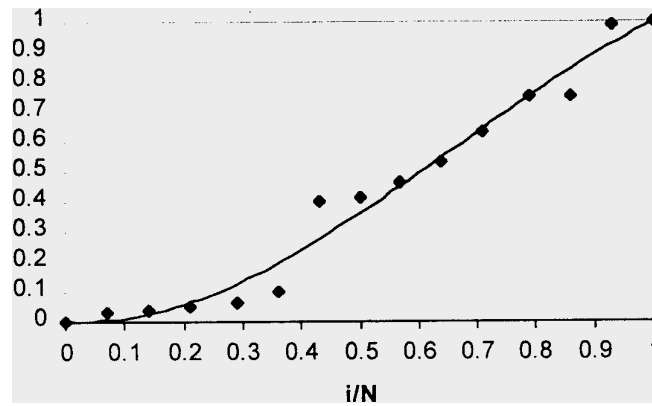


Figure 2 . Total time test plot for three pumps based on calendar time (data is taken from table 2)