Magnetic characterisation of electrical transformer cores from 50 to 400 Hz

About the Company

Carroll & Meynell Transformers Ltd (C&M) originally started life in 1970 as an electrical contractor. Over time it developed into a supplier of electrical equipment and also a transformer manufacturer. At some stage the supply of electrical equipment was separated from Carroll & Meynell into a subsidiary company Teesside Industrial Controls Ltd (TIC) leaving Carroll & Meynell to concentrate on the transformer manufacturing business, both companies still being owned by Carroll and Meynell. In 2008 the business became Carroll & Meynell Transformers Ltd.

The product range of electrical transformers covers anything in size from about the size of your fist to transformers weighing in at about 5 Tonnes. This covers a power range from a few VA to nearly 1MVA, in both single phase and three phase items. Other wound gear such as chokes and inductors also complete C&M manufacturing portfolio. The main areas of trade are:

     i.   The Construction Industry
     ii.   Marine and Off-shore Applications
     iii.   Charging systems for uninterruptable power supplies
     iv.   Rail infrastructure, Signalling and other Power applications
     v.   Mining Industry
     vi.   Variable Power Supplies
     vii.   General Power Distribution Applications

Most of our products are custom designed to meet the specific needs of individual applications.

Background Information

As a company C&M predominantly deal with 50/60 Hz wound gear units, Transformers and Chokes. These items are generally designed at 50 Hz. In the event they are specified specifically for 60Hz then the operational flux of the core is reduced. For a 50 Hz transformer generally we operate at 1.4 Tesla for basic magnetic steel and 1.5 Tesla for higher grade low loss steels. For a 60 Hz transformer we would reduce the operating flux level to generate the same core losses as for a 50 Hz transformer. For a 50/60 Hz transformer we would design as a standard 50 Hz unit, when the unit is connected to a 60 Hz supply the losses per cycle decreases as the operating flux decreases, but the number of cycles increases pushing the total losses back up. The net effect of the 60 Hz operation on a 50 Hz transformer is to reduce the total losses in the core.

The Project Brief

In 2014 the EU introduces a set of legislation limiting the energy losses of transformers of specific rating. As such, in order to comply with this legislation transformer designers need to have far more data about the B-H loop behaviour of the various steels they work with, and in particular newer low loss grades not available until recently. Further in many cases the data for the steel was restricted to the most common operating design flux levels and also the 50/60 Hz frequencies but there is now a move to higher frequency usage.

Over the past few years C&M has been asked to quote for higher operating frequency units in the range up to 400 Hz. The data needed for the characteristics of various steels under these frequency conditions is not readily available.

Existing and new grades of electrical transformer steels with laminations from 0.3 mm, 0.23 mm and 0.1 mm in conventional magnetic Si-Iron 'transformer steel' and much thinner wound amorphous ferromagnetic alloy ribbon-based materials are used to make magnetic cores. Understanding the energy losses and the hysteresis behaviour (coercivity and permeability) in these materials at higher frequencies is key to this project.

The purpose of this project is to investigate the magnetic characteristics of the electrical steels used to build the magnetic core of transformer obtained by measuring the B-H hysteresis loops for up to 4 different types of magnetic core at frequencies from 50 Hz up to 400 Hz in 50 Hz steps with the addition of a 60 Hz test set. This specifically requires: core loss, permeability and coercivity at a range of peak flux densities at each frequency tested.
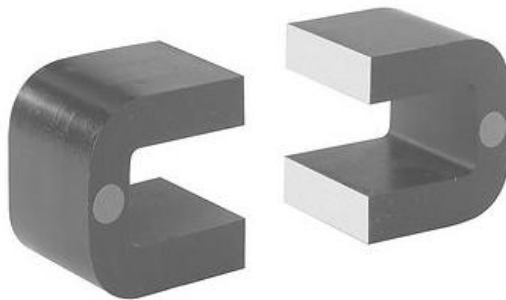
It should be noted that for most 50-60 Hz applications the core losses are considered to be just associated with the hysteresis loss, i.e. the area within the B-H loop. In fact, there are two components to the overall core losses the hysteresis loss and eddy current losses, at the lower frequencies the eddy current losses are small however these will start to increase at higher frequencies so you will have to separate them out for the project.

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Further Details

The fundamental equation linking the core to the applied electrical supply is

$$V = 4.44 \, B \, A \, N \, F$$

V is the system voltage
B the peak operating flux level of the core
A the cross sectional area of the core
N the number of turns of the coil around the core the voltage is applied to
F is the frequency of the supply

The B-H loop

If we wrap a coil around a magnetic core and pass a current of sinusoidal form through the coil we create a driving force that will magnetize the core. As the current increases in one direction the field level in the core will increase. As the current reduces the field also will reduce, then as the current starts to increase in the opposite sense the field will increase in the opposite sense to that on the first half of the cycle.

The driving force is denoted by the letter H and the field generated as B with the relationship between the two defined as

$$B = \mu H$$

Where μ is known as the permeability, this at first appears to be a simple linear equation whereby μ is a constant of proportionality. Unfortunately μ may not be a simple constant.

Before we introduce a magnetic material into the system let us just consider a coil of wire with a current flowing

The driving force H is given by

$$H = N \, I \, / \, L$$

Where N is the number of turns I the current and L the length of the coil.
This leads to

$$B = \mu H = \mu \, N \, I \, / \, L$$

With no magnetic material μ is designated μo this is known as the permeability of free space. One of the fundamental constants of the universe.

If we now introduce a magnetic material into the system then the value of μ will change. It is normal to divide μ into two components

$$\mu = \mu o \, \mu r$$

where μr is the relative permeability
thus

$$B = \mu o \, \mu r \, H$$

Again this at first appears to be a linear equation however while μo is a constant μr varies with the magnetized state of the magnetic material. It can also be defined in different ways for a material.
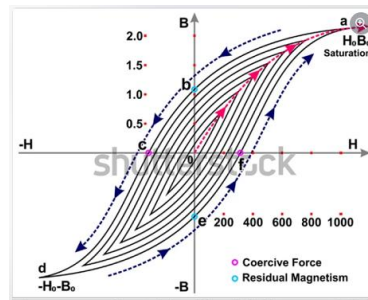
TYPICAL SET OF B-H LOOPS WITH A SERIES OF MINOR LOOPS GOING UP TO A FULL SATURATION LOOP

If we consider a specific transformer which has been built for 50Hz operation at a specific voltage V then from the

$$V = 4.44 \, B \, A \, N \, F$$

Then the transformer will have been designed with a core of a specific area and number of turns to meet an optimum maximum flux excursion

That appears to be a nonsense statement "Optimum" and "Maximum" together. For an optimum design i.e. the most cost effective we set the maximum flux excursion possible that will not overheat the core or require excessive driving current in the coil.

You will notice the B-H loops are not simple lines going from one maxima to the other they are in fact loops the area inside each loop represents the power losses that are dissipated in the form of heat into the core material. It is the control of this power loss that is the underlying reason for this project.

Taking our transformer operating at 50Hz on a Voltage V system and moving it to another system of voltage V but with a 60Hz frequency then given the other factor of the transformer have been fixed in its manufacture A and N, as F has increased by 20% the peak B will automatically decrease by 20%. This will result in roughly a 40% reduction in the losses of the B-H loop. Off-setting some of this loss is the fact that each of these loss cycles is occurring at a greater rate i.e. 20% more cycles so the net reduction in losses will be about 20% when moving a transformer from a 50Hz system to a 60Hz system.

The steel types
0.3mm thick GOSS   (Grain Oriented Silicon Steel)
0.1mm thick GOSS
Amorphous – Possibly available during project timescale

The cores have been wound as a standard HWR90/32 pair of "C" cores