LIFETIME ESTIMATION FROM ACCELERATED RELIABILITY TESTING USING FINITE ELEMENTS ANALYSIS

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Abstract: *The paper is focused at the study of the reliability and of the lifetime of ball bearings, using reliability accelerated testing. The main objectives of this paper are: the estimation of the lifetime and reliability of ball bearings. Taking into account the aspects regarding the statistical processing of experimental data, we determined the main reliability parameters, which in turn determine the main characteristics regarding the performance and the warranty period of the ball bearings. In this paper, the analysis with finite elements was used to validate and to compare the data resulted from the accelerated reliability tests of the ball bearings.*

Keywords: reliability, ball bearings, mean life, accelerated reliability testing.

1. INTRODUCTION

Ball bearings are used primarily to support rotating shafts in mechanical equipment. They can be found in everything from personal computers to passenger cars. They are of simple design and can be precision made in mass production quantities [1]. They can support heavy loads over a wide speed range and do it virtually friction free. They come in many different sizes and shapes, are relatively inexpensive, and require little or no maintenance. The essential components of a ball bearing are defined as follows (figure 1): 1. the inner ring; 2. the outer ring; 3. the balls; 4. the cage.

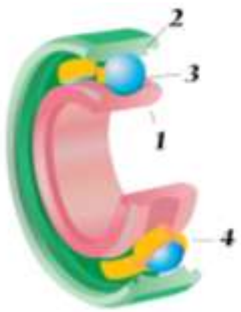


Fig. 1. Ball bearing

The rolling element bearing is subject to forces from gears, pulleys, or other components. These forces simultaneously act on the bearing from many different directions. The direction in which force is exerted on the bearing helps identify the type of load on the bearing: radial loads are exerted on the bearing on a plane perpendicular (90°) to the shaft. Axial loads, or thrust loads, are exerted on the bearing on a plane parallel to the centre of the shaft. Combination loads exert both a radial and axial load on the bearing. Bearing life refers to the amount of time any bearing will perform in a specified operation before failure. Bearing life is commonly defined in terms of L-10 life, which is sometimes referred to as B10.

A reliability test is represented by an experiment performed to determine the parameters of reliability for a well-defined product. The main reliability parameters during reliability tests is mean time to failure, knowing that, based on the existing relations between reliability parameters, they can be easily deduced from one in other. Many of the products produced today for complex technical systems have very high reliability under normal use conditions.

Reliability accelerated tests (ART) are statistically based sampling tests performed to approximate the long term reliability of a product before products are mass produced in manufacturing. These tests also provide acceleration factors that are used to estimate the mean time to failure, life expectancies of a product under test. There are different types of accelerated experiments plans in use, which include subjective, traditional, best traditional, and statistically optimum and compromise plans. Accelerated reliability models relate the failure rate or the life of a product to a given stress such that measurements taken during accelerated testing can then be extrapolated back to the expected performance under normal operating conditions. The implicit working assumption here is that the stress will not change the shape of the failure distribution. The most significant acceleration models are: Arrhenius, Eyring, Inverse Power Law; Life - Thermal Cycling, Life - Vibration, Life – Humidity [2,3].

2. EXPERIMENTAL SECTION

The design of the ART 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 [4]. The result of ART is the reliability estimated by statistical and mathematical means, using specific software. Thus, for the design of the ART plans and for the processing of statistical data obtained from the quantitative accelerated life test in this paper we used the ALTA 7 software.

2.1. Ball bearing tested

In the table 1 is described the geometric and constructive aspects of the radial ball bearings type 6307, used for the accelerated reliability testing. The radial ball bearings type 6307 is described in figure 2.

Tab. 1. The characteristics of the ball bearings type 6307

Type	Deep groove Ball Bearings
Material	Chrome steel Gcr15
Inner Diameter	35 mm
Outer Diameter	80 mm

Width	21 mm
Mass	0.457 kg
Dynamic load rating	33.4 kN
Static load rating	19.3 kN
Limiting Speed	10000 RPM

Fig. 2. The radial ball bearings type 6307

2.2. Experimental equipment

Nowadays, we observe a general tendency in the testing activity of the ball bearings, by using testing benches of very high complexity, which allow the realization of the tests in particular conditions and on several ball bearings simultaneously. Such a stand was used for the case study from this paper, where we tested simultaneously, in accelerated regime 4 radial ball bearings, type 6307.

2.3. Experiments results

Using the testing stand of the ball bearings, we realized accelerated reliability tests with the purpose of reducing the testing duration and the material costs associated with these tests. The results obtained at the accelerated reliability testing (table 2) of the ball bearings for the 2 accelerated stress regimes are: for the first accelerated stress regime 800 daN; for the maximum accelerated stress level 1160 daN.

Tab. 2. Number of cycles until failure - force

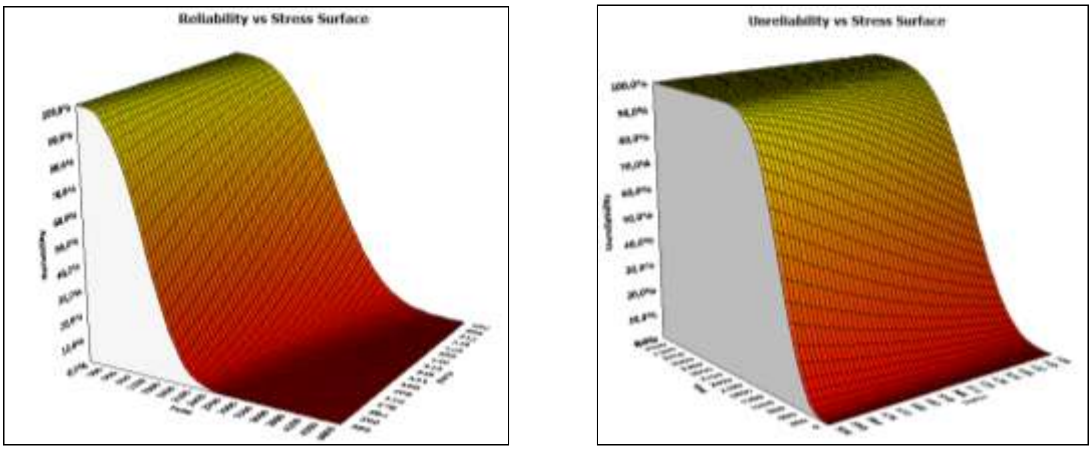
Nr.	Number of cycles until failure [hrs]	Force [daN]
1	289	800
2	380	800
3	476	800
4	590	800
5	723	800
6	845	800
7	59	1160

8	98	1160
9	172	1160
10	232	1160
11	248	1160
12	260	1160

2.4. Statistical data analysis

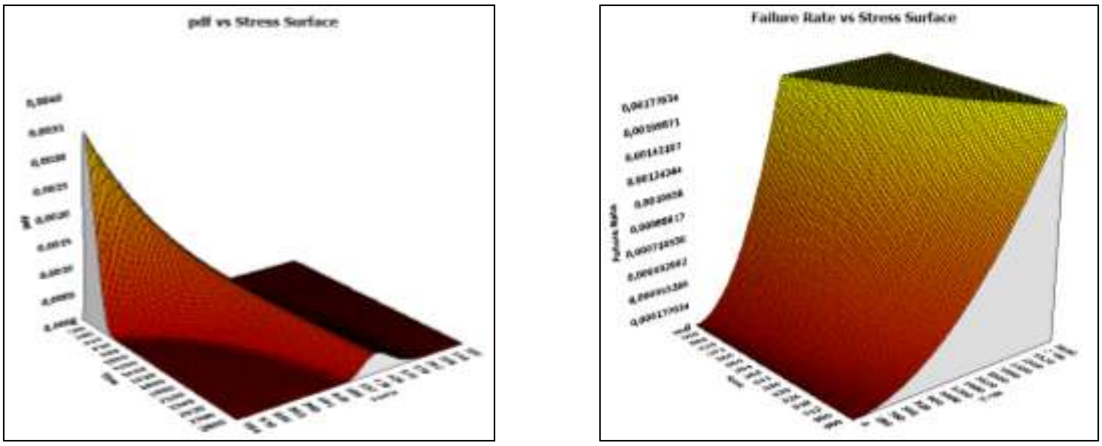
The main reliability indicators followed during the accelerated reliability tests of the ball bearings are: B10, the mean life, the reliability function, the unreliability function, the failure rate, the probability density function [5].

The reliability function represents an essential quantitative measure of reliability and has an important practical utility in the study of accelerated reliability tests. The unreliability function shows out the lack of reliability of the ball bearings. The reliability and the unreliability depending on the number of hours until failure and on the stress level in normal testing regime (500 daN). The values of the reliability function and of the unreliability function are plotted in figure 3 a,b. A plot of the probability density function (pdf) at a given stress level (figure 4.a). A plot of the failure rate over time at a given stress level. This can display the instantaneous failure rate at a given stress level in a two-dimensional plot or the failure rate vs. time vs. stress in a three-dimensional plot (figure 4.b).



a) reliability function *b) unreliability function*

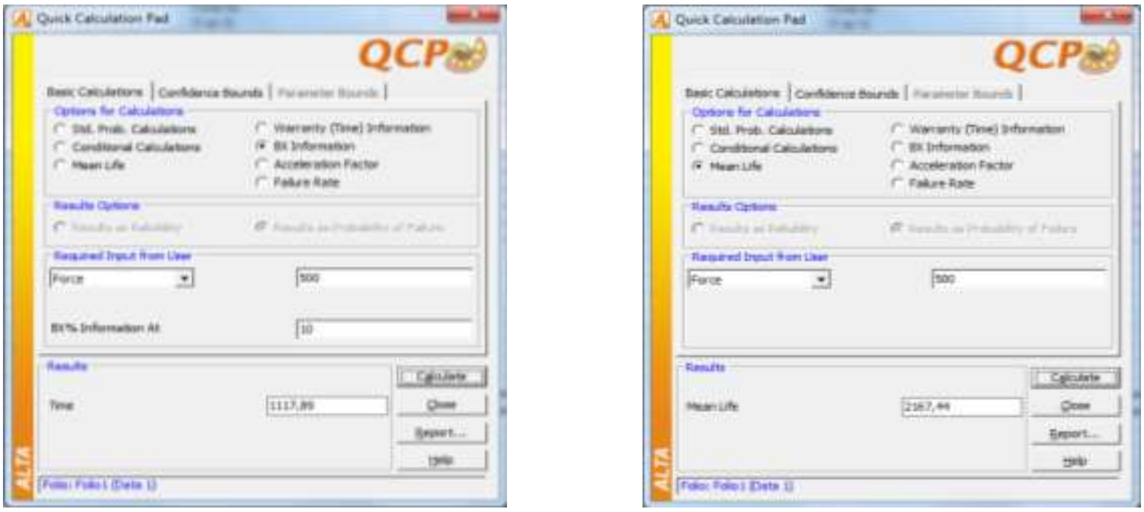
Fig. 3. Reliability indicators for the radial ball bearings type 6307



a) probability density function *b) failure rate*

Fig. 4. Reliability indicators for the radial ball bearings type 6307

The term BX is derived from the terminology used by bearing manufacturers, specifically the B10 life. B10 life refers to the time by which 10% of the bearings would fail (figure 5.a). Mean Life returns the mean life at the 50% confidence level (figure 5.b).

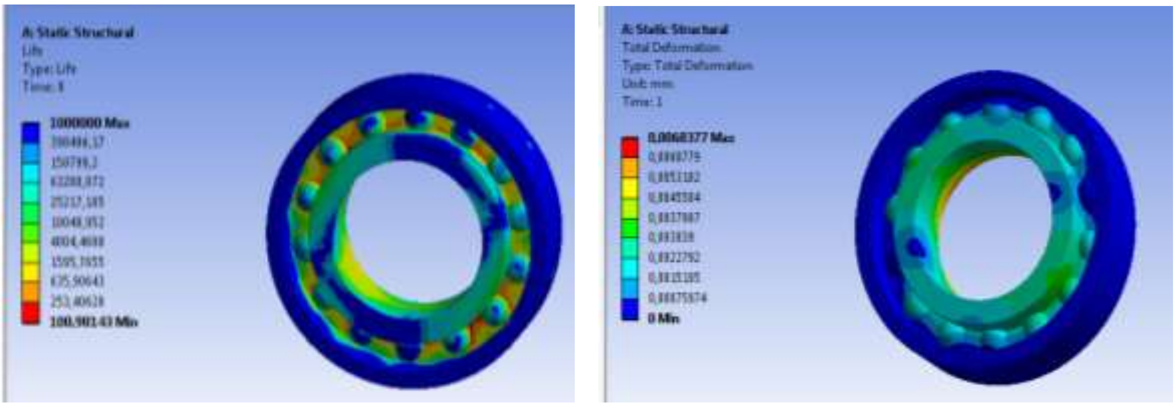


a) B10 parameters *b) mean life*

Fig. 5. Reliability indicators for the radial ball bearings type 6307

3. FINITE-ELEMENT METHOD SIMULATIONS

FEA (Finite Element Analysis) consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A large part of a fatigue analysis [6] is getting an accurate description of the fatigue material properties. Since fatigue is so empirical, sample fatigue curves are included only for structural steel and aluminium materials. These properties are included as a guide only with intent for the user to provide his/her own fatigue data for more accurate analysis. The focus of fatigue in ANSYS [7] is to provide useful information to the design engineer when fatigue failure may be a concern. Fatigue results can have a convergence attached. A stress-life (figure 6.a) approach has been adopted for conducting a fatigue analysis. Several options such as accounting for mean stress and loading conditions are available. In figure 6.b, the total deformations of the ball bearings are described.

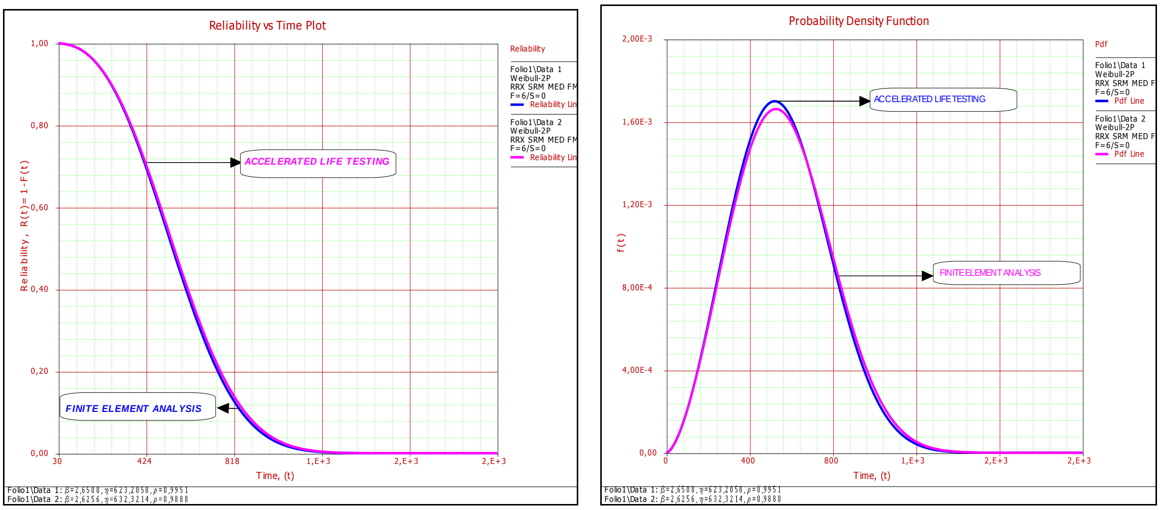


a) Stress Life *b) Total deformation*

Fig. 6. Finite Element Analysis of the radial ball bearings type 6307

4. RELIABILITY VALIDATION TEST

The equivalence between the experimental accelerated tests and the ones analyzed with finite elements implies carrying out a basic principle: the conservation of distribution laws of the failure times: the distribution functions of the different failures must remain the same, with the condition of increasing the speed of occurrence of failures.



a) reliability *b) probability density function*

Fig. 7. Accelerated reliability testing vs. finite element analysis of ball bearings type 6307

In this paper, the accelerated reliability tests will be validated by modelling the distribution laws (Weibull) of the failure times and of the parameters specific to this distribution. When the modelling refers to the distribution law of the failure times, such as the Weibull law, it is necessary to exist an approximate value for the form parameter β in the case of functioning in accelerated regime experimental, as well as in the case of analysis with finite elements of with the accelerated stresses. For the case study- the accelerated reliability testing of ball bearings in the case the experimental accelerated tests, the form parameter $\beta = 2.65$, and in the case of the simulation with finite elements the form parameter $\beta = 2.62$. The data from the accelerated regime and the simulated data with finite elements are introduced into the Weibull 7 programme and the main reliability parameters are determined and plotted (the reliability function - figure 7.a, the probability density- figure 7.b).

5. CONCLUSION

A basic goal of the ART technology is to describe what and how one can rapidly obtain objective and accurate initial information for accurate prediction of quality, reliability, maintainability, availability, and other measurements during the product's design and manufacturing. The main desirable results of ART are reduction of time and cost for product development and the ability to rapidly find causes for product degradation and failures. At some industrial products (from the aviation, nuclear and electronic fields), 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. For this reason we opted for the accelerated life testing methods and finite element simulations in this paper.

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