ASPECTS REGARDING THE LOSSES IN THE MAGNETIC CIRCUIT OF ELECTRICAL TRANSFORMERS

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ABSTRACT: *The paper was motivated by the importance of electrical transformers in electrical installations for the production, transport and distribution of electric power. Starting from this consideration, the author wanted to present some aspects regarding the losses in the magnetic circuit of the transformers and the magnitudes that characterize and influence these losses.*

KEY-WORDS: electrical transformer, magnetic losses, magnetic circuit, magnetic permeability, magnetic induction

1. INTRODUCTION

In order to acquire an overview of magnetic circuits, an analysis of the magnitudes that characterize and influence them can be created, starting with magnetic permeability. It is known that the magnetic permeability of the magnetic materials is variable and depends on the intensity of the magnetic field.

The dependence between magnetic permeability and magnetic field strength is shown in Figure 1[1-2].

As can be seen from Figure 1, for the representation of dependence μ=f(H), it started from the initial magnetic permeability(μ_{in}) specific to relatively weak magnetic fields whose intensity tends to zero, it has continued with the maximum magnetic permeability(μ_m) specific to the maximum intensity of the magnetic field and was completed by the downward representation of the magnetic permeability up to the saturation value (μ_{sat}) [1-2].

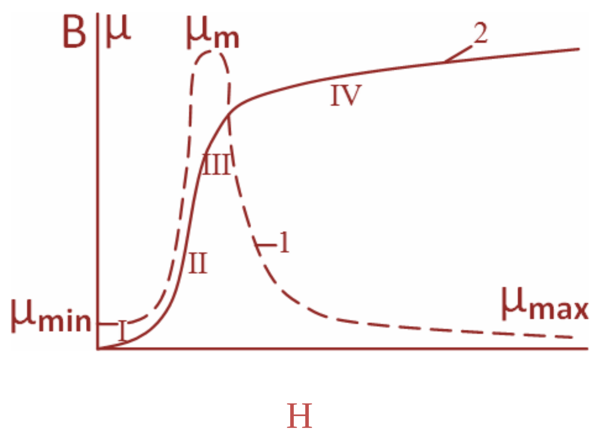

Figure 1. Dependencies μ=f(H)- curve 1 și B=f(H)-curve 2 for magnetic materials

Magnetic permeability(μ) can be expressed in terms of relative magnetic permeability(μ_r) of a material given by the absolute magnetic permeability of the vacuum(μ_0) according to [1-2]:

$$\mu = \mu_r \cdot \mu_0 \quad (1)$$

$$\mu_r = \frac{\mu}{\mu_0}$$

in which: μ_0 – magnetic constant of the vacuum($\mu_0 = 4\pi \cdot 10^{-7}$ H/m)

To study the magnetic field in practice, the dependence between magnetic induction and magnetic field intensity is used, and is also known as the magnetization curve. This dependence is represented in Figure 1 by curve 2, which highlights the initial magnetization curve B=f(H) [1-2].

The alley of this variation curve is obtained when the material is fully demagnetized and the magnetic field gradually amplifies. The magnetization curve 2 of Figure 1, successively highlights four areas, with the following meanings[1-2]:

- zone I -characterized by the fact that magnetic induction(B) increases relatively slowly;
- zone II- characterized in that the magnetic induction (B) increases almost instantaneously;
- zone III- characterized by the fact that magnetic induction(B) increases slowly, resulting in a large curvature;
- zone IV- characterized by the fact that magnetic induction (B) grows very slowly, due to the fact that magnetic saturation has occurred, which means that the magnetic moments of all domains are already oriented.

For the study of magnetic materials, apart from absolute magnetic permeability (μ) and relative permeability(μ_r), other magnetic permeabilities may also be used:

- dynamic magnetic permeability,
- magnetic impulse permeability,
- complex magnetic permeability,
- differential magnetic permeability.

Of these, the most commonly used is the relative differential permeability expressed by the relationship:

$$\mu_{rd} = \frac{1}{\mu_0} \cdot \frac{dB}{dH}$$

2. Study on the influence of the electrotechnical steel characteristics on the losses in the core of the transformers

It is well-known that the market economy, among other desideratums, also aims at streamlining the technological flows. This goal is to support energy audits, which primarily identify the optimal solutions to reduce losses. Starting from this goal, the aim of the paper is to identify the possibilities of reducing the losses in relatively small power transformers. Starting from the premise that the electric transformer is a major impact equipment in the operation of the electrical installations, it can be said that any possibility of reducing the losses represents an increase in their efficiency.Taking into account this aspect, the paper focused on the losses occurring in the magnetic circuit of electric transformers.

One of the measures to reduce the losses in the magnetic circuit of the transformers is to reduce the losses due to the eddy currents. The special measures to reduce the losses generated by the eddy currents are to increase the resistivity of the magnetic materials and to interrupt the eddy current circuits through the insulation.

Similarly to dielectrics, it can be said that losses through magnetic hysteresis in the magnetic circuit of the transformers are due to internal friction. They are emphasized on the uninterrupted orientation of the domains, at the same time as changing the direction of the field. Losses by magnetic hysteresis are proportional to[1-2]:

- the surface of the hysteresis cycle,
- frequency,
- square of magnetic induction.

A measure of loss reduction by magnetic hysteresis can be concretized from the design phase of electric machines by the selection of materials with a small hysteresis cycle.

Losses due to swirling currents are essentially loss Joule effects, losses occurring when the eddy currents pass through the magnetic material, or through the magnetic core, to the electrical transformers. The value of these losses is directly proportional to the square of the frequency and the induction and inversely proportional to the resistivity.

The reduction of these losses, in the case of the frequencies of the thousands of hertzes, can be concretized through the realization of the magnetic circuits from the isolated channels between them. At higher frequencies, the materials that are used which are composed of separate parts of the magnetic material insulated from one another or from high resistivity magnetic material. The measures to reduce the losses due to the swirling currents aim at reducing the magnetic permeability of the magnetic circuit of an electric transformer[1-2].

In the case where the magnetic circuit is made of isolated plates, the reduction of the magnetic permeability is made according to a filling coefficient $k_{\mathbf{u}}$=0,90÷0,96. This coefficient represents the ratio between the volume of magnetic material and the total volume of the magnetic circuit, including insulation and incomplete contact of the transformer wires[1-2].

The electrotechnical steel is used to achieve the magnetic core tolerances in the transformer configuration. Silicon electrotechnical steel is a silicon iron alloy in which the percentage of silicon varies within the range 0,5÷5%. The purpose of iron alloy with silicon is to increase resistivity, the phenomenon that leads to:

- reducing coercive force and thereby loss of magnetic hysteresis;
- reducing the losses due to swirling currents;
- reducing magnetic induction to saturation.

The effect of reducing the magnetic induction to saturation is not an advantage, but cumulatively the other effects that are favorable justify the process of alloying the iron with silicon.

Based on the statistical data, it can be said that the silicon electrotechnical steel occupies the first place as an application, of all the magnetic materials used in the construction of electrical machines[1-2].

This alloy is mainly used for industrial frequencies below 500 Hz, and in some cases (assuming a constant magnetic field) for frequencies greater than 10,000 Hz. Silicon-grade electrotechnical steel is produced by manufacturing plants, exclusively in the form of laminated sheets of standardized size or rolled-up ribbon.

Typically, for the construction of electric machines, steel wires of the thickness 0,25÷1 mm are used, and in special cases the thickness of the tiles can be much smaller reaching up to 0,1 mm[1-5].

In order not to change the properties of electrotechnical steel sheets sensitively, the manufacturing plants use cold rolling. By this process of rolling steel sheets, the quality of the sheets is greatly increased by uniformity of thicknesses, reduction of surface roughness, etc. The essential change generated by this lamination process is the acquisition of the texture. This is realized by the fact that the crystals are oriented in the rolling direction, as a result of which the steel sheet acquires magnetic anisotropy. The so-textured steel sheet has increased magnetic permeability and reduced coercive loss and force when the magnetic field is in the rolling direction. Otherwise, the steel sheet will have a low magnetic permeability, increased loss and high coercive force if the magnetic field has a perpendicular direction to the rolling direction.

The percentage of silicon entering the iron alloy compound greatly influences the magnetic and mechanical properties of the steel tiles.

Simultaneously with increasing the percentage of silicon, the effects (reduction of losses, etc.) listed above due to alloying are also amplified.

Starting from the silicon content and taking into account the qualities that correspond to them, electrotechnical steel trolleys can be divided into[1-5]:

- weak alloys for which the silicon content is less than 1,8% ,
- medium alloyed grades for which the silicon content is less than 2,8% ,
- alloyed grades for which the silicon content is less than 3,8% ,
- high alloyed tungsten for which the silicon content is higher than 3,8%.

Low-grade silicon steels are soft and suitable for small-sized and complicated details. Magnetic circuits of DC and AC electric motors and low-power transformers are made from similar components.

Steel with a low silicon content is also called the dynamo plate or DC generator.

The steels with a high silicon content have a relatively high hardness and are suitable for large components and simple shapes. The components of this type are used for the construction of the magnetic circuits of the transformers and are also called the transformer plate. Also cold rolled steel sheet can be called transformer plate because it is mainly used in the construction of electric transformers. Referring to the chemical composition of the steels, it should be noted that the transformer plate, contains silicon in a percentage of less than 3%[1-5].

The use of silicon electrotechnical steels necessarily implies the determination of the losses due to eddy currents and the hysteresis phenomenon. For a portion of a magnetic circuit made of electrotechnical steel wires, the total iron losses(P_{Fe}), is calculated using the relationship [1-5]:

$$P_{Fe} = k_d \cdot p_{Fe} \cdot M_{Fe} \quad [W]$$

where:

M_{Fe}–mass of the steel portion[kg];

k_d–experimental coefficient, which takes into account the increase in losses due to mechanical machining (cutting, stamping, etc.) of steel tiles (k_d=1,7÷4);

p_{Fe}–specific losses [W/kg].

Mechanical operations cause mechanical stress due to the increase in additional losses. These losses can be reduced by thermal processing (heating) after mechanical machining.

Specific losses are the losses per kilogram at the corresponding induction and frequency. Specific losses are determined by laboratory studies at a frequency of 50 Hz and an induction of 1T and it is noted with p_1 [W/kg].

It is obvious that for some modes the frequency shifts are insignificant, while for other modes the frequency changes are significant[7].

For calculating losses and induction, the following relationship is used:

$$p_{Fe}=\left(\frac{f}{50}\right)^{\alpha} \cdot B^2 \cdot p_1 \left[\frac{W}{kg}\right]$$

where:

α=1÷2. Most often it is admitted α=1,3.

From the relationship (5) we can see that a major influence on the magnetic core losses is the magnetic induction of the magnetic material, namely the tola from which it is made. Considering this, it can be said that in order to reduce the losses in the magnetic core of the transformers it is necessary that the tolerances from which the magnetic core of the transformers is made should have a magnetic induction of relatively low value.

4. CONCLUSIONS

1. Based on statistical data, silicon electrotechnical steel can be said to be the first application of all of the magnetic

materials used in the construction of electric cars.
2. The special measures to reduce the losses generated by the eddy currents are to increase the resistivity of the magnetic materials and to interrupt the eddy current circuits through the insulation.
3. With reference to the chemical composition of steels, it should be noted that the transformer plate, contains silicon at a lower percentage of 3%.
4. In order to reduce losses in the magnetic core of the transformers, it is necessary to use relatively low magnetic induction.

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