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ROLLING BEARINGS' OPERATING FEATURES AS A FUNCTION OF THEIR ELEMENTS HARDNESS

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Abstract

In this paper investigations concern relations between constructional and operational features of rolling elements have been presented. In described experiments bearing raceways hardness was accepted as a variable constructional feature, and tested operating features were: motion resistance inside the bearings and their fatigue life. Described investigations were carried out on example of bearings used in popular transport means – bicycles.

Keywords*: rolling bearing, bicycle, bearing's element hardness, motion resistance, fatigue life*

1. Introduction

The task of rolling bearings in all kinds of machines and mechanical devices, including different means of transport, involves transmission of load with rotational or linear motion of the elements undergoing bearing. Rolling and slide bearings can be used for this purpose. To make decision as to which kind of bearing to use, the below listed factors are to be taken into consideration:

- load: kind (static or dynamic) value, direction and sense,
- desirable life,
- rotational speed,
- stiffness.

When one decides about rolling bearing application, the next step should be a choice of the bearing kind concern first of all:

- type of bearing: transverse, longitudinal, thurst,
- shape of rolling elements: balls, cylinder, cones, barrels or needles,
- geometric dimensions of bearings.

To make a choice one can use catalogues of bearings which include specific data on the above presented factors concerning bearings of a given producer. Some of the rolling bearing features are standardized at the national (PN), European (EN) or global (ISO) levels which makes the choice of a bearing much easier in case it needs to be changed.

In standard applications, a set of bearings contained in catalogues available on the market is absolutely sufficient and then there is no need to analyze factors determining particular functional qualities. However, the demand for applications of rolling bearings in which standard ones do not accomplish the assigned tasks or accomplish them insufficiently, is constantly growing. Thus, it is necessary to use special bearings and in such applications relations between structural features (mainly material and geometric) of bearings elements and their functional qualities are of importance.

In this paper, a fragment of a study of such relations has been presented, and the bearing track hardness was accepted as a variable constructional feature and operating features were: motion resistance in the bearings and their fatigue life. The tests were carried out on the example of bearings used for transport means as popular as the bicycle.

The purpose of this work was to verify the hypothesis that hardness of elements of rolling bearings could be accepted as a controllable factor for choosing functional features of a special type of rolling bearings.

2. Design features of bearings

Rolling bearings, like all other products, are identified by three constructional features:

- material,
- geometric,
- dynamic.

Identification of each of them involves matching its constructional form *II* with system of dimensions *W*. In a symbolic denotation it can be presented in the form of equation:

$$C_k = \Pi \cup W \quad (1)$$

The first of the above mentioned design feature components – constructional form *II* defines features in terms of quality, whereas, system of dimensions *W* - identifies properties of the design feature in terms of quantity and can be recorded as a logical sum:

$$W = \sum_{i=1}^{n} (N_i \cup /T_i/) \quad (2)$$

where: N_i – the *i-th* nominal dimension,
T_i – value of the *i-th* dimension tolerance and its field location.

An analysis of the influence of all the three design features on the bearings functional quality makes it possible to say that a feature of special importance is the material characteristics. This finding provides better possibilities for production of special bearings which can be operated in conditions in which operation of typical bearings could be impossible. Thanks to advances observed in the field of material engineering the offer of constructional materials used for production of rolling bearings elements has been significantly extended.

3. Features of special rolling bearings

A special bearing or more often an unconventional bearing system (single bearing is rarely used as a kinematical pair) is understood as such a structural solutions in which each of the above mentioned features differs from a typical one. The differences can be of qualitative character in terms of constructional form *II*, or quantitative ones – concerning a single dimension or their group, from dimension system *W*.

Research in the field of *Machinery design and operation*, aims mainly at improving the machine performance parameters. In case of rolling bearings, it covers improving: bearing capacity, boundary rotational speed, operating temperature.

There also occur situations in which bearing nodes do not carry high loads and the working environment is not an additional threat to correct operation of bearings. Such cases occur e.g. in medicine and industries using micro and nanotechnologies.

The widespread opinion that hardness of working surfaces of bearing elements should be possibly great is only partially true. There are many theories which account for the phenomena of initiation and growth of rolling bearing elements fatigue strength, e.g. [5]. All of them have one feature in common – they make the course of the surface wear processes dependent on the bearing pair external load value, thereby on values of contact stresses. Thus, hardness which is to be required from bearings made of different constructional materials should be treated as the function of load.

Searching of new constructional materials used for production of elements of rolling bearings has two goals. One of them covers searching for materials of bigger hardness, the second one covers searching for materials whose hardness is lower, though sufficient in given conditions. A good example of sudden progress in the first field of the research is application of ceramics – chemical compounds, e.g. nitrates, borides, oxides and carbides of such elements as: zircon, aluminum, cobalt, silicon, wolfram in construction of machines including the process of rolling bearings manufacture.

Hardness of ceramics is not always the most important factor for the choice of material for production of rolling bearings elements. The factor of more importance is often the material resistance to high temperatures – creep-resistance. Moreover, this group is characterized by significantly lower density as compared to steel, which is of special importance for bearings operating at high rotational speeds *n* (that is for great values of high-speedness coefficients $d{\cdot}n > 2 \cdot 10^6$ mm/min.).

Steel whose hardness is definitely lower (30÷35 HRC) than typical (60÷63 HRC) can also be considered as unconventional constructional material in a traditional approach to rolling bearings. There are known examples of kinematical pairs with rolling friction whose steel elements hardness was 30÷35HRC and in specified conditions they performed their functions properly. Elements of rolling bearings (rings, balls, baskets) are also manufactured from high-molecular plastics, e.g.: polyacetal, (POM), polyamide (PA), polyetheretherketone (PEEK), polyphenylene-sulfide (PPS) and others whose hardness was in the range from 76÷98 HRM. These bearings performed their functions for $1{,}5 \cdot 10^6$ revolutions with small external load equal to 49N which can be found to be of sufficient durability for special applications [4].

In literature, there are given ways of defining the value change caused by hardness decrease. One of them [5] contains experimentally obtained dependence in the form:

$$L_2 = L_1 \cdot e^{0,1(HRC_2 - HRC_1)} \tag{3}$$

where: $L_{n(10)}$ – fatigue life of bearings with elements hardness, respectively, HRC_1 and HRC_2, where $HRC_1 < HRC_2$.

It was also found that due to fatigue life it is advantageous when the balls of the bearing are harder than the track. Maximum life was reached for a bearing whose balls were harder by 2 degrees HRC than the ring with raceway. This dependence has been presented in Fig.1.

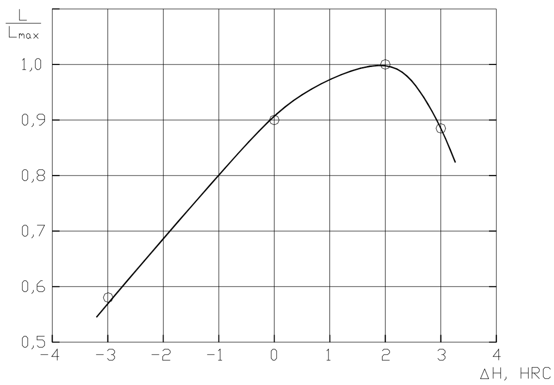

Fig.1. Life as a function of difference between toughness of balls and bearing ($\Delta H = H_{ball} - H_{raceway}$) [2]

Although there is no remark like that in the paper, it should be supposed that the results of this research can be used only to a certain limited degree, concerning both the type of constructional material and its hardness value. This statement was one of the main circumstances to take up the research described below.

4. Conditions of experimental tests

Tests were carried out on a test object in which there was a possibility of control of the force loading a system of two oblique bearings [1, 2]. The objects of research were bearings whose constructional forms corresponded to bearings used in such a popular transport means as bicycles. Due to some factors, including conditions in which bicycles are used, special bearings, both in range of geometry and the constructional material properties, were applied.

Axial force P_x was being changed (the bearing initial tension) within the range ⟨50;100⟩, whereas transverse load P_y was constant and equal to 250 N. The value of constant load was defined on the basis of statistic anatomic features of potential bicycle users, taking into consideration geometric design features of the selected bicycle type. In these conditions the resultant load of a pair of bearings was also variable.

Measurements were taken at bearings rotational speeds n=23s^{-1}. Such a value was accepted in order to reduce the time of testing. This procedure was possible because the frequency of load changes at the areas of balls contact with tracks has no practical importance in range of the bearings fatigue life, for the accepted scope of this research.

Life of bearings was measured by the number of performed work cycles (revolutions) and it was determined on the basis of motion resistances M_f in bearings. As the real time of bearings life L^* one accepted time over which resistances in bearings reached the same values as initial resistances – Fig. 2. Since rotational speed n was constant during tests, function $L_{n(10)}$=f(t) was the same as function $L_{n(10)}$=f(n), similarly to the relations of M_f motion resistances with these input quantities.

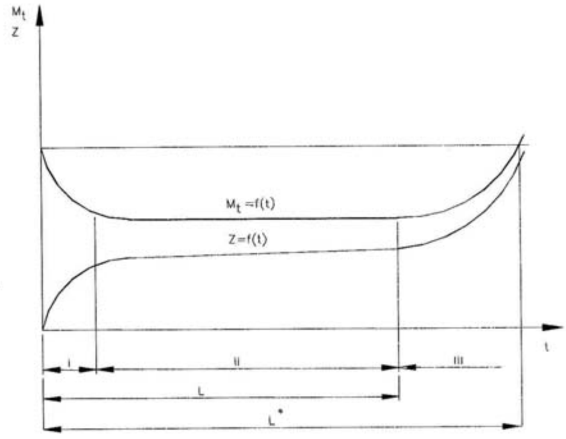

Fig. 2. The graphic interpretation of way of the bearing real life L^* determination on the basis of its motion resistance changes [3]

In order to make an assessment of the influence of hardness on the above mentioned functional qualities, tests for three values and hardness were performed. External rings used as samples, were made of steel C45 and after thermal machining they were characterized by nominal hardness 150, 300 and 450 HV. Acceptance of such hardness values resulted from the fact that it was possible to machine the rings after thermal machining which provided better conditions for comparison of the tests results.

5. Tests results

In result of the carried out tests, relations between two functional qualities of bearings, that is, resistance of M_f motion and life $L_{n(10)}$ have been recognized, with coefficient ∂, defining conditions of fitting of balls with diameter d_b to the track with profile curvature radius r_b, defined from formula:

$$\delta = \frac{2r_b}{d_b} \tag{4}$$

equal to 1.05

These relations for three different values of axial force P_x have been presented in Figs: 3 and 4. In both cases the influence of hardness on the bearings functional features is visible.

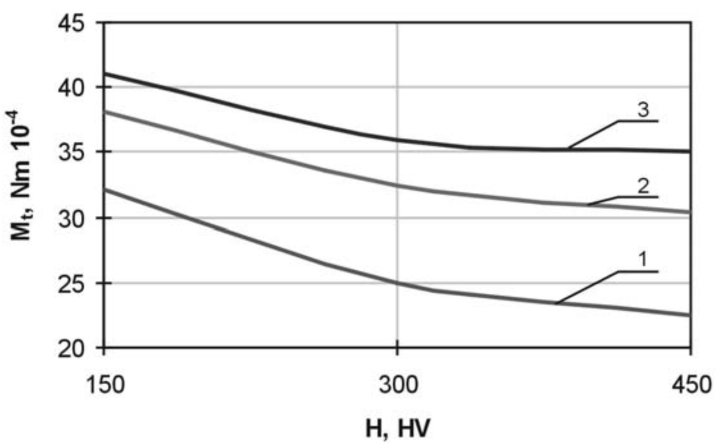

Fig.3. Dependences of resistances to motion M_f on the hardness H of tested bearing internal ring for: 1) P_x=100, b) P_x=75N, c) P_x=50N

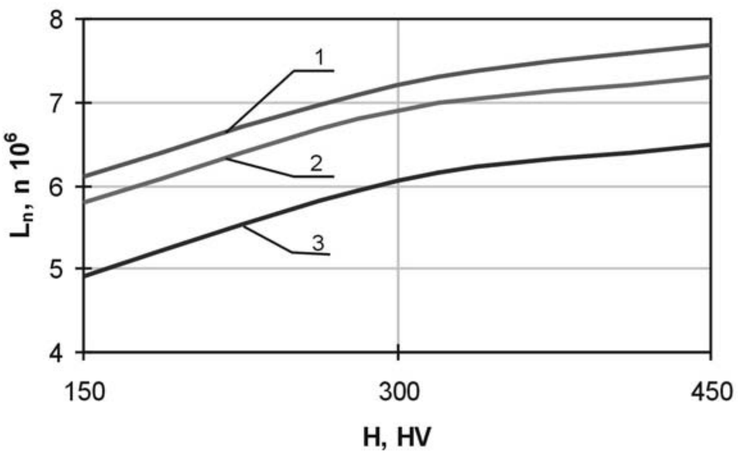

Fig.4. Dependence of fatigue life $L_{n(10)}$ on the hardness H of tested bearing internal ring H for: 1)P_x=100N, b)P_x=75N, c) P_x=50N

In any of the recorded relations occurrence of local extremes was found. The observed functions are of monotonic character but with a decreasing gradient.

The same relations have been presented in the form of spatial graphs – Figs. 5 and 6.

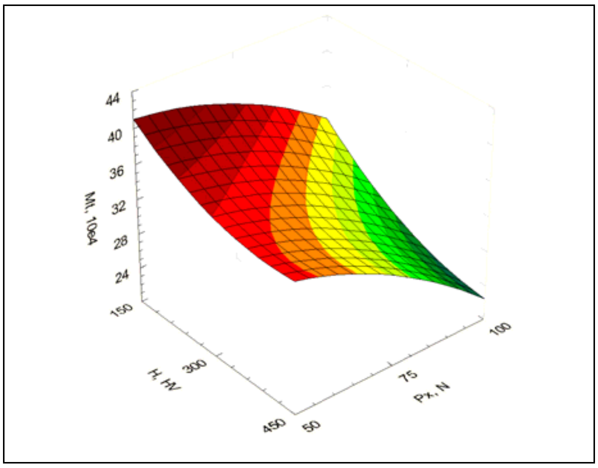

Fig.5 Resistances to motion M_f in the function of the hardness H of bearing internal ring and of axial load P_x

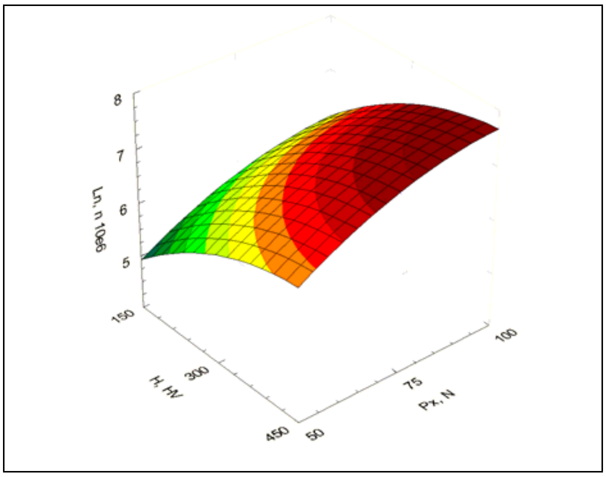

Fig. 6. Life of bearings $L_{n(10)}$ in the function of the hardness H of bearing internal ring and of axial loads P_x

The obtained results were elaborated statistically and the recorded changes were described by equations of regression in the form of a second degree polynominal. Their forms are, respectively:

- for motion resistances:

$$M_f = 43,594 + 0,271P_x - 0,063H - 0,003P_x^2 - 2,467 \cdot 10^{-4} P_x H + 9,259 \cdot 10^{-5} H^2 \qquad (5)$$

- for fatigue life:

$$L_{n(10)} = 0,111 + 0,086P_x + 0,014H - 4,133 \cdot 10^{-4} P_x^2 - 1,481 \cdot 10^{-5} H^2 \qquad (6)$$

Also, coefficients of multiple correlation R have been calculated for accepted regression models, with normally accepted value of significance level α=0,05. Coefficient values: 0,9325 (for M_f) and 0,8965 (for $L_{n(10)}$) prove good fitting of models with results of measurements obtained from experimental tests.

6. Conclusions

In result of carried out tests, the relations between functional qualities of special bearings and factors such as: constructional – hardness H and operational – axial load P_x have been discovered. This allows to control functional qualities by means of the studied factors. Thus, the set goal has been reached.

Also, thanks to development of mathematical models, two-factor optimization of rolling bearings basic features such as, undoubtedly, motion resistance and fatigue life, will be possible.

Satisfactory values of quantities describing the bearing functional qualities obtained in specific conditions confirm the possibility and purposefulness of using special types of rolling bearings and, with more and more often applied flexible manufacturing systems in the range of technology and organization, their use is also possible and economically justified.

References

[1] Styp-Rekowski, M., *Sposób pomiaru momentu tarcia w skośnych łożyskach tocznych*. Patent nr 205198 z dnia 7.10.2009.

[2] Styp-Rekowski, M., *Urządzenie do pomiaru oporów ruchu*. Patent nr 205199 z dnia 7.10.2009.

[3] Styp-Rekowski, M., *Znaczenie cech konstrukcyjnych dla trwałości skośnych łożysk kulkowych*. Wydawnictwa ATR Bydgoszcz, 2001.

[4] Tsukamoto, N., Kimura, Y., *Frictional Properties of Various Kinds of Plastics as Rolling Bearings Material*. Proc. of I^st World Tribology Congress. Mechanical Engineering Publications Ltd., pp. 812÷816, London 1997.

[5] Zwirlein, O., Schlicht, H., *Rolling Contact Fatigue Mechanisms – Accelerated Testing versus Field Performance. in: Rolling Contact Fatigue Testing of Bearing Steels*. ASTM STP 771, , pp. 358÷379 Philadelphia (USA), 1982.