Modeling of a Novel Three-Dimensional Magnetization Structure for Laminated Silicon Steel

Yongjian Li[1], Qingxin Yang[2], Jianguo Zhu[3], Zhigang Zhao[1], Xiaojing Liu[1], Changgeng Zhang[1]
[1]Province-Ministry Joint Key Laboratory of EFEAR, Hebei University of Technology, Tianjin, 300130, China
[2] Tianjin Key Laboratory of AEEET, Tianjin Polytechnic University, Tianjin, 300387, China,
[3]School of Electrical, Mechanical and Mechatronic Systems, University of Technology, Sydney, NSW 2007, Australia
herolyj@hebut.edu.cn

***Abstract*—A novel three-dimensional (3-D) magnetic properties tester for laminated silicon steel specimen has been designed and constructed. The magnetization structure is the critical part of the tester especially for the magnetic properties of the laminated silicon steel in perpendicular direction of grain oriented. To guarantee the experimental precision and accurately analyze the 3-D magnetic properties of the laminated silicon steel, a symmetrical 3-D magnetic flux path in the magnetization structure fit for given dimension of specimen has been calculated and modeled. Magnetic flux in each direction has been homogenized and concentrated on the top of the core poles by means of finite element analysis. Therefore, magnetic properties in each direction of the laminated specimen can be really concerned and analyzed in practical engineering.**

***Index Terms*—3-D magnetization structure, homogeneous field core shoes, laminated silicon steel, magnetic concentrated effect.**

I. INTRODUCTION

Laminated silicon steel is widely applied in electrical engineering, such as power transformer, electrical machine, and magnet. Large-scale electromagnetic simulations of the core magnetic materials are key factors in design of electrical apparatus. Comprehensive measurement of the magnetic properties is very important, especially in the rotating magnetization conditions. A set of engineering-oriented Testing Electromagnetic Analysis Methods, the benchmark models, named Problem 21 Family has been established to test various analysis methods and systematically investigate the engineering stray-field loss problem [1]. Considering the rotational magnetic properties in the plane of the silicon steel, 2-D rotational measurement methods have been adopted by some researchers by using square rotational single sheet tester with square specimen and different field sensing coils [2]-[3]. Due to the influences may not only in the plane but the laminated perpendicular direction, the traditional modeling methods in 1-D or 2-D, however, need to be improved and do further evaluation. Reference [4]-[5] introduced the 3-D testing system for isotropic soft magnetic composite materials. However, modeling and analysis of the 3-D magnetic properties for the laminated silicon steel is rarely reported. Consequently, the authors have a number of valuable benchmarking studies on a novel 3-D magnetization structure for laminated silicon steel.

II. MODELING OF THE 3-D MAGNETIZATION STRUCTURE

The magnetization structure in 3-D testing system consists of three orthogonal "C-type" cores, six multilayer excitation windings which are wound around the three pairs of orthogonal core-poles, as shown in Fig.1. The "C-type" cores are laminated structure with high grain-oriented material of HiB, which can generate higher magnetic flux density and decrease core loss caused by leakage flux, compared with the core-yoke magnetization structure. To concentrate magnetic flux density and enhance the excitation field, terminals of the core are shaped in terrace with edge. A cubic laminated silicon steel specimen with *B-H* sensing coils is placed in the center of the tester.

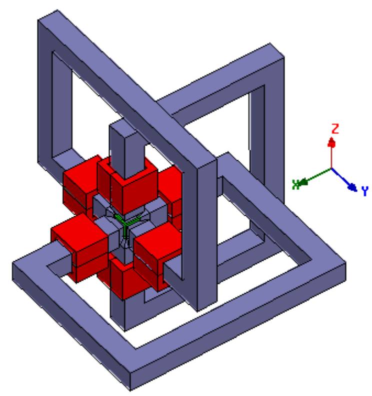


Fig.1. Novel 3-D magnetization model

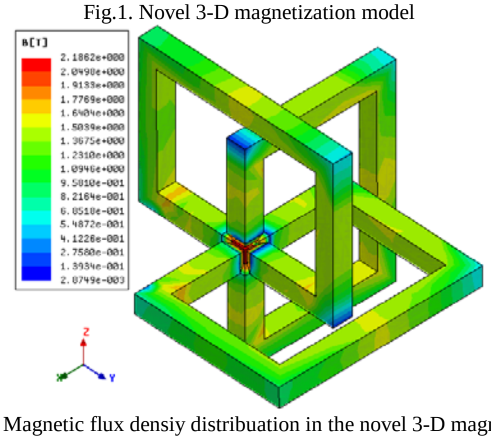
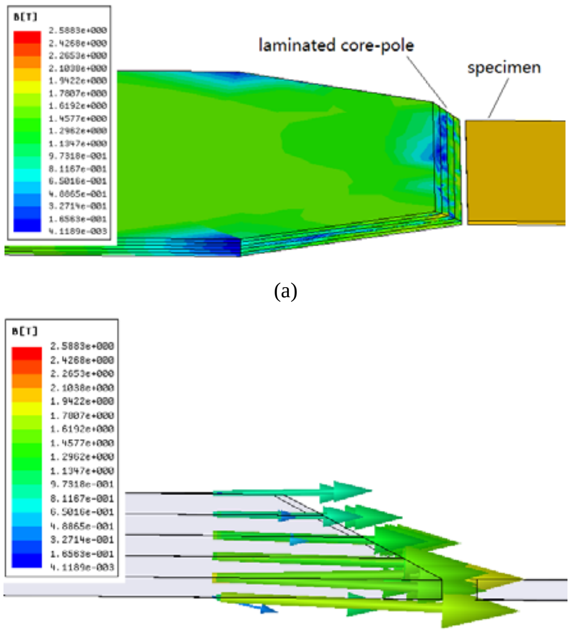


Fig. 2. Magnetic flux densiy distribuation in the novel 3-D magnetization model

The 3-D magnetization structure is modeled by means of finite element method to evaluate the magnetic flux distributions in the core. Grain-oriented direction is set to along the block material model of core, which can simulate the grain-oriented silicon steel lamination. Fig. 2 shows the magnetic flux distributions in the three cores with the same excitation conditions. It can be seen that the magnetic flux distributions in the three "C-type" cores are nearly the same, and shows relatively uniform in each core of the magnetic circuit. Stronger magnetic flux density is obtained in the center area of the cores. Therefore, the concentrated and uniform magnetic field can be obtained in the cubic center. This magnetic concentrated effect is modeled as shown in Fig.3.



(a)

(b)

Fig. 3. Modeling of the magnetic concentrated effect: (a) Magnetic flux density distributions of the cutting laminated core and specimen, (b) Cross section of the magnetic flux density distributions of the model

III. Modeling of the Homogeneous Field Core Shoes

The laminated silicon steel specimen placed in the center of the three orthogonal core poles needs to be magnetized by strong and homogeneous field. Between the two materials, however, there placed the thin sensing coils and generate air gaps. This can make the sensing field far away from uniformity. To reduce this influence, six guarding pieces around the cubic specimen with sensing coils are designed and named to homogeneous field core shoes, which are the same material and same laminated direction as the specimen, as shown in Fig. 4. These shoes can significantly improve uniformity of the magnetic field at the specimen surface, hence improve the measurement accuracy. The comparison of the magnetic field distributions in the condition with and without homogeneous field core shoes is shown in Fig. 5. This structure can also significantly decrease the equivalent reluctance of the magnetization structure and the excitation current required magnetizing the specimen.

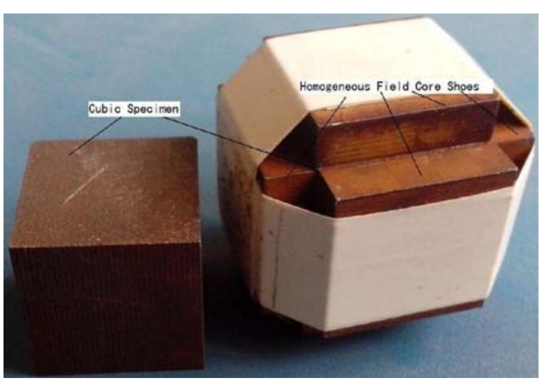
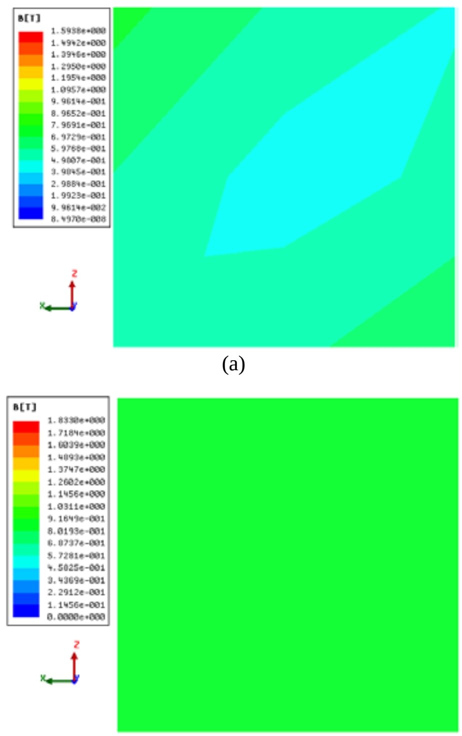


Fig. 4. Cubic specimen with homogeneous field core shoes

IV. Conclusion

Different from the traditional 1-D and 2-D testing magnetization structure, the designed and modeled novel 3-D structure can generate stronger and relatively uniform magnetic field in three orthogonal directions. Therefore, the 3-D magnetic properties of laminated silicon steel can be measured and comprehensively studied. The “C-type” core and magnetic concentrated core-pole structures can generate stronger magnetic field and may magnetize the laminated silicon steel specimen to saturation state. Meanwhile, the structure of homogeneous field core shoes between the specimen and core-poles may ensure the uniformity of the sensing field. Consequently, the 3-D magnetic properties measurement and modeling can be carried out. More detailed modeling and analysis of the 3-D magnetization structure will be presented in the full paper.



(a)

(b)

Fig. 5. Magnetic field distributions of the specimen without and with homogeneous field core shoes: (a) Without homogeneous field core shoes, (b) With homogeneous field core shoes

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