RFE3

Three-dimensional RF Electric Fields in Conductive Media

Field Precision
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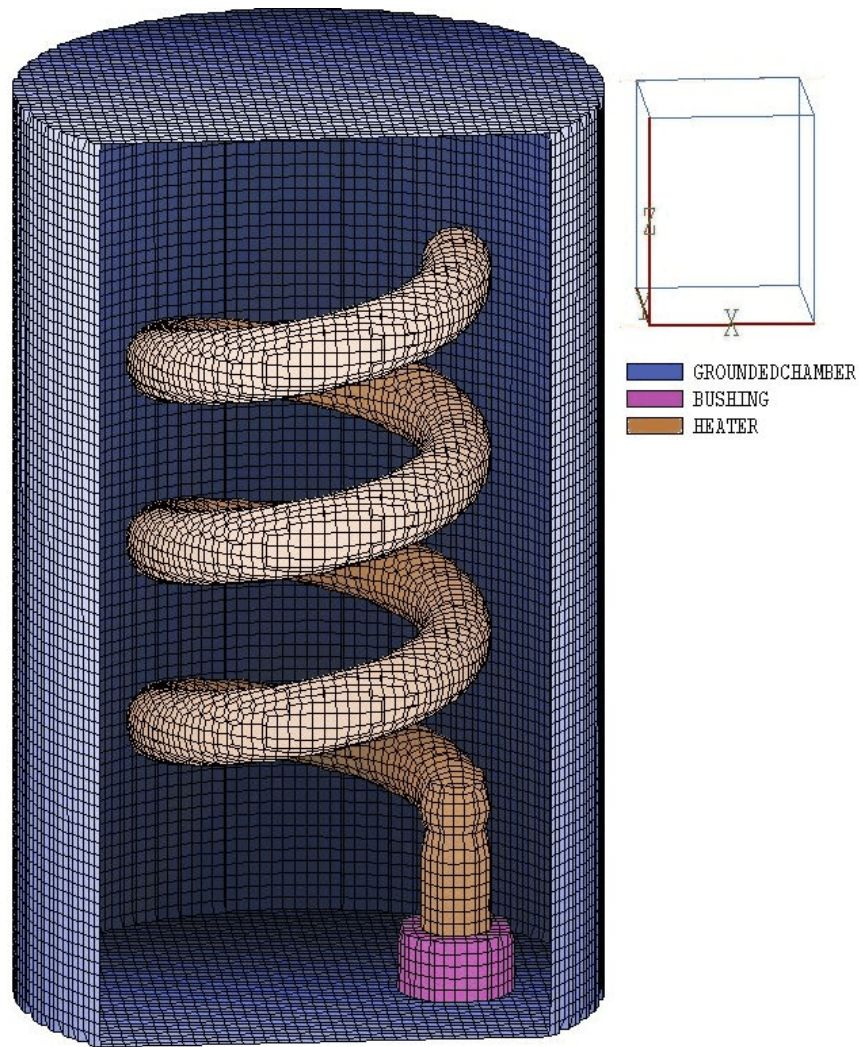**Telephone: 505-220-3975, FAX: 505-294-0222**

Figure 1.1. Geometry for the WALKTHROUGH example.

1.2. Test run

A quick way to understand the solution procedure is to step through an example. We want to find the capacitance and resistance between the helical electrode and the grounded chamber shown in Figure 1.1. The chamber is filled with purified water. This calculation would clearly be quite difficult with analytic methods. For reference, the conducting chamber has a radius of 5.0 cm and a height of 15.0 cm. To begin, transfer the examples files WALKTHROUGH.MIN, WALKTHROUGH.RIN and WALKTHROUGH.SCR to a working directory like \AMAZE\BUFFER. Run the program launcher AMAZE.EXE and make sure the program and data directories are set correctly (*i.e.*, to \AMAZE and \AMAZE\BUFFER).

Table 1.1. Contents of the file WALKTHROUGH.MIN

```
* File WALKTHROUGH.MIN
* Units in cm
GLOBAL
  XMesh
     -5.20  5.20  0.20
  End
  YMesh
     -5.20  5.20  0.20
  End
  ZMesh
     -0.20 15.20  0.20
  End
  RegName(1) Chamber
  RegName(2) ConductiveMedium
  RegName(3) Bushing
  RegName(4) Heater
END

PART
  Region GroundedChamber
  Type Box
  Fab  10.40  10.40  15.40
  Shift  0.00  0.00  7.50
END

PART
  Region ConductiveMedium
  Type Cylinder
  Fab  5.00  15.00
  Shift  0.00  0.00  7.50
  Surface Region Chamber
  Coat Chamber Chamber
END
```

```
PART
  Region Bushing
  Type Cylinder
  Fab 1.00 1.20
  Shift  2.50  0.00  0.40
  Surface Region Chamber
  Surface Region ConductiveMedium
  Coat Chamber Chamber
END

PART
  Region Heater
  Type Cylinder
  Fab  0.60  6.00
  Shift 2.50 0.00 0.50
  Surface Region Bushing
  Surface Region ConductiveMedium
END

PART
  Region Heater
  Type Helix
  Fab  2.50 0.60  9.00  3.00
  Shift 0.00 0.00 3.00
  Surface Region ConductiveMedium
END

ENDFILE
```

Run **MetaMesh** and click on the command *LOAD MIN FILE* in the *FILE* menu. Pick WALKTHROUGH.MIN in the dialog and click *OK*. You can view or edit the script with the *EDIT MIN FILE* command in the *FILE* menu. Table 1.1 shows the contents of the file. A relatively small number of commands is sufficient to define the complex geometry. Click on the *PROCESS MESH* command. **MetaMesh** sets up a foundation mesh, divides the volume into regions that represent physical entities, and then fits designated surfaces. The program requires about 5 seconds to create a mesh with 220,000 elements. Click on the *SAVE MESH* command in the *FILE* menu. The resulting file WALKTHROUGH.MDF will be used as input by **RFE3**. At this point you can experiment with some of the plotting capabilities of **MetaMesh** before proceeding to the next step. Figure 1.1 was created using commands in the *PLOT3D* menu.

Table 1.2. Contents of the file WALKTHROUGH.RIN

```
* File: WALKTHROUGH.RIN
Freq = 0.1
ResTarget = 1.5E-7
MaxCycle = 1500
DUnit = 100.0
NCheck = 25
Omega = 1.80
* Grounded chamber
Potential(1) = 0.0
* Purified water (0.1 MOhm-cm)
Epsi(2) = 81.0
Sigma(2) = 1.0E-3
* Busing
Epsi(3) = 2.71
Sigma(3) = 0.0
* Heater
Potential(4) = 1.0 (0.0)
ENDFILE
```

We shall perform two different calculations by making small changes to the **RFE3** control script WALKTHROUGH.RIN. Table 1.2 shows the file set up for a calculation of the resistance between the electrode and the chamber. We use low-frequency excitation so that the real current density is much higher than the displacement current density. The ratio of current densities is given by:

$$\frac{j_r}{j_d} = \frac{\sigma}{2\pi f \epsilon_r \epsilon_o} \ . \tag{1.1}$$

For $\sigma = 0.001$ S/m, $\epsilon_r = 81.0$ and $f = 0.1$ Hz, the ratio is $j_r/j_d = 2.220 \times 10^6$. From **AMaze** run **RFE3** and choose the command *START RUN* in the *RUN* menu. In the dialog pick the file WALKTHOUGH.RIN and click *OK*. The program reads the mesh file, analyzes parameters in the script, calculates coupling coefficients for the finite-element calculation, carries out a relaxation solution for the complex potential and then records values the data file WALKTHROUGH.ROU. The entire process takes less than 50 seconds.

Next run **RFE3View.** Before proceeding to plots, we shall check some numeric results. Click on *RUN SCRIPT* in the *FILE OPERATIONS* menu

Table 1.3. Contents of the file WALKTHROUGH.SCR

```
*  File WALKTHROUGH.SCR
*   NReg        RegName
*   ==============================
*     1         GROUNDEDCHAMBER
*     2         CONDUCTIVEMEDIUM
*     3         BUSHING
*     4         HEATER
INPUT WALKTHROUGH.ROU
OUTPUT WALKTHROUGH
FULLANALYSIS
REGION 1
REGION 2
REGION 3
REGION 4
ENDFILE
```

and choose the file WALKTHROUGH.SCR. Table 1.3 shows the contents of the file. In response, the program automatically loads the data file WALKTHROUGH.ROU, opens a file WALKTHROUGH.DAT for output, performs calculations of volumetric quantities through the solution space and then analyzes volume and surface integrals for Regions 1 (surrounding chamber), 2 (conductive medium), 3 (bushing) and 4 (helical electrode). The program menu is inactive during the time (a few minutes) required for the calculations.

Choose *EDIT DATA FILE* in the *FILE OPERATIONS* menu and open WALKTHROUGH.DAT. The first section shows results from the global analysis. The time-average power dissipation is 6.26264×10^{-4} W for an applied voltage of amplitude $V_\text{o} = 1$ V. From the equation

$$\overline{P} = \frac{V_o^2}{2R} \,, \tag{1.2}$$

we infer a resistance of 798.4 Ω. The surface integrals in the region analysis of the conducting chamber (Region 1) give the following values for real and displacement current: $I_\text{r} = 1.273 \times 10^{-3}$ A and $I_\text{d} = 5.741 \times 10^{-10}$ A. The ratio of currents (2.222×10^{6}) agrees with the prediction of Eq. (1.1). The value of I_r implies a resistance of 785.5 Ω (a difference of 1.6% from the value determined from the volume integral). The integral over the surface of the helix gives a real current $I_\text{r} = 1.156 \times 10^{-3}$ A for an implied resistance of 865.1 Ω. The differences in the results illustrate
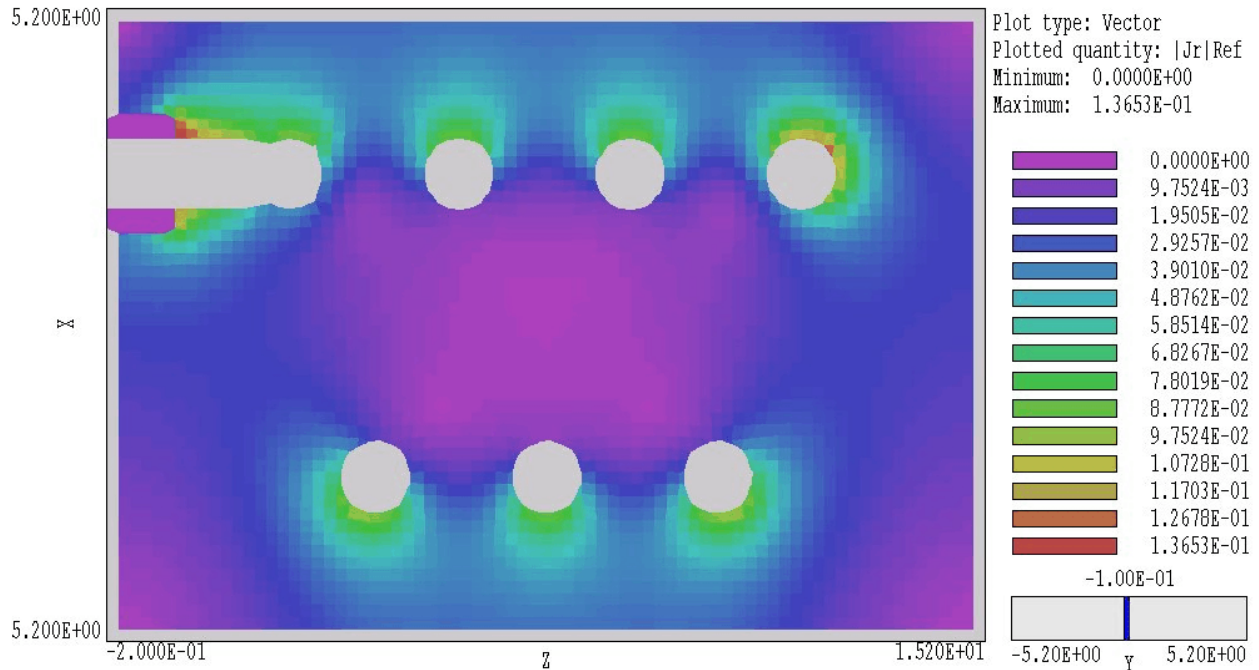
Figure 1.2. Element plot of the magnitude of real current at the reference phase of 0° in the plane *y* = -0.1)

accuracy limitations in numerical calculations. The volume integral involves an average over many elements and gives the highest accuracy. The surface integrals involve identification of and field interpolations over facets. The method achieves the best accuracy on flat or gently-curved surfaces (such as the chamber wall) and may encounter errors on complex sharply-curved surfaces (such as the helical electrode).

Close WALKTHROUGH.DAT and return to the main menu. Click on *SLICE PLOTS* and then choose *SLICE NORMAL TO Y* in the *CHANGE VIEW* menu. In the *PLOT CONTROL* menu, click on *SLICE PLOT STYLE* and choose *ELEMENT*. Finally, under *PLOT QUANTITIES* in the *PLOT CONTROL* menu pick |Jr|REF. You should see a plot similar to that of Fig. 1.2. The figure shows variations of the amplitude of real current density in the plane y = -0.10. The plot is created at a reference phase of 0.0° for an applied voltage of the form $V(t) = V_o \cos(2\pi ft)$. As expected, the current density concentrates on the outside of the helical electrode and the equals zero inside the bushing.

To complete the analysis, we shall make small changes in the input script for a calculation of the assembly capacitance. Return to **RFE3** (or rerun it from **AMaze** if you closed the program). Choose *EDIT SCRIPT FILE* in the *FILE* menu and load WALKTHROUGH.RIN. Change the line FREQ = 0.1 to FREQ = 1.0E6 and change the line SIGMA(2) = 1.0E-3 to SIGMA(2) = 0.0. Save the file, exit the editor and rerun the solution. Return to **RFE3View** and rerun the script WALKTHROUGH.SCR to analyze the revised field solution. The global analysis gives the following values for field energy U: 4.49165×10^{-10} J (water) and 1.23185×10^{-12} J (bushing). The field energy density is given by $\epsilon_o \epsilon_r (\mathbf{E} \cdot \mathbf{E}^*)/2$, where $\mathbf{E}$ is the complex electric field vector. Using the formula $U = CV^2/2$, the predicted total capacitance is 9.008×10^{-10} F. The water accounts for 99.7% of the capacitance. The predicted amplitude of the displacement current at 1 MHz is $I_{do} = 2\pi f C V_o = 5.660 \times 10^{-3}$ A. For comparison, the surface integral of displacement current density over the chamber wall gives 5.754×10^{-3} A.

In this section we have seen a few of the capabilities of **RFE3** and **RFE3View**. At this point, you can experiment with plotting capabilities of the post-processor. Figure 1.3 illustrates some 3D capabilities. The plot shows a cutaway view of the chamber and electrode with a surface that follows the contour $|\phi| = 0.6$ at a reference phase of 0.0°. It is important to note that the demonstration addressed two special cases where conduction was dominated by either real or displacement current. The true power of RFE3 lies in its ability to handle intermediate cases where both real and displacement currents play significant roles.
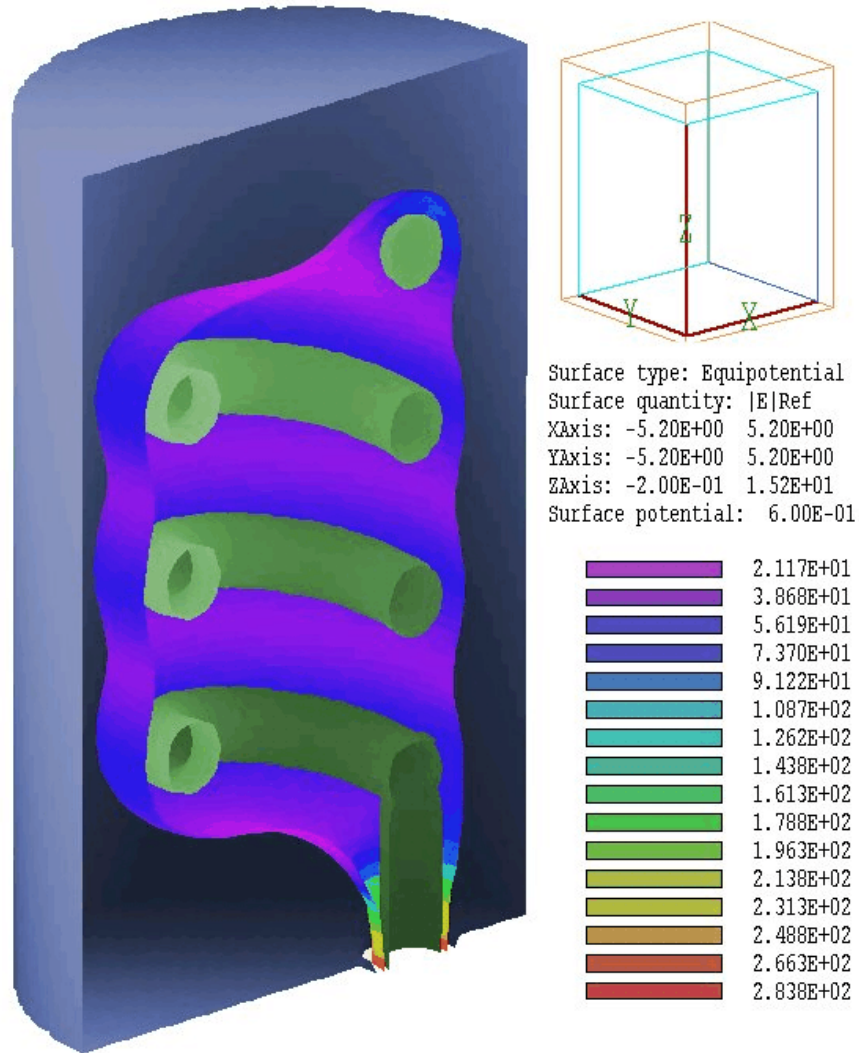
Surface type: Equipotential
Surface quantity: |E|Ref
XAxis: -5.20E+00 5.20E+00
YAxis: -5.20E+00 5.20E+00
ZAxis: -2.00E-01 1.52E+01
Surface potential: 6.00E-01

	2.117E+01
	3.868E+01
	5.619E+01
	7.370E+01
	9.122E+01
	1.087E+02
	1.262E+02
	1.438E+02
	1.613E+02
	1.788E+02
	1.963E+02
	2.138E+02
	2.313E+02
	2.488E+02
	2.663E+02
	2.838E+02

Figure 1.3. Three-dimensional cutaway view of the chamber and helical electrodes along with a calculated surface of $|\phi| = 0.6$ V. Color coding on the equipotential surface shows the magnitude of the electric field.