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Increasing the lifetime of roller bearings by using precision deep rolling

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Abstract

It is a well-known fact that residual stresses can improve the lifetime of machined parts. Especially the lifetime of roller bearings is mainly affected by the residual stress state. Conventional machining processes like grinding and honing do not induce high compressive residual stresses in depth of 150 µm to 200 µm to affect the lifetime of roller bearings. Using a defined cutting edge in a hard turning process and applying a subsequent deep rolling procedure, the residual stresses can be shifted to a highly compressive state in great depth. However, due to grinding and honing roller bearings can be machined in a high quality of surface roughness, shape and geometry. In hard turning experiments it could be shown that a comparable part quality to grinding can be reached, if a suitable clamping technique is applied. Within the literature there is no knowledge about the part quality after deep rolling. According to the theory, deep rolling does not affect the shape of the machined parts. It smooths the surface, increases the hardness and induces compressive residual stresses. In deep rolling of roller bearings of the type NU206 C3 high compressive stresses in the subsurface region cause unacceptable shape changes. Within this paper, the shape deviation due to residual stresses is investigated and the main effects on residual stress state and shape deviation are identified. A procedure is introduced how to identify the optimal deep rolling process with respect to the roller bearings lifetime and the surface roughness-, shape- and geometry quality.

Deep rolling, residual stresses, distortion

1. Introduction

In contrast to conventional machining of roller bearing inner rings by grinding and honing, hard turning provides a much higher flexibility and a better ecobalance [1]. However, the desired part quality does not suit the requirements for an optimal bearing performance. Especially the accessible surface roughness is not of a very high quality. One possibility achieving better surface qualities, comparable to grinding processes, is to apply deep rolling. The main advantages of deep rolling are the smoothening of the surface due to the plastic deformation and the induction of high compressive residual stresses [2].

For roller bearings Hacke et al. proved that higher compressive residual stresses within the subsurface area can increase the lifetime of roller bearings up to 100 % [3]. The compressive stresses were induced by an overloading of the bearing within the first $1.5x10^6$ revolutions. Neubauer et al. are using this effect to calculate a specific surface integrity design for roller bearings [4].

Due to machining processes the surface integrity design can be induced into roller bearings during the manufacturing process. As shown by Thiele and Melkote [5] and Denkena et al. [6] within a hard turning process the residual stress state can be influenced. However, the obtainable residual stress states are not suitable to increase the lifetime of roller bearings. Röttger has shown that deep rolling can induce very high compressive stresses [2].

For machining roller bearings, very high requirements on part quality and surface roughness are applied. However, the effect of deep rolling on part geometry and deformation is not analysed in literature. This paper will cover the deep rolling process and its influence on part quality in means of surface roughness and part distortion. Experiments and simulations for part distortion are conducted to identify the optimal process parameters for deep rolling bearing inner rings.

2. Experimental setup

For the experiments inner rings of NU206 C3 roller bearings are machined by hard turning and deep rolling on a high precision lathe Hembrug Slantbed Microturn 100. Within the experiments the mechanical loads on the subsurface are changed by a variation of rolling parameters (table 1). The parameters are varied in three steps. Hydrostatic rolling tools (ECOROLL HG2, HG3 and HG6) are used to conduct the experiments. During the experiments the rolling forces are measured using a 3D-dynamometer Kistler type 9121.

Table 1 Experimental rolling parameters

Rolling pressure p_w [MPa]	Ball diameter d_k [mm]	Rolling overlap o_R [%]
20; 30; 38	2.2; 3.175; 6.35	60; 80; 99

The rings are pre-machined in a volume production. So, standard quality requirements are reached. In the experiments the machining and deep rolling of the runway are applied in the same clamping, thus no reduction of quality occurs due to clamping errors. For the machining a hard turning process with a carbide cutting insert DNMA150616 is coated with Ti(C,N) and Al_2O_3. Constant parameters are applied for all specimens (v_c = 100 m/min, f = 0.1 mm and a_p = 0.1 mm).

To analyse part quality, the surface roughness is measured tactile by a Perthometer Concept from Mahr. The part geometry is measured with a 3D-coordinate measurement system Leitz PMM 866. To analyse the effect of deep rolling on residual stresses X-ray measurements are performed with an XRD 3000 P.

After hard turning the part quality of the inner ring is identified to describe the effect of deep rolling on part deformation. Due to the use of a high precision lathe and a hydraulic expansion mandrel for clamping the roundness of the rings is less than 4 µm. The machined areas have a mean surface roughness of Rz = 1.28 µm, Rk = 0.53 µm and Rpk = 0.34 µm.

3. Surface integrity through deep rolling

During the experiments the deep rolling force F_r is increasing linearly with the rolling pressure p_w (figure 1). Due to this gain of mechanical loads on the surface the roughness values decrease. Besides rolling pressure also the overlap and the ball diameter affect the surface roughness. Large diameter and overlap factors reduce surface roughness below Rz < 0.8 µm.

As presented in figure 1 the rolling pressure increases the maximum compressive stress. The Hertzian contact describes the effect of ball diameter. A small ball diameter leads to a maximum Hertzian contact stress close to the surface. By increasing the ball diameter the distance from the surface of the maximum Hertzian contact stress increases, so do the maximum compressive residual stress values. With increasing overlap the maximum compressive stress moves to greater depth and larger values.

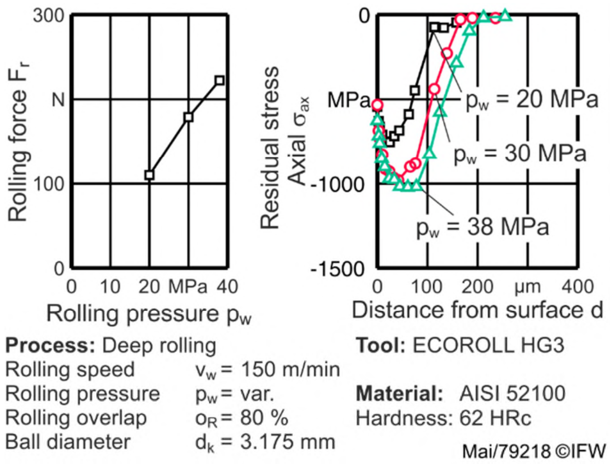

Figure 1. Residual stresses by deep rolling with different pressures

4. Bearing distortion

After the hard turning process the bearing rings fulfil all geometry requirements. After deep rolling high compressive stresses are induced, which leads to a deformation of the bearing inner ring (figure 2). The maximum deformation h_{max} is measured and simulated with the method from Denkena and Dreier [7]. All measured deformation values plotted over the rolling force which increases linearly (figure 2). The measured and simulated values correlate well, which is shown in figure 2 for the runway surface.

Another effect can be identified from the simulation. Within the simulation it is possible to show the residual stress state before and after the deformation. As shown for the different residual stresses induced by a changing rolling pressure, the deformation shifts the residual stress state more into the tensile area. An error can be identified by 14 %.

With the informations from the simulation a strategy can be identified to avoid the deformation of the inner ring by a preconditioning during the turning operation.

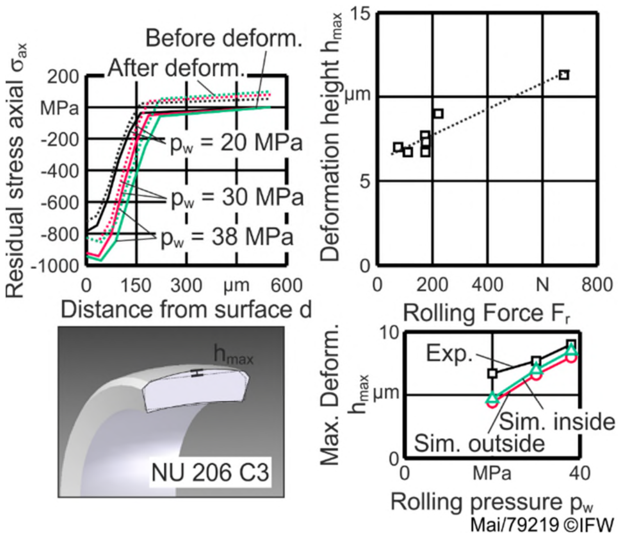

Figure 2. Residual stresses by deep rolling with different pressures

5. Conclusion

In summary, deep rolling for roller bearing inner rings can create very smooth surface roughness. However, the induced residual stresses lead to unacceptable part distortion. By simulating the deformation the preconditioning can be realized in the hard turning operation.

In the future the resulting residual stresses need to be calculated from the process parameters. And the interaction with the pre-machining needs to be analysed. Especially the interaction between the surface roughness before and after the deep rolling process has to be identified.

6. Acknowledgement

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