Management Systems in Production Engineering

2014, No 3 (15), pp 140-144

DOI 10.12914/MSPE-09-03-2014

RELIABILITY MODELING BASED ON INCOMPLETE DATA: OIL PUMP APPLICATION

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Abstract:
The reliability analysis for industrial maintenance is now increasingly demanded by the industrialists in the world. Indeed, the modern manufacturing facilities are equipped by data acquisition and monitoring system, these systems generates a large volume of data. These data can be used to infer future decisions affecting the health facilities. These data can be used to infer future decisions affecting the state of the exploited equipment. However, in most practical cases the data used in reliability modelling are incomplete or not reliable. In this context, to analyze the reliability of an oil pump, this work proposes to examine and treat the incomplete, incorrect or aberrant data to the reliability modeling of an oil pump. The objective of this paper is to propose a suitable methodology for replacing the incomplete data using a regression method.

Key words: *reliability estimation, reliability algorithms, lifetime distribution, Weibull distribution, availability, oil pump, data gathering, incomplete data*

INTRODUCTION

The reliability in industrial system is given from the analysis of its components, throughout the lifecycle of the system. The reliability models, which have been developed in the literature in several applications [1-6]. These models can be divided into two main groups: functional models, which describe the system from a definite time. The second, in a point of view on dynamic models, which describe the behavior of operating time of a time independent system functional models. Both models in the practical reality in industrials process, using a variety of data, either correct data or uncertain or incomplete data. That to describe the system behavior, in order to provided the decision making in the planning of maintenance actions [7-11]. This work proposes the study of the reliability methods, used in reliability calculations based on incomplete data at each stage of system development, is part of an overall methodology involves two major phases: the predicted reliability and operational reliability. The principle study in this work is to consider a system is made up of basic components, and its reliability depends on both the reliability of its components and how the functioning or failure of each component affects the functioning or failure of the entire system. This work proposes to examine and treat the incomplete, incorrect or aberrant data to the reliability modeling of an oil pump subject of our study.

RELIABILITY MODELING IN INDUSTRIAL SYSTEMS

The reliability models are used to calculate the probability of failure in particular structure in global system composites, but not for the calculation of synchronization properties of the system although it is undoubtedly of value, its usefulness in systems analysis real-time must be questioned, because these systems require a functionally correct behavior not only but also the correct temporal behavior [12]. In contrast, time-dependent models are much less well developed in several applications [13-16]. This work was conducted in order to find algorithms to calculate the average execution time of a set of processes in the presence of distrust, there has been little work undertaken to determine the probability distribution of the time system execution using incomplete data. For this, this study is based on the use of the Weibull. It is a law of reliability with three parameters that can take into account periods when the failure rate is not constant (youth and age) as well as λ (t) the period of life which is constant.

This law allows [18-19]:

- an estimate of the MTBF,
- calculations λ (t) and R (t) and their graphical representations,
- with the shape parameter β guide diagnosis.

The mathematical expression is given by the probability density:

$$f(t) = \frac{\beta}{\eta} \cdot \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \cdot e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \qquad with\ t \geq 0 \qquad (1)$$

And the distribution function:

$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \qquad (2)$$

And the reliability is given by:

$$R(t) = 1 - F(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \qquad (3)$$

For the failure rate:

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{f(t)}{1-F(t)} = \frac{\beta}{\eta}\cdot\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}\cdot e^{\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \cdot \frac{1}{e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}} \Rightarrow \lambda(t) = \frac{\beta}{\eta}\cdot\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \quad (4)$$

Finley the MTBF and the standard deviation are given by [20]:

$$E(t) = MTBF = \int_0^{\infty} t.f(t).d(t) = \lim_{x\to\infty}\int_0^{x} t.f(t).d(t) \quad (5)$$

$$E(t) = MTBF = \lim_{x\to\infty}\int_0^{x} t.\frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}.e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}.dt \quad (6)$$

$$E(t) = MTBF = \gamma + \eta.\Gamma\left(1+\frac{1}{\beta}\right) = A\eta + \gamma \quad (7)$$

Where Γ is a complex mathematical function, A and B are parameters from tables and are calculated from the reliability law. The parameters of the Weibull distribution are the, shown in the figure 1:

β → Setting form > 0 dimensionless,

If β > 1, the failure rate is increasing, characteristic of the old area

1.5 < β < 2.5 tiredness,

3 < β < 4: wear, corrosion,

If β = 1, the failure rate is constant, characteristic of the maturity zone,

If β < 1, the failure rate is decreasing characteristic of the area youth.

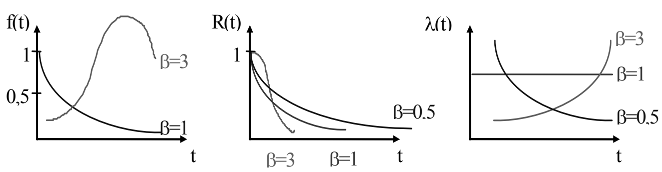

Fig. 1 Distribution function f (t), the reliability R (t) and l (t) failure rate all over time and changes in β

Note: γ = 0 and β = 1, we obtain the exponential distribution, a particular case of Weibull given by the equation (8).

$$\lambda = \frac{1}{\eta} = \frac{1}{MTBF} \quad (8)$$

To calculate the life associated with a reliability threshold, it is interesting to know how far the reliability reaches a predetermined threshold.

$$R(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \Rightarrow \ln R(t) = -\left(\frac{t-\gamma}{\eta}\right)^{\beta} \Rightarrow \ln\frac{1}{R(t)} = \left(\frac{t-\gamma}{\eta}\right)^{\beta} \quad (9)$$

$$\Rightarrow \frac{t-\gamma}{\eta} = \left(\ln\frac{1}{R(t)}\right)^{\frac{1}{\beta}} \Rightarrow t = \eta\cdot\left(\ln\frac{1}{R(t)}\right)^{\frac{1}{\beta}} + \gamma \quad (10)$$

Weibull paper

This paper serves to read graphically Weibull parameters of a Weibull distribution in the case where the parameter is null. Indeed the distribution function associated with a Weibull parameters β = 0, is defined by [21]:

$$F(t) = 1 - e^{\left(\frac{t}{\eta}\right)^{\beta}} \Leftrightarrow \ln(1-F(t)) = -\left(\frac{t}{\eta}\right)^{\beta} \quad (11)$$

$$\Leftrightarrow -\ln(1-F(t)) = \left(\frac{t}{\eta}\right)^{\beta}$$

$$\Leftrightarrow \ln(-\ln(1-F(t))) = \beta\ln\frac{t}{\eta}$$

$$\Leftrightarrow \ln(-\ln(1-F(t))) = \beta\ln t - \beta\ln\eta$$

$$\Leftrightarrow Y = \beta X - \beta\ln\eta$$

The last equation is obtained the equation of a line in the red mark (O, X, Y) where 0 is the point corresponding to X = 0 and Y = 0 or t = 1 and F (t) = 1 - 1 / e. The parameter is read directly at the intersection of the previous straight line with the x-axis as it is measured in logarithmic scale. The parameter β is the Director of the previous right coefficient, simply draw a line parallel to the previous one through the point X = 0 and Y = 0 and read directly the director of this coefficient on the right axis of equation X = - 1

Graphic determination of the parameters of Weibull law

Preparation of data: determining the pairs (ti, fi) by means rows or rows median:

- calculation of TBF,
- ranking TBF ascending,
- N = number of TBF,
- search data F (i) represents the probability of failure at the time corresponding to the failed th TBF.

If N > 50, TBF by grouping classes with cumulative frequency [22-23]:

$$F(i) = \frac{i}{N} = \frac{\sum R_i}{N} \approx F(t) \quad (12)$$

If 20 <N ≤ 50, a row "i" is assigned to each failure (approximation of the average rankings):

$$F(i) = \frac{i}{N+1} \approx F(t) \quad (13)$$

If N ≤ 20, a row "i" is assigned to each failure (median rank approximation):

$$F(i) = \frac{i = 0.3}{N+0.4} \approx F(t) \quad (14)$$

Maintainability based on reliability

Calculating the maintainability is based on the equation (15), the maintainability can be characterized by its MTTR Average time Technical Repair.

With the repair rate is given by:

$$MTTR = \frac{\sum Temps\ d'interventionpour\ pannes}{Nombre\ de\ pannes} \quad (15)$$

$$\mu = \frac{1}{MTTR} \quad (16)$$

Also, the availability is usually measured by the probability that an entity E is able to perform a required function under given conditions at a given time function. The ability is otherwise referred to as "unavailable"; its measure is rated A (t):

$$A(t) = 1 - A(t) \quad (17)$$

The ability of a device to function when it is seeking is characterized by the MUT and MDT, increase the availability of equipment is to reduce the number of these cases and to reduce the time necessary to resolve the causes of these:

$$D = \frac{MTBF}{MTBF + MTTR} \quad (18)$$

For an element has good availability, it must:

– have the least possible downtime,
– being quickly repaired if it breaks down.

The failure rate λ(t) of the system is approximately equal to the sum of individual failure rate:

$$\lambda(t) = \sum_{i=1}^{n} \lambda_i(t) \quad (19)$$

The failure rate λ(t) give the probability that an entity loses its ability to perform a function for the interval [t, t + dt], knowing that she was not failing in [0, t].

INDUSTRIAL APPLICATION: CENTRIFUGAL PUMP

For the considered system in this work, the historical failures of the pump was raised with care and properly maintained should never fails during operation. The table 1 below shows the history and type of pump failure, according to the failure history, the latter can be grouped into four groups:

– group A: Failures of wear of bearings and bearings,
– group B: Failure of seals,
– group C: extrinsic defects and group D: electrical faults.

Table 1
History of pump failures

	Failure type A		Failure type B		Failure type C		Failure type D	
Ordre N°	TBF(h)	TTR(h)	TBF(h)	TTR(h)	TBF(h)	TTR(h)	TBF(h)	TTR(h)
1	620	1410	230	62	1200	48	9710	528
2	1220	450	3256	922				
3	1525	1102						
4	2471	551						
5	3193	481						
6	4410	1162						
7	5594	684						

The summary data table is given by the table 2.

Table 2
Summary of data

Failure type	Number of failure
A	7
B	2
C	1
D	1

N is the number of failures by classes, average consecutive interventions to these classes.

The figure 2 is an indicator of the availability n.t estimates the loss of availability due to each class. It also indicates the costs of failure, assuming C = Knt therefore allows selecting the order of support failure modes according to their criticality by classes A and B.

The study the reliability of fragile items by Weibull, we used the the summary of uptime between bearing failures due to wear is the following table 3.

So we have N = 7, which is the sample size as N <20, in this case to calculate the frequencies F (i), we use the approximation formula of median ranks: F(i) = (i-0.3) / (0.4 N), which is very close to the cumulative distribution function F(t).

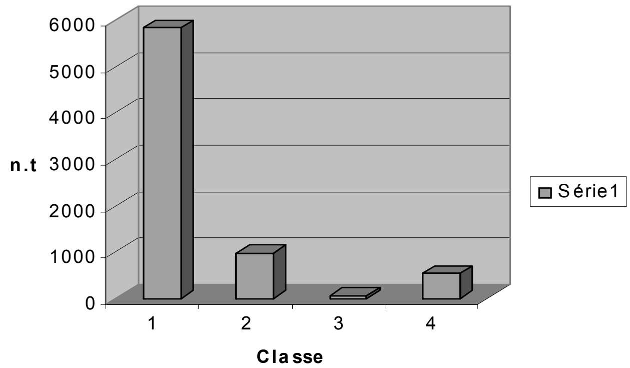

Fig. 2 Histogram availability

Table 3
Summary (TBF)

N° (i)	TBF [h]
1	620
2	1220
3	1525
4	2471
5	3193
6	4410
7	5594

In our case N = 7, one must seek the expression of F (t), the application of Weibull model for the distribution of failures.

From the table 4 we determine the parameters of the law by the paper Weibull, shown in the figure 3.

Table 4
Graphic adjustment

Ordre i	TBF [hours]	F (i)	F (t) approximated by %
1	620	0,094	9,4
2	1220	0,229	22,9
3	1525	0,364	36,4
4	2471	0,5	50
5	3193	0,635	63,5
6	4410	0,77	77
7	5594	0,905	90,5

The calculation result of the probability density function f (t), the distribution function F (t), reliability R (t) the instantaneous failure rate λ (t) are given in the Table 5 and shown in the figures 4 and 5.

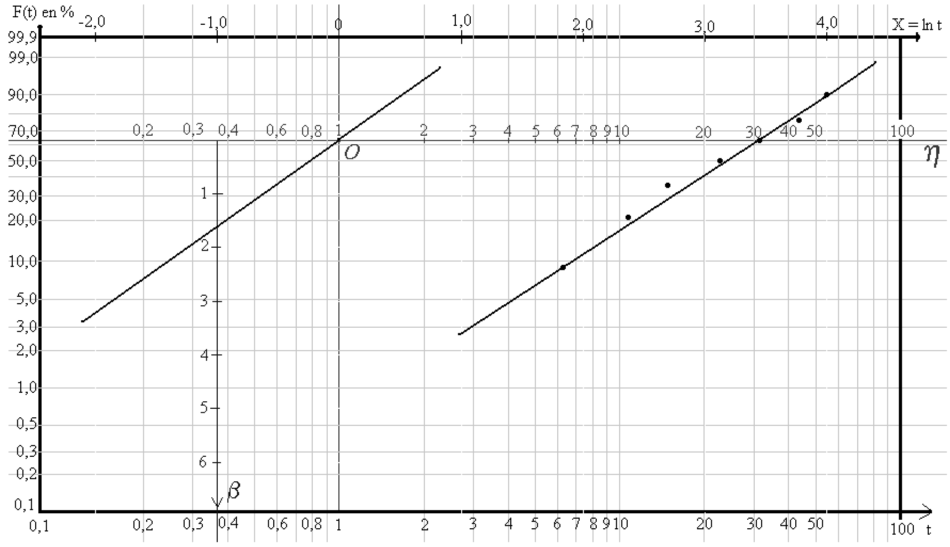

Fig. 3 Weibull paper of the examined pump

Table 5
Calculation result

Ordre i	TBF	F (i)	F (t)	f (t)	R (t)	λ (t)
1	620	0,094	0,07331924	0,0001821	0,92668076	0,00019651
2	1220	0,229	0,20140705	0,00023555	0,79859295	0,00029496
3	1525	0,364	0,27487071	0,00024452	0,72512929	0,00033721
4	2471	0,5	0,50127133	0,00022466	0,49872867	0,00045047
5	3193	0,635	0,64951252	0,00018413	0,35048748	0,00052535
6	4410	0,77	0,82754382	0,00010997	0,17245618	0,00063767
7	5594	0,905	0,92357496	5.621.10-5	0,07642504	0,00073549

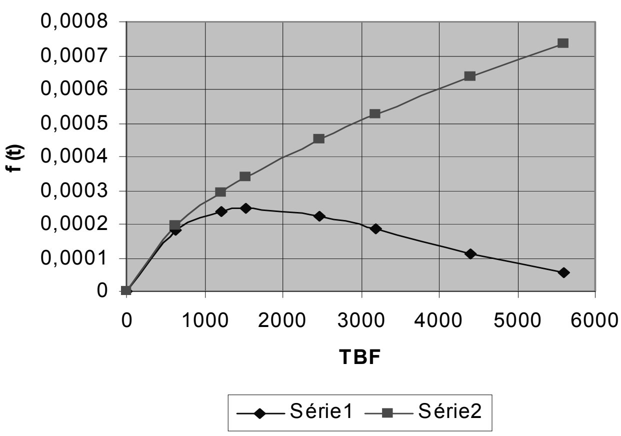

Fig. 4 Distribution function and the failure rate-TBF

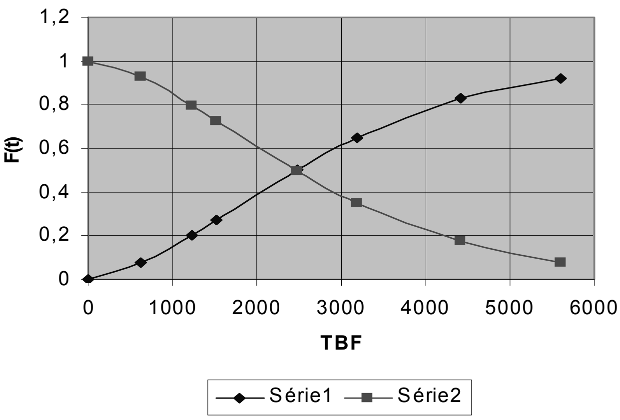

Fig. 5 Reliability and distribution function-TBF

CONCLUSION

Given the foregoing it can be argued that considers the following essential and crucial to improve the reliability and quality of centrifugal pumps:

– make failure analysis by providing the means to better know the costs and causes of failures in order to increase the profitability of pumping stations,
– use the recommendations of disassembly and reassembly or an expert to follow a methodology for selecting centrifugal pumps system,
– make a collaboration between maintenance and production on pump problems to resolve operating problems. definition of the model solution can become mathematically impossible for outside small systems.

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