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HABILITATION THESIS

SUMMARY

RESEARCHES ON THE RELIABILITY OF THE INDUSTRIAL PRODUCTS

Field: Industrial Engineering

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BRAŞOV, 2017

The habilitation thesis, entitled *Researches on the Reliability of the Industrial Products* represents a synthesis of the scientific, professional and academic activity in the field of Industrial Engineering of the author, which started after fulfilling the PhD thesis, named *Optimization of the Bearing Reliability Tests*, on 19th March 1999, at the University Transylvania from Brasov, thesis elaborated under the coordination and supervision of prof.univ.dr.ing. Ion POPESCU.

The main scientific achievements of the author are the subject of the section titled *Scientific and Professional Achievements* and represent the most consistent part of the Habilitation Thesis. This section begins with an introduction in which contains a brief review of the emergence, development and evolution of the research area called Reliability. Thus, there are highlighted the stages through which this concept has evolved from treating laws of degradation and deterioration of physical elements and systems, to security / ensuring their operational safety and until the modern approach where reliability is equals quality over time.

The first chapter, entitled *Researches on the estimation of parameters and reliability indicators*, is organized in five subchapters.

The first subchapter contains a description of the main tools of reliability engineering. These are the functions used to model different aspects of the reliability. Also, in this subchapter are briefly presented some elements of the estimation theory, as well as the main estimation methods. This subchapter ends with the classification and presentation of the usual reliability tests used to collect experimental data for product reliability analysis.

The second subchapter, entitled *Researches on the estimation of parameters and reliability indicators in Weibull distribution*, points out several contributions of the author in this research direction:

- Comparative studies on how to estimate the localization parameter of the three parameters Weibull distribution. In this study, it is proposed a method of estimating the localization parameter from the maximum value condition of the correlation coefficient. The validation of the method is done by considering two examples, on one hand one from the literature and on the other hand, the punctual estimation of the parameters by the proposed method, in comparison with the established methods, customized for the three parameters distribution.
- *Optimized design of test plans*. The mathematical model of the optimization problem consists of an objective function representing the total cost of the reliability test as well as a system of restrictions consisting of: the maximum number of products that can be mounted simultaneously on the test machine and which are operating throughout under identical conditions, the type of test performed, the precision of the shape parameter estimation, and precision of the scale parameter estimation. The proposed optimization method is, in fact, a problem of non-linear optimization, using integers, of the parameters r and n , which are defining the failure terminated tests of the products.
- *Statistical inferences for experimental results obtained from time terminated tests*. Unlike the failure terminated tests or complete tests, in which were developed techniques for obtaining inferences and verifying the statistical hypothesis starting from the punctual estimates of the Weibull distribution parameters and using the maximum likelihood method, in the case of time terminated tests, these procedures cannot be applied due to the specificity of this type of test. Determining the confidence intervals for the Weibull distribution parameters as well as testing the statistical assumptions regarding the distribution parameters can be done by taking into account that the duration t_c of the test can be considered to be included between the duration of censored tests at r and $r + 1$ failures and by using two random variables independent of the distribution parameters. It is also proposed an algorithm that allows these random variables values to be determined using Monte-Carlo numerical simulation.
- *Bayesian parametric estimation methods*. These methods are a way to increase the precision of estimates based on the idea that before a product reliability test is performed, there is some

information about its reliability, which, if not neglected, would contribute to its more accurate characterization. The research starts from a two-dimensional model, proposed in the 1970s, which allows simultaneous estimation of the two distribution parameters. The contribution of the author consists of a method of fully specifying the previous distributions used in the construction of this model based on objective information obtained from the reliability tests, combined with the results of the Monte - Carlo numerical simulation. The properties of the BLIE estimators applied to the Weibull distribution are used.

During the third subchapter, 1.3 *Research on the estimation of parameters and reliability indicators for the exponential distribution*, is illustrated how bootstrap estimators are used, as well as their accuracy for different types of exponentially distributed samples. This estimation technique, developed in recent years and based on the intensive use of computers, is addressed in particular to solving situations in which the point estimator calculus is difficult and in which ordinary statistical theory cannot be applied to obtain mathematical expressions. The model of the exponential distribution has been chosen for several reasons: the distribution has a relatively simple mathematical expression; due to the properties presented by the random variable and the realization of statistical inferences of maximum likelihood does not present major calculation difficulties. The conclusion that has been reached is that this method leads to results similar to the estimates of maximum likelihood applied to complete and very poorly censored samples, or for situations where estimates are not displaced.

The fourth subchapter, entitled *Researches on the estimation of Rayleigh's parameters and reliability indicators*, presents a way to achieve statistical inferences for statistical model parameters, based on asymptotic properties of punctual estimators of maximum likelihood method, an aspect which is poorly treated and solved in the literature. In this case, the Fisher information matrix was used, as well as the Delta method, which allows computing the dispersion of a function that has as argument the value of the estimation of the parameters of the analyzed distribution.

The first chapter ends with *the Research on the estimation of parameters and reliability indicators for lognormal distribution*. The novelty of this study is represented by the method proposed for calculating the confidence intervals of the testing time estimation so that it is possible to achieve more realistic planning activities and appropriate allocation of resources for the testing activities.

Chapter 2, entitled *Researches on the reliability of industrial products*, is structured in four subchapters comprising:

- *Preliminary reliability of bearings*. The purpose of using reliability models and statistical methods to analyze experimental results, obtained by observing defects types and deterioration phenomena, is to assess the preliminary reliability of products. Consequently, the overall assessment of the product lifetime should allow for the overall consideration of the possibilities of failure by realistically linking the accidental causes of deterioration to the controlled, determined ones. The predicted bearings reliability assessment model underlying the research is based on the following assumptions: the estimation of the bearings preliminary reliability is performed for the normal operating period of the products, a period characterized by a constant failure rate; the statistical model used to characterize each distinctive type of damage is the exponential distribution; the reliability system of a bearing, obtained by considering all distinctive typological damage mechanisms that can become effective as a result of concrete operating conditions, is a series system. This results from fault tree analysis specific to a bearing case; for simplifying the calculus there are neglected: interdependencies, combinations and overlaps of effects that may occur in different types of deterioration.
- *Determination of bearings reliability indicators using experimental data obtained by tests performed by sudden death method*. The reliability tests carried out by the method of the sudden death consist in the random grouping of the products tested n , in ℓ subsets, and the consideration of each subset as an ensemble of m ($n = \ell \cdot m$) elements in series. Due to the

specificity of this type of test, the estimation of Weibull distribution parameters and bearings reliability indicators show a number of particularities as against the case of time or failure terminated tests. In this research topic, these particularities have been detailed and a numerical simulation algorithm has been proposed by means of which the values of three random variables independent of the distribution parameters can be determined. These random variables allow for the statistical inferences for the Weibull distribution parameters and for nominal durability. This subchapter ends with a case study for LM11949 / LM11910 tapered roller bearing.

- *Reliability analysis of the trailed scarifier.* The scarifier is a machine for dislodging the earth, boulders and roots, hard strata of material fixed to the soil, or for dismantling the compacted material, asphalt and rocky substrate to facilitate the scraping of land of relatively weak rocks. The research, in this case, consists in identifying the statistical model best suited to modeling the life of the scarifying teeth, estimating model parameters and achieving statistical inferences. Four statistical distributions used in reliability analyzes were taken into account: Weibull distribution, lognormal distribution, exponential distribution and normal distribution. Using the general goodness of-fit test, Anderson-Darling, applied to the experimental data led to the decision to use the three parameters Weibull distribution. To analyze the lifetime of the scarifying tooth were used the experimental results obtained from trailed scarifier functioning.
- *Reliability analysis of the veneer-cutting machine.* The data used in this case study was collected over a period of one year, January ÷ December 2004. During this period, the machine operated continuously, 24 hours a day, seven days out of seven, realizing a veneer with thicknesses between 0.5 and 1.2 mm. The statistical processing of the operating times, between two accidental failures, was aimed at identifying a statistical model and its full specification. To achieve this goal, two Mathcad programs have been implemented. The first program is intended to verify statistical homogeneity (random character check, identification and elimination of aberrant values), as well as to test the goodness of-fit of experimental data with the chosen statistical model. The second program allows to estimate the parameters of the statistical distribution by: the modified moments method, the correlation coefficient method, the least squares method, the maximum likelihood method and the classical method of the moments. Achieved results enabled the realization of realistic maintenance strategies for the veneer-cutting machine.

The second section of the Habilitation Thesis, entitled *Career Evolution and Development Plans*, contains a brief presentation of the professional evolution of the author from the graduation of the faculty to the present. Further on are presented the expected evolution directions of the professional activities by continuing the scientific research and improving the didactic activity for the disciplines in the field of industrial engineering, the dissemination of the results of the researches carried out by the author, as well as by the increase of the international recognition.

The Habilitation thesis ends with the bibliography containing all the references used in drafting the present paper.