ภาคผนวก ง

โปรแกรมสำหรับคำนวณความเข้มสนามแม่เหล็กใน Helmholtz coils

ค.1 โปรแกรมหลักสำหรับคำนวณความเข้มสนามแม่เหล็กใน Square Helmholtz coil

```matlab
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% File name: SQ_Helmholtz_finite_3D_SWG11.m                                      %
% This program is used for calcaulation of magneetic field inside a square Helmholtz coil with finite cross section %

clear all

%This section for input of coil parameters
J=25;     %number of layers
N=23;     %numer of turns in the odd layers

%Wire parameters
d=3.078e-3;
resistivity=2.665; %Ohms/km

W=N*d;% Coil width
H=d+sqrt(3)*d/2*J;%Coil height

a_avg=0.15; %average coil width
c_avg=0.544506*a_avg; %average coil space

I=16.34; %coil current
%End of input coil parameters



%Calculation of B0
x=0; y=0; z=0;
%***************B0 Calculation*********
        B0=0;
        for j=1:2:J     %Odd layers
            a=a_avg-H/2+d/2+(j-1)*(sqrt(3)*d/2);
            for n=1:1:N
                c=c_avg-W/2+d*(n-0.5);
                Arbitrary_square_coils %call subprogram
                B0=B0+Bz;
            end
        end

        for j=2:2:J     %Even layers
```

```matlab
            a=a_avg-H/2+d/2+(j-1)*(sqrt(3)*d/2);
                for n=1:1:N-1
                    c=c_avg-W/2+d*n;
                    Arbitrary_square_coils %call subprogram
                    B0=B0+Bz;
                end
            end
%**************End of B0 Calculation*********


%Define locations (1 quadrant) for field calculation
X=0:0.0005:0.03;
Y=X;
Z=0;

temp=size(X); Point_x=temp(2);
temp=size(Y); Point_y=temp(2);
temp=size(Z); Point_z=temp(2);

z=Z;
%calculation of Bz
for k=1:1:Point_x
    x=X(k);
for i=1:1:Point_y
    y=Y(i);
%**************Bz Calculation from individual pairs of square loops
            B1=0;
                for j=1:2:J     %Odd layers
                    a=a_avg-H/2+d/2+(j-1)*(sqrt(3)*d/2);
                    for n=1:1:N
                        c=c_avg-W/2+d*(n-0.5);
                        Arbitrary_square_coils %call subprogram
                        B1=B1+Bz;
                    end
                end

                for j=2:2:J     %Even layers
                    a=a_avg-H/2+d/2+(j-1)*(sqrt(3)*d/2);
                    for n=1:1:N-1
                        c=c_avg-W/2+d*n;
```

```matlab
                Arbitrary_square_coils  %call subprogram
                B1=B1+Bz;
            end
        end
%***************End of Bz Calculation*********

    B(i,k)=B1;
end
end

%Copy data in first quadrant to 2-4 quadrant
Bq1=flipud(B);
Bq12=[fliplr(Bq1(:,2:Point_x)) Bq1];
Bfull=[Bq12; flipud(Bq12(1:(Point_y-1),:))];

%define full range
X=-0.03:0.0005:0.03;
Y=X;
Z=z;



clear B1 Bz a c n Bq12 Bq2 Bq34 temp i j k x y z B Bq1 Point_x Point_y Point_z

save SQ_SWG11_xy_plane_z20mm.mat %save calculated field

figure(1)
mesh(X*1000,Y*1000,Bfull/B0*100)

figure(2)
contour(X*1000,Y*1000,Bfull/B0*100)
```

ค.2 โปรแกรมย่อยสำหรับคำนวณความเข้มสนามแม่เหล็กใน Square Helmholtz coil

```
% File name: Arbitrary_square_coils.m
%input parameters include observed position (x,y,z), coil radius (a),
%coil spacing (2c)
%Current, I

%i=1, j=1, k=1
Bz1=(x-a)*(y-a)/sqrt((x-a)*(x-a)+(y-a)*(y-a)+(z-c)*(z-c))*(1/((x-a)*(x-a)+(z-c)*(z-c))+1/((y-a)*(y-a)+(z-c)*(z-c)));
%i=1, j=1, k=2
Bz2=(x-a)*(y-a)/sqrt((x-a)*(x-a)+(y-a)*(y-a)+(z+c)*(z+c))*(1/((x-a)*(x-a)+(z+c)*(z+c))+1/((y-a)*(y-a)+(z+c)*(z+c)));
%i=1, j=2, k=1
Bz3=-(x-a)*(y+a)/sqrt((x-a)*(x-a)+(y+a)*(y+a)+(z-c)*(z-c))*(1/((x-a)*(x-a)+(z-c)*(z-c))+1/((y+a)*(y+a)+(z-c)*(z-c)));
%i=1, j=2, k=2
Bz4=-(x-a)*(y+a)/sqrt((x-a)*(x-a)+(y+a)*(y+a)+(z+c)*(z+c))*(1/((x-a)*(x-a)+(z+c)*(z+c))+1/((y+a)*(y+a)+(z+c)*(z+c)));
%i=2, j=1, k=1
Bz5=-(x+a)*(y-a)/sqrt((x+a)*(x+a)+(y-a)*(y-a)+(z-c)*(z-c))*(1/((x+a)*(x+a)+(z-c)*(z-c))+1/((y-a)*(y-a)+(z-c)*(z-c)));
%i=2, j=1, k=2
Bz6=-(x+a)*(y-a)/sqrt((x+a)*(x+a)+(y-a)*(y-a)+(z+c)*(z+c))*(1/((x+a)*(x+a)+(z+c)*(z+c))+1/((y-a)*(y-a)+(z+c)*(z+c)));
%i=2, j=2, k=1
Bz7=(x+a)*(y+a)/sqrt((x+a)*(x+a)+(y+a)*(y+a)+(z-c)*(z-c))*(1/((x+a)*(x+a)+(z-c)*(z-c))+1/((y+a)*(y+a)+(z-c)*(z-c)));
%i=2, j=2, k=1
Bz8=(x+a)*(y+a)/sqrt((x+a)*(x+a)+(y+a)*(y+a)+(z+c)*(z+c))*(1/((x+a)*(x+a)+(z+c)*(z+c))+1/((y+a)*(y+a)+(z+c)*(z+c)));


clear Bz1 Bz2 Bz3 Bz4 Bz5 Bz6 Bz7 Bz8
Bz=(Bz1+Bz2+Bz3+Bz4+Bz5+Bz6+Bz7+Bz8)*1e-7*I;
```

ค.3 โปรแกรมหลักสำหรับคำนวณความเข้มสนามแม่เหล็กใน Circular Helmholtz coil

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% File name: ROUND_Helmholtz_finite_3D_SWG11.m                %
% This program is used for calculation of magnetic field inside a circular Helmholtz coil with finite cross section

clear all

%define coil parameters
a_avg=0.155; %average coil radius
c_avg=0.5*a_avg; %average coil space

I=15.4; %coil current
```

```matlab
J=26;    %number of layers
N=22;    %numer of turns in the odd layers

%Wire parameters
d=3.078e-3;
resistivity=2.665; %Ohms/km

W=N*d;  %coil width
H=d+sqrt(3)*d/2*J; %coil height




%Calculation of B0
 z=0;
p=0;
%**************B0 Calculation*********
            B0=0;
            for j=1:2:J    %Odd layers
                a=a_avg-H/2+d/2+(j-1)*(sqrt(3)*d/2);
                for n=1:1:N
                    c=c_avg-W/2+d*(n-0.5);
                    Arbitrary_round_coils %call subprogram
                    B0=B0+Bz;
                end
            end

            for j=2:2:J    %Even layers
                a=a_avg-H/2+d/2+(j-1)*(sqrt(3)*d/2);
                for n=1:1:N-1
                    c=c_avg-W/2+d*n;
                    Arbitrary_round_coils %call subprogram
                    B0=B0+Bz;
                end
            end
%**************End of B0 Calculation*********

%Define locations (1 quadrant) for field calculation
X=0:0.005:0.03;
Y=X;
Z=0;
```

```matlab
temp=size(X); Point_x=temp(2);
temp=size(Y); Point_y=temp(2);
temp=size(Z); Point_z=temp(2);


z=Z;
for k=1:1:Point_x
    x=X(k);
for i=1:1:Point_y
    y=Y(i);
    p=sqrt(x^2+y^2); %convert to cylindrical coordinate
%***************Bz Calculation*********
            B1=0;
            for j=1:2:J     %Odd layers
                a=a_avg-H/2+d/2+(j-1)*(sqrt(3)*d/2);
                for n=1:1:N
                    c=c_avg-W/2+d*(n-0.5);
                    Arbitrary_round_coils %call subprogram
                    B1=B1+Bz;
                end
            end

            for j=2:2:J     %Even layers
                a=a_avg-H/2+d/2+(j-1)*(sqrt(3)*d/2);
                for n=1:1:N-1
                    c=c_avg-W/2+d*n;
                    Arbitrary_round_coils %call subprogram
                    B1=B1+Bz;
                end
            end
%***************End of Bz Calculation*********

    B(i,k)=B1;
end
end

 %Copy data in first quadrant to 2-4 quadrant
Bq1=flipud(B);
Bq12=[fliplr(Bq1(:,2:Point_x)) Bq1];
Bfull=[Bq12; flipud(Bq12(1:(Point_y-1),:))];
```

```
%define full range
X=-0.03:0.005:0.03;
Y=X;

clear B1 Bz a c n Bq12 Bq2 Bq34 temp i j k x y z p Bq1 B
clear Point_x Point_y Point_z

save ROUND_SWG11_xy_plane.mat %save data


figure(1)
mesh(X*1000,Y*1000,Bfull/B0*100)

figure(2)
contour(X*1000,Y*1000,Bfull/B0*100)
```

ค.4 โปรแกรมย่อยสำหรับคำนวณความเข้มสนามแม่เหล็กใน Circular Helmholtz coil

```
%This subprogram for calculation of Bz in a pair of circular loops
  %input parameters include observed position (p,z), coil radius (a),
%coil spacing (2c)
%Current, I

 m1=4*a*p/((p+a)*(p+a)+(z-c)*(z-c));
[K1,E1] = ellipke(m1);
Bz1=1/sqrt((p+a)*(p+a)+(z-c)*(z-c))*(K1+E1*((2*a*(p+a)/(((p+a)^2+(z-c)^2)*(1-m1)))-1/(1-m1)));

m2=4*a*p/((p+a)*(p+a)+(z+c)*(z+c));
[K2,E2] = ellipke(m2);
Bz2=1/sqrt((p+a)*(p+a)+(z+c)*(z+c))*(K2+E2*((2*a*(p+a)/(((p+a)^2+(z+c)^2)*(1-m2)))-1/(1-m2)));

Bz=(Bz1+Bz2)*2e-7*I;

clear m1 m2 K1 K2 E1 E2 Bz1 Bz2
```