CHAPTER 6

DERIVATION OF THE FORMULAE

6.1 Maximum Power Handling by a Core

The voltage equation of a transformer for square wave input is

$$V = 4 f B_{max} N A_{core} \times 10^{-8} \quad \text{---------} \quad (6-1)$$

The core will handle maximum power when all the window area is occupied. The window area at this condition is

$$W = \frac{N_1 I_1}{J_1} + \frac{N_2 I_2}{J_2} \quad ; \text{ neglecting } \frac{N_3 I_3}{J_3}$$

$$= \frac{2NI}{J} \quad ; \text{ for } J_1 = J_2 \quad \text{----}(6-2)$$

from (6 - 1) and (6 - 2) we have

$$V = 4 f B_{max} \frac{W J}{2 I} A_{core} \times 10^{-8}$$

$$P_{max} = VI = 2 f B_{max} J W A_{core} \times 10^{-8} \quad \text{-------} \quad (6-3)$$

The equation (6 - 3) is not accurate because

1. the conductor can not completely fill the window area
2. a small space must be provided for the feedback winding
3. a stacking factor must be taken into account. Thus a factor must be put into eq. (6 - 3) so that it will be of practical use. The result is

$$P_{max} = 2 K_w B_{max} f J W A_{core} \times 10^{-8} \quad \text{--------------}(6-4)$$

The following of K_W are recommended

$$K_W = 0.5 \quad \text{for pot core}$$
$$= 0.4 \quad \text{for EE core.}$$

6.2 Optimum Feedback Voltage

V_{FB} must be selected properly or too much power will be dissipated in R_1 or R_2 .

The power dissipated in R_1 and R_2 can be found from

$$P = P_{R_2} + P_{R_1}$$

$$= \frac{(V_{in} + I_B R_1)^2}{R_2} + \frac{(V_{FB} - V_{BE}(sat))^2}{R_1} \quad \text{----- (6 - 5)}$$

Combine equations (6 - 5) , (3 - 13) , (3 - 14) the result is

$$P = \frac{V_{BE}(sat) I_B (V_{in} + V_{FB} - V_{BE}(sat))^2}{(V_{FB} - V_{BE}(sat))(V_{in} - V_{BE}(sat))} + I_B (V_{FB} - V_{BE}(sat))$$

$$\text{----------------- (6 - 6)}$$

Differentiate eq. (6 - 6) with respect to V_{FB} and equate it to zero we will get the optimum value of V_{FB} as a function of V_{in} and V_{BE} (sat) as follows :

$$V_{in} (V_{FB})^2 - 2 V_{in} V_{BE}(sat) V_{FB} - V_{in}^2 V_{BE}(sat)$$
$$+ V_{in} (V_{BE}(sat))^2 - (V_{BE}(sat))^3 = 0 \quad \text{--------- (6 - 7)}$$

The result of eq.(6 - 7) is tabulated in the Feedback Voltage Table (p. 46)

If $I_B R_1$ is negligible in comparison with V_{in} eq. (6 - 5) is reduced to

$$P = \frac{V_{in}^2}{R_2} + \frac{(V_{FB} - V_{BE\,(sat)})^2}{R_1} \qquad \text{------- (6 - 8)}$$

Substitute eq.(3 - 13) and (3 - 14) into eq. (6-8)

$$P = \frac{I_B}{V_{FB} - V_{BE\,(sat)}} \times \left[\frac{V_{in}^2 \; V_{BE\,(sat)}}{V_{in} \; V_{BE\,(sat)}} + (V_{FB} - V_{BE(sat)})^2 \right]$$

-------- (6 - 9)

Differentiate eq. 6 - 9 with respect to V_{FB} and equate to zero, the result is

$$V_{FB} = \sqrt{V_{in} \; V_{BE\,(sat)}} + V_{BE(sat)} \qquad \text{----------- (6 - 10)}$$

Eq. (6 - 10) is useful in the case where V_{in} , $V_{BE(sat)}$ are different from those in the Feedback Voltage Table and also the condition $V_{in} \gg I_B R_1$ is attained.

6.3 Optimum Current Density

Voltage drop in a transformer coil is

$$v_d = IR$$

$$= I \frac{(p \; lw \; N)}{A} \qquad \text{----------- (6 - 11)}$$

where p = resistivity in ohm - cm

lw = mean length of one turn of the coil

A = cross sectional area of the coil conductor.

$$J = \frac{I}{A} \qquad \text{-----------} \quad (6 - 12)$$

Substitute eq. (6 - 12) into eq. (6 - 11)

$$v_d = \rho \, l_w N J \qquad \text{------------} \quad (6 - 13)$$

Define the fraction of allowable voltage drop in wire

$$n = \frac{v_d}{V_{out}} \qquad \text{------------} \quad (6 - 14)$$

Combine equations (6 - 1) , (6 - 4) , (6 - 13) , and (6 - 14) the result is

$$J = \left[\frac{2 P_{max} \quad n}{K_w \rho \, l_w \, W} \right]^{1/2} \qquad \text{-------------} \quad (6 - 15)$$

The value of n = 0.005 upto 0.01 is recommended

Power loss in the coil

$$P_{coil} = I^2 R = I \, v_d$$

The fraction of power in the output coil to the power output is

$$\frac{P_{output\ coil}}{P_{out}} = \frac{I_o \, v_d}{I_o \, V_{out}} = \frac{v_d}{V_{out}} \approx n \qquad \text{-------} (6 - 16)$$

Because the loss in the output and input coil are about the same. Therefore, total loss in percent in coils is approximately twice the allowable voltage drop, n .

6.4 The B - H curve of TDK H 5 B Ferite (Ref. 6)

The circuit for determining a hysteresis loop is shown in Fig. 9. The core is excited by the 150 - Hz voltage.

Since $v_x = i_1 R_1$

$$H = \frac{N_1 i_1}{l} = \frac{N_1}{R_1 l} v_x \qquad \text{---------------} \; (6-17)$$

Similarly, since $R_2 >> 1/w\,C_2$ at 150 Hz

$$i_2 \cong \frac{v_2}{R_2}$$

$$v_y = \frac{1}{C_2}\int i\,d\,t = \frac{1}{C_2}\int \frac{v_2}{R_2}\,dt$$

$$= \frac{N_2\,A}{R_2\,C_2}\int \frac{dB}{dt}\,dt$$

$$B = \frac{R_2\,C_2}{N_2\,A}\,v_y \qquad \text{----------} \; (6-18)$$

From Fig. 8 : v_y = 50 mV/div. , v_x = 500 mV/div.

x - axis : $H = \dfrac{(200)(500 \times 10^{-3})}{(10)(3.76 \times 15^2)}$ = 266 amp-turn/m/div.

$= 266 \times 0.01257 = 3.33$ oersted/div.

y - axis : $B = \dfrac{(10^5)(1.1 \times 10^{-6})(50 \times 10^{-3})}{(300)(0.94 \times 10^{-4})} = 0.194$ weber/m^2/div.

= 1940 gauss/div.

The loop area of Fig. 8 measured by a planimeter is 2.21 div^2 which is :

$2.21 \times 1940 \times 3.33 = 14.1 \times 10^2$ oersted - gauss

Thus the power loss of TDK, H 5 B, 2616 ferrite core at 2.75×10^3 H_z is :

$$P_h = W_h V f x 10^{-7}$$

$$= \frac{(14.1 \times 10^3)(3.54)(2.75 \times 10^3) \times 10^{-7}}{4\pi}$$

$$= 1.092 \text{ W}$$