About the analisys of simultaneous induction hardening method of pinions with circular coil

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Abstract ***This paper proposes simultaneous hardening method of pinions with eddy currents using circular coil. This proceeding remark in little clear advantage face from individual treatment of pinions tooth. The heating analysis of treat piece needs solution of thermal diffusion problems coupled with eddy currents problem. Therefore the experiments number in designing process can be decreased and a better knowledge of the process can be obtained.***

Keywords: ***Electromagnetic field coupled with thermal, numerical simulation.***

I. INTRODUCTION

In the latest time a new method has been developed in the hardening process. The numeric analysis is coupled with thermal diffusion. Now, the methods can be used for all kinds of geometry types and they can consider the change of both the electromagnetic and thermal parameters accourding to temperature. Close to Curie point (normally, being under austenitic temperature), the B-H relation very dependend on temperature, passing from iron-magnetic environment form to air. Regarding to this reason, the eddy's current problems and thermal diffusion are strongly coupled in the Curie point zone. All the methods of numerical solving warn a kind of instability. Branded programs, adopt the linear pattern [1], where the B-H relation is linear, the magnetic permeability is adjusting according to the highest effective value of the magnetic induction. The pattern allows adopting the sinusoidal regime and the images too for the sizes of the electromagnetic field and its equations. The results are acceptable for the specialists. Another refined method, such as "rough force" (see the FLUX package) or "harmonious balance" [2] is a big time and memory consumer and it doesn't lead to a better accurate solution.

This paper recommends an efficient procedure for hardening in eddy currents, for pinion's tooth, which must accomplish high productivity and an equable dental treatment, compared to the usual technologies. The recommended solutions are analysed with FLUX-2D package programme.

II. ELECTROMAGNETIC FIELD PROBLEM

In case of parallel – plane structure, the magnetic field problem can be reduced to the determination of a potential vector with a single component, which verifies an similar equation with that of the scalar potential:

$$-\operatorname{div}(\nu \operatorname{grad} A) + \sigma \frac{\partial A}{\partial t} = C \cdot J_0 .$$

Must wrote $\nu = \frac{1}{\mu}$ and considered that $\boldsymbol{J}_0$ = kJ_0. The constants values C, which can be different on disjoining conducting domain, which the results on global current assessment on these sub-domains. The Dirichlet boundary condition for A comes from the imposed boundary conditions to normal element of magnetic induction.

$$A = g_A$$

The Neumann boundary conditions for A results from the imposed boundary condition to tangential component of H:

$$-\nu \frac{\partial A}{\partial n} = f$$

II. FINITE ELEMENT METHOD

We take:

$$A = A_0 + \sum_{i=1}^{N} \alpha_i \varphi_i$$

where A_0 is a known component which has Dirichlet boundary condition $A_0 = f_A$, and φ_i are given functions, independent linear, which have Dirichlet boundary condition null (named form functions). Using Galerkin procedure, we project the equation (1) on test function φ_k and we incorporate it in parts and obtain:

$$\int_{\Omega} \nu \,\mathrm{grad}\varphi_k \,\mathrm{grad} A \,\mathrm{d}\Omega - \int_{\Omega} \sigma \frac{\partial A}{\partial t} \varphi_k \,\mathrm{d}\Omega + $$
$$+ \int_{S''} f \varphi_k \,\mathrm{d} l = - \int_{\Omega} J_0 \varphi_k \,\mathrm{d}\Omega + \int_{\Omega} C \varphi_k \,\mathrm{d}\Omega$$

we take into account of (4), result equation system

$$\sum_{i=1}^{N} \left(a_{ki} \alpha_i + a'_{ki} \frac{d\alpha_i}{dt} \right) = b_k, \quad k = 1,2,\cdots,N,$$

where:

$$a_{ki} = \int_{\Omega} \nu \,\mathrm{grad}\,\varphi_k \cdot \mathrm{grad}\,\varphi_i \,\mathrm{d}\Omega;$$

$$a'_{ki} = \int_{\Omega} \sigma \varphi_k \varphi_i \,\mathrm{d}\Omega.$$

$$b_k = - \int_{\Omega} \mu \,\mathrm{grad}\, A_0 \cdot \mathrm{grad}\,\varphi_k \,\mathrm{d}\Omega + \int_{\Omega} \sigma \frac{\partial A_0}{\partial t} \varphi_k \,\mathrm{d}\Omega -$$
$$- \int_{\Omega} J_0 \varphi_k \,\mathrm{d}\Omega - \int_{S''} f \varphi_k \,\mathrm{d} l + \int_{\Omega} C \varphi_k \,\mathrm{d}\Omega.$$

III. THERMAL DIFFUSION PROBLEM

The diffusion of thermal field is describe by equation:

$$-\,\mathrm{div}\, \lambda \mathrm{grad} T + c \frac{\partial T}{\partial t} = p$$

where c is volume thermal capacity, λ is thermal conductibility and p volume power density who transform himself from electromagnetic form in heat. To equation we add the boundary condition:

$$-\,\lambda \frac{\partial T}{\partial n} = \alpha (T - T_e)$$

And, initial condition for temperature: $T(0) = T_{in}$.

Time discretisation of equation (10) its doing through Crank-Nicholson technique, and space discretisation through finite element method.

IV. THE COUPLED OF THERMAL DIFFUSION PROBLEMS WITH EDDY CURRENTS

Material parameters from eddy currents problem (B-H characteristic and resistivity) depend from temperature, in time material parameters from thermal problem depend from the result of eddy currents problem (power density) and temperature (thermal capacity and thermal conductibility). From that reason, each adopt time steps for thermal problem, it return to eddy currents problem and diffusion problem, material parameter proofs. If the correction is not significant, we go to the next time step. If its signalize instability in time, then the time step must reduce.

V. NUMERICAL SIMULATION AND RESULTS

The simultaneous hardening of pinions teeth has a few important advantages compared to individual hardening:
- the necessary time to hardening of pinions reduce almost N times, where N is the pinions tooth number;
- at the same value of the current, the supplying tension grows N times, agreed for supplying equipment of achievement at high frequency;
- because the electromagnetic and thermal field periodicity, the obtained hardening is uniform for all teeth;
- the generated heat is not diffused useless to the neighbouring teeth, and has a better efficiency.

At gear wheels with bigger module it was made a hardening inductor for one tooth. This method of simultaneous hardening of pinion teeth consist in making a circular coil system which must surround all the pinion teeth, similar to winding synchronic machine rotor with N poles. This form is created to let with levity the change of the gear wheel with another. Is not so different from the case of the electrical machine, the frontal zone of the heating coil system has the appearance of a funnel that allows the pinions inserting.

Numerical simulation allows to determine accurately the relationship between the frequencies used, the power density and the desired treatment depth.

The optimal frequency can be estimated by the penetration depth of induced currents.

The process consists in performing a single hardening at 8 kHz using an inductor as shown in figure 1.

The inductor is dimensioned in order to assure a distribution of the currents in the piece which implies the optimal heat treatment.

The magnetic flux density depencence with the magnetic field strength and temperature of the steel is shown in figure 2 for circular conductor.

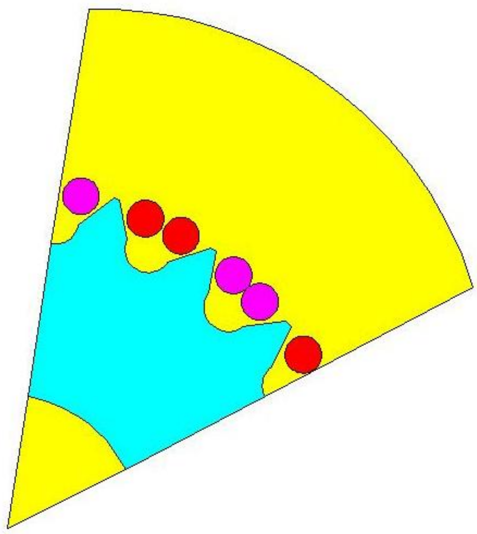

Figure1. The model of the system for simultaneous hardening of pinion teeth with circular coil

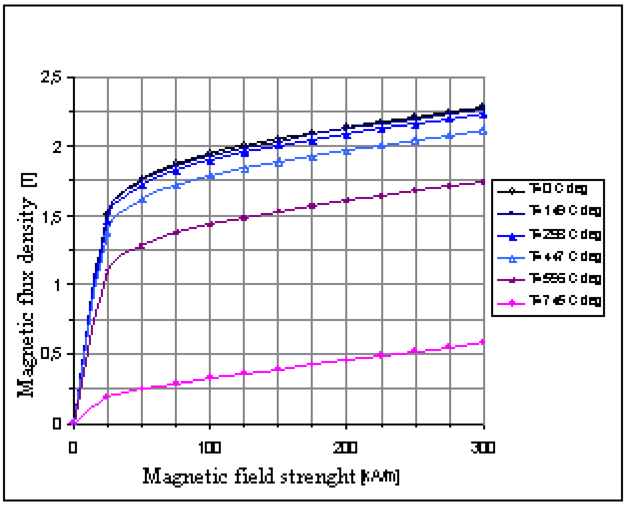

Figure 2. The magnetic flux density depencence with the magnetic field strength and temperature of the steel

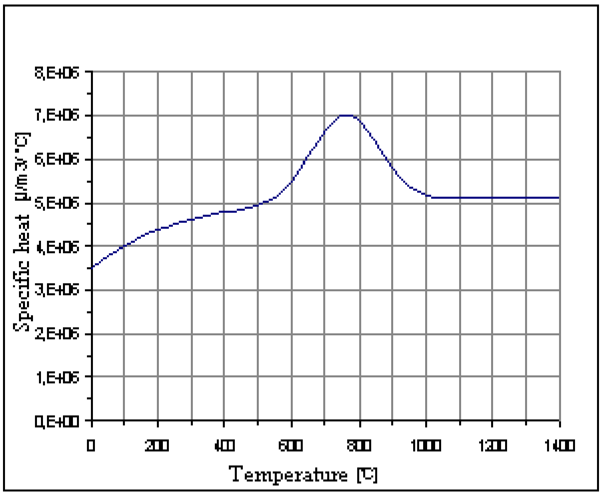

Figure 5. The specific heat dependence with the temperature of the steel.

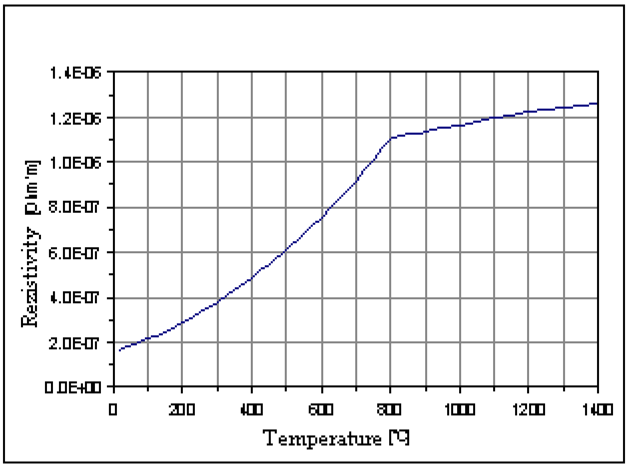

Figure 3. The rezistivity dependence with the temperature of the steel

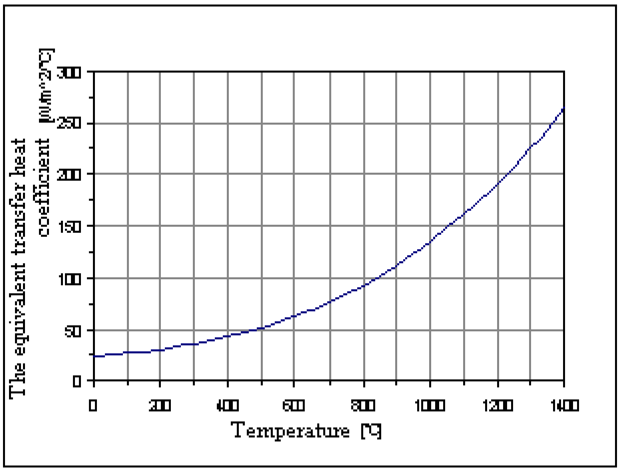

Figure 6. The equivalent transfer heat coefficient dependence with the temperature

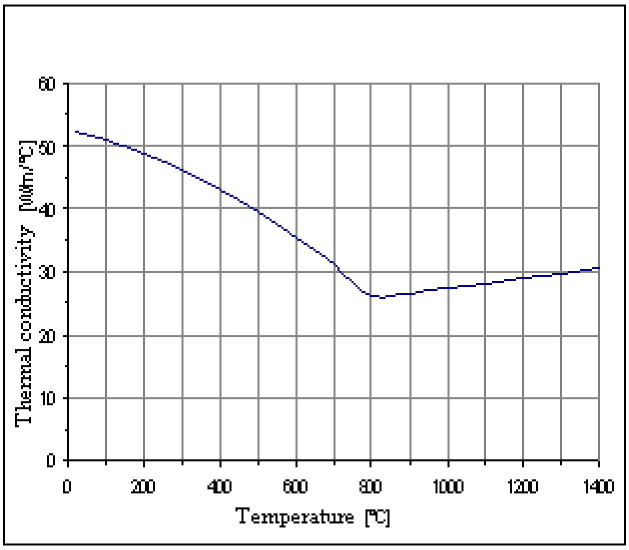

Figure 4. The thermal conductivity depencence with the temperature of the steel

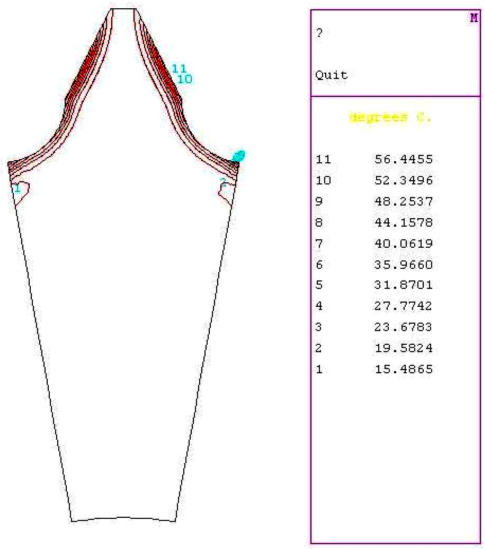

Figure 7. Thermal field distribution into the tooth at time 0.1 sec

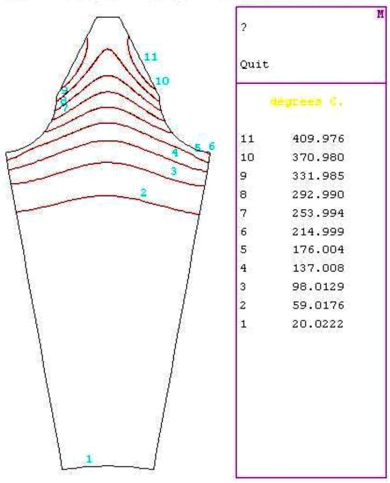

Figure 8. Thermal field distribution into the tooth at time 6.98 sec

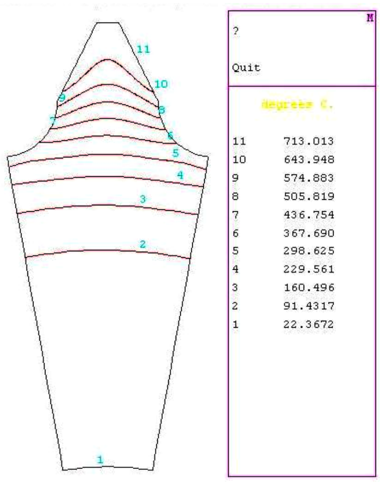

Figure 9. Thermal field distribution into the tooth at time 17.48 sec

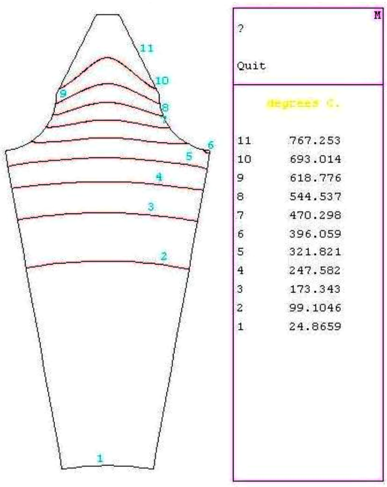

Figure 10. Thermal field distribution into the tooth at time 21.28 sec

IV. CONCLUSIONS

The numeric simulation of superficial hardening process is a complex problem, where are resolve simultaneous two field non-linear problems one of eddy currents and thermal diffusion. The non-linear problems of eddy currents is provide from non-linear relation of **B-H**, in time the non-linear of thermal problem provide from dependence with temperature of thermal parameters (thermal conductibility, thermal capacity, thermal transfer coefficient on surface).

The coupled of two problems result from strong dependence of relation **B-H** with temperature, in electromagnetic field problem and thermal field source, given by Joule lost, in thermal diffusion problem. The non-linear of **B-H** relation is solve by admit the pseudo-linear model, where $\mathbf{B} = \mu(B)\mathbf{H}$ is, magnetic permeability is iterating accurate in magnetic induction function.

The model great advantage is result from the possibility to adopt the sinusoidal regime and complex image, the numeric form of field equation leading to one algebraic equation system with complex coefficient.

The two coupled field problems is solve with time discretisation procedure, where at each time step, it is make the iterative correction of electromagnetic and thermal parameters.

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