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Parametric Study of Heating in a Ferrite Core Using SolidWorks Simulation Tools

by Gregory K. Ovrebo

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14. ABSTRACT

I compared simulation of steady-state heating in a ferrite core using two different analysis tools, a wide range of different heating and convection parameters. The tools, CosmosWorks and FloWorks, are associated with the SolidWorks solid modeling software. I show that FlowWorks is the better tool for heat-transfer problems with convection.

15. SUBJECT TERMS

Simulation, heat transfer, ferrite, SolidWorks

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1. Introduction

SolidWorks modeling software has several analysis tools available to its users. Two of these tools are CosmosWorks, a finite-element code primarily for mechanical simulations, and FloWorks, a computational fluid dynamics code useful for heat transfer problems. I did a parametric study of temperature increases in the Magnetics model 48020-EC ferrite core using CosmosWorks and FloWorks in order to compare the results delivered by these two SolidWorks tools.

2. CosmosWorks Simulation

I began with a simulation of heat transfer and convection using CosmosWorks. The ferrite core was modeled in SolidWorks. The core is shaped like the letter E; it is 3.15 inches long, 1.5 inches high, and 0.78 inches wide. I modeled heating in the core as a surface source on the e-shaped sides of the core. Heat generation in the core was varied from 0.5 W to 20 W, with half of that total heat applied to each side of the core. I assumed a starting temperature of 20 °C in the core. I modeled convection only on the top and ends of the core, with heat transfer coefficients ranging from 1 W/m^2-K up to 50 W/m^2-K. Figure 1 illustrates the surfaces selected for heating and convection. The figure on the left shows the surfaces of the ferrite core to which heat was applied in the CosmosWorks calculation. The figure on the right shows the surfaces to which convection was applied.

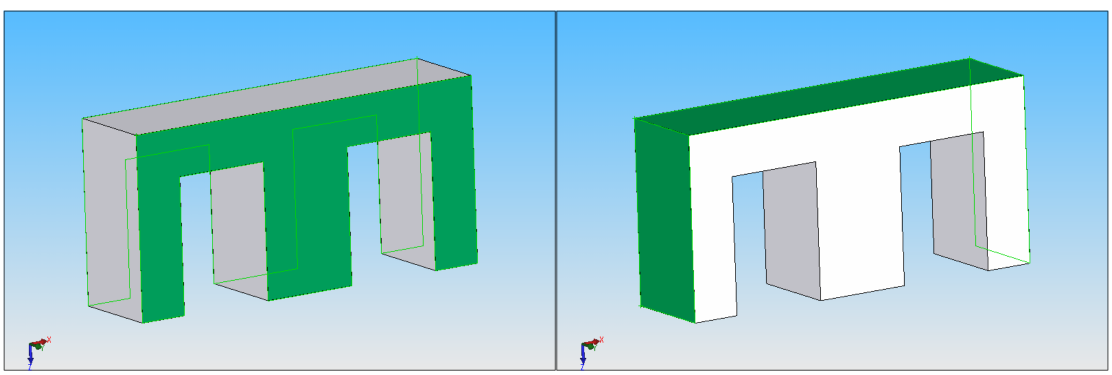

Figure 1. Left: heated surfaces in ComsmosWorks simulation. Right: convection surfaces.

Using a standard formula for convection over a flat surface, I calculated an approximate heat transfer coefficient of 14 W/m^2-K on the top of the ferrite core generated by air moving at 1 m/s. The heat transfer coefficient (or film coefficient) is calculated by

$$h = \frac{N_u \cdot k_f}{L}, \tag{1}$$

where $N_u = 0.664\, Re^{1/2}\, Pr^{1/3}$ Nusselt number

$Re = \frac{L \cdot V}{\nu}$ Reynolds number

$Pr = 0.7$ Prandtl number for air at 300 K

$L = 8$ cm characteristic distance

$V = 1$ m/s air velocity

$\nu = 0.1511\ cm^2/s$ kinematic viscosity of air at 293 K

$k_f = 26.1$ mW/m·K thermal conductivity at 300 K

Note that ν, the viscosity of air, will change substantially as the temperature changes, and the relationship between air velocity and heat transfer coefficient should be seen only as an approximation.

I used 14 W/m^2-K and 1 m/s as an upper limit for natural convection. Muffin fans, like those used in computer cases, have air velocities in the range of approximately 2 to 5 m/s. Large industrial fans have higher air velocities, generating approximately 5 to 15 m/s.

Figure 2 is a log-log plot showing the maximum temperature on the core calculated by CosmosWorks compared to the heat transfer coefficient for six different levels of heat generation. I cut off the plot at 50 W/m^2-K, which corresponds roughly to a velocity of 12.8 m/s, or 27.5 mph. Higher heat transfer coefficients were possible only with unrealistically high air velocities.

Figure 3 shows maximum solid temperature vs. the air velocity on the core surface, as determined by the calculation of the Nusselt number.

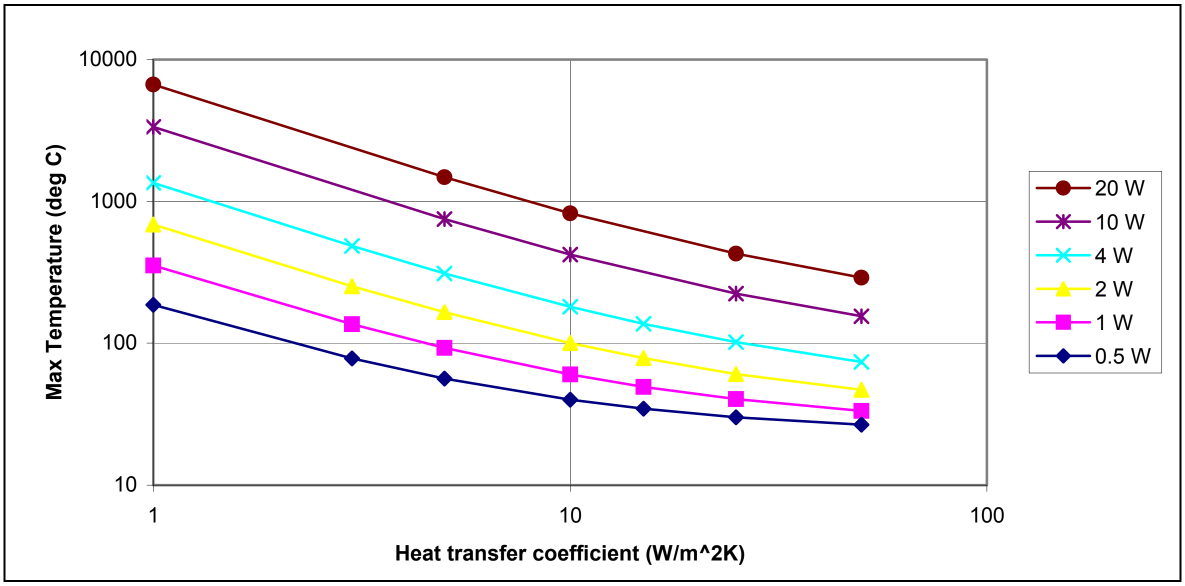

Figure 2. Maximum temperature in the ferrite core vs. heat transfer coefficient, from CosmosWorks simulation.

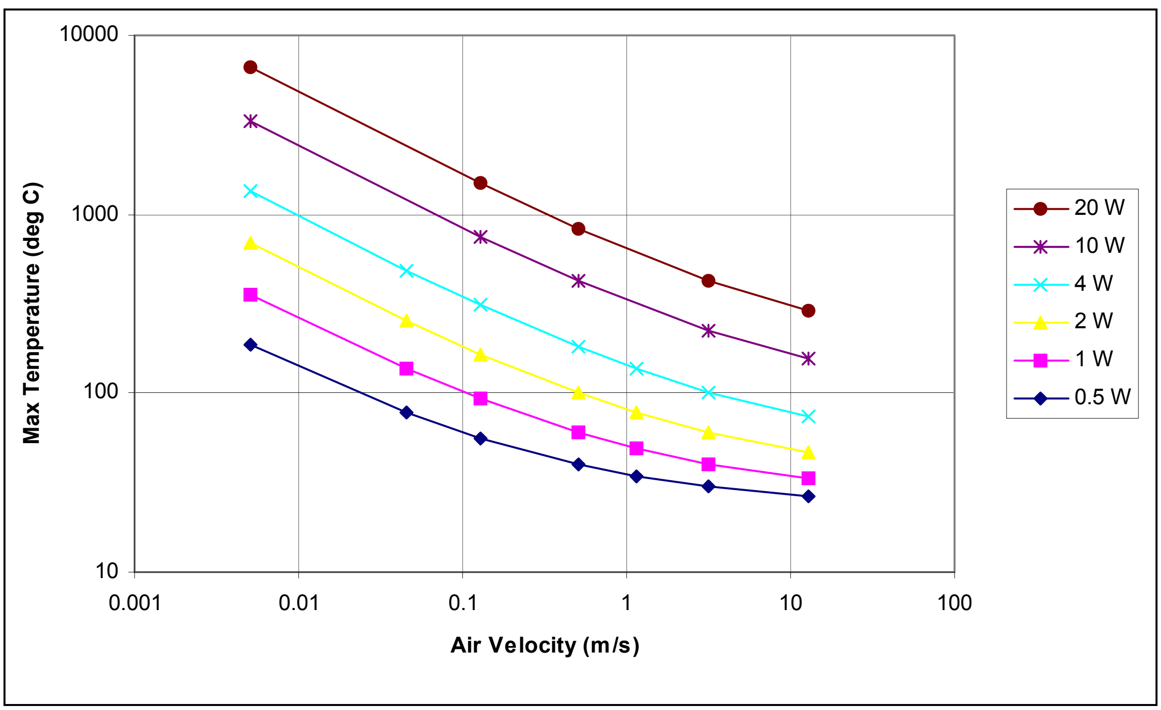

Figure 3. Maximum temperature in the ferrite core vs. air velocity, from CosmosWorks simulation.

The CosmosWorks simulations show substantial heating of the ferrite core for heat transfer levels higher than a watt or two with only natural convection. For instance, with 0.5 W of heat and a heat transfer coefficient of 10 W/m^2-K (corresponding to an air velocity of 0.5 m/s), CosmosWorks predicted a maximum temperature of 40 °C. But if heat transfer rises to 2 W and convection remains at 10 W/m^2-K, the maximum temperature on the core rises to 100 °C. At 4 W, the temperature rises to 180 °C, and at 20 W the maximum temperature is predicted to rise above 800 °C.

Note that trivial changes in convection below 1 m/s air velocity generate large changes in maximum temperature. Consider, for instance, the case where heat generation is 2 W. At 3 W/m^2-K (corresponding to an air velocity of about 0.05 m/s) we get a maximum solid temperature of 252 °C; at 1 W/m^2-K (corresponding to an air velocity of about 0.005 m/s) we get a maximum solid temperature of 685 °C. Setting convection to zero yielded an enormous negative value which is likely an overflow error.

3. FloWorks Simulation

My next step was to perform simulations of the same problem using FloWorks. I used the same model 48020EC ferrite core modeled in SolidWorks. The simulation was configured as an external flow problem, with an air temperature of 50 °C. Heat generation was modeled as a uniform volume source, with rates ranging from 0.5 W to 20 W. Convection is modeled in FloWorks as a flow of air on selected surfaces. For my simulations, I varied air velocity between 0.005 m/s and 12.5 m/s, with flow normal to the top and ends of the core. These air velocities corresponded to the heat transfer coefficients used in the CosmosWorks simulations.

3.1 Convection with Radiation

The first FloWorks simulation included both convection and radiation as energy transfer mechanisms. The ferrite core was modeled as having an emissivity value of 0.5, meaning that half of the energy incident on the model was absorbed and transmitted again, and half of the incident energy was reflected. Higher emissivity values (making the core more like an ideal blackbody) yield lower temperatures, while lower emissivity values yield higher temperatures. The results of that simulation are plotted in figure 4.

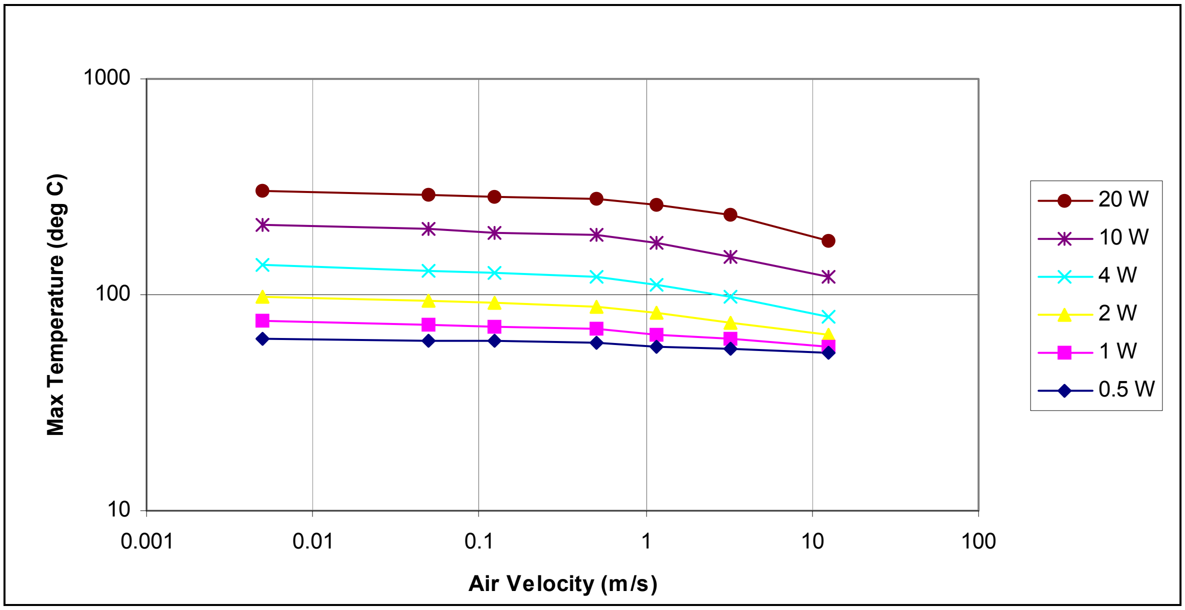

Figure 4. Maximum temperature in the ferrite core vs. air velocity, from FloWorks simulation.

For air velocities below 1 m/s (the natural convection region), changes in air velocity (and thus convection) yield only modest changes in calculated maximum temperatures. This result is what one would expect in actual convection. There is also a “knee” in the plots of maximum temperature vs. air velocity near 1 m/s, above which velocity natural convection transitions to forced convection. The slope of the curve increases, reflecting more efficient heat removal with higher air speeds.

Comparing the FloWorks results to those of CosmosWorks, the maximum temperatures in the natural convection region as calculated by FloWorks were substantially lower than those calculated by CosmosWorks. The FloWorks results are also more in line with our expectations of core heating.

3.2 Convection Without Radiation

A second set of calculations was performed with FloWorks without the radiation component of heat transfer from the core. I wanted to gauge the importance of this setting to the FloWorks configuration. Figure 5 shows the results of simulations identical to those done in FloWorks earlier, except that heat is removed from the model by convection alone.

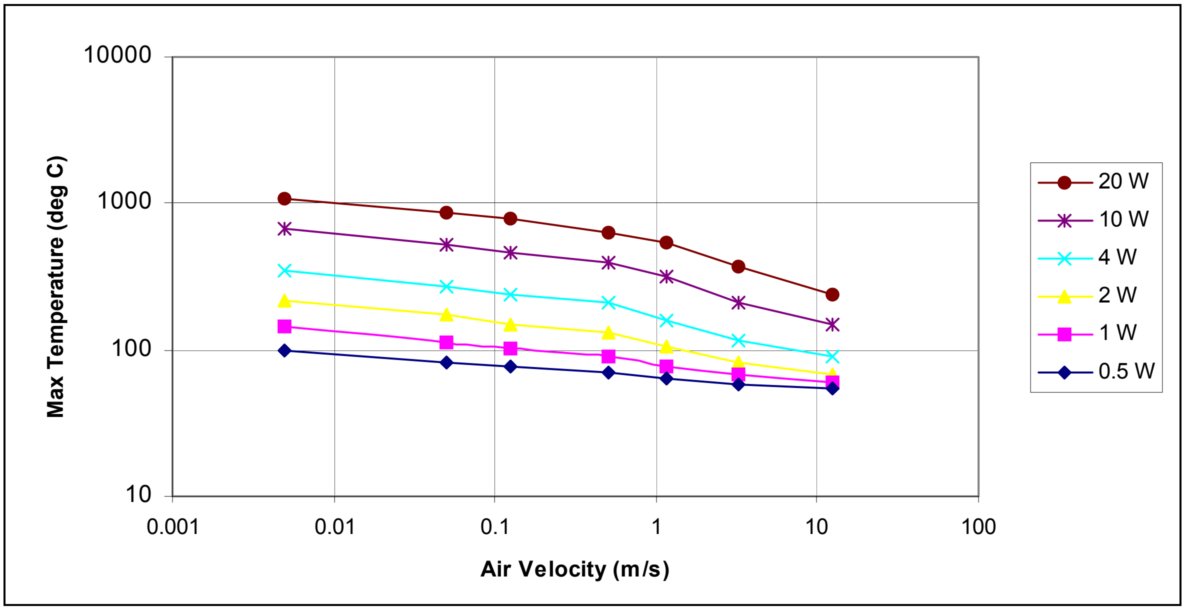

Figure 5. Maximum temperature in the ferrite core vs. air velocity, from FloWorks simulation using convection only (no radiation).

While the curves plotted in this graph have the same general shape as those in figure 3, the temperatures calculated without radiation transfer are notably higher than those calculated with radiation transfer. In the cases of higher watts and lower convection, temperatures are hundreds of degrees higher without radiation. This result is somewhat puzzling because radiation is not expected to be a major heat transfer mechanism at relatively low temperatures.

4. Conclusions

Comparison of results from both CosmosWorks and FloWorks simulations of the E-shaped ferrite core indicate that FloWorks is the better tool for heat transfer problems involving convection. Temperature levels calculated by FloWorks are in line with real-world expectations, as are changes in temperature predicted by varying levels of natural convection. However, some questions remain about relying too heavily on this analysis tool because FloWorks predicts different results for cases with and without radiation, even in low-wattage, moderate temperature problems.

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