MAGNETIC CORE SATURATION

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Abstract

Electrical machines or electrical equipment made of magnetic core materials (soft iron, steel) often undergo erratic behaviors during operation due to the saturation of the core as a result of the nonlinearity of circuit parameters of the core. The inrush current of slightly loaded or an unloaded transformer causes saturation of the core during energisation of which the stating current can rise ten times the rating current and even the connection of three phase induction motor in star-delta helps to reduces its starting current to avoid saturation of the lamination core. Core saturation when not controlled can generate heat with high order of harmonics which can lead to lamination breakdown, losses and reducing the life span and the efficiency of the machines. This paper presents the effect of magnetic domains alignment, core inductive reactance, material and core dimensions, current, voltage and frequency of the power supply on the saturation of the magnetic core. It also suggests the possible methods of limiting the saturation of magnetic core

Keywords: Magnetic core materials, saturation, harmonics, magnetic domains, current

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Introduction

Electrical machines particularly transformers and motors often generate heat and losses when connected to power system in operating condition [1]. It is not possible to discover magnetic core saturation with Multimeter. The technician can test the insulation of the coil and the winding which he may finally conclude that the heating is as a result of short circuit or lamination breakdown. The motor may even be disconnected from the supply, remove the winding and replaced with the new ones yet the problem persist and after few hours of running, the motor breakdown again. You may discover that there is no problem in both main and control circuits. Many other electrical appliances made of magnetic core materials like transformers, electric motors, electromagnets, relays and solenoids got heated, vibrated and produced magnetic noise, and yet there is no solution to the problems. The technician may not have knowledge on core saturation and how much more of diagnosing what he has no knowledge about [2]. Lack of measuring device for diagnostic procedure make the situation more difficult that one cannot discover fault caused by core saturation. The knowledge of its theoretical background and the effect of the related terms are therefore necessary before thinking about the possible means of reducing magnetic saturation. Cores of different materials have different saturation levels and different permeabilities is investigated and simulated by Matlab.

Alignments of magnetic domains

Current carrying conductors have magnetic fields around them and the effect of the fields reduce as one move far away from the conductors. A magnetic core consists of tiny magnets or the domains inside the core align themselves in random directions and cancel each other but with the application of the external applied field, the domains align themselves in parallel to the initial fields created by current carrying conductors. The new field created is the sum of the field of current carrying conductors and that created by the tiny magnets or domains which now become stronger and penetrate through the magnetic core. As the external field applied begins to increase, the intensity of the flux or the flux density increases and all the domains will align parallel to the fields, and any further increment in the field gives no corresponding increase in the flux density and the current at this time is at the highest value. The core is said to be saturated at this point [3].

Inductive reactance of the core

As the core reaches a saturation point, there is decrease in inductive reactance of the core to zero inductive reactance. The only impedance is the low winding resistance and the impedance from the power source. The current from the power system begins to flow in the winding as there is no impedance to oppose it. The current is higher than the rated current of the machine and as a result heat is generated both in the core and within the winding and no other magnetic power can result. In this condition the core is said to be saturated and there will be no more magnetic domains for further alignment. As the core saturates in transformer, the inductance reduces depending on the degree of saturation. The magnetizing current increases causing copper loss.

Magnetic component and semiconductor components like transistors, diodes, capacitors can be damaged as a result of the heat generated during the saturation of the core.

Material and core dimensions

The saturation level of any core depends on the material and core dimensions or its design. The ferromagnetic material cannot go beyond the level of saturation and after saturation of the core, and any further increase in magnetic field force (mmf) does not result in the corresponding increase in magnetic field flux.

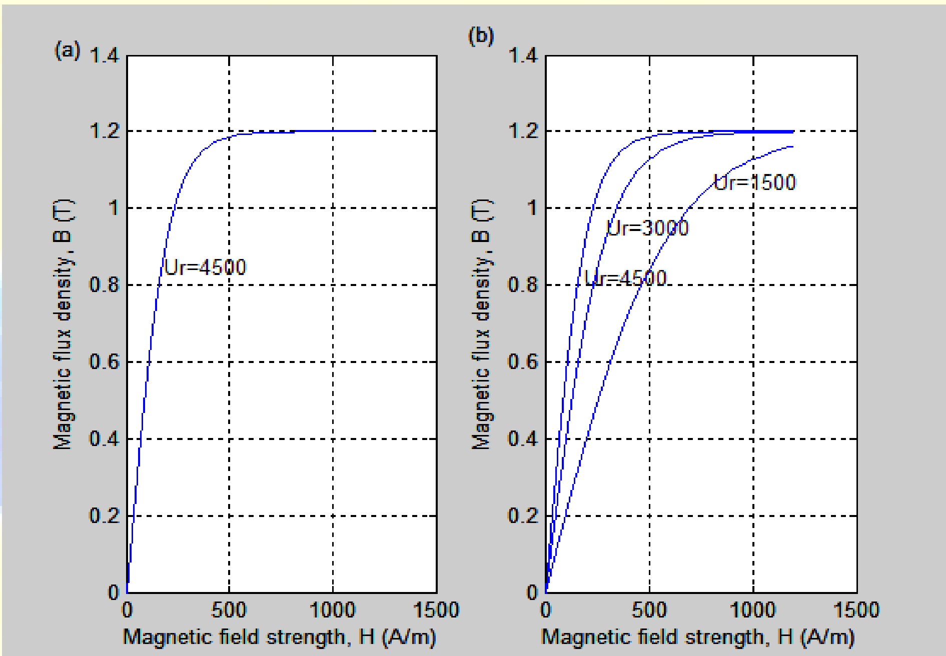

Fig. 1: BH curve

The saturation of magnetic core of any electrical machine depends upon the relation between the magnetic flux to the magnetizing force known as the magnetic permeability (Ur) of that core. Three different ferromagnetic materials are simulated through Matlab and the result is the BH characteristic curve shown in Figure 1. Figure 1(a) shows the result of characteristic curve obtained when the permeability of the first core is B=4500. The second and third cores are simulated and the results of the three cores are shown separately in Figure 1(b). The first core begins to saturate at B=0.6T and saturates completely at B=1.2T. The steeper the curve the higher is the permeability. Iron core used in transformer saturates at 1.6-2.2T, while ferrites saturate at 0.2-0.5T and some of the amorphous alloys saturate at 1.2-1.3T. The higher the permeability, the higher the flux density and the faster the saturation of magnetic core material from a given magnetization force [4].

The magnetic hysteresis loop in Figure 2 shows the characteristics of the ferromagnetic core graphically of the nonlinearity between the magnetic flux and the magnetizing force. After saturation, some of the tiny magnets do not align themselves randomly but align in original magnetizing field and as a result the magnetic flux do not completely disappear from the core after saturation because the magnetic core retains its some of its magnetism even if the current has stopped flowing through the coil. This ability of the core to retain its magnetism after magnetization has stopped is known as retentivity or remanence and the amount of flux present in the core is called residual magnetism.

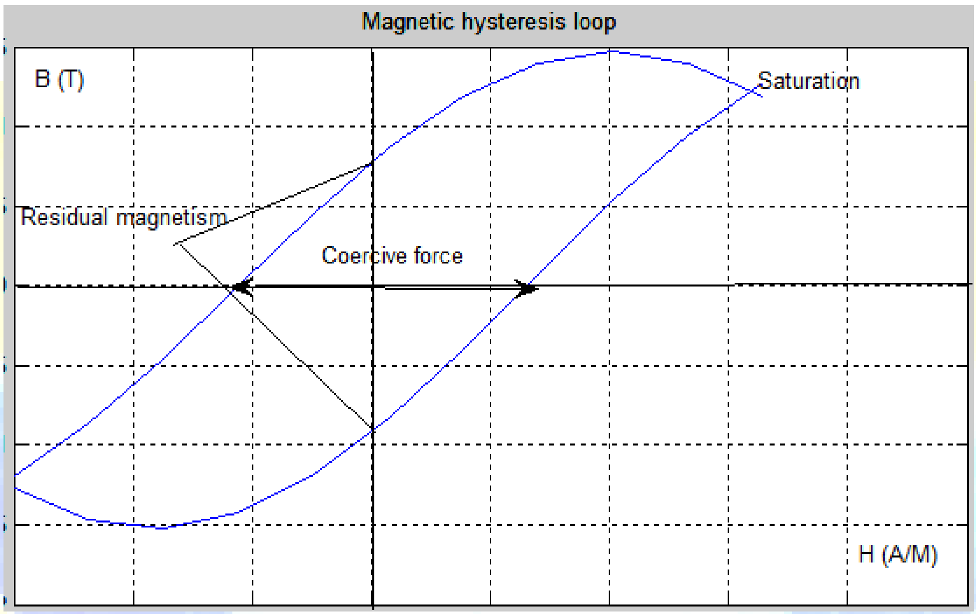

Fig. 2: Magnetic hysteresis loop

Some ferromagnetic materials have high retentivity (magnetically hard) with large hysteresis loop and this makes them to be suitable for producing permanent magnets while others with low retentivity (magnetically soft) with narrow magnetic hysteresis loop (iron or silicon steel) and small amount of residual magnetism. These make them suitable for transformer, relays and solenoids. These ferromagnetic materials in [5] are easily magnetized and demagnetized and they are called soft magnetic materials. When the direction of current flowing through the coil is reversed, the residual magnetic flux is reduced to zero and the magnetic field strength, H known as Coercive force becomes negative. The core is magnetized in opposite direction and the continuous increase in magnetizing current will bring the core into saturation on the opposite side again

Current

The magnetization force in [6] is directly proportional to the current inside the core. The nonlinearity operations of transformers and inductors when high current passes through them to saturation point cause harmonic generation and intermodulation distortion. The maximum magnetic field is limited by core saturation to 2T in core transformers and electromagnets which is contributed to the power utility transformer to be so large. The applications of saturation can be found in saturable core transformer which limits current for arc welding and ferroresonant transformers for voltage regulation. The magnetization force is given as:

$$H = \frac{0.4\pi NI}{L}(Oersted)$$
(1)

Where N=Number of turns; I=Current in amperes and L=Magnetic path length in cm. One A/cm is equal to 0.7958 Oersted

Voltage and frequency of the supply

Electrical machines made of ferromagnetic materials should be powered by the supply voltage and frequency in accordance with the specifications of the manufacture. The variation in any of these two parameters can be accompanied by the saturation of the core materials and harmonic generation. The applied or output voltage (V) is directly proportional to the core flux density (B), the cross sectional area (A), in cm^2, number of turns (N) and the switching frequency (f), in Hertz. If the voltage is of sine wave, the voltage is given by:

$$V = \frac{4.44ABNf}{10^8}$$
(2)

The no-load loss or core loss of a transformer is the power consumed to sustain the magnetic field in transformer core and the loss is independent of the load connected to it. The skin effect within winding conductors can reduce the cross sectional area for electron flow, and thereby increasing the resistance as the frequency rises which lead to power loss through resistive dissipation. Transformer core loss increases with increasing frequency, so transformers are designed with size that will operate efficiently at certain range of frequencies. Operation of transformer under excessive frequency creates harmonics like that of nonlinear loads.

Methods of limiting core saturation

Introduction of air gap to the core will reduce hysteresis loss and will give the core more efficiency than the core without an air gap

Good design of the core in such that the magnetic field densities remain below the level which is achieved by making the relationship between magnetic field force and the magnetic flux more linear throughout the flux cycle as it makes magnetization current waveform to be less distorted. Magnetic core of low heat conduction and free from harmonic generation within reasonable, suitable and appropriate tolerance should be produced by the manufacturer

Material core should be made of low flux densities that give allowable limit between the normal flux peaks and the core saturation limits in order to withstand abnormal conditions such as variation of frequency and DC offset. Bent core or punched holes should be avoided to minimize iron loss

Losses due hysteresis can be minimized by using core material with narrow hysteresis loop. Thin laminations reduce core thickness thereby reducing eddy current loss. Core should not be allowed to be in longer operation than its life span due to thermal aging which can lead to inability of the core to withstand the stress of the operation condition.

Results and discussions

The nonlinearity of parameters (magnetic flux density, magnetic flux and current) of the core is investigated through Matlab simulation and the result shows that cores have different saturation points with different permeabilities.. In magnetic hysteresis loop, the flux density increases as the magnetic field increases until at saturation point when it becomes level and constant as the magnetic field strength continues to increase.

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