Cogging Torque Computation and Meshing for Radial Electrical Motors in Flux®

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All electrical motor designers know that the computation of cogging torque is a tricky task in 3D. Indeed, the amplitude of this quantity is almost the same as the numerical noise. In most cases a classical meshing methodology is not sufficient and specific methodology must be used. At CEDRAT, the application team, thanks to its experience has developed methodologies to successfully compute cogging torque in most of cases.
This article presents a specific meshing methodology to compute cogging torque for 2D and 3D radial electrical machine. It begins with some general recommendation concerning the definition of the geometry in order to facilitate the meshing operation. Then, it presents the specific meshing methodology applied to a **2D SPM motor** and to a **3D IPM motor.**

Some general recommendations

As already said, cogging torque computation is a difficult task. To make sure our chances are as good as possible, it is necessary to correctly build the motor geometry. In fact, meshing quality is strongly linked to a correct geometry balance (example: stator construction based on duplications of the half of a tooth) and of course to the absence of unnecessary points or lines. Another point, in 3D it is important to correctly define the sliding cylinder, that is, to define it at the middle of the air gap and to surround completely the rotor part. The good way to compute cogging torque is to make sure these different points are correctly considered.

An efficient meshing methodology

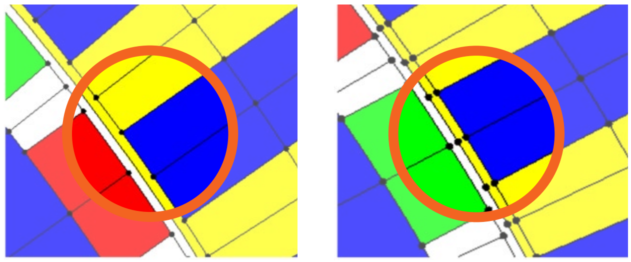
In this part, we present a meshing methodology that can be applied on 2D and 3D (extruded from 2D) radial electrical motor with main goal to get an accurate cogging torque.

» 2D model and meshing methodology

To get an accurate cogging torque, it can be necessary to use a specific meshing method. The main principle of this efficient method is to have a very regular meshing in the air gap. For this purpose, we propose to modify the mesh of the exterior air gap layer (fixed part), that is, to impose mapped mesh elements instead of triangular mesh elements (classical mesh). Along the air gap, we advice to impose 40 elements per cogging torque period to increase accuracy (Fig. 2c) - 40 elements per cogging torque period) but according to the periodicity of the motor consider, you have to adapt the number of element in order to obtain the best compromise between computation time and accuracy (Fig. 2b) - 13 elements per cogging torque period). Period of cogging torque in mechanical degree is obtained by the formula:

$$\frac{360}{LCM\left(Nb_{Rotor.poles}, Nb_{Stator.Tooth}\right)}$$

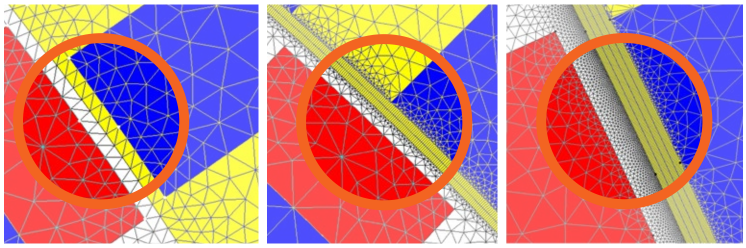
To make mesh elements the most regular as possible according to the geometry, additional points must be added on the line at the middle of the air gap. In particular, points in front of slot openings are created (Fig. 1).
Then, it is necessary to create arithmetic mesh lines to adjust discretisation of each part of the line at the middle in the air gap according to slot and to open slot in order to have the most regular mesh of the whole surface. The face must be structured in order to mesh them with mapped element (Fig. 2b).



a) Classical meshing method. *b) Efficient meshing method with additional points and lines.*

Figure 1: Geometry of the air gap according to the classical and to the efficient meshing method.

If we apply a classical meshing method without considering a smart discretisation, the mesh of these parts is done as illustrated by Fig. 2a. According to the periodicity of this motor (0.45 mechanical degree), the classical mesh is not sufficient to compute cogging torque.
Finally, the computation step must be adapted to get an elementary move equal to the length of the edge of a quadrangular element (Ideal case, 40 steps per cogging torque period – Simplify case, 13 steps per cogging torque period).
With the classical mesh method, cogging torque obtained can be inaccurate, not centered in 0 N.m and not periodic as shown in the curve above (Fig. 3 Blue curve).



a) Classical method *b) Efficient method (simplified case)* *b) Efficient method (ideal case)*

Figure 2: Mesh according to the classical and to the efficient meshing method (simplified and ideal case).

With the efficient meshing method, the cogging torque is more accurate and periodic (Fig. 3, Pink and green curve). According to Table I and to Fig. 3, the efficient mesh methodology is very effective. Moreover, if you correctly adjust the number of elements in the air gap and size of computation step, we obtain a good compromise between computation time and accuracy.

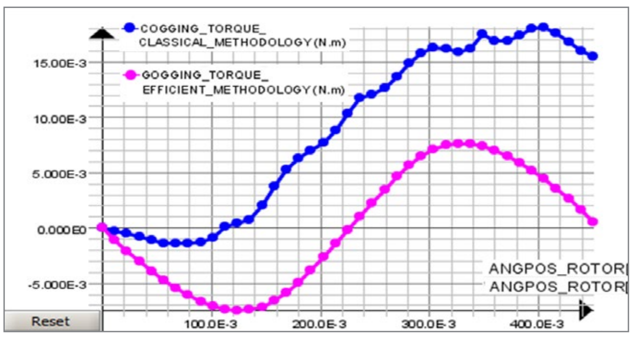


Figure 3: Cogging torque computation according to the classical and to the efficient meshing method.

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Method	Mesh element order	Number of nodes	Computation time
Classical meshing method	2nd	16605	30"
Efficient meshing method - Ideal case	2nd	273412	6'30"
Efficient meshing method - Simplify case	2nd	49768	1'

Table I: Meshing characteristics and computation time.

» 3D model and meshing methodology

This part present the meshing methodology used to get an accurate cogging torque for 3D motor extruded from 2D. We also compare the mesh and the results obtained with a classical meshing method and with the efficient meshing method.

In Flux, the most efficient way to build a 3D radial motor with a constant axial shape is to generate a 2D model and extrude to 3D. In the 2D project, we recommend building the additional points on the line at the middle of the air gap (same method as used for 2D motor). Then, it is necessary to delete the infinite box and to import the Flux 2D model as Flux object in a Flux 3D project. Once import is done, it is very helpful to use the macro *"ExtrudeFaceRegion"*. In fact, that is the fast way to build the 3D geometry, the macro automatically defines the regions according to the 2D model besides extrude volume and associate extrude meshing. Finally, it is just necessary to add the sliding cylinder and the infinite box. At this step, if the geometry is meshed we obtain the results presented by Fig. 4(b).

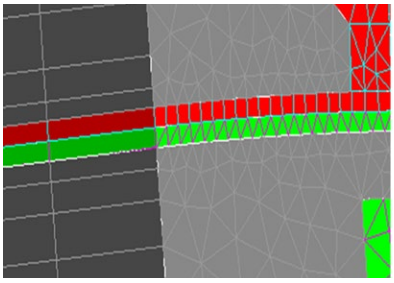
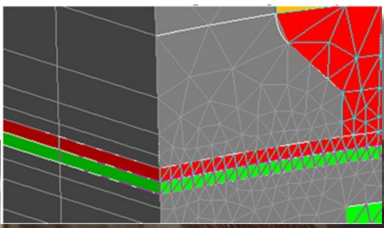


Figure 4: Meshing according to the classical and to the efficient meshing method.

b) Efficient meshing method.



a) Classical meshing method.

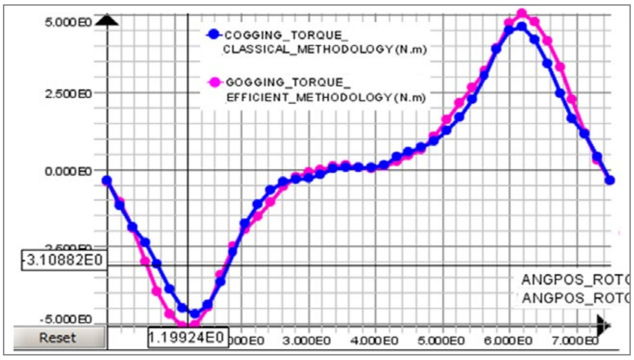


Figure 5: Comparison of the results.

Of course, the computation step is also adapted to get an elementary move equal to the length of the edge of a quadrangular element.

According to the period of the cogging torque (7.5 mechanical degree), this case is less demonstrative but we note that **with mapped element we obtain a better accuracy** concerning the evaluation of amplitude. Once again, the meshing methodology is very effective.

Conclusion

Cogging torque computation has always been a complex work specifically in 3D. Nowadays, Flux tools combined with CEDRAT experience in this domain lead to make this work easier. In this article we have demonstrated the ability of a meshing methodology in order to obtain an efficient meshing to compute cogging torque for radial motor (2D and 3D applications).

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