



VEBKO ONLINE HELP

CT “Excitation Test”, Part 3

Category	tester
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1 Imported Content

Saturation phenomenon and non-linear behavior in transformer

As you know, inductor is a linear element but if its voltage exceeds a specific limit, the inductor is saturated and enters the non-linear area. What we mean by saturation of the inductor is the saturation of its core. In fact, when the voltage exceeds the threshold, the core loses its ability to pass more flux and so it is saturated and the inductor turns non-linear. But by drawing the saturation curve of a "CT", you can see that there is also a non-linear area in the lower voltages. Up to now we have said that in higher voltages the inductor becomes excited and turns non-linear. To explain non-linear area in a lower voltage, the parallel circuit of a "CT" is drawn. In this parallel circuit, the turns ratio of the "CT" which is a transformer is "1:N". "Rs" indicate the resistance of the "CT". In the parallel branch, " R_{eddy} " and " R_h " stand for Foucault and hysteresis losses of the coil and L stands for the magnetizing inductance of the "CT" secondary. To perform the excitation test, secondary of the "CT" is fed by voltage and check to see what non-linear element is causing the "CT" to show a non-linear behavior even in lower voltages.

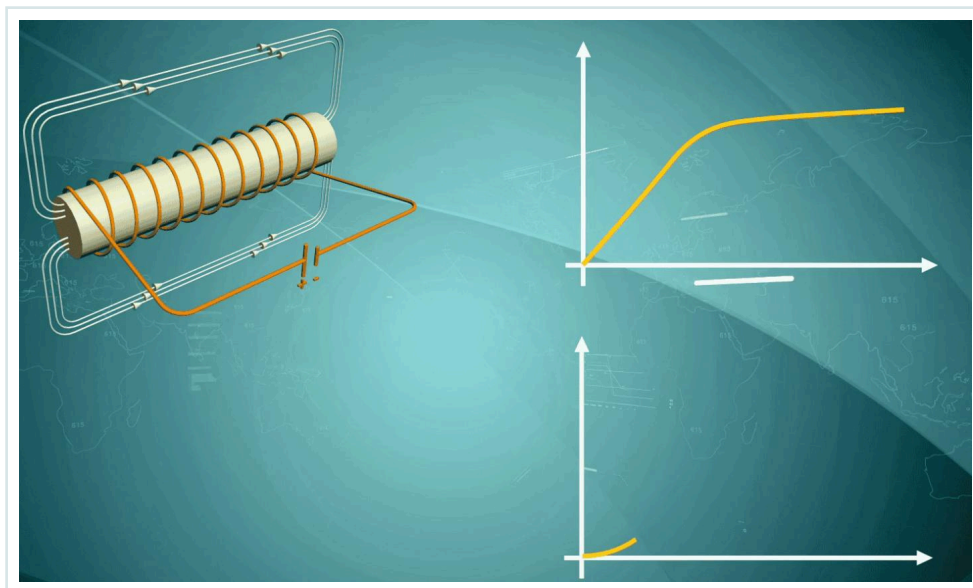


Figure 1

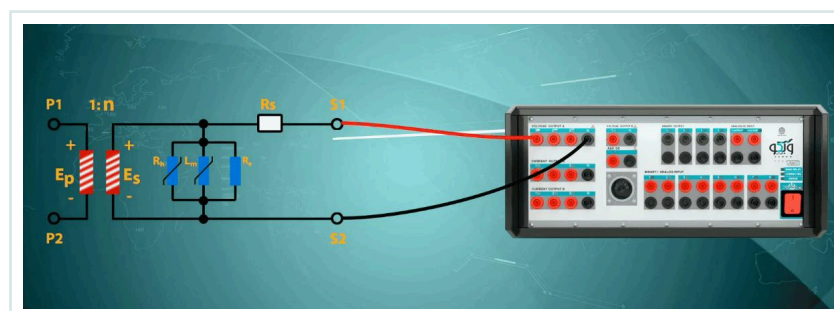


Figure 2

As mentioned before, the losses of core include Foucault and hysteresis. Therefore, to analyze the non-linear behavior of the transformer, we need to examine the Foucault and hysteresis losses. Foucault losses are caused by Eddy Current which occurs in the core segment because of time-varying flux in the core and voltage induction. Since the flux is directly dependent on the voltage, we can say that the Foucault losses are the result of a pure resistance. The relation of the Foucault losses is achieved through an empirical method and is as you can see:

$$P_c = P_f + P_h$$

$$\frac{d\phi}{dt} \Rightarrow \text{Eddy Current} \Rightarrow P_f = K_e (B * f)^2$$

Figure 3

In this relation, "B" is the flux density which equals "V/f". By substituting this relation, Foucault losses can be rewritten as $P_f = V^2/R_e$.

$$P_c = P_f + P_h$$

$$\frac{d\phi}{dt} \Rightarrow \text{Eddy Current} \Rightarrow P_f = K_e (B * f)^2$$

$$B = \frac{V}{f} \Rightarrow P_f = K_e \left(\frac{V}{f} * f \right)^2 \Rightarrow P_f = K_e (V)^2 \Rightarrow P_f = \frac{V^2}{R_e}$$

Figure 4

From this relation it can be deduced that the Foucault losses are caused by a fixed resistance that are not dependent on voltage and cannot be the reason for the non-linear behavior of the transformer in lower voltages. So, it is only possible that the hysteresis losses are the reason for the non-linear behavior in the "CT". Hysteresis losses occur in the core due to the residual magnetism. This means that passing of the magnetic flux through the metal core in a direction causes the core to be magnetized and turn into a weak magnet; so in the next half-cycle, a small amount of energy is lost to remove the magnetic effect of the previous half-cycle and this is being constantly repeated. The empirical relation of hysteresis is as you can see:

$$P_c = P_f + P_h$$

$$\frac{d\phi}{dt} \Rightarrow \text{Eddy Current} \Rightarrow P_f = K_e (B * f)^2$$

$$B = \frac{V}{f} \Rightarrow P_f = K_e \left(\frac{V}{f} * f \right)^2 \Rightarrow P_f = K_e (V)^2 \Rightarrow P_f = \frac{V^2}{R_e}$$

P_f : Linear P_h : None Linear

Figure 5

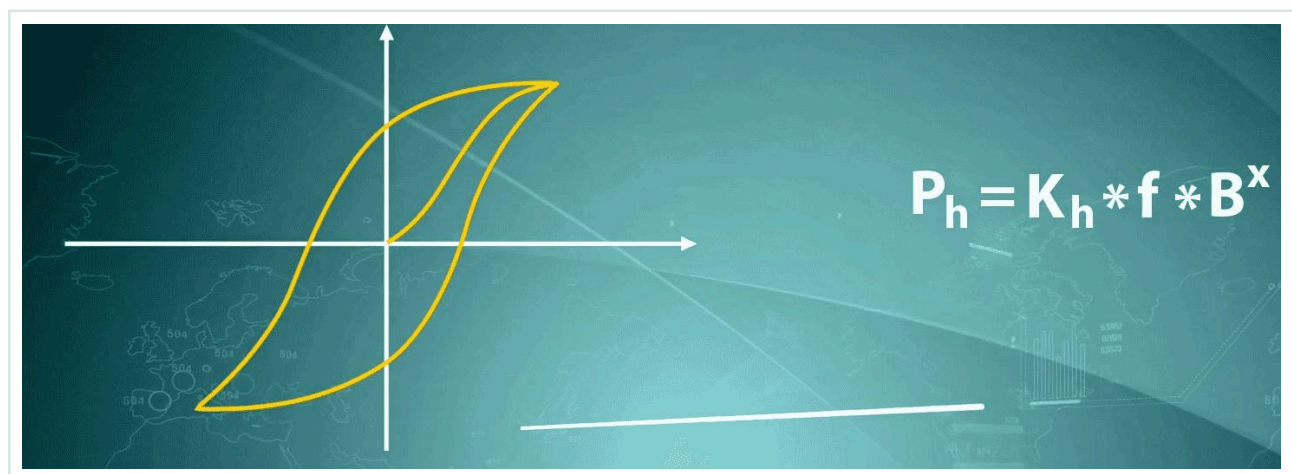


Figure 6

The value of "x" depends on the material of the core and can vary from 1.5 to 2.5. Also, in this relation, "B" is the flux density which equals "V/f" and by substituting it, the Hysteresis losses can be rewritten as you can see:

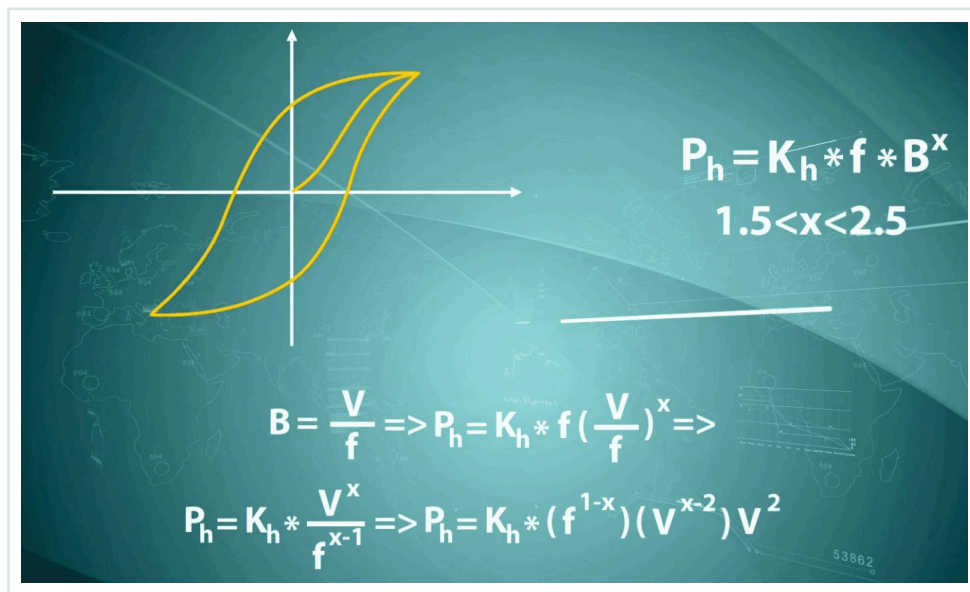


Figure 7

From the resulted relation, it is obvious that the hysteresis resistance is non-linear and dependent on the its voltage

$$B = \frac{V}{f} \Rightarrow P_h = K_h * f * \left(\frac{V}{f}\right)^x \Rightarrow$$

$$P_h = K_h * \frac{V^x}{f^{x-1}} \Rightarrow P_h = K_h * (f^{1-x}) * (V^{x-2}) * V^2$$

Figure 8

The effect of this resistance in the total equivalent resistance of the "CT" in the lower voltages is significant. But from a specific voltage upwards, the effect of this resistance decreases and causes the "CT" current and voltage relation to approach linearity. This causes the relation between voltage and current to be non-linear in a specific range in the lower voltages.

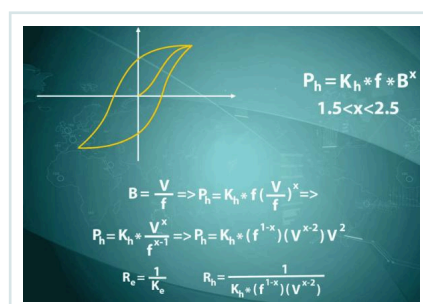


Figure 9

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