07 - 10 September 2009

PROCEEDINGS

54. IWK

Internationales Wissenschaftliches Kolloquium

International Scientific Colloquium

Information Technology and Electrical Engineering - Devices and Systems, Materials and Technologies for the Future

Faculty of Electrical Engineering and Information Technology

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Dr. h. c. Prof. h. c.
Peter Scharff

Redaktion: Referat Marketing
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Univ.-Prof. Dr.-Ing. Frank Berger

Redaktionsschluss: 17. August 2009

Technische Realisierung (USB-Flash-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag: isle
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilmenau

ISBN (USB-Flash-Ausgabe): 978-3-938843-45-1
ISBN (Druckausgabe der Kurzfassungen): 978-3-938843-44-4

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=14089

IMPROVEMENTS IN INDUCTION HARDENING BY ADAPTED FIELD GUIDING

Alexander Ulferts, Bernard Nacke

Institute for Electrotechnology, Leibniz University of Hannover

ABSTRACT

High dynamic loads and the trend to reduce the effective weight of mechanical parts lead to the need for optimization in manufacturing of gear wheels in automotive and aerospace industry. To withstand high mechanical loads a high impact strength is required at the surface. By induction heating a hard martensitic microstructure is archived by a selective surface hardening process to follow the contour of the gear.

The recent paper presents the results of the numerical FEM investigation of the heating behavior of an induction heating system to harden gear wheels. The electromagnetic and thermal effects of the addition of the work piece field guide leading to the major improvement of hardening quality will be illustrated and discussed. A comparison to recent solutions of temperature homogenization and a assessment of future potentials complete the paper.

Index Terms— Induction heating, induction hardening, FEM modelling, electromagnetic field optimization, surface hardening of transmission gears

1. INTRODUCTION

Improving the mechanical behaviour of gear wheels and other moving mechanical parts leads to the optimization of the surface structure of the work piece. To get a homogenous surface hardening profile the electromagnetic field has to be homogenized. Vast parts of this homogenization are adjusted by adapting the frequency of the inductor current, the heating time and the inductor geometry. In recent induction heating processes the inductor geometry is improved by flux concentrators to guide the magnetic field. In induction hardening processes of gear wheels local overheating effects at the edges at root and tip of the gear appear as drawback of the system design. An investigation at a numerical FEM model showed the beneficial effect of a major reduction of local overheating effects if a work piece field guide is added to the heating system. A defined guiding of the magnetic field close to the work piece improves the homogenization of the magnetic field which leads to a homogenous temperature distribution in the gear and an improved hardening quality.

Thanks to eldec Schwenk Induction GmbH for inustrial development, verification and testing.

2. BASICS OF INDUCTION HARDENING

The aim of the hardening process is an improvement of surface quality of the work piece. The surface shall have a high abrasion restistance, a high fatigue strength limit and a high static strength. For gear wheels a hard surface but a ductile core is needed to fulfill all requirements. For steels with a sufficient amount of carbon an induction hardening process can be applied. The hardening process contains the heating process by induction and the subsequent cooling procedure. During this process the previously heated material changes its structure into a hard martensitic one. By applying alternating electromagnetic fields to the workpiece, eddy currents are induced at the surface of the gear wheel. Joule losses lead to the heating effect at the surface. The thickness of the heated material depends on the heating time and frequency of the inductor current. [1] High frequencies of the inductor current lead to a thin heated layer of material.

The behaviour of the process follows the laws of Maxwell:

$$rot(\frac{1}{\mu}rot\vec{A}) = -j\,\omega\,\kappa\,\vec{A} + \vec{S}_i \tag{1}$$

The resulting heating process can be described by:

$$c_p\rho\frac{\partial\vartheta}{\partial t} = div(\lambda\,grad\,\vartheta) + p \tag{2}$$

Due to the fact, that all material parameters vary with temperature, the set of differential equations is a nonlinear one. An analytic analysis of the heating problem is not possible. The finite element analysis solving this drawback is presented in the following sections.

Induction heating is often done by applying a current with a single frequency to the inductor. For hardening of work pieces with a less complex geometry this approach works very well. In case of gears this leads to unhomogenous heating during the process and to an unhomogenous distribution of hardness at the surface. [1] For that reason the inductor is fed by multifrequency currents. In this investigation a MF current of 10 kHz and a HF current of 250 kHz is applied to the inductor. The heating time was set to 300 milliseconds. The resulting MF field leads to a sufficient heating of the root and lower part of the flank of the gear. The MF field leads to a proper heating of the upper flank and the tip of the gear wheel. This combination of high- and low-frequency fields is necessary to fullfill all requirements of the hardening process.

3. FINITE ELEMENT MODELLING OF THE PROCESS

Three different configurations of the induction heating system have been analyzed in this paper. In every case a fragment of a complete gear, a quarter of a tooth has been modeled. Sliced elements of the inductor with field guiding elements are shown in the geometry. (Figures 1 and 2) In the first setup a flat inductor coil has been used without any field influencing elements at the gear wheel. Figure 1 shows the second configuration with a lateral ring of copper located half of a millimeter away from the root edge of the gear.

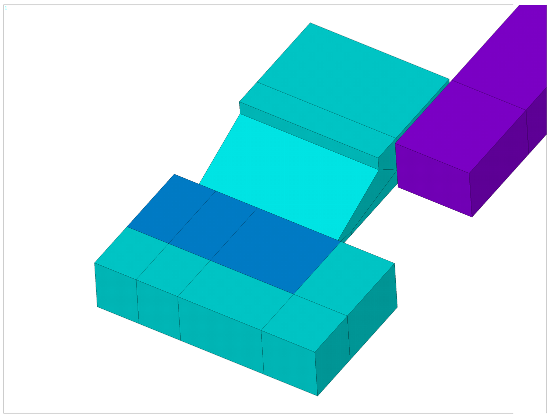

Fig. 1. Geometry with lateral shortcut ring

Besides the generation of eddy currents at the surface of the gear simultaneously eddy currents are induced in the so called shortcut ring. The magnetic field connected to these currents acts contrary to the magnetic field in the gear.

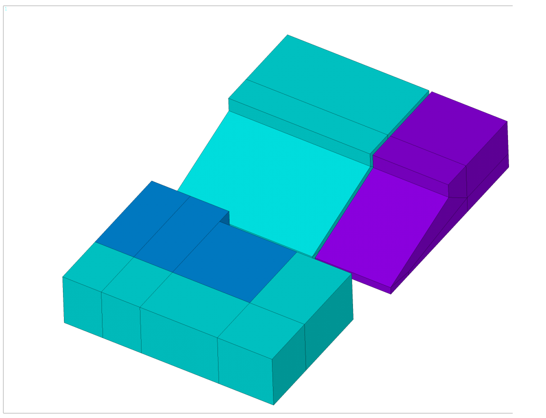

Fig. 2. Geometry with lateral flux concentrator

In the third configuration the copper ring was replaced by a high permeable ring with a high ohmic resistivity (Figure 2). The ring is formed according the contour of the gear wheel. The lateral magnetic field of the gear is guided through this material to the deeper regions of the gear.

4. INDUCTION HARDENING WITHOUT FIELD-INFLUENCING ELEMENTS

The first calculation has been done without any field influencing elements at the gear. Figure 3 shows the result of the hardening process. The distribution of the hardened zones are illustrated for a half of a tooth. The left plane of the gear acts as symmetry plane. The zones in strong green are hardened adequately according the requirements. A overheated zone shows the area in yellow. All other parts of the gear are not hardened sufficiently. Increasing the heating power would lead to stronger overheating effects up to local melting of the material at the root edge as illustrated. A homogenous heat distribution has to be reached by adaption of the electromagnetic field distribution in the system.

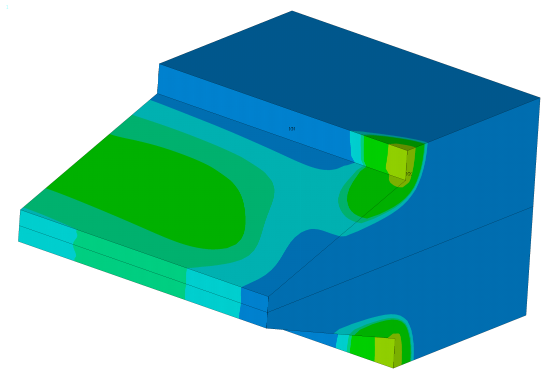

Fig. 3. Induction hardening process without field guiding elements at work piece

5. INDUCTION HARDENING WITH A LATERAL SHORTCUT ELEMENT

Adding a shortcut ring of copper to the system leads to results illustrated in Figure 4. The low resistivity of the shortcut ring leads to high eddy currents in the ring which are responsible for a high magnetic field inside. The vectors of the magnetic field are orientated opposite to the magnetic field in the gear and especially opposite to the field at the root edge.

This field generated in the copper ring compensates the strong magnetic field at the root egde and the local overheating disappears. Without that overheating the heating power can be adjusted to improve the distribution of heat at the gear surface. Characteristic for the

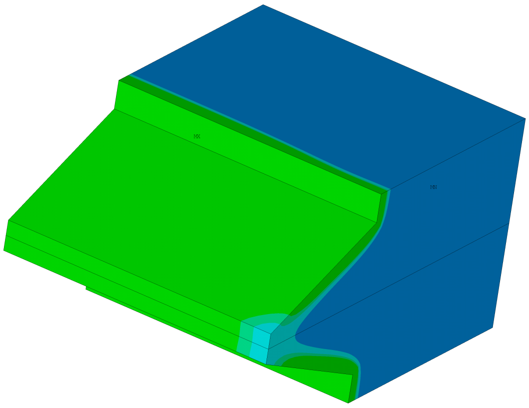

Fig. 4. Induction hardening process with shortcut ring at work piece

heating with a lateral copper ring is a cold spot at the tip edge of the gar. The redistribution of the magnetic field leads to a cold zone at the tip. This zone is not hardened. Especially for this region the magnetic field has to be attracted more by this zone. For this configuration a flat coil has been used without any steps adapting the local distance to the work piece.

Also an adaption and optimization of the inductor geometry does not compensate the cold spot at the tip of the gear completely. The solution of the following section reduced this effect.

6. INDUCTION HARDING PROCESS WITH A LATERAL FLUX CONCENTRATOR

In the third configuration the ring of copper has been replaced by a high permeable ring which contour was shaped according the contour of the gear. This ring acts more like a magnetic field guide. The high ohmic resistivity leads to very small induced eddy currents inside. The lateral field of the work piece is distributed more homogenous in the gear.

Compensational effects due to magnetic fields induced into the flux concentrator do practically not occur. Figure 5 shows the result of the hardening process if performed with a flat inductor. Compared with the process without any field influencing elements the hardened zones are noticeably larger. But large cold spots during heating occur at the root and tip edge. Only by increasing of the heating power an adequate distribution of hardness is not possible. Figure 6 shows the same configuration with an adapted inductor. The distance between the gear surface and the inner segments of the inductor is larger than the distance of the segments near to the edge. This stepwise distribution of the distance to the work piece is often named ”undercut“. This inhomogenous distance between gear and inductor leads to a redistribution of the heating power

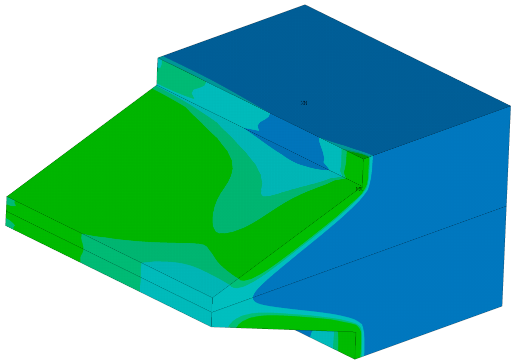

Fig. 5. Induction hardening process with lateral flux concentrator at work piece

in the gear. The surface is hardened at every point at the surface adequately. As drawback a larger overheated zone is visible. Compared to the system with a lateral copper ring especially the tip of the gear is hardened at every point at the surface. By adjustment of the total heating power the slight overheating at the root edges can be minimized to an admissible level.

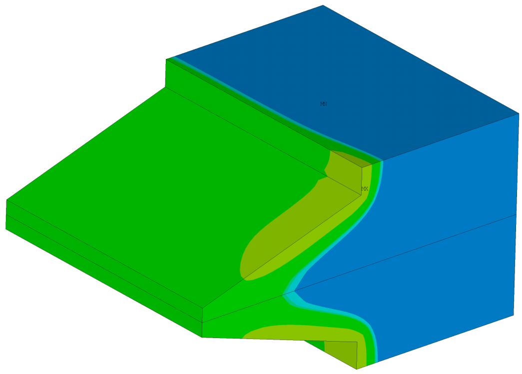

Fig. 6. Induction hardening process with lateral flux concentrator at work piece and adapted inductor with undercut

In future investigations the advantages of the shortcut ring and a lateral flux concentrator shall combined into one heating system. The distribution of the magnetic field inside the gear will be influenced by the flux concentrator. The overheating effects at the root will be reduced by a field compensating shortcut ring.

7. CONCLUSION

In this paper three different configurations of an induction hardening process of gear wheels have been discussed, which all have been tested and used in industrial processes. The big difference of the hardening results show the potential of improvement in this field.

In general the following three process configurations are possible:

1. Process without field influencing elements at the gear

2. Process with a lateral positioned shortcut ring of copper

3. Process with a lateral flux concentrator guiding the magnetic field

If no field influencing elements are present during the process, the distribution of hardened zones is very inhomogenous. Big parts of the surface are not hardened at all, other parts are overheated. This process does not fullfill the industrial requirements of hardening.

To compensate the inhomogenous distribution a ring of copper was added at the side of the gear wheel. By induction of eddy currents into this ring and the connected magnetic field a redistribution of the magnetic field in the gear is performed leading to a more homogenous heating of the surface and consequently to much better hardening results. But a cold zone at the tip edge of the wheel leads to a lack of hardness in this region.

By replacing the copper ring by a high permeable ring with a high ohmic resisticity, the heating behaviour could be improved in most of the zones at the surface. Every part of the surface fullfills the industrial requirement of hardness. As drawback a local overheating of the root edge area of the gear appears.

In future investigations and processes a combination of a lateral work piece flux concentrator and a field compensating shortcut ring could solve all drwabacks of the presented systems. A homogenous heating without local overheating effects could be possible.

8. REFERENCES

[1] Elmar Wrona, *Numerische Simulation des Erwärmungsprozesses für das induktive Randschichthärten komplexer Geometrien*, Ph.D. thesis, Hannover, 2005.