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PRELIMINARY RELIABILITY OF BEARINGS

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ABSTRACT

The use of bearings in very different domains, characterized by working conditions with high variety, implies that the failing modes of the bearings are various, also. The purpose of using reliability models and statistical models for the analysis of the experimental results, obtained by observing different types of failures and deterioration phenomena, is represented by evaluating the preliminary reliability of the products. As a consequence, the overall look at the lifespan of products has to allow for the global accounting of failing possibilities, through realist intertwining of the accidental causes for failing with the controlled, determined ones. The image has to be filled in with its static aspect. It is understood that the preliminary reliabilities calculated have to be considered as static values with resulting distributions, accounting for the fact that all the service conditions (cycle, precision, temperature, environment etc.), external loadings, dimensions and material properties present a specific variability.

Keywords: preliminary reliability, bearings, durability, fault tree analysis

1. INTRODUCTION

The analysis of the factors that influence the durability and lead to the failure of the bearings, in the case of an actual application, is made difficult a lot by the variety of the existing failure modes, as well as because of the multitude of causes that lead to failure, of their interactions and cumulative effects [1,2,3].

At the start of the failing process, an incident caused by a combination of unfavourable and unpredictable factors can offer a general view and information considering the causes and the unfavourable and factors that generated the failure. The failing process evolves [4], fast from this moment, the occurrence of new failing phenomena that always lead to deep exfoliation, breaking of material and, finally, the complete destruction of the bearings.

The occurrence, the type and the evolution of the failing phenomena in bearings (Fig. 1) are determined by the following groups of factors [4]:

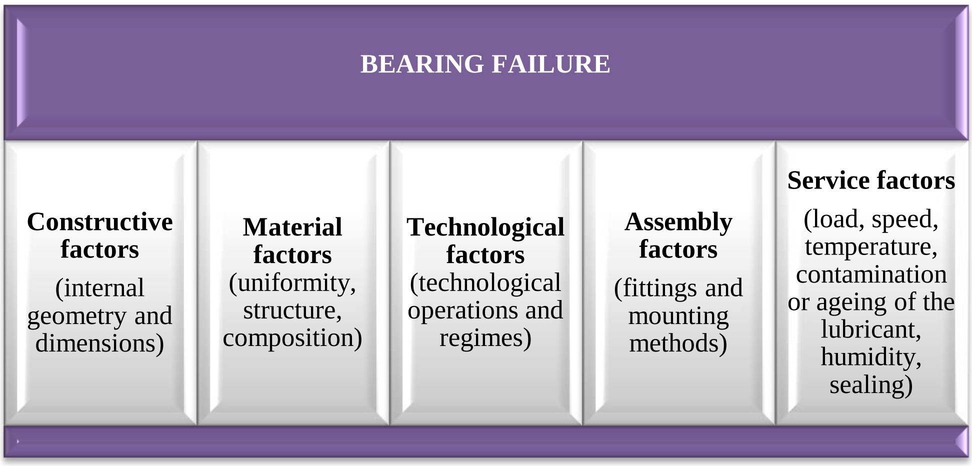


Fig. 1.Factors of Bearing Failure

Of these, the material factors are of considering importance, because their influence cannot be altered with the technologies in the manufacturing process of bearings. The most part of the factors mentioned above is theoretically or experimentally controllable, fact that allows the design, manufacture and use of the bearings in close relation to the modern reliability requirements [4].

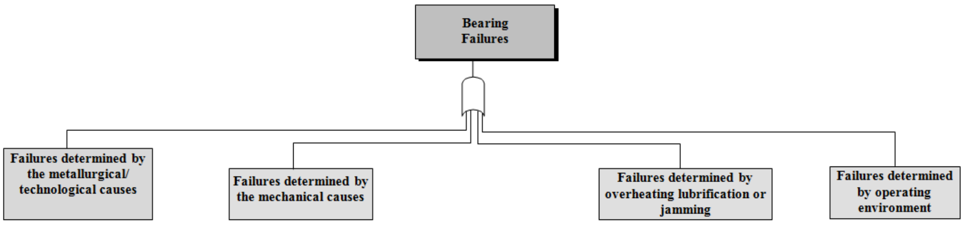
In normal conditions, concerning the factors mentioned before, which are for a steel with a uniform considered composition and structure, usual geometry and dimensions, correct technology and mounting, correct service (no overloads, moderate speed and abundant lubrication with recommended lubricants), it is appreciated that the failure of the bearings occurs through the rolling contact fatigue of the material. Because of this, in the case of bearings, the notion of reliability/durability has been correlated for long only to the possibility of working until contact fatigue failure occurs. Though, in numerous applications, the replacement of the bearings is also dictated by other reasons: the surfaces quality, the clearance, the vibrations and the noise, the spinning irregularity or blocking, the lubricant quality, the temperature increase, the results of other failing phenomena and typologies. Thus, the notion of bearing failure does not refer only to the complete destruction of them, but, according to the specific of the application, to the reduction, drop or worsening of the working capacity or performances, also.

Accounting for the fact that some phenomena have a rapid evolution and they do not leave time for an inspection-replacement decision and that others evolve slowly and, thus, they can be followed in time, the evaluation of causes and factors that led to the failure is recommended to be done in the following succession:

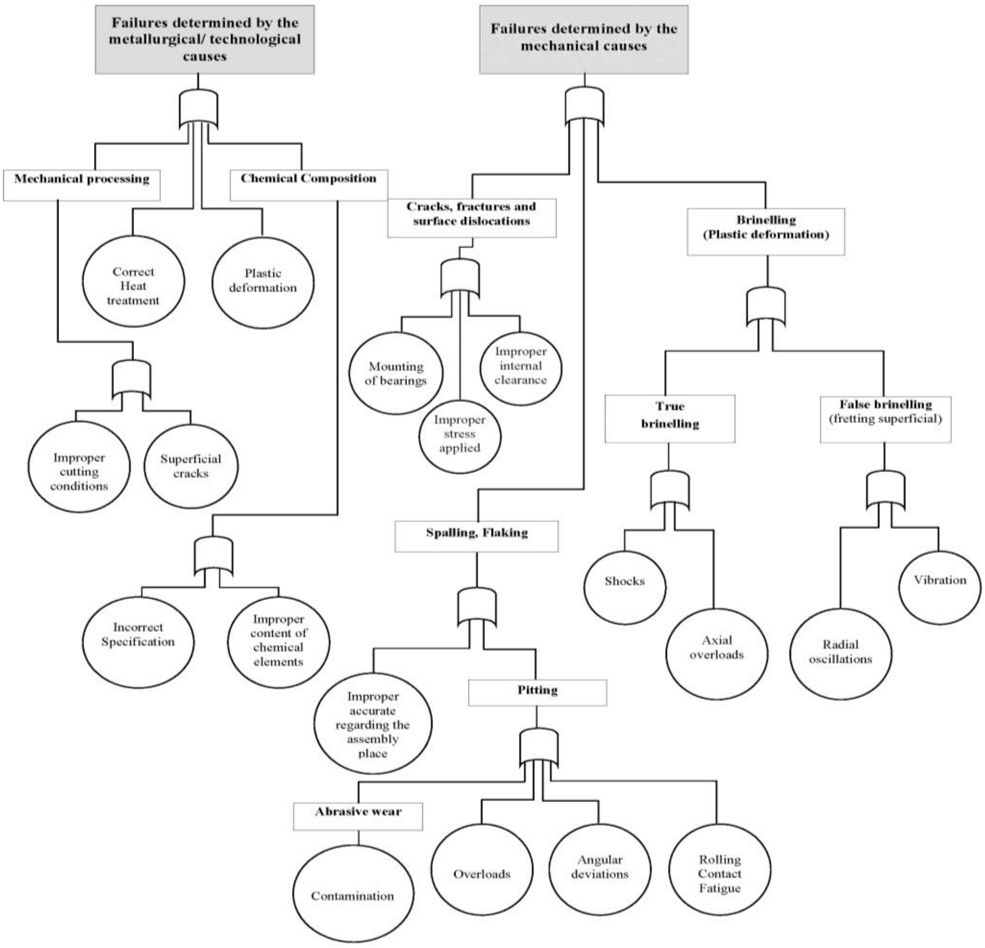
- inspection without dismantling: through monitoring vibrations, noise, temperature, uniform rotation;
- inspection with disassembling and maybe reassembling with quantitative and qualitative evaluations of the defects.

It is also recommended that this analysis to be done only related to actual working conditions [1, 5].Under this condition, the evaluation of causes proves a very difficult task. The bearing failure, as well as the factors that influence the reliability, can be studied from a quality standpoint through the tree analysis which consists in determining the failure modes and the identification of the unwanted combinations of events that influence the general behavior [6]. The method is called fault tree analysis.

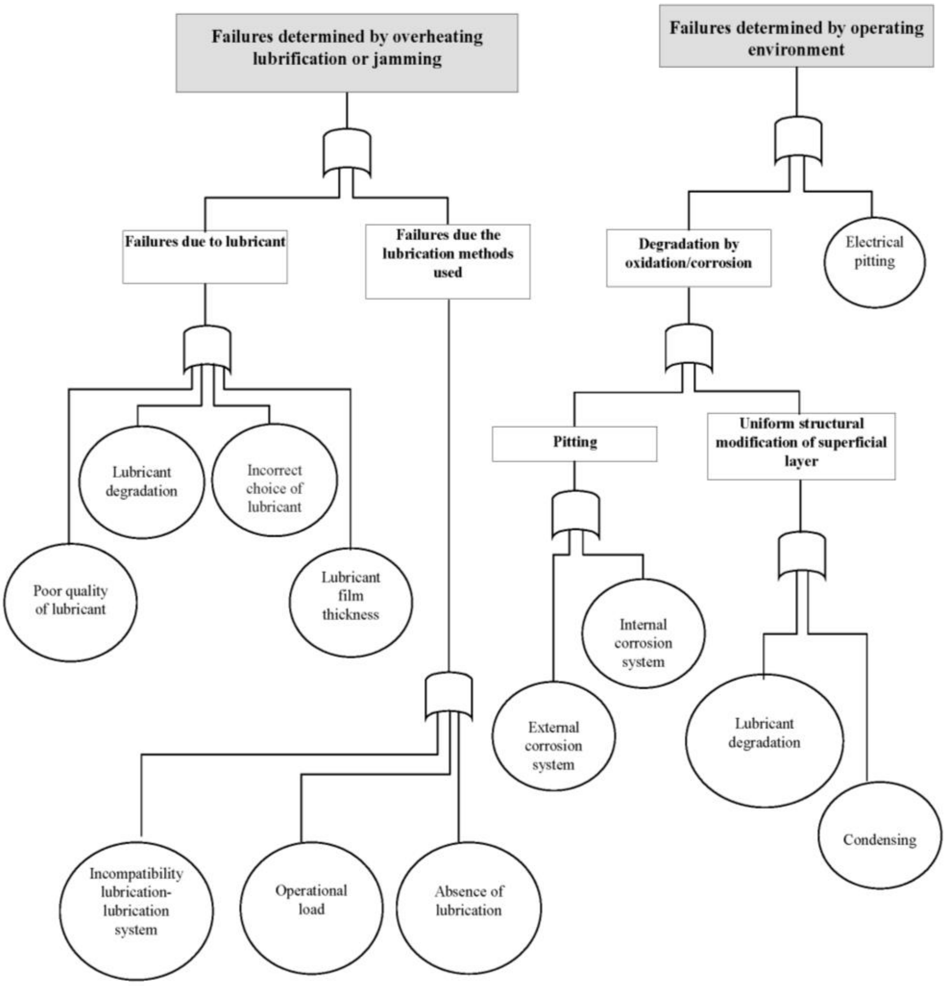
The analysis procedure consists of specifying some events [7], called initial events, which have influence on the functioning of the system and the estimation of the set of events that result from this one, using a set of operators or gates. Figure 2 presents the fault tree [8] associated to a bearing, for the general case. This method is recommended for the analysis of products, for which the unwanted events (the ones that start the failure) are independent, being effective in the qualitative establishing the relations among the failure mechanisms. The fault tree analysis can be also used to get quantitative results. In this case, it is necessary to fill the analysis with fault probabilities or frequencies.



a)



b)



c)

Fig. 2. Bearing failures (a) and detailed modes of failures (b and c)

2. DETERMINING THE PRELIMINARY RELIABILITY

In the case of bearings, lack of insufficient data (from reliability tests) to define the distributions for each type of failure makes the usual calculation for bearings to separately consider, in relation with the durability, contact fatigue [4, 9, 10, 12] or abrasive wear [4, 11]. Otherwise, boundary conditions and adequate specifications are established.

If, in the case of contact fatigue failure phenomena, the lifespan of the bearings is calculated accounting for the static character of the initiation and failure development [13], in the case of abrasive wear, the calculation is deterministic.

The evaluation of bearings preliminary reliability is done, in general, as a first computational step for the components' reliability of a complex mechanical system. The model to evaluate the preliminary reliability of bearings is described in Fig. 3.

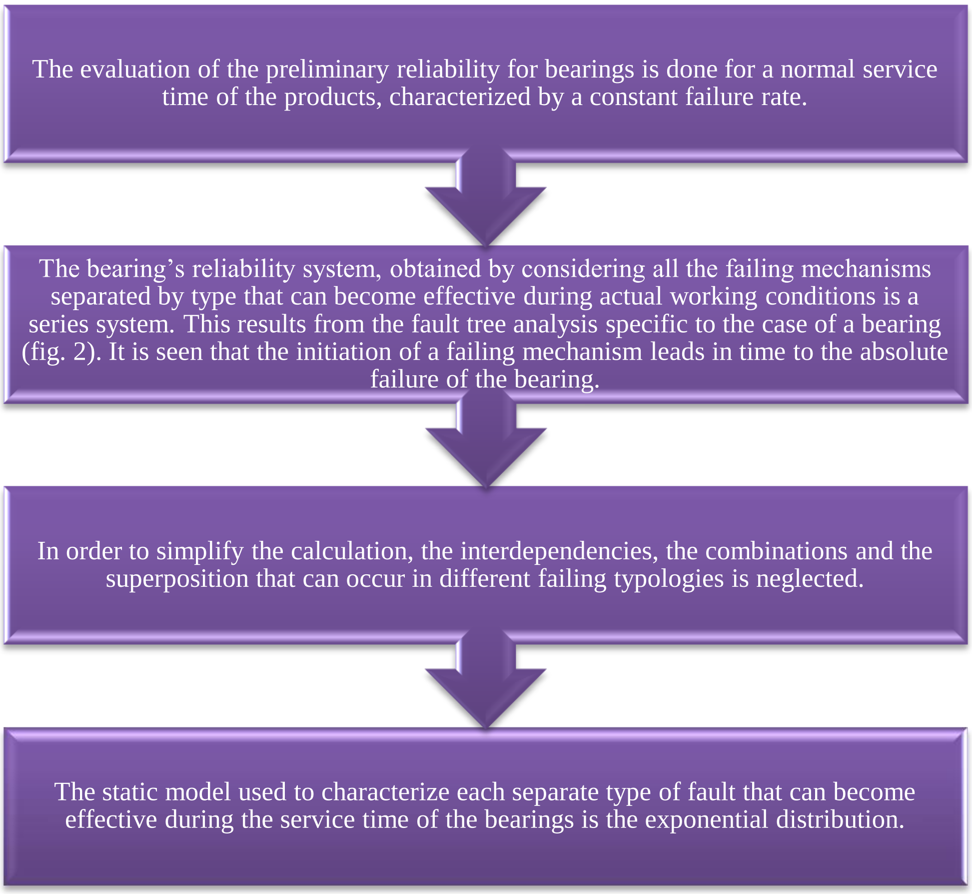


Fig. 3. Hypothesis of preliminary reliability

The reliability of the bearing, considering all the cumulative failure possibilities, can be determined with the following expression [11]:

$$R_c(t)=R_1(t)\cdot R_2(t)\cdot\ldots\cdot R_m(t)=\prod_{i=1}^{m}R_i(t) \qquad (1)$$

and is obviously influenced by the number of failures ($\lambda=\overline{1,m}$), different typological.

On the basis of simplifying hypothesis presented above, the expression (1) can be written as follows:

$$R_c(t)=e^{-\lambda_c\cdot t}=e^{-\sum_{i=1}^{m}\lambda_{ci}\cdot t} \qquad (2)$$

where λ_c is the value of the actual failure rate and λ_{ci} represents the failure rate value of each failing type considered.

In conclusion, for evaluating the reliability, it is necessary to set the values $\lambda_{ci}, i=\overline{1,m}$. This can be done either through existing data base that holds quantitative information obtained by monitoring similar products in service, that work in similar conditions to the analyzed bearing, or on the basis of adequate norms and recommendations.

In the case of contact fatigue failure, the modeling for bearing lifespan is done using Weibull distribution. For the usual values of the shape parameter (β=10/9 for ball bearings and β=9/8 for roller bearings), the reliability function for bearings can be written as:

$$R_{OC}(L) = e^{\ln(0.9)\cdot\left(\frac{L}{L_{10}}\right)^{1.1}} \qquad (3)$$

and the failure rate function is:

$$z_{OC}(L) = -\frac{\ln(0.9)\cdot 1.1}{L_{10}}\cdot\left(\frac{L}{L_{10}}\right)^{0.1} \qquad (4)$$

Relation (4) indicates a function slightly increasing with the rate of failure. Within the preliminary reliability studies for bearings [14], theWeibull distribution having the shape parameter β=1.1 can be approximated by a normal distribution for β=1.0. In this case we have:

$$R_{OC}(L) = e^{\ln(0.9)\cdot\left(\frac{L}{L_{10}}\right)^{1.1}} = e^{-\lambda_{OC}\cdot t} \qquad (5)$$

and

$$z_{OC}(L) = -\frac{\ln(0.9)}{L_{10}} = \lambda_{OC} \qquad (6)$$

In the relations (3) to (6), L_{10} is the basic rating life of the analyzed bearing. This value is calculated based on the catalog value for the basic dynamic load (*C*) and the equivalent dynamic bearing load (*P*). This last one is found on the basis of the radial (*Fr*) and axial (*Fa*) forces that load the bearing during service. Besides the method of globally quantifying the influence of the actual service conditions and environmental ones over the reliability of the bearings, it can also be used the values for the failure rate, characteristics for other failure mechanisms.

In this case, a preliminary analysis is necessary for highlighting the rest of the failure mechanisms than may occur as a result of the actual service conditions of the analyzed bearing.

The actual value for the failure rate is calculated using the expression:

$$\lambda_C = \lambda_{OC} + \sum_{i=1}^{m-1}\lambda_{ci} \qquad (7)$$

on the basis of the individual values of the failure rate λ_{ci}, attributed to the other modes of failure.

3. CASE STUDY

To highlight the use of the resulted algorithm, a simplified theoretical example is presented, for calculating the preliminary reliability, for a 6307 type radial ball bearing used in the drive of a shaft for rolling stock equipment. This type of bearing has been selected for the imposed durability of: L_h=50000 hours.

The calculus for the bearing reliability from the rolling contact fatigue condition, by using the relations (5) and (6), is:

$$z_{OC} = \lambda_{OC} = -\frac{\ln(0.9)}{50000} = 2.107\cdot 10^{-6} \text{ failures/hours} \qquad (8)$$

The quantitative information regarding the rest of the failure mechanisms that may occur as a result of the actual service conditions for the bearings for the rolling stock were taken from specialized literature [2,4]. The main reported failures are:

Table 1. Hypothesis of preliminary reliability [2, 4]

▪ Pitting:	7.01 %		▪ Fissures, breakings:	1.25 %
▪ Abrasive wear:	12.06 %		▪ Electrical current:	57.75 %
▪ Impressions:	2.09 %		▪ Other:	5.47 %
▪ Corrosion:	14.38 %			

The values for the failure rate ($\lambda_{ci}, i = \overline{1, m-1}$) can be simply determined starting from the failure rate (λ_{0c}), calculated before, from the contact fatigue condition, knowing that this has a 7.01% share in the total of failures. It results:

Table 2. Failure rates

Failure mechanism	Failure rate, λ_{ci} , [10^{-6} failures/hour]		Failure mechanism	Failure rate, λ_{ci} , [10^{-6} failures/hour]
▪ Abrasive wear	3.625		▪ Crakes, breakings	0.373
▪ Impressions	0.628		▪ Electrical current	17.360
▪ Corrosion	4.323		▪ Other	1.644

For the analysed case, the reliability of the bearings, determined by cumulative failures, is obtained using the relations (1) and (2): $R_c(t) = e^{-30.06 \cdot 10^{-6} \cdot t}$.

The preliminary reliability for the bearings results by considering the reliability caused by accidental failures [15]: $\lambda_{Ac} = 100 \cdot 10^{-6}$ failures/hours.

According to the equation (2), the expression of the preliminary reliability for the considered bearing is: $R(t) = e^{130.06 \cdot 10^{-6} \cdot t}$.

Knowing the expression for the reliability function, the calculus for the bearing reliability, for a certain lifetime, becomes very simple. The value for the reliability of bearing 6307, after a service life of *t*=500 hours is: $R(500) = 0.937$.

4. CONCLUSION

As a result of the research to evaluate the preliminary reliability of bearings, the following conclusions can be pointed out:

- the developed algorithm for evaluating the preliminary reliability of the bearings allows for the global accounting for all failure possibilities that may become effective in the case of a certain application;
- to evaluate the preliminary reliability for bearings, as constructive elements of a complex mechanical system, this model accounts for the specific variability of the service conditions during normal service time;
- the calculus method allows for evaluating the global durability of a system, by considering the contribution of all the bearings to the system deterioration;
- this model can be a very useful instrument for calculus and analysis of the reliability for a mechanical system, especially in the technical project stage.

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