Anisotropic Heat Transfer in Orthocyclically Wound Coils

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Abstract

Tecnotion produces linear motors for the high tech automation and semiconductor markets. Orthocyclically wound coils give the best performance because the largest number of windings can be packed into a given volume, as opposed to "wild winding", where the windings fall where they may. Additionally, the anisotropic heat conduction perpendicular to the wire direction is optimized because each winding is positioned exactly next to all six of its neighbors, maximizing the contact surface. A thorough understanding of the thermal performance is necessary to understand and predict the motor performance for those applications that require nanometer positioning accuracy, for example in the semiconductor industry.

Heat transport through such a structure can be modeled in two ways: with the emphasis either on geometry or on the material properties. The computational cost of the geometrical approach can be estimated from figure 1, which shows a typical orthocyclically wound coil. In order to simplify the geometrical assembly, each winding has been modeled as a closed loop, rather than all windings as a single helix. (It can easily be shown that this is a sensible approximation, because the winding-to-winding heat conduction across the insulator layer is greater that the conduction along the circumference of the coil.) A typical wire diameter is 0.5 mm. The insulator, at 10 um typical thickness, requires an enormous number of mesh elements in order to be modeled accurately. This method quickly becomes unpractical, especially because the number of windings in a typical coil is in the hundreds. What we can do instead is calculate the effective transverse conductivity from a 2D model, see Figure 2. This has been verified against thermal measurements of our coils. However, trying to understand the heat flow in a motor with such anisotropic heat transfer in its coils is difficult. COMSOL Multiphysics® offers the possibility to model materials with anisotropic conductivity. Even though the coil is not really made from anisotropic materials, it can accurately be modeled this way.

It is easy to model an anisotropic material with a diagonal conductivity matrix, but in COMSOL Multiphysics® 4.3a and earlier this only works if the three components line up with the system axes. Tilting the main conduction direction (which is the direction of the wires) away from e.g. the z-axis requires a bit of basic linear algebra with rotation matrices, and results in a symmetric conductivity matrix. By approximating the geometrical shape of the coil with a number of pie segments, we were able to simulate anisotropic heat conduction, preferentially in the "around" direction. Figure 3 shows the result: the heat can be seen to spread distinctly anisotropically. This has been experimentally validated. COMSOL Multiphysics® 4.3b has a new feature that allows

a bent object from an anisotropic material to be modeled much more easily. The two approaches are compared. Tecnotion also manufactures band coils (flat wire), which exhibit preferential heat transport in two directions, and the advantages for coil cooling are discussed.

Figures used in the abstract

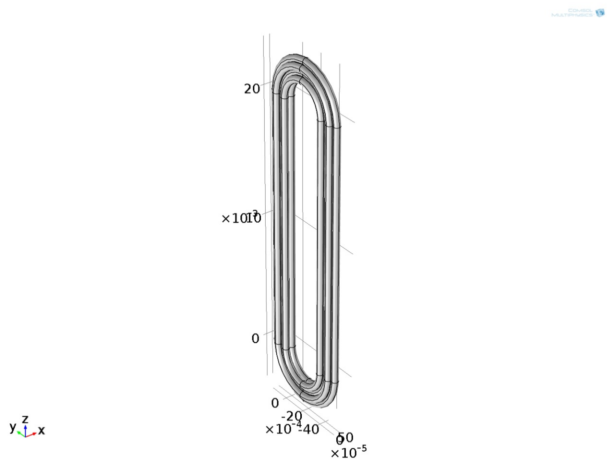

Figure 1: Simplified geometrical model of orthocyclically wound coil. Note that the number of windings is unusually low (~10), the range 100-400 is usual.

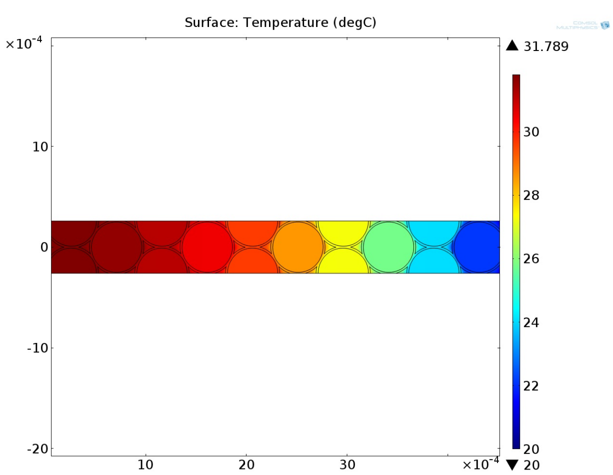

Figure 2: 2D representation of heat conduction in a coil, lateral to the winding direction. Head dissipation is uniform.

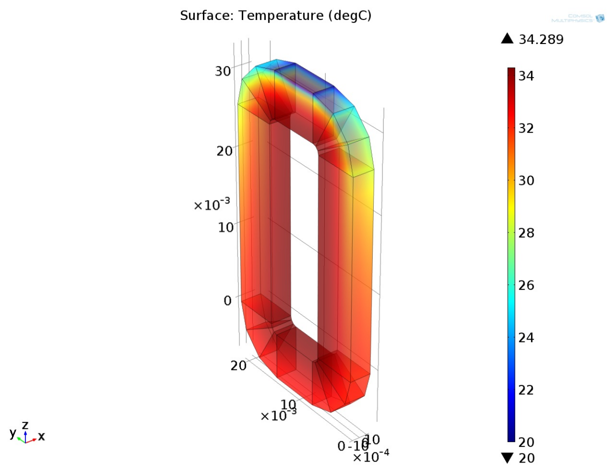

Figure 3: Heat transport model of a coil. Heat dissipation is spread uniformly across the coil volume; the top surface is kept at room temperature. While no windings are simulated, conductivity is modeled as anisotropic in the direction of the windings.