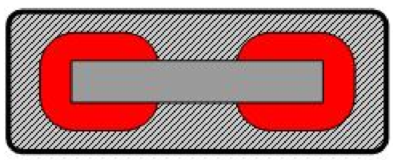
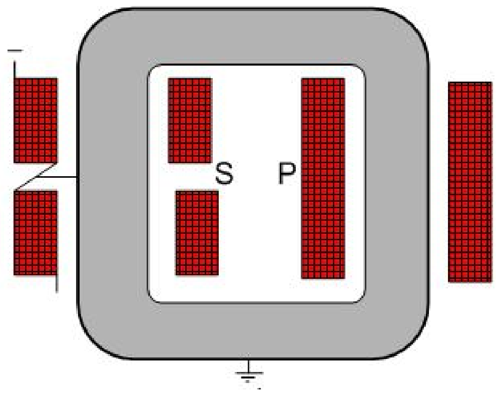
Topic2/ Design1

Designing high voltage ,
potted transformers 10kV, 0.1A, 1500Hz

Input parameters

For this type of transformers the designer uses 2 legs C-core with good 4 mil grain oriented steel. In order to avoid problems with high voltage between primary and secondary windings they have to be wound on the different legs. The transformer has to be potted in a case.
The resonance frequency of the transformer capacity and no-load inductance has to be min. 3-5 times higher than the nominal operation frequency. For this reason the designer has to use air gaps in the core, thicker layer insulation and set the secondary winding in a double section bobbin. If possible the core and the tap between 2 secondary sections should be connected to the ground. Note that the resonance frequency can set 2-3 times lower than the operating frequency using an additional secondary winding with capacitive load.





Primary	Voltage	120V +-10%, 1500Hz, rectangular wave form
	Wire	Cu, round, single insulated
	Layer insulation	No
	Final insulation	No
	Winding	Alone per leg on tube potted in case
Secondary	Nominal output voltage	10000V
	Nominal output current	0.1A @ 100 kOhm
	Wire	Cu, round, single insulated
	Layer insulation	>5 mil, in order to limit the layer capacitance for higher resonance frequency
	Final insulation	NO
	Winding	2 Alone per leg on tube, potted in case
Core	Steel	M2, 4 mil
Case	SPotting	Vacuum, no air in the windings
Design	Insulation class	B, max. operating temperature 120C

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Name	:2 X SU 60/20.6 gS	M
Steel	-:M2 0.007" => M68-0.18mm	
Number of Sections	-:1	
max.Cu-Fill Factor	%:87.8	
max. parallel Wires	:1	
Induction on Load	T:0.783	
Max. Induction	T:0.814	
Max.Cu-Temp.rise on load	°K:77.8	
Max.Cu-Temp.rise no-load	°K:48.1	
Regulation	%:11.7	
I^Inrush/I^nom-Factor	*:24.8	
Input Current No-Load	%:32.2	

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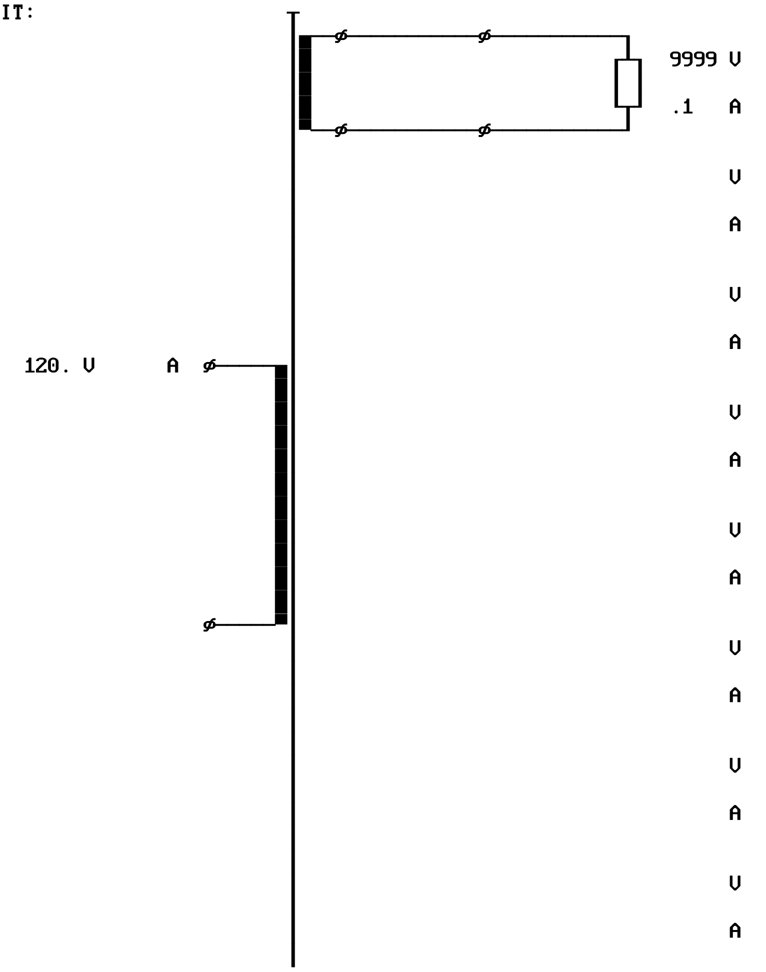
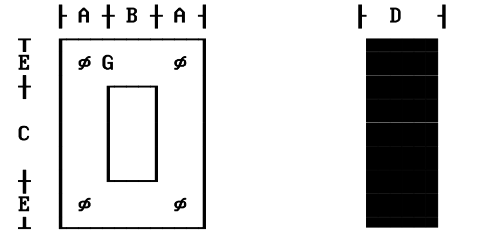
PRIMARY	U(V)	I(A)	SECOND.	1---	2---	3---	4---	5---	6---	7---	8---
Circuit-:1	120.		Circuit-:11								
Overvlt*:1.00	.		Volta. V:9999								
Wire :0.0	.		Curre. A:.1								
I/L. mil:5.	.		Wire :0								
I/E. mil:0.	.		I/L mil:5.0								
Formfac.:1.00	.		I/E mil:10.0								
Fre.Hz:1500	.										
dI/Io :100	.										

Regulat. %:50.0	Steel -:9	Cooling *:1.00	Bobbin -:1
Udiode V:0.8	Induction T:0.78	Force ft/s:0.00	P/S-Order -:3
dUdiode V:.1	Remanence *:0.35	Bracket -:1	Rac/Rdc *:1.25
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:0.70
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:70	Gap *:10.00	Channel in:0.00	Horizontal -:1
Time 1 Min:30.0	Annealed -:1	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:1.0	Stacking *:0.95	Rth-varni.*:1.00	Spread %:0
Time 2 Min:30.0	Hole -:1	Rth-comp. *:1.00	Selection -:2
Load 2 *:1.0	Assembly -:1	Case -:1	Criterion -:2

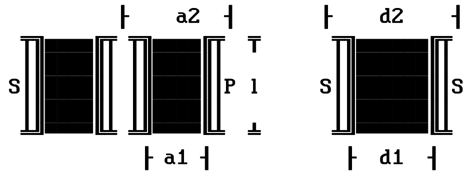
CIRCUIT:



Name :2XSU 60/20.6 gS M
Steel :M2 0.007" => M68-0.18mm /7.09



with two bobbins

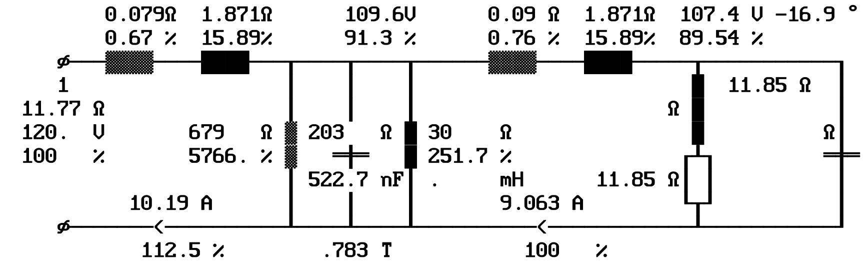


Weight lb:1.34
Gap total in:0.000
A-Limb in:0.78
B-Width in:0.78
C-Height in:2.47
D-Stack in:0.81
E-Yoke 1 in:0.78
F-Yoke 2 in:0.78
G-Hole in:0.00
Radiator Fin :0
Radiator Chan. :0
a1 cm:0.91
a2 cm:1.53
d1 cm 0.92
d2 cm 1.79
l cm:2.22
lp cm:
ls cm:
Margin cm:0.13

X- Length 1 in:3.21
Y- Width 1 in:4.11
Z- Height 1 in:1.65
x- Length 2 in:0.00
y- Width 2 in:0.00
z- Height 2 in:0.00
w- Thickness in:0.04
Material :
Potted :

	Typ	Windun	MTI	DN	DN	Par	D/ø mil	B/ø mil	W/L	L	I/L mil	I/E mil	Weight lb	RWH %
1 2 3 4 5 6 7 8	1	66.9	C00	12.5	12.5	1	76.3	76.3	27	2.5	5.	.	.437	85.
1 2 3 4 5 6 7 8	11	6140.2	C00	33.5	33.5	1	6.7	6.7	293	20.	5.	10.	.311	87.
TOTAL													.748	87.

NOMINAL OPERATION	at Temperature °C 117.3	and	Overvoltage 1.00
Output Power on Load	W:973.8	Output Power of Transfor.	W:973.8
Cu Losses	W:15.53	Fe-Losses active	W:17.69
Short-Circuit-Volt. cold	%:30.97	Regulation	%:11.68
Instantaneous pow. .5/95&	W:366.3	Efficiency of Transformer	%:96.7
dT Fe average Surface	°K:78.4	dT primary	°K:76.9
dT Case aver. Surface	°K:65.2	dT secondary	°K:77.8



DUTY CYCLE OPERATION	at Amb.Temperature °C 40.	and	Overvoltage 1.00
dT Fe average Surface	°K:78.4	dT primary	°K:76.9
dT Gehäuse av. Surface	°K:65.2	dT secondary	°K:77.8

NO LOAD OPERATION	at Amb.Temperature °C 40.	and	Overvoltage 1.00
Losses active	W:19.57	Losses reactive	VAr:393.5
Current factor	%:32.22	Induction	T:.814
dT Fe average Surface	°K:53.	dT primary	°K:48.1
dT Gehäuse av. Surface	°K:42.9	Rezonance frequency	kHz:3.9

SHORT-CIRCUIT OPERATION	at Amb.Temperature °C 40.	and	Overvoltage 1.00
Losses active	W:117.5	Losses reactive	VAr:3948.
Current factor cold	%:322.9	Induction	T:.424
dT Fe average Surface	°K:6231.	dT primary	°K:6529.
dT Gehäuse av. Surface	°K:5754.	dT secondary	°K:6855.

PRIMARY (Tap:1)	1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output V	:120.							
Out. Voltage no load V	:							
Current Input/Output A	:10.19							
Load on output Ω	:							
Power factor of load	:							
Current in segment A	:10.19							
Current density A/in^2	:2229.							
Icc-Current cold A	:32.92							
Io -Current A	:3.284							
Inrush Current peak ^A	:356.3							
Inrush Current rms A	:138.9							
Cu-Losses W	:8.2							
Resistance cold Ω	:.0453							
Reactance Ω	:1.871							
Eddy-Current Factor	:1.25							

SECONDARY	1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage V	:9867.							
Output Current A	:0.099							
Out. Voltage no load V	:10456							
Sec. Voltage V	:9867.							
Sec. Current A	:0.099							
Current density A/in^2	:2798.							
Sec. Voltage cold V	:9898.							
Load on output Ω	:99990							
Power factor of load	:1.000							
Icc cold A	:0.34							
Cu-Losses warm W	:7.36							
Resistance cold Ω	:542.2							
Reactance Ω	:15783							
Eddy-Current Factor	:1.							
Capacitor mF	:.							

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About spacing within a high voltage "dry" transformer

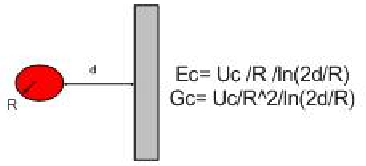
In order to avoid corona and partial discharging within a transformer we have to follow some very important rules about the **value** (V/cm) and the **form** (V/cm^2) of the electrical field.

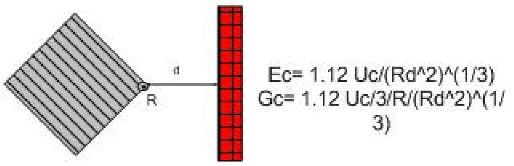
1. The electrical field between 2 parallel, naked wires with the radius R, in air with temperature 25C and pressure 1 at, that will produce the corona effect can be calculated with following formula:

   Ec = 33.7 x (1 +0.242/R^0.5) in kV/cm

2. The most critical form of the electrical field for corona has 2 parallel, naked wires. Note that the same form has the configuration of one wire and one plate. All other configurations of electrodes with the same radius an distances as 2 parallel, naked wires have less critical form of electrical field.

The most critical configurations for corona within a transformer are shown in the following picture.





Example 1

Find the voltage between the wire and plate that will produce the corona the following parameters of the configuration:

- R = 40mil = 0.1016cm
- D = 1 in = 2.54cm

This is the electrical field that will produce the corona:

Ec = 33.7 (1 +0.242/0.1016)^0.5) = 59.28 kV/cm

This is the voltage between the wire and the plate that will produce the electrical field 59.28 kV/cm and corona:

Uc = Ec R ln(2d/R)) = 59.28 *0.1017 ln(5.08/0.1016) = 23.56kV

Example 2

Find the voltage between the corner of the core and the winding that will produce the corona the following parameters of the configuration:

- R = 40mil = 0.1016cm
- D = 1 in = 2.54cm

Out of the first example we know Uc = 23.56kV and calculate the gradient of the magnetic field for the configuration wire-plate.

$$Gc = Uc / R^2 / \ln(2d/R) = 238 \text{ kV/cm}^2$$

In order to get corona in the configuration core-winding the gradient of magnetic field has to have the value of 238 kV/cm^2 and the voltage between the winding and the core has to be:

$$1.12\ Ucw\text{-}c / 3R/(Rd^2)^{(1/3)} = 238$$

And

$$Ucw\text{-}c = 63 \text{ kV} > 23.56 \text{ kV}$$

Note that the radius of the core corner is smaller than 40 mil = 0.1016cm.

About spacing within a high voltage potted transformer

Normally all small power, high voltage transformers are potted in a case. The check in procedure of spacing has more steps:

1. Selection of the best representative model of configuration and calculation of the max. gradient of the electrical field

2. Calculation the dimensions of the high voltage screened cable with the same gradient of the magnetic field as calculated in the step 1, using the formula :

   $$Gc = Uo/Ri^2/\ln(2(Ro)/Ri)$$

3. Selection the resin with a high non-linear specific ohmic conductivity

   $$Gama = AE^n$$

4. Calculation of the electrical field with the influence of the resin non-linearity of the specific ohmic conductivity

   $$E = kUo/(Ro^k+Ri^k)/Ri^k$$

where;

- Uo => voltage between the screen and inside round wire
- Ri => radius of the inside round wire
- Ro => inside radius of the screen
- A => constant
- E => electrical field
- n => factor of resin non-linearity :$2 < n < 4$, $k = n/(1+n)$

Example 3

The distance between the inside corner of our secondary winding to the core is 75mil = 0.19cm.
The wire radius is (6.7/2 mil = 0.0085cm.
Uo = 10kV

1. For the configuration corner-plate the value of the gradient of the magnetic field is:

   G = 1.12Uo/3/R/(Rd^2)^0.333
   G = 1.12 x 10 /3/0.0085/0.0085/0.19^2)^0.333 = 6494 kV/cm^2

2. Using:

   Uo/Ri^2/ln(2(Ro)/Ri) = 6494
   and
   Ro = Ri + d

   follows: Ri = 0.023cm, Ro = 0.023 + 0.19 = 0.213cm

3. Select the resin with n = 2 or better (n>2); k = n/(1+n)=2/3 = 0.666

4. And finally the max. electrical field

   E = 0.666 10 / 0.023^0.666 /(0.213^0.666-0.023^0.66) = 300 kV/cm

If you get any problem with this result you need to increase the thickness of the tube and/or the wire size