

LOSS CALCULATION OF INDUCTION MOTOR WITH RING WINDINGS BY “ANSYS MAXWELL”

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Abstract – The paper presents calculation methods for determining different loss type in electrical machine by “ANSYS Maxwell”. Authors give detailed instruction to the user for finding these parameters and describe the types of losses that are put into the program by the developers.

Keywords - calculation, loss, ANSYS, ANSYS Maxwell.

I. INTRODUCTION

The determination of losses in an electrical machine is one of the tasks that must be performed during the electromagnetic calculation. Standard induction motors are calculated by the method described in I. Kopylov’s book. [1].

Usually empirical formulas are used to calculate losses. For the analysis of an induction motor with ring windings (IMRW), this technique cannot be applied due to the design features [2]. For the electromagnetic calculations of nonclassical electrical machines “ANSYS Maxwell” program can be used, where it is possible to obtain numerical values of losses.

II. LOSSES TYPE IN “ANSYS MAXWELL”

First of all you need to understand how “ANSYS Maxwell” calculates losses, what mathematics was used by developers. The program presents several types of losses [3]:

1) Core Loss - loss in iron;

2) Solid Loss - electrical losses for conductors of the “Solid” type, i.e. losses in the array that are determined from the distribution of the calculated eddy current density.

3) Stranded Loss - this is ohmic loss in windings of the “Stranded” type, i.e. multi-turn coils, are determined by the formula:

$$P = \frac{1}{\sigma_V} \int J^2 dV, \quad (1)$$

where

σ – electrical conductivity;

J – current density;

V – volume.

4) Stranded LossR - the same losses as type 3, but for a three-phase machine, are determined as:

$$P = 3I^2 R, \quad (2)$$

where I – current,

R – phase resistance that is determined by user, not by program.

In turn, so called “Core Loss” includes three components:

1) eddy current losses:

$$p_c = k_c (f B_m)^2 \quad (3)$$

2) hysteresis losses:

$$p_h = k_h f B_m^2 \quad (4)$$

3) additional losses:

$$p_e = k_e (f B_m)^{1.5} \quad (5)$$

Thus, the loss in the iron:

$$P = p_c + p_h + p_e \quad (6)$$

In the formula 3 eddy current coefficient:

$$k_c = \pi^2 \sigma^2 \frac{d^2}{\delta} \quad (7)$$

Also in the formulas 3-5:

σ – electrical conductivity;

d – steel sheet thickness;

k_h - hysteresis coefficient;

k_e - additional loss factor;

B_m - maximum value of the magnetic induction;

f - frequency.

Then the developers of the program enter the following equations:

$$K_1 = k_h f + k_c f^2 \quad (8)$$

$$K_2 = k_e f^{1.5} \quad (9)$$

To obtain the values for K_1 and K_2 , the program minimizes the following polynomial:

$$\text{err}(K_1, K_2) = \sum_i [p_{vi} - (K_1 B_{mi}^2 + K_2 B_{mi}^{1.5})]^2 = \min \quad (10),$$

where p_{vi} и B_{mi} - the loss and magnetic induction values at the i -th point, taken from the loss curve, which must be specified by the user.

Then, we can determine the hysteresis coefficient and the coefficient of additional losses due to K_1 and K_2 :

$$k_h = \frac{K_1 - k_c f_0^2}{f_0}, \quad (11)$$

$$k_e = \frac{K_2}{f_0^{1.5}}, \quad (12)$$

where f_0 - frequency for specified loss curve.

III. CALCULATION RULES

The calculation model of the IMRW electromagnetic core is shown in Fig 1.

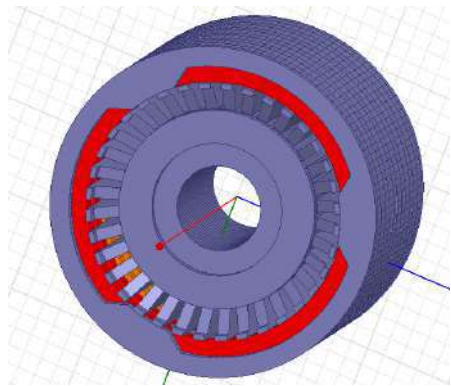


Fig. 1. Calculation model of IMRW

Let us consider the calculation of core loss. In order to make it, you have to set the material properties in the model. In our case, steel 2211 was used as the material of the cores, tips, stator yokes and the rotor body. The magnetization curve $B = f(H)$ was plotted (Fig. 3), as well as the specific loss curve in steel $p = f(B_{max})$ for the frequency $f = 50$ Hz and the thickness of the steel sheet $d = 0.5$ mm (Fig. 23).

Based on the given specific loss curve, the program calculates the K_h , K_c , K_e coefficients, as shown in Fig. 3. The IMRW core loss will be calculated by these coefficients. The graphs $B = f(H)$ and $p = f(B_{max})$ according to [4].

In the settings we have marked those bodies for which it is necessary to calculate the core loss (Fig. 2). It is should be mentioned that in the “Defined in Material” column the program automatically marks bodies from ferromagnet material, i.e. shows, in which bodies core loss cans be calculated.

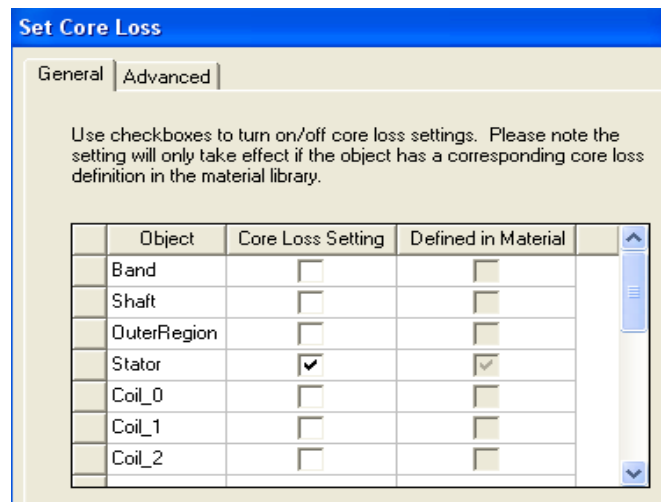


Fig. 2. Indicating the parts of the model that give the loss in steel

To calculate the losses in copper coils, i.e. “Stranded LossR“, it is necessary to set the resistance for direct current of the coils.

IMRW coils have $W = 40$ number of turns, they are wound from a circular wire with a diameter $d = 1.13$ mm. Then the resistance of the coil cans be determined as:

$$R = \rho \frac{L}{S} = \rho \frac{IW}{\frac{\pi d^2}{4}} = 0.0175 \frac{19.415}{0.67} = 0.6 \text{ Ohm} ,$$

where L – coil wire length,
 S – wire cross section.

The phase has 2 coils, so phase resistance is $R_{ph}=1.2$ Ohm.

The result of calculating the losses in steel is shown in Fig. 4, the numerical value of the loss is $P = 50$ W.

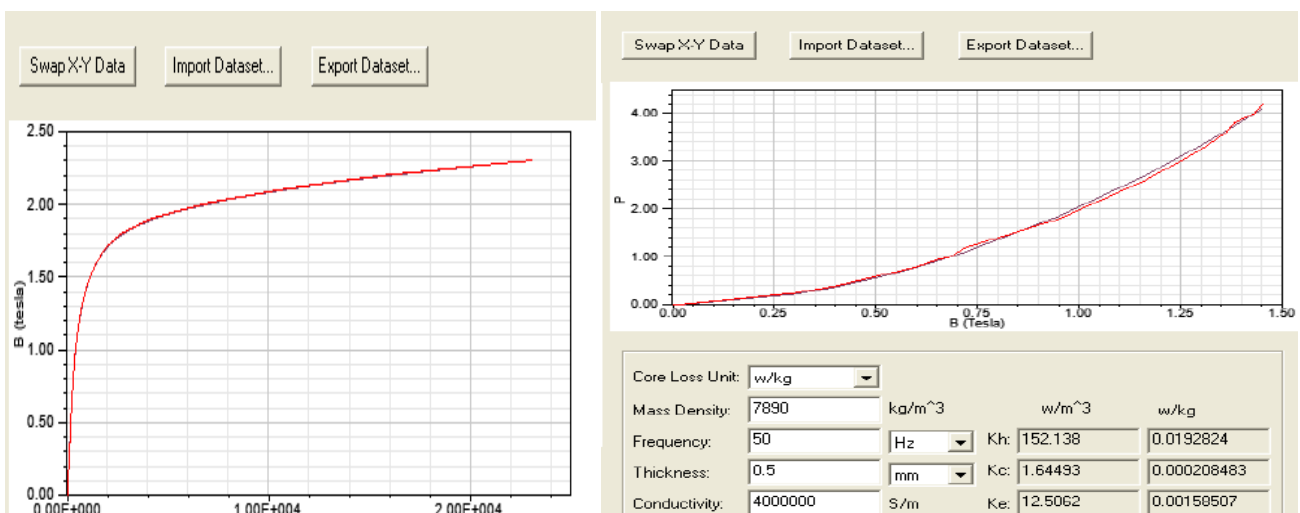


Fig. 3. Magnetization curve and specific loss curve for steel 2211

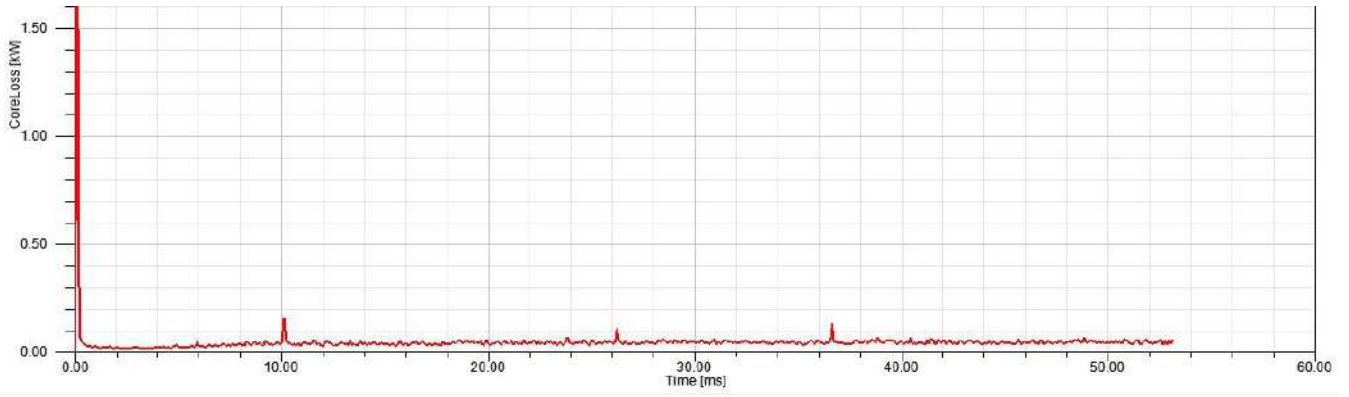


Fig. 4. Calculation of core loss in IMRW

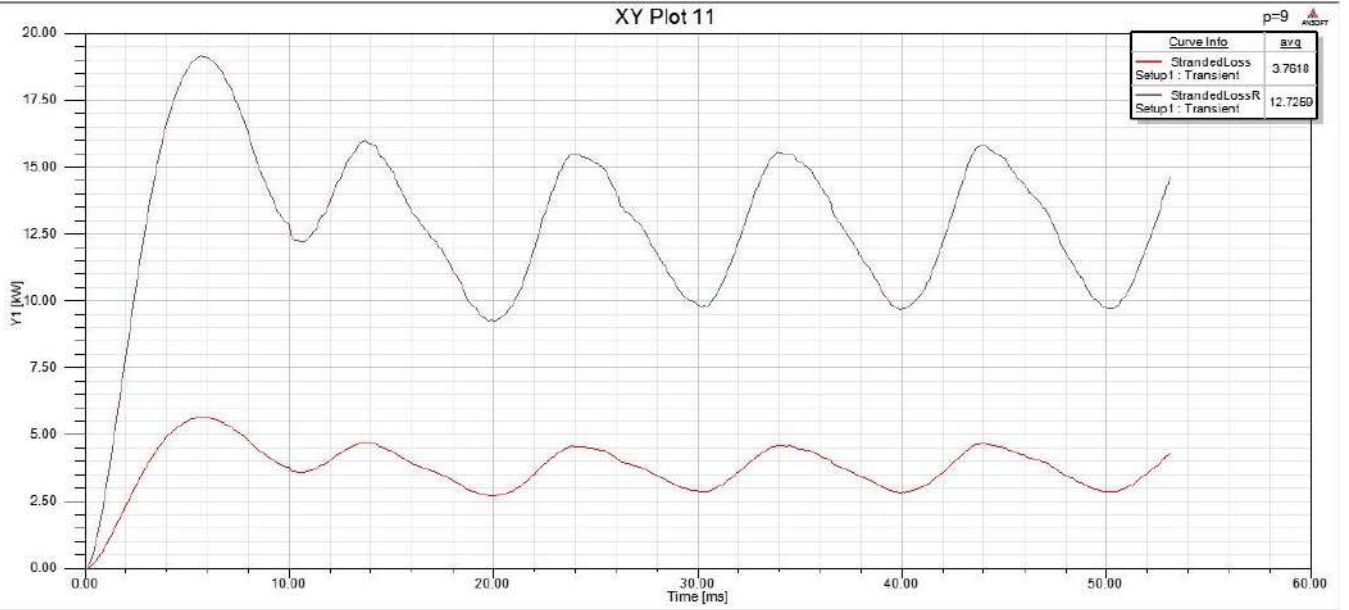


Fig. 5. Copper losses in stator windings

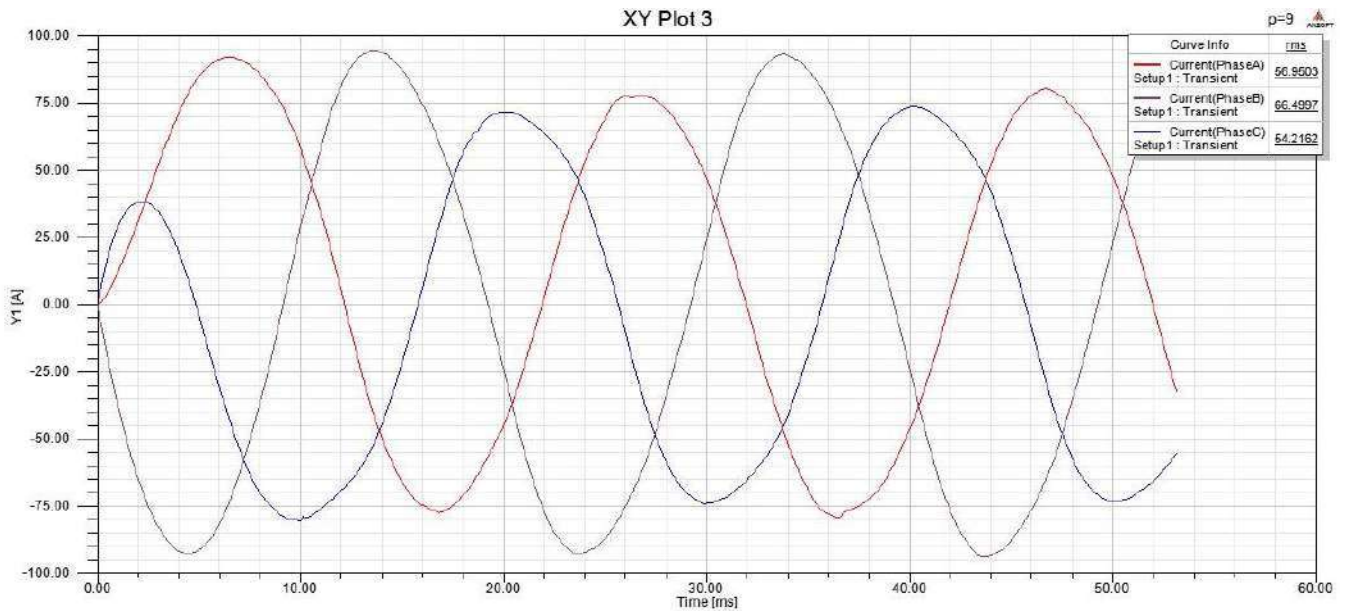


Fig. 6. Phase currents of the stator winding

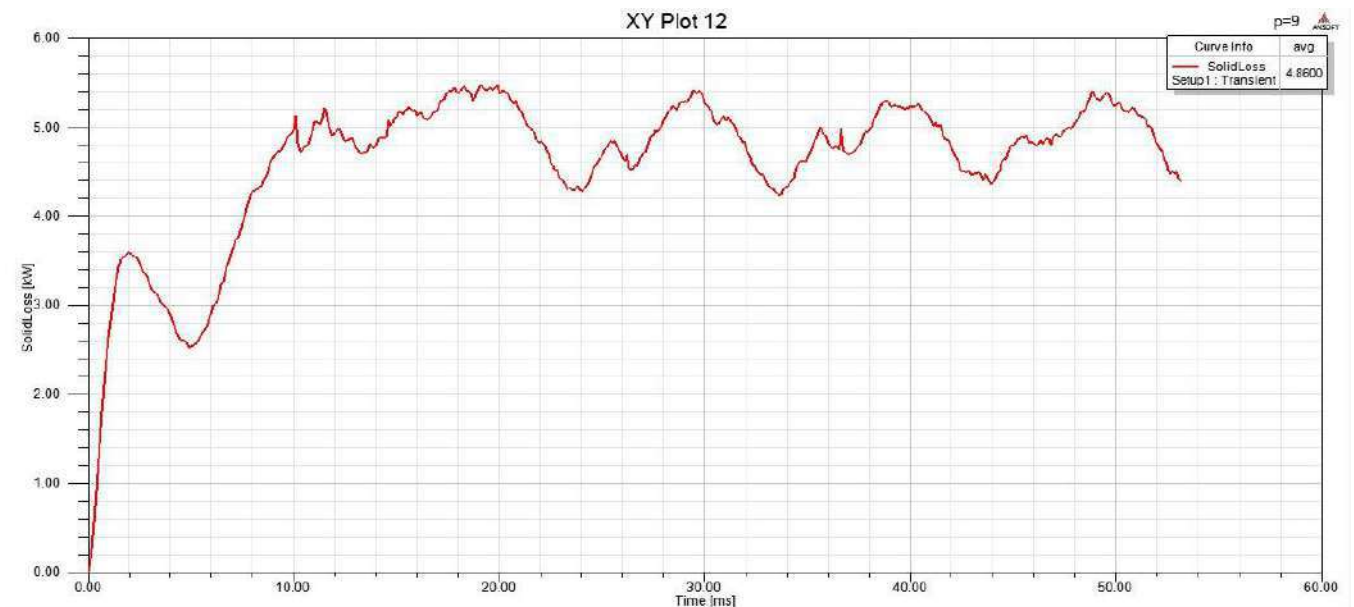


Fig. 7. Determination of eddy current losses

The graphs of the phase currents are shown in Fig. 6. According to Fig. 6, the average value of the phase current in the stator windings is $I = 60$ A. According to (2) copper losses are:

$$P = 3 \cdot 59^2 \cdot 1.2 = 12.5 \text{ kW} \quad (13)$$

Due to Fig.5 you can see that copper loss is $P = 12.7$ kW, this value corresponds to the value obtained by the formula (2) in the expression (13). The values of the SolidLoss, i.e. losses because of eddy currents are $P = 5$ kW (Fig. 7).

IV. CONCLUSION

"ANSYS Maxwell" program allows you to calculate the core loss and copper loss. Determination of losses in steel is based on the coefficients, which are calculated on the basis of specific loss graphs. To correctly calculate the core loss, it is necessary to know the specific losses for a particular steel type and for a certain sheet thickness. Copper losses are calculated by the classical formula (2).

Difficulties in the calculation are associated, first of all, with the correctness of determining the properties of materials, because curves for each type of steel are determined experimentally and, unfortunately, are not available for all types of steels.

In general, the loss calculation in "ANSYS Maxwell" is based on the same empirical formulas as in I. Kopylov's method, but the program also takes into account the distribution of the eddy currents density, induction vectors and magnetic field strength.

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