

Speeding up the iron losses calculation using a clustering technic

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The Finite Element method is widely used to study and design electromagnetic devices. This method is very accurate but often requires huge computational time even during the post processing step where quantities of interest are calculated. In this communication we propose to apply the K-Means method in order to reduce the computational time of the iron losses distribution in a postprocessing stage. Indeed, the iron losses distribution calculation relies only on the calculation on only few elements of mesh and not on all elements like in the standard method. The proposed method is tested on a nonlinear magnetic example based on a linear actuator showing a good agreement between the iron losses distribution obtained by the standard and the proposed methods.

Index Terms—Finite Element Model, Iron Losses calculation, K-Means method

I. INTRODUCTION

FINITE ELEMENT (FE) models are widely used now for the design and the study of electromagnetic devices. Such models lead to virtual prototypes representing very accurately the behavior of the real device. However, these kinds of models are very time consuming. This is the reason why lot of research is going on model order reduction technic in order to speed up the solving of the FE models [1], [2]. However, the postprocessing step once the FE model has been solved can be also time consuming especially when a local quantity should be calculated on numerous nodes or elements of the mesh. An alternative consists in using techniques in order to select some specific nodes or elements on which the local quantity is calculated and then to extrapolate on entities of the mesh. Recently, in [3], a method based on Energy Conserving Sampling and Weighting method has been proposed in order to calculate the force by only calculating local forces on specific points.

In this communication, we propose to apply a clustering method, the K-Mean method [4], in order to speed up the calculation of the iron losses distribution. The method is first described and then tested on a linear actuator where a comparison with the FE model is carried out.

II. DESCRIPTION OF THE METHOD

Let consider a device modeled by the FE method in the time domain. We are interested in calculating the iron losses distribution in the ferromagnetic material. A standard method consists in determining the time evolution of the magnetic flux density $\mathbf{B}_e(\mathbf{t})$ on each element e of the mesh by solving the FE model in the time domain considering a non-linear but univoc behavior of the ferromagnetic materials. Then, in a post processing step, from $\mathbf{B}_e(\mathbf{t})$ on a period, the iron losses are determined in each element e of the mesh [5]. If the number of elements E in the ferromagnetic region is high, the time for the postprocessing step can be significant. However, in practice, it appears that in numerous elements, the term $\mathbf{B}_e(\mathbf{t})$ is quite similar leading to almost equivalent iron losses. The idea is then to find a way to determine a reduced number K of clusters

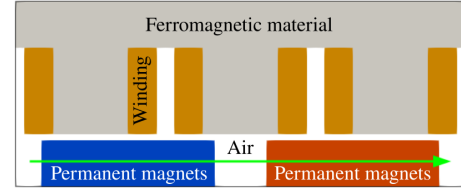


Fig. 1. Geometry of the linear device under study.

gathering elements with similar iron losses. In each cluster i , the iron losses are calculated on only one element e_i and then the iron losses are imposed to the same value on other elements belonging to the cluster i . The number of iron losses calculation from $\mathbf{B}_e(\mathbf{t})$ is then done on only K elements.

To determine these K subregions and their associated element e_i , we propose to use the K-Means method [4]. First, the iron losses distribution is determined for N different operating points of our considered device. We denote by $\mathbf{P}_e$ the $N \times 1$ vector containing the iron losses values corresponding to the N operating points on an element e . Second, we construct then E vectors $\mathbf{P}_e$ which are the inputs of the K-Means algorithm. The outputs of the K-means algorithm are K clusters each corresponding to a set of indices of elements and K centroids which correspond to element indices $(e_1, \dots, e_k)$.

III. APPLICATION

A linear three phase permanent magnet actuator is considered, which geometry is presented in Fig. 1. The three phase winding of the stator is supplied by sinusoidal currents. We denote by I the current magnitude and I_n its nominal value. The linear movement of the rotor is taken into account by means of the locked step method. The $B(H)$ curve of ferromagnetic core is assumed to have a nonlinear behavior (see Fig. 2). In the following, we compare the iron losses distribution in the ferromagnetic core obtained by the K-Means method to the standard one consisting in calculating on each element in the ferromagnetic region the iron losses.

First, we have carried out three Finite Element simulations for different operating points $A=(I=0, \Psi=0)$, $B=(I=I_n, \Psi=60^\circ)$

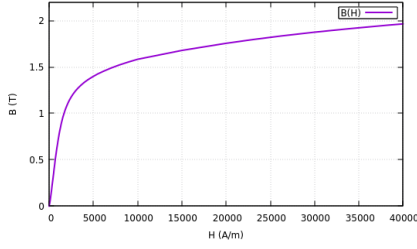


Fig. 2. B(H) curve of the ferromagnetic material.

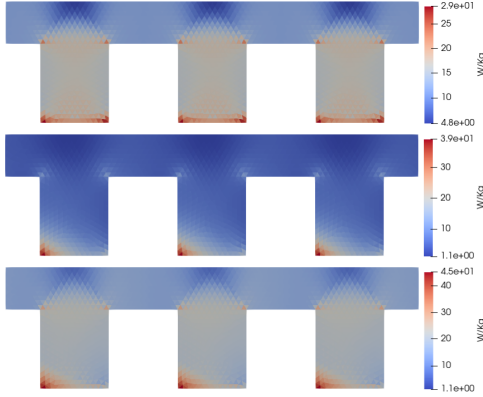


Fig. 3. Iron losses distributions for the three considered operating points A=($I=0, \Psi=0$) (top), B=($I=I_n, \Psi=60^\circ$) (middle) and C=($I=I_n, \Psi=0^\circ$) (bottom).

and C=($I=I_n, \Psi=0^\circ$) with Ψ the phase shift between the current and the EMF. This simulation has been carried out accounting the movement on one mechanical period enabling to calculate the losses on each element belonging to the iron core. In Fig. 3, we give the three iron losses distributions. Applying the clustering technic, we obtain $R=10$ different clusters and their centroid (see Fig. 4). With the clustering method, the iron losses will be only calculated on the R centroids and then assumed to be constant on their corresponding cluster.

We have considered a new operating point ($I=I_n, \Psi=75^\circ$). We give in Fig. 5 the iron losses distribution obtained with the clustering method and the standard one. Due to the fact that the iron losses are constant on each cluster, the distribution given by the clustering method is less smooth. In Fig. 5, we give also the distribution of the difference between the iron losses obtained by both methods. We can see that this error is acceptable and is the highest in the region where the variation of the losses is significant like at the corners of the tooth tip. The region with an error greater than 10% are very localized. Consequently, it appears an error less than 1% between the total losses obtained by the clustering technic (1.438W) and

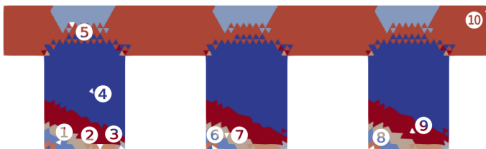


Fig. 4. 10 different regions obtained by clustering and the 10 elements on which the calculation of Iron losses will be carried out.

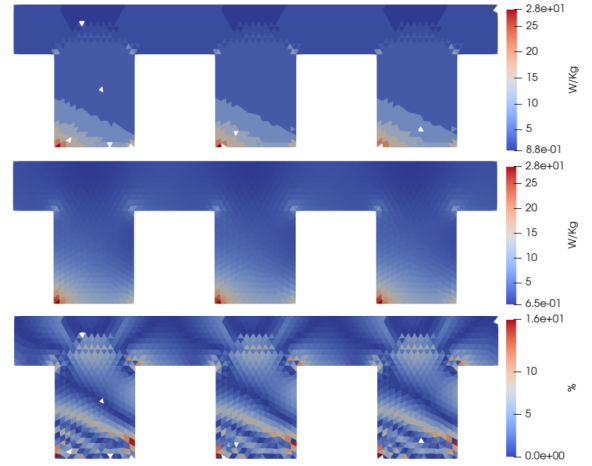


Fig. 5. Iron losses distribution obtained by the clustering method (Top) and by solving the FE model (middle). At the bottom, the distribution of the error (%) is also given. The white points are the points where the iron losses were calculated from the time evolution of the magnetic flux density for the clustering method. At these points the iron losses are equal to the one given by the FE model.

the one obtained by the FE method (1.448W). These good results are obtained by calculating only the iron losses in $R=10$ elements instead of on the 2731 elements of the iron core, so the postprocessing stage can be highly shortened.

IV. CONCLUSION

We have proposed a simple method based on a clustering technic in order to reduce the calculation time of the iron losses distribution. The application on a linear actuator shows that the method leads to accurate results and reduces drastically the calculation time. Research is ongoing now to find the optimal number K of clusters as well as an evaluation of the proposed method on a wider range of operating points.

V. ACKNOWLEDGEMENT

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