

Solving TEAM Workshop Problem 15 With FARADAY

We have found that many people with NDE (Non-Destructive Evaluation) models opt to run [TEAM Workshop Problem #15](#) in FARADAY. This may be to test the reliability of FARADAY on a problem with known results during their free 30 day evaluation, or for some practice when they already own the program. This paper is intended to provide them with some help and educational observations. Thus, this paper doesn't attempt to quantify for you how well FARADAY can solve this particular problem. Rather, it will demonstrate the affect that various decisions about modeling the problem have on the solution time and accuracy in order to teach users how to do this type of problem to whatever level of accuracy they require.

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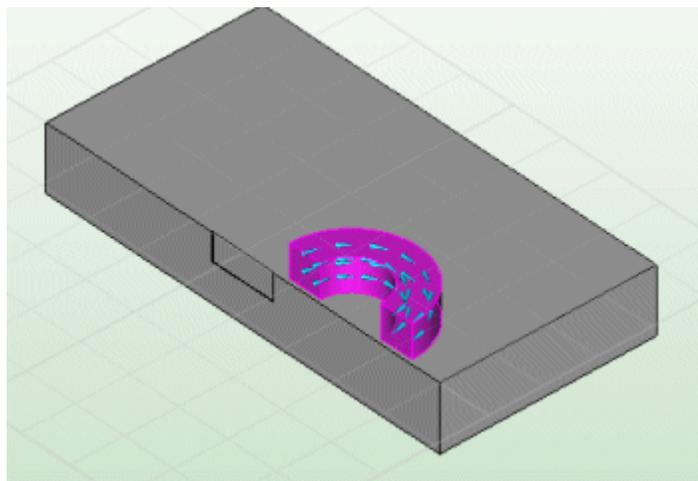
Building the Geometry

Building a Plate with a Slot in it

Deciding how to build this plate is complicated by the fact that the [TEAM Workshop Problem #15 description](#) doesn't say how big the plate used in the measurement was. However, the results appear to be relative to a point much further away from the defect than the coil is moved during the experiment, so it is fair to assume that the plate is large enough to be effectively "infinite" in size. That means the decision about how large to build it in FARADAY is one of choosing how big will be "big enough" to get the results you would like. In order to get results over the whole range of reported results, the plate will be made big enough that the coil does not reach the edge. In order to not waste solver time by meshing more geometry than is necessary, it will not be made very much bigger. Figuring out exactly how big that should be will require some trial and observation.

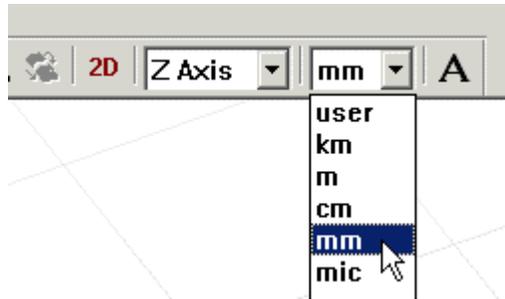
Since this geometry is symmetric about the center for all coil locations, and since the number of unknowns required to solve the model can be reduced (hence reducing the solution time) by using this symmetry, only a half model will be produced.

The objective then will be to make a half-plate (with defect) large enough that when the coil is in its final position the geometry will look somewhat like this:



Here is one method to make a plate like this:

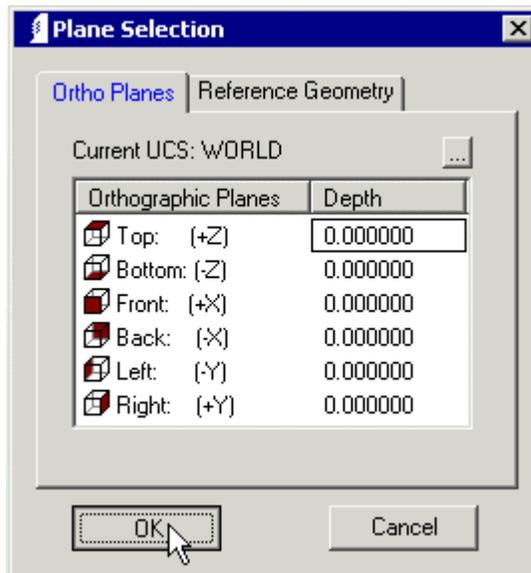
1. Set the units to mm



2. For convenience you may wish to set the Geometry Limits to +/-50 mm
3. Select 2D mode



4. Select the plane z=0



5. Select the rectangle drawing tool



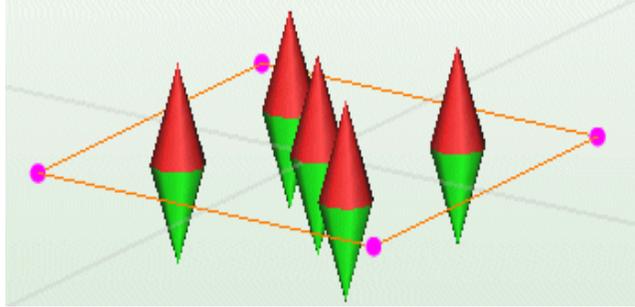
Make the rectangle from the points -40, -40 to 40, 40

6. Click the 2D button to return to 3D
7. Select sweep normal



then select the rectangle

8. Make sure the green cones point downwards (use **>Ctrl-left-click<** if necessary)



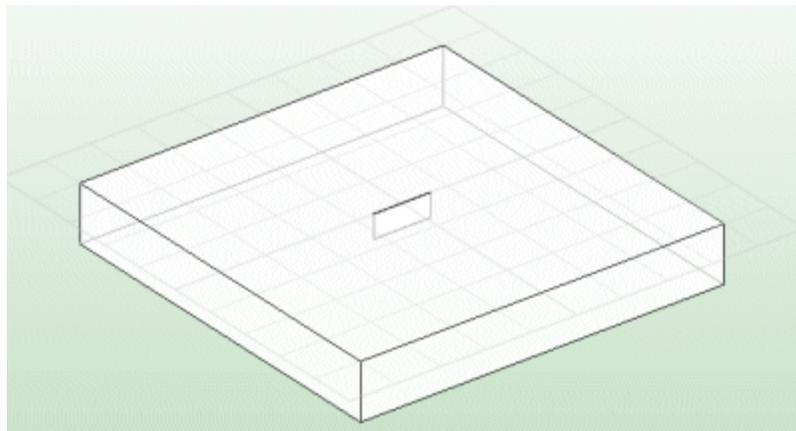
9. Make the sweep distance 12.22
10. Return to the z=0 plane and draw a rectangle from -6.3 -0.14 to 6.3 0.14
11. Return to 3D mode and sweep this surface downwards by 5 mm
12. Use the undefine surface tool to get rid of this surface



13. Use the define volume tool to make the whole block a volume



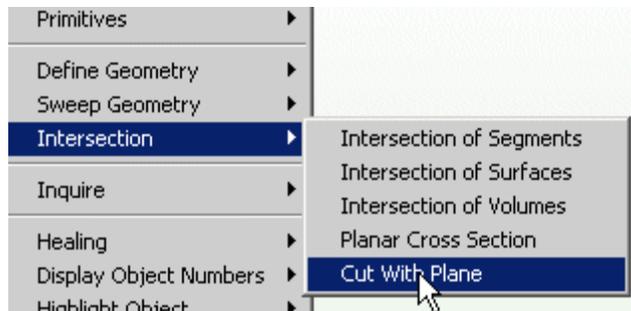
You now have a full block with a rectangular slot defect that will look like this in translucent viewing mode



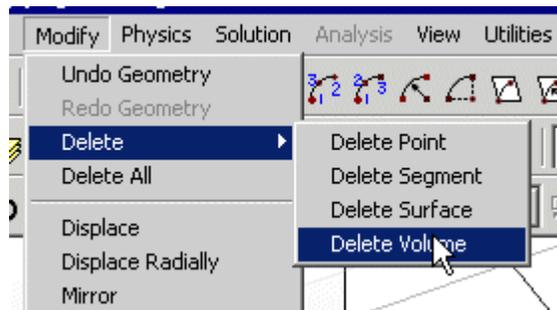
□

To turn this into a half model:

1. Choose the Cut-With-Plane option from the Geometry menu



2. Choose 0 0 0 as the reference point, and 0 1 0 as the normal direction for the plane. This will divide the plate into 2 half-plates
3. Use the Delete Volume tool to delete the unwanted $y < 0$ half-plate



The advantage of this tool compared to the normal Segment Delete is that it won't delete any part of the half-plate you want to keep.

You will now have a half-plate with defect.

Building a coil

To build the half-coil for Problem #1:

1. On the $y=0$ plane draw a rectangle from (6.15, 0.88) to (12.4, 0.88+6.15)
2. In 3D mode select the circular sweep option:



3. Sweep the rectangle 180 degrees using the reference points (0, 0, 0) and (0, 0, 1)

Solving Problem #1

Setting Up the Physics

1. In **Physics Global Setup**, set Inductance mode
2. In **Physics Global Setup**, set 900 Hz
3. In the **Material Table** create a 3.06×10^7 S/m conductor, then apply it to the plate
4. In **Symmetry and Periodicity Setup** specify that the model is antisymmetric about $y=0$
5. Put a **Volume Current** of 3790 A in the coil
6. Assign the coil as **Volume Conductor #1**

7. Assign Volume Conductor #1 as having 1 A (per turn - together with the total current this make a 3790 turn coil).

Setting up the Solver

FARADAY has both a FEM and a BEM solver available. Since this is an open region problem, and furthermore has no nonlinear materials, the BEM solver is expected to be superior. This is the default setting, so the **Solver Setup** does not need to be used. With the BEM solver the plate will require 2D elements and the coil will require 3D elements.

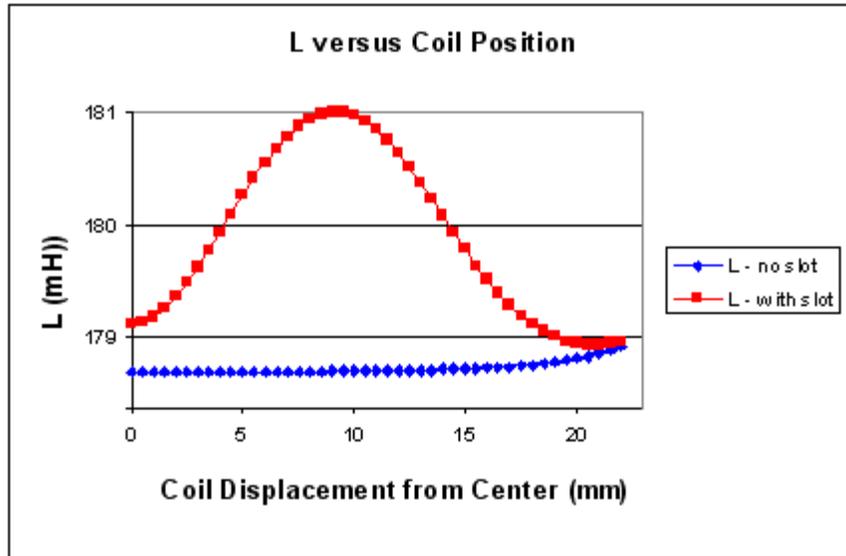
It is sometimes useful to get a quick solution by selecting the menu **Solution > 2D Triangular Elements > Automatic All** and requesting 1 element. This produces the minimum number of elements that maps onto the geometry with reasonable node angles. However, with so much of the geometry being large rectangular surfaces this will probably be too crude to be informative. So, 1000 elements were used as the "seed" instead. This produced a total of 1700 elements. The majority were on the long skinny surfaces of the defect. The rest of the geometry had elements of approximately the same size as the skin depth for this conductor at 900 MHz (if they were much larger than the skin depth the result would probably not be useful). This should produce a good enough initial result to make informed decisions about modifying the number, if necessary.

The computation of results from the coil is very easy for BEM, so the number of 3D elements put into the coil will be chosen as 100 Brick Elements, and it is unlikely that this number will need to be modified.

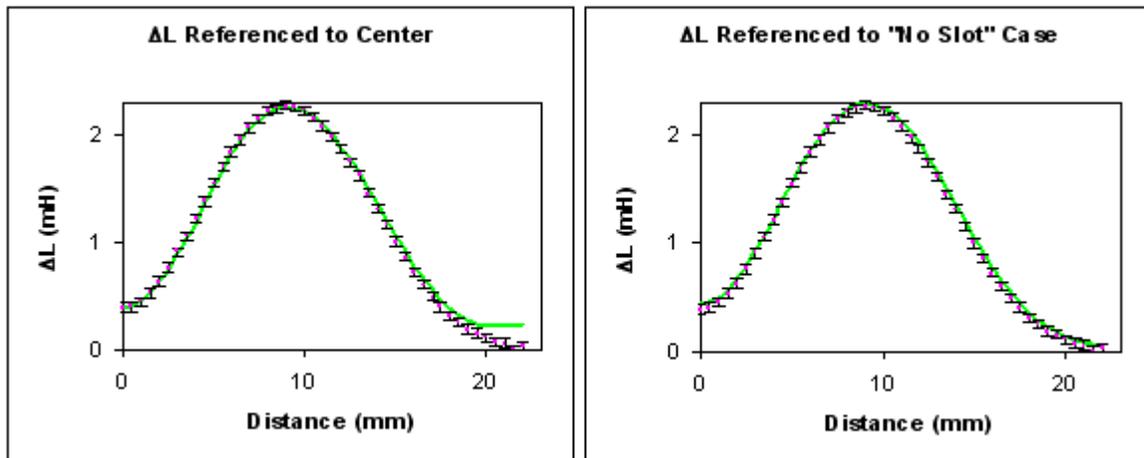
Solving and Analyzing the Results

To solve the model a Parametric was setup to automatically move the coil outwards from the center in 0.5 mm steps and to record L & R at each position. When you run this problem you may notice that the first parametric step is much slower than the rest. This is because with BEM & with the coil being displaced, the 2D elements are unaffected by the parametric. Thus, the matrix accumulation only needs to be done on the first step, and the remaining steps are significantly faster.

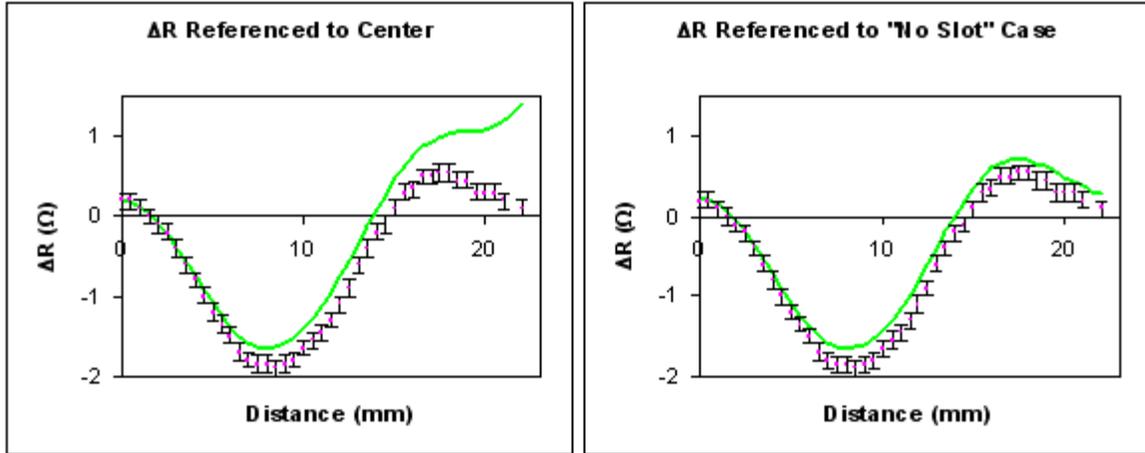
Since the TEAM Problem Results table (#3 in the write-up) references change in L & R rather than actual values, the data in the Parametric Results Table was copied to the Windows clipboard, and from there into Excel. The problem write-up references the difference in L & R to a measurement far from the slot. Due to the small size of the modeled plate, this cannot be done for this model. The figure below illustrates this. It shows the actual inductance calculated with and without the slot present. For a very large plate the blue curve would be a horizontal line. For a finite sized plate there is variation in L at different locations, and the smaller the plate the larger the variation.



There are a few approaches that could be taken here. If we reference the data to a point far from the slot, we will see a lot of effect due to the finite size. An alternative would be to reference it to the center point and adjust such that this value of $\Delta(L)$ matches the measure value. Since the center point is the most unaffected by the finite plate size, this is probably the best approach. However, if we assume the effect of the finite size and the effect of the slot are independent then we could also choose to reference each L value with the slot present to L at the same coil position without the slot present. This will produce a closer match to the experimental data. For example, below is shown $\Delta(L)$ for a small plate where $\Delta(L)$ is referenced to a single value and where it is referenced to the "no slot" data. The points with error bars are the measure data, the green curves are the FARADAY results. Clearly compensating for the finite size by referencing to "no slot" data make the result match better:

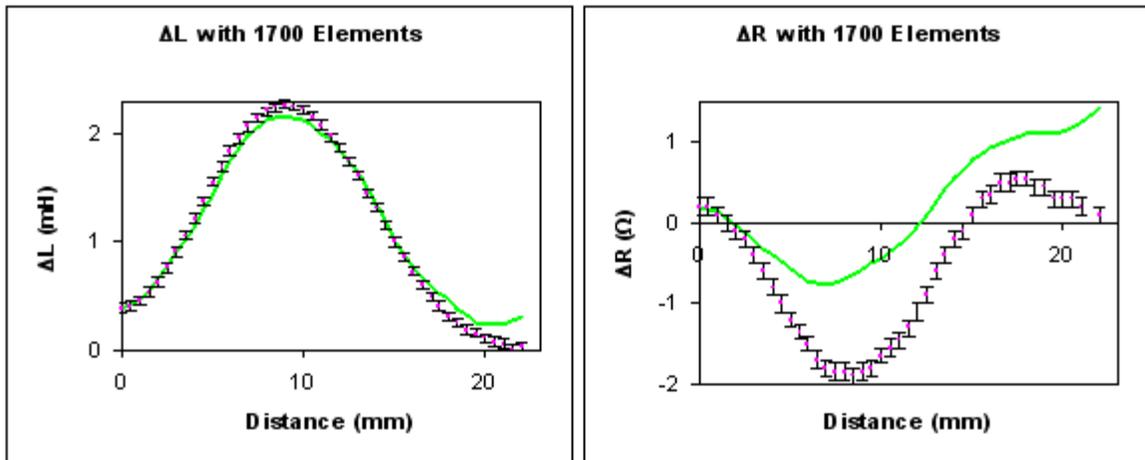


The same benefit can be found for R .



Although this technique may be perfectly valid for a given real world problem - such as determining the difference in inductance for a coil beside a given plate due to a defect in the plate - it is not faithful to the intent of the TEAM 15 problem. This problem says to make a large plate and reference the data to a single point to verify that the curve is correct. Therefore, any simulation should reference to a single point, then make the plate as large as necessary to show that it can match the real data rather than adjust the reference in a way that accounts for the finite plate size. Therefore, all the data differences shown below are relative to the center, then adjusted so that the first point matches the measured data. This makes the start of the curve artificially good, but is justified by how well the rest of the curve traces out correct trend.

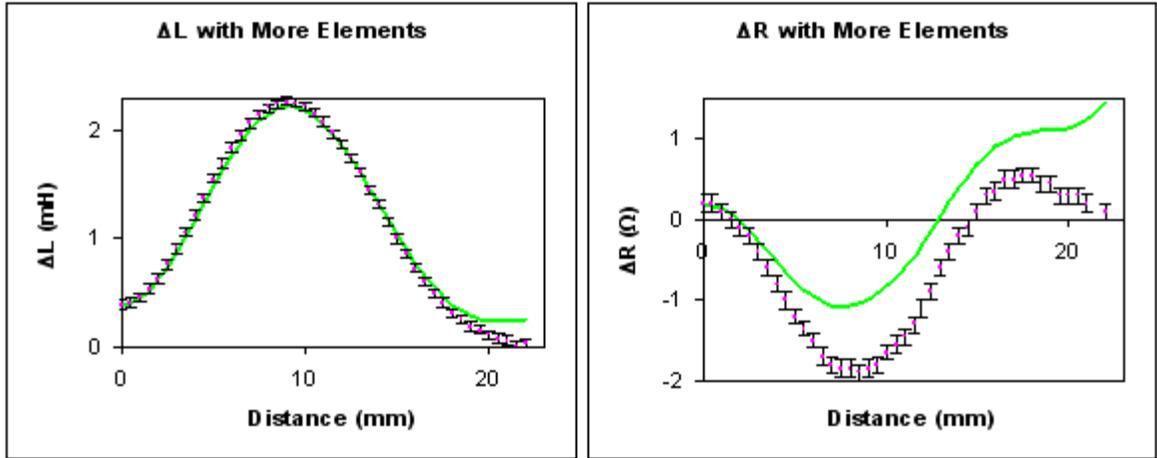
The graph below shows results from FARADAY as a continuous green curve, and the measured results from the [TEAM Workshop Problem #15 description](#) as points with error bars:



Clearly the L results are more accurate than the R results for this setup. That is because the calculation made by FARADAY gives the impedance, then divides it into real and imaginary parts. In this problem the phase is approximately 83° , so there relative error is much higher in the real part than in the imaginary part.

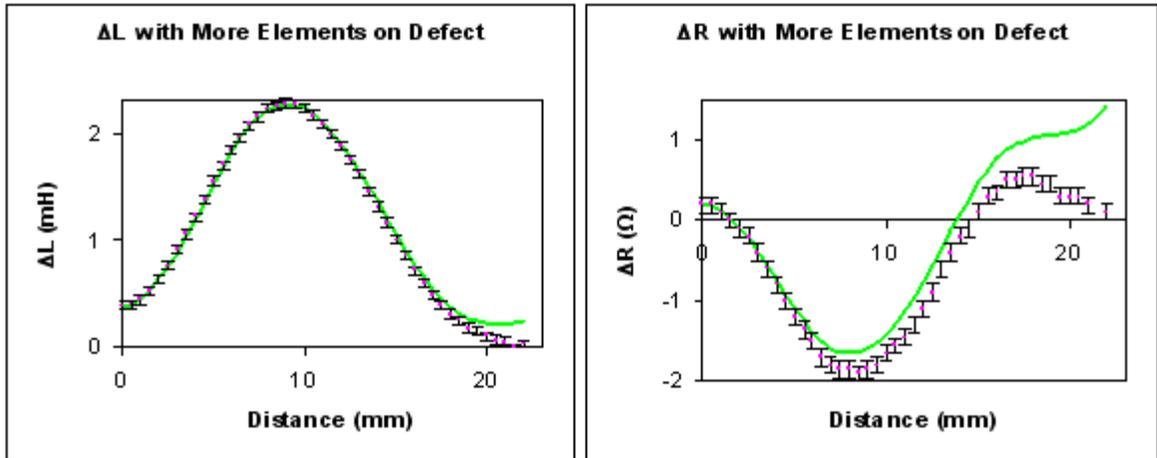
In order to get a better result, a larger number of elements can be used. You could use the **Automatic All** option again, or you could use your knowledge about what is important to assign them where they will help the most. It is mostly the top surface of the plate that affects the

inductance of the coil. Therefore, the next results show **Automatic Local** with 2000 "seed" elements on the top surface of the plate:

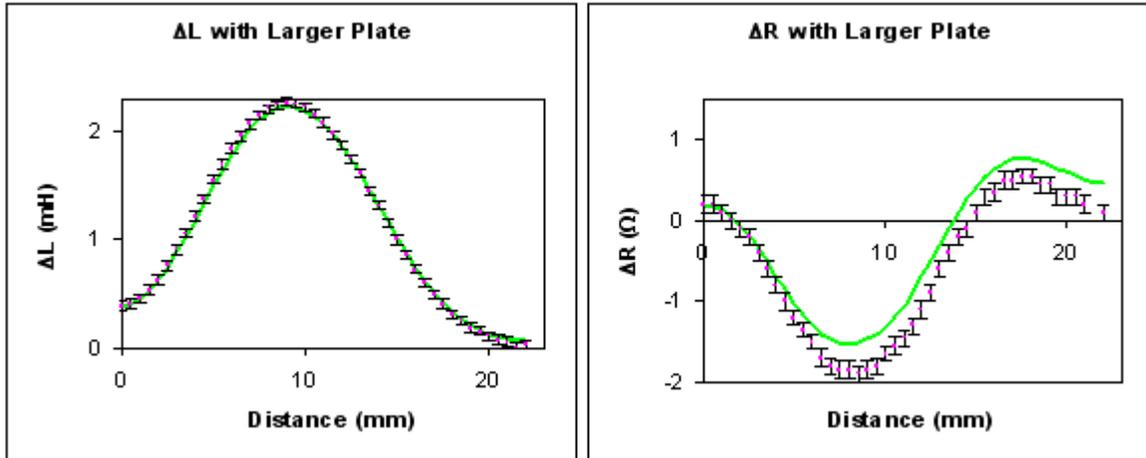


The L result now passes through all error bars except at the very end. The R result is now smoother and closer to the experimental data.

Since the shape of the curve is due to the defect, the next thing to do is try more elements on the defect itself. In fact, the elements on the defect shouldn't be larger than $\sim 10\times$ its width and by this standard some of the elements are too big. However, even smaller elements will produce an even better result. So, the next plot shows the effect of putting 500 "seed" elements on the large defect surface:

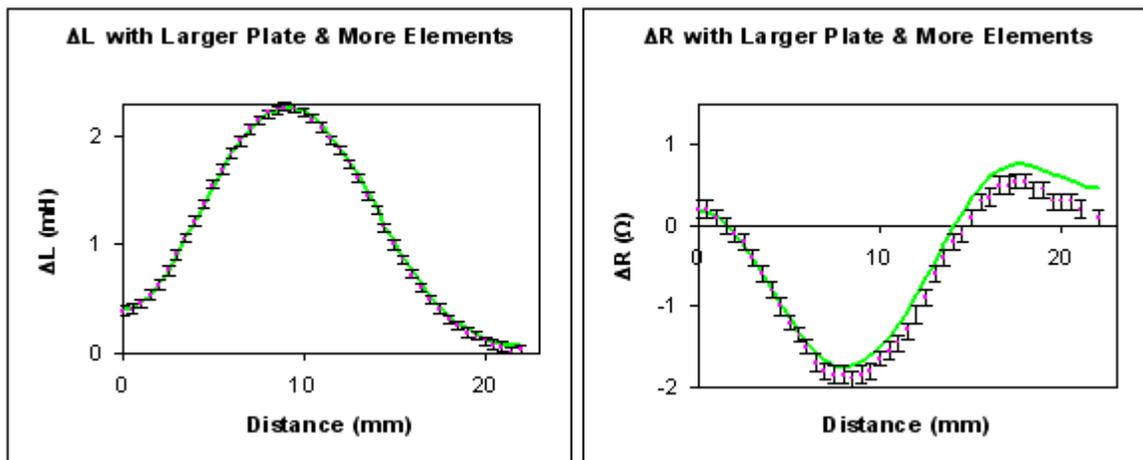


Now the L curve goes through the center of all error bars except at the end, and R is even closer to the measured data. It is now clear that that the last few mm of the FARADAY results are being affected by the proximity to the edge of the model. The results below show the effect of increasing the plate size by 12 mm on the total width and length (hence, the end position of the coil is now 6 mm further from an edge). The element density is chosen to be similar to the very first simulation result above.



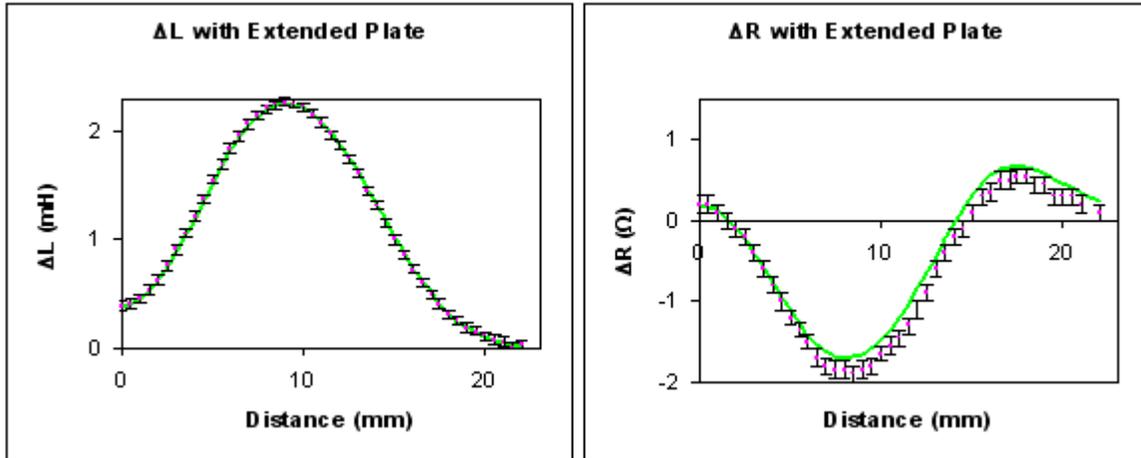
The L results are now within the error bars everywhere, and the R result is much better than it was with the same element density and a smaller plate.

Finally, the element density on the top plate and defect was again increased to be comparable to the best "smaller plate" result:



The L results now look very good everywhere. The R results are the best obtained yet. They seem to be more affected by the finite plate size than the L results. A user wishing to further improve on this result should thus make the plate even larger. It shouldn't be necessary to do this in all directions, just in the direction the coil is moving. For the same element density this will, of course, make the problem take longer to solve. **This is the essential trade-off when solving a problem: in general, the higher the element density, and the more closely the geometry matches the real geometry, the better the result will be - but the longer it will take to obtain it.**

As an example of how the problem can now be solved more efficiently using what was learned, the graph below shows results from adding a 40 mm extension to the plate in the direction of motion of the coil. Since the coil will not pass over this section it was applied very few elements - increasing the total by less than 10%. So, the result below fits the data in the central part comparably to the one above, and fits the end better, but solved in much less time due to using about half as many elements.

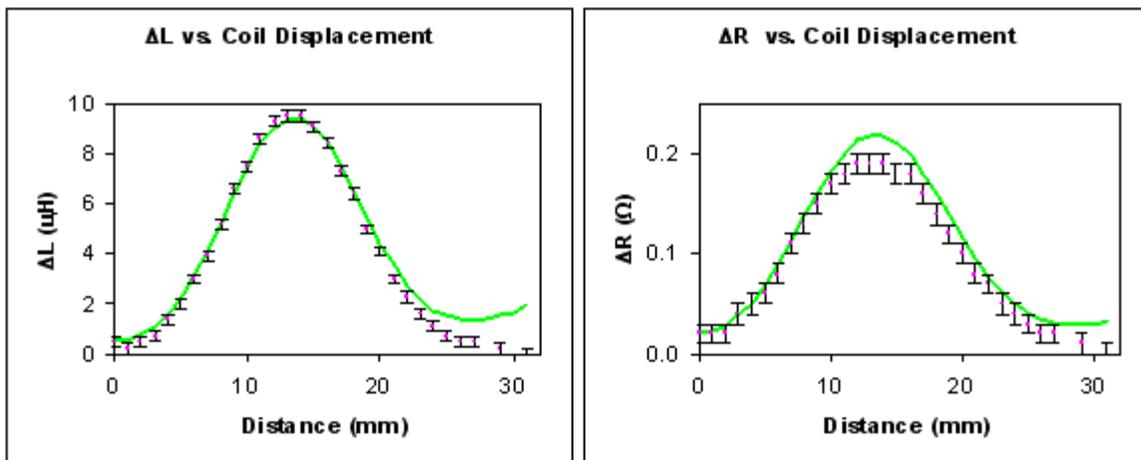


In fact, the most efficient element distribution would be found by using the self-adaptive solver rather than manually assigning the elements locally. However, using the self-adaptive solver in a parametric will have a time disadvantage because the element matrix will need to be rebuilt for every step.

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Solving Problem #2

Using the same process as for problem #1, a model was built, elements put on it, and a Parametric was run. The result is shown below:



This result is much like that obtained in Problem #1, so a user wanting better agreement with the measured data can again increase the plate size and number of elements. Due to the longer range of motion there is more surface area required, and due to the higher frequency the skin depth is smaller and a higher element density is required. Therefore, you can expect any given level of agreement with measurement to take longer to solve with Problem #2 than with Problem #1.

Note that the [TEAM Workshop Problem #15 description](#) seems to have problems with the error description for #2. The values cited in the footnote of Table #3 don't match the significant figures

shown in the table. Hence, for the purpose of placing error bars on the graph it was assumed that the correct values would be 0.01 Ohm for R and 0.2 uH for L.

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Using Fields Mode

Although Inductance mode seems the obvious choice for solving this problem, since it doesn't involve partial inductances it is possible to get the same results in Fields mode. Two options from the Analysis menu can give the necessary information:

1. **Resistance and Inductance from Flux Linkage**

When you request the Flux Linkage on a coil, FARADAY will also give you the voltage on the coil. These are very simply related since $V = -d\{\text{flux linkage}\}/dt$. Therefore, the voltage is just the flux linkage phase shifted by 90 degrees and multiplied by the angular frequency.

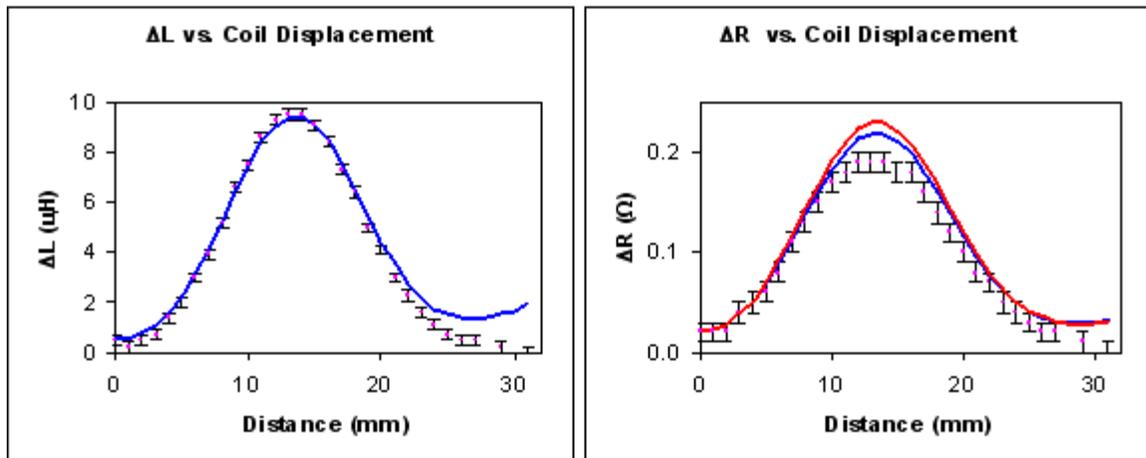
In both cases, the answer is for a single turn since Fields mode only has the total Amp-turns for the coil.

2. **Resistance from the Power Loss**

Since there is only one power source in this model, the real part of the power loss in the block must also be the real power loss pulled from that source. Hence, a power loss calculation on the block enables us to compute the resistance seen by the coil.

The same is not true for inductance and the imaginary part of the power loss. Although this contributes, the block itself also has self-inductance, so the power loss on the block does not give all the contributions.

The plot below shows results from a Fields mode solution with 1 A at a phase of 0 (to simplify calculations) in the coil. The complex impedance is obtained from V/I ($=1$ for the applied current) and R & L are obtained from this. Those results are plotted in blue. Also, the resistance is obtained from $P_{\text{real}} = R * I^2 = R$ (since $I=1$). These results are plotted in red. **In both cases the results are multiplied by N^2 to get the impedance for N turns.**



The results obtained from the voltage are identical to those obtained in Inductance mode, and overlay the green line on the plot. The resistance obtained from the power calculation is very close to the resistance obtained from the other calculations. The greatest discrepancy occurs at the peak of the response curve.

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