Engineering Electromagnetics –Experiment 3

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Abstract

This experiment illustrates the distribution of the spatial magnetic field that is produced by an electric current loop and provide an intuitive way to calculate the magnetic field distribution and plot the relevant graphs through MATLAB.

1 Background

From the Biot–Savart law, we could derive the magnetic field on a current coil into various parts and integrate them seperately to get the total magnetic field that produced by the current in the coil.

$$d\mathbf{H} = \frac{I\,d\mathbf{L} \times \mathbf{a}_R}{4\pi R^2} = \frac{I\,d\mathbf{L} \times \mathbf{R}}{4\pi R^3} \tag{1}$$

After the integration, the total magnetic field of a current coil equals:

$$\mathbf{H} = \frac{I\left(\pi a^2\right)\mathbf{a}_z}{2\pi\left(a^2 + z_0^2\right)^{3/2}} \tag{2}$$

2 Two Current Loop with Same Current Direction

2.1 Define the Paraments

To make the magnetic field more presise, we split each dimension of the space into 100 tiles. The black rectangele in the figure represents the region $y = [-2, 2]$, $z = [-1, 1]$.

```
ym=10;  %Set the range of y direction in the field domain
zm=10; %Set the range of z direction in the field domain
y=linspace(-ym,ym,100); % Equally divide y axis into 100 parts
z=linspace(-zm,zm,100); % Equally divide z axis into 100 parts

a=2; %Input the radius of the current loop
I=500; %Input the current value in the current loop
C=I/(4*pi);     %Merge the constants
N=50;         %Se t the number of division

theta0=linspace(0,2*pi,N+1);   %Division of the angle of circumference
theta1=theta0(1:N);
x1=a*cos(theta1); y1=a*sin(theta1);  %The start point coordinate of each segment of the loop
theta2=theta0(2:N+1);
x2=a*cos(theta2); y2=a*sin(theta2);  %The ending point coordinate of each segment of the loop

zc=1; xc=(x2+x1)./2; yc=(y2+y1)./2; %Calculate the 3 coordinate components of the midpoint
% of each segment of the loop.
dlz=0;dlx=x2-x1;dly=y2-y1;    %Calculate the 3 length components of each segment vector dl.

NGx=100; NGy=100;    %Grid dimension
Hy=zeros(100);Hz=zeros(100);H=zeros(100);         %Construct the H matrix
```

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2.2 Calculate the Sum of the Magnetic Field

```
    %% first coil
    for i=1:NGy          %Loop computation of the value of H(x,y) in each grid
        for j=1:NGx
            rx=0-xc; ry=y(j)-yc; rz=z(i)-zc; %Calculate the 3 length components of the radius vector r,
            % and r is in the z = 0 plane.
            r3=sqrt(rx.^2+ry.^2+rz.^2).^3;      %Calculate r cube (r3)
            dlXr_y=dlz.*rx-dlx.*rz;       %Calculate the y, z components of the cross product dl×r,
            %x component is 0.
            dlXr_z=dlx.*ry-dly.*rx;
            Hy(i,j)=sum(C.*dlXr_y./r3);       %Accumulate the magnetic field intensity created
            %by each segment of the loop.
            Hz(i,j)=sum(C.*dlXr_z./r3);
            H=(Hy.^2+Hz.^2).^0.5;           %Calculate the magnitude of H
        end
    end

    %% add the mag field of the second coil
    zc2 = -1;
Hy2=zeros(100);Hz2=zeros(100);H2=zeros(100);
for i=1:NGy          %Loop computation of the value of H(x,y) in each grid
    for j=1:NGx
        rx=0-xc; ry=y(j)-yc; rz=z(i)-zc2; %Calculate the 3 length components of the radius vector r,
        % and r is in the z = 0 plane.
        r3=sqrt(rx.^2+ry.^2+rz.^2).^3;      %Calculate r cube (r3)
        dlXr_y=dlz.*rx-dlx.*rz;       %Calculate the y, z components of the cross product dl×r,
        %x component is 0.
        dlXr_z=dlx.*ry-dly.*rx;
        Hy2(i,j)=sum(C.*dlXr_y./r3);       %Accumulate the magnetic field intensity created
        %by each segment of the loop.
        Hz2(i,j)=sum(C.*dlXr_z./r3);
        H2=(Hy2.^2+Hz2.^2).^0.5;           %Calculate the magnitude of H
    end
end
```

After that, we sum up the magnetic field generated by each current loop respectively.

```
    Hy = Hy + Hy2;
    Hz = Hz + Hz2;
    H = H + H2;
```

2.3 Plot the Diagram

Magnetic field intensity vector distribution:

```
    %% plot1
    figure1 = figure; %define figure
    h = quiver(y,z,Hy,Hz,'autoscalefactor',1.25);       %Plot the vector graph of the magnetic field intensi
    set(h,'linewidth',1.2)
    hold on;
    title({'the plot of magnetic field intensity vector distribution';'(represented by arrows) 樊青远 118124
    pbaspect([1 1 1]);
```

```
axis([-3,3,-3,3]);
plot(2,1,'ro',-2,1,'bo'),       %Standard coil section
plot(2,-1,'ro',-2,-1,'bo'),       %Standard coil section
xlabel('y/m','fontsize',12),ylabel('z/m','fontsize',12),       %Label the axis
set(gcf,'Position',[10 10 500 500]);
saveas(figure1,'../fig/A1.jpg');
```

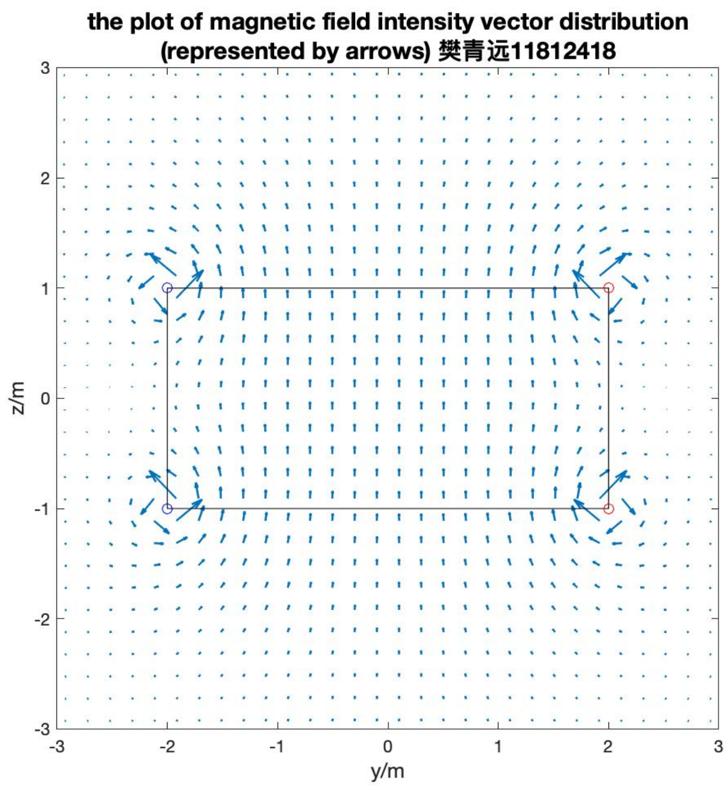

Figure 1. the plot of magnetic field intensity vector distribution (represented by arrows).

Magnetic field intensity magnitude distribution:

```
%% plot2
figure1 = figure; %define figure
surf(y,z,H);%Plot the graph of magnetic field intensity
shading interp; %disable the grid
colormap default; %set the colour map
hold on;
title({'the plot of magnetic field intensity magnitude distribution';'樊青远 11812418'}, 'fontsize',12);
pbaspect([1 1 1]);
axis([-3,3,-3,3,0,1000])
xlabel('y/m','fontsize',12),ylabel('z/m','fontsize',12),zlabel('H','fontsize',12);
colorbar;
```

```
    set(gcf,'Position',[10 10 500 500]);
    saveas(figure1,'../fig/A2.jpg');
```

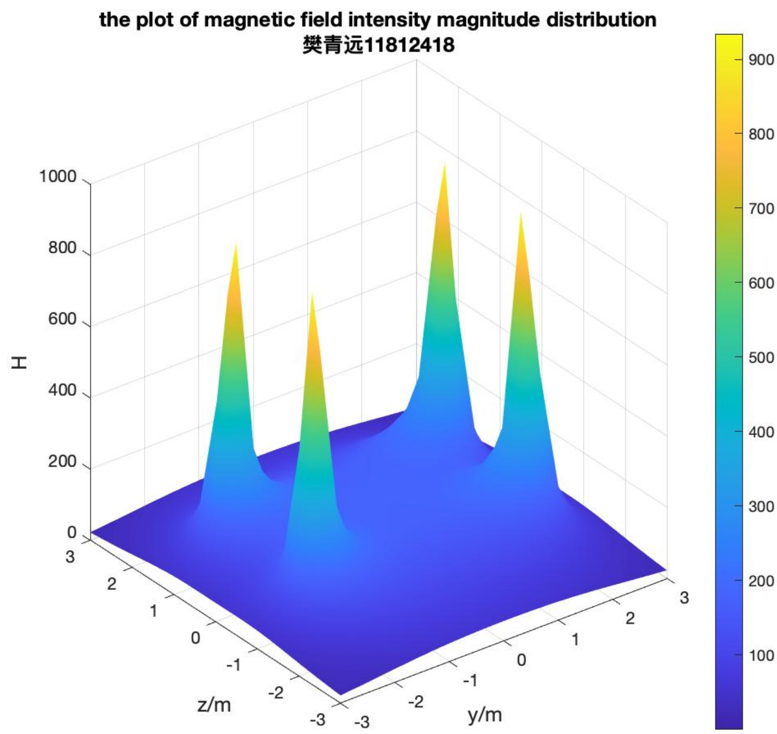

Figure 2. The plot of magnetic field intensity magnitude distribution.

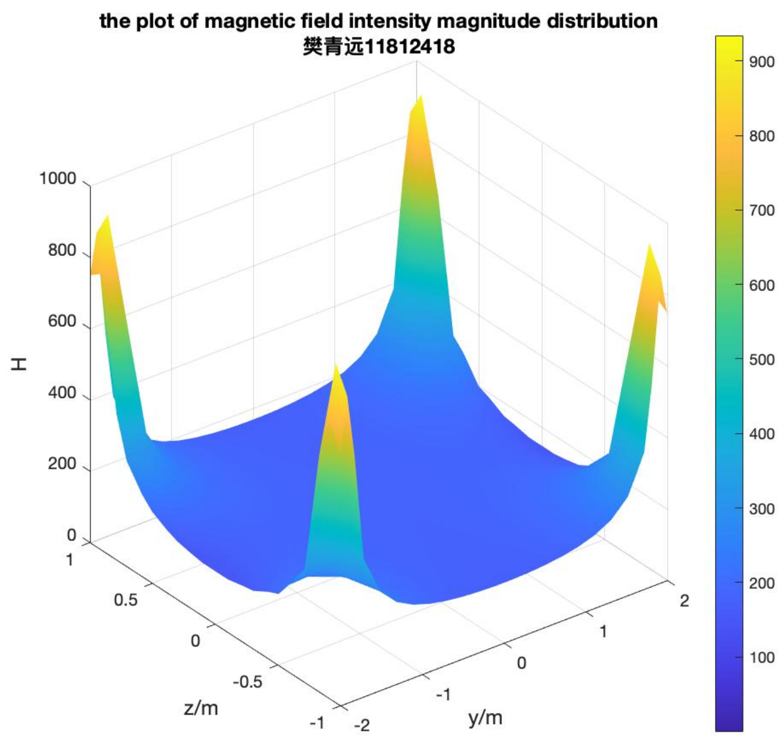

Figure 3. The plot of magnetic field intensity magnitude distribution.($y = [-2, 2]$, $z = [-1, 1]$)

Magnetic line:

```
%% plot3
figure1 = figure; %define figure
theta=[0 50 60 70 80 90 100 110 120 130 180 230 240 250 260 270 280 290 300 310].*pi/180;    %Set
ys=2.2*cos(theta);         %Set the streamline starting circle’ s y coordinate
zs=2.2*sin(theta);          %Set the streamline starting circle’ s z coordinate
streamline(y,z,Hy,Hz,ys,zs); %Outwardly plot the magnetic line of force from the starting circle.
streamline(y,z,-Hy,-Hz,ys,zs); %Inwardly plot the magnetic line of force from the starting circle
xlabel('y/m','fontsize',12),ylabel('z/m','fontsize',12);
title({'the plot of magnetic line';'樊青远 11812418'}, 'fontsize',14);
pbaspect([1 1 1]);
set(gcf,'Position',[10 10 500 500]);
saveas(figure1,'../fig/A3.jpg');
```

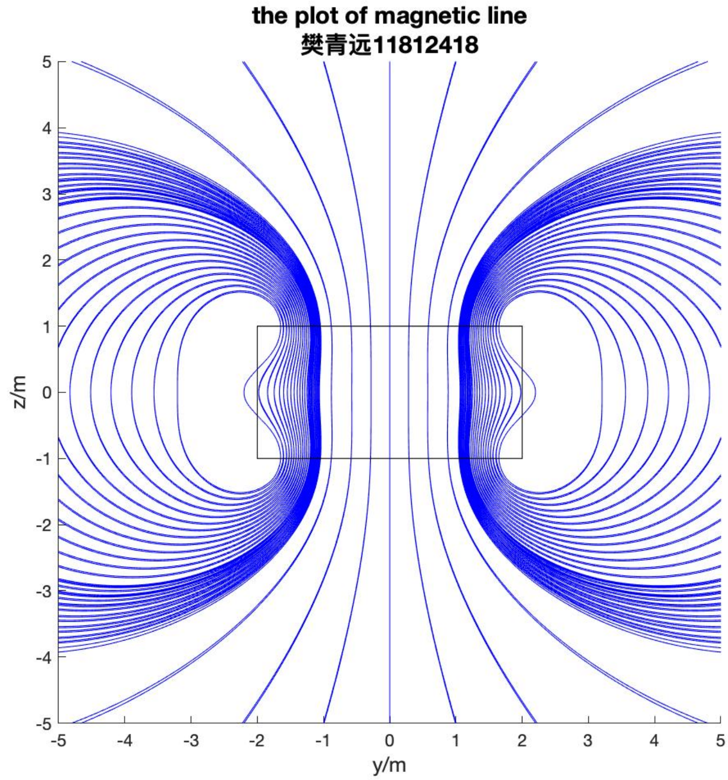

Figure 4. The plot of magnetic line.

2.4 Analyze

Fron the diagram, we could figure out that at the space between the two current loop, the direction of the magnetic field could be approximate as perpendicular to $x - y$ plane, especially in region $y = [-2, 2], z = [-1, 1]$.

From figure 4, we could also find out that every magnetic line is closed.

The peak of the magnetic field intensity will always occurs on the current loop.

3 Two Current Loop with Same Current Direction

3.1 Define the Paraments

To make the magnetic field more presise, we split each dimension of the space into 100 tiles. The black rectangele in the figure represents the region $y = [-2, 2]$, $z = [-1, 1]$.

```
ym=10;  %Set the range of y direction in the field domain
zm=10; %Set the range of z direction in the field domain
y=linspace(-ym,ym,100); % Equally divide y axis into 100 parts
z=linspace(-zm,zm,100); % Equally divide z axis into 100 parts

a=2; %Input the radius of the current loop
I=500; %Input the current value in the current loop
C=I/(4*pi);     %Merge the constants
N=50;          %Se t the number of division

theta0=linspace(0,2*pi,N+1);   %Division of the angle of circumference
theta1=theta0(1:N);
x1=a*cos(theta1); y1=a*sin(theta1);  %The start point coordinate of each segment of the loop
theta2=theta0(2:N+1);
x2=a*cos(theta2); y2=a*sin(theta2);  %The ending point coordinate of each segment of the loop

zc=1; xc=(x2+x1)./2; yc=(y2+y1)./2; %Calculate the 3 coordinate components of the midpoint
% of each segment of the loop.
dlz=0;dlx=x2-x1;dly=y2-y1;    %Calculate the 3 length components of each segment vector dl.

NGx=100; NGy=100;   %Grid dimension
Hy=zeros(100);Hz=zeros(100);H=zeros(100);         %Construct the H matrix
```

3.2 Calculate the Sum of the Magnetic Field

```
%% first coil
for i=1:NGy         %Loop computation of the value of H(x,y) in each grid
    for j=1:NGx
        rx=0-xc; ry=y(j)-yc; rz=z(i)-zc; %Calculate the 3 length components of the radius vector r,
        % and r is in the z = 0 plane.
        r3=sqrt(rx.^2+ry.^2+rz.^2).^3;      %Calculate r cube (r3)
        dlXr_y=dlz.*rx-dlx.*rz;       %Calculate the y, z components of the cross product dl×r,
        %x component is 0.
        dlXr_z=dlx.*ry-dly.*rx;
        Hy(i,j)=sum(C.*dlXr_y./r3);       %Accumulate the magnetic field intensity created
        %by each segment of the loop.
        Hz(i,j)=sum(C.*dlXr_z./r3);
        H=(Hy.^2+Hz.^2).^0.5;           %Calculate the magnitude of H
    end
end

%% add the mag field of the second coil
zc2 = -1;
Hy2=zeros(100);Hz2=zeros(100);H2=zeros(100);
for i=1:NGy         %Loop computation of the value of H(x,y) in each grid
    for j=1:NGx
        rx=0-xc; ry=y(j)-yc; rz=z(i)-zc2; %Calculate the 3 length components of the radius vector r,
        % and r is in the z = 0 plane.
        r3=sqrt(rx.^2+ry.^2+rz.^2).^3;      %Calculate r cube (r3)
        dlXr_y=dlz.*rx-dlx.*rz;       %Calculate the y, z components of the cross product dl×r,
```

```
        %x component is 0.
        dlXr_z=dlx.*ry-dly.*rx;
        Hy2(i,j)=sum(C.*dlXr_y./r3);        %Accumulate the magnetic field intensity created
        %by each segment of the loop.
        Hz2(i,j)=sum(C.*dlXr_z./r3);
        H2=(Hy2.^2+Hz2.^2).^0.5;            %Calculate the magnitude of H
    end
end
```

After that, we sum up the magnetic field generated by each current loop respectively. However, as the current direction of the second current loop is opposite to the first one, so we minus the magnetic field generate by the second current on the first current loop.

```
    Hy = Hy - Hy2;
    Hz = Hz - Hz2;
    H = H - H2;
```

3.3 Plot the Diagram

Magnetic field intensity vector distribution:

```
    %% plot1
    figure1 = figure; %define figure
    h = quiver(y,z,Hy,Hz,'autoscalefactor',1.25);       %Plot the vector graph of the magnetic field intensi
    set(h,'linewidth',1.2)
    hold on;
    title({'the plot of magnetic field intensity vector distribution';'(represented by arrows) 樊青远 118124
    pbaspect([1 1 1]);
    axis([-3,3,-3,3]);
    plot(2,1,'ro',-2,1,'bo'),       %Standard coil section
    plot(2,-1,'ro',-2,-1,'bo'),      %Standard coil section
    xlabel('y/m','fontsize',12),ylabel('z/m','fontsize',12),      %Label the axis
    set(gcf,'Position',[10 10 500 500]);
    saveas(figure1,'../fig/B1.jpg');
```

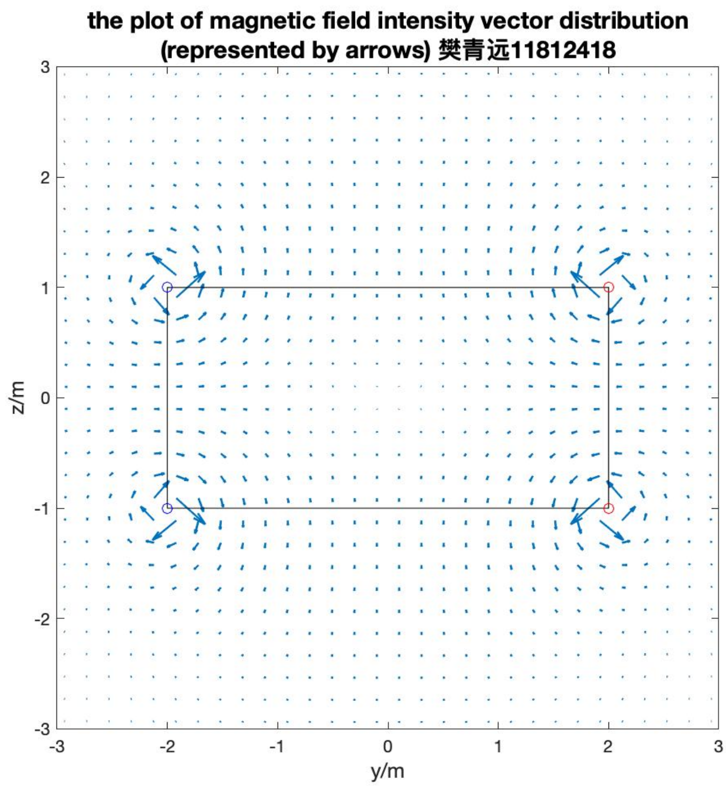

Figure 5. the plot of magnetic field intensity vector distribution (represented by arrows).

Magnetic field intensity magnitude distribution:

```
%% plot2
figure1 = figure; %define figure
surf(y,z,H);%Plot the graph of magnetic field intensity
shading interp; %disable the grid
colormap default; %set the colour map
hold on;
title({'the plot of magnetic field intensity magnitude distribution';'樊青远 11812418'}, 'fontsize',12);
pbaspect([1 1 1]);
axis([-3,3,-3,3,0,1000])
xlabel('y/m','fontsize',12),ylabel('z/m','fontsize',12),zlabel('H','fontsize',12);
colorbar;
set(gcf,'Position',[10 10 500 500]);
saveas(figure1,'../fig/B2.jpg');
```

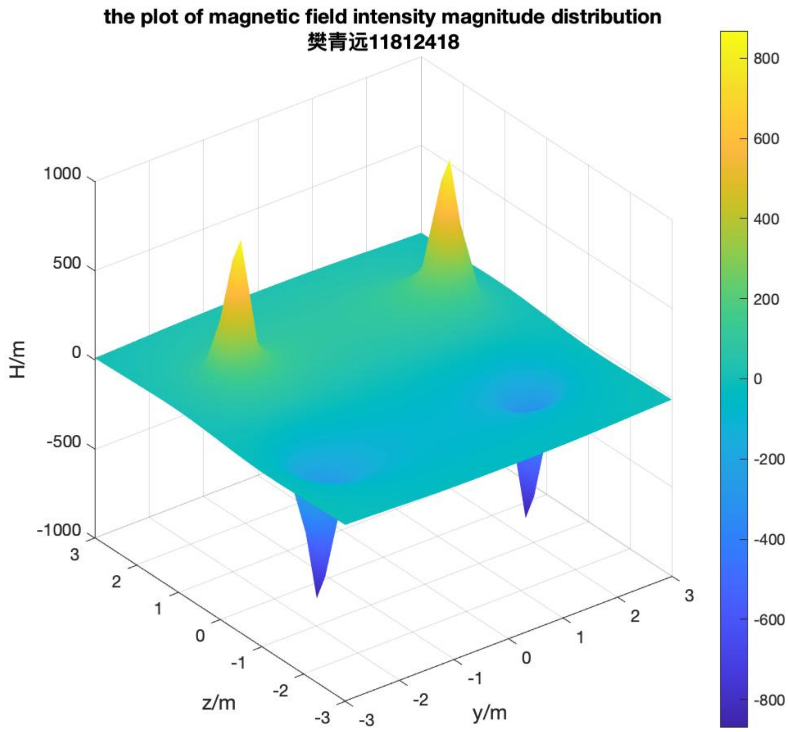

Figure 6. The plot of magnetic field intensity magnitude distribution.

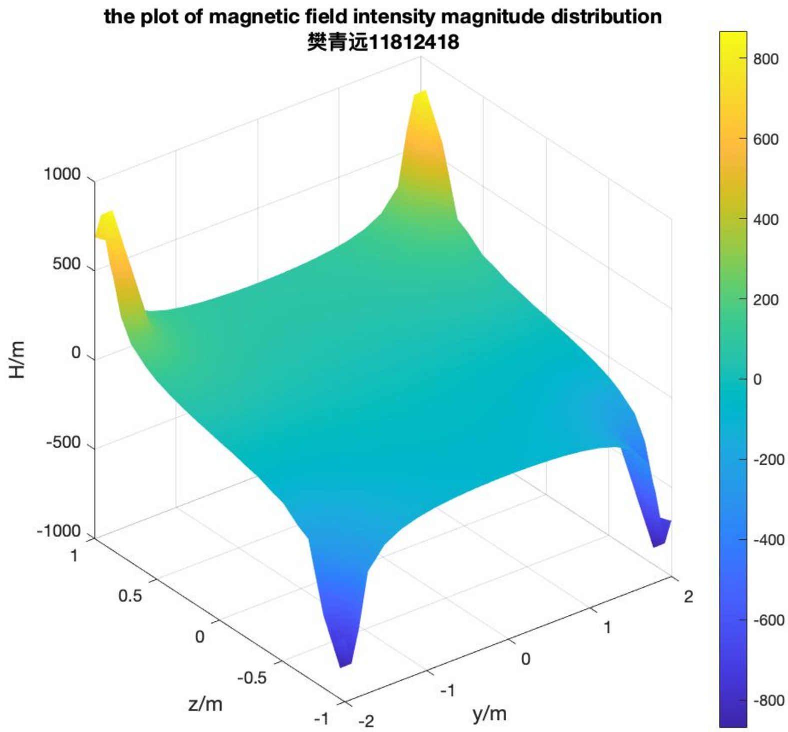

Figure 7. The plot of magnetic field intensity magnitude distribution.($y = [-2, 2]$, $z = [-1, 1]$)

Magnetic line:

```
%% plot3
figure1 = figure; %define figure
theta=[0 50 60 70 80 90 100 110 120 130 180 230 240 250 260 270 280 290 300 310].*pi/180;   %Set
ys=2.2*cos(theta);        %Set the streamline starting circle' s y coordinate
zs=2.2*sin(theta);         %Set the streamline starting circle' s z coordinate
streamline(y,z,Hy,Hz,ys,zs); %Outwardly plot the magnetic line of force from the starting circle.
streamline(y,z,-Hy,-Hz,ys,zs); %Inwardly plot the magnetic line of force from the starting circle
xlabel('y/m','fontsize',12),ylabel('z/m','fontsize',12);
title({'the plot of magnetic line';'樊青远 11812418'}, 'fontsize',14);
pbaspect([1 1 1]);
set(gcf,'Position',[10 10 500 500]);
saveas(figure1,'../fig/B3.jpg');
```

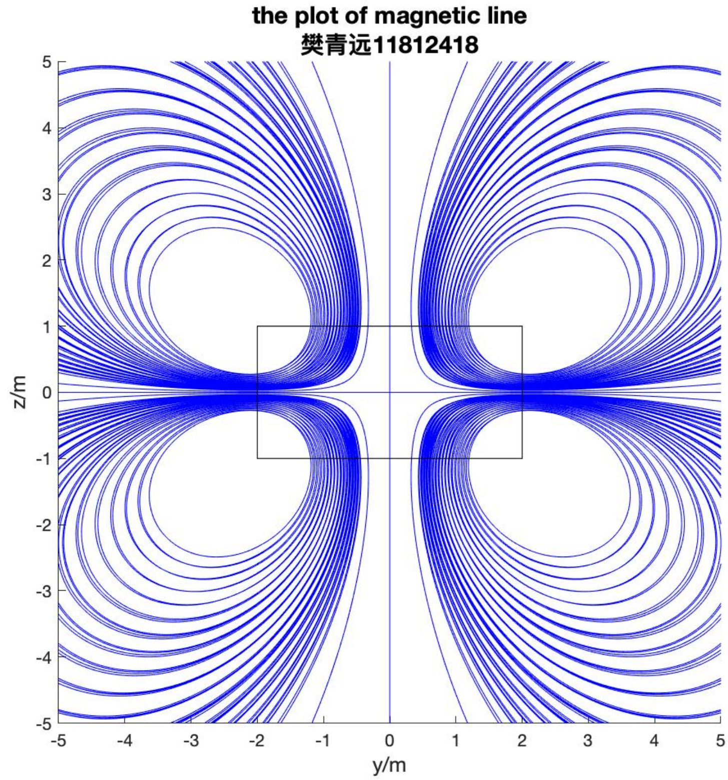

Figure 8. The plot of magnetic line.

3.4 Analyze

Fron the diagram, we could figure out that at the line pass through the two current loops, the direction of the magnetic field could be approximate as perpendicular to $x - y$ plane, especially in region $y = [-2, 2], z = [-1, 1]$.

The magnetic field intensity at the origin of the axis equals zero.

From figure 8, we could also find out that every magnetic line is closed.

The peak of the magnetic field intensity will always occurs on the current loop.

4 Inspiration

From this experiment, we've learn a intuitive way to plot the charactristic properties that the magnetic field generated by current loop(s) and deepen our understanding of the application of the Biot–Savart law.

We also recognized that the more tiles to seperate one plane, the result will be more accurate.