Challenges in Reverse Engineering of Unknown Gears by 5-axes-milling

G. Goch, M. Fuhrmann, K. Lübke, D. Stöbener, A. v. Freyberg
Bremen Institute for Metrology, Automation and Quality Science – BIMAQ, University of Bremen, Germany

m.fuhrmann@bimaq.de

Abstract

Reverse engineering of damaged gears means manufacturing small batches of gears with a wide range of geometries. For this task a special production process is required. Firstly, both material and geometry of the damaged gear have to be identified. Secondly, manufacturing has to be sufficiantly flexible but also efficient. The best solution for this task is to apply a manufacturing process, which can use standard tools for the various gear geometries. Gear hobbing as the standard manufacturing process requires a gear dependent tool, whereas 5-axes milling can use universal milling cutters in this field of application.

1 Introduction

The European Union agreed to cover about 20% of the electric energy supply by renewable energies in 2020. According to this, wind energy becomes increasingly important, but the rapid evolution of wind turbines is at the expense of reliability. Insurance statistics revealed that in many cases the gear boxes are the origin of malfunctions. A failing wind turbine gear box can often be fixed by replacing the spur gears or bearings. But, repairing is expensive and the delivery times are long. Thus, alternative solutions are requested, especially from the operating companies. Regarding gears, a manufacturing process would be interesting, which is independent of gear-specific tools like hobs [1]. 5-axes milling is considered to be a feasible approach for the flexible reproduction of almost every type of gear [2].

2 Gear manufacturing with a 5-axes milling machine

Reverse engineering by 5-axes milling may significantly reduce the delivery time of spare parts, as no tool adjusted to the exact gear geometry has to be ordered. The process consists of five steps (Figure 1). At the beginning, there are no design

drawings and no material information available from the manufacturer. Thus, the first step is to determine all the necessary gear parameters required for manufacturing. Material characteristics and the method of heat treatment are derived by a metallurgical analysis. The gear geometry can be evaluated on the basis of a holistic measurement with a coordinate measuring machine, covering preferably every flank of the gear [3]. Certainly, badly damaged flanks may have to be omitted. The resulting scatter plot has to be approximated by a holistic approach to evaluate the nominal geometrical parameters (see section 3).

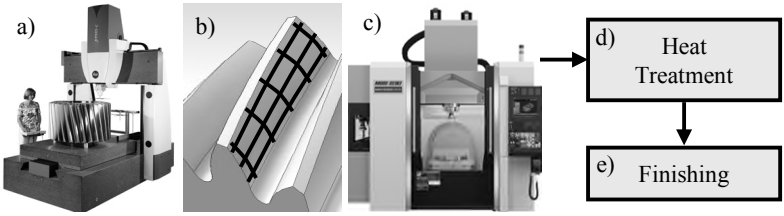

Figure 1: Gear production process using a 5-axes milling machine: a) areal measurement [Hexagon Metrology GmbH], b) evaluation of gear parameters, c) 5-axes machining based on a CAD-model [Mori Seiki GmbH], d) heat treatment and e) finishing.

Based on the determined parameters, a CAD model of the gear has to be created to generate the machining code for the 5-axes milling process. This code generation, based on a solid model, will be performed by a CAM software. The complex geometry of the flanks can usually be described by splines with a mathematical accuracy considerably below one micrometer. Additionally, modern gears are designed with modifications like tip relief or crowning. These modifications may differ between the two flanks of one tooth, for example for gears in wind turbines with a preferred direction of rotation. Their implementation in these models is still ongoing work. Vendor requests revealed that upcoming software updates will include gear modifications in the CAD model. A first possible solution to realize such modifications for 5-axes milled gears may be a correction of the flanks by the finishing process. But, this might reduce the effective local hardening depth by several 10 µm.

The next steps of the process chain consist of the gear cutting by means of the machining code, a subsequent heat treatment according to the metallurgical analysis and a finishing process, e. g. gear grinding.

3 Holistic gear approximation

The first step of reverse engineering of large cylindrical gears aims at the evaluation of the production parameters of the gear. Beside material and heat treatment parameters, the knowledge about the nominal gear geometry is essential for the reproduction. Some parameters for defining the base body, like tip circle or number of teeth, are very easy to determine. On the other hand, the exact geometry of the flanks themselves is complex to define. Regarding the profile of a flank, usually three different parts have to be defined, each having great impact on the gear's operation characteristics. From tip to root the first part is the tip relief to calm the meshing. The second part is the involute, the area of mutual contact with the mating gear, mostly created with modifications. The last part is the root relief providing space to the mating tooth.

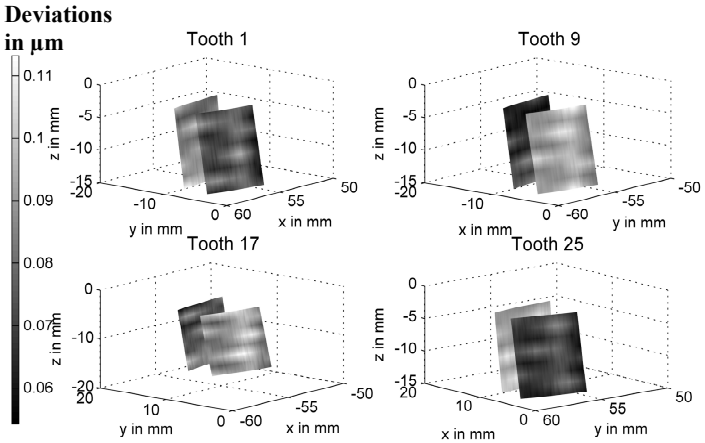

Figure 2: Holistic approximation of a gear where levels of gray indicate the deviations between four measured teeth and their nominal geometry.

The evaluation of the flank geometry is a multi-step process. The initial values for the gear parameters can be found by a single profile scanning on the gear and some manually probed points in different heights. Based on these initial values, a measuring process with an areal probing of preferably every flank can be started. Such an extensive database is required for reducing the effect of deviations due to

the manufacturing process and wear. By approximating the resulting scatter plot (comparably to [4]), the exact production parameters of the gear can be obtained. Figure 2 illustrates such a holistic approximation by showing the differences between a measured gear and its ideal geometry.

4 Conclusion

For the standard manufacturing techniques of gears (e.g. hobbing) detailed CAD-models are not necessary. Thus, most software tools only provide volume models of basic gears without gear modifications. Furthermore, for a 5-axes milling of gears also the geometries of both tip and root of the teeth need to be modeled within the CAD-CAM software chain. Concerning the measurement of unknown gears a few commercial software solutions exist. But, they can not automatically determine all required gear parameters and they do not offer the possibility to sufficiently characterize the usual modifications of gear flanks.

Acknowledgement

A part of the research described in this paper was funded by the German Research Foundation (DFG – Deutsche Forschungsgemeinschaft) within the project B9 of the collaborative research center 570 “Distortion Engineering”. The authors also gratefully acknowledge the support of the Machine Tool Technologies Research Foundation (MTTRF) and the DP Technology Corp. providing a high-precision 5-axes milling system (Mori Seiki NMV 5000 DCG) and an efficient CAM Software system (ESPRIT).

References:

[1] Bouzakis, K. D., Lili, E., Michailidis, N., Friderikos, O., 2008, Manufacturing of cylindrical gears by generating cutting processes: A critical synthesis of analysis methods, CIRP Annals - Manufacturing Technology, 57/2: p. 676-696.

[2] von Freyberg, A.; Fuhrmann, M.; Lübke, K.; Stöbener, D.; Goch, G.: Gear production on a 5-axes-milling machine. In: MTTRF - Machine Tool Technologies Research Foundation (Hrsg.): MTTRF Annual Meeting 2009, Shanghai, P.R. China. 2009, p. 125-140.

[3] Goch, G.: Gear metrology. Annals of the CIRP 52/II (2003), p. 659-695.

[4] Lotze, W.: Zahnradmessung mit Koordinatenmessgeräten. Grundlagen und Algorithmen für die 3D-Auswertung nach dem Flächenmodell. Dresden, 2005.