3D MAGNETIC FIELD AND EDDY LOSS CALCULATIONS FOR IRON DOMINATED ACCELERATOR MAGNETS USING ANSYS COMPARED WITH RESULTS OF NONCOMMERCIAL CODES*

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Abstract

The design of fast ramped superferric magnets with repetition rates in the order of 1Hz requires reliable software tools to calculate the complex 3D magnetic field quality as well as the impact of eddy currents and hysteresis losses. Various technological construction details should be taken into account to obtain a high field quality. We present a methodical study of these problems based on ANSYS calculations for simplified dipole models. The results of this analysis are compared with recently published results obtained by different special codes, i.e. an integral and the FIT method. The time dependencies of the eddy current power due to longitudinal magnetic field component at the yoke ends, the transient field distribution in the yoke volume and the total eddy current loss are investigated, using identical geometries with the same magnetic and electric properties of the lamination steel as used by the other codes. According to the results of this investigation the application potential of the different methods is discussed.

INTRODUCTION

FEM analysis of transient processes in laminated superferric magnets needs a detailed understanding of modeling algorithm and the underlying codes. We compare different calculation methods with the aim to choose a proper tool for the description of 3D eddy current problems. For this purpose we had investigated the results obtained by us and other authors using different codes for identical geometries and the same material properties.

SIMPLIFIED GEOMETRY AND STEEL PROPERTIES

For easy model creation and direct comparison of the results a simplified but close to the real geometry of the iron yoke and the coil of an experimentally tested dipole magnet have been chosen. The eddy current losses in the laminated yoke should be calculated for a triangular cycle from 0 to 2 Tesla and back to 0 with a ramp rate dB/dt of 4 T/s, using the same magnetic and electrical properties of the steel. The yoke was laminated and at the end parts the laminations have horizontal slits to supress eddy current effects due to the longitudinal magnet field componentt B_z, (fig.1). The geometries of the coils were simplified (original and alternative (Fig. 2; the electrical conductivity between the laminations was assumed to be zero. Along the z-axis in the yoke the eddy current loss due to B_z has to be calculated with a sufficient time resolution of the instantaneous power loss during the operation cycle.

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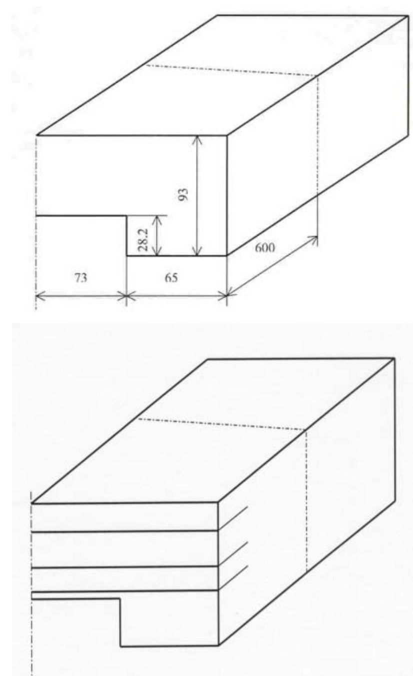

Figure 1: Simplified geometry of the iron yoke.

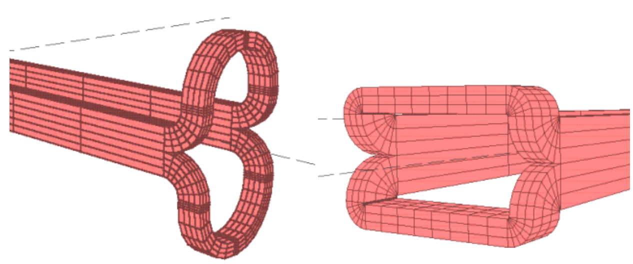

Figure 2: Simplified geometry of the coils. On the left is the standard coil whereas on the right is the small coil.

The B(H) and μ(H) curves for laminated steel in the lamination plane (x-, y-axis) are presented in [4]. The anisotropy of magnetic properties in laminated steel is expressed by introducing the reduced permeability μ(B) in the z direction, transverse to the lamination plates, depending on their packing factor f_p. For f_p=1 the μ(B) function is isotropic. For f_p = 0.98 the μ(B) is given in Fig.3. It is practically constant up to B=1.6 T. A conductivity value of $3.2 \cdot 10^6 / \Omega m$ and a packing factor f_p = 0.98 was used for the lamination steel of the yoke.

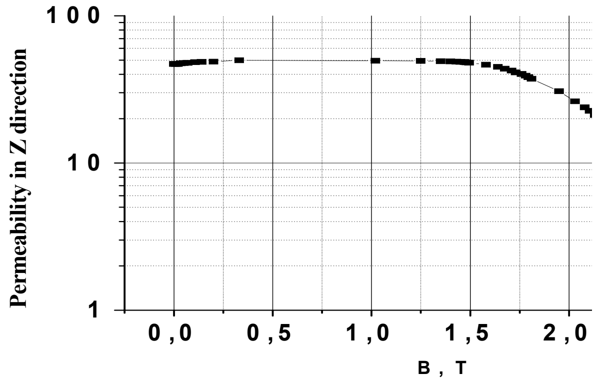

Figure 3: Permeability μ(B) in the longitudinal z direction of the yoke with packing facktor f_p=0.98.

METHODS AND CODES

ANSYS

This code is multiphysical and can solve a wide class of electromagnetic, thermal and mechanical tasks as well as coupled problems. In the calculations of both magneto-static and eddy current problems the magnetic edge elements, formulated in respect of the magnetic vector potential are used.

Integral Method (INT)

This method is described in [2,3]. It solves the integral equation for the magnetization vector in the nonlinear magnetic media and the integro-differential equation for the current density simulation in thin plates improved for modelling eddy currents in laminated ferromagnetic objects. It is assumed that the currents circulate only in the lamination plane and that eddy currents, induced in the coil conductor may be neglected. The developed method ignores hysteresis effects.

FIT Method

This method is described in [5,6]. The magneto-quasistatic subset of the Maxwell equations is formulated in terms of a line-integrated magnetic vector potential using the Finite Integration Technique for geometrical discretisation. The model is linearised by a successive-approximation technique with relaxation based on backtracking. A single-diagonal implicit Runge-Kutta method is used for time stepping.

RESULTS

It was possible to carry out a direct comparison of the two codes ANSYS and INT:

ANSYS

ANSYS can deal with two different dependencies of μ(H): one –nonlinear and second-μ=const. So if we use a nonlinear dependence of μ in the transversal (xy) plane, we have to use μ=const in the z direction. Fig. 3 shows, that up to B=1.5-1.7 T μ(B)=const=1/(1-fp). For the eddy current losses each packing factor correspond to some μ=const, depending on finally on B_{max},. Packing factor=1 corresponds to the same nonlinear dependence. The time dependencies of the loss power for different μ_z=const the and isotropic μ(B) are shown in Fig. 4.

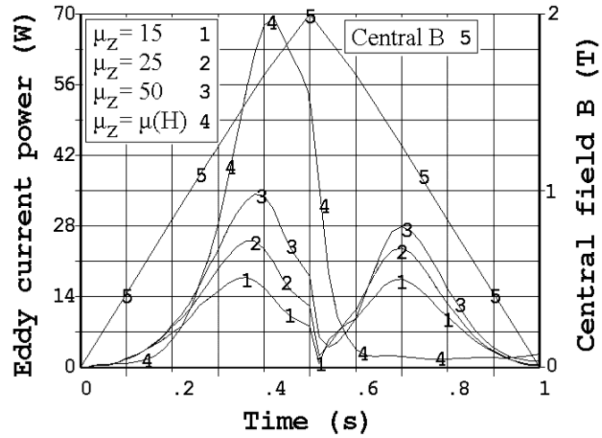

Figure 4: Time dependencies of eddy current loss calculated using ANSYS.

Integral method

For the same cases and original coil the time dependencies of the eddy current loss are shown in Fig. 5 [4].

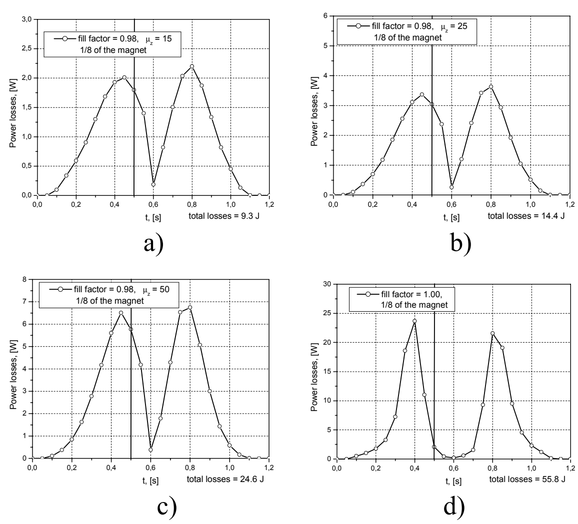

Figure 5: Time dependencies for the given μ_z by INT.

The calculated functions P(t) for various μ_z =const differs even qualitatively: for ANSYS the second peak decreases with increasing μ_z wereas it is slightly higher in the results of INT. This differences is most distingtive in the isotropic case: curve 4 in Fig.4 and curve d) in Fig.5.

The eddy current loss per cycle data obtained by ANSYS and INT are presented in Table 1

Table 1: Intergal loss per cycle

μ_z	15	25	50	f_p=1
	Losses, J			
ANSYS	8.9	11.3	13.9	15.9
INT	9.3	14.4	24.6	55.8

It is obvious, that INT gives significant higher eddy current losses for μ_z>25: The dependence of power vs time for nonlinear μ_z(B) is shown in Fig. 6.

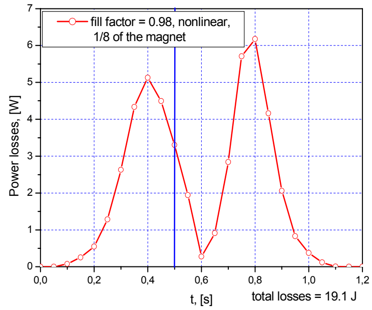

Figure 6: Time dependence of eddy current power for f_p=0.98 calculated by Integral method.

FIT results.

The time dependencies for the original and small coils are shown in Fig. 6 for nonlinear μ(B), corresponding to f_p=0.98. A summary of the loss data is presented in Table 2 [7];

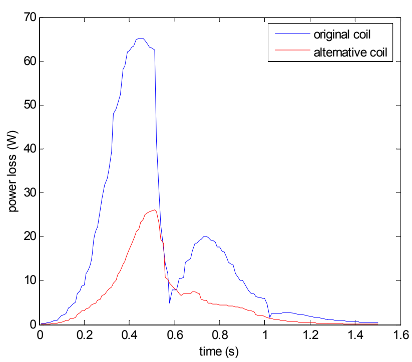

Figure 7: Time dependencies of eddy current power.

The second peak is three times lower then the fist one, and the effect is similar to the ANSYS results, contrary to the INT method (see Fig.6). The loss data are summarized in Table 2; [7];.

Table 2: FIT method results

	yoke	Loss, J
standard coil	standard yoke	22.7
	yoke with hor. cuts	24.4
small. coil	standard yoke	8.03

The FIT data show an increase of the losses when the horisontal the cuts are added, wereas ANSYS found a loss reduction as expected by physical reasons.

Experimental data

Based on the experimental data [8,], the eddy current contribution of B_z was estimated to 9-10 W for the models with the original coil while it was estimated to 3 W for models with the small coil.

COMPARISON

Comparison of the eddy current loss data

The results for the different cases are summarized as follows: INT obtain 19.1 J, FIT gives 22.7 J, ANSYS find the data range of 11.3-13.9. The values obtained by ANSYS are close to the experimental data, wereas INT and FIT methods gives two times larger loss results

Comparison of the time dependence P(t)

For the same nonlinear B-H dependence (maximum μ =4000) in all directions (f_p=1.0) the time dependencies of the power losses for ANSYS and INT are showing a complete different behaviour.

Comparison of loss results from INT and FIT

The time dependence of the loss for a packing factor of 0.98 with nonlinear $\mu_z = \mu_z$ (B) was calculated by INT and FIT. The losses are similar - 22.7 J from the FIT method, and 19.1 from the INT method. Nevertheless the time dependence differs also completely and the absolut value is 2 times higher than obtained in calorimetric measurements (9-10 J).

CONCLUSION

The comparison has shown that ANSYS gives results, close to the experimental data, whereas non commercial codes fail even for a simplified geometry of the laminated yoke. The real yoke assembly also consists of massive endplates, longitudinal (welded) brackets (with long holes). The attempts to solve such detail geometries by self-made codes is difficult also due to inadequate pre and post processing features as well as lacking interfaces for CAD models.

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