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Hybrid machining of roller bearing inner rings by hard turning and deep rolling

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ABSTRACT

Hard turning and deep rolling are two processes with high potential to face the challenge of highly flexible and productive machining of hardened parts. On the one hand, the processes of grinding and honing are very productive to manufacture roller bearings, but on the other hand they are very inefficient for frequently changing part geometries. In addition, they do not lead to an increased endurance due to high compressive residual stresses. Hard turning and deep rolling are appropriate processes to achieve this. A hybrid process of hard turning and deep rolling can help to shorten the process chain and to optimize the influence on surface quality, because of defined contacts between tool and surface. A concept of machining roller bearing inner rings with a hybrid process is presented. A force model to predict the resulting turn-rolling forces is introduced. Additionally the effect of feed and the new process parameter shift in feed direction x_f on surface roughness are discussed within this paper.

1. Introduction

Within the last decades the production of bearings has evolved to a highly automatic and effective process chain, which is very productive but in most cases also inflexible. Often the manufacturing lines are designed to machine one single size of bearings. Changing to different types of bearings is expensive and time consuming. This obtains especially for hard machining by grinding and honing. An alternative to these abrasive processes is hard turning, as mentioned by Matsumoto et al. (1999). It is much more flexible and, due to high precision machines, the accuracy of the machined parts is comparable to grinding processes, König et al. (1993). However, grinding is still commonly used in bearing industry. Within the next years smaller batch sizes and individual parts will require a massive amount of flexibility in manufacturing process chains Wiendahl et al. (2007) predicts. At the same time the surface integrity gets much more important for highly loaded parts, Jawahir et al. (2011). Neubauer et al. (2013) mentions, due to the tightening of resources, bearings have to last longer or have to decrease size and weight.

The surface integrity, especially surface topography and residual stresses are relevant parameters to influence the performance of bearings parts (Jouini et al., 2013). For roller bearings an increased endurance can be achieved by high compressive residual stresses within the subsurface area and very smooth surfaces with high material contact areas, shown by Neubauer et al. (2013). Loading induced compressive stresses lead to an increase of 100% of the roller bearings endurance shown by the experiments of Neubauer et al. (2013). Common grinding and honing processes are not able to induce such high compressive stresses into roller bearings (Guo and Yen, 2004). A possible alternative to grinding and honing could be hard turning and deep rolling, as presented by Röttger (2003). Deep rolling induces high compressive stresses (Yen et al., 2005) and reduces the surface roughness (Luca et al., 2005). Hard turning and deep rolling have got similar kinematics and can be performed in the same machines. Both are conducted at similar rotation velocities and feed values.

To face the challenge of highly effective and flexible processes in today's bearing manufacture and an improved surface integrity design the development of innovative processes is essential. The current paper highlights the hard turn-rolling process, which is a hybrid process, applying hard turning and deep rolling at the same time. Denkena et al. (2007) and Axinte and Gindy (2004) have presented similar concepts for soft machining. First Axinte and Gindy introduced the turning assisted deep cold rolling. The presented tool enables a simultaneous manufacturing in one tool holder, where the cutting insert and the deep rolling tool have a fixed position to each other. Denkena et al. developed a tool, which also combines both processes in one tool holder. They also enable both tools to be adjusted to each other by shifting the deep rolling

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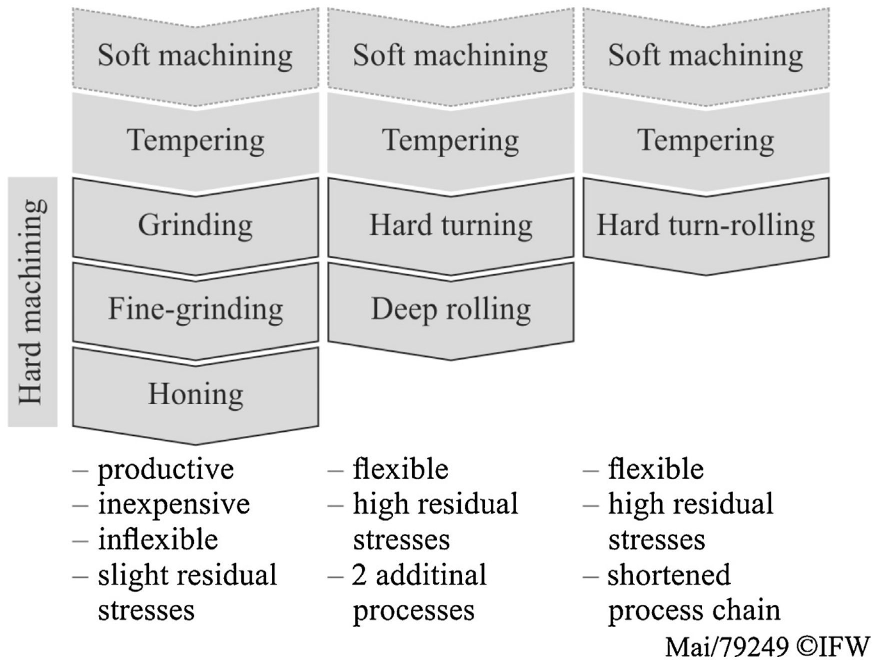

Fig. 1. Conventional and future process chains for manufacturing roller bearings.

ball in feed direction, presented by Denkena et al. (2010). Fig. 1 compares the conventional process chain for bearing manufacturing with hard turning, deep rolling and hard turn-rolling.

Axinte as well as Denkena focused on presenting the combined tool for turn-rolling and its general effect on surface roughness and residual stresses. In the case of the tool presented by Axinte and Gindy the surface roughness decreases from Rt = 3.9–6.1 μm in turning to Rt = 1.6–2.1 μm. This shows already the advantage of the presented process. Axinte and Gindy show that turn-rolling leads to surface improvements without costing more process time. Denkena et al. concentrated more on the effect on residual stresses in turn-rolling of aluminum. Comparing the combined process with deep rolling the maximum compressive residual stresses reach almost the same values with a smaller penetration depth.

Besides the advantage of a shortened process time, some other aspects have to be considered in hard turn-rolling. In case of hard turning, very high temperatures are achieved within the process. Comparable to a warm shot peening process presented by Wick et al. (2000) this could lead to residual stress state in higher depth from the surface and to a smaller surface roughness due to more plastic deformations in the subsequent deep rolling process. The aim of this paper is to present a turn-rolling tool to machine hardened roller bearings and to define the process parameters which describe the hybrid process. A comparison of the hard turn-rolling with conventional hard turning and deep rolling will show the general potential of the process to improve surface quality. Additionally the process forces are discussed within a force model to predict the mechanical loads for the machine tool.

2. The hybrid process turn-rolling

This chapter introduces a hybrid turn-rolling tool for hard machining and its process parameters. In order to utilize the elevated workpiece temperatures of hard turning for the subsequent rolling process the distance between the cutting edge and the deep rolling tool has to be as short as possible. Therefore, the deep rolling tool is mounted to a modified tool holder. The principle is shown in Fig. 2, left. By using a deep rolling tool and a cutting insert with the same radius, both tools can be adjusted to each other, as shown in Fig. 2, right.

Due to the dimensions of the tool holder, the rolling tool and the workpiece diameter $d = 37.5$ mm, it is necessary to tilt the deep rolling tool ($\phi_W = 50°$). Otherwise as in the combined process by Denkena et al. the rolling tool would not get in contact with the bearing surface. The tilt angle ϕ_W also reduces the distance between cutting insert and rolling element x_c to a minimum value of $x_c = 13$ mm. A guide shifts the rolling element related to the cutting edge. Measuring the shift with an indicating caliper the rolling element can be adjusted very precisely (±2 μm). This concept allows a more precise surface modification then the turning assisted deep rolling by Axinte and Gindy. Fig. 3 presents the theoretical advantage of this shift x_f in feed direction. By positioning the rolling element directly behind the cutting insert, high contact stresses in greater depth will occur, because of the hertzian contact. However, due to the same radius of the insert and the ball, there will be no influence on the surface roughness. Is the rolling element shifted by the half feed value ($x_f = f/2$), the contact area becomes smaller and localized to the surface roughness peaks. This will lead to a smoothening of the surface roughness.

Due to the combination of both processes some process parameters of the single processes cannot be chosen unequal simultaneously. For example cutting speed v_c and rolling speed v_W or feed f and rolling feed f_W have to be the same value. Fig. 2 and Table 1

Table 1
Process parameters of the hard turn-rolling process.

Process parameter	Symbol	Unit
Cutting speed	v_c	m/min
Feed	f	mm
Depth of cut	a_p	mm
Edge radius	r_ε	mm
Rolling tool diameter	d_k	mm
Rolling pressure	p_W	MPa
Rolling tilt angle	ϕ_W	°
Distance in cutting direction	x_c	mm
Rolling shift	x_f	μm