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Computer-Aided Design of a Direct Current Electromagnet

The paper presents the mathematical model and the simulation of a direct current electromagnet used for the transport of the steel ingots. For the simulation of any device one must dispose of a mathematical model, able to describe as accurately as possible the phenomena that take place. As the processes occurred in the case of an electromagnet are of an electromagnetic nature, one used the model of the electromagnetic potentials, and the simulation was performed with the help of the specialised software ANSYS.

Keywords: *electromagnet, modelling, simulation*

1. The mathematical model of the process

Generally, for a certain moment t and a random point P , [1] the main equation of the model has the form (1):

$$\mu\sigma \frac{\partial \bar{A}}{\partial t} + \text{rot} (\text{rot} \bar{A}) = \mu \bar{J}_a \quad (1)$$

where:

μ, σ are the magnetic permeability and the electric conductivity, respectively, of the environment where the point P is located, called material properties;

\bar{A} is the magnetic potential vector;

\bar{J}_a is the density of the adduction current, also called excitation current.

Admitting as known the dimensions μ, σ, \bar{J}_a , the only unknown term in equation (1) is the vector dimension \bar{A} , which, in general, is a function both of time and of space of the form (2):

$$\bar{A} = \bar{A}(t, P) \quad (2)$$

The solving of equation (1) consists precisely in determining the vector

function $\bar{A}(t,P)$. As the exact, analytical solving is possible only in some particular cases, in the paper one used an approximate, numerical method, i.e. the method of finite elements.[3]

2. The stages of application of the finite elements

Any computer-aided design software involves passing through three stages: pre-processing, processing (solving) and post-processing.

With small differences from one software to the other, in each of the three stages one has to take the steps presented below.

2.1. The Pre-Processing Stage

The design of the electromagnet is done by imposing certain initial data:

- Power supply voltage: $U=220V$;
- Force in the entrefer: $F=28 \times 10^3 \text{ daN}$;
- The entrefer / air gap $\delta=1,57\text{mm}$;
- Temperature increase compared to that of the ambient environment : $\theta=70^\circ\text{C}$.
- Relative action time: $q=2$.

First of all one established the geometry of the electromagnet, which is mainly made of two parts: the magnetic circuit and the exception coil. [2]

The geometric model of the electromagnet is drawn with specialised drawing software and in the simulation software, fig.1.

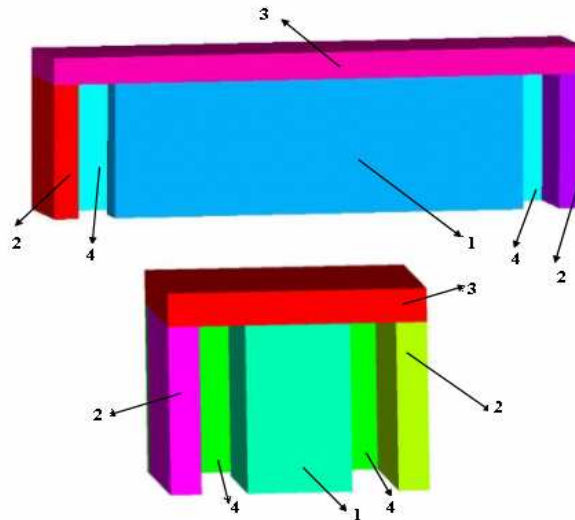


Figure 1. The geometric model of the electromagnet

The constitutive parts of the electromagnet are:

- 1 – pole, with the length LP and width BP.
- 2 – columns, with the length LC and width BC; we choose BC=LC.
- 3 – yoke, with the thickness (height) h_y.
- 4 – window, with the length LF, width BF and height HF.

For the choice of material constants, one considered that the core and the armature are made of steel, and the relative magnetic permeability μ_r is calculated based on the fundamental magnetisation curve, which was delimited through points and for the type of steel used; it has the shape in fig.7.

As the coil is made of aluminium, one introduced the values: $\mu_r=1$, electric resistivity $\rho=3,57 \times 10^{-8}$.

For the air one introduced only the value $\mu_r=1$.

Then one chose finite elements of a tetrahedral shape and one obtained the model with finite elements. The accuracy of the results increases as the number of finite elements increases, but this will also prolong the working time.

Taking into account the performances of the computer used, one realised a network of finite elements with medium density, made of 90538 finite elements and 17015 knots.

2.2. The Processing Stage

In order to impose the frontier conditions, the geometrical model also contains a layer of air, disposed around the geometrical model shown in fig.1, as presented in fig.2.

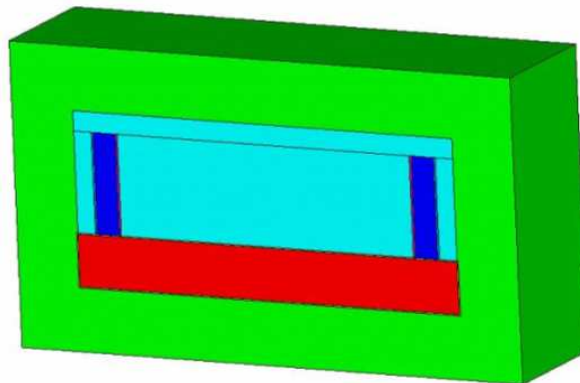


Figure 2. Geometrical model delimited by air space

The network of finite elements for the coils is presented fig.3, from which one remarks that the density of finite elements is higher in the coil curves, where the direction of the current density is permanently modified.

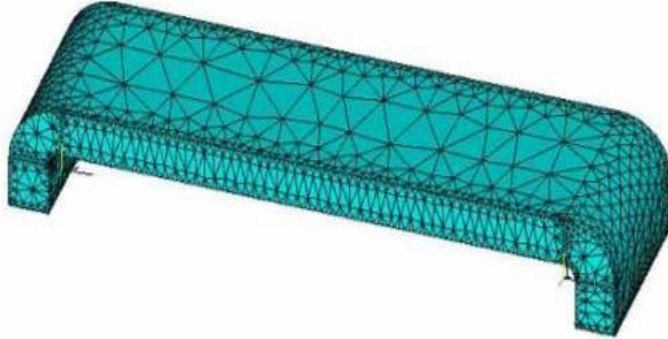


Figure 3. Digitised model

2.3. The Post-Processing Stage

The results of the simulation consist in the spatial distributions of the dimensions describing the electromagnet operation. Among these, one remarks as very important the distribution of the magnetic induction, as on its basis one can verify if the spectrum of the magnetic field has the theoretical shape and one can obtain the position of the operation point on the fundamental magnetisation curve, which is an indication of the magnetic strains to which the electromagnets is subjected.

For a longitudinal section the distribution of the magnetic induction, under the shape of coloured outlines, is presented in fig.4.

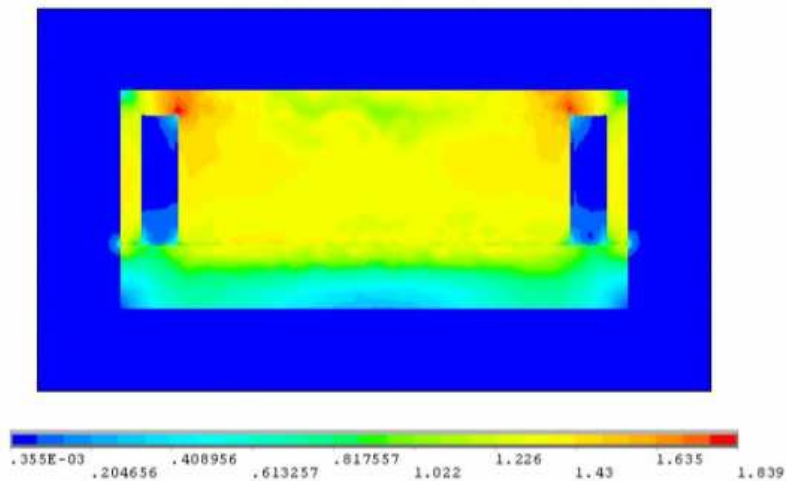


Figure 4. Distribution of the magnetic induction

In the areas of passage from a pole to the yoke a brisk change is produced of the direction of the magnetic field lines, which enable the magnetic induction to reach relatively high values.

This results from the fig.4, where the respective areas are coloured in red, to which a value of approximately 1.8T corresponds. This value of the magnetic induction makes the respective areas be saturated, but, considering that the volume of such zones is much smaller than that of the magnetic circuit, their contribution to the magnetic field strain is negligible. For this reason, the following section will ignore the zone of passage between the portions of the magnetic circuit.

From fig.4. it also results that the majority of the core is coloured in yellow, and to this colour a magnetic induction of around 1.4 corresponds.

One determined the variation of the values of magnetic induction along a straight line contained in the median longitudinal plane, situated on the upper surface of the armature. Considering only the portion of this straight line contained in the pole, the result obtained is presented in fig.5.

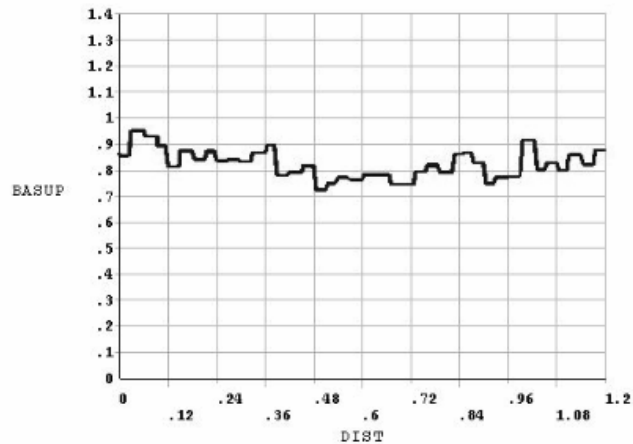


Figure 5. Variation of the values of magnetic induction along a straight line contained in the median longitudinal plane, situated on the upper surface of the armature

3. Conclusion

In the areas of passage from a pole to the yoke a brisk change of the directions of the magnetic field lines takes place, which enables the magnetic induction to reach relatively high values. This results from fig.4, where the respective areas are coloured in red, to which corresponds a value of approximately 1.8T.

This value of the magnetic induction makes the respective areas be saturated, but, considering that the volume of such areas is much smaller than that of the magnetic circuit, their contribution of the magnetic circuit strain is negligible.

The method presented in the paper can be used by all those who have as domain of activity engineering applications of physical processes.

References

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