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Using model symmetry to shorten computation time in COMSOL Multiphysics

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***Abstract* — The purpose of the simulations is to work out the behavior of a system without the need of a physical realization of the model. The more elaborate a model is, the more it mirrors reality. However, the model growth in addition with sufficient numerical precision drastically increase the computation time. This paper describes the exploitation of symmetry in models to lower simulation times without affecting the result precision.**

***Keywords* — boundary conditions, COMSOL, magnetic fields, symmetry, transformer**

I. Introduction

The main purpose of computers in the time of their debut in the world was a fast way of solving systems of equations, linear and differential alike, which were till then laboriously computed by hand by people. Even though the computers helped, they weren't that quick (that is, if the notion of "quick" would be defined by someone from the 21st century). Nowadays we live in an age in which, by comparison, enormous computing power is freely available in the form of home PCs.

People after all this time still solve systems of equations - for example, in the form of simulations. Simulations have a huge advantage in the fact that a system (for example a device, a component etc.) doesn't need to be manufactured and then tested, but a simulation of a system can be created and then solved for. However, when we want the simulation to resemble reality with sufficient precision it always costs computation time. Sometimes the computation simply takes too long. Fortunately, symmetry can be used to chop the model down in size, which saves precious simulation time and memory resources.

II. Benefits and types of symmetries

When a model exhibits symmetry (when a plane slices through the model in such a way that it divides the original model into two or more identical sub-models) one can exploit this fact to shorten the computation time of a problem. There are many types of symmetries a model can have (not just planar ones), but the most important are:

- Axial symmetry
- Symmetry and antisymmetry planes
- Symmetry and antisymmetry lines[1]

A. Axial symmetry

Axial symmetry is most common in 3D models which have a cylindrical symmetry for example a toroid core of an inductor, an iron cylinder, a sphere and so on. This further illustrates the following figure (Fig. 1). On the figure, there is a circle which center is 60 mm offset from the z-plane (the dashed line) and the circle's diameter is 30 mm. If we revolve that circle around the dashed line, we get an object which is depicted in the figure below (Fig. 2), called a toroid [1].

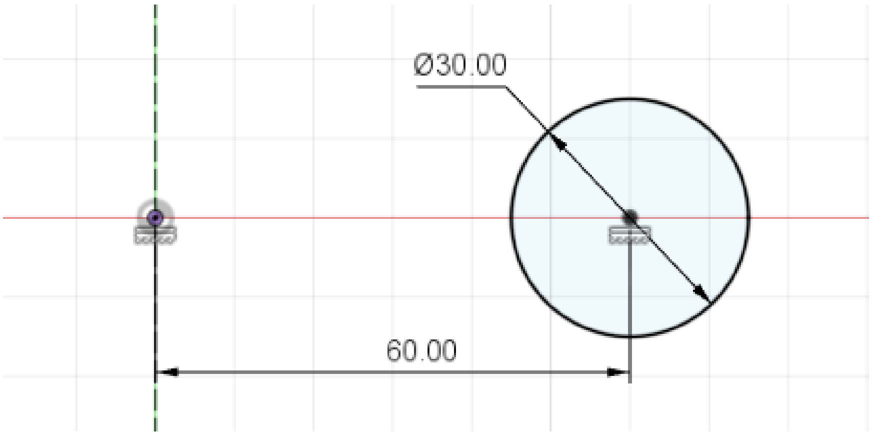

Fig. 1: An example geometry created in Fusion 360 to demonstrate axial symmetry. A circle has been defined which is offset from the z-axis (the dashed line).

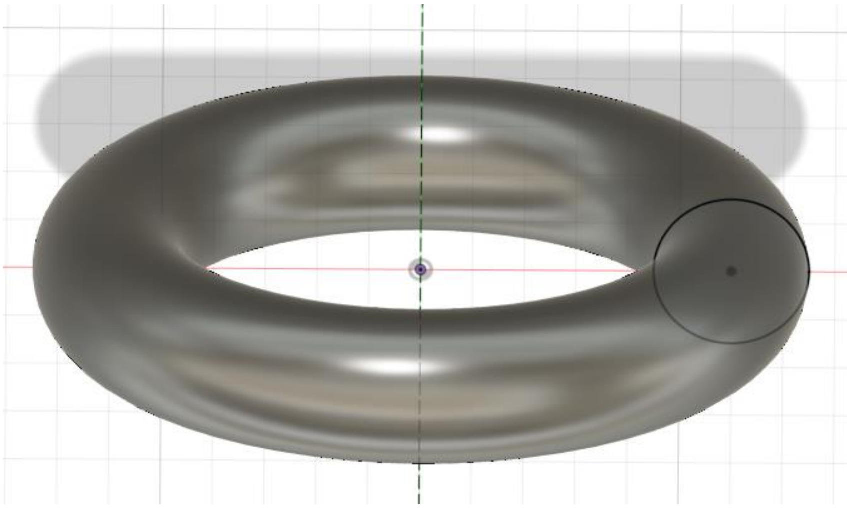

Fig. 2: When we plot one revolution of the circle around the z-axis from Fig. 1, the resulting shape is a toroid with an inner diameter of 90 mm and an outer diameter of 150 mm.

Because we used the operation of revolution around an axis to create the shape in Fig. 2, the toroid is therefore axisymmetric around the z-axis. When simulating such a model of a toroid core we can exploit this fact to drastically shorten the computation time of the 3D model, because usually 2D axisymmetric models exhibit a lot shorter computation time with the addition of lesser RAM requirements while preserving the simulation accuracy of the 3D model. We can use symmetries in all study types that are mostly used (time domain, frequency domain, stationary studies, etc.) [1].

B. Planar and linear symmetry

Symmetry planes (symmetry lines) are common in many 3D (2D) models. As it was mentioned, when using planar or linear symmetry, the model looks the same from both sides of the dividing plane or line. Every type of physics (heat transfer, electric and magnetic fields, solid mechanics…) has different types of symmetry conditions, which must be applied on the symmetry boundaries or lines. Some physics require symmetry conditions while some others require antisymmetry ones [1].

In general, we use symmetry planes on domains (objects) of a model which has the same material properties and boundary conditions. On the other hand, we use antisymmetry for domains where loads or sources are present. But determining whether to use symmetry or antisymmetry conditions requires the study of the model in combination with the physics used [1].

An example of planar symmetry used in 2D models is shown below (Fig. 3). We can see that rectangles (for the sake of an example), or in this case, two concentric squares, have 4 symmetry lines labeled *a*, *b*, *c* and *d*. Due to the knowledge that when a model is symmetrical, we can effectively shrink the size of the model by a factor of 2 (or more when using combinations of symmetries), we can divide the model using any of the four symmetry lines [2].

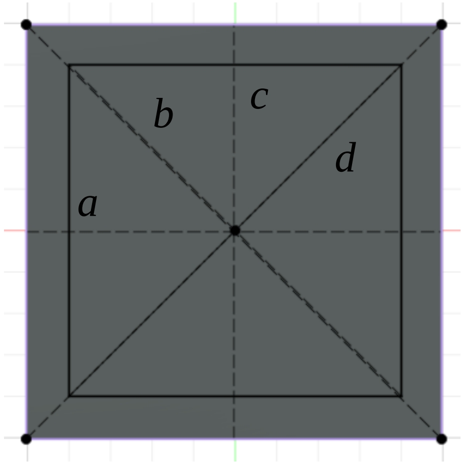

Fig. 3: Example of symmetry lines applicable to the example model consisting of a square core (the inner square) surrounded by a coil of wire (outer square rim).

In the figure below (Fig. 4) we can see how the computational model simplifies if we use various symmetry lines of the model. When a constant density mesh is used to discretize the model (which is a step in the preparation of the model for numerical analysis) in both the full 2D model and the symmetric one, because the model got smaller, the computation time must become shorter. Or taken from another perspective, when we use a denser mesh in the smaller model, we can achieve more precise simulation results during the same computation time as when simulating the whole model with a coarser mesh [2].

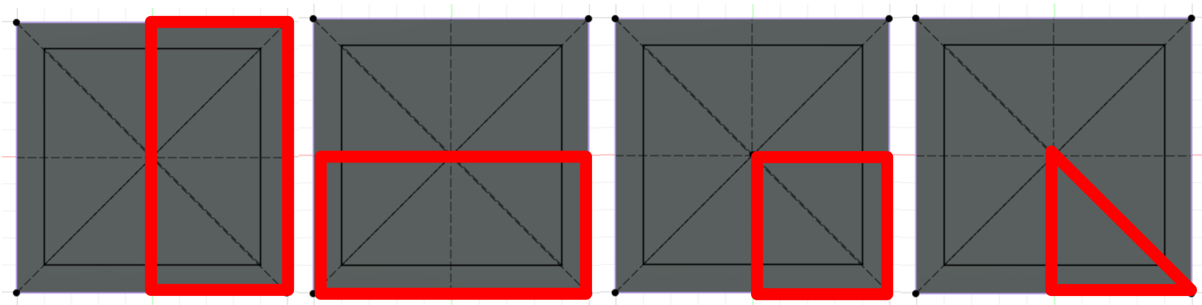

Fig. 4: The symmetric sub-models created from the 2D model when different symmetry lines were used for the sub-model determination (from left to right: sub-model determined by the *c* symmetry line, next in the *a* symmetry line, next by a combination of the *a*-*c* symmetry lines and last by the combination of the *a*-*b*-*c* symmetry lines.

The same logic applies to 3D models, but the difference here is that there usually are no distinct symmetry lines, but rather symmetry planes, which cut the 3D body into smaller, identical 3D sub-bodies. This is depicted on the figure below (Fig. 5), where a solid prism can be cut by its symmetry planes into a smaller number of identical objects [2].

We can see that using model symmetry is a powerful tool to simplify the model and make the computations shorter or more precise in the same time window. However, one must carefully consider if using symmetry is possible and what boundary conditions should be applied to the smaller model. That is always determined by the specific model and the physics used [2].

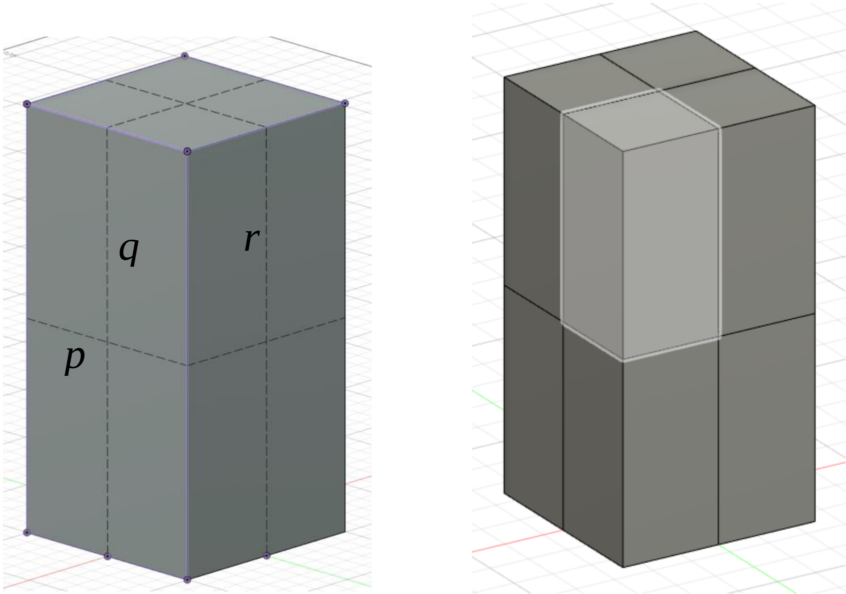

Fig. 5: Left image - a prism can be cut into 2 halves by 3 symmetry planes *p*, *q* and *r* (the diagonal symmetries that were present in Fig. 3 are ignored here, but can be also implemented). The highlighted sub-body on the right image was created by cutting the original body by the *p*-*q*-*r* symmetry planes.

III. An example of using planar symmetry on a model with magnetic fields

To verify that using symmetry truly yields the same (or more precise) solutions compared to the original model, a 3D COMSOL Multiphysics project was created. The paper doesn't allow for the detailed description of the model or the simulation configuration, but it can be found in the references ([3]), which contains the model and how to create it in detail. Because this paper addresses the problem of symmetry, only the symmetry configuration is described here.

In the figure below (Fig. 6) we can see the model of the E-core transformer. Looking at this model we can see that multiple symmetry plane could be defined here. When you follow the modelling steps in ([3]), the computation yields output graphs representing the input and output current and voltage of the transformer when a 25 V, 50 Hz sinusoidal input voltage is applied to the primary winding via a current limiting 100 Ω resistor. Both windings consist of 300 turns of copper wire with a cross-section of 1 mm^2. The secondary side is loaded with a 10 kΩ resistor. The schematic of such a circuit is shown below (Fig. 7) [3].

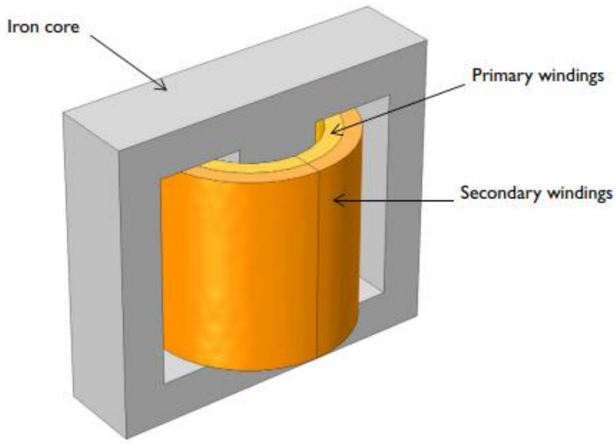

Fig. 6: A model of an E-Core soft-iron transformer with a stacked primary and secondary winding. The transformer is surrounded by an air domain in this model [3].

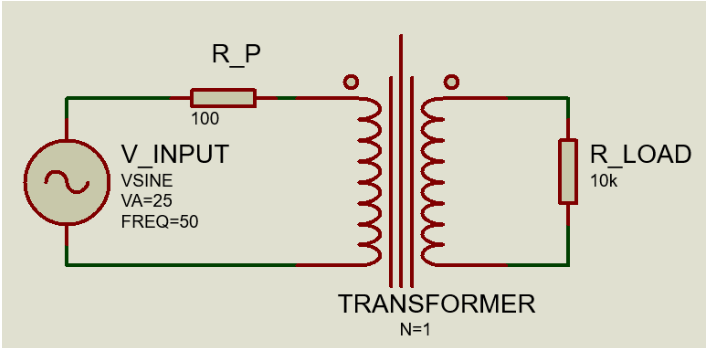

Fig. 7: Schematic of the electrical circuit established in the simulation model. Because the primary and secondary winding has an equal number of turns, the turn ratio (N) is 1.

The results of the simulation for times between 0 and 60 ms (3 periods of the input voltage) are shown below (Fig. 8). The simulation computed the waveforms from 120 discrete timesteps in the specified time interval. The input and output currents have an amplitude of 0,18 A and 0,0018 A respectively [3].

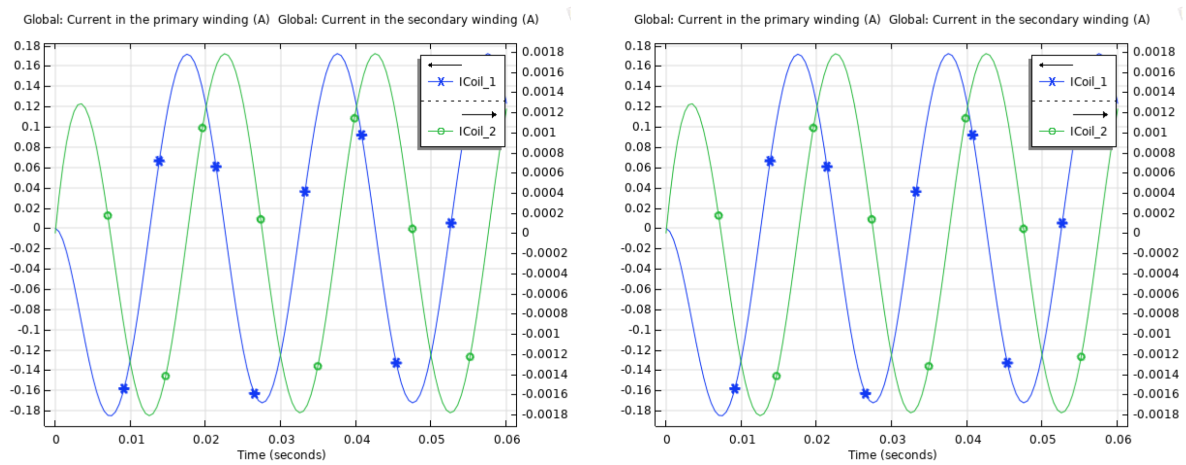

Fig. 8: The input and output currents from the simulation of the model with (right) and without (left) using symmetry. We can see that these waveforms are identical

We can exploit the model symmetry like it is shown in the figure below (Fig. 9), where a model was created which is 1/8 of the original model. After changing the geometry some changes have to be made considering the boundary conditions and the coil geometry (since the coils are now half in height and a quarter in length) [3].

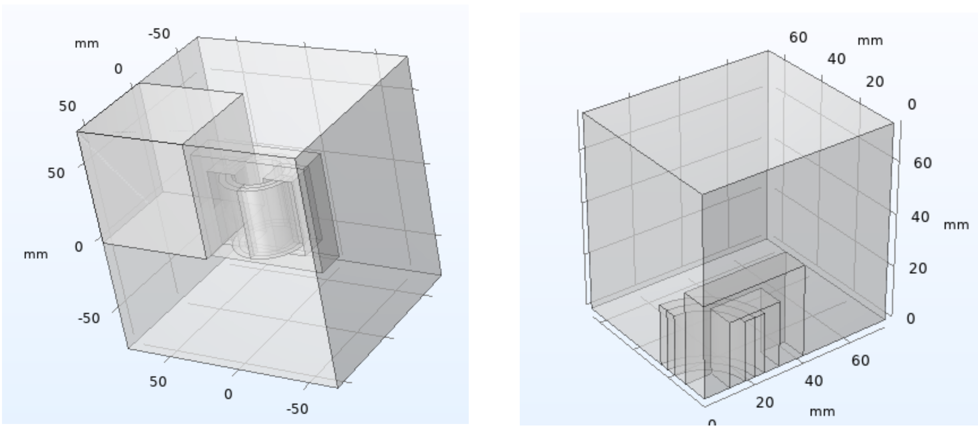

Fig. 9: Model after using the symmetry present in the original model. The resulting symmetry is analogous to the definition of the sub-model in Fig. 5.

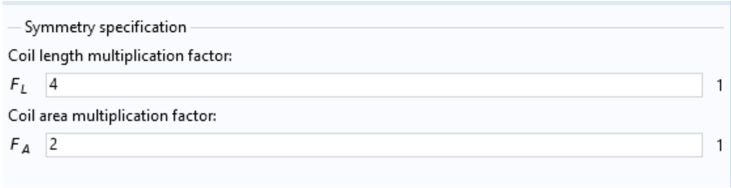

Fig. 10: Changes to the primary and secondary coil domains in the magnetic fields interface since the coil in the symmetry model is 4 times shorter and 2 times narrower, which must be compensated for in the computation

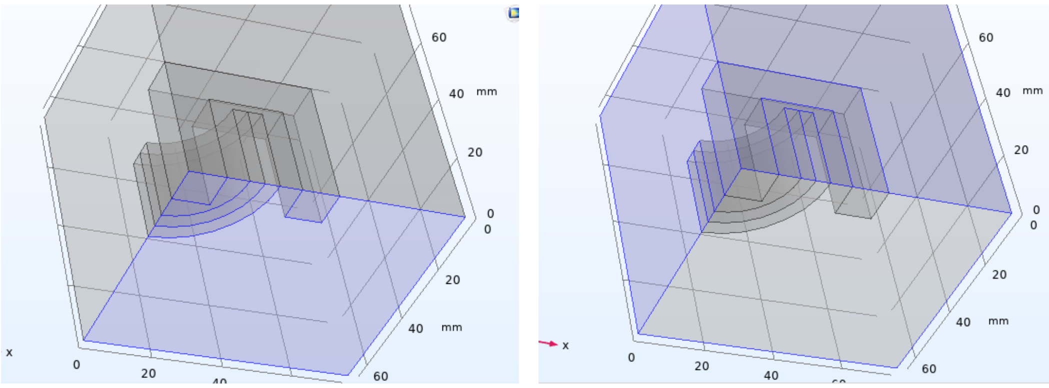

Fig. 11: Adequate boundary conditions must be applied to the model - left picture - boundaries which are specified as perfect magnetic conductor; right picture - boundaries which are defined as magnetic isolation

After applying the changes to the model which are depicted in the figures above (Fig. 10 and Fig. 11). The outputs of the simulation are shown in Fig. *8*. The only difference between the simulations are the computation times, which are shown in the table below (**Chyba! Nenašiel sa žiaden zdroj odkazov.** 1). We can see that using symmetry one can speed up the computations significantly, so it is most recommended to use them when it is possible especially in finer and more complex models.

Table 1
Units for Magnetic Properties

	Coil geometry analysis duration	**Magnetic field analysis duration**	**Total simulation time**
Original model	8 s	47 s	55 s
Model with symmetry	7 s	14 s	21 s
Absolute reduction via symmetry	1 s	33 s	34 s
Relative reduction via symmetry	12,5 %	70,21 %	61,19 %

IV. Conclusion

In this paper, we covered the possibility of exploiting symmetry for lowering computation times when simulating a 3D model in the time domain. A basic model of an iron core transformer was created, and a simulation has been computed to find the current waveforms of the primary and secondary coil currents when a 25 V 50 Hz voltage waveform is fed to the primary winding. The model was then truncated to incorporate just one fourth of the original model by the means of symmetry, which reduced the computation times by 61,19% without sacrificing simulation accuracy.

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