Coupled Electromagnetic and Heat Transfer Analysis of an Induction Heated Fusing Roller

Abaqus Technology Brief

Summary

With the continually increasing demand for electric power, energy consumption is becoming a critical aspect of device design. The high-tech industry, for example, has embraced induction heating technology to reduce the power consumed by fusers in laser printers.

Computer modeling plays a fundamental role in shortening design cycles. In designing an induction fuser, it is essential to analyze the warm-up time as well as the uniformity of the temperature distribution in the roller. Such an analysis helps to determine the possibility of satisfying objectives early in the design cycle.

In this Technology Brief we demonstrate the modeling of an induction heated fuser using the co-simulation functionality of Abaqus/Standard. Electromagnetic and heat transfer analyses are co-simulated to compute the temperature history of the fuser roller. The advanced meshing capabilities of Abaqus/CAE are utilized to generate the type of high quality mesh required for computing eddy currents in very thin conductors.

Background

Laser printing typically happens in three stages. In the first stage, the desired printing pattern is created in the form of an electrostatically charged powder (toner) on a tape. In the second stage, the printing pattern is electrostatically deposited onto the paper. In the third and final stage, the toner is melted by transferring heat to the toner via a fusing roller. In order to melt the toner, the fusing roller must be preheated to a certain temperature.

Two competing factors enter the design of the heating process of a fusing roller: the warm-up time and the energy consumption of the fuser. Traditional methods used for heating the fusing roller, such as a halogen lamp, typically have long warm-up times. To reduce warm-up times an idle temperature is maintained; this, however, consumes energy even when the printer is not in use. Furthermore, the heating process is inefficient as the lamp itself needs to be heated and other thermal energy losses occur due to leakage. Induction heating technology provides a significant advantage over traditional methods by reducing warm-up times and heating the roller directly, thus reducing energy losses. Due to the short warm-up times, the need to maintain an idle temperature is eliminated, saving a significant amount of energy.

Model and Analysis

We consider a modified version of the induction heated fuser design proposed by Konica Minolta in their patent [1]. The full 3D geometry of the fuser is shown in Figure 1. The end view of the fuser is shown in Figure 2, with the coil removed from display for clarity. The model consists of a current-carrying coil wound around a coil bobbin. The different sections of the core (main core, end cores and center core) form a magnetic circuit together with the roller and the surrounding air. The end cores and center core are supported by the coil bobbin while the main core is supported by the "core support." The length of the roller is 220mm. The diameter and thickness of the roller are 47mm and 10mm, respectively. The roller consists of a very thin conducting sheet supported by a non-conducting layered material composed of resin and rubber to provide structural flexibility and strength to the roller. The thickness of the conducting sheet is 0.1mm, which is an order of magnitude less than the thickness of the roller.

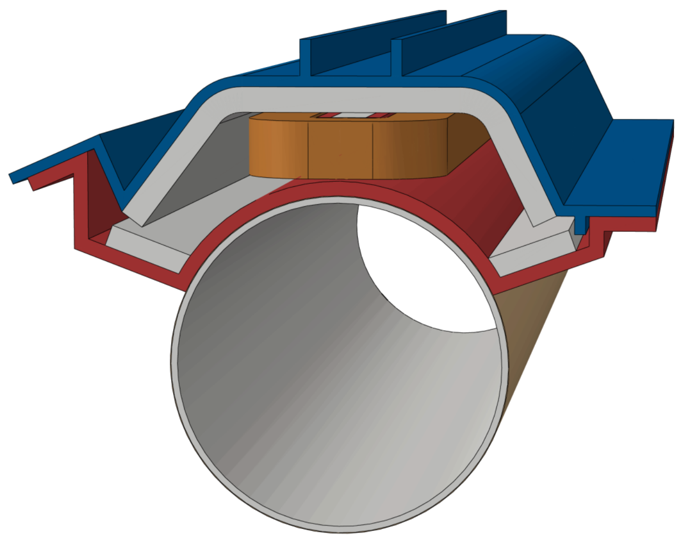

Figure 1: Geometry of induction heated fuser

Key Abaqus Features and Benefits

- *Co-simulation between electromagnetic and heat transfer analyses*
- *Advanced meshing capabilities in Abaqus/CAE for resolving skin depth in conductors*
- *Convection-diffusion heat transfer elements to account for motion*

Material Properties

The cores are assumed to be made of a soft magnetic material with an initial relative magnetic permeability of 500. Since the reluctance of the circuit that carries magnetic flux is large, the magnetic field in the cores is far

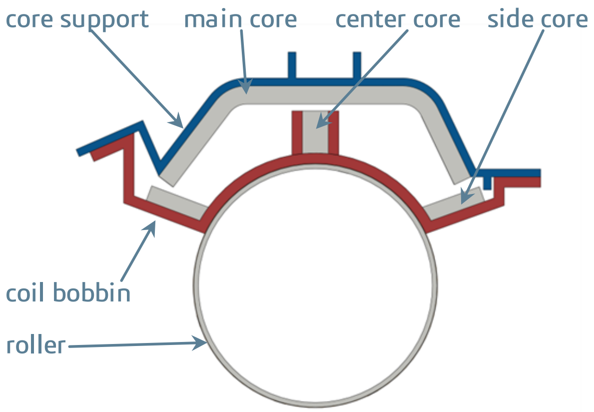

Figure 2: End view of the fuser (coil is not shown)

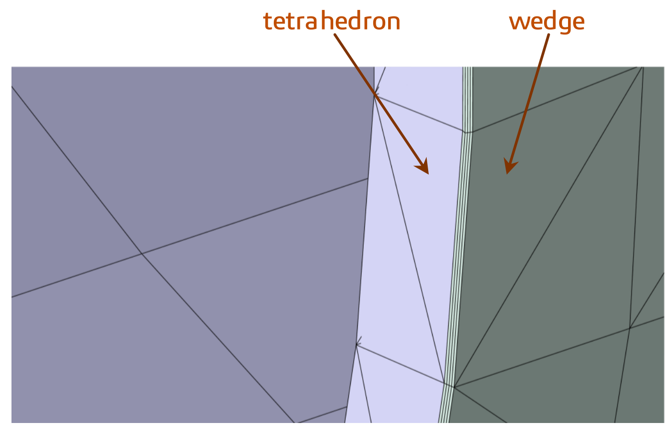

Figure 4: Wedge elements resolve the electromagnetic field through the thickness of a very thin conductor without constraining the element size in the rest of the model.

from saturation and hence nonlinear magnetic properties need not be considered. This assumption is confirmed by examining the results. The conducting material in the roller is assumed to have an electrical conductivity of 1.44×10^7 S/m. The density, thermal conductivity and specific heat of this material are taken to be 8908 kg/m^3, 90.9 W/m-K, and 4400 J/kg-K, respectively. The rest of the materials are assumed to be non-permeable and non-conducting.

Mesh

One of the most challenging aspects of modeling induction heating applications is the consideration of skin depth. Skin depth characterizes the extent to which the magnetic field, and hence the induced currents, penetrate the surface of a conductor and is often very small compared to the other geometric dimensions of the model. It is thus challenging to create a quality mesh that has disparate element sizes in different directions and in different regions of the model. Abaqus/CAE has the superior meshing functionality required for generating such meshes. Boundary layer meshing and the generation of meshes that contain a mixture of hexahedral, tetrahedral, and wedge elements are supported.

Figures 3 and 4 illustrate the mesh for the induction heated fuser model. Due to the extruded nature of the geometry, the electromagnetic field near the straight section of the coil is fairly invariant along the length, while the field varies significantly near the edges where the coil turns around. The complete mesh, shown in Figure 3, reflects these expectations by using a coarse extruded mesh in the center region of the model and a dense tetrahedral mesh in the end regions. The double-biased mesh seed specification in the center region imposes larger elements at the center of the model to reduce mesh size and smaller elements towards the end regions to transition to the dense mesh. The extruded mesh consists of hexahedral and wedge elements and allows for elements with large aspect ratios between the longitudinal and transverse directions of the coil.

Figure 4 demonstrates the quality of the mesh generated in the roller. The thickness of the conducting part of the roller is an order of magnitude smaller than the typical dimensions of the structure. The mesh consists of four wedge elements through the thickness of the conducting layer. These wedge elements resolve the electromagnetic field through the thickness of the conductor without constraining the element size in the rest of the domain.

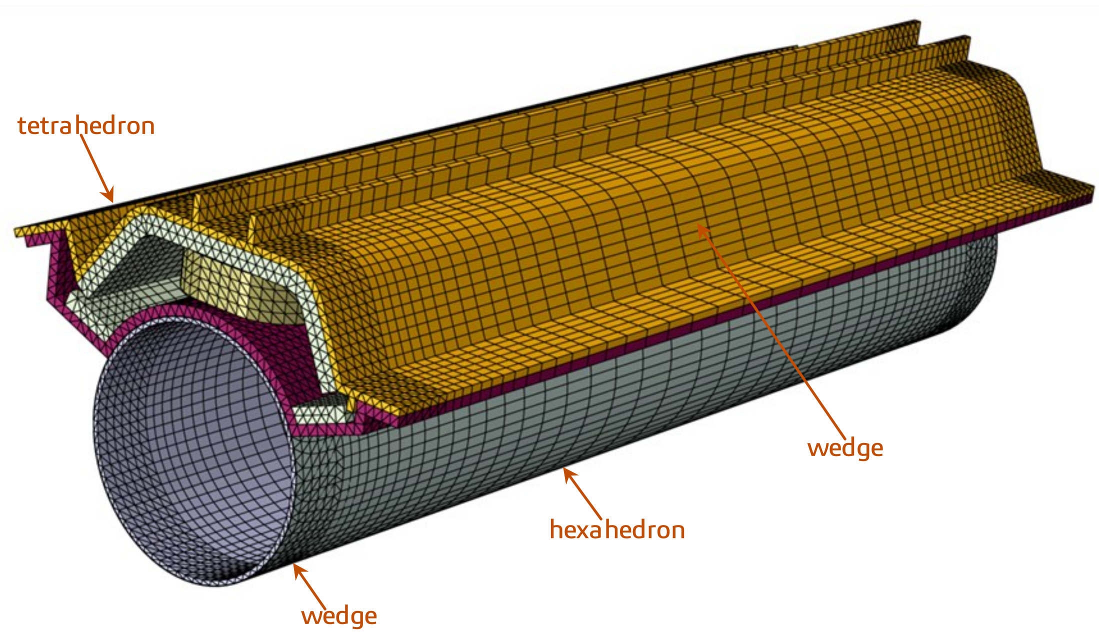

Figure 3: Mesh consisting of a mix of hexahedral, tetrahedral and wedge elements

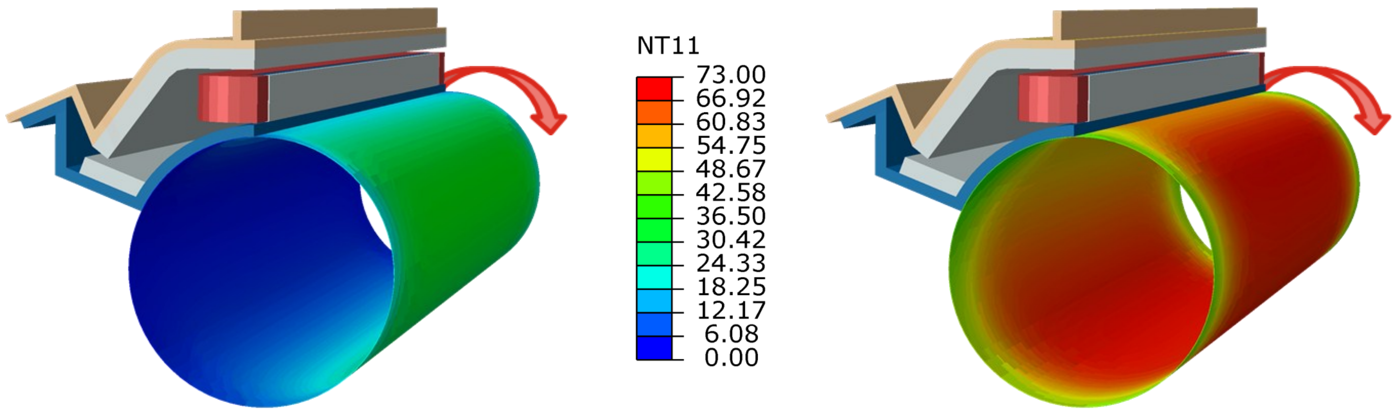

Figure 5: Contour plots of temperature when the roller completes a half rotation (left) and two full rotations (right)

Analysis Method

To compute the temperature distribution and time evolution, a coupled electromagnetic-heat transfer analysis is performed using the co-simulation feature of Abaqus/Standard. A time harmonic electromagnetic analysis is employed to compute the Joule heat generated from eddy currents induced in the roller. A transient heat transfer analysis (comprised of only the roller) is employed to compute the temperature in the roller. The Abaqus Co-Simulation Engine automatically maps the Joule heat and temperature in the roller between the two analysis procedures at frequent intervals. Since the time scale of the electromagnetic response is much smaller than the time scale of the temperature evolution, the time harmonic electromagnetic procedure employs a pseudo time scale that is of the same order as that of heat transfer procedure. To account for the motion of the roller, convection-diffusion heat transfer elements are used in the heat transfer procedure. The current density in the coil is set to $5.0x10^6$ A/m^2 at 10 kHz.

Results

The contour plots of the temperature in the roller are shown in Figure 5 when the roller completes a half rotation (left) and two full rotations (right). The time elapsed for two full rotations of the roller is 4 sec. As can be seen from the figure, a nearly uniform temperature rise is achieved over four seconds confirming the short rise times of induction-heated fusers. An overlay plot of the magnetic flux density in the roller (contour plot) and cores (vector plot) is shown in Figure 6. A view cut is employed for the vector plot in the cores for the sake of clarity. Finally, a contour plot of magnetic flux density through the cores is shown in Figure 7. From this figure, we can see that the maximum magnetic flux density in the cores is much smaller than the magnetic flux density at saturation (typically around 2.0T), thus confirming the assumption of linear magnetic response of the cores. Abaqus/Standard is capable of considering nonlinear B-H properties of a magnetic material, if required.

Conclusions

In this Technology Brief, we demonstrated how to compute the temperature evolution in the roller of an induction-heated fuser by performing a coupled electromagnetic-heat transfer analysis using the co-simulation capability of Abaqus/Standard. The lead time required for heating the roller as well as the uniformity of the temperature field in the roller were investigated. The results of the simulations confirm the short warm-up times of induction-heated fusers.

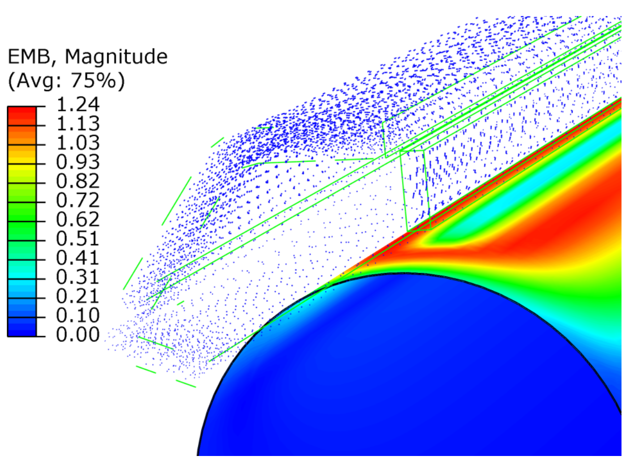

Figure 6: Overlay plot of magnetic flux density consisting of a contour plot in the roller and a vector plot in the cores (a view cut at the symmetry plane is employed for the vector plot)

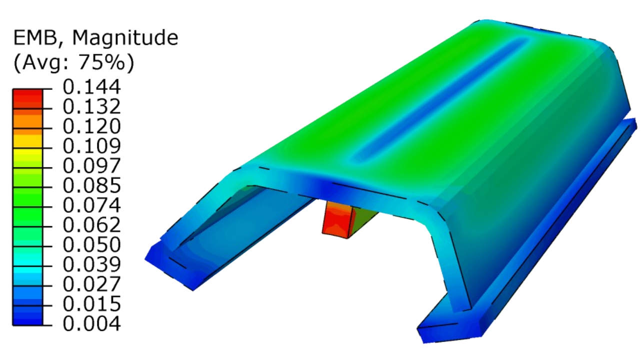

Figure 7: Contour plot of magnetic flux density in the cores confirms the assumption of linear magnetic response

References

1. Y. Mizumo, "Induction heating unit, fixing apparatus and image forming apparatus," U.S. Patent 13/253,471.

Abaqus References

For additional information on the Abaqus capabilities referred to in this document please see the following Abaqus 6.13 documentation references:

- Abaqus Analysis User's Manual
  - "Electromagnetic-to-structural and electromagnetic-to-thermal co-simulation," Section 17.3.3
  - "Eddy current analysis," Section 6.7.5
  - "Uncoupled heat transfer analysis," Section 6.5.2

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