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Adjusting surface integrity of gears using wire EDM to increase the flank load carrying capacity

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Abstract

High performance gears require high geometrical qualities. For these aspects expensive grinding processes are indispensable as finishing processes. This paper deals with the investigation of wire EDM (WEDM) as a technological substitution to grinding from part functionality point of view. Geometrical gear quality, surface integrity and load carrying capacity for WEDM and ground gears were analyzed and compared. No difference regarding gear shape was found for both processes. Residual stress and hardening profiles did not show significant differences. The topography features the process typical characteristics. Following, load carrying capacity of the tooth flank surfaces was investigated. The WEDM finished gears last three times longer than the ground gears due to a beneficial running-in topography formation with increased tribological characteristics.

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Nomenclature

α_n	normal pressure angle
β_2	helix angle of the workpiece
q	allowance
M_1	torque
m_n	normal module
z_1	number of teeth of the pinion
z_2	number of teeth of the gear
σ_{RS}	residual stresses
t	temperature
a	axis distance
n_1	rotation speed
b	gear width
d_a	tip diameter
x	addendum modification
C_α	tip relief
C_β	lead crowning

1. Introduction

In powertrain applications, gears are one of the most common mechanical elements. The application of gears ranges from low power, e.g. clocks, to high power applications, e.g. marine. To manufacture a gear, several process chains can be realized. In many of them, fine machining is the final machining process. Therefore, fine machining is the most important quality defining step in gear manufacturing.

This paper deals with the comparison of the load carrying capacity of gears finished by the common profile grinding process and the WEDM process as possible technological alternative. In particular, the influence of the finishing processes on the manufacturing related workpiece properties are taken into account.

Heavily loaded rolling contacts such as the gear tooth flank contact, are complex tribological systems. These systems are

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characterized by the interactions between the contact partners, the lubricant and the surrounding medium. The properties of the tribological system significantly affect the behavior in terms of friction, wear and fatigue in rolling contact. In the past, several experimental in gear running trials have been conducted. The rolling strength is significantly influenced by the material, the peripheral zone properties of the heat treatment, the surface finish as well as the operating parameters [1, 2, 3, 4, 5]. The friction of the rolling contact results from the type of lubrication, the contact temperature as well as the surface roughness and kinematic conditions in the contact gap [3, 6, 7, 8]. In order to decrease the friction in tooth contact and increase the flank load carrying capacity, the surface structure is modified [7, 8]. Compared to the 2D values Ra and Rz a complete surface topography measurement gives more information about the orientation and shape of manufactured surface features. Using an optimized surface topography, a reduction of the friction and a higher load carrying capacity in rolling contact can be realized [8].

2. Goal of study and trial conditions

The use of gears in high power density application requires high quality in terms of geometry and surface properties, in order to ensure structurally intended functionality. In the conventional process chain, the required quality of the gear is achieved by a grinding process after heat treatment. Because of the required additional machines and tools for gear grinding, this process leads to increased costs.

Because of this, alternative and more cost-effective process chains are of particular interest in industry. WEDM has been proposed as an alternative and innovative method for hard finishing of spur gears especially for prototype applications, see [9]. The WEDM process is characterized by high flexibility regarding workpiece geometry, since no special tools are required. The process forms the geometry easily by the axis movement of the wire electrode.

The general equal technological capabilities of contemporary EDM processes compared to other machining technologies was already shown in other works. Welling for example showed that WEDM provides an alternative to the established broaching process for the production of fir tree slots as shown by similar performance in according fatigue tests, cf. [10]. In another research work, the fatigue bending strength was investigated for WEDM samples under going cyclic loading. The results show that for titanium, similar bending fatigue strength of wire-eroded components and corresponding ground specimens are achieved. The analysis of the thermally influenced rim zones in the cross section showed that for both processes similar extents, although the surface roughness of the ground sample was significantly lower [11].

In order to evaluate the WEDM process as possible alternative, the final part functionality and the process induced surface integrity have to be analyzed in detail. Two processes with comparable surface integrities and therefore obligatory resulting similar utilization performance could then be treated as comprehensive alternatives from a technological point of view. Ideally, the manufacturing process can be adjusted in such a way that the required surface integrity can be deterministically achieved.

But in industrial practice, the generation of a desired surface integrity of high performance components is still an iterative process based on experience. Despite the findings of researchers correlating the process parameters with the resulting surface integrity, it is not possible to deduce the required process parameters from a given desired surface integrity. An example of this so-called inverse surface integrity problem is given in [12]. A collaborative work of the CIRP studied if a workpiece surface with defined compressive residual stresses of 200 MPa could be manufactured by experts using different machining strategies. The results – ranging from -800 MPa to + 600 MPa – show impressively that still a deterministic achievement of this goal is not possible.

The concept of Process Signatures is a promising strategy to achieve a knowledge-based solution of this inverse surface integrity problem, [13]. A first step within this context is to identify comparable machining technologies for a given industrial test case. Figure 1 gives an overview of the gear data used in the presented investigation, the production process chain of the gear and the test rig concept for investigating the rolling strength.

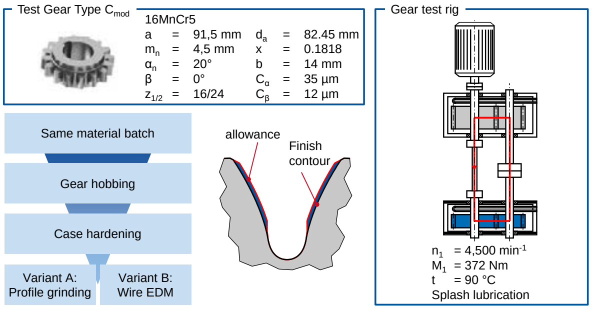

Fig. 1. Gear variants and test rig

A standard test gear geometry (C_{mod}-type) is used [1, 3, 6]. Compared to the conventional gear design of the C-type test gear set, flank modifications are defined with a tip relief of $C_a = 35$ µm and lead crowning that amounts to $C_\beta = 12$ µm. The gear load carrying capacity test rig is in according to ISO14635, with a center distance of a = 91.5 mm and was run under splash lubrication controlled to T = 90 °C [14]. Using the common profile grinding and the WEDM process, two different surface topographies were adjusted on the tooth flank surface on the pinion. All test pinions were paired with a profile ground gear.

3. Gear manufacturing

All machining processes were performed at RWTH Aachen University allowing a detailed control of the test parts properties. After turning, the parts were hobbed on a gear hobbing machine Gleason-Pfauter P600/800. The hob was a coated PM-HSS tool [15]. After soft machining the parts were