

CDS 301 Spring 2013
Scientific Information and Data Visualization
Project 3

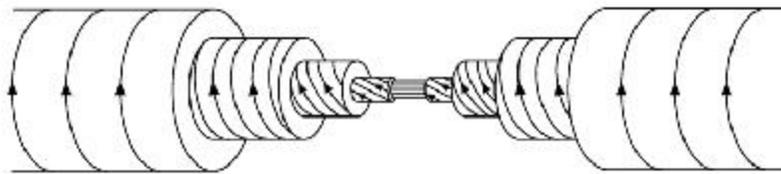
Assignment Date: April 23, 2013
Due Date: May 07, 2013

Visualization of a 3-D Magnetic Flux Rope (MFR)

1. Introduction

The goal of this project is to draw an object named magnetic flux rope (MFR). An MFR has a 3-D cylindrical shape, with helical magnetic field lines wrapping around the surface of the cylinder. You are required to draw the cylindrical surface as well as the helical magnetic field lines, in order to fully illustrate the structure of MFR

One basic drawing of the flux rope is illustrated in Figure 1.



Interior Structure of Flux Rope

Figure 1: A basic drawing of MFR

One simple version of visualization of MFR is illustrated in Figure 2

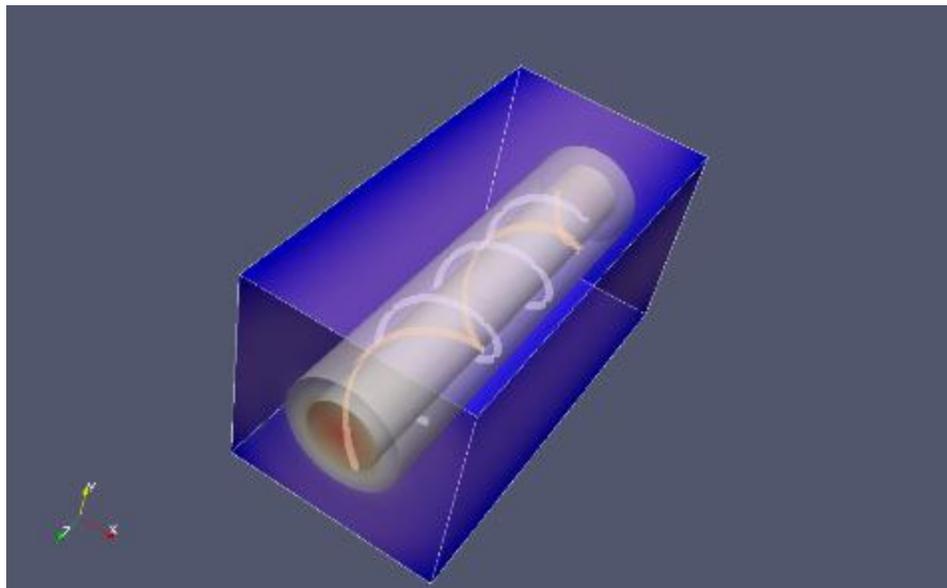


Figure 2: Sample 3-D visualization of MFR

2. Description of Magnetic Flux Rope

An MFR is an important scientific object in space science and plasma physics. It may appear in many places, including in the Sun's atmosphere, the space between planets, and in laboratories. It is composed of organized magnetic field lines and electric current, thus carrying a large amount of energy with it. The eruption of MFR on the Sun and its subsequent interaction with the Earth is the primary driver of severe space weather that affect society and life.

The mathematic equation governing MFR is the Bessel differential equation as follows:

$$\nabla^2 \vec{B} + \alpha^2 \vec{B} = 0$$

where \mathbf{B} is the vector magnetic field, and α a constant characterizing the tightness of the helical shape (or equivalently, the strength of electric current, or energy in the system). The mathematic solution of this equation in a cylindrical geometry is a set of three scalar functions that describe the three components of the vector magnetic field along the r (radial), ϕ (azimuth) and z (axial) directions, respectively:

$$B_r = 0$$

$$B_\phi = B_0 J_1(\alpha r)$$

$$B_z = B_0 J_0(\alpha r)$$

Where B_0 and α are constants; both can be chosen as value 1 in this project. J_0 and J_1 are the zeroth and first order Bessel functions, respectively.

The Bessel function is one of the well-defined classical functions, whose information can be found in many mathematic books. Its solution can be found in almost all mathematic software packages. For more information, one can refer to the WIKI page at http://en.wikipedia.org/wiki/Bessel_function. The graphic illustration of the Bessel function is shown in Figure 3.

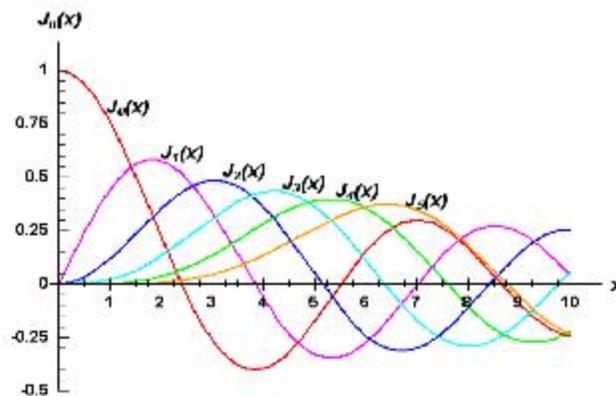


Figure 3: Graphic Solution of Bessel function

In MATLAB, $J_0 = \text{besselj}(0, x)$, and $J_1 = \text{besselj}(1, x)$. One can explore the Bessel function through

```
>>x=[0:0.01:5]
>>J0=besselj(0,x)
>>plot(x,J0)
```

3. Project requirement

You are asked to implement a set of software programs, using MATLAB, to visualize the 3-D MFR structure. The code shall, at least, fulfill the following visualization tasks.

- (1) Calculate the vector magnetic field in a 3-D data box of x $[-2, 2]$, y $[-2, 2]$ and z $[0, 10]$. For each data point, convert $[x, y, z]$ into $[r, \phi, z]$, or from Cartesian to Cylindrical coordinates, then use the Bessel function to calculate $[B_r, B_\phi, B_z]$. You further need to convert $[B_r, B_\phi, B_z]$ into $[B_x, B_y, B_z]$, or from Cylindrical to Cartesian transform
- (2) Calculate the magnitude of the magnetic field at each data point. This is to create a 3-D scalar data of magnetic field.
- (3) (Figure 1) Show the contours of scalar magnetic field at the slices of $x=0$, $y=0$ and $z=5$.
- (4) (Figure 2) Show the 3-D isosurface of scalar magnetic field with the magnitude of 0.5.
- (5) (Figure 3) Show a cylindrical surface at radius $r = 1.5$. Shading and lighting is needed in order to have a 3-D appearance. Transparency is also needed in order to show the other side of the cylinder.
- (6) (Figure 4) Show helical magnetic field lines at the surface $r=1.5$ (added onto Figure 3). This is about showing the stream lines with a selected set of seed points on the edge ($z=0$) of the surface ($r=1.5$).
- (7) (Figure 5) Add another surface with helical lines at radius $r=0.5$ onto Figure (4).
- (8) (Animation 1) Create an animation of the 3-D scene showing in task (7)
- (9) (Figure 6) Make a Figure with your own preference that can explore the data very well. This should demonstrate your creativity and the mastering of various visualization techniques.

You are free to choose color, viewing angle, lighting and other visualization effect, in order to achieve the best visualization results.

Submission: electronic submission only. You need to submit the following files through email:

- (1) A project report (in either WORD or PDF format). The report should have at least the following sections (but briefly, please) : introduction, methodology, results and conclusion, in order for an average reader to understand the report. The report should also contain all the Figures generated (Figure 1, 2, 3, 4, 5 and 6, at least); each Figure should have a standalone caption to explain the Figure.
- (2) Animation file from task-8.
- (3) The MATLAB program or programs that implement the required tasks. You are free to organize the required tasks into any number of individual MATLAB program files. However, the smaller the number, the better.