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Surface integrity aspects of milled large hardened gears

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Abstract

With the rising performance of wind turbines the requirements for large scale gears are growing. Due to the bigger loads based on the higher megawatt output per turbine gears especially at slewing bearings need to be hardened. Rising demands for better gear qualities and higher loads require a hard machining of these hardened gears. The development of special cutting materials for geometrically well-defined cutting edge processes enables the manufactures to mill these gears in hardened condition on standard milling machines. The process of milling hardened gears needs control of the surface integrity of the tooth flanks. The generation of white etching areas must be avoided and can be influenced by process parameters (e.g. cutting speed and feed rate). Preferably compressive residual stresses should be generated in the surface and sub-surface of the tooth flank. The paper describes the potentials of milling theses hardened gears instead of grinding and reveals the generated surface integrity state.

Keywords: Gear cutting; surface integrity; large scale components

1. Introduction

Large-diameter ball bearings are provided with gears for many applications in order to ensure the turning and positioning of the respective technical facilities. Due to the high forces which have to be transmitted, hard machining of gears is unavoidable in many cases.

A classic application for a positioning operation realized by teethed large-diameter ball bearings is a wind turbine. In these systems they are either applied as yaw (azimuth) bearings or as rotor blade pitch bearings [1].

In recent years, an enormous increase in megawatt performance per wind energy system (WES) is recorded. A closer look shows a doubling of nominal power in megawatts every three to four years [1]. Due to this rise in performance, the components applied are of increasing size so that the used large-diameter ball bearings have to absorb greater forces and moments. With the current power stage of 5 to 6 MW (as prototypes even up to 7.5 MW), the mass to be moved as well as the loads to be absorbed increased due to the increased performance (one rotor blade bearing of a modern WES needs to bear wind loads of up to 30 t). This increase in mass caused an increase of noise emission [1] as well as an increase in the number of required drives for the azimuth and rotor blade pitch. Furthermore a hardened gear is necessary due to the high load. Related to the respective design of the large-diameter ball bearing and the maximum achievable accuracy resulting from distortion and deformation due to heat treatment, a hard machining of teeth at the end of the process chain is applicable in order to meet the required accuracy.

Another classical application of geared large-diameter ball bearings are tunnel driving machines. The use of these special machines requires large-diameter ball bearings to rotate continuously, as the rotary motion of the drilling shield is generated by these bearings. Shield diameters of 16 meters are nowadays rather the standard than the exception. Partly up to 24 hydraulically operated pinions are running in these tunnel driving machines as drive of the large-diameter ball bearings and therefore of the drilling shield. The modules for gears in this special type of large-diameter ball bearings range from 40 to 44 mm. Modern high performance gearing machines with machining diameters of 10,000 mm can

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manufacture gears up to module 60. Tooth widths of 400 to 600 mm are thereby no curiosity.

However deformations result from the machining and hardening processes, which can cause a tooth traces total variance of 1 to partially 2 mm in gearing. Hard machining is therefore inevitable.

In the named applications such as WES and tunnel driving machines as well as in other applications up to 10,000 mm diameter hard machining of gears is mostly performed by a geometrically well-defined cutting edge.

The application of modern, extremely hard cutting materials enables an economic optimization of manufacturing with additional direct influence on the surface integrity of the workpiece. The durability of the workpiece can thereby be significantly influenced.

2. Investigation in industry

The tests for this project were carried out specifically under realistic industrial conditions in order to ensure a transferability of the results into practice right from the beginning. An internally toothed gear is chosen as test workpiece (see table 1).

The workpiece for the research program consists of a high-alloyed steel of type 42CrMo4 (EN 1.7225; AISI 4137). The tooth flanks were induction hardened for the tests and have a surface hardness of 56 to 58 HRC.

The workpieces were manufactured at a gear hobbing machine of type Liebherr LC 4000 (see figure 1) in single tooth gap machining.

Table 1. Geometry of the test workpieces

Module	m	14 mm
Number of teeth	z	-162
Addendum modification	$m \cdot x$	-7 mm
Pressure angle	α	20 °
Helix angle	β	0 °
Pitch diameter	d	-2268 mm
Gearing width	b	200 mm
Outer ring diameter	d_a	2500 mm

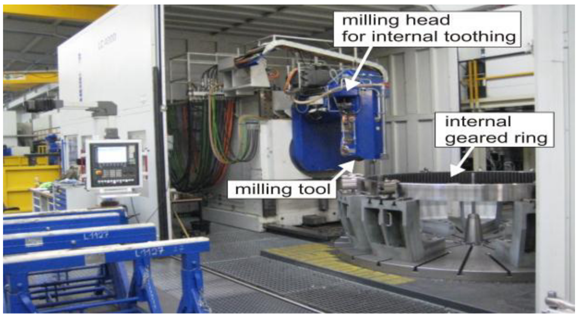

Figure 1. Experimental setup

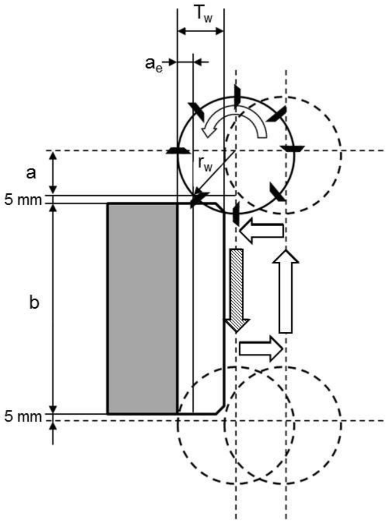

Figure 2. Principle of single tooth gap form milling in up-cut mode

Up-cut milling was chosen as milling strategy in order to introduce normal forces into the workpiece support and not to lift the gear from the workpiece clamping. Figure 2 shows the principle of single tooth gap form milling as it was executed in the tests.

Also Bouzakis has confirmed that up-cut milling with cutting speeds between 100 and 200 m/min is beneficial compared to down-milling [2]. As cutting materials for the tests, coated tungsten carbide P20-P40 types as well as uncoated P25 types were used. Theses materials represent the current cutting materials for the geometrically well-defined dry machining of hardened gears applied in practice [3].

In the context of these tests further modern high-performance cutting materials were tested in order to achieve process optimization. As for the tested ultrafine grained tungsten carbide (UF-HM) as well as for the examined polycrystalline boron nitride (PCBN) tool, the ideal technological application parameters for hard machining of gears were determined in tests [4, 5]. The comparison of the two modern cutting materials led to the conclusion that the tungsten carbide is superior to the PCBN under economic and technological aspects. For this reason only limited tests on PCBN are presented here. The PCBN was used with a content of 90% CBN due to the higher ductility [6, 7, 8, 9].

Following the chip removal analyses, hardened gearings with the respective ideal technological parameters were milled with each cutting material. Subsequently, the analysis of gearings concerning a thermal influence on the surface integrity, namely thermal overload, was executed. In the following the