CONSIDERATIONS REGARDING THE RELIABILITY ASSESSMENT OF THE ROLLER BEARING PROVIDING MOVEMENT IN THE DIRECTION OF ANTI-AIRCRAFT GUNS

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DOI: 10.19062/1842-9238.2021.19.1.5

Abstract: *This paper analyzes a method of evaluating the reliability of the rolling bearing in anti-aircraft guns. In evaluating its reliability, the factors that depend on the operating conditions of the anti-aircraft gun are taken into account, as well as the factors of design, technology, materials and assembly.*

Keywords: reliability, failure rate, anti-aircraft gun, rolling bearing

1. INTRODUCTION

The reliability of a technical system must be considered as a quantity with the resulting distributions, given that external stresses, dimensions, material properties and operating conditions have a specific variability.

Currently, due to insufficient data to define the distributions for each type of damage, the calculation of rolling bearings is performed separately for wear at variable contact stresses and for wear in environments with abrasive particles.

In the case of the deterioration phenomenon due to the contact demands of the constructive elements, the durability of the rolling bearings is determined taking into account the statistical character of the initiation and development of the defect, and for establishing the abrasive wear the calculations are deterministic.

2. DETERMINATION OF RELIABILITY IN THE ROLLER BEARING OF ROTATING GUN MOUNTING

At the bottom of the steering platform at the base of the anti-aircraft guns, a rolling bearing is mounted, which ensures the rotation of the moving part of the anti-aircraft gun in the desired direction. The rolling bearing also has the role of taking over the reactions that appear horizontally and vertically, both in static position, but especially under the conditions in which shots are fired (FIG.1).

In order to determine the reliability, or to highlight the specific failures, in this paper we are going to use the FMEA method - Failure Modes and Effects Analysis. By applying this method, there result the causes and effects of the defect, thus offering us the possibility to diminish or even eliminate them.

In order to evaluate the reliability of the rolling bearing, the following hypotheses are considered:

− the statistical model used in the characterization of each type of failure is of exponential type;

− the evaluation of the forecast reliability of the analyzed rolling bearing is determined for the operation period, when the failure rate is constant;

− interdependencies, combinations and overlaps of effects that may occur for different ways of damage are neglected.

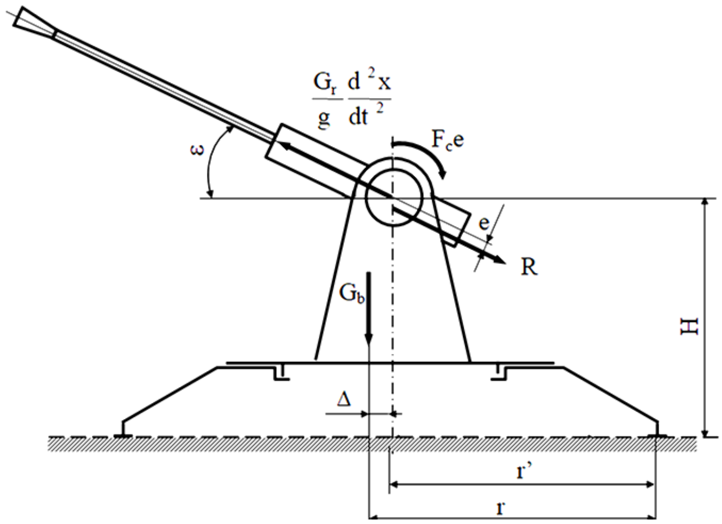

FIG. 1. The forces and the moments that appear during the operation of the anti-aircraft gun

Taking into account the possibilities of failure of the rolling bearing, its reliability, considered as a system, is given by the relation [2]:

$$R_{tot}(t) = R_1(t) \cdot \ldots \cdot R_n(t) = \prod_{i=1}^{n} R_i(t) \tag{1}$$

Based on the simplified hypotheses presented above, the reliability of the rolling bearing can be expressed as follows [1]:

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

where:

λ_C – is the effective value of the failure rate;

λ_{ci} - represents the value of the failure rate for each type of damage.

To evaluate the reliability of the rolling bearing it is necessary to establish the values λ_{ci}, $i = 1, \ldots, m$. This can be done either through a database containing quantitative information obtained as a result of operating similar products, under conditions similar to the analyzed rolling bearing, or on the basis of appropriate recommendations and regulations.

In the case of the damage phenomenon caused by variable contact stresses, the modeling of the rolling bearing durability is achieved by using the Weibull distribution. For the regular values of the shape parameter of this distribution *(β)* the reliability function of the rolling bearing R_{OC} relation (2), we can express [4]:

$$R_{OC}(L) = e^{\ln(0,9)\left(\frac{L}{L_{10}}\right)^{1,1}} \tag{3}$$

and the function of the failure rate is [4]:

$$z_{OC}(L) = -\frac{\ln(0,9) \cdot 1,1}{L_{10}} \left(\frac{L}{L_{10}} \right)^{0,1} \tag{4}$$

Relation (4) indicates a slightly increasing function for the failure rate. In general, in determining the reliability of rolling bearings, the Weibull distribution function with the shape parameter $\beta = 1,1$ can be approximated by the exponential distribution, for $\beta = 1$.

In this case, it results:

$$R_{OC}(L) = e^{\ln(0,9)\frac{L}{L_{10}}} = e^{-\lambda_{OC} \cdot L} \tag{5}$$

and:

$$z_{OC}(L) = -\frac{\ln(0,9)}{L_{10}} = \lambda_{OC} \tag{6}$$

In relations (3) … (6), L_{10} is noted the nominal durability of the analyzed rolling bearing. This quantity is calculated using the relations based on the value of the basic dynamic load *(C)* and the equivalent load *(P)*. The latter is assessed on the basis of radial and axial forces (F_r and F_a) which act upon the rolling bearing during the operation of the anti-aircraft gun.

The loading forces acting upon the rolling bearing during the firing of the anti-aircraft gun are, in most cases, variable. Figure 2 [5], shows the calculation scheme of these reactions (internal forces), depending on the load of the analyzed technical system.

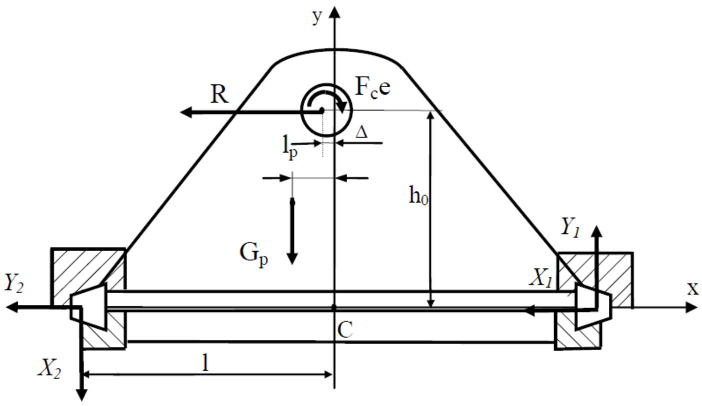

FIG. 2. The reactions (internal forces) that appear in the rolling bearing

The following notations were used in the scheme:

- R - the result and force of the calculation resistances on the recoil mass;
- G_p - weight of the pivoting part;
- $F_c \cdot e$ - the moment of dynamic action;
- X_1, Y_1, X_2, Y_2 - the reactions that occur in the rolling bearing;
- l_p - the pivoting weight arm G_p in relation to the axis of the rolling bearing;
- h_0 - the force arm R, in relation to the point of intersection of the reaction with the axis of the rolling bearing;
- l - the radius of disposition of the rolling bodies of the bearing;
- x_n - the eccentricity between the axis of symmetry of the rolling bearing and the axis of the cradle bearings.

The reactions occurring in the rolling bearing, during the firing of anti-aircraft guns, for the angle of inclination in height of the barrel of the cannon $\varphi = 0$, result from the following equilibrium equations:

$$\begin{cases} \sum_{i=1}^{n} F_x = -X_1 - X_2 - 2R = 0 \\ \sum_{i=1}^{n} F_y = Y_1 - Y_2 - G_p = 0 \\ \sum_{i=1}^{n} M_c = 2F_c e - 2Rh_0 - G_p l_p - (Y_1 + X_2) l = 0 \end{cases} \tag{7}$$

In this case, the horizontal reactions have the value equal to zero, and the vertical reactions are determined by the relations:

$$\begin{cases} Y_1 = \dfrac{2F_c e - 2Rh_0 + G_p (l - l_p)}{2l} \\ Y_2 = \dfrac{2F_c e - 2Rh_0 - G_p (l + l_p)}{2l} \end{cases} \tag{7'}$$

If the firing forces are not taken into account, the reactions that occur in the rolling bearing are:

$$\begin{cases} \sum_{i=1}^{n} F_x^{'} = -X^{'}_1 - X^{'}_2 = 0 \\ \sum_{i=1}^{n} F_y^{'} = Y_1^{'} - Y_2^{'} - G_p = 0 \\ \sum_{i=1}^{n} M_c = -G_p l_p - (Y_1 + Y_2) l = 0 \end{cases} \tag{8}$$

From system (8) there result the vertical and horizontal components of the reactions:

$$\begin{cases} Y_1^{'} = \dfrac{G_p (l - l_p)}{2l} \\ Y_2^{'} = H_1 - G_p \end{cases} \tag{8'}$$

$$\begin{cases} R_1^{'} = X_1^{'} \\ R_2^{'} = X_2^{'} \end{cases} \tag{8''}$$

If anti-aircraft gunfire is fired, the resulting reactions in the rolling bearing are:

$$\begin{cases} \sum_{i=1}^{n} F_x = -X_1^{''} - X_2^{''} - R = 0 \\ \sum_{i=1}^{n} F_y = Y_1^{''} - Y_2^{''} - G_p = 0 \\ \sum_{i=1}^{n} M_c = 2F_c e - 2Rh_0 - G_p l_p - (Y_1^{''} + Y_2^{''}) l = 0 \end{cases} \tag{9}$$

The vertical reactions in this case are determined by the relations:

$$\begin{cases} Y_1^{"} = \dfrac{F_c e - R h_0 + G_p (l + l_p)}{2l} \\ Y_2^{"} = \dfrac{F_c e - R h_0 - G_p (l + l_p)}{2l} \end{cases} \quad (9')$$

The resulting forces are determined by the relations:

$$\begin{aligned} R_1^{"} &= \sqrt{X_1^{"2} + Y_1^{"2}} \\ R_2^{"} &= \sqrt{X_2^{"2} + Y_2^{"2}} \end{aligned} \quad (10)$$

The effect of internal and external forces on the rolling bearing will be the same as that of an average equivalent dynamic load [7]:

$$P_m = \left[\frac{1}{N_0} \int_0^{N_0} \left[X \cdot V \cdot F_r(N_0) + \lambda \cdot F_a(N_0) \right]^P dN \right]^{\frac{1}{P}} \quad (11)$$

The calculation performed by relation (11) is laborious and a simplified calculation is preferred, which consists of multiplying the equivalent dynamic load given by relation (12), with experimentally determined coefficients, depending on the actual operating conditions of the rolling bearing [3]:

$$P = f_p \left(X \cdot V \cdot F_r + Y \cdot F_a \right) \quad (12)$$

where:

f_p- represents the correction factor of the equivalent dynamic load and has the form, [3]:

$$f_p = f_z \cdot f_d \cdot f_v \cdot f_s \cdot f_t^{-1} \quad (13)$$

In relation (13), the five factors used represent [6]:

f_z - additional factor that depends on the precision of the teeth; it applies to roller bearing assemblies used for gears transmissions. The precision of the inner cylindrical gear being normal, with the division and shape error of 0,02 - 0.05mm, there results f_z = *1,1 – 1,3*;

f_d - regime factor depending on the type of machine of which the mounting with rolling bearings is part. For the studied case, f_d = *2,0 – 3,5*;

f_v - additional factor, it applies only in case of belt or chain drive; in this case the value of the coefficient $f_v = 1$;

f_s - shock factor; for the studied case, f_s = *1,8 – 2,3*;

f_t - temperature factor. The regime temperature being lower than 100^0C, the coefficient has the value $f_t = 1$.

The operating, environmental and precision conditions affect the reliability of the rolling bearings, so that the effective value of the failure rate is obtained by means of the relation:

$$\lambda_C = K_{OC} \cdot \lambda_{OC} \tag{14}$$

In equation (14), K_{OC} represents a correction coefficient depending on the field of use of the rolling bearing. For rolling bearings used in military anti-aircraft artillery, the values of this coefficient are $K_{OC}=120\text{-}150$ [6].

In addition to the way of quantifying the influence of actual operating and environmental conditions on the reliability of the rolling bearing, the values of the failure rate, specific to the other damage mechanisms, can also be used. In this case, a preliminary analysis is required to highlight the ways of failure that may occur as a result of the concrete conditions in which the analyzed rolling bearing operates. The effective value of the failure rate is determined by the relation:

$$\lambda_C = \lambda_{OC} + \sum_{i=1}^{m-1} \lambda_{ci} \tag{15}$$

based on the individual values of the failure rate λ_{ci}, corresponding to the other forms of damage.

During the firing of anti-aircraft guns, the reliability of the rolling bearing is to some extent influenced by accidental damage. The reliability of the rolling bearing (R) will be equal to multiplying the reliability caused by the cumulative degradations (R_c) by the reliability caused by the accidental defects (R_{AC}):

$$R(t) = R_{AC}(t) \cdot R_C(t) = e^{-\left(\lambda_{AC} + \lambda_{OC} + \sum_{i=1}^{m-1} \lambda_{ci}\right) \cdot t} = e^{-(\lambda_{AC} + K_{OP} \cdot \lambda_{OP}) \cdot t} \tag{16}$$

3. CONCLUSIONS

Taking into account the functional parameters specific to the military technology, with reference to anti-aircraft guns, a great importance must be given in terms of the reliability of the component constructive elements.

Thus obtained values of the reliability of rolling bearing that ensures the movement in the direction of the anti-aircraft guns, as well as of the other constructive elements component of them, are the basis for the elaboration of the necessary documentation for an optimal preventive maintenance.

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