BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXVIII No. 1/2016	47 – 52	Seria Tehnică

The Reliability Analysis of Shafts Testing under Rotating Bending Stress Using the Accelerated Fatigue Testing

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Abstract

This paper presents a simulation of the Monte Carlo of accelerated fatigue testing for mechanical components of shaft type. Simulation of cycles to failure using Monte Carlo method will be achieved by increasing a type of stress, namely: rotating bending stress. The main indicators of reliability determined and plotted in this paper are: B10 life, mean life, reliability function, function non reliability, failure rate, probability density function and warranty time. The result of this fatigue accelerated testing is estimated reliability of statistical and mathematical means using specific programs. By using these accelerated tests was obtained a significant reduction of the test time and material costs associated with these types of tests.

Key words: *reliability, mean life, shaft, fatigue accelerated testing, Monte Carlo simulation*

Introduction

The shafts are machine elements which rotate about their axes of geometrical and have the main function to transmit the moment of torsion through other bodies which are supporting or assembled (roller, gears, connecting rods, couplers), and then the to transmit mechanical power. Accordingly a shaft is used for the transmission of torque and bending moment. Parts of a shaft are: the shaft body (a); the blocking portions (b) - on which there are mounted the various components; bearing portions (c) - which support shaft in camps.

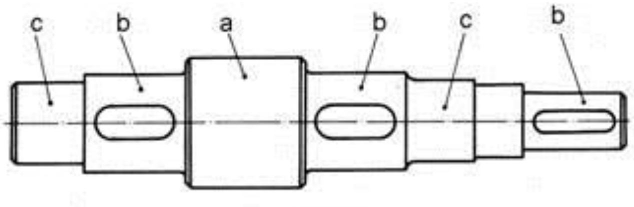


Fig. 1. Shaft components [1]

To obtain a quantitative measure of resistance to fatigue it is necessary to carry out tests under controlled conditions and for this purpose a wide variety of fatigue testing machines is available. Many different methods of fatigue testing can be adapted, from laboratory tests on smooth specimens under the simplest stress conditions, to tests on full-scale components and structures under conditions simulating those occurring in practice. Tests on laboratory specimens are used primarily for determining the influence on fatigue resistance of such factors as alloy content, heat-treatment or surface finish, because the results can be obtained quickly and economically [2].

These modifying factors that affect fatigue resistance of materials and S-N curves are eight: surface finish; shape and distribution of inclusions; grain size and direction; specimen or component size; load type; surface treatments; temperature; environment (corrosion). The surface finish of a part may affect its fatigue life by introducing stress concentration resulting from surface roughness. The dimension of the test piece may also affect fatigue strength of materials. With the exclusion of surface finish as initiation event, fatigue failure depends on metallurgical factors, being originated either by a slip band mechanism or by inclusions or second-phase particles somewhere in some surface grain. Thermal treatments may influence fatigue strength of metals. At variance with the thermo-mechanical ones that create favorable residual stress states, thermal treatments are applied with the purpose to produce metallurgical transformations capable to transform, even completely, the mechanical characteristics of the alloy [2].

If a mechanical product requires, for example, 10^7-10^8 cycles to cause a failure from fatigue in normal use condition, by using an accelerated life test we can obtain the same result in 10^5 cycles. The design of the accelerated life test and the interpretation of data require the understanding of the relation, in the course of the destructive process considered, between the level of stress and the failure rate [3].

A common way of tackling these problems is to expose the products to sufficient overstress to bring the mean time to failure down to an acceptable level. Thereafter, one tries to "extrapolate" from the information obtained under over stress to normal use conditions. This approach is called Accelerated Life Testing (ALT) or overstress testing. In these tests, reliability practitioners may force the product to fail more quickly than it would under normal use conditions [4].

The primary scope of an ALT is to estimate the life distribution and quantities of interest at a use condition. This estimation involves extrapolation from higher stress levels by using an acceleration model, and thus includes the model error and statistical uncertainty. Sometimes, the model error outweighs the statistical one. The model error may be reduced or eliminated only by better understanding the failure mechanisms and using a more accurate model, whereas the statistical uncertainty can be reduced by carefully selecting a good test plan. A typical test plan is characterized by the stress levels, the number of test units allocated to each level, and their censoring times [5].

Accelerated experiments is used in electronics (resistors, lasers, liquid crystal displays, electronic bounds, switches, relays, cells and batteries) in the study of metals and composite materials, but also for certain components and mechanical assemblies (hydraulic components, tools, bearings). The degree of interdisciplinary of research in the field of accelerated experiments is complex and can include the following industries: manufacturing engineering, the aerospace industry, the nuclear industry, the electronic industry, the dental industry, the pharmaceutical industry and the industry of renewable energy resources. The most significant acceleration models is: Arrhenius, Eyring, Inverse Power Law; Life - Thermal Cycling, Life - Voltage, Life - Vibration, Life - Humidity, Life - Temperature – Humidity [6].

In the case study of this paper, we applied a cyclical mechanical stress and temperature. During the cyclical stress the most frequently used are the metallic components and systems and the phenomenon is fatigue. The degradation by fatigue involves a variety of aspects regarding to: the type of stress; the shape of the part; the quality of the part that will be processed; the environment of the part's operation.

Monte Carlo Simulation

In Monte Carlo simulation, random failure cycles from each element's failure distribution are generated. These failure cycles are then combined in accordance with the way the elements are arranged reliability-wise within the system. The overall results are analyzed in order to determine the behaviour of the entire system. It is assumed that the reliability values for the elements have been determined using standard (or accelerated) life data analysis techniques, so that the reliability function for each component is known [7]. ALTA software use Monte Carlo simulation for generating cycles to failure that can be analyzed directly in a standard folio. Monte Carlo utility provides randomly generated data sets based on a specified model, distribution and parameters [8]. Using the Monte Carlo method it is simulated N stages of a product with the help of an acceleration model (Inverse Power Law) and statistical distribution (Weibull) which are suited to the analyzed case study. The number of specimens subjected to accelerated fatigue tests: we used 15 shafts and 3 levels of testing: 75 Hz, 100 Hz and 125 Hz. Using the parameters (β=10.142; k= 0.0000000003; n= 2.0018) and the three accelerated levels, it is simulated with the help of ALTA7 software the values for the number of cycles to failure in accelerated conditions (fig. 2).

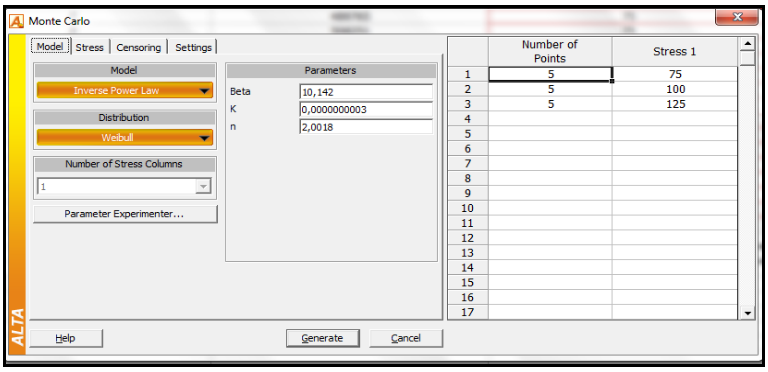


Fig. 2. Monte Carlo simulation

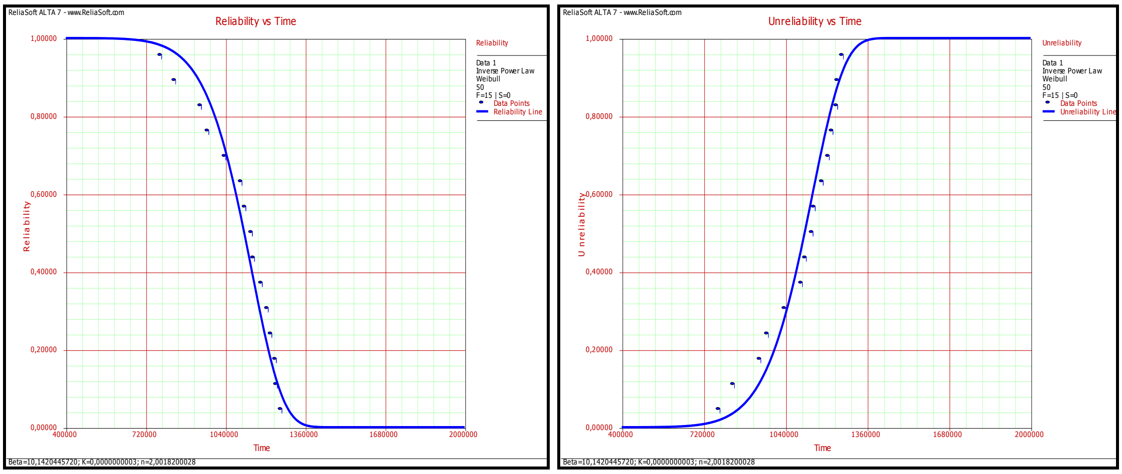
The number of cycles to failure in normal testing conditions for the shafts under rotating bending test [9] is described in table 1.

Table 1. The number of cycles to failure in accelerated conditions

Nr.crt	The number of cycles to failure in accelerated testing conditions	Rotating bending [Hz]
1.	430675	75
2.	489765	75
3.	508251	75
4.	542992	75
5.	550997	75
6.	208965	100
7.	234798	100
8.	287890	100
9.	295772	100
10.	301686	100
11.	124679	125
12.	165783	125
13.	178645	125
14.	198763	125
15.	201783	125

The Statistical Analysis of Accelerated Life Data

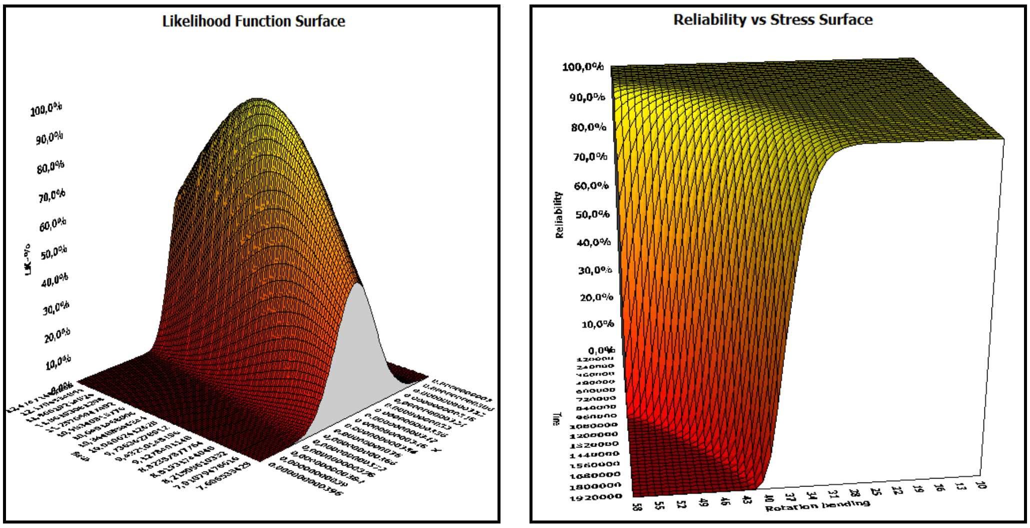
The characteristics of reliability (reliability indicators) mean a measure by which reliability is expressed quantitatively or one of its characteristics. In reliability is a large number of indicators, however, none of these indicators cannot completely reliable measure, but only estimates one of its characteristics. Reliability indicators following in the accelerated reliability testing of shafts are: B10 life, mean life, reliability function, the unreliability function, failure rate, probability density function, warranty time. Reliability function (fig. 3.a) is a indicator of the shafts, expressed by the probability that the shaft will perform its required function under given conditions for a stated time interval. Cumulative density function (cdf) or unreliability function (fig. 3.b) is the probability of failure, or the probability that our time-to-failure is in the region of 0 and t.



a) reliability function b) cumulative density function

Fig. 3. Reliability indicators of shafts

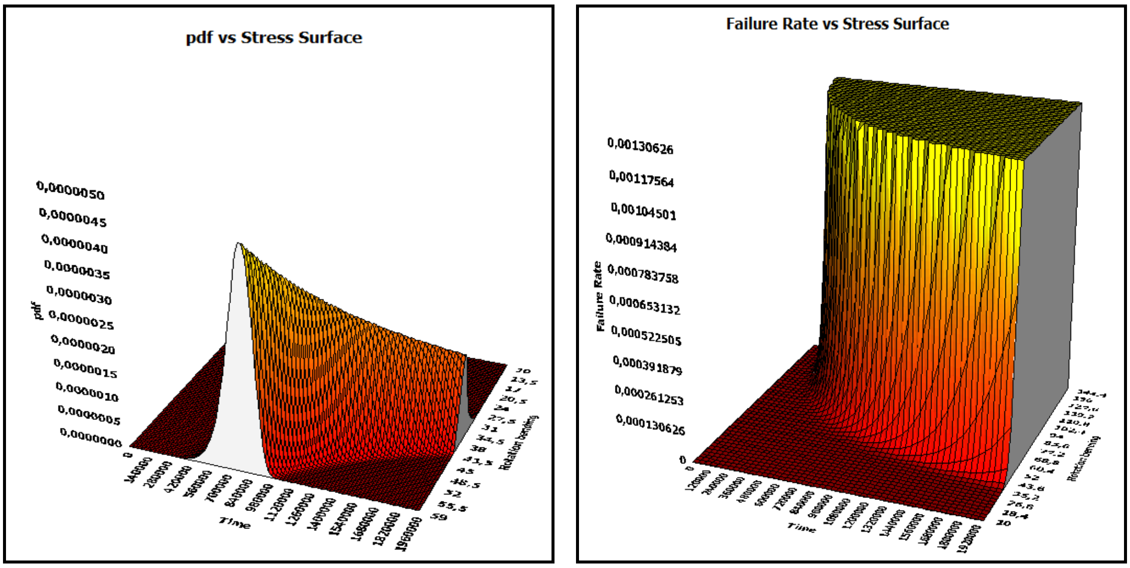
ALTA software contains a feature that allows the generation of a three-dimensional representation of the likelihood function (fig. 4.a). This best represents two-parameter distributions, with the values of the parameters on the x and y axes and the log-likelihood value on the z axis. Using the calculated values (the number of cycles in normal testing conditions), the reliability function 3D (fig. 4.b) were plotted.



a) likelihood function b) reliability function

Fig. 4. Three-dimensional plots of reliability indicators

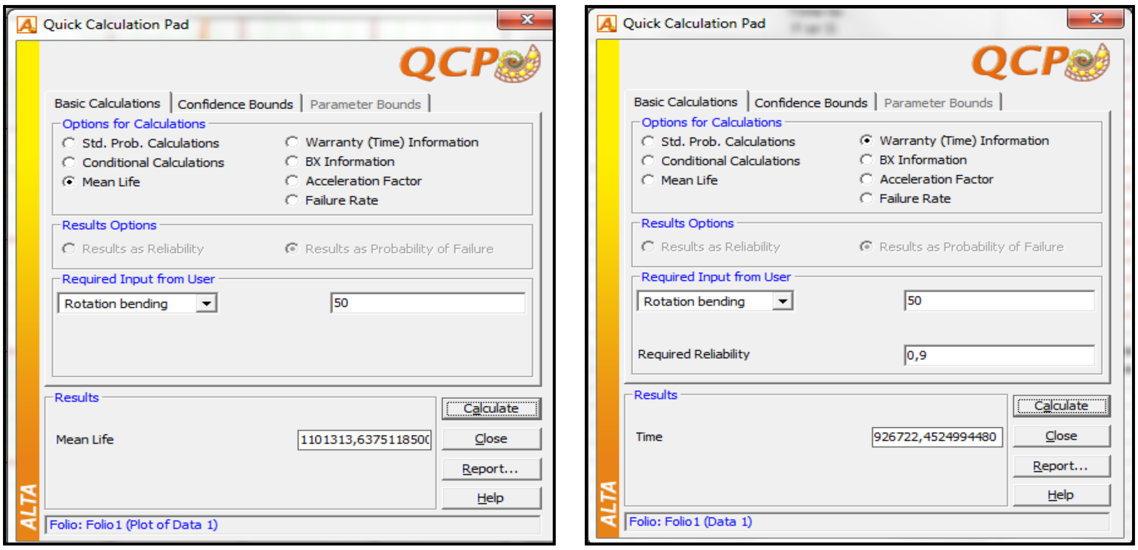
Probability density function (pdf) represents the ratio of the number of shaft failures in an interval to the total number of products gives an estimate corresponding to the interval (fig. 5.a). Failure rate represents the number of failures per unit time that can be expected to occur for the shaft (fig. 5.b).



a) probability density function b) failure rate

Fig. 5. Three-dimensional plots of reliability indicators

The main purpose of accelerated tests is to determine the life time in normal testing conditions. Using the data resulted from accelerated life tests we can determine the mean number of cycles to failure of shafts in normal testing conditions. The mean number of cycles to failure for the tested shafts was of 1101313 (fig. 6.a). A more accurate way of determining the warranty time would be to use Quick Calculation Pad (QCP). Reliable life or warranty time represents the estimated time when the reliability will be equal to a specified goal. By selecting the Warranty Time Information option and entering 50 Hz for the rotation bending and 90 for the required reliability, a warranty time of 926711 cycles can be determined, as shown next in Figure 6.b.



a) mean life b) warranty information

Fig. 6. Reliability indicators

Conclusions

The growing global competition determined the manufacturers to develop products having multiple characteristics and high reliability, at reduced costs, as fast as possible. At some mechanical products for which a high reliability is estimated, the determination of the life time and of the reliability parameters, under normal stress conditions, implies a long testing period. The challenges raised by these requests motivate the manufacturers to develop and to use efficient reliability methods that include the accelerated tests. For the case study under analysis, Figure 10 shows the mean number of cycles to failure in the normal testing conditions, from the simulation with the Monte Carlo method. We may notice that, by using the accelerated life tests, the testing time has been reduced by 3.5 times. The main objective of the accelerated testing on the shafts to reduce the number of cycles using the accelerated test was validated.

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Analiza fiabilităţii arborilor testaţi la solicitare de încovoiere la rotaţie utilizând testele accelerate la oboseală

Rezumat

În această lucrare se prezintă o simulare prin metoda Monte Carlo a încercărilor accelerate de fiabilitate pentru componentele mecanice de tip arbori. Simularea ciclurilor de defectare utilizând metoda Monte Carlo se va realiza prin intensificarea unui tip de solicitare şi anume: solicitarea de încovoiere cu rotaţie. Principalii indicatori de fiabilitate determinaţi şi reprezentaţi grafic în cadrul acestei lucrări sunt: B10, media timpului de funcţionare, funcţia de fiabilitate, funcţia de non-fiabilitate, rata de defectare, densitatea de probabilitate, timpul de garanţie. Rezultatul acestor încercări accelerate de fiabilitate este fiabilitatea estimată cu mijloace statistico-matematice utilizând programe specifice. Prin utilizarea acestor încercări accelerate s-a obţinut o reducere semnificativă a timpului de testare şi a costurilor materiale aferente acestor tipuri de teste.