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Finite Solenoid

The magnetic field within an empty-core current-carrying solenoid is traditionally calculated using analytical means. The solenoid is assumed to be ideally infinite and without edge effects, such that Ampere's law can be utilized to find the magnetic field in the direction parallel to the solenoid's length. However, finite solenoids have edge effects which make calculations using Ampere's law infeasible. As such, computational methods must be used to discover the nature of a finite solenoid.

Numerical integration was used to sum the magnetic field contribution from current segments along the solenoid. This method was used to find the magnetic field at many points in space. The results were displayed in a two-dimensional color plot in MATLAB. The solenoid was 5 meters long, with a radius of 1m, 100 turns, and a current of 1A.

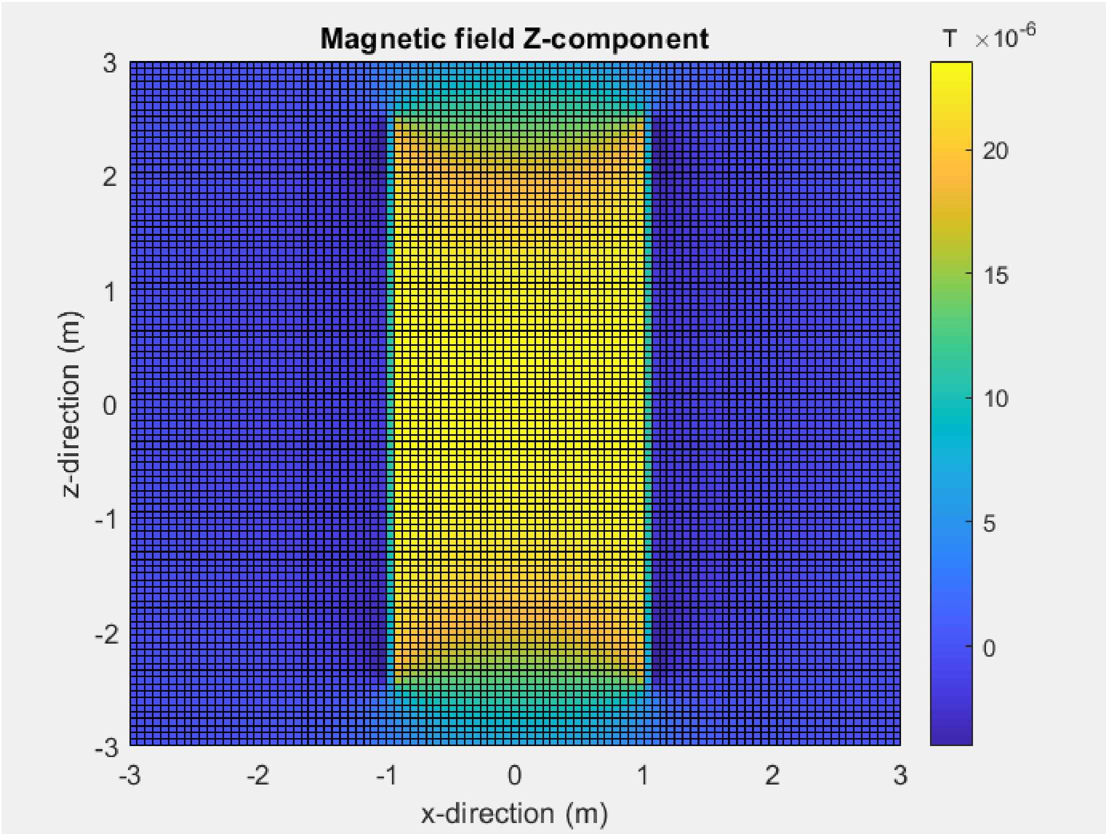

Fig. 1a. Top view of solenoid in the x-z plane. 100 Turns, 10m length, 1A current; Color corresponds to the strength of the z-component of the magnetic field, in Teslas

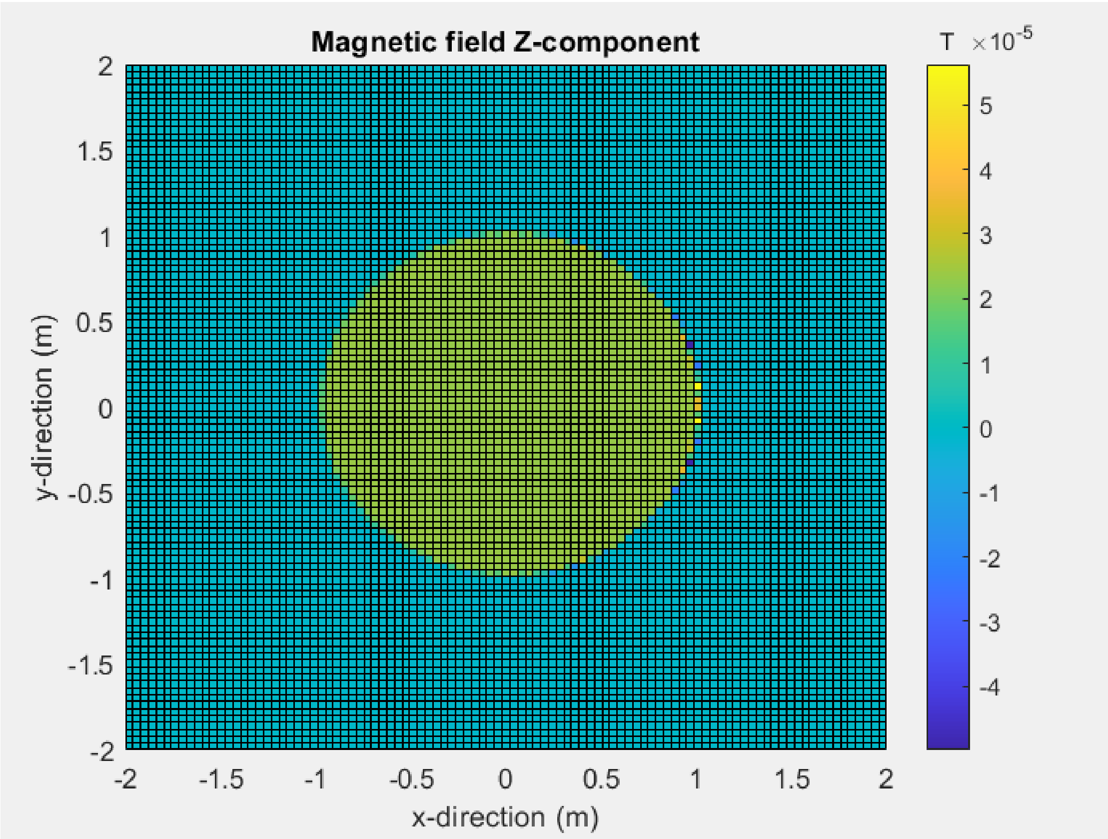

Fig. 1b. Front view of solenoid in the x-y plane, z = 0

As shown in the figures, the strength of the magnetic field in the center of the solenoid neared approximately 2.5*10^-5 T. Using the equation B = u_onI, one obtains a theoretical magnetic field strength of 2.51*10^-5 T. Therefore, the analytical approximation is accurate to a high degree of precision.

Fig. 1a shows the strength of the magnetic field decreasing at the ends of the solenoid, which is unaccounted for in an ideal solenoid. There are also negative magnetic field components near the outside of the solenoid at the edges, suggesting that the magnetic-field loops back around on the outside of the solenoid.

Fig. 1b shows the how the field strength increases near the wire. In the figure, the magnetic field strength increases to near 3*10^-5 T near the right side, where the solenoid wire intersects with the x-y plane. This is a detail unaccounted for in the analytical solution.

In order to get a better qualitative intuition for the finite solenoid in 3D space, the solenoid and its magnetic field were also plotted in Mathematica. This solenoid had 50 turns, 1A current, was 2m long, had a radius of 1m, and a current of 1A.

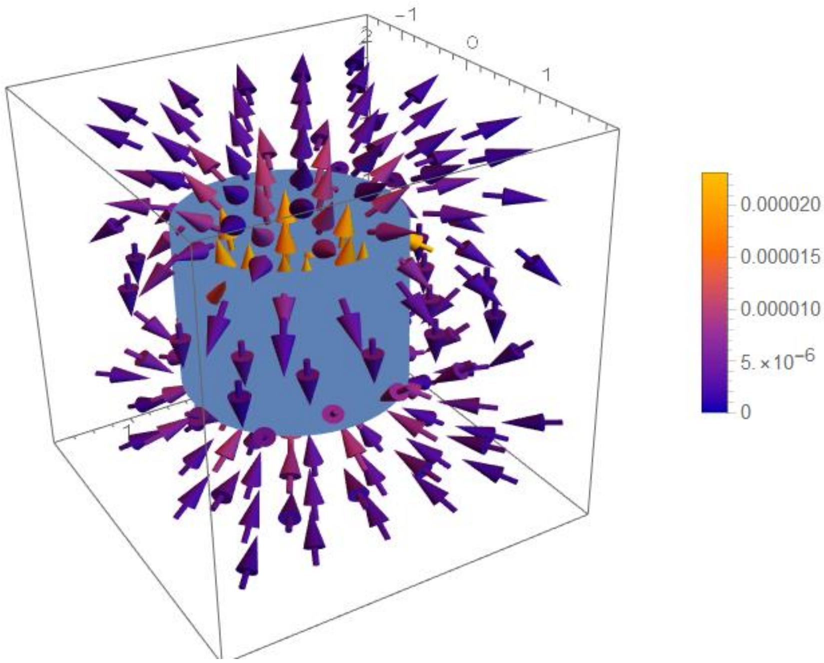

Fig. 2a. Isometric view of 3D solenoid

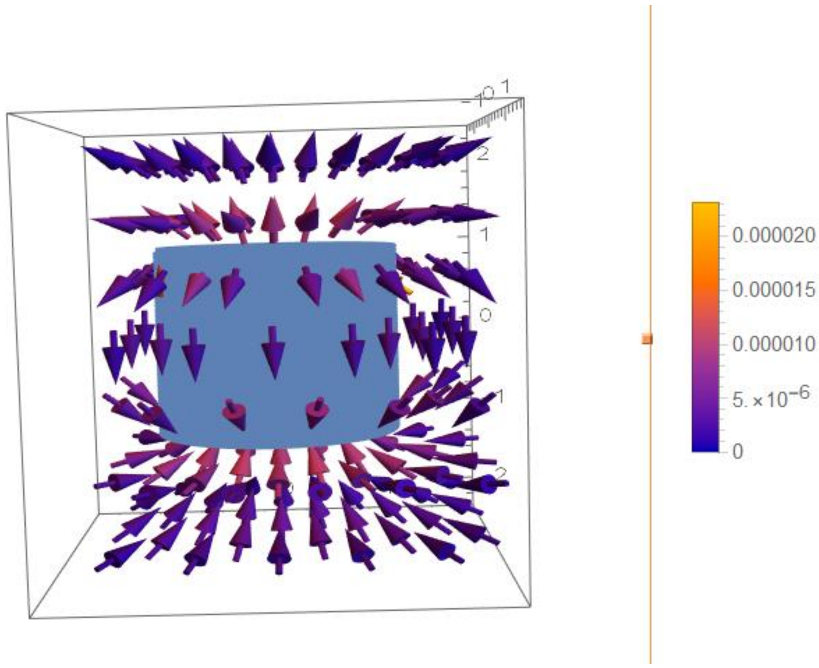

Fig. 2b. Side view of 3D solenoid

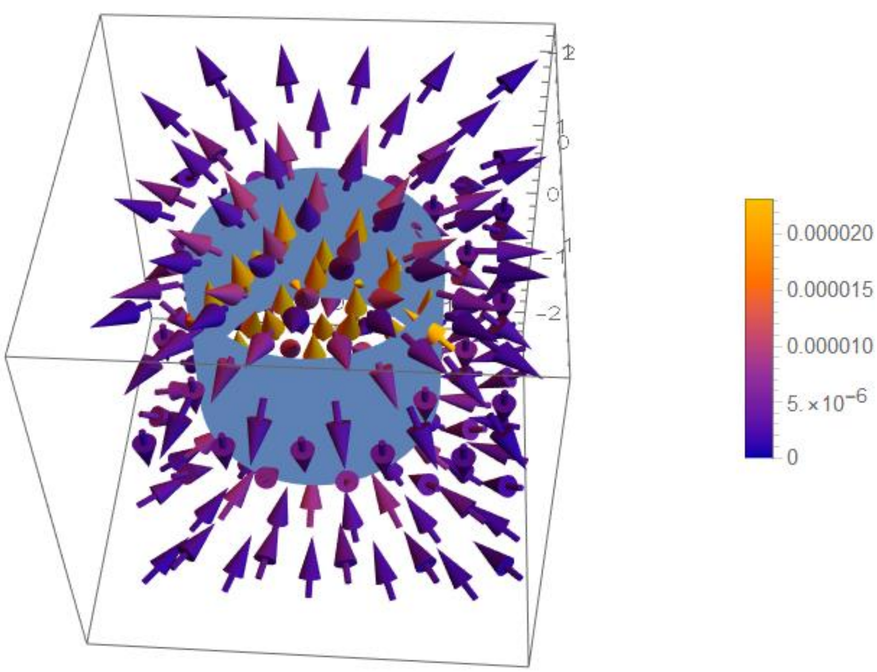

Fig. 2c. Top view of 3D solenoid.

The magnitude of the magnetic field within the solenoid approximated 2.3*10^-5 T. Analytical approaches would predict a field of 3.14*10^-5 T. The discrepancy between the finite and infinite solenoid is larger in this case because the radius and length of this solenoid were of comparable magnitude. This model further confirms that the field loops back around on the outside of the solenoid, with a very low magnitude.

Overall, the finite solenoid differs from the infinite solenoid in that the field strength is strongest near the wires, the field strength decreases near the ends of the solenoid, and the field faces the opposite direction outside of the solenoid. These are non-idealities were explored through the use of computation and numerical integration.