Mesh Deformation Method Based On Affine Transformation Applied In Electromagnetic Finite Element Analysis

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Abstract

A mesh deformation technique based on affine transformation is proposed to avoid re-meshing in this paper. To promote the speed of mesh generation, an improved mesh smoothing method is proposed in the initial mesh generation. An affine transformation is used to realize the mesh deformation. Magnetic field calculation of an induction motor is used to test the proposed method. The numerical results demonstrate that the proposed method can obtain a qualified mesh without re-meshing in small deformation.

1 Mesh Deformation Method based on affine transformation

In the electromagnetic optimization process, the solution region needs to be re-meshed during finite element analysis iterations to obtain an optimal solution. Unendurable computational burden has been a critical issue for electromagnetic optimization. In this regard, an affine transformation based mesh deformation method with a novel smoothing function is proposed to avoid re-meshing when the design region is changed. The process of proposed mesh deformation method is: generate initial mesh with the novel smoothing function, identify the deformation boundary based on signed distance function [1] and build the mapping set of nodes needs to be moved, operate affine transformation on the nodes in mapping set and obtain new mesh pattern.

1.1 Novel smoothing function

Smoothing function is usually used to improve the distribution of the mesh nodes [1]. A novel smoothing force (NSF) function is proposed here to mimic the force of a spring, in which both attractive and repulsive forces are considered. The formula is as follows:

$$F(d)=\frac{\left(-0.2\times(\ln(3.3\times10^{-5}\times d)+0.26)\right)}{\ln(3.3\times10^{-5}\times d)+0.26} \quad (1)$$

where d is normalized length and $F(d)$ is the force between mesh nodes, which determines the moving direction of nodes. When the normalized distance is less than 1, the nodes are too close and repulsive force is needed; when the normalized length is more than 1, the nodes are too far away and attractive force is implemented.

1.2 Affine transformation

The affine transformation performs a linear mapping between coordinate systems [3]. In our case, the affine transformation is used to transform nodes T into nodes K with following equations:

$$\begin{bmatrix} K_x \\ K_y \\ K_z \end{bmatrix} = \begin{bmatrix} S_1 & 0 & 0 \\ 0 & S_2 & 0 \\ 0 & 0 & S_3 \end{bmatrix} \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} \quad (2)$$

Where, S_1, S_2 and S_3 are scaling factors, K_x, K_y, K_z *and* T_x, T_y, T_z are the coordinates of nodes in the mesh before and after deformation.

2 Numerical Calculation

To validate the effectiveness of the proposed method, the magnetic field calculation of an induction motor [4] is computed. In the induction motor design, the shaft radius of the motor is increased from 30mm to 30.3mm. Table 1 gives the comparison between re-meshing and the proposed mesh deformation method. Table 2 demonstrates the comparison of the three designated points P_0, P_1 and P_2 selected to compare the density of the magnetic flux obtained with the re-meshing algorithm [1] and the proposed method.

From Table 1, it is shown that 46.6s is needed to generate the initial mesh when the shaft radius is 30mm. It takes 2.5s to complete the new mesh generation when the shaft radius is changed. In contrast, it takes 49.9s to re-mesh the new structure. In the aspect of mesh quality, the average quality q_{avg} of proposed method and re-mesh method are the same and the minimum quality q_{min} of proposed method is slightly degraded than re-mesh method. Table 2 demonstrates that the results of magnetic flux density calculated using the proposed mesh deformation method and re-mesh method have equivalent quality, which demonstrates the effectiveness of the proposed method.

Table 1
COMPARISON BETWEEN REMESHING AND PROPOSED METHOD

algorithm	*time(s)*	q_{avg}	q_{min}
remesh	46.6+49.9	0.70	0.55
proposed method	46.6+2.5	0.70	0.54

Table 2
COMPARISON OF FLUX DENSITY IN DIFFERENT LOCATIONS

algorithm	P_0 (0.064mm,0.009mm)	P_1 (0.029*mm*,0.037*mm)*	P_2 (0.015*mm*,0.035*mm)*
remesh	1.7534556T	1.1009080T	0.3192744T
proposed method	1.7534550T	1.1009082T	0.3192743T

3 Conclusion

A mesh deformation technique based on affine transformation is proposed aiming to avoid re-meshing in the optimization process of electromagnetic devices. Numerical results for solving an induction motor are testified that the proposed method can avoid re-meshing in small deformation of structure.

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