

Homogeneous nested bearings

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Abstract. The solutions presented in the paper are based on the possibility to obtain stacked bearings by mounting two bearings if the outer diameter of one corresponds to the inner diameter of the second. Another variant is to specifically design an inner ring with two raceways, one for the lower bearing and the other one for the upper bearing. The paper presents solutions of this type by using bearings of the same type (homogeneous). Regardless of the chosen variant, the final solution presents two layers of rolling bodies or, in other words, a single intermediate ring. The construction of nested bearings must primarily take into consideration the balancing of the static and dynamic basic load rating ensured by the two layers of rolling bodies. This objective can be achieved by adequately establishing the radius and number of balls in the two layers. The advantage of such a construction is that it allows obtaining high rotational speeds. From a theoretical point of view, one can conclude that the maximum speed results as the sum of the values for the two bearings.

1. Introduction

Although the use of bearings is varied, in the machine tools domain, medium and large dimensions are used. In order to obtain the high speeds required by modern cutting processes, specially designed bearings are used or a replacement of this type of motion transmission with another variant which, in most cases, is more expensive.

To increase the performance of bearings, rolling elements are made from non-metallic materials such as ceramics (Silicon Nitride-Si₃N₄ or Zirconium Oxide-ZrO₂). Ceramic bearings are developed for industrial applications under special operating conditions or in corrosion environments [1]. The silicon nitride material is associated with the longest life of materials. However, the dynamic capacity of a full silicon nitride bearing will be only 5% to 12% compared to that of an all-steel bearing, of similar geometry [2].

Because balls made of ceramic materials are lighter (up to 40% less than steel ones) [3], speeds of about 10~40% greater are possible. The low density of ceramics makes them attractive as ball or roller materials for very high speed bearings. This benefit is due to the fact that the fatigue life of very high speed ball bearings can be reduced as a result of excessive centrifugal force on the balls and subsequent increased stress at the outer race [4]. Lower mass balls can diminish this fatigue life reduction. Concluding, ceramic balls are lighter and the ball could easily achieve a higher speed and, in operation, less energy is needed to maintain the rotation. The drawback is that ceramic rolling elements are usually harder than the steel raceway. Under the circumstances, in time, a groove will form in the raceways. In the same way, because ceramic is frequently harder than steel rings, it



generates an increase of stresses, and an overall decrease of load capacity. Another variant used is a full ceramic bearing. Because of the above-mentioned ceramic characteristics, such bearings are noisy at high speeds and prone to cracks at high loads.

If any bearing catalogue is analysed, it is possible to outline the following idea. The maximum speed [min^{-1}] at which a bearing is operating is a decreasing function in relation to the size increase and width decrease of the bearing. In the case of steel ball bearings, higher speeds, for example over $10,000 \text{ min}^{-1}$, are only possible for small size bearings. According to [5], starting from the size of 30 mm of inner diameter for a radial ball bearing, a $15,000 \text{ min}^{-1}$ speed limitation is reached. Growing only one-step, for the inner diameter of 32 mm, the maximum speed limit is $15,000 \text{ min}^{-1}$.

2. Concept origin

Many inventors have made recourse to a solution meant to increase the maximum bearing speed limit, namely that of making single-bearings using common bearings or producing equivalent special bearings designed as independent entities.

The concept of "stacked bearings" has been proved since 1924, being the subject of a French patent [6]. The patent focuses on a bearing composed of two bearings. The constructive solution shown in figure 1 proposes a bearing composed of two radial ball bearings 11 and 12, distinctly dissimilar in size and implicit having different static and dynamic loading capacities. To minimize the radial size of the assembly, a bush 14, with two steps, is used. The patent does not explicitly state that the two bearings can be assembled into one another. The assertion that this compound carries a maximum limit speed equal to the double limit speed of the component bearings is not true. The maximum limit speed is obtained as the sum of the maximum limit revolutions of the bearings comprised by the bearing as further presented.

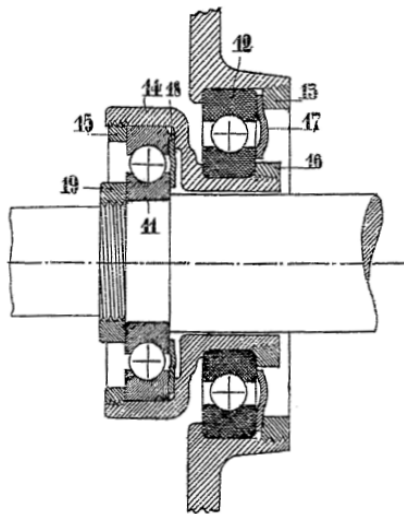


Figure 1. Bearing assembly with two-stage intermediate bushing [6].

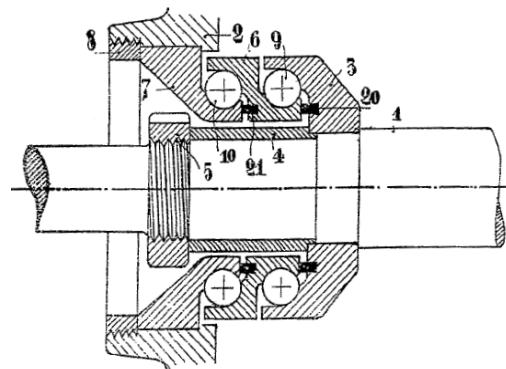


Figure 2. Stacked radial axial bearing [6].

The solution presented in figure 1 may have been a starting point for the solution presented in figure 2. In this case, the bearing does not have two distinct bearings, but represents a radial-axial bearing, even if the author does not emphasize this in the description and in his claims [6]. The bush 6 is an intermediate ring of the bearing, cumulating the functions of the bush 14 of the assembly from figure 1, the outer ring of the bearing 11 and the inner ring of the bearing 12.

An obvious example of "stacked bearing" given in [6] is shown in figure 3. This is in fact a combination of a two-row radial ball bearing on the inner floor of the construction and a radial ball bearing on the outer floor. The outer ring of the two-row ball bearing from the inner floor is modified; on the outside, there is the rolling path for the ball bearings in the outer layer. The inner ring of the

bearing in the outer layer is not presented. The differentiation of the ball diameters from the two floors of the bearing highlights the intention of the author to ensure equalization of the static and dynamic loading capacities of the two floors.

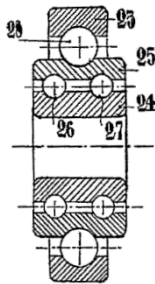


Figure 3. Stacked radial bearing [6].

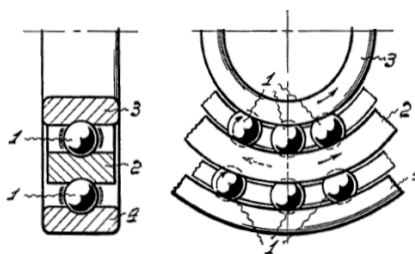


Figure 4. Stacked radial, single row ball bearing [7].

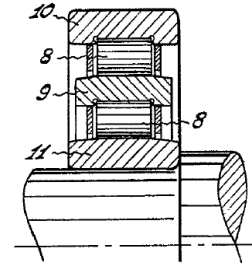


Figure 5. Stacked bearing with rollers on one row [7].

The concept of "stacked bearings" is used in [7] to designate bearings similar to those in figure 3. This patent discloses a claim of a very general nature "bearing, characterised in that at least two rings are separated from one another by a free (free-rotation) ring disposed between an outer ring and an inner one". The description and drawings accompanying the invention explicitly convey the concept by several constructive solutions, all of which have a single intermediate ring.

The stacked radial, single row ball bearing shown in figure 4 is a bearing equivalent to the assembly shown in figure 3. Balls 1, from figure 4, are the same in size, suggesting particular concern for the construction principle and not for the equalization of loading capacities in the two layers.

Figure 5 shows the construction of a "stacked bearing" obtained by combining two radial roller bearings. The intermediate ring 9 and the rollers in the inner bearing layer can axially translate relatively to the inner ring 11 and to the rollers in the outer bearing layer. This detail should be taken into consideration because, if unsolved, it inevitably leads to the failure of the bearing. This is not a universal solution because this type of bearing cannot be obtained by combining NU or N type bearing. The only possibility is to combine one NU bearing with a NUP bearing, the last one being placed on the inside.

3. Stacked bearings obtained by assembling

The solutions presented in the article address the issue of manufacturing bearings capable of carrying high speed, but available at reduced cost and without significant technological modifications in relation to currently used bearings. The main objective that led to the conceiving of these types of bearings, regardless of their constructive type, was the increase of the maximum limit speed that these bearings are capable of carrying. The developed constructive solutions are achievable without or with minimum modifications of the current manufacturing technology of bearings. As the significant increase of the maximum limit speed was the main objective pursued by the authors, subsequent research addressed the development of specific constructive solutions, establishing of optimization modalities of these solutions and refining of the mathematical model, as a prior step to experimental research.

A realistic solution satisfying largely the imposed requirements is given by stacked bearings. This original concept is based on the combination of two bearings, one mounted within the other, thus yielding a bearing with two intermediary layers of roller bodies. The exterior race of the interior bearing and the interior race of the exterior bearing form a single body, the intermediary race, a machinery part characteristic for planetary bearings. Based on the particularity that the inner ring is in fact a combination of the two rings, and if we take into account the resulting motion trajectory for the elements of the ensemble, this new type of bearing can also be called a planetary bearing similarly to a planetary gear. Planetary bearings can be obtained by combining different types of existing bearings.

A homogeneous planetary bearing is obtained by using two similar type bearings. By using two different types of bearings a mixed planetary bearing is obtained.

Because bearings could be identified with a nominal exterior diameter, the same as the interior diameter of other bearings of the same or different types, the idea emerged to assemble two bearings one within the other, as shown in figure 6. The next step was to identify a model that should describe the operation of such an assembly and the performance study. The developed model highlighted that the maximum limit speed of the assembly is theoretically equal to the sum of the maximum limit speeds of the component bearings.



Figure 6. Assembly of homogenous stacked radial ball bearing.

In a stacked bearing, either the interior or the exterior ring is fixed, depending on the mounting diagram, figure 7. The intermediary ring rotates in the same sense as the mobile ring. The rolling bodies rotate both around their axes and around the axis of the bearing in the same sense as the mobile rings.

The name “planetary bearing” assigned by the authors to this new class of bearings may be motivated by the aforementioned movements of the components of such a bearing, even though the name as such may not be entirely accurate.

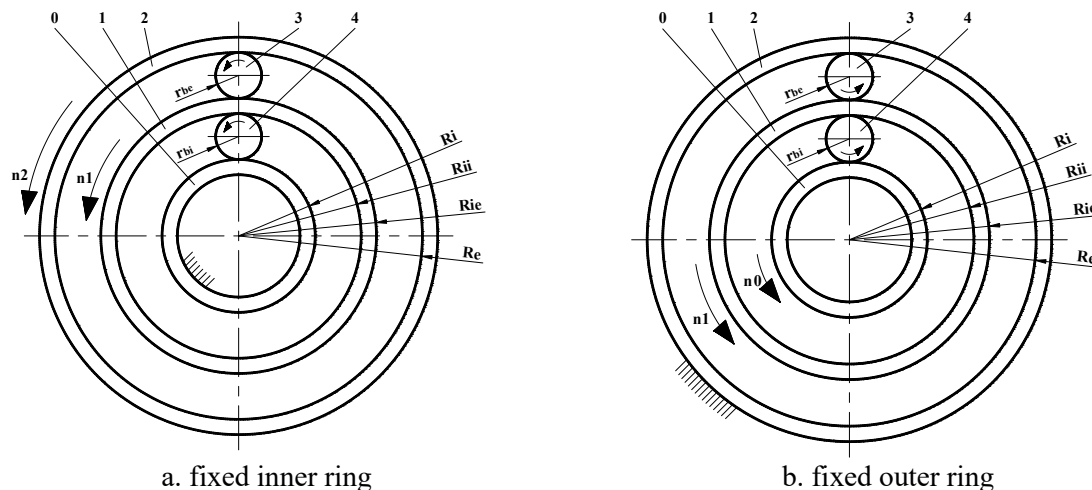


Figure 7. Motions of the component elements of a stacked bearing.

In planetary bearings, under real conditions, the value of the intermediary race speed - as well as that of the rolling bodies - is not constant and determined, being dependent on several aspects: friction coefficients, clearances, the magnitude of the pre-stressing, lubrication, temperature, etc.

From the point of view of commercial bearings, one can identify practical solutions that correspond to a pair that balances either identical widths or similar loading capacities. The data presented in table 1 correspond to a perfect match regarding the width of bearing.

There are many typo-dimensions of radial or radial-axial bearings available where the (nominal) exterior diameter of one is equal to the interior diameter of bearings of the same or different type. When assembling one bearing within another one of the same type, a homogenous bearing is achieved. Figure 8 a, b, c, d shows some examples of homogenous bearings obtained by assembling. Considering the mode of obtaining of a planetary bearing, their symbolisation can be of "exterior bearing symbol"/"interior bearing symbol" type.

Table 1. Example of matching of two ball bearings [8].

Bearing type		Dimensions [mm]			Basic load ratings [kN]		Limiting speed [min ⁻¹]
		d	D	B	C _r	C _{0r}	
interior	6200	10	30	9	5.10	2.40	24000
exterior	6906	30	47	9	7.25	5.00	14000

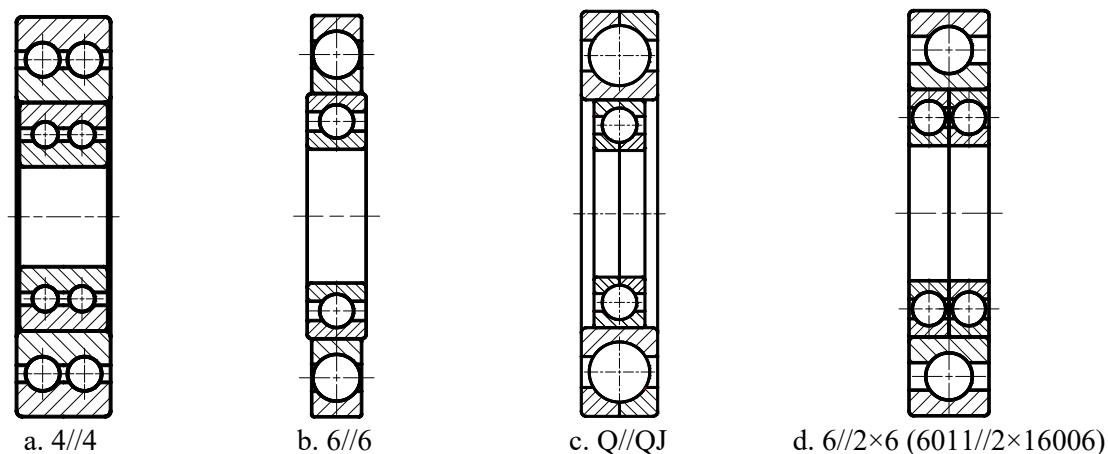


Figure 8. Examples of homogenous planetary (ball) bearings obtained by assembling.

The manufacturers' catalogues indicate a certain performance for each typo-dimension of bearing. From the viewpoint of stacked bearings, the values of the basic loads and of the capable maximum limit speeds are of importance. The ratio of the basic loads for exterior and interior bearings indicates that, in the great majority of combinations, the basic load - both static and dynamic - of the exterior bearing is significantly higher than that of the interior bearing. As the basic load of the planetary bearing is equal to the smallest of the basic loads of the component bearings, equalising measures of the basic loads of the two layers of the planetary bearing is recommended. A solution could be the utilisation of two bearings in the interior layer as presented in figure 8.d.

According to [9], a well-known bearings manufacturer, there is no precise method to indicate at what maximum speed a bearing may operate. To complicate even more the speed assessment, in the case of duplex mounting, as frequent in high-speed machine tool spindles, bearing preload and contact angle affect (decrease) the permissible speeds. The estimated values of the maximum limit speeds of the stacked bearings, obtained by assembling, are determined based on the maximum limit speed values given in the catalogue for the component bearings of the respective bearings.

4. Nested bearings

In stacked bearings, the interior ring of the exterior bearing and the exterior ring of the interior bearing form a single body, the "intermediary ring" and, typically, the same width is selected for both rings. The intermediary ring does not need to have the same thickness as the one resulted from the assembly of the two bearings. In order to overcome the rise in radial dimensions, it is possible to design a common intermediary ring used simultaneously by the inside and outside bearing. In the absence of

another criterion, on a nested bearing the values of the diameters of the balls in the two layers are determined such that the static and dynamic loading capacities are equal.

Considering what has been stated above, the authors of this article have developed a concept based on three rings bearings, presented in figure 15. The invention relates to a radial-axial planetary ball bearing, figure 15.a. This bearing has an inner ring 1 made of two symmetrical elements (a, b), an intermediate ring 2 and an outer ring 3, as well made of two symmetrical components (c, d). The rolling bodies are of the same diameter and are arranged in concentric layers.

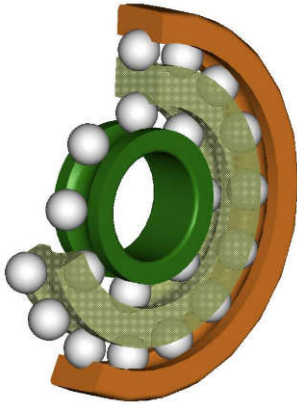


Figure 9. Nested radial ball bearing, homogenous, type 6//6, with equally sized balls on the two layers.

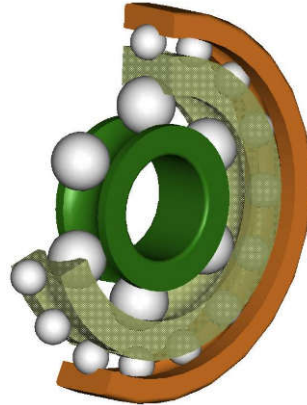


Figure 10. Nested radial ball bearing, homogenous, type 6//6, with the balls' radius on the inner layer bigger than the one on the external layer.

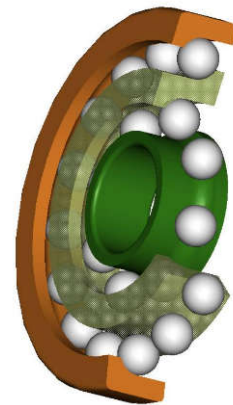


Figure 11. Nested angular ball bearing, homogenous, type 7//7, with equally sized balls on the two layers.

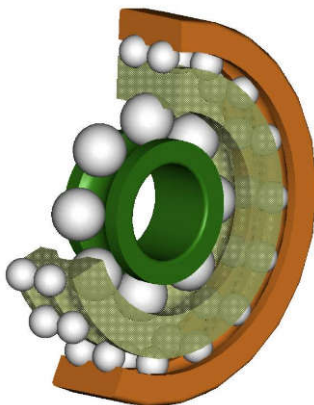


Figure 12. Nested ball bearing, mixed, type 4//6, with the balls' radius on the inner layer bigger than the one on the external layer.

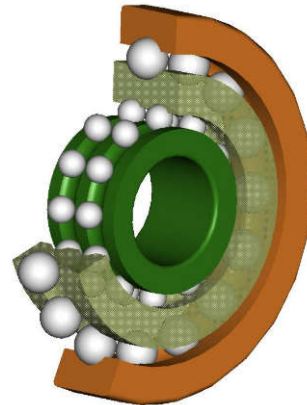


Figure 13. Nested ball bearing, mixed, type 6//4, with the balls' radius on the inner layer smaller than the one on the external layer.

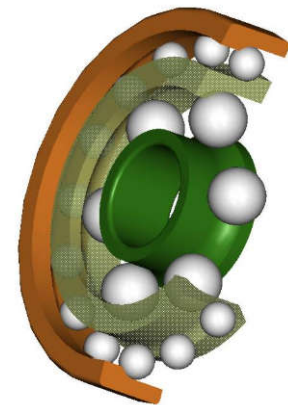


Figure 14. Nested angular ball bearing, homogenous, type 7//7, with the balls' radius on the inner layer smaller than the one on the external layer.

In another variant, figure 15.b, the bearing has an inner ring 6, made of symmetrical elements c and d. The outer ring consists of two lateral parts (g, h) and an intermediate element i. The major difference is related to the number of ball rows and to their size. In this case, the balls are placed in two rows at the exterior.

The variants from figure 15.c and d are practically variations of those presented in the first place, in figure 15.d. with the balls having the same size. This invention is endorsed by Romanian patent RO 123080 [10].

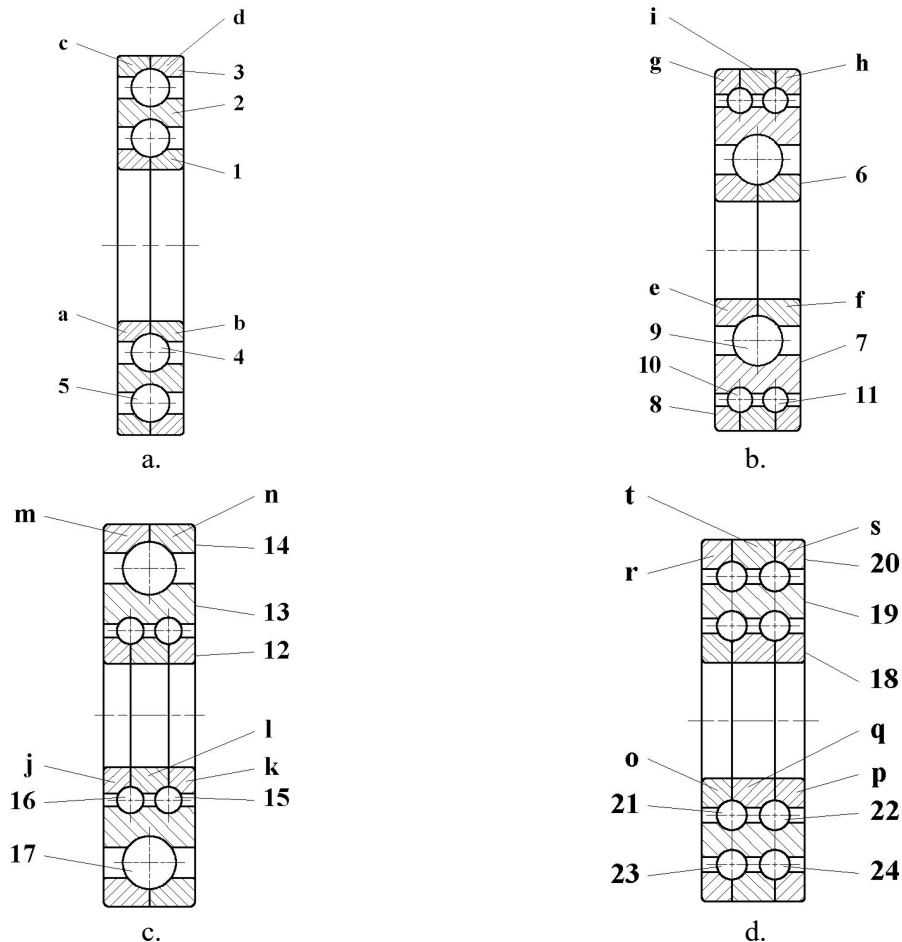


Figure 15. Radial-Axial bearings with three rings.

5. Conclusions

Several authors have proposed special bearings construction, designed to be used at high and very high speeds. Thus, the concepts of "stacked", "nested" and "planetary" bearings appeared. These concepts are principally identical, all identifying the presence of at least one intermediate ring and at least two layers of rolling bodies.

There are bearings available for which the value of the exterior diameter is equal to the interior diameter of other bearings. Two such bearings can be mounted one within the other, forming a stacked bearing obtained by assembling. The two bearings of a stacked bearing obtained by assembling can be of the same or of different types. The load capacity of this type of bearing is equal to the smallest load capacity of the component bearings, and the maximum limit speed is equal to the sum of the maximum limit speeds of the component bearings. This latter quality, the significant increase of the maximum limit speed of the bearings, is obtained by minimum constructive and technological modifications in relation to the existing practical solutions, and has represented another objective pursued by the authors.

In nested bearings, a specific machinery part can be identified, the intermediary race, which is not present in existing bearings, either radial or radial-axial. Nested bearings can be homogenous, if the two components are of the same type, other variants generating heterogeneous combination.

The diversity of bearing types creates the possibility to design, by different combinations, a high number of different nested bearings types. Their conception must also take into consideration the equalization of static and dynamic basic load rating of the two component bearings. This objective can be achieved by adequately establishing the radius value and the number of balls used in the two layers. An efficient solution is the utilisation of rolling bodies of different sizes in the two layers. Another solution highlighted by the authors is that of using two rows of rolling bodies in one of the layers of the bearing.

The main advantages of the nested bearing could be summarised as follows:

- strong increase in maximum limit speed;
- the eventual grip of rolling elements from one layer is not simultaneous with the other while the bearing still retains its functionality;
- there are no technological difficulties to manufacture such bearings since they are essentially the same as actual commercial products.

The disadvantages of these solutions are the following:

- larger radial dimensions;
- overall rigidity of the bearing is diminished;
- possible differences in static and dynamic loading capacity between the two layers of the bearing.

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