Research on advances in roller bearing manufacturing

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Abstract. In general the manufacturing of bearing require strict technological step that are performed on highly specialized equipments that require timely adjustments at batch changes. The process of forging and heat treatment stages consume the most amount of energy but the most expensive stage is the grinding operation. An alternative to grinding and honing processes is hybrid machining by combined hard turning and rolling process. One main development directions of all major roller bearing manufacturers is improving durability of bearings by reducing the roughness by inducing high residual stresses in the surface layers of bearing rings and improving the profile of roller for reduced contact stress. Rolling can induce higher surface stresses and reduce roughness with benefits to the durability of the bearings. The present paper presents and analysis of the technological route for bearing ring and bearing roller and focuses on the research direction on the advances in manufacturing/ machining methods for bearing rings and rollers.

1. Introduction
Roller bearings are key components in all drive system of machine tools, automobiles and in general in all industrial machinery. Although roller bearings are seemingly simple machine parts, their internal geometry is quite complicated [1, 2]. Roller bearings products are key components in the drive systems of the very machine tools on which this manufacturer relies and are critical to the machine’s functionality, durability and machining accuracy, the condition of these components greatly influences the most vital performance characteristics of the machine tool.

The manufacturing processes of roller bearings are complex and require a succession of stages (production route) that takes place in different sectors of a factory, also the manufacturing process is inflexible involving many adjustments of machine tools usually specialized, when changing between different types of manufacturing batches [3, 4]. Also, the development of accurate bearing design methodologies and the increased profitability of bearing production in small or medium series of manufacturing has led to the emergence on an increasing scale of special bearings, designed and made to withstand optimally under certain well-defined conditions. This is a modern trend that is becoming more and more pronounced worldwide, to the detriment of the production of general purpose bearings.

The general directions of optimization of the bearings and implicitly of the components take into account increased L_{10} durability and reduced P_{max} contact pressure [5].

The main manufacturer of roller bearings, in the field of industrial bearings, are SKF Group Schaeffler Group, Timken, NSK, NTN, JTEKT, Rothe Erde, Wafangdian Bearing Group, Minebea Mitumi and C&U [6].

The main development directions of major roller bearing manufacturer are on improving wind turbine generators bearings, electrically-insulated bearings for electrical traction motor designs,
stationary electric motors (medium and large types), generators and special applications including submersible pumps that aren’t affected by high frequency electrical current. Another important direction is providing customers extended support beyond sales and customer service, by developing and improving application through which customers initiate inspection and diagnostic on various bearings. Also, developing Artificial Intelligence system in order to determine early failure on highly complex and large manufacturing system by processing information from a array of sensors. Development of SMART type bearings with sensor integration is an important investment direction for the major manufactures. This category is specific to the automotive field. Another main business direction in bearings manufacture is the bearing refurbish business for special applications [5-9].

2. Analysis of bearing components manufacturing steps

2.1. Analysis of bearing ring manufacturing

The structure of a roller bearing consists of inner ring, outer rings, roller and cages, optional rivets can be used and various seals. The materials used for bearing manufacture of the main components rings and roller are 100Cr6 - ISO 683-17 (AISI 52100) and 100CrMnSi6-4. For each component various manufacturing steps have been identified.

A typical technological route for an interior or exterior bearing ring will be as follows, figure 1.

![Technological route for an interior or exterior bearing](image)

Figure 1. Technological route for an interior or exterior bearing.

In order to increase the flexibility of the process and to reduce the manufacture process steps various researches and methodologies have been identified regarding the possibilities of reduction of the production route, mainly in the machining sector such as Trenpro process [6].

In general it is considered that the forging and heat treatment stages consume the most amount of energy but the most expensive stage is the grinding operation.

The Trenpro process uses helical cutters contacting on the external shell surfaces, which continuously gain in cutting height from the infeed side, from figure 2. The tube is conveyed through the cutting/rolling stand in the axial direction as a result of the continuous rotating motion and is cut into individual rings in the process. The Trenpro process is highly efficient, with a machining time of 4 seconds for ring with a diameter of 47mm. [10].
The process of hard turning is used for finishing of parts (roller rings) with high accuracy of material with hardness over 45-47 HRC, with cutting materials such as pCBN, ceramics or coated carbide. In the past these parts could only be machined by grinding and a series of authors consider hard turning a viable replacement for grinding operation of bearing rings. König pointed out that it is much more flexible and that, due to high-precision machines, the accuracy of hard-turned parts is comparable to grinding processes [11]. Jouini showed that surface integrity and surface topography residual induced stresses are parameters of interest and that influence bearing performance [12]. The experiments performed by Jouini indicate that rolling contact fatigue life increases as Ra value decreases from a value of 0.32 million cycle for a Ra=0.25 mm to a value of 5.2 million cycles for Ra=0.11 mm [12]. By precision hard turning machining a surface roughness Ra=0.11 mm can be achieved [13]. In this case the raceway roughness is similar to the values after the break-in period.

One of the methods to increase the durability of the bearings is low element roughness and high residual induced stresses [14]. Rolling is considered an alternative to honing and grinding processes. Rolling can induce high surface stresses in the material compared to honing and grinding [15]. Hybrid processing processes were initially proposed by Axinte and Gindy [16].

Denkena B., Groove T. and Maiss O. studied the influence of hard turning machining and rolling on the surface quality of bearing rings [17]. Whereas the durability of bearings can be improved by reducing the roughness on rolling surfaces and by inducing high residual stresses in the surface layers of the rings during machining processes. Since grinding processes can generate a low roughness of the machining surface, but cannot induce stresses in the surface layers and by high precision hard pressing a surface quality similar to grinding can be obtained.

The machining process combines the processes of hard turning and deep rolling in a single process to reduce machining time and improve surface quality. [17]. One of the advantages of the process is that an efficient positioning of the rolling tool is obtained with respect to the roughness tips that form roughness, the schematics of the process is presented in figure 3.

The roughness of the resulting surface is significantly influenced by the initial roughness. For smooth surfaces (Rz = 1 μm) high overlapping factors must be used to improve the surface quality. In any case, even very low initial roughness values and overlap factor close to 100% will not remove the lowest points of the profile base, after rolling. The hardness of the machined bearings is too high to smooth the surfaces in total [17].

Figure 2. Trenpro process for ring machining.
After processing, a superior surface quality is obtained by using a lower feed rate than the turning surface. The surface roughness Rz can be improved by up to 24%. Effect explained by the defined, controlled contact between the rolling element and the roughness that forms the roughness. Not all the mechanisms of deformation of the irregularities on the machined surface are known.

The effect of the white layer generated in turning processes, is studied some papers, and indicate that white layers can amplify contact fatigue [18]. On the other hand Denkena claims that white layers they do not influence bearing durability [19]. In general the white layer is removed during grinding.

2.2. Analysis of bearing roller manufacturing

In general the manufacturing process of roller uses cold forming of roller from forged bar or wires for a diameter of roller less than 40 mm diameter, as presented in figure 4. For roller with a diameter larger the 40 mm the roller are machine by turning from forged bars.

The identified research directions are on the one hand classic directions, known for improving the performance of bearings in general, namely increasing durability, reducing noise, increasing loads but also distinguishes a series of research on role design by designing logarithmic profiles. The main
authors that stand out in research on obtaining logarithmic profiles are: Lundberg who developed the first logarithmic function for these bulging profiles to reduce pressures and achieve uniformity of contact pressure. The relationship proposed by Lunberg was improved by Johns-Gohar who improved the function for the convenience of manufacturing. However, the Johns-Gohar profile produces edge loading when the roller is tilted. Fujiwara and Kawase from NTN improved the relationship proposed by Johns-Gohar by adding parameters $K_1$: multiple of $Q$, $K_2$: the ratio between the length of the bulge and the $z_m$: the difference between the cylindrical profile and the crowning at the end of the effective length contact, as presented in figure 5 [5].

![Figure 5. $K_1$ and $K_2$ used for curvature definition proposed by Fujiwara H and Kawase T [5].](image)

Recent studies show that the multi-radius profile can also have very good results in contact geometry, the verification of contact stress mathematical models are made by FEA simulations that allow incrementally loading of the models and determine the stress distribution. In both cases the processing costs are particularly high. If the surface of the roller is not executed very well, the uniform stress distribution cannot be obtained [20-22].

3. Conclusions

Based on the presented considerations and analysis one can conclude:

- There are a number of researches carried out both by researchers from university centre, for example, Spiridon Cretu from the Institute of Technical University of Iasi but also by companies such as top companies such as researchers Hiroki FUJIWARA, Tatsuo KAWASE from NTN, SKF, Timken from the field of bearing production.
- The major manufacturers are extending the area of services provided to the client offering various services and solutions alongside technical support and sales such as electronic application for predictive maintenance of various equipments.
- Regarding ring manufacturing the general tendency of consumers to use Just In Time logistics elements puts pressure on bearing manufacturers to work in small batches, given that bearing lines are intended for large series and mass production. Manufacture of bearing rings in small batches requires long adjustment times of high productivity equipment. Hence the result the need to increase flexibility of the manufacturing routes and replace the highly costly grinding process with hard turning or combined process of hard turning and rolling. In the case of combined hard turning and rolling process with the added benefit of increased residual stresses and reduces roughness.
- Regarding roller manufacturing the problem of determining of optimal profile of the roller is current problem addressed by mathematical modelling and FEA simulations. It is necessary to apply
the extension of known calculation models and adjust the known parameters for a wide range of bearing types.

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