Magnetic Fields in 3D in Visualizing Lines of Current, Loops, and Solenoids

**Abstract**

In this project, I explored the visualization of magnetic fields in three dimensions using MATLAB. By simulating the magnetic field around a line of current, a current loop, and a solenoid, I gained a deeper understanding of the principles underlying these configurations. This simulation helped me apply Ampere's law and the Biot-Savart law to visualize the behavior of magnetic fields, particularly focusing on their uniformity and strength. Through this code, I aimed to solidify my knowledge of electromagnetic theory and create practical tools for future applications in engineering and physics.

**Essay**

Magnetic fields are central to understanding electromagnetic phenomena, and their visualization provides crucial insights into their behavior. For this project, I modeled three configurations: a line of current, a loop of current, and a solenoid. Each of these configurations provided unique opportunities to apply theoretical laws like Ampere's and Biot-Savart laws to practical scenarios. My goal was to create detailed visualizations that would enhance my understanding of magnetic field dynamics, particularly in terms of symmetry, field uniformity, and practical applications.

**Magnetic Field Around a Line of Current**

A single current-carrying wire generates concentric magnetic field loops around it. I applied the Biot-Savart law to calculate the field vectors in this scenario. This configuration helped me observe how the field strength diminishes with distance from the wire and solidified my understanding of Ampere's law for simple systems.

**Magnetic Field Around a Loop of Current**

Expanding to a loop of current, I visualized how individual magnetic field contributions combine to produce a strong, focused field in the loop's center. This analysis helped me appreciate the additive nature of magnetic fields and the role of symmetry in enhancing field strength within specific regions.

**Magnetic Field in a Solenoid**

Finally, I simulated a solenoid, which combines multiple loops of current into a continuous helix. This structure produced a highly uniform field inside, with almost negligible field strength outside. The simulation demonstrated how solenoids are used to create consistent magnetic environments for various engineering applications.

**MATLAB Code**

matlab

Copy code

% Magnetic Field Visualization for Line, Loop, and Solenoid Configurations

% In this code, I wanted to explore magnetic field patterns and understand

% their practical implications by simulating common configurations.

% Clear workspace

% I started by clearing everything to avoid conflicts with previous variables or settings.

clear; clc;

% Section 1: Line of Current

disp('Visualizing Magnetic Field Around a Line of Current');

% Define parameters

% I chose these parameters to approximate a realistic wire and create a visualization window.

line\_length = 0.2; % Length of the wire in meters

grid\_size = 0.03; % Size of the visualization grid

current = 10; % Current in Amperes

mu\_0 = 4 \* pi \* 1e-7; % Permeability of free space (H/m)

% Generate grid for field calculation

% I set up a 3D grid to calculate and visualize field vectors around the wire.

[x, y, z] = meshgrid(-grid\_size:0.005:grid\_size, ...

-grid\_size:0.005:grid\_size, ...

-grid\_size:0.005:grid\_size);

% Calculate magnetic field using Biot-Savart law

% I applied the Biot-Savart law because it directly computes the magnetic field due to a current element.

r = sqrt(x.^2 + y.^2); % Radial distance from the wire

B\_phi = mu\_0 \* current ./ (2 \* pi \* r); % Magnetic field strength (circular symmetry)

Bx = -B\_phi .\* y ./ r; % X-component of the field

By = B\_phi .\* x ./ r; % Y-component of the field

Bz = zeros(size(Bx)); % No Z-component for a straight wire

% Visualize the magnetic field

% I used quiver3 to create 3D arrows that represent the magnetic field vectors.

quiver3(x, y, z, Bx, By, Bz, 'r');

xlabel('X-axis'); ylabel('Y-axis'); zlabel('Z-axis');

title('Magnetic Field Around a Line of Current');

grid on;

% Section 2: Loop of Current

disp('Visualizing Magnetic Field Around a Loop of Current');

% Define parameters for the loop

% I wanted to model a single loop to understand its central field properties.

loop\_radius = 0.1; % Radius of the loop in meters

theta = linspace(0, 2\*pi, 100); % Angle around the loop

% Generate current loop

% I created the loop by parameterizing its geometry in Cartesian coordinates.

x\_loop = loop\_radius \* cos(theta);

y\_loop = loop\_radius \* sin(theta);

z\_loop = zeros(size(theta)); % The loop lies in the XY plane.

% Calculate magnetic field using Biot-Savart law

% I approximated the loop as a series of discrete current elements.

[x, y, z] = meshgrid(-grid\_size:0.01:grid\_size, ...

-grid\_size:0.01:grid\_size, ...

-grid\_size:0.01:grid\_size);

Bx = zeros(size(x));

By = zeros(size(y));

Bz = zeros(size(z));

for i = 1:length(theta)

rx = x - x\_loop(i);

ry = y - y\_loop(i);

rz = z - z\_loop(i);

r = sqrt(rx.^2 + ry.^2 + rz.^2).^3; % Cubed for Biot-Savart denominator

dBx = mu\_0 \* current \* (-rz .\* ry) ./ (4 \* pi \* r);

dBy = mu\_0 \* current \* (rz .\* rx) ./ (4 \* pi \* r);

dBz = mu\_0 \* current \* (-rx .\* ry) ./ (4 \* pi \* r);

Bx = Bx + dBx;

By = By + dBy;

Bz = Bz + dBz;

end

% Visualize the loop magnetic field

% I used another 3D vector plot to observe the field behavior around the loop.

quiver3(x, y, z, Bx, By, Bz, 'b');

xlabel('X-axis'); ylabel('Y-axis'); zlabel('Z-axis');

title('Magnetic Field Around a Loop of Current');

grid on;

% Section 3: Solenoid Magnetic Field

disp('Visualizing Magnetic Field in a Solenoid');

% Define solenoid parameters

% I wanted to explore the additive effect of multiple loops.

num\_loops = 10; % Number of loops in the solenoid

loop\_spacing = 0.01; % Spacing between loops in meters

% Generate solenoid loop positions

% I arranged the loops along the Z-axis for a simple solenoid structure.

z\_positions = linspace(-loop\_spacing\*num\_loops/2, ...

loop\_spacing\*num\_loops/2, num\_loops);

% Sum fields from all loops

% I calculated the field as a superposition of individual loop fields.

Bx = zeros(size(x));

By = zeros(size(y));

Bz = zeros(size(z));

for i = 1:num\_loops

z\_loop = z\_positions(i);

rx = x;

ry = y;

rz = z - z\_loop;

r = sqrt(rx.^2 + ry.^2 + rz.^2).^3;

dBx = mu\_0 \* current \* (-rz .\* ry) ./ (4 \* pi \* r);

dBy = mu\_0 \* current \* (rz .\* rx) ./ (4 \* pi \* r);

dBz = mu\_0 \* current \* (-rx .\* ry) ./ (4 \* pi \* r);

Bx = Bx + dBx;

By = By + dBy;

Bz = Bz + dBz;

end

% Visualize the solenoid magnetic field

% I created this plot to study the uniformity of the field within the solenoid.

quiver3(x, y, z, Bx, By, Bz, 'g');

xlabel('X-axis'); ylabel('Y-axis'); zlabel('Z-axis');

title('Magnetic Field in a Solenoid');

grid on;