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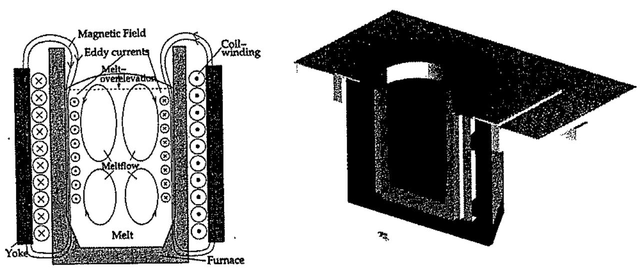
Coupled electromagnetic, structural-dynamic and acoustic simulation of an induction furnace

D. van Riesen, K. Hameyer
Institute of Electrical Machines (IEM)
RWTH Aachen University
Schinkelstraße 4, D-52056 Aachen, Germany
e-mail: riesen@iem.rwth-aachen.de

***Abstract*—Induction furnaces for melting metals are well understood and optimised electromagnetically. New challenges arise, however, when regarding the whole device. Especially the vibrations and the air-borne sound are of importance, as the frequency of operation and the rated power of the devices are rising quickly. Since the vibrations are a result of the electromagnetic forces, a coupled simulation is required that regards all relevant effects. In this paper, the methods for the electromagnetic, structural-dynamic and acoustic simulations are presented as well as the coupling procedures. In the structural-dynamic part, a fluid-structure-interaction is used to regard the effect of the liquid melt.**

I. Introduction

Induction furnaces are, from the electromagnetic point of view, rather simple devices. Fig. 1(a) shows the principle of operation. An outer coil is driven with a sinusoidal current. The magnetic field produced penetrates the melt, which acts as a short-circuited secondary coil. Eddy currents produce losses, which then heat up the melt. The magnetic field, together with the currents, both in the coil and the melt, produces Lorentz forces. The constant component produces a material flow in the melt, while the alternating component produces vibrations of the structure.



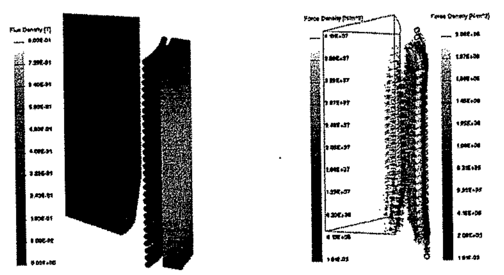
(a) Principle of operation (b) Geometry

Fig. 1. The induction furnace.

Fig. 1(b) shows the geometry of an induction furnace. Advances in power electronics have permitted to raise the power and the operating frequency. Power supply frequency (50-60 Hz) devices are replaced by mid-frequency (250 Hz) furnaces, which allow for higher power induced in the melt and thus reduced melting times. The regarded furnace is designed to melt 6 tons of gray cast iron, with a rated power of 4.5 MW. The coil current is 18 kA with a rated frequency of 250 Hz. These high currents produce also very high Lorentz forces. The vibrations can no longer be neglected. In combination with the raised frequency (500 Hz, twice the electric frequency), the acoustic noise produced must be regarded as well. Such large and cost-intensive devices cannot be analysed and optimised with prototypes. Therefore, a simulation method regarding the electromagnetic fields, the structural-dynamic vibrations and the acoustic noise is needed. This paper presents the three simulations and the coupling between them.

II. Electromagnetic Simulation

The furnace is driven with a single-frequency sinusoidal current. Due to the construction, large air gaps are present. Thus, no saturation takes place. The electromagnetic simulation uses a time-harmonic formulation with linear material properties. Fig. 2 shows the flux density and the resulting Lorentz forces.



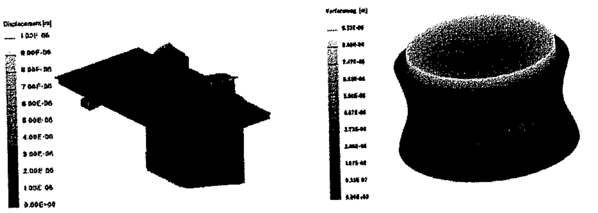
(a) Flux density. (b) Lorentz force.

Fig. 2. Flux density (a) and resulting Lorentz force (b).

Due to symmetry considerations, only a 30°-model is built. While different combinations of electric and magnetic potentials are possible [1], [2], a formulation with the magnetic vector potential $\vec{A}$ and the electric vector potential $\vec{T}$ is used, since it allows to regard the coil windings as current driven eddy current regions. The electromagnetic simulation is implemented in the open-source software iMOOSE[3].

III. Structural-dynamic Simulation

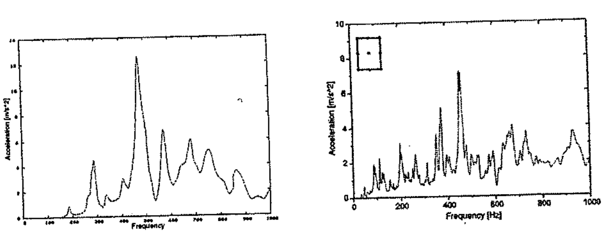
The Lorentz forces resulting from the electromagnetic simulation are transformed to a structural-dynamic model. This model has to take into account constructive details. The symmetry is not as pronounced as in the electromagnetic case. Therefore, a 180° model is used.



(a) Deformation at 470 Hz. (b) Deformation of the melt.

Fig. 3. Deformation of the structure (a) and the melt (b) at 470 Hz.

In the structural-dynamic model, brick elements are used because of their higher accuracy. In the first step, a modal analysis is performed. The modes are superposed to gain the deformation. Alternatively, the system equation can be solved directly. The melt is regarded either as mass elements on the crucible or with a fluid-structure interaction. The latter allows to compute the vibrations on the free surface of the melt, to take into account also the acoustic noise produced there. The structural-dynamic simulation is performed using the software Ansys [4]. Fig. 3(a) shows a deformation plot at 470 Hz, while Fig. 3(b) shows the deformation of the melt simulated with the fluid-structure interaction.



(a) Simulated. (b) Measured.

Fig. 4. Simulated and measured accelerations of the back cover plate.

Measurements of the eigenfrequencies and eigenmodes of the structure show a good agreement with the simulated values. Fig. 4 shows the mean acceleration values for the back cover plate as an example.

IV. Acoustic simulation

The displacement values of the structure obtained from the structural-dynamic simulation are transferred to another F.E. model of the induction furnace. This is a surface model, representing the outer surfaces of the device. Triangular elements are used. The coupling of the models is performed via a geometrical search algorithm. The acoustic noise emanating from the structure is computed using a boundary element solver [5].

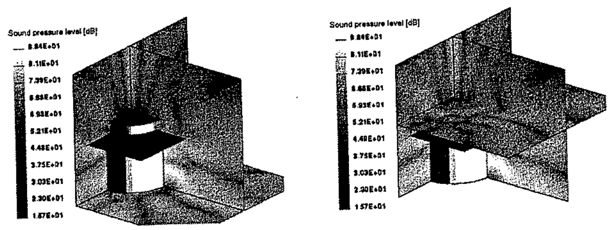


Fig. 5. Sound pressure level distribution around the induction furnace.

Fig. 5 shows the sound pressure distribution computed on areas around the furnace. The distribution and amplitude can be used to evaluate the effect of different constructive measures. Alternatively, the acoustic power is used as an integral quantity for comparison.

V. Conclusion

The electromagnetic, structural-dynamic and acoustic simulation of an induction furnace using coupled F.E. methods has been presented. More details about the simulation results and measurements will be included in the full paper.

References

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