Ausfall eines Getriebes durch Zahnbruch
Photo: © IW

Measurement techniques for precision forging

A shortened "precision-forging" process chain requires, apart from stable manufacturing processes, a fast and thorough quality inspection of the components. Quality criteria such as form deviations, hardness properties and operating strength of precision-forged gear wheels with integrated heat treatment are acquired within the process chain, evaluated and used for the optimisation of the manufacturing processes.

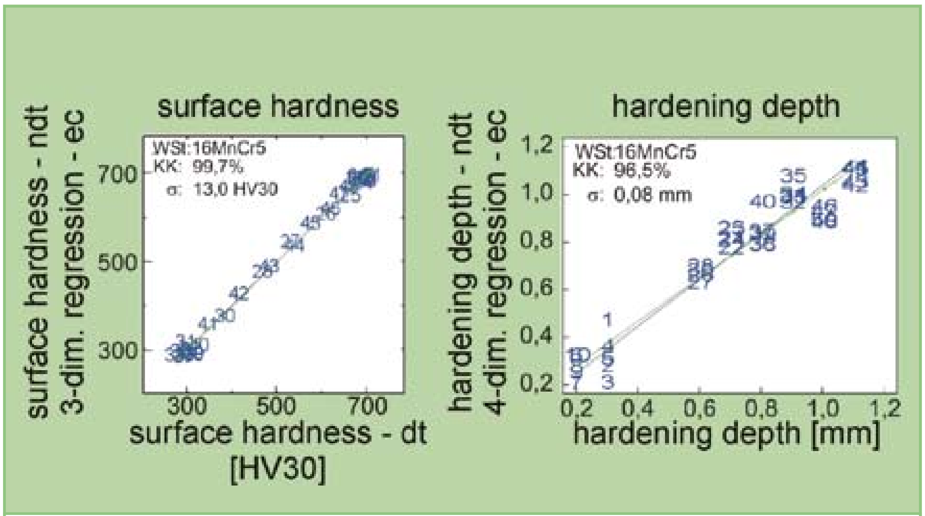
An integrated component inspection for process analysis and process control opens up new possibilities for the economic manufacturing of highly stressed mechanical engineering parts of high quality. The production-related objective acquisition and monitoring of relevant component characteristics within the process cycle is thereby of substantial importance for process control and to achieve a high level of process security.

In shape or not in shape

In order to reliably control the process chain for the manufacturing of precision-forged high-performance components which has been developed in connection with the collaborative research center 489 (SFB 489), production-related geometry control of the intermediates is essential. The characterisation of the geometry information informs about the type and intensity of the deviations and thus supplies the actual data for process feedback control.
By this way for example the wear of the forming dies or formal defects resulting from the integrated heat treatment can be detected.
The typical process-induced geometry deviations occurring during the precision-forging process possess completely different systematics than deviations occurring during the metal-cutting manufacturing process. As a consequence of the forming in the forging die, geometry deviations that are individually and coincidentally distributed over the teeth result, making an areal measurement of all teeth of the gear wheel necessary. The line shaped acquisition of the tooth profiles employed in traditional gear metrology is insufficient here, since local defects are not recognized with adequate security. For a fast and areal acquisition of the entire tooth geometry of the precision-forged gear wheels an optical gear wheel measuring system based on the fringe projection technology was developed and constructed. With the optical and areal acquisition an analysis of the gearing geometry is made possible, as well as drastically reducing the testing cycles compared to conventional gear wheel measurement.
The results of the optical geometry acquisition of precision-forged gearwheels are best presented as three-dimensional deviation images. This kind of presentation already permits a qualitative evaluation of geometry deviations of the teeth. Especially the locally and coincidentally distributed geometry deviations typical for precision forging and thermally induced systematic deviations can be detected easily. A quantitative analysis of the geometry deviations can be done using the areal characteristics developed during the project.

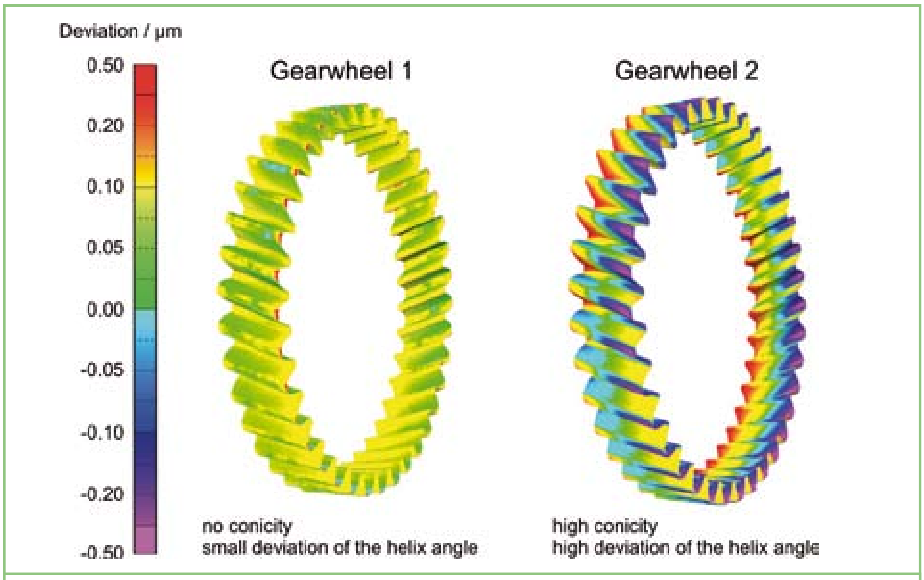
Hard shell, soft core

The task of providing high abrasion resistance and fatigue strength of highly stressed gears demands graduated material properties within the tooth. This is a hard and abrasion-resistant surface layer with an appropriate hardening depth, inherent compressive stress and a ductile high-strength tooth core transferring the tooth load. By an integrated heat treatment of the precision forged gear wheels from the forging heat using a water-air spray cooling, newly developed at the Institute of Materials Science, the necessary material properties of the gears are being accomplished. The necessary profiling and surface quality of the teeth are reached by the subsequent hard finishing within the process chain. The re-

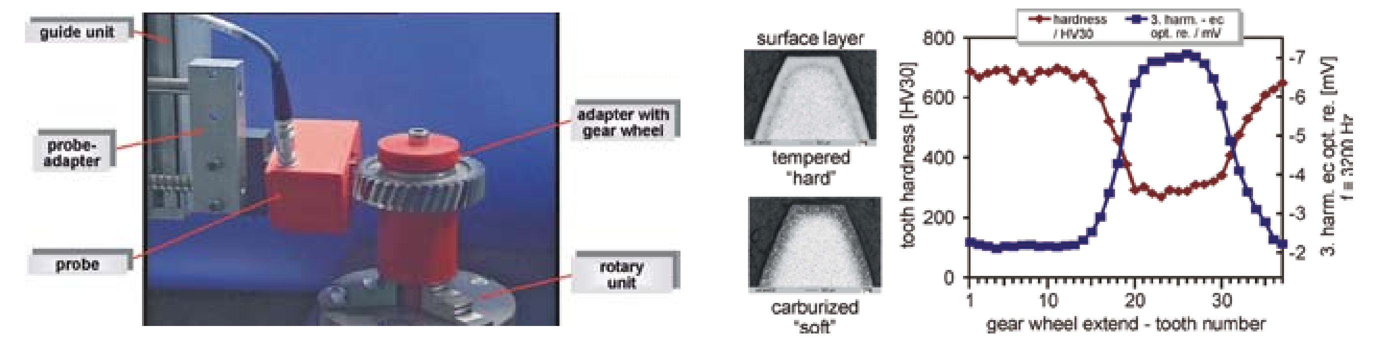


Correlation of destructive and non-destructive testing.
Photo: © IMR

quired quality of the gear wheels demands testing of the hardness properties of the gears within the process chain in order to achieve quality assurance by process control. Dealing with high performance components made of ferromagnetic materials, non-destructive magnet-inductive testing procedures combined with harmonic analysis of eddy current signals for the acquisition of material characteristics are a natural choice. With the harmonic analysis of eddy current signals, a measuring technique has been developed at the Institute of Materials Science which allows non-destructive, fast and accurate acquisition of hardness values of gear wheels.
For the realisation of a non-destructive process-related hardness testing within the process chain an integrated measuring probe for the acquisition of the surface hardness of the whole tooth system area as well as a single tooth measuring probe for the acquisition of the surface hardness and hardening depth of single teeth were developed.
During the testing of a set of different conventionally machined reference gearwheels made of the case hardening steel 16MnCr5 with a defined surface hardness and different hardening depths a specific batch could be clearly identified as faulty. The reference set with a hardening depth of 0.5mm showed varying tooth hardness of "hard" and "soft" teeth over the extent of the gearing as a result of a faulty heat treatment, which was clearly visible in the 3rd harmonic of the eddy current signal.
Due to physical correlations of the magnetic and mechanical hardness approximately linear dependences between the hardness values measured by non-destructive testing and those measured by the Vickers method exist.
Based on these connections the multi-dimensional regression of significant harmonic signals shows a high degree of correlation with the Vickers method as a measure for the good congruence of the non-destructive and conventional testing technique.



Three-dimensional representation of gearing deviations
Photo: © IMR



Automated single-tooth hardness testing. Faulty hardening of an industrially produced gearwheel.
Photo: © IW

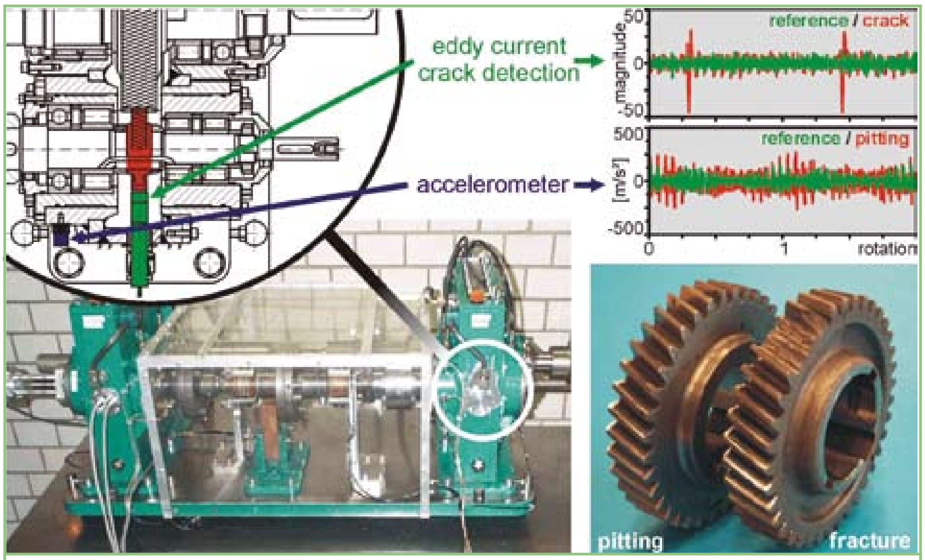
Apart from the hardness the hardening depth is another important hardness characteristic regarding operating strength of gearings. With selected significant harmonic measured values concerning the hardening depth there are furthermore possibilities to determine the hardening depth in a non-destructive way with a high level of accuracy by multi-dimensional linear regression. These results clearly show that grain structure changes in the surface layer caused by alloy changes or heat treatment can be sensitively detected by harmonic analysis of eddy current signals and that local hardness values of single teeth can be acquired by non-destructive test methods. It has been shown exemplarily that also with the conventional fabrication of gearwheels made of case hardening steel non-destructive hardness testing is useful for quality control.

Bearing the load

An evaluation of the component properties running smoothness, tooth flank strength and tooth root strength after finishing of precision forged gear wheels requires the testing under realistic operating conditions. Precision forged gear wheels are compared to conventionally machined ones in order to detect influences of precision forging, heat treatment and hard finishing on quality and component properties. The testing regarding tooth flank strength and tooth root strength at the special test bench for helical gear wheels can also detect influences of surface condition and geometry deviations. This enables other sectional projects to optimise the component a well as the particular manufacturing steps.

To evaluate the running and noise behaviour, the analysis of vibration and structure-borne sound is used. The application of special analytical methods allows the recognition of teeth mesh specific vibration signatures, the assignment of accordant causes of excitation and permits the classification of the corresponding component's condition. Thereby it is possible to detect and relate damages at an early stage. For the early detection of cracks in the tooth root eddy current sensors have been integrated. A crack changes the distribution of the eddy currents within the component, thereby causing a change in the amplitude of the signal.

The integration of testing methods for fast geometry acquisition and for non-destructive hardness testing within the process chain "precision forging of helical gear wheels" as well as a subsequent test under realistic load conditions allows component testing and optimisation of manufacturing steps in the context of quality control. During every day operation gear wheels and gear units are subjected to highest levels of stress. By using process-integrated testing techniques the reliability can be enhanced. After all, one defective tooth is already one defective tooth too much.



Special test bench for helical gear wheels
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