Comparison – Scale Modelling of a Copper Annulus

As part of a modeling exercise carried out in 2000 at INCO in Sudbury by Ben Polzer, the step response over a copper annulus was measured. In this paper, these data are compared with the response of MultiLoop III. The MultiLoop III comparisons are run for meshes with 101, 452 and 1501 nodes that simulate the annulus. In addition to the simple annular tests, MultiLoop III's variable resistance functionality is also tested by modelling the annulus as a disk-mesh with a variable conductivity (resistive core). Results presented here were computed with the *standard* solver residuals and *near* block-relaxation coupling preference options. The smooth basis function option was used to compute the coupling between the annulus and the system antennae.

Files used in this paper are archived in MLPIII Comparison / ScaleModelAnnulus.

The scale model reference data acquired by INCO are plotted in Figures 1 and 2. The scale model was made of copper and had an outer diameter of 0.4 m and an inner diameter of 0.2 m. The annulus was placed inside, and slightly off the centre of, a large rectangular loop. Data were acquired on profile 1.2 cm over the center of the loop. The step response of the annulus was measured at 2500 Hz., with channels spaced in 20 equal intervals over each half cycle. Data were archived, and are compared here, using continuous normalization in %. The system geometry is illustrated in Figures 3 and 4, and more details can be found in the archived files.

The numerical models were built using meshes generated by Pebble, using an outer diameter of 4m and an inner diameter of 2 m. The meshes were then imported into MultiLoop III and scaled by a factor of 10, resulting in a total dimensional scale factor of 100 with respect to the scale model data. Accordingly, since the comparison data are normalized, scale model theory (refer to Grant and West for details) allows us to compare the simulated and scale model data by increasing the resistance used by a factor of 10,000. (Scaling was done as a matter of convenience, since number formatting in MultiLoop III assumes meter+ sized objects.)

Using trial and error fitting of the decays and profile shapes, the simulated surface resistance of the scaled annulus was determined to be approximately 0.003 Ω: so the surface resistance of the scale model is inferred to be 3×10^{-7} Ω. The annulus was shifted by 1 cm is X (scale model distance) from its stated position so that the peak responses of the scale model Z-component profile were aligned with those from MultiLoop III.

Results for the annulus are presented in Figures 5 to 11, and for the disk in Figure 12 and 13. The scale model data are plotted as points, with data at plotted every 10^{th} location to avoid clutter. The simulated data are plotted as lines. Agreement with the scale model data is very good. Any differences between the two data sets are explained in the figure captions.

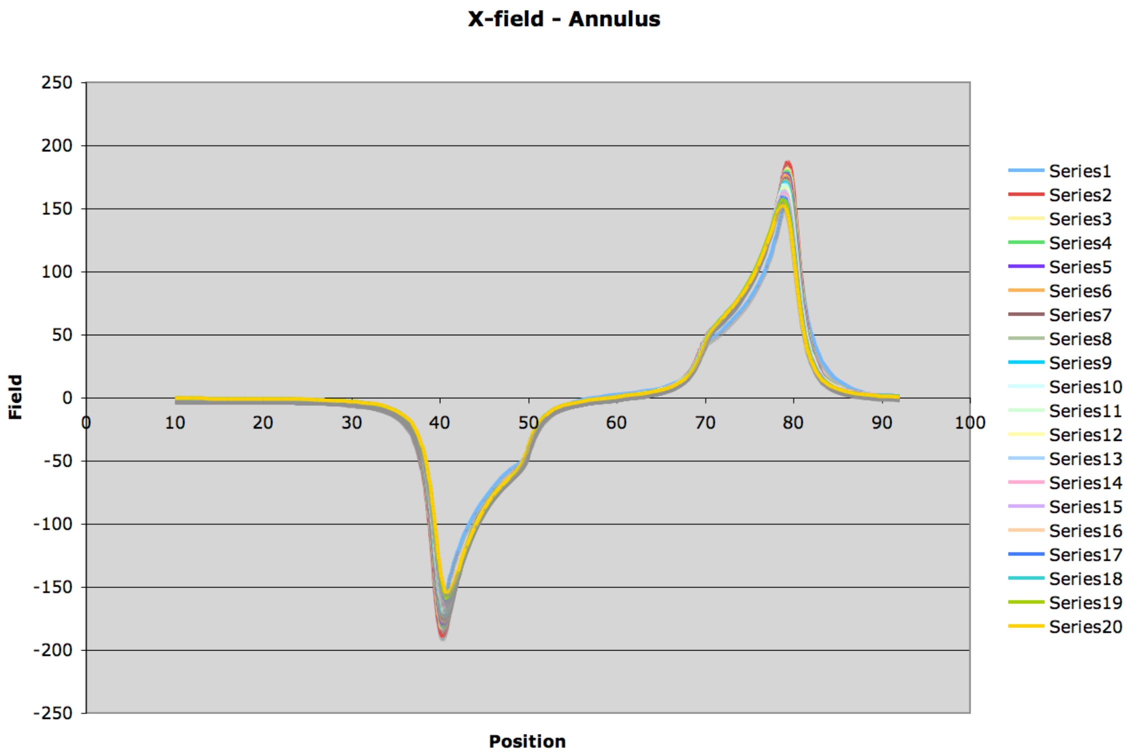

Figure 1: Scale model X component response measured at the INCO lab.

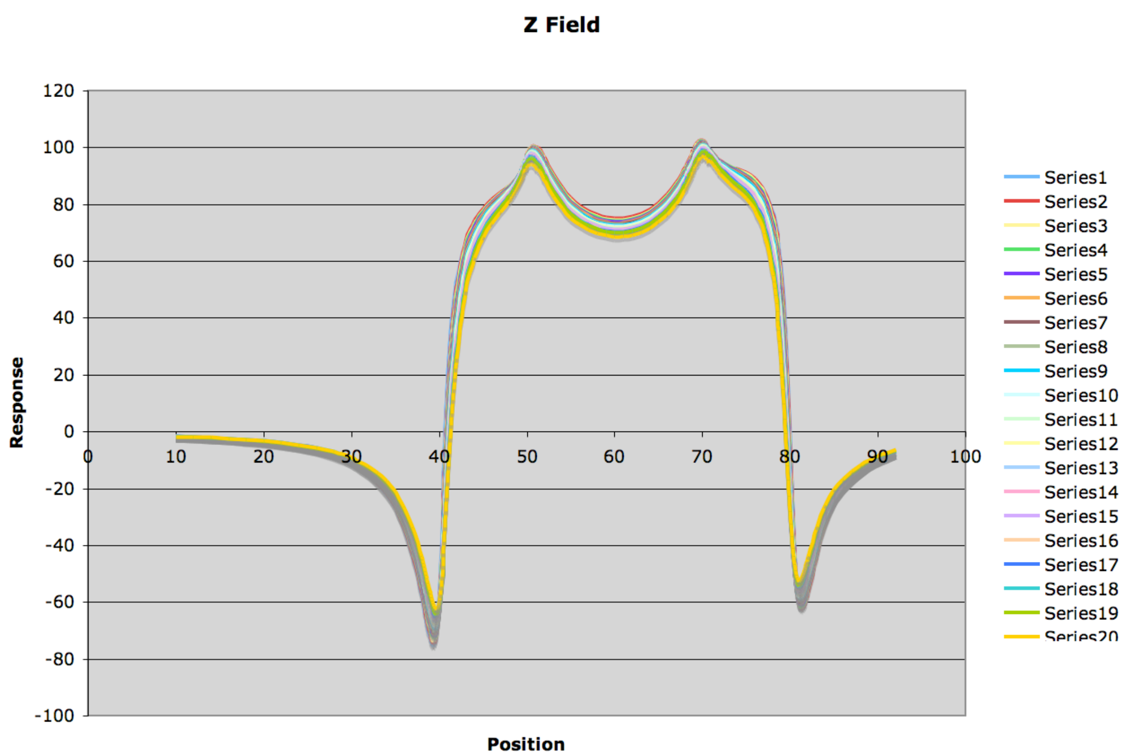

Figure 2: Scale model Z component response measured at the INCO lab.

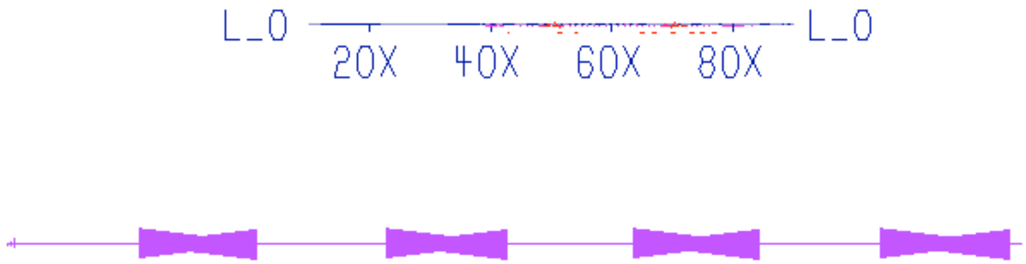

Figure 3: Side view showing the loop and line. The annulus spans 40.5m to 80.5m in X, and -20m to 20m in Y (MultiLoop III coordinates).

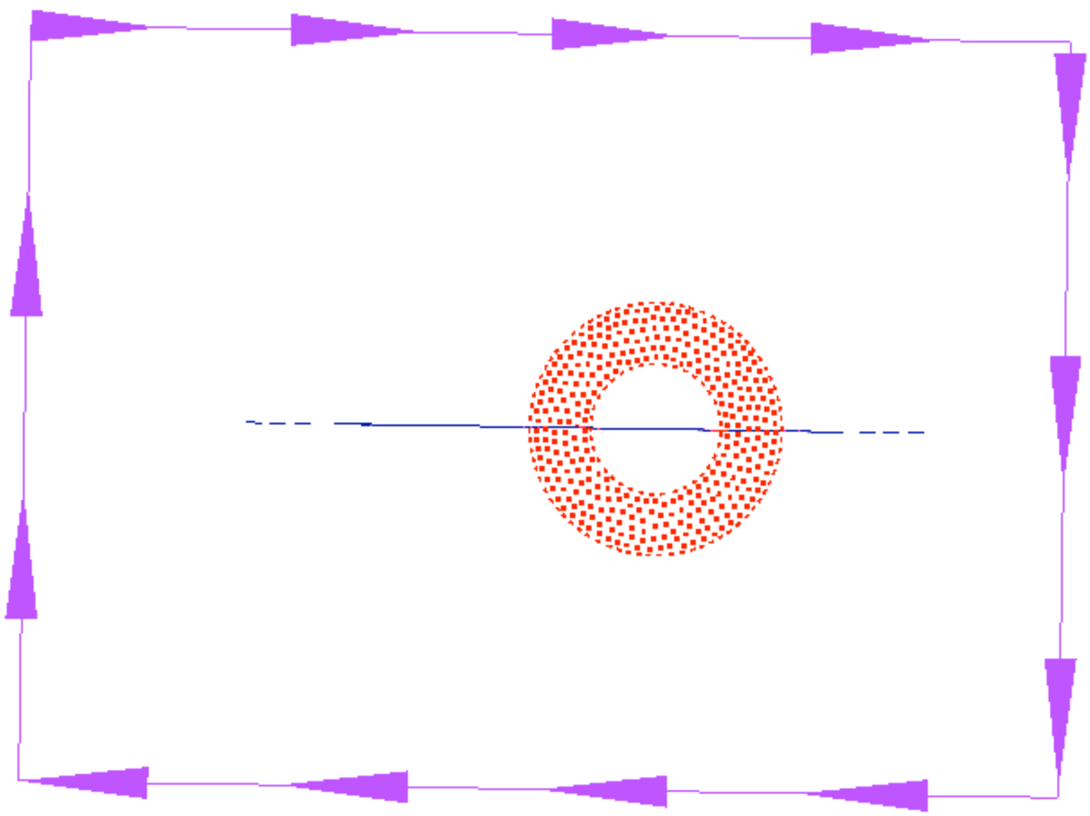

Figure 4: Top view showing the loop, line and annulus.

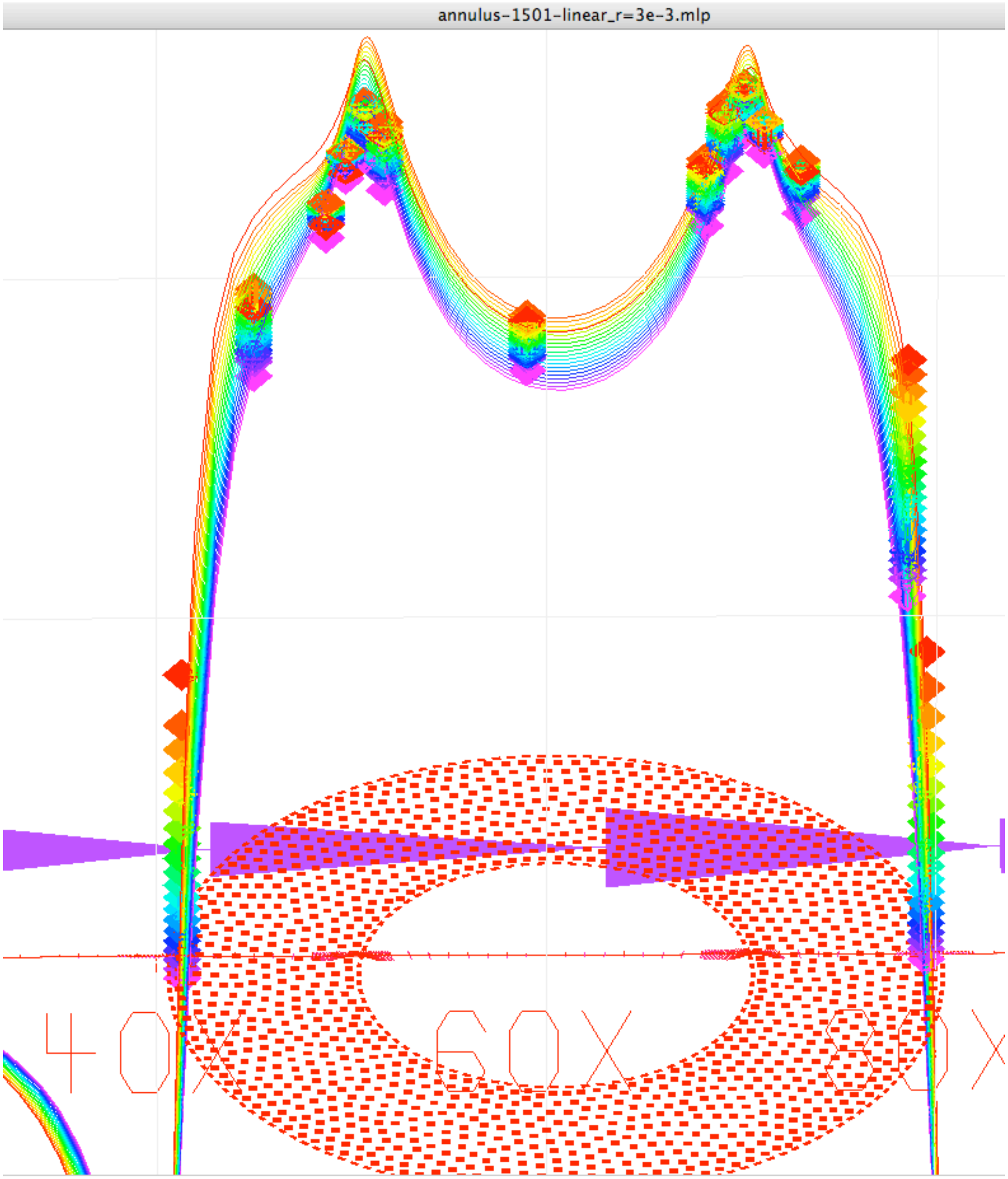

Figure 5: Comparison of MultiLoop III for a 1501 node annulus with scale model data (Z-component) for the section of profile over the annulus. There are probably small positioning errors which cause the simulated and scale model profiles to differ, particularly where the field gradients are large near the edges of the annulus. The resistance used in the simulation is a rough estimate, and the quality of the fit could be improved by refining the resistance estimate.

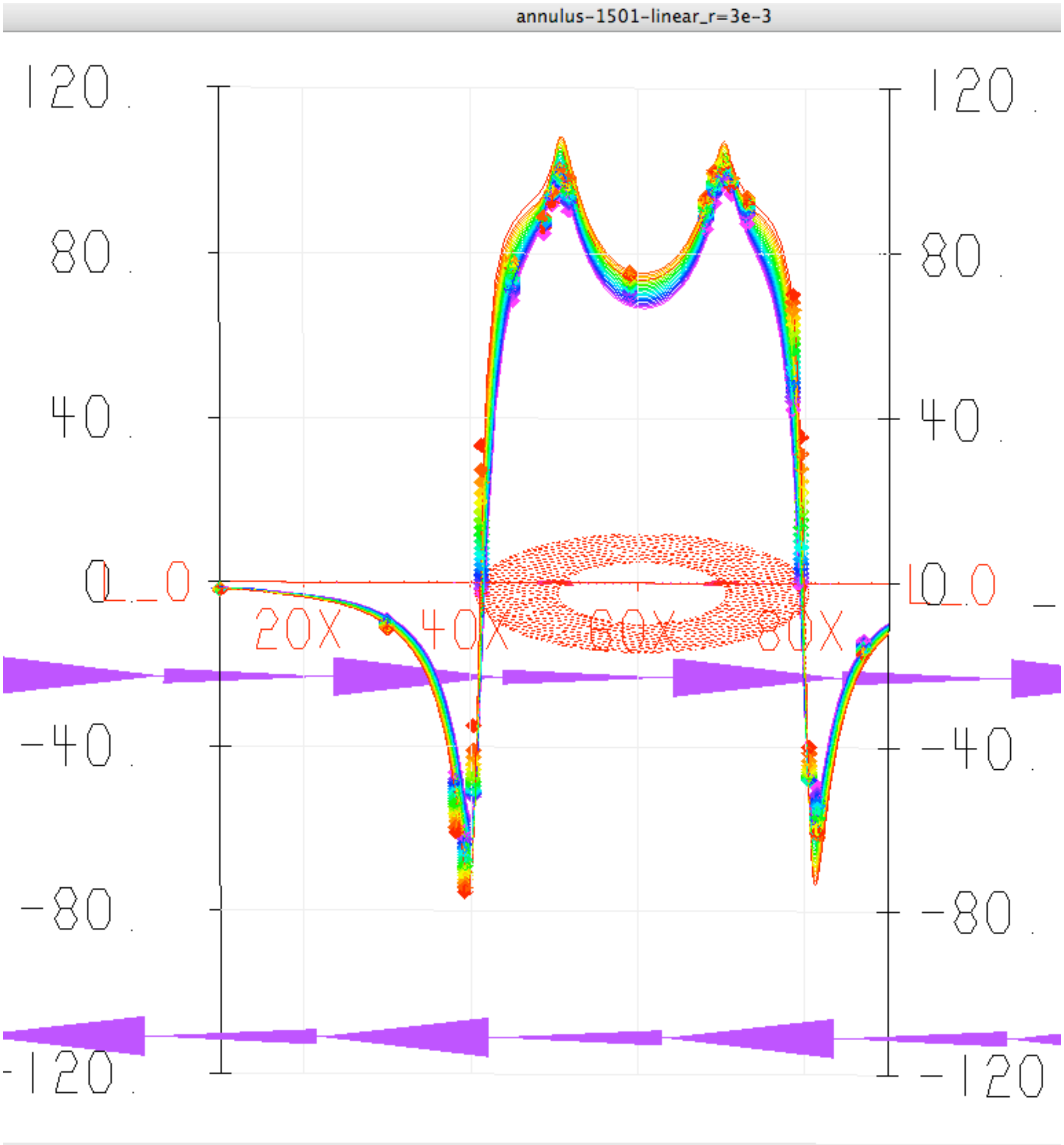

Figure 6: Z-component comparison (full profile, 1501 nodes).

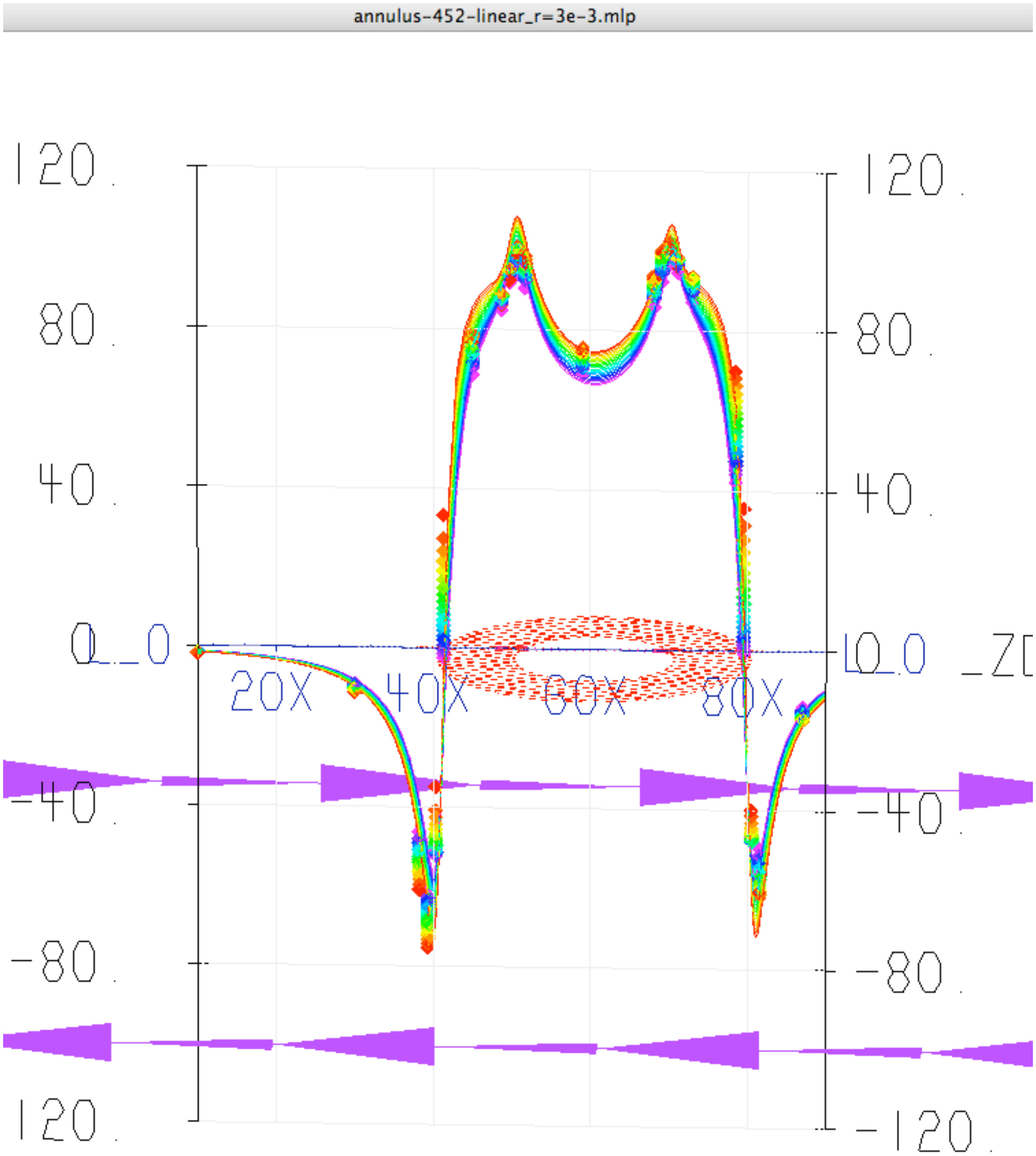

Figure 7: Z-component comparison (full profile, 452 nodes).

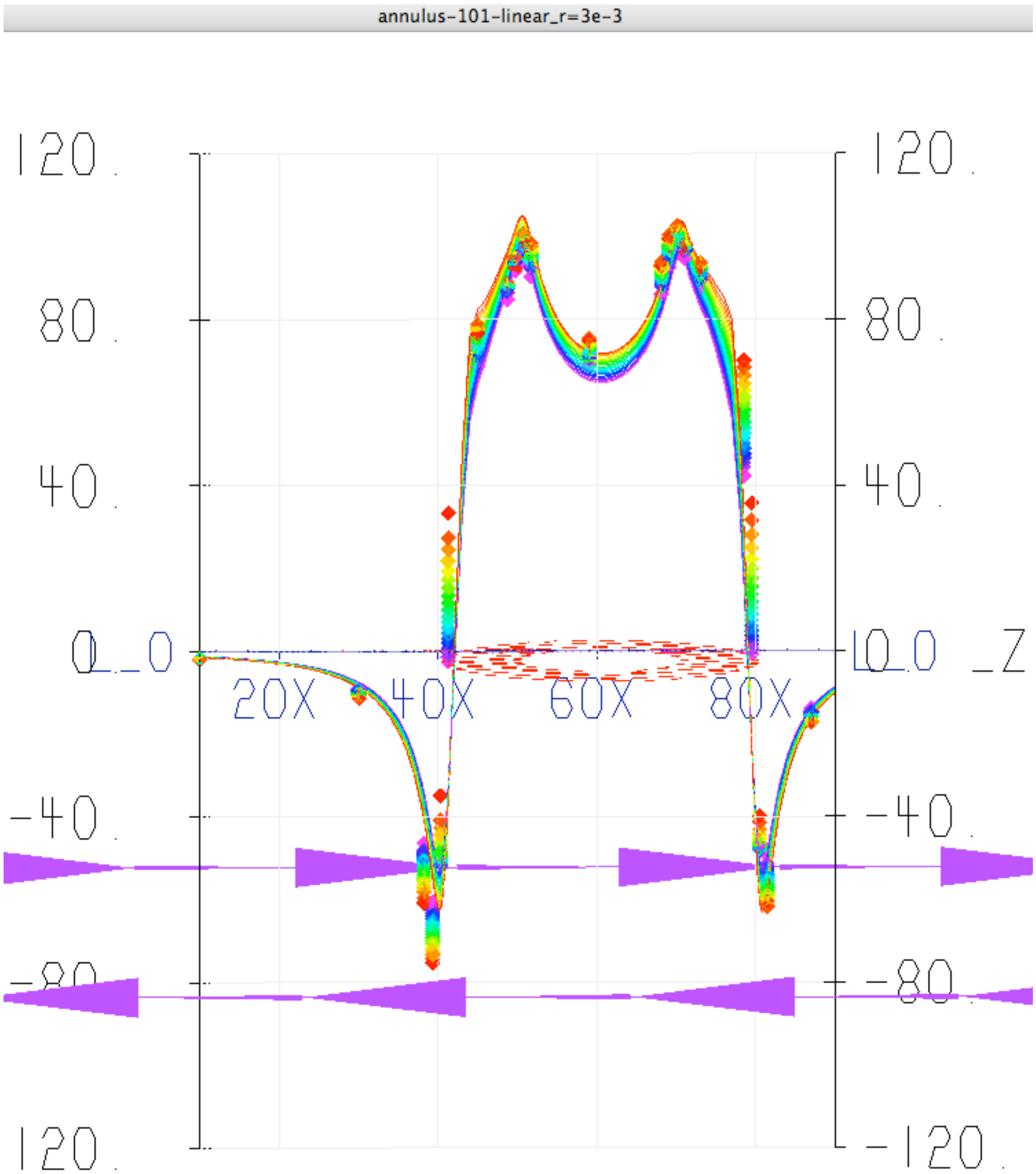

Figure 8: Z-component comparison (full profile, 101 nodes). Here the basis functions are relatively large compared to the width of the annular rings, so the simulated annulus appears to be narrower than in the 400 and 1500 point cases.

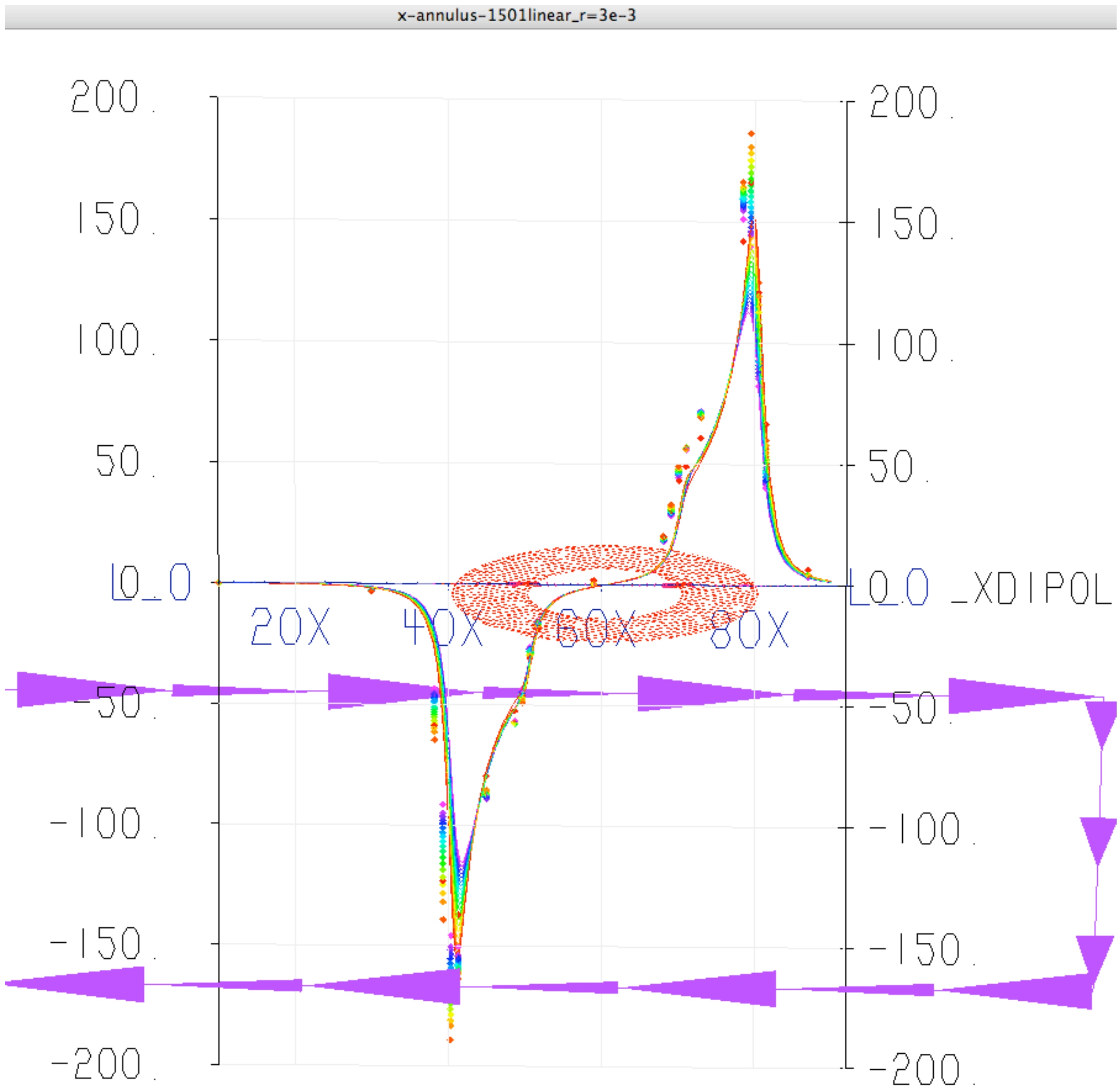

Figure 9: X-component comparison (full profile, 1501 nodes). The X-component is a measure of the surface current density. Near the edges of a conductor, in the inductive limit, the tangential current density varies as the inverse square root of distance from the edge. The ability of a numerical solver to simulate this behaviour depends on the basis representation. Fewer basis functions will lead to a more "rounded" representation, as seen in Figures 10 and 11: the peak current density is simulated less accurately as the number of nodes used in the simulation decreases. However, the solution accurately estimates the average current density over extent of the basis function. In comparisons made using half-sheet models, the fields are further removed from the edges of the surface of the conductor. In those comparisons, the match the experimental and comparison data is very good.

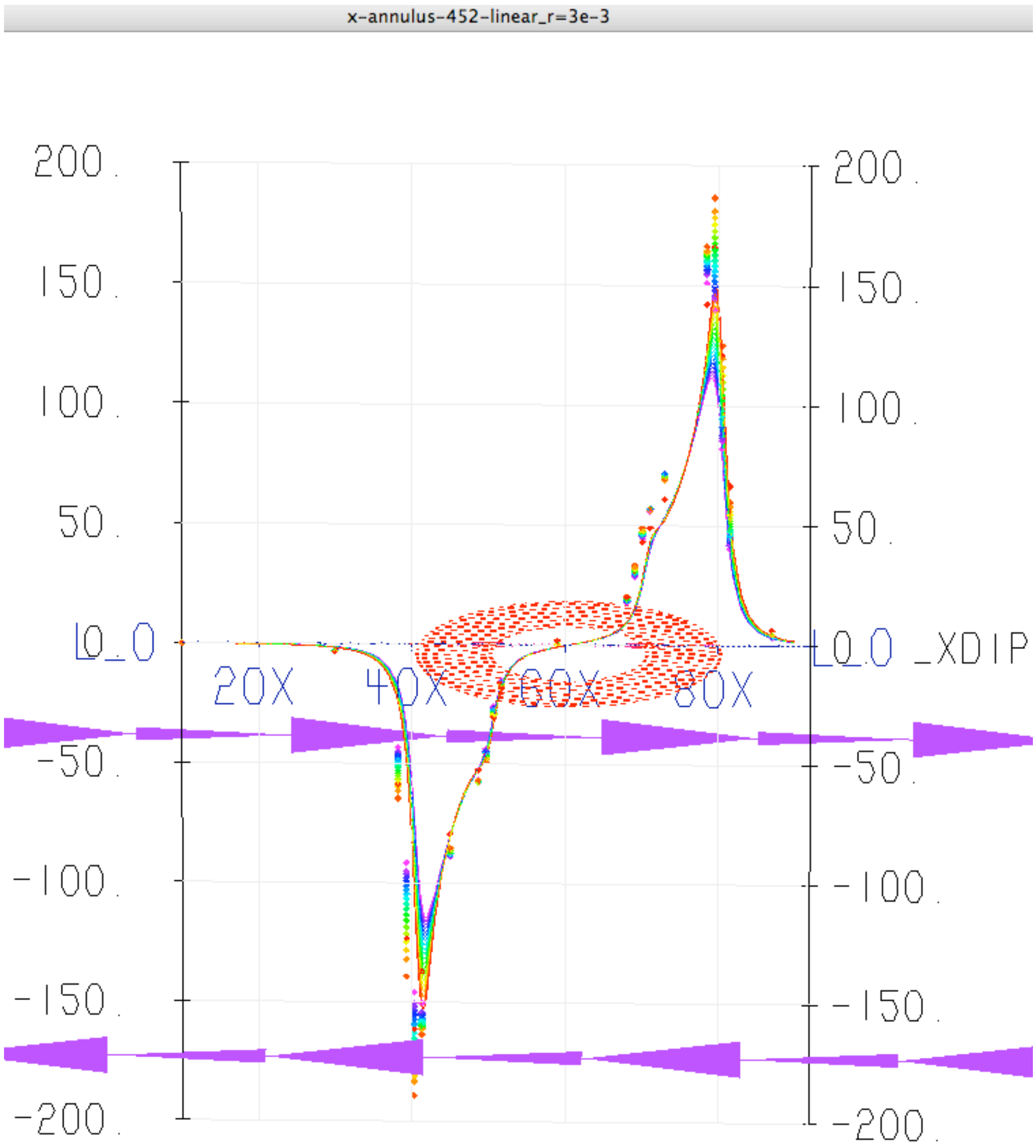

Figure 10: X-component comparison (full profile, 452 nodes). Slight positioning mismatches between the scale and simulated models is apparent.

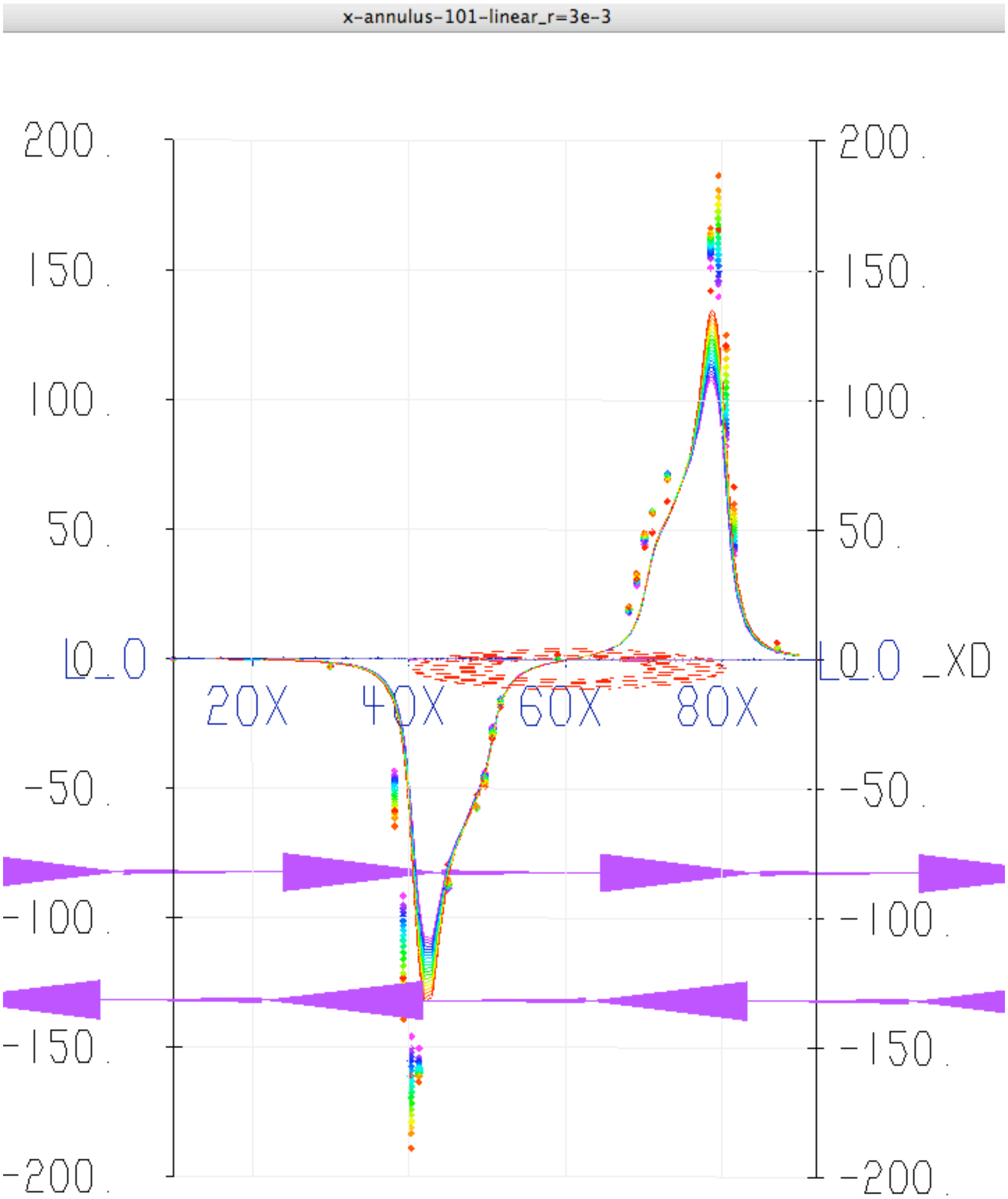

Figure 11: X-component comparison (full profile, 101 nodes)

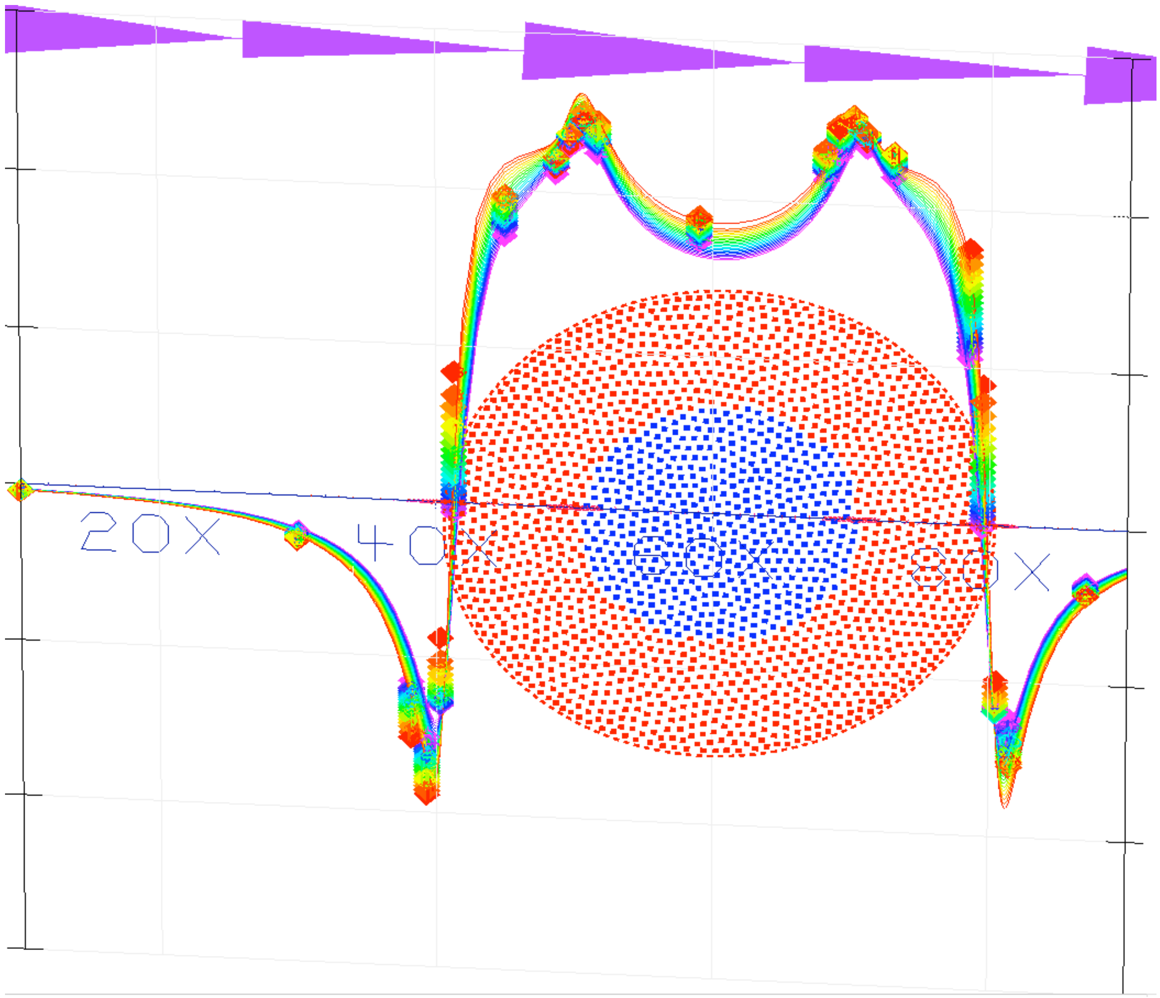

Figure 12: Z-component simulation of an annulus using a disk (2001 nodes) with a resistive centre. The resistance function used was: IF (X*X+Y*Y < 100,10,3e-3) with the centre of the expression located at 60.5,0,0.

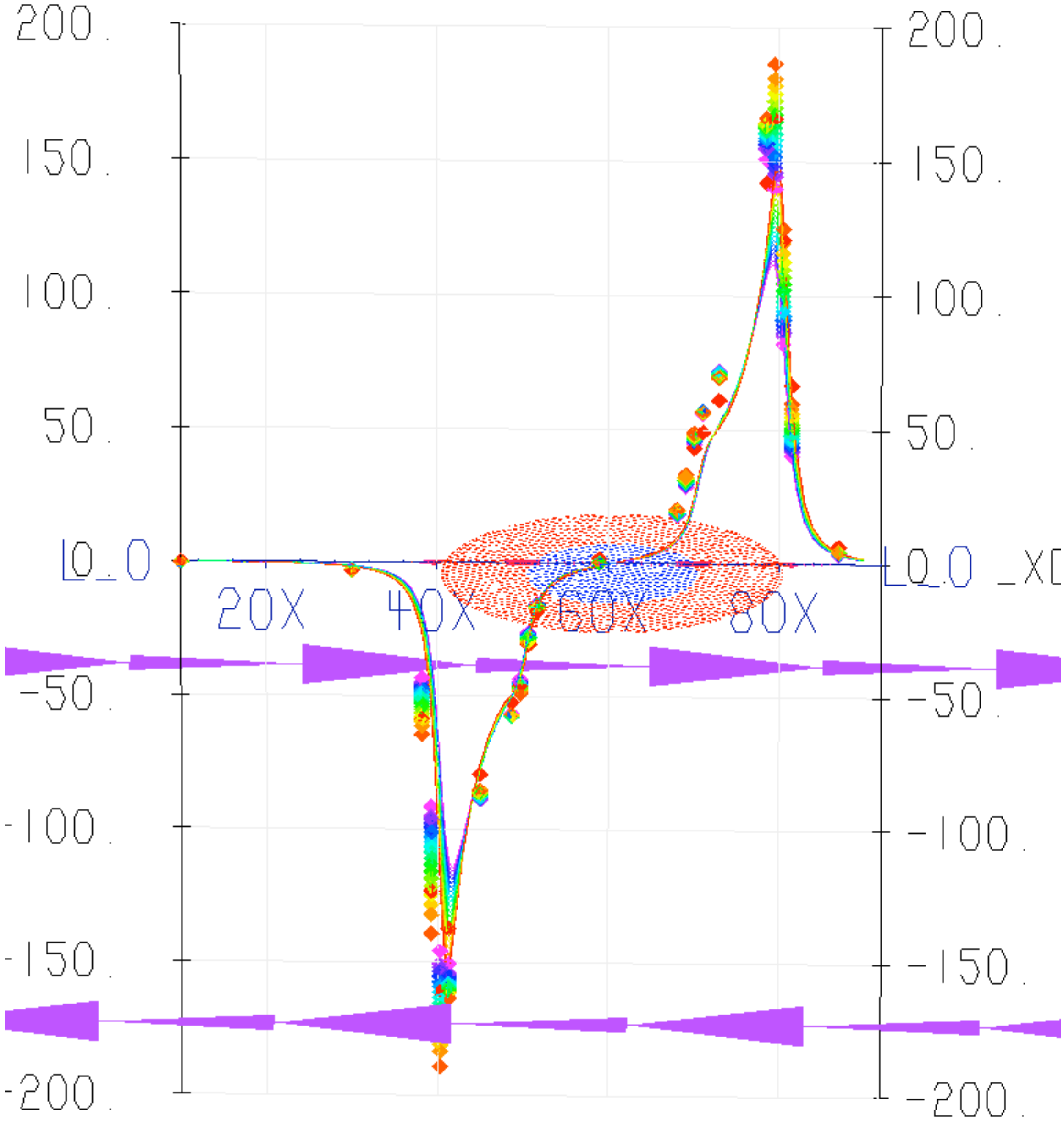

Figure 13: Z-component simulation of an annulus using a disk (2001 nodes) with a resistive centre. Again, slight position errors are apparent.