Homework 2 – Permanent Magnets, AC Excitation and Transformers

This homework is to be solved on paper and to be submitted to the "Homework Box" in front of the Machinery Lab.

Q.1. (20 pts) Permanent Magnets

Consider the magnetic circuit shown in Figure 1.1 which is composed of a permanent magnet, an infinitely permeable core and an air gap. The B-H characteristics (only in 2^{nd} quadrant) of the permanent magnet (NdFeB) is also shown in Figure 1.1. The gap length, g is 5 mm. The area of the core, A is 2 cm^2 and same everywhere. The demagnetization characteristics on Figure 1.1 is approximated as a straight line.

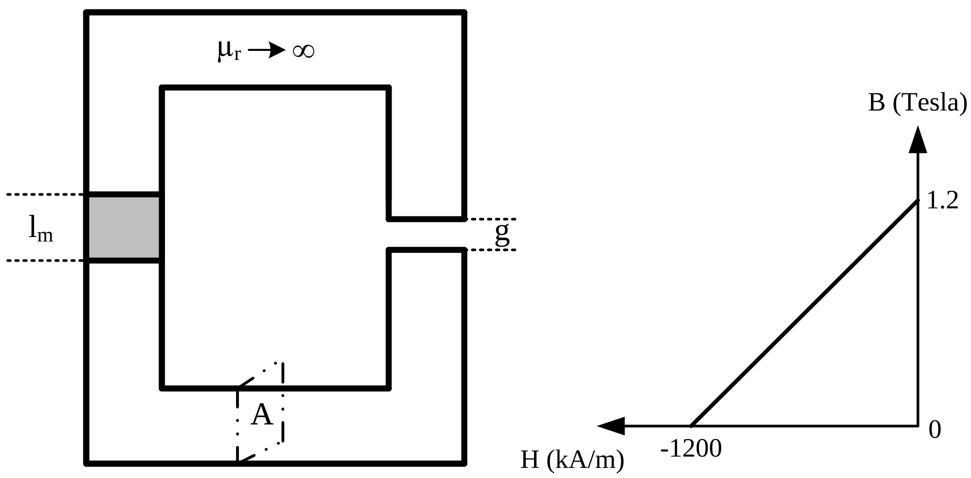

Figure 1.1: The magnetic circuit and B-H characteristics of the permanent magnet

A. Obtain the load line (on the 2nd quadrant) if the magnet length (l_m) is 1 cm. Sketch both characteristics on the same graph.

B. Determine the operating point (B and H) of the magnet.

C. Determine the maximum energy product of the permanent magnet and the corresponding operating point.

D. What may be done to operate the magnet at its maximum energy product operating point?

E. Suppose that the magnet length is increased. On which direction the operating point moves?

F. Suppose that the air gap is removed. What will be the operating point?

G. Suppose that another magnet is placed into the air gap with a thickness of g, polarity of which is such that the magnets are as connected in series. What will be the operating point?

Q.2. (30 pts) AC Excitation

Consider the 50 Hz single phase transformer and the B-H characteristics of its core shown in Figure 2.1.

$A = 86\ cm^2$, $l = 60\ cm$, $N_1 = 60$ turns, $N_2 = 120$ turns

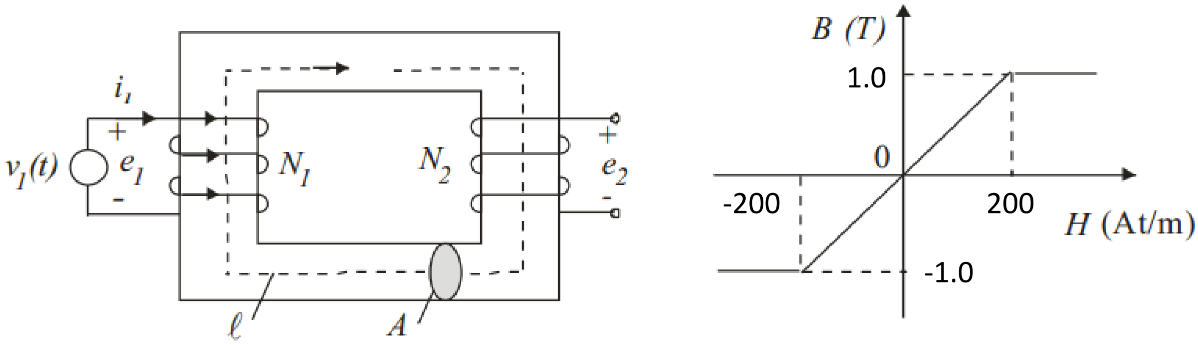

Figure 2.1: The transformer and its B-H characteristics

A. Is this transformer a step-up or a step-down transformer? Give reasoning.

B. Suppose that the transformer is excited from only the primary winding. At which excitation current (i_1) does this transformer starts to saturate? What is the rms value of this current if the excitation is AC?

C. Without saturating the core, what is the maximum value of the secondary induced voltage, E_2? By neglecting the copper loss and leakage flux components, write down the time domain expression of the maximum secondary terminal voltage, $e_2(t)$.

D. What may be done to increase the maximum induced voltage without saturating the core? Feel free to change any given parameters, but you need to state the drawbacks of your proposition.

E. Calculate the rms value of the magnetization current for the conditions in part (B), I_m and write down its time domain expression, $i_m(t)$.

F. Roughly sketch $e_2(t)$ and $i_m(t)$ on the same graph. Clearly indicate maximum points, zero crossings etc. Comment on the phase difference. Explain the meaning of it in terms of power definitions.

G. Calculate the hysteresis loss. What can be said about the core loss by looking at your answer?

Q.3. (50 pts) Single Phase Transformers

Consider a single phase, step-up transformer with 10 kVA, 50 Hz, 220V/440V ratings.

Part I: Transformer Tests

A. What is the rated current at the secondary side of this transformer?

B. Results of some tests applied to this transformer are as follows:

Open circuit test (the instruments are placed on the <u>low voltage side</u>):

$$\mathbf{V_1 = 220V\ I_1 = 1.39\ Amps,\ P_1 = 230\ Watts}$$

Short circuit test (the instruments are placed on the <u>high voltage side</u>):

$$\mathbf{V_2 = 17.7\ Volts,\ I_2 = 22.7\ Amps,\ P_2 = 257\ Watts}$$

Draw the complete equivalent circuit of this transformer and find all the parameters by using the test results. State your assumptions and approximations clearly!

Part II: Transformer Loading

A load is connected to the secondary of the transformer in Part I such that the secondary voltage is 440V when 10 kVA is delivered to the load at unity power factor.

Find the ***primary voltage*** and ***primary current*** by the use of a simplified equivalent circuit with the exciting branch moved to the primary terminals.

Part III: Regulation and Efficiency

Three different loads are connected to the transformer in Part I such that the secondary voltage is 440V at the specified load condition. For each case, calculate the ***primary voltage*** and ***input (real) power*** by using a simplified equivalent circuit where the exciting branch is moved to the primary terminals (as in Part II).

A. Load 1: 8 kW, unity power factor

B. Load 2: 8 kW, 0.8 power factor, lagging

C. Load 3: 8 kW, 0.8 power factor, leading

D. For each load, by using the data you obtained, calculate the following and <u>comment</u>:

$$100 \times \frac{V_{2,no-load} - V_{2,load}}{V_{2,rated}}$$

$$100 \times \frac{P_{out}}{P_{in}}$$

Note that what we have defined in part (D) are nothing but ***regulation*** and ***efficienc***y.