International Scientific Colloquium
Modelling for Electromagnetic Processing
Hannover, March 24-26, 2003

3D-Modelling of the Transient Heating Process for Induction Surface Hardening

E. Wrona, B. Nacke, D. Resetov

Abstract

The present paper illustrates the possibilities of 3D-modelling of the transient heating process for induction surface hardening. It gives an overview of the developed numerical simulation tool and its features. Some more details of the calculation structure, which includes the coupling of electromagnetic with thermal field, are also presented. Moreover, the usage of the simulation tool on heating of gears is shown and the influence of the induction frequency and power on the temperature distribution is presented.

Introduction

Induction surface hardening is a state of the art technique to improve the properties of mechanical devices. In comparison to case-hardening it has advantages like a very fast hardening time and offers the possibility to integrate the hardening-installation in the production line. Besides it allows partial hardening [1].

The traditional way to investigate the shape of the inductor and the hardening parameters like induction-frequency or heating time is the experimental way. But the geometry of many work-pieces is complex as well as the desired hardening-profiles, which leads to long development time and high costs.

3D-Modelling of the transient heating process for induction surface hardening is a useful method to solve new hardening tasks. The influence of inductor-geometry, frequency and heating-time on the temperature-distribution in the whole work-piece can be analysed, in order to get the best as possible inductor-shape and hardening-parameters for experimental hardening.

1. Numerical Model

The ANSYS 6.0 package was used as numerical simulation software, which is based on the finite element method (FEM). The basic tools were used and the macros were modified if necessary. The developed package enables the three-dimensional numerical calculation of the transient heating process with coupled electromagnetic and thermal field.

1.1. Program Features

The developed calculation tool offers varied simulation features. Electric resistivity, permeability, thermal conductivity and specific heat capacity are included as temperature dependent components. In addition to that in 2D-Modelling the field strength dependence of the permeability is included. 3D-Modelling with ANSYS does not allow the implementation of this feature. For axis symmetric configurations the rotation of the work-piece is taken into account.

1.2. Method of Calculation

The simulation procedure strictly follows a modular concept. The main file contains variable calculation parameters, like current density and frequency or heating time, and accesses the macros for geometric, electric and thermal information. This structure enables choosing between electromagnetic or coupled electromagnetic and thermal calculation via flag in the main file. The model was build on so called physical environments. One environment includes the electric, the other the thermal data.

Fig. 1 shows the complete flow-chart. First a harmonic electromagnetic calculation starts with temperature dependent electric resistivity ρ and permeability µ. The result, the Joule heat, is used as input data for the following transient thermal analysis, again with temperature dependent variables. Each thermal calculation is done for a given global time step Δt, but the span of the sub-steps dt are chosen by ANSYS in a given range.

The result of the calculation is the three-dimensional temperature distribution T(x, y, z) in the work-piece. If the final time step t_{max} is not reached, another electromagnetic calculation starts considering the new temperature dependent values of the electric variables. After this, the thermal calculation starts beginning with the temperature distribution from the last global time-step.

2. Heating of gears

The heating of gears was investigated as an calculation example. Because of its complex geometry the heating process must be modelled three-dimensional. Fig. 2 shows an example of the modelled heating-configuration with enclosed inductor. The aim is to reach a temperature distribution close to the contour of the gear in order to get a uniform hardening profile.

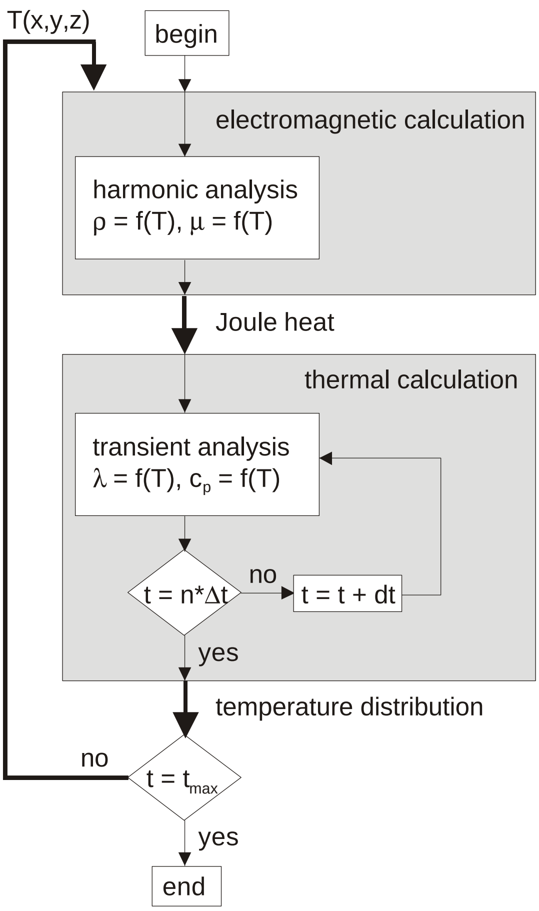

Fig. 1. Flow-chart of calculation

Fig. 2. Heating-configuration for induction hardening of gears

For the purpose of numerical simulation the model was reduced taking the advantage of the symmetry conditions. The estimated large radius of the gear allows to model only half of a cog in circular direction.

As you can see in Fig. 3, the net of the surface area is very fine, because the high frequencies used for induction surface hardening leads to small penetration depths of the electromagnetic field. In contrast to that, the other parts of the gear have a coarser grid.

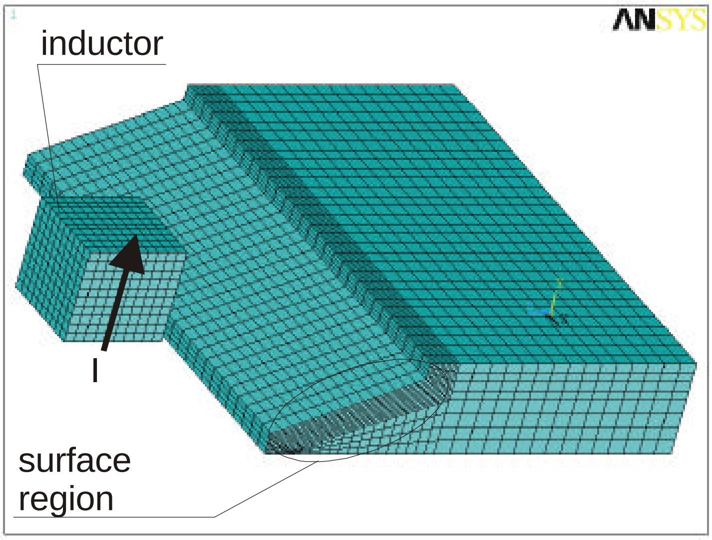

Fig. 3. Net of the simulation model

3. Results of Calculation

The following results show the influence of the induction frequency concerning the temperature distribution, especially in the cog-region. The current density in the inductor was controlled in the way, that the maximum temperature in the work-piece is about 950 °C after the heating-time of 1 s.

Material properties were used for induction hardening steel. The electromagnetic field-strength-dependence of the permeability was additionally taken into account. The electromagnetic field at the work-piece surface was calculated. The resulting relative permeability was $\mu_r = 10$ [2], which is the starting value for temperature dependence of the permeability.

3.1. Single Frequency Process

Fig. 4 shows typical temperature-distributions for different frequencies. If low frequencies are used, the penetration depth is large, which leads to overheating at the space between the cogs. Using high frequencies the maximum temperature is reached at the tip of a cog, because of a small penetration depth. If the aim is to reach homogeneous temperature distribution at the flank of the cog, the used frequency should be somewhere in the middle. It is not possible to get a uniform temperature-distribution close to the contour of the cog using a single frequency process.

3.2. Dual Frequency Process

Concerning the results of single frequency heating, simultaneous dual frequency heating with medium (MF) and high frequencies (HF) could be the key to reach a temperature distribution close to the contour of the cog. In existing hardening-facilities the power supply combines MF- with HF-power into one output transformer and finally into one inductor [3]. Gears have already been successfully hardened with the dual frequency method.

The numerical simulation model has to be adapted. ANSYS does not allow to model simultaneously two inductor-frequencies. But it is possible to implement different current-frequencies and –densities in very short periods of time, so that the whole heating process could be assumed as simultaneous dual frequency heating.

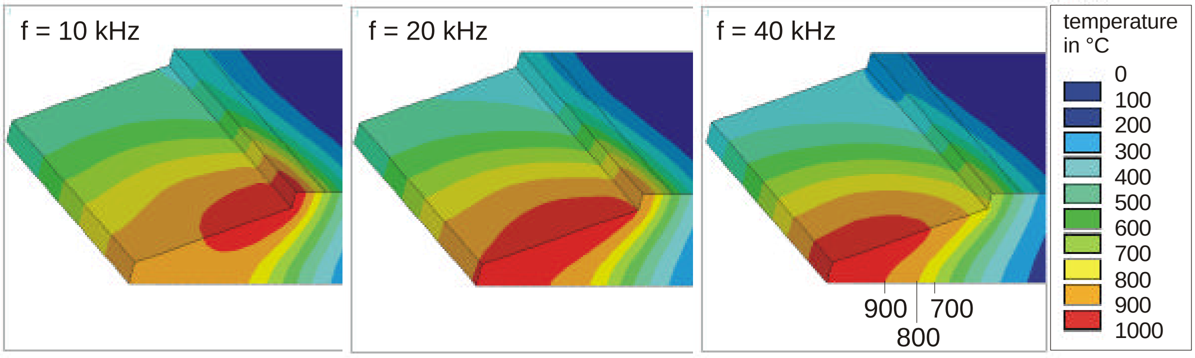

Fig. 4. Influence of frequency on temperature-distribution

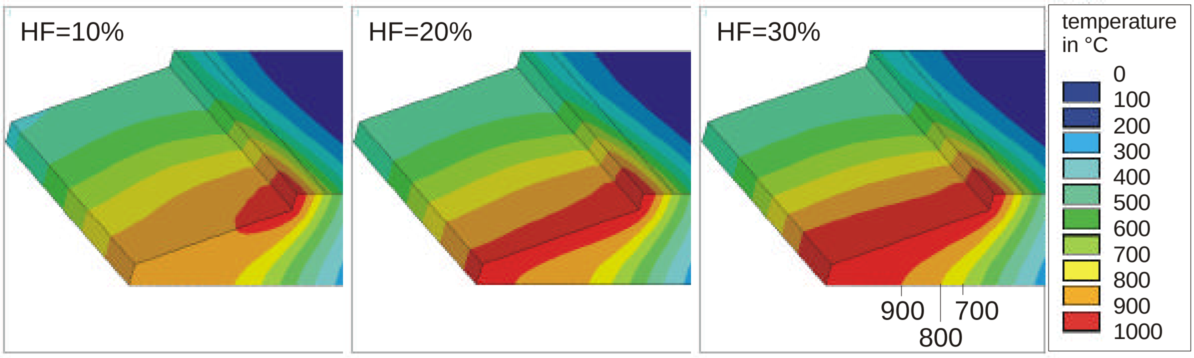

Fig. 5. Influence of power-ratio HF/MF on temperature-distribution

To point out the influence of MF- and HF-power, calculations with different power-rates of HF/MF were done. The frequencies themselves were constant (MF 5 kHz, HF 150 kHz). The total heating power of MF and HF was constant, too.

Typical temperature distributions for three rates of HF/MF show Fig. 5. The rate of 10 % HF leads to overheating of the space between the cogs, while heating with 30 % HF results in high temperatures at the tip of the cog. In this examples the optimum is at a power-rate of 20 % HF.

4. Comparison with Experimental Investigations

Experimental investigations with dual frequency heating have already been done for gears [3]. The experiments show an identically influence of the power-rate as in numerical calculation. Low HF-power leads to overheating of the space between the cogs, high HF-power to overheating of the tip of the cog.

Conclusions

The presented numerical simulation model is a powerful tool for 3D-calculations of transient induction heating processes. It enables the evaluation of the temperature-distribution within the whole work-piece, which is the basis for the prediction of the resulting hardening profile. The calculation examples show the influence of the induction frequency on the temperature-distribution within the work-piece. Single frequency process does not allow a heating profile close to the contour of the gear Dual frequency process enables a uniform heating profile for a special ratio of HF- to MF-power.

References

[1] Benkowsky, G.: *Induktionserwärmung: Härten, Glühen, Schmelzen, Löten, Schweißen*. Verlag Technik GmbH, Berlin, 1990.

[2] Sieber, H.-J.: *Bestimmung der Permeabilität und ihrer Rückwirkung auf die Energieübertragung beim induktiven Härten*. Dissertation, University of Aachen, 1978, p.63

[3] Schwenk, W., Peter, H.-J.: *Anwendungen des Zweifrequenz-Simultanverfahrens zum induktiven Randschichthärten*. elektrowärme international, Vol. 60, 2002, pp. 13-18.

Authors

Prof. Dr.-Ing. Nacke, Bernard
Dipl.-Ing. Wrona, Elmar
Cand. el. Resetov, Dimitri
Institute for Electrothermal Processes
University of Hannover
Wilhelm-Busch-Str. 4
D-30167 Hannover, Germany
E-mail: ewh@ewh.uni-hannover.de