Transformer Design for a X-Ray Device

high-frequency, high-voltage transformer that will be used in a X-Ray device

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Abstract

In this report, it is supposed to design a high-frequency, high-voltage transformer that will be used in a X-Ray device.The transformer design will be given step by step.

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Chapter 1. Introduction

```
The specs of the transformer are as follows:
* Single Phase, High Frequency High Voltage Transformer
* Primary Winding Voltage ± 417 V (peak to peak 834 V for pulsing)
* Secondary Winding Voltage ± 12.5 kV (peak to peak 25 kV for pulsing)
* Rated Power 30 kW (for maximum 100 milisecond)
* Switching Frequency Minimum 100 kHz
* Ambient Temperature 0-40 °C
```

Chapter 2. Core Selection

```
% In this code, it is supposed to design a high-frequency,
% high-voltage transformer that will be used in a X-Ray device.
%-------------------------------------------------------------------------
% Huseyin YURUK
%----------------------------------------
% Following design guide is used:
% Magnetics Ferrite Power Design 2013
%----------------------------------------
% Core Selection by WaAc product
% The power handling capacity of a transformer core can also be determined
% by its
% WaAc product, where Wa is the available core window area, and Ac is
% the effective
% core cross-sectional area.
% Area Product Distribution (WaAc)
% WaAc = (Po * Dcma) / (Kt * Bmax * f)
% where
% WaAc = Product of window area and core area (cm4)
% Po = Power Out (watts)
% Dcma = Current Density (cir. mils/amp)
% Bmax = Flux Density (gauss)
% ƒ = frequency (hertz)
% Kt = Topology constant  (Full-bridge = 0.0014)
Po = 30 * 10^3;     % input parameter
f = 100 * 10^3;     % input parameter
Kt = 0.0014;
% for cir. mils to mm^2 see below link
% conversion see http://www.convertunits.com/from/mm%5E2/to/circular+mil
% 1mm^2 ~1973.5 cir. mils
J = 2.5;            % current density A/mm^2
Dcma = 1973.5 / J;
Bmax = 0.47 * 10^4; % P type core has the 0.47T max. flux density
WaAc = Po * Dcma / (Kt * Bmax * f)

%%%%%%
```

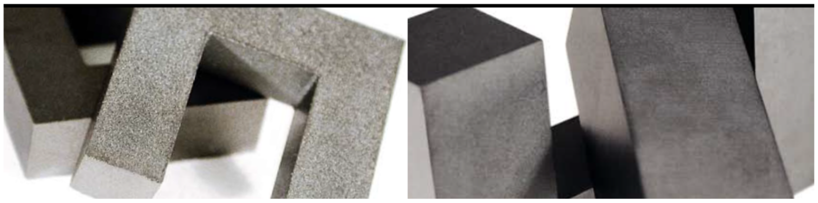
```
Using the equation shown above, the WaAc product is calculated.

WaAc =  35.9909

Then the Area Product Distribution (WaAc) Chart is used to
select the appropriate core.

From the Magnetics Ferrite Catalog (2013) U core is selected.
The detail are given below.
```

Typical Power Handling Chart

Power in Watts 20 kHz	50 kHz	100 kHz	250 kHz	Pot, RS, DS	E Cores	RM, PQ, EP	UU, UI, UR	ETD, EER, EC	EFD, Planar	Toroid
11700	19000	26500	51500		49928 EE		49330 UU 49332 UU 49920 UU 49925 UI 49925 UU			49725 TC 49740 TC

U, I Cores

U cores are ideal for power transformer applications. The long legs of U core support low leakage inductance designs and facilitate superior voltage isolation. U/I combinations provide for economical assembly.



P Material

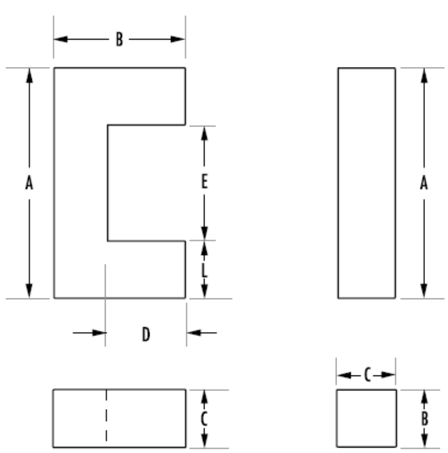
A low-medium frequency general-purpose power converter material. Engineered for lowest losses between 80 - 100°C. Available in almost all core sizes and shapes.

Initial Perm (25°C; ≤ 10 kHz) .... 2,500 ± 25%
Saturation Flux Density (4,700 G at 15 Oe, 25°C) ....470 mT, 11.9 A-T/cm
Curie Temperature .... 210°C

```
U cores are ideal for power transformer applications.
The long legs of U core support low
leakage inductance designs
and facilitate superior voltage isolation.
```

TYPE/SIZE	ORDERING CODE	MAGNETIC DATA l_e (mm)	A_e (mm²)	A min (mm²)	V_e (mm³)	WaAc (cm⁴)	Weight (grams per set)	HARDWARE Bobbins	Clips
U 102/57/25	**0_49925UC**	308	645	645	199,000	121	988		

TYPE/SIZE	ORDERING CODE	DIMENSIONS (mm) A	B	C	D	E	L
U 102/57/25	**0_49925UC**	101.6 ± 1.5	57.1 ± 0.4	25.4 ± 0.6	31.7 ± 0.75	50.8 ± 1	25.4 ± 0.8



Chapter 3. Determine # of Turns

```
% The calculation of primary and secondary turns
% and the wire size selection
% Np = Vp * 10^8 / (4 * B * Ac * f)
% Ns = (Vs / Vp ) * Np
% Ip = Pin / Vp_rms
% Is = Po / Vs_rms
% where
% Np = number of turns on the primary
% Ns = number of turns on the secondary
% Ip = primary current
% Is = secondary current
% Ac = core area in cm^2
Vin = 417;                % input parameter
Vout = 12.5 * 10^3;       % input parameter
Vp_peak = Vin * 4 / pi();     % 1st harmonic peak value
Vs_peak = Vout * 4 / pi();     % 1st harmonic peak value
B = 0.2 * 10^4;                % operating B value
Ac = 645 * 10^-2;              % Ae effective are for the choosen ferrite
n_eff = 0.98;                  % 98% efficiency assumed
Vp_rms = Vp_peak / sqrt(2);     % rms value
Vs_rms = Vs_peak / sqrt(2);    % rms value
Np = Vp_rms * 10^8 / (4*B*Ac*f);
Ns = (Vs_rms / Vp_rms) * Np;
Pin = Po / n_eff;
Ip = Pin / Vp_rms;
Is = Po / Vs_rms;

%%%%%%

Using the equation shown above, the Np, Ns, Ip, Is are calculated.

Np =  7.2758    take Np as 7
Ns =  218.0999     take Ns as 218
Ip = 81.5387
Is = 2.6657
```

Chapter 4. Window Utilization & Cable Selection

```
% Approximately primary and secondary wire size are can be calculated
% as follows:
% Ku * Wa = Np*Awp + Ns*Aws
% Ku is fill factor
% Ku = s1*s2*s3*s4
% s1: wire isulation,  conductor area/wire area
% s2: fill factor,  wound area/usable window area
% s3: effective window, usable window area/window area
% s4: insulation factor, sable window area/usable window area + insulation
% Note that at 100Khz to minimize skin effect AWG26 is used
% for more details see below link
% http://coefs.uncc.edu/mnoras/files/2013/03/
% Transformer-and-Inductor-Design-Handbook_Chapter_4.pdf
% assume
% Np*Awp = 1.1 * Ns*Aws (to allow for losses)

% for AWG26 @100kHz
s1 = 0.79;
s2 = 0.61;
s3 = 0.6;
s4 = 1;
Ku = s1*s2*s3*s4;

D = 31.7;             % core dimensions in mm
E = 50.8;             % core dimensions in mm
Wa = 2 * D*E * 10^-2; % available core window area cm^2
Aws = Ku * Wa * 10^2 / (2.1 * Ns);   % mm^2
Awp = 1.1 * Ns * Aws / Np;          % mm^2

% mm^2   %requirred wire size for choosen current density
Awp_req = Ip / J;
Aws_req = Is / J;

%%%%%%
```

```
Due to 100Khz operation to minimize skin effect AWG26 cable size is used.
By regarding the window utilization factor Ku which is calculated as Ku = 0.2891,
allowable wire area
for primary side is Awp = 67.0429  [mm^2]
for secondary side is Aws = 2.0332 [mm^2]

From the choosen current density J = 2.5000 [A/mm^2] , requirred wire size
for primary side Awp_req = 32.6155
for secondary side Aws_req = 1.0663
```

Chapter 5. Losses

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Cupper Losses

```
% cupper losses will be calculated
% length of one turn coil will be calculated as follow
% primary and secondary window area assumed equal
% radius of the coil, radius_acoil = C/2 + D/2; [mm]
% length of the coil, length_acoil = 2 * pi * radius_acoil
% where C, D see dimensions
% total coil length:
% for primary side Np * length_acoil * 10^-3
% for secondary side Ns * length_acoil * 10^-3

Icarry_cap_AWG26 = 0.361;       %[A] current rate for the AWG26 size cable
area_AWG26 = 0.129;             % [mm^2]
ohm_AWG26 = 0.13386;            % [Ohm/m]
Icarry_cap_AWG26_J = J * area_AWG26; % [A] current rate by considering J value
C = 25.4;       % dimensions of the core [mm]
D = 31.7;       % dimensions of the core [mm]
radius_acoil = C/2 + D/2;   % [mm]
length_acoil = 2 * pi()* radius_acoil;  % [mm]

% primary side loss calculation
Nstrand_pri = ceil(Ip / Icarry_cap_AWG26);  % number of AWG26 size cable
tot_length_coil_pri = round(Np) * length_acoil * 10^-3; % [m]
res_coil_pri = ohm_AWG26 * tot_length_coil_pri / Nstrand_pri;   % [ohm]
loss_coil_pri = Ip^2 * res_coil_pri;       % [W]

% secondary side loss calculation
Nstrand_sec = ceil(Is / Icarry_cap_AWG26);  % number of AWG26 size cable
tot_length_coil_sec = round(Ns) * length_acoil * 10^-3; % [m]
res_coil_sec = ohm_AWG26 * tot_length_coil_sec / Nstrand_sec;   % [ohm]
loss_coil_sec = Is^2 * res_coil_sec;       % [W]

tot_loss_cupper = loss_coil_pri + loss_coil_sec;    %[W]
%%%%%%
```

Cupper loss calculation of the primary and secondary side is given above. Total loss of the cupper is calculated as 9.5947