RALE Transformer Design System Examples

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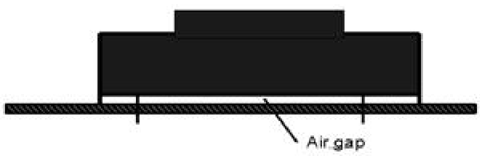
Table of Contents

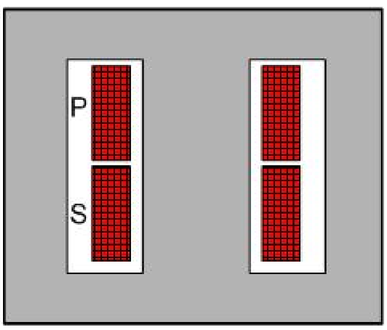
Topic1 / Design1

Designing inherently short-circuit-proof, potted safety transformers 12V, 0.166A in accordance with IEC 61558

Input parameters

Primary	Voltage	120V +-10%, 60Hz, sine wave
	Wire	Cu, round, single insulated
	Layer insulation	No
	Final insulation	No
Secondary	Nominal output voltage	12V
	Nominal output current	0.15A @ 80 Ohm
	Wire	Cu, round, single insulated
	Layer insulation	No
	Final insulation	
Core	Size	EI 25, stack ¾, no holes
	Steel	
		M45, alternate stacking, not annealed
Bobbin	Size	For core EI 25/(3/4)
	Typ	Double section
Case	Size	1” x 0.75” x 1.25”, potted
Design	Insulation class	B, max. operating temperature 120C, max. short-circuit temperature 175C
	Ambient temperature	40C
	Regulation	100%, for min short-circuit current and max. output power
	Induction	1.1T, to limit the no-load temperature due to the high value of the regulation





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#*0                          DIAGNOSE                        Page 0

 Name                          :1 X EI 25/(3/4)     1280-0
 Steel                        -:M45 Gauge 24 / 0.0250"

 Number of Sections           -:2
 max.Cu-Fill Factor           %:89.9
 max. parallel Wires           :1

 Induction on Load            T:1.274
 Max. Induction               T:1.628

 Max.Cu-Temp.rise on load   °K:49.
 Max.Cu-Temp.rise no-load   °K:30.4
 Regulation                   %:98.8

 I^Inrush/I^nom-Factor        *:4.
 Input Current No-Load        %:91.7
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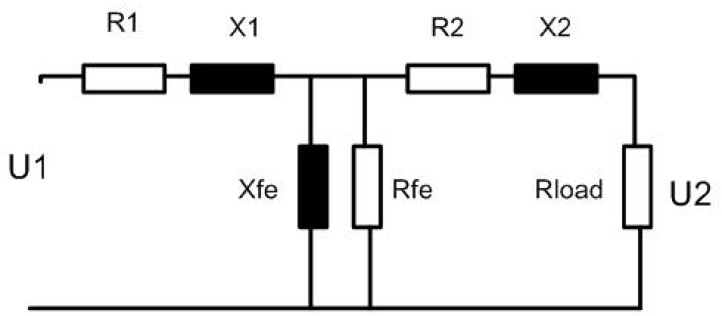


Fig. 5a

Low Frequency Scheme of a Transformer

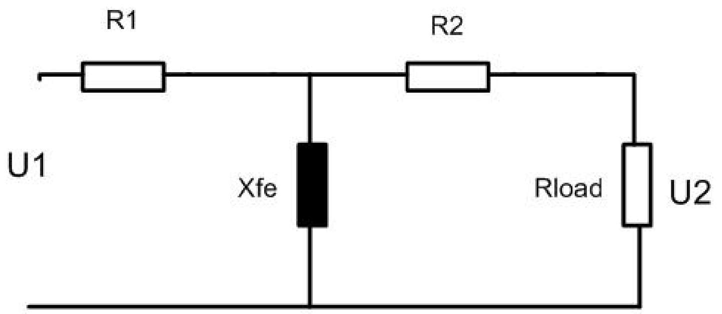


Fig. 5b

Low Frequency, Low Power (<5VA)
Scheme of a Transformer

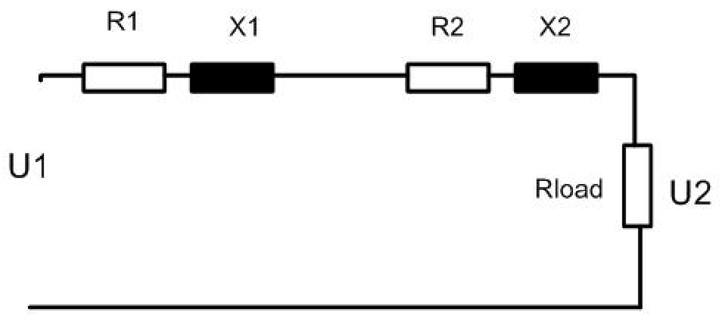


Fig. 5c

Low Frequency, > 5VA Power, Low Induction (< 1T)
Scheme of a Double-Section Transformer

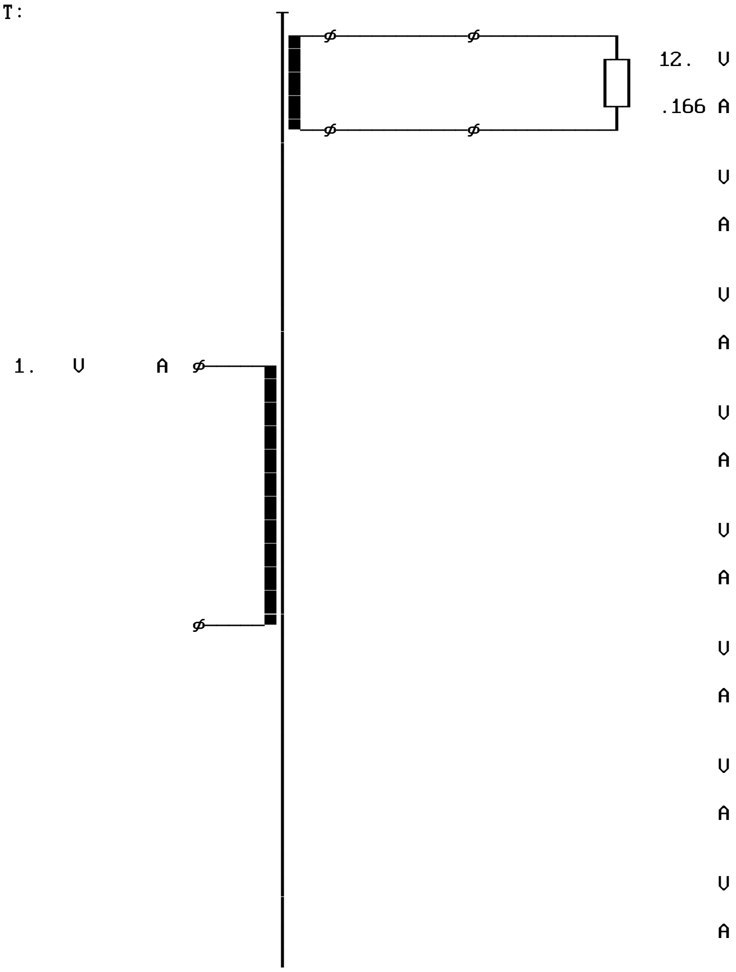
Fig. 5

07-26-2008/20:14:17/14.43 Input and Circuit Page 1

PRIMARY	U(V)	I(A)	SECOND.	1---	2---	3---	4---	5---	6---	7---	8---
Circuit-:1	1.		Circuit-:11								
Overvlt*:1.10	.		Volta. V:12.								
Wire :0.0	.		Curre. A:.166								
I/L. mil:0.	.		Wire :0								
I/E. mil:0.	.		I/L mil:0.0								
Formfac.:1.11	.		I/E mil:0.0								
Fre.Hz:60	.										
dI/Io :100	.										

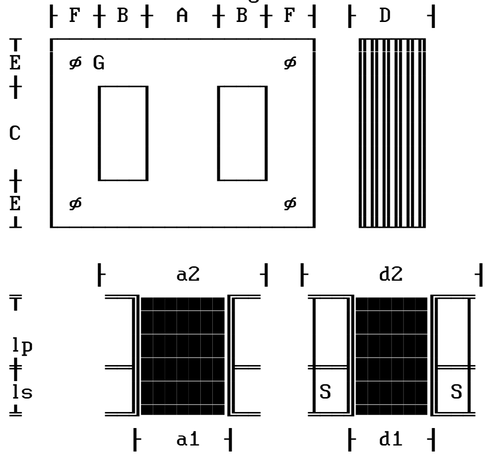
Regulat. %:100.0	Steel -:17	Cooling *:1.00	Bobbin -:2
Udiode V:0.8	Induction T:1.27	Force ft/s:0.00	P/S-Order -:1
dUdiode V:.1	Remanence *:0.35	Bracket -:0	Rac/Rdc *:1.05
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:0.90
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:75	Gap *:1.00	Channel in:0.00	Horizontal -:1
Time 1 Min:30.0	Annealed -:0	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:1.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:30.0	Hole -:1	Rth-comp. *:2.00	Selection -:2
Load 2 *:1.0	Assembly -:1	Case -:1	Criterion -:1

CIRCUIT:

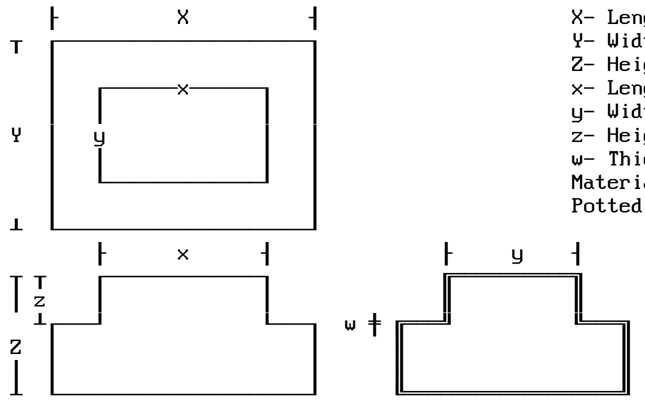


07-26-2008/20:14:17 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XEI 25/(3/4) 1280-0
Steel :M45 Gauge 24 / 0.0250" /25.59



Weight lb:.1
Gap total in:0.000
A-Limb in:0.25
B-Width in:0.25
C-Height in:0.50
D-Stack in:0.75
E-Yoke 1 in:0.13
F-Yoke 2 in:0.13
G-Hole in:0.00
Radiator Fin :0
Radiator Chan. :0
a1 cm:0.33
a2 cm:0.73
d1 cm 0.81
d2 cm 1.24
l cm:
lp cm:0.20
ls cm:0.20
Margin cm:0.04



X- Length 1 in:1.03
Y- Width 1 in:0.78
Z- Height 1 in:1.28
x- Length 2 in:0.78
y- Width 2 in:0.53
z- Height 2 in:0.25
w- Thickness in:0.01
Material :
Potted :

	Typ	Windun	MTI	DN	DN	Par	D/φ mil	B/φ mil	W/L	L	I/L mil	I/E mil	Weight lb	RWH %
1 2 3 4 5 6 7 8	1	20.1	C00	20.0	20.0	1	32.	32.	5	4.1	.	.	.015	89.
1 2 3 4 5 6 7 8	11	481.6	C00	33.5	33.5	1	6.7	6.7	25	19.	.	.	.015	78.
TOTAL													.029	89.

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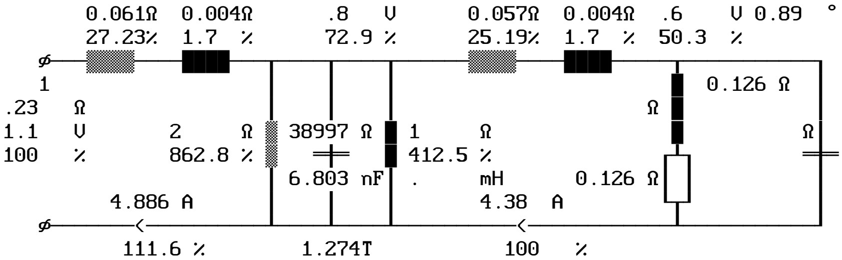
07-26-2008/20:14:17 General Data Page 3

NOMINAL OPERATION at Temperature °C 88.8 and Overvoltage 1.10			
Output Power on Load	W:2.42	Output Power of Transfor.	W:2.42
Cu Losses	W:2.55	Fe-Losses active	W:.33
Short-Circuit-Volt. cold	%:41.52	Regulation	%:98.81
Instantaneous pow. .5/95&	W:3.	Efficiency of Transformer	%:45.67
dT Fe average Surface	°K:43.8	dT primary	°K:49.
dT Case aver. Surface	°K:40.5	dT secondary	°K:48.7



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.10			
dT Fe average Surface	°K:43.9	dT primary	°K:49.
dT Gehäuse av. Surface	°K:40.6	dT secondary	°K:48.7

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.10			
Losses active	W:1.66	Losses reactive	VAr:4.64
Current factor	%:91.68	Induction	T:1.628
dT Fe average Surface	°K:27.6	dT primary	°K:30.4
dT Gehäuse av. Surface	°K:25.5	Rezonance frequency	kHz:38.9

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.10			
Losses active	W:12.89	Losses reactive	VAr:1.16
Current factor cold	%:240.9	Induction	T:.822
dT Fe average Surface	°K:104.7	dT primary	°K:121.3
dT Gehäuse av. Surface	°K:95.5	dT secondary	°K:121.

PRIMARY (Tap:1)	1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output V:	1.1							
Out. Voltage no load V:								
Current Input/Output A:	4.886							
Load on output Ω:								
Power factor of load :								
Current in segment A:	4.886							
Current density A/in^2:	6099.							
Icc-Current cold A:	11.77							
Io -Current A:	4.479							
Inrush Current peak ^A:	27.59							
Inrush Current rms A:	11.3							
Cu-Losses W:	1.5							
Resistance cold Ω:	.0491							
Reactance Ω:	.0038							
Eddy-Current Factor :	1.							

SECONDARY	1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage V:	13.24							
Output Current A:	0.183							
Out. Voltage no load V:	24.5							
Sec. Voltage V:	13.24							
Sec. Current A:	0.183							
Current density A/in^2:	5192.							
Sec. Voltage cold V:	14.7							
Load on output Ω:	72.28							
Power factor of load :	1.000							
Icc cold A:	0.48							
Cu-Losses warm W:	1.088							
Resistance cold Ω:	25.99							
Reactance Ω:	2.194							
Eddy-Current Factor :	1.							
Capacitor mF:	.							

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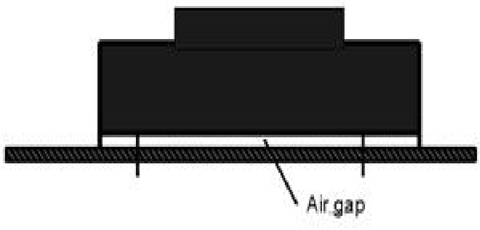
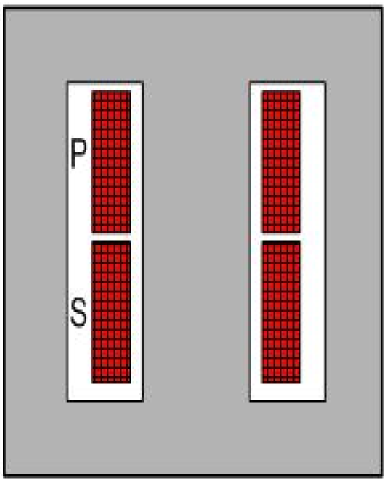
Topic1 / Design2

Designing inherently current limited, potted safety transformers 10V, 5A in accordance with UL 1585 Class 2

Input parameters

Primary	Voltage	120V +-10%, 60Hz, sine wave
	Wire	Cu, round, single insulated
	Layer insulation	No
	Final insulation	No, due to the potting
Secondary	Nominal and no-load output rms voltage	10V on load, 15V no-load
	Nominal and max. short-circuit rms output current	5A @ 2 Ohm and <8A @ 0.03 Ohm after 60 sec in short-circuit operation mode
	Wire	Cu, round, single insulated
	Layer insulation	No
	Final insulation	No, due to the potting
Core	Size	EE 125/2 with 2 E parts from core EI 125
	Steel	M45, alternate stacking, not annealed
Bobbin	Size	2 EI 125/2 single section bobbins
Case	Size	This transformer is designed without case. With the case the temperature rise will be lower.
Design	Insulation class	B, max. operating temperature 120C, max. short-circuit temperature 175C
	Ambient temperature	40C
	Regulation	50%, in order to limit the no-load output voltage (<15Vrms)
	Induction	<0.3T, to limit the short-circuit current (<8A) and losses with a very high leaking reactance





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 Name                          :1 X EIL 125/(2)-5/7
 Steel                        -:M45 Gauge 24 / 0.0250"

 Number of Sections           -:2
 max.Cu-Fill Factor           %:84.1
 max. parallel Wires           :1

 Induction on Load            T:0.243
 Max. Induction               T:0.312

 Max.Cu-Temp.rise on load    °K:25.9
 Max.Cu-Temp.rise no-load    °K:3.8
 Regulation                   %:52.7

 I^Inrush/I^nom-Factor        *:.
 Input Current No-Load        %:2.6
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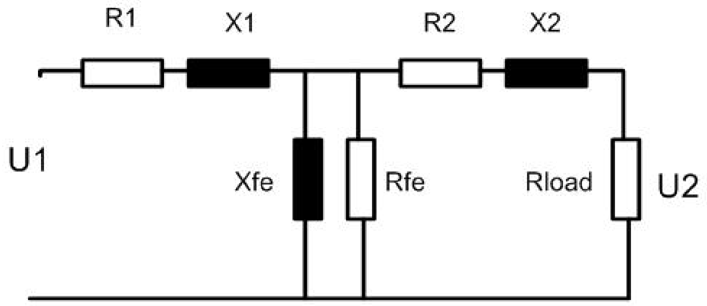

Fig. 5a

Low Frequency Scheme of a Transformer

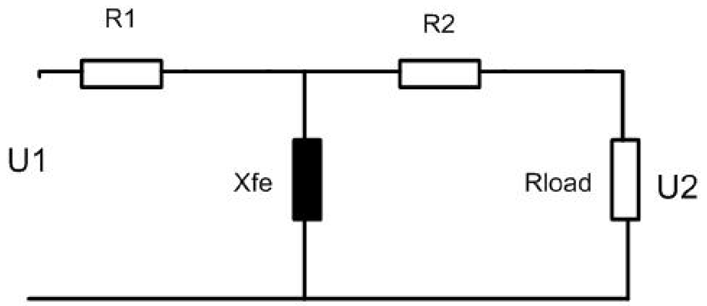

Fig. 5b

Low Frequency, Low Power (<5VA)
Scheme of a Transformer

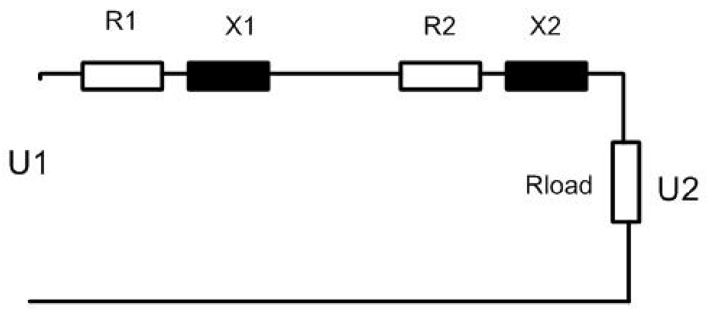

Fig. 5c

Low Frequency, > 5VA Power, Low Induction (< 1T)
Scheme of a Double-Section Transformer

Fig. 5

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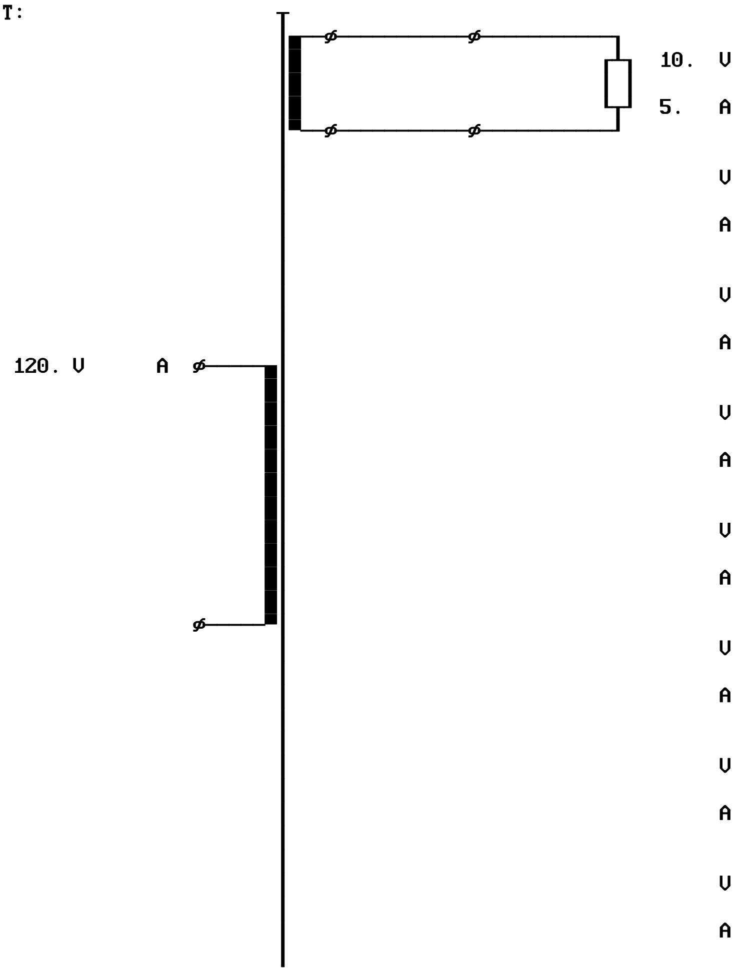
07-27-2008/12:36:33/14.43 Input and Circuit Page 1

PRIMARY	U(V) I(A)	SECOND. 1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:1	120.	Circuit-:11
Overvlt*:1.00	.	Volta. V:10.
Wire :0.0	.	Curre. A:5.
I/L. mil:0.	.	Wire :0
I/E. mil:0.	.	I/L mil:0.0
Formfac.:1.11	.	I/E mil:0.0
Fre.Hz:60	.	
dI/Io :100	.	

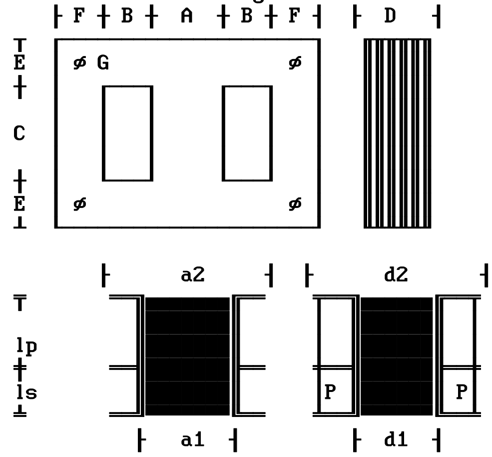
Regulat. %:50.0	Steel -:17	Cooling *:1.00	Bobbin -:2
Udiode V:0.8	Induction T:0.24	Force ft/s:0.00	P/S-Order -:2
dUdiode V:.1	Remanence *:0.35	Bracket -:0	Rac/Rdc *:1.05
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:2.00
Tmp. Amb.°C:25	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:20	Gap *:1.00	Channel in:0.00	Horizontal -:1
Time 1 Min:1.0	Annealed -:0	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:1.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:999.0	Hole -:1	Rth-comp. *:2.00	Selection -:2
Load 2 *:1.0	Assembly -:1	Case -:0	Criterion -:1

CIRCUIT:



07-27-2008/12:36:33 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XEIL 125/(2)-5/7
Steel :M45 Gauge 24 / 0.0250" /25.59



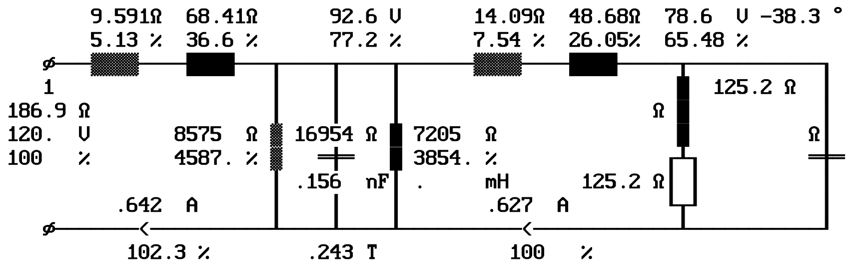
Weight lb:7.74
Gap total in:0.000
A-Limb in:1.25
B-Width in:0.63
C-Height in:3.75
D-Stack in:2.01
E-Yoke 1 in:0.63
F-Yoke 2 in:0.63
G-Hole in:0.219
Radiator Fin :0
Radiator Chan. :0
a1 cm:1.39
a2 cm:2.46
d1 cm 2.24
d2 cm 3.50
l cm:
lp cm:1.45
ls cm:2.04
Margin cm:0.08

X- Length 1 in:
Y- Width 1 in:
Z- Height 1 in:
x- Length 2 in:
y- Width 2 in:
z- Height 2 in:
w- Thickness in:
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	910.	C00	21.0	21.0	1	28.5	28.5	65	13.	.	.	1.596	82.
1 2 3 4 5 6 7 8	11	115.0	C00	13.5	13.5	1	67.9	67.9	19	5.9	.	.	1.148	84.
TOTAL													2.743	84.

07-27-2008/12:36:33	General Data	Page 3

NOMINAL OPERATION	at Temperature °C 50.1	and	Overvoltage 1.00
Output Power on Load	W:49.3	Output Power of Transfor.	W:49.3
Cu Losses	W:9.5	Fe-Losses active	W:1.
Short-Circuit-Volt. cold	%:63.15	Regulation	%:52.72
Instantaneous pow. .5/95&	W:28.6	Efficiency of Transformer	%:82.44
dT Fe average Surface	°K:21.4	dT primary	°K:24.4
dT Case aver. Surface	°K:.	dT secondary	°K:25.9



DUTY CYCLE OPERATION	at Amb.Temperature °C 25.	and	Overvoltage 1.00
dT Fe average Surface	°K:21.4	dT primary	°K:24.4
dT Gehäuse av. Surface	°K:.	dT secondary	°K:25.9

NO LOAD OPERATION	at Amb.Temperature °C 25.	and	Overvoltage 1.00
Losses active	W:1.45	Losses reactive	VAr:1.4
Current factor	%:2.62	Induction	T:.312
dT Fe average Surface	°K:4.	dT primary	°K:3.8
dT Gehäuse av. Surface	°K:.	Rezonance frequency	kHz:2.9

SHORT-CIRCUIT OPERATION	at Amb.Temperature °C 25.	and	Overvoltage 1.00
Losses active	W:21.01	Losses reactive	VAr:120.1
Current factor cold	%:158.4	Induction	T:.132
dT Fe average Surface	°K:44.2	dT primary	°K:52.5
dT Gehäuse av. Surface	°K:.	dT secondary	°K:56.3

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:	0.642							
Load on output Ω:								
Power factor of load :								
Current in segment A:	0.642							
Current density A/in^2:	1006.							
Icc-Current cold A:	1.02							
Io -Current A:	0.017							
Inrush Current peak ^A:	0.							
Inrush Current rms A:	0.							
Cu-Losses W:	4.							
Resistance cold Ω:	8.502							
Reactance Ω:	68.41							
Eddy-Current Factor :	1.01							

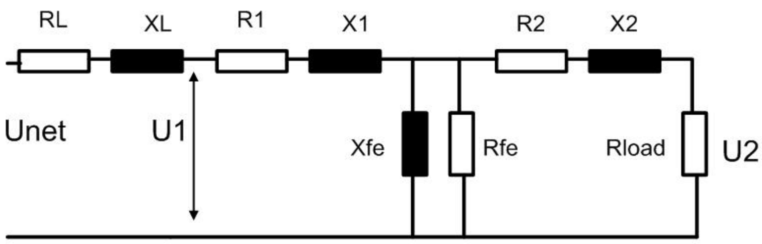
SECONDARY	1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage V:	9.93							
Output Current A:	4.965							
Out. Voltage no load V:	15.05							
Sec. Voltage V:	9.93							
Sec. Current A:	4.965							
Current density A/in^2:	1371.							
Sec. Voltage cold V:	10.1							
Load on output Ω:	2.							
Power factor of load :	1.000							
Icc cold A:	7.91							
Cu-Losses warm W:	5.55							
Resistance cold Ω:	.1897							
Reactance Ω:	.7776							
Eddy-Current Factor :	1.06							
Capacitor mF:	.							

Topic1 / Design3

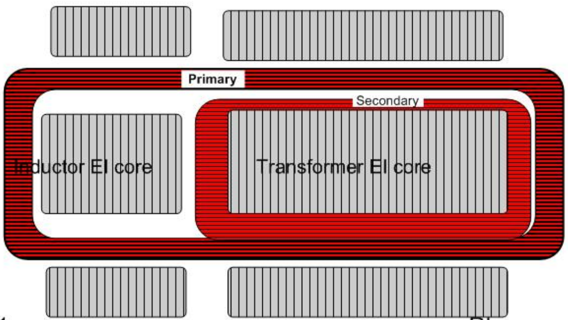
Designing inherently current limited single phase transformer 24V, 100A with integrated inductor

Genaral information

There are 2 constructions for creating a transformer with an integrated inductor:



Integrated inductor on the primary side



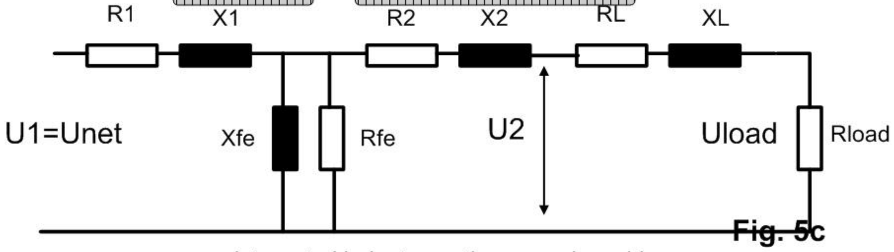
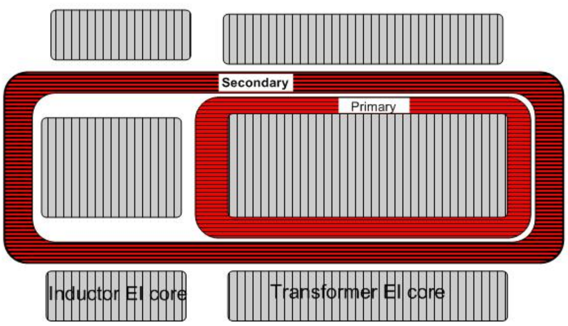


Fig. 5c

Integrated inductor on the secondary side

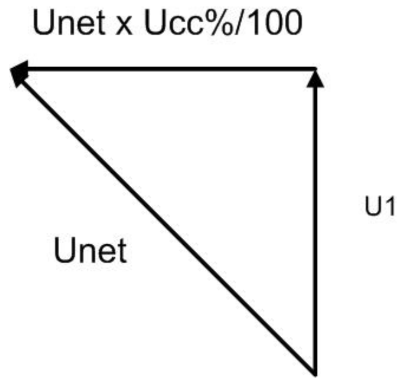


Normally the construction with the primary outside is used more often due to the fact that it protects the transformer part from voltage spikes, harmonics and it limits the inrush current. Note that the Rale Design Software doesn't support the design of the transformer with the integrated inductor full automatically. You have to design it in 2 steps; first the "transformer" and then the "inductor".
Assume the following operation mode:

- Unet = 400V, 60Hz
- Short-circuit current has to be Icc = 2 x Inominal; Ucc% = 50%
- 9 minutes @ Inominal, 1 minute @ Icc

For this operation mode the "transformer" input voltage is:

U1 = Unet x (1 – (Ucc%/100)^2) ^0.5 = 400 x (1 – 0.5^2)^0.5 = 346.4V



"Transformer" Input parameters

Primary	Voltage	346.4V -10% +24% (no-load at Unet +10%), 60Hz, sine wave
	Wire	Cu, round, single insulated
	Layer insulation	5 mil
	Final insulation	5 mil
Secondary	Nominal output rms voltage	24V on load
	Nominal current	100A
	Wire	Cu, square, single insulated
	Layer insulation	No
	Final insulation	12 mil
Core	Size	EI 250/3
	Steel	M19, alternate stacking, not annealed
Tube	Size	2.5 x 3 x 3.7
Design	Insulation class	F, max. operating temperature 155C @ 1 minute 200A and 9 minutes 100A
	Ambient temperature	40C
	Induction	<1.2T, max no-load induction 1.5T

"Transformer" output parameters

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#*0                          DIAGNOSE                    Page 0

 Name                          :1 X EI 250/(3)
 Steel                        -:M19 Gauge 26 / 0.0185"

 Number of Sections           -:3
 max.Cu-Fill Factor           %:90.
 max. parallel Wires           :2

 Induction on Load            T:1.215
 Max. Induction               T:1.235

 Max.Cu-Temp.rise on load   °K:111.
 Max.Cu-Temp.rise no-load   °K:21.1
 Regulation                   %:3.1

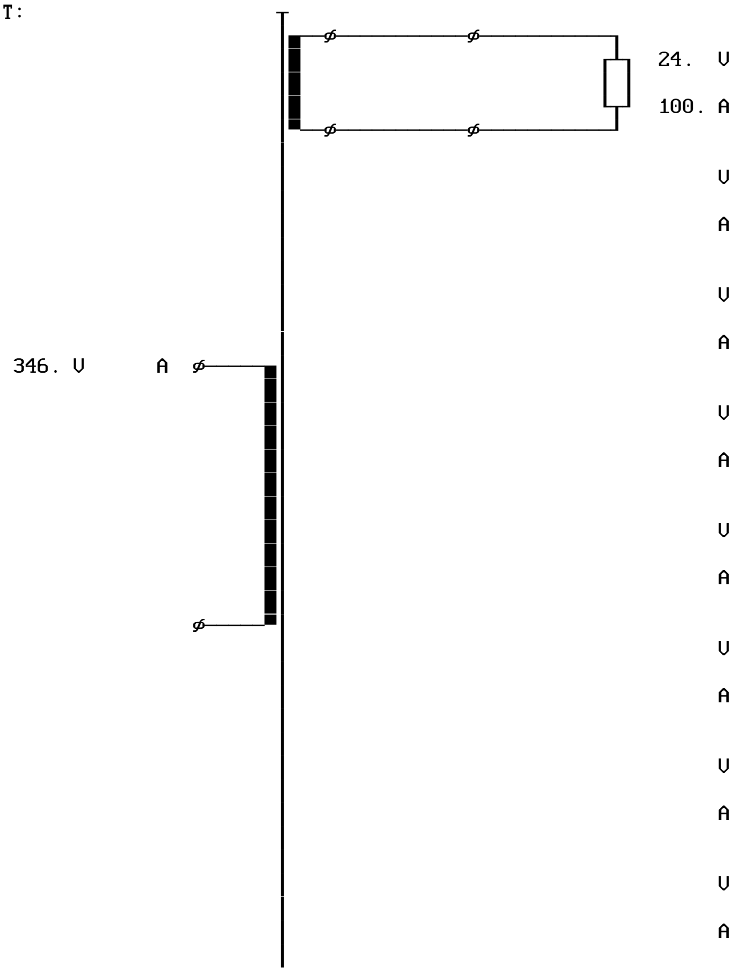
 I^Inrush/I^nom-Factor        *:10.1
 Input Current No-Load        %:2.6
```

07-28-2008/19:27:04/14.43 Input and Circuit Page 1

PRIMARY	U(V) I(A)	SECOND. 1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:1	346.	Circuit-:11
Overvlt*:1.00	.	Volta. V:24.
Wire :0.0	.	Curre. A:100.
I/L. mil:5.	.	Wire :3
I/E. mil:0.	.	I/L mil:0.0
Formfac.:1.11	.	I/E mil:12.0
Fre.Hz:60	.	
dI/Io :100	.	

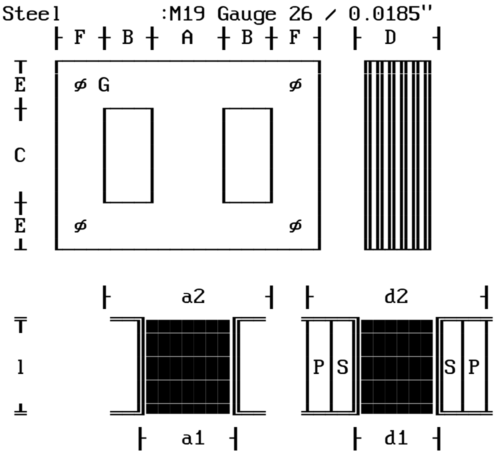
Regulat. %:50.0	Steel -:28	Cooling *:1.00	Bobbin -:3
Udiode V:0.8	Induction T:1.21	Force ft/s:0.00	P/S-Order -:2
dUdiode V:.1	Remanence *:0.35	Bracket -:1	Rac/Rdc *:1.10
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:2.00
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:115	Gap *:1.00	Channel in:0.00	Horizontal -:1
Time 1 Min:1.0	Annealed -:0	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:2.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:9.0	Hole -:1	Rth-comp. *:2.00	Selection -:1
Load 2 *:1.0	Assembly -:1	Case -:0	Criterion -:2

CIRCUIT:



07-28-2008/19:27:04 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XEI 250/(3)
Steel :M19 Gauge 26 / 0.0185" /18.5



Weight	lb:30.55
Gap total	in:0.000
A-Limb	in:2.50
B-Width	in:1.25
C-Height	in:3.75
D-Stack	in:3.00
E-Yoke 1	in:1.25
F-Yoke 2	in:1.25
G-Hole	in:0.333
Radiator Fin	:0
Radiator Chan.	:0
a1	cm:2.75
a2	cm:4.93
d1	cm 3.25
d2	cm 5.93
l	cm:3.48
lp	cm:
ls	cm:
Margin	cm:0.14

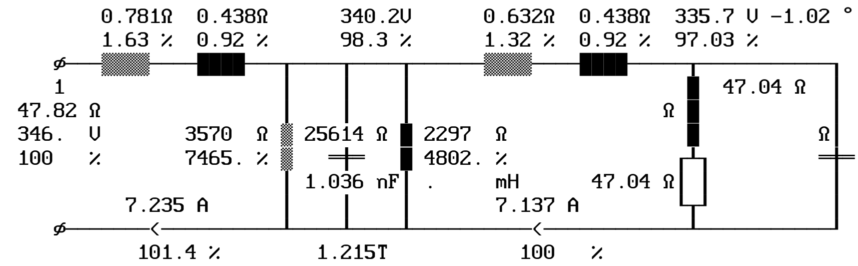
X- Length 1	in:
Y- Width 1	in:
Z- Height 1	in:
x- Length 2	in:
y- Width 2	in:
z- Height 2	in:
w- Thickness	in:
Material	:
Potted	:

	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	224.	C00	12.5	12.5	1	76.3	76.3	42	5.2	5.	.	5.362	49.
1 2 3 4 5 6 7 8	11	16.0	C11	5.0	5.0	2	182.	182.	17	1.8	.	12.	4.513	40.
TOTAL													9.876	90.

07-28-2008/19:27:04 General Data Page 3

NOMINAL OPERATION at Temperature °C 118.8 and Overvoltage 1.00

Output Power on Load	W:2396.	Output Power of Transfor.	W:2396.
Cu Losses	W:73.07	Fe-Losses active	W:32.42
Short-Circuit-Volt. cold	%:2.77	Regulation	%:3.06
Instantaneous pow. .5/95&	W:5789.	Efficiency of Transformer	%:95.78
dT Fe average Surface	°K:58.3	dT primary	°K:78.9
dT Case aver. Surface	°K:.	dT secondary	°K:78.7



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

dT Fe average Surface	°K:77.7	dT primary	°K:111.
dT Gehäuse av. Surface	°K:.	dT secondary	°K:110.7

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

Losses active	W:33.56	Losses reactive	VAr:56.52
Current factor	%:2.63	Induction	T:1.235
dT Fe average Surface	°K:26.	dT primary	°K:21.1
dT Gehäuse av. Surface	°K:.	Rezonance frequency	kHz:2.

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

Losses active	W:67795	Losses reactive	VAr:59834
Current factor cold	%:3612.	Induction	T:.584
dT Fe average Surface	°K:1477.	dT primary	°K:2128.
dT Gehäuse av. Surface	°K:.	dT secondary	°K:2690.

PRIMARY (Tap:1)	1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output V	:346.							
Out. Voltage no load V	:							
Current Input/Output A	:7.235							
Load on output Ω	:							
Power factor of load	:							
Current in segment A	:7.235							
Current density A/in^2	:1582.							
Icc-Current cold A	:261.3							
Io -Current A	:0.19							
Inrush Current peak ^A	:102.9							
Inrush Current rms A	:47.54							
Cu-Losses W	:40.9							
Resistance cold Ω	:.5559							
Reactance Ω	:.4381							
Eddy-Current Factor	:1.01							

SECONDARY	1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage V	:23.98							
Output Current A	:99.91							
Out. Voltage no load V	:24.7							
Sec. Voltage V	:23.98							
Sec. Current A	:99.91							
Current density A/in^2	:1508.							
Sec. Voltage cold V	:24.2							
Load on output Ω	:.24							
Power factor of load	:1.000							
Icc cold A	:3657.							
Cu-Losses warm W	:32.18							
Resistance cold Ω	:.0022							
Reactance Ω	:.0022							
Eddy-Current Factor	:1.04							
Capacitor mF	:.							

***

^

"Inductor" Input parameters

After the "transformer" design we know the following "inductor" parameters:

- The nominal current I1n = 7.235A
- The number of turns and the wire size
- Max. peak value of the current through the "inductor"
  1.41 x Icc = 1.41 x 2 x7.235 = 20.4A
- The core shape and steel
- Frequency f = 60 Hz

The nominal inductance of the "inductor has to be:

L = Unet x Ucc%/100 / I1n / 2 / Pi / f = 346.4 x 0.5/7.235/376 =0.06366H
L = 63.66mH linear up to = 20.4A

In the short-circuit mode of the "transformer" the "inductor" is set under the voltage of 346.4V. Using the formula:

U = 4.44 x f x W x B x Kfe x Afe

And:

- f = 60
- W = 224 (turns of the primary winding)
- B = 1.5T@20.4A^
- Afe the cross section of the "inductor" core

We calculate the stack of the "inductor" core 2.5"

Winding	RMS Inductance	63.66mH @ 20.4A^&1,5T realized with 224 turns , calculated with "transformer" design
	Wire	Cu, round, single insulated AWG 12.5, calculated with "transformer" design
	Layer insulation	5 mil
	Final insulation	5 mil
	Nominal rms current	100Arms, 60Hz
Core	Size	EI 250/2.5
	Steel	M19, alternate stacking, not annealed
Tube	Size	2.5 x 3 x 3.7
Design	Insulation class	F, max. operating temperature 155C @ 1 minute 200A and 9 minutes 100A
	Ambient temperature	40C
	Induction	<1.2T, max no-load induction 1.5/

"Inductor"output parameters

```
Name and Type of the Bobbin  :3   /1 X EI 250/(2_5)
Steel                       -:M19 Gauge 26 / 0.0185"
Used Space of the Bobbin    %: 51.4
Number of wires in parallel  :1         at RacRdc : 1.028/0.

Max. Current          Imax   A:2.04 20.4 .    .    .    30.6 .    40.8
Inductance         at Imax  mH:62.7 63.3 0.   0.   0.   62.1 0.   61.7
Nominal Induction at Imax   T:0.11 1.14 0.   0.   0.   1.69 0.   2.24
Minimal Induction at Imax   T:0.1  1.02 0.   0.   0.   1.49 0.   1.98
Maximal Induction at Imax   T:0.13 1.33 0.   0.   0.   1.95 0.   2.02

Nominal Current Inom    rms A: 7.23
Inductance   at Inom       mH: 63.45 Bei Ith^A: 10.19
Induction    at Inom peak   T: .571  Bei Ith^A: 10.19

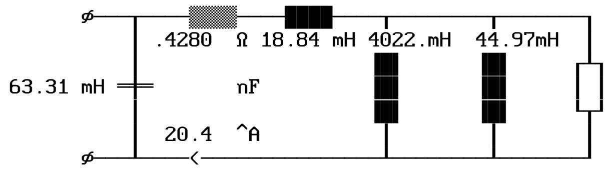
Max. dT                    °K:54.3
Max. dT  at Inom           °K:41.    at Pcu W: 28.58 and Pfe W: 34.28
Q_Factor at Inom             :44.9   at Pcu W: 28.58
```

07-28-2008/23:28:57/14.44 INPUT and OUTPUT Seite 1

	L(mH)	I(A)		1---	2---	3---	4---	5---	6---	7---	8---
Schema :1.	61.6	20.4	Harmo. -:1								
L-Type *:2.			Curre. A:7.23								
Wire -:0.			Angle °:0.								
In/L mil:5.											
In/E mil:5.											
Al/Cu -:1.											
Fre.Hz:60											
Ripple %:10.											

Q-Factor :50	Steel -:28	Cooling *:1	Bobbin -:3
Cal.Freq.Hz:60	Induction T:1.41	Ventil. m/s:0	Stomach *:1
L@Freq. .Hz:60	Plate -:1	Brackets -:1	Rac/Rdc *:1.05
:0	W/kg *:1	Radiator -:0	Space Fac. *:.9
Amb.Temp.°C:40	VAr/kg *:1	Chassis -:1	Force -:1
Tmp.rise °K:115	Gap posit.*:1	Channel in:0.	Windintech.-:1
Time 1 Min:1	Annealed -:1	Cu-Surfac.*:1	Impregnat. -:2
Load 1 *:2	Stack.Fac.*:1	Rth-Varn. *:1	Full Layer -:0
Time 2 Min:9	Hole -:0	Rth-Comp. *:1	Selection -:1
Load 2 *:1	Core Asse.-:2	Case -:0	Criteriom -:2

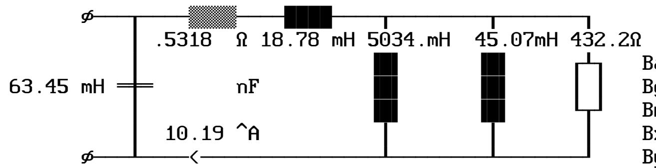
Type of the Inductance L=U/Ieff/Ω1



Bave T: 1.139
Bgap T: 1.015
Bmax T: 1.330

Nominal operation mode at the temperature °C 81.03

Nominal current Inom rms A:7.23	Peak current of Inom ^A:10.19
Al/Cu Losses/phase W:28.58	Steel Losses/phase(activ) W:34.28
Addy current losses factor :1.028	Q-Factor :44.87
dT Fe (average) °K:35.88	dT Winding (hot spot) ^°K:41.03
dT Case (average) °K:0.0	dT Windig (average) °K:40.70



Bave T: 0.571
Bgap T: 0.508
Bmax T: 0.666
Bx T: 0.033
By T: 0.014

Harmonics	:1.	0.	0.	0.	0.	0.	0.	0.
Current rms	A:7.23	.	.	.	.	.	.	.
Al/Cu Losses	W:28.58	.	.	.	0.	.	.	.
Fe-Losses	W:34.28	.	.	.	.	.	.	.

Duty cycle operation mode at the amboent temperature °C 94.30

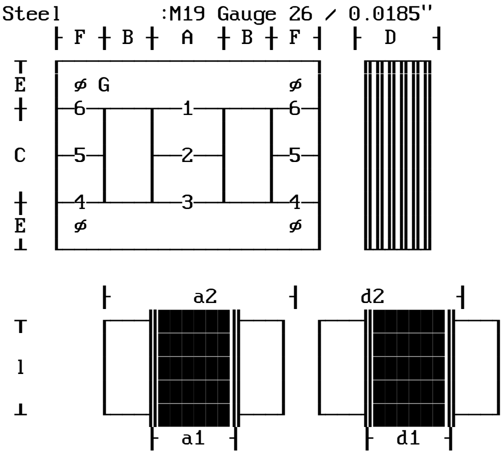
dT Steel (average) °K:43.90	dT Winding (hot spot) °K:54.30
dT Case (average) °K:0.0	dT Winding (average) °K:53.86

Inductance and induction at the impressed peak current

Current	^A	2.04	20.4	.	.	.	30.6	.	40.8	.
Induction	^T	.113	1.14	.	.	.	1.691	.	2.243	.
L=U1/Ω1/I1	mH									
L=U1/Ω1/Ieff	mH	62.75	63.31	0.	0.	0.	62.13	0.	61.78	0.
L=ΣU*t/^I	mH									
L=dU/Ω1/dI	mH									
Leaking Ind.	mH	19.17	18.84	0.	0.	0.	19.46	0.	19.66	0.
Gap-Induct.	mH	44.51	44.97	0.	0.	0.	44.05	0.	43.76	0.

07-28-2008/23:28:57 / BOBBIN / STEEL / CASE / WINDING   Seite 2

Name :1XEI 250/(2_5)
Steel :M19 Gauge 26 / 0.0185"



/18.5
Weight lb:25.46

A-Limb(Dia.) in:2.50
B-Width in:1.25
C-Height in:3.75
D-Stack/Dia. in:2.50
E-Yoke in:1.25
F-Rearyoke in:1.25
G-Hole in:0
Radiator Ribs :0
Radiator Chann.:0
a1 cm:2.75
a2 cm:4.93
d1 cm 2.75
d2 cm 5.43
l cm:3.48
lp cm:
ls cm:
Margin cm:0.14

X- Lenght 1 in:
Y- Width 1 in:
Z- Height 1 in:
x- Lenght 2 in:
y- Width 2 in:
z- Height 2 in:
w- Thicknes in:
SPK Material :
Compound in^3:

Chann./Wind. in:0.00
Chann.=>core in:0.00

	Windng	T	AWG	AWG	Para	D/ø mil	B/ø mil	Pitch mil	T/L	L	I/L mil	I/E mil	Weight lb	RWH %
1 2 3 4	224.	0	12.5	12.5	1	76.3	76.3		42.4	5.28	5.	5.	4.129	51.

Order Layers Turns								
Position Gap in	1 0.11	2 0.	3 0.	4 0.	5 0.	6 0.11	7 0.	8 0.
Voltag.V Curren.A	34.22 1.446	345.3 14.46	0. 0.	0. 0.	0. 0.	508.3 21.70	0. 0.	673.9 28.93

Order :
Customer :
Remarks :

Date :07-28-2008
Time :23:28:57

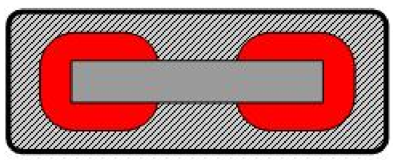
***

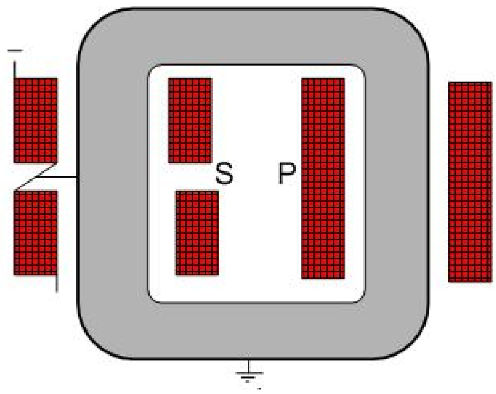
Topic2/ Design1

***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

```
#*0                        DIAGNOSE                        Page 0

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

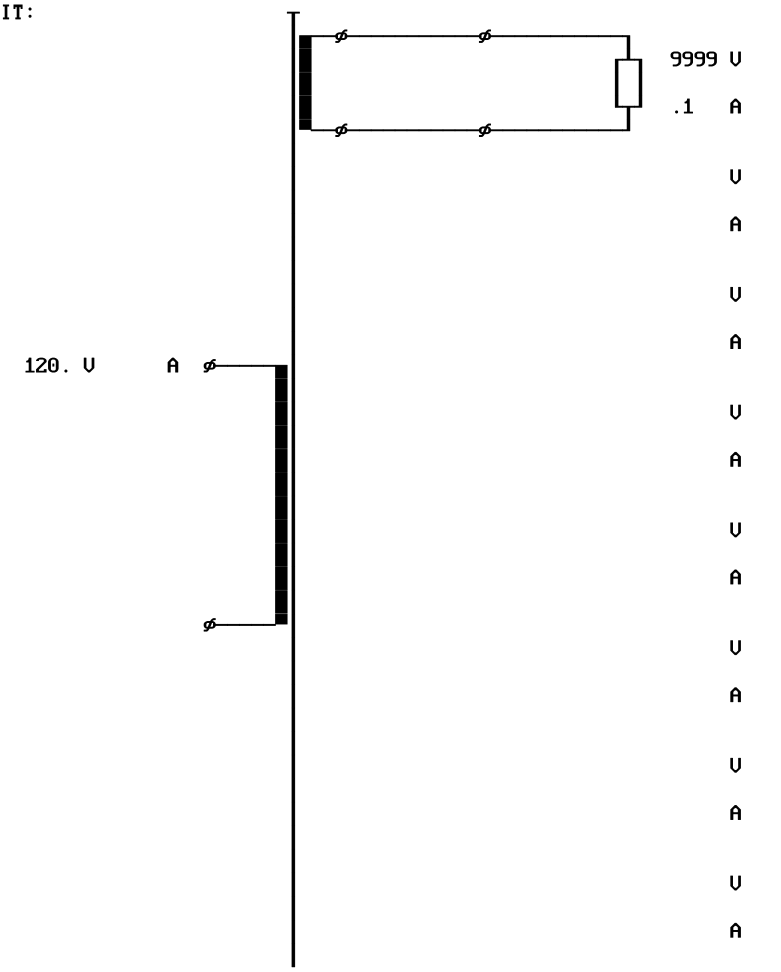
I^Inrush/I^nom-Factor        *:24.8
Input Current No-Load        %:32.2
```

07-29-2008/16:07:33/14.43 Input and Circuit Page 1

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

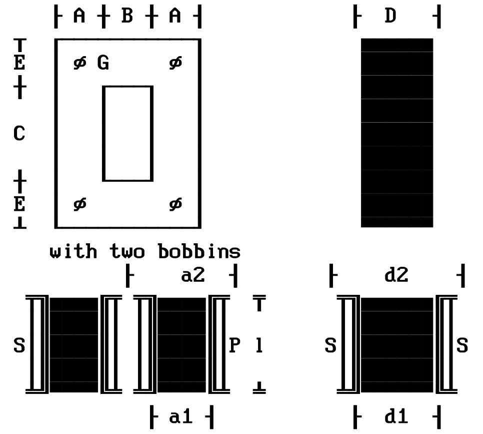
CIRCUIT:



07-29-2008/16:07:33 CORE / BOBBIN / STEEL / CASE Page 2

Name :2XSU 60/20.6 gS M

Steel :M2 0.007" => M68-0.18mm /7.09



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

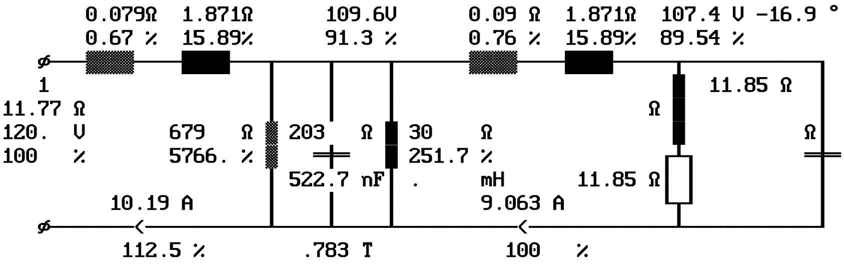
X- Length 1	in:3.21
Y- Width 1	in:4.11
Z- Height 1	in:1.65
x- Length 2	in:0.00
y- Width 2	in:0.00
z- Height 2	in:0.00
w- Thickness	in:0.04
Material	:
Potted	:

	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.

07-29-2008/16:07:33 General Data Page 3

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:.							

***

About spacing within a high voltage "dry" transformer

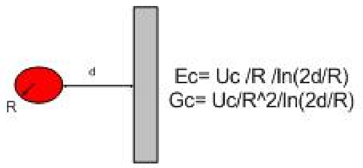
In order to avoid corona and partial discharging within a transformer we have to follow some very important rules about the **value** (V/cm) and the **form** (V/cm^2) of the electrical field.

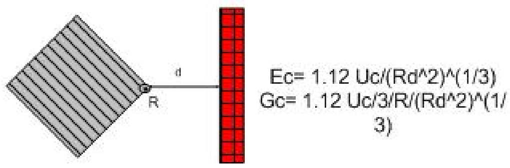
1. The electrical field between 2 parallel, naked wires with the radius R, in air with temperature 25C and pressure 1 at, that will produce the corona effect can be calculated with following formula:

   $Ec = 33.7 \times (1 + 0.242/R^{0.5})$ 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:

$$Ec = 33.7\ (1 + 0.242/0.1016)^{0.5}) = 59.28 \text{ kV/cm}$$

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

$$Uc = Ec\ R \ln(2d/R)) = 59.28 * 0.1017 \ln(5.08/0.1016) = 23.56 \text{kV}$$

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

Topic3 / Design1

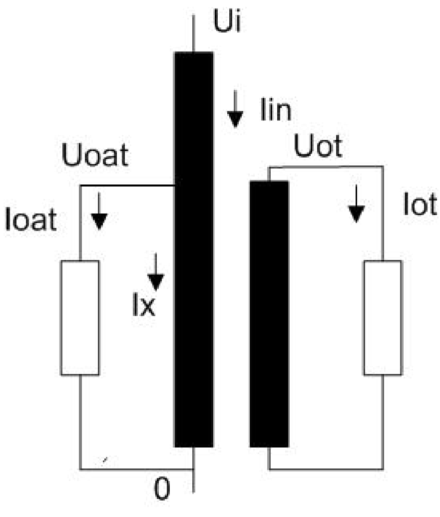
Designing mixed operation mode transformer, 230V/115V, 10A in autotransformer and 230V/115V, 10A galvanic separated connection

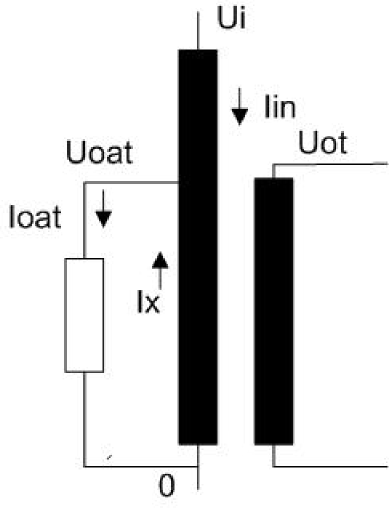
Input parameters

Input	Voltage	230V, +-10%, 50/60Hz, sine wave
	Wire	Cu, round, single insulated
Output	Nominal output voltage	115V, in autotransformer connection 115V, galvanic separated connection
	Nominal output current	10A, in autotransformer connection 10A, galvanic separated connection
	Wire	Cu, round, single insulated
Core	Steel	M19, alternate stacking, not annealed
Bobbin	Type	Single section
Design	Insulation class	B, max. operating temperature 120C,
	Ambient temperature	40C

Modifying the wire size from thermal point of view

Due to the fact that the program supports only the full load operation mode we need to compare the currents in both, full load and partial load operation mode (disconnected one of both 10A loads) and modify the wire size by hand in the segment Uoat-0.
In the full load operation mode the current Ix has amount of 0.348A (view 3. design page). If you disconnect the load of the galvanic separated winding the amount of the current Ix changes to 4.188A and the temperature rise from 60K to 112K (view design page 4)
Changing the wire size in the segment Uoat-0 from AWG 26 to AWG 20.5 the temperature rise can be set back to the amount of approx. 50K (view the last 2 design pages)





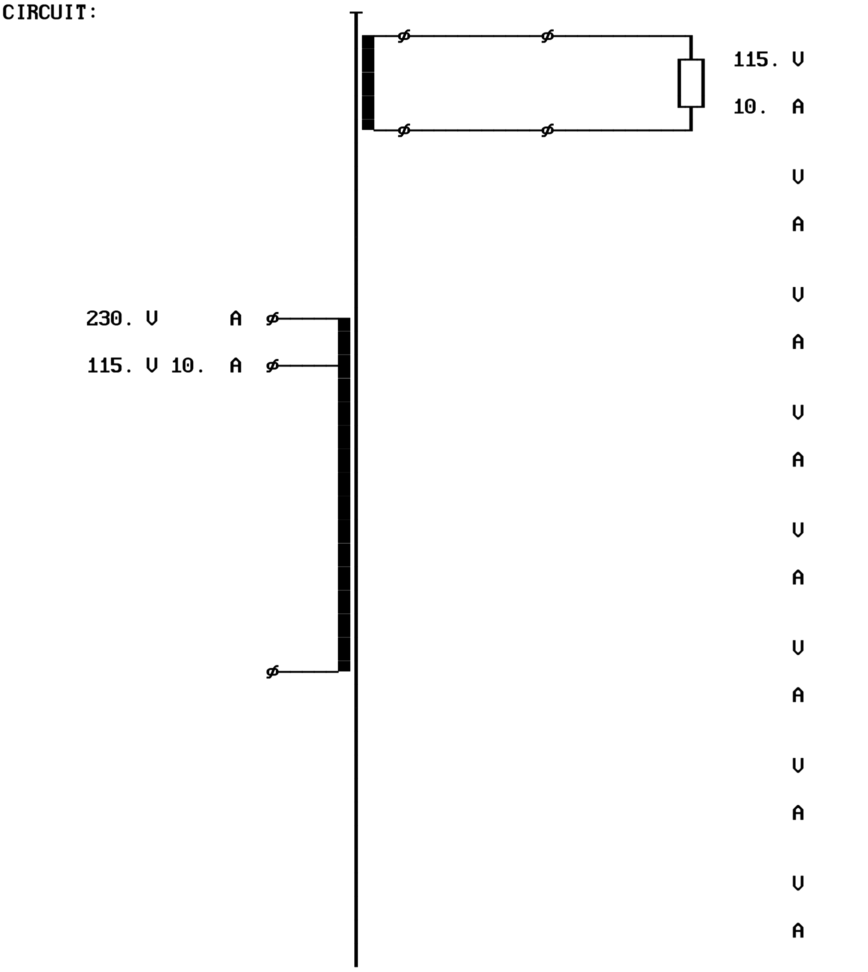
Design page 1

```
08-07-2008/18:07:31/14.43    Input and Circuit                 Page 1

PRIMARY        U(V) I(A)  SECOND.  1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:1     115. 10.   Circuit-:11
Overvlt*:1.00  230.       Volta. V:115.
Wire    :0.0   .          Curre. A:10.
I/L. mil:0.    .          Wire    :0
I/E. mil:5.    .          I/L  mil:0.0
Formfac.:1.11  .          I/E  mil:0.0
Fre.Hz:50      .
dI/Io   :100   .

Regulat.  %:50.0  Steel      -:22    Cooling   *:1.00   Bobbin     -:1
Udiode    V:0.8   Induction  T:1.30  Force  ft/s:0.00   P/S-Order  -:1
dUdiode   V:.1    Remanence  *:0.35  Bracket   -:1      Rac/Rdc    *:1.05
Ripple    %:5.    W/kg       *:1.00  Radiator  -:0      Space      *:0.95
Tmp. Amb.°C:40    VAr/kg     *:1.00  Chassis   -:1.00   Vertical   -:1
Tmp.rise °K:60    Gap        *:1.00  Channel  in:0.00   Horizontal -:1
Time 1  Min:30.0  Annealed   -:0     Cu-Surface*:1.00   Impregnat. -:2
Load 1    *:1.0   Stacking   *:1.00  Rth-varni.*:1.00   Spread     %:0
Time 2  Min:30.0  Hole       -:1     Rth-comp. *:1.00   Selection  -:0
Load 2    *:1.0   Assembly   -:1     Case      -:0      Criterion  -:0
```

CIRCUIT:



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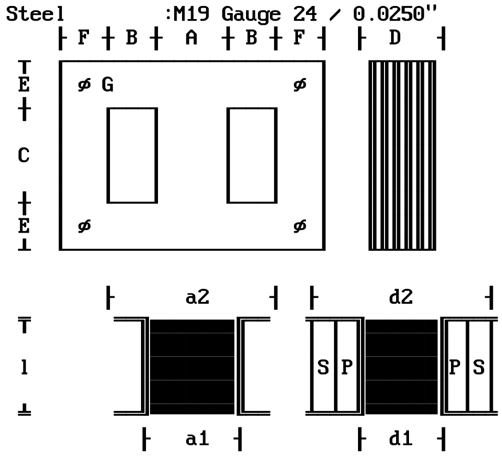
Design page 2

08-07-2008/18:07:31 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XEI 200/(2) R /EI 2HW/(2)
Steel :M19 Gauge 24 / 0.0250"



	/25.59
Weight	lb:19.52
Gap total	in:0.000
A-Limb	in:2.00
B-Width	in:1.50
C-Height	in:3.74
D-Stack	in:2.02
E-Yoke 1	in:1.25
F-Yoke 2	in:1.25
G-Hole	in:0.31
Radiator Fin	:0
Radiator Chan.	:0
a1	cm:2.18
a2	cm:4.94
d1	cm 2.18
d2	cm 4.94
l	cm:3.60
lp	cm:
ls	cm:
Margin	cm:0.07

X- Length 1	in:
Y- Width 1	in:
Z- Height 1	in:
x- Length 2	in:
y- Width 2	in:
z- Height 2	in:
w- Thickness	in:
Material	:
Potted	:

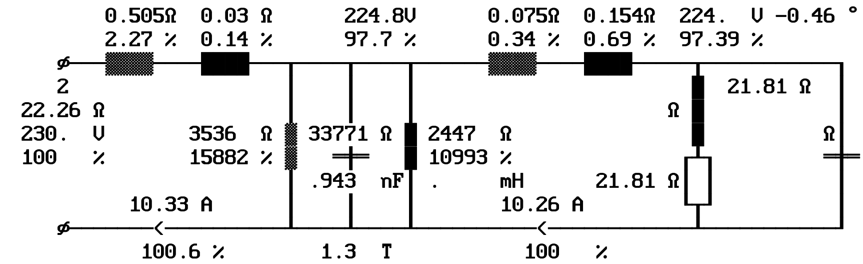
	Typ	Windun	MTI	DN	DN	Par	D/ø mil	B/ø mil	W/L	L	I/L mil	I/E mil	Weight lb	RWH %
1	1	154.8	C00	26.0	26.0	1	15.9	15.9	205	.76	.	5.	.086	1.3
2	1	308.1	C00	12.5	12.5	1	76.3	76.3	44	3.5	.	5.	2.206	24.
3														
4														
5														
6														
7														
8														
1	11	161.6	C00	11.0	11.0	1	90.7	90.7	37	4.3	.	.	4.179	36.
2														
3														
4														
5														
6														
7														
8														
TOTAL													6.471	63.

***

Design page 3

08-07-2008/18:07:31	General Data	Page 3

NOMINAL OPERATION	at Temperature °C 100.3	and Overvoltage 1.00	
Output Power on Load	W:2299.	Output Power of Transfor.	W:2299.
Cu Losses	W:61.88	Fe-Losses active	W:14.29
Short-Circuit-Volt. cold	%:2.03	Regulation	%:2.68
Instantaneous pow. .5/95&	W:950.	Efficiency of Transformer	%:96.79
dT Fe average Surface	°K:48.	dT primary	°K:60.9
dT Case aver. Surface	°K:.	dT secondary	°K:59.8



DUTY CYCLE OPERATION	at Amb.Temperature °C 40.	and Overvoltage 1.00	
dT Fe average Surface	°K:48.	dT primary	°K:60.9
dT Gehäuse av. Surface	°K:.	dT secondary	°K:59.8

NO LOAD OPERATION	at Amb.Temperature °C 40.	and Overvoltage 1.00	
Losses active	W:14.33	Losses reactive	VAr:22.78
Current factor	%:1.13	Induction	T:1.328
dT Fe average Surface	°K:13.2	dT primary	°K:11.7
dT Gehäuse av. Surface	°K:.	Rezonance frequency	kHz:1.9

SHORT-CIRCUIT OPERATION	at Amb.Temperature °C 40.	and Overvoltage 1.00	
Losses active	W:10843	Losses reactive	VAr:44587
Current factor cold	%:4933.	Induction	T:1.206
dT Fe average Surface	°K:3264.	dT primary	°K:4278.
dT Gehäuse av. Surface	°K:.	dT secondary	°K:3943.

PRIMARY (Tap:2)		1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output	V:	115.	230.						
Out. Voltage no load	V:	115.7							
Current Input/Output	A:	10.	10.33						
Load on output	Ω:	11.5							
Power factor of load	:	1.000							
Current in segment	A:	0.348	10.33						
Current density A/in^2	:	1752.	2259.						
Icc-Current cold	A:	530.6	509.7						
Io -Current	A:		0.117						
Inrush Current peak ^	A:		47.65						
Inrush Current rms	A:		18.71						
Cu-Losses	W:		33.2						
Resistance cold	Ω:	4.709	4.938						
Reactance	Ω:	.091	.0893						
Eddy-Current Factor	:	1.	1.						

SECONDARY		1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage	V:	114.9							
Output Current	A:	10.							
Out. Voltage no load	V:	120.4							
Sec. Voltage	V:	114.9							
Sec. Current	A:	10.							
Current density A/in^2	:	1547.							
Sec. Voltage cold	V:	116.2							
Load on output	Ω:	11.5							
Power factor of load	:	1.000							
Icc cold	A:	463.7							
Cu-Losses warm	W:	28.71							
Resistance cold	Ω:	.2168							
Reactance	Ω:	.0992							
Eddy-Current Factor	:	1.							
Capacitor	mF:	.							

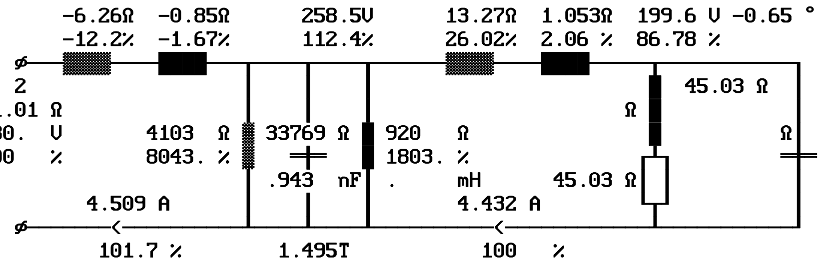
***

Design page 4

08-07-2008/18:14:58 General Data Page 3

NOMINAL OPERATION at Temperature °C 147.4 and Overvoltage 1.00

Output Power on Load	W:884.6	Output Power of Transfor.	W:884.6
Cu Losses	W:133.3	Fe-Losses active	W:16.28
Short-Circuit-Volt. cold	%:0.88	Regulation	%:15.23
Instantaneous pow. .5/95&	W:1671.	Efficiency of Transformer	%:85.53
dT Fe average Surface	°K:81.5	dT primary	°K:112.8
dT Case aver. Surface	°K:.	dT secondary	°K:102.1



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

dT Fe average Surface	°K:81.5	dT primary	°K:112.8
dT Gehäuse av. Surface	°K:.	dT secondary	°K:102.1

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

Losses active	W:14.33	Losses reactive	VAr:22.77
Current factor	%:2.59	Induction	T:1.328
dT Fe average Surface	°K:13.2	dT primary	°K:11.7
dT Gehäuse av. Surface	°K:.	Rezonance frequency	kHz:3.

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

Losses active	W:10846	Losses reactive	VAr:44602
Current factor cold	%:11309	Induction	T:1.206
dT Fe average Surface	°K:3266.	dT primary	°K:4280.
dT Gehäuse av. Surface	°K:.	dT secondary	°K:3945.

PRIMARY (Tap:2)		1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output	V:	99.8	230.						
Out. Voltage no load	V:	115.7							
Current Input/Output	A:	8.679	4.509						
Load on output	Ω:	11.5							
Power factor of load	:	1.000							
Current in segment	A:	4.188	4.509						
Current density A/in^2	:	21077	986.2						
Icc-Current cold	A:	530.7	509.9						
Io -Current	A:		0.117						
Inrush Current peak ^	A:		49.01						
Inrush Current rms	A:		19.53						
Cu-Losses	W:		133.3						
Resistance cold	Ω:	4.710	4.939						
Reactance	Ω:	.0911	.0893						
Eddy-Current Factor	:	1.	1.						

SECONDARY		1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage	V:	135.5							
Output Current	A:	0.136							
Out. Voltage no load	V:	120.4							
Sec. Voltage	V:	135.5							
Sec. Current	A:	0.136							
Current density A/in^2	:	20.99							
Sec. Voltage cold	V:	130.9							
Load on output	Ω:	999.							
Power factor of load	:	1.000							
Icc cold	A:	463.6							
Cu-Losses warm	W:	.006							
Resistance cold	Ω:	.2168							
Reactance	Ω:	.0992							
Eddy-Current Factor	:	1.							
Capacitor	mF:	.							

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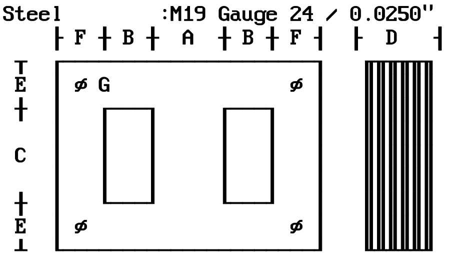
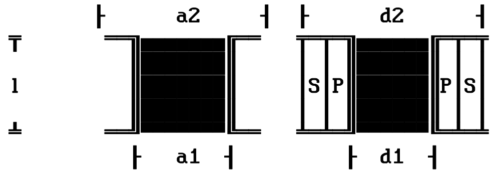
Design page 5

08-07-2008/18:16:47 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XEI 200/(2) R /EI 2HW/(2)
Steel :M19 Gauge 24 / 0.0250" /25.59





Weight lb:19.52
Gap total in:0.000
A-Limb in:2.00
B-Width in:1.50
C-Height in:3.74
D-Stack in:2.02
E-Yoke 1 in:1.25
F-Yoke 2 in:1.25
G-Hole in:0.31
Radiator Fin :0
Radiator Chan. :0
a1 cm:2.18
a2 cm:4.94
d1 cm 2.18
d2 cm 4.94
l cm:3.60
lp cm:
ls cm:
Margin cm:0.07

X- Length 1 in:
Y- Width 1 in:
Z- Height 1 in:
x- Length 2 in:
y- Width 2 in:
z- Height 2 in:
w- Thickness in:
Material :
Potted :

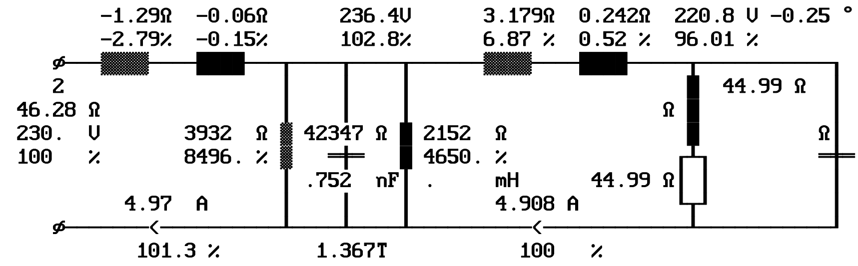
	Typ	Windun	MTI	DN	DN	Par	D/ø mil	B/ø mil	W/L	L	I/L mil	I/E mil	Weight lb	RWH %
1	1	154.8	C00	20.5	20.5	1	30.2	30.2	111	1.4	.	5.	.315	4.8
2	1	308.1	C00	12.5	12.5	1	76.3	76.3	44	3.5	.	5.	2.273	24.
3														
4														
5														
6														
7														
8														
1	11	161.6	C00	11.0	11.0	1	90.7	90.7	37	4.3	.	.	4.104	36.
2														
3														
4														
5														
6														
7														
8														
TOTAL													6.693	60.

***

Design page 6

08-07-2008/18:16:47 General Data Page 3

NOMINAL OPERATION at Temperature °C 88.4 and Overvoltage 1.00
Output Power on Load W:1083. Output Power of Transfor. W:1083.
Cu Losses W:44.65 Fe-Losses active W:14.22
Short-Circuit-Volt. cold %:0.94 Regulation %:4.15
Instantaneous pow. .5/95& W:3466. Efficiency of Transformer %:94.85
dT Fe average Surface °K:40.3 dT primary °K:50.4
dT Case aver. Surface °K:. dT secondary °K:46.4



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
dT Fe average Surface °K:40.3 dT primary °K:50.4
dT Gehäuse av. Surface °K:. dT secondary °K:46.4

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
Losses active W:14.28 Losses reactive VAr:22.45
Current factor %:2.33 Induction T:1.329
dT Fe average Surface °K:13.2 dT primary °K:11.7
dT Gehäuse av. Surface °K:. Rezonance frequency kHz:2.2

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
Losses active W:11360 Losses reactive VAr:43744
Current factor cold %:10650 Induction T:1.111
dT Fe average Surface °K:3334. dT primary °K:4413.
dT Gehäuse av. Surface °K:. dT secondary °K:3987.

PRIMARY (Tap:2)	1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output V:	110.8	230.						
Out. Voltage no load V:	115.6							
Current Input/Output A:	9.639	4.97						
Load on output Ω:	11.5							
Power factor of load :	1.000							
Current in segment A:	4.671	4.97						
Current density A/in^2:	6521.	1087.						
Icc-Current cold A:	599.5	529.3						
Io -Current A:		0.116						
Inrush Current peak ^A:		88.87						
Inrush Current rms A:		39.01						
Cu-Losses W:		44.6						
Resistance cold Ω:	1.329	1.565						
Reactance Ω:	.0898	.0881						
Eddy-Current Factor :	1.	1.						

SECONDARY	1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage V:	123.9							
Output Current A:	0.124							
Out. Voltage no load V:	120.5							
Sec. Voltage V:	123.9							
Sec. Current A:	0.124							
Current density A/in^2:	19.2							
Sec. Voltage cold V:	123.3							
Load on output Ω:	999.							
Power factor of load :	1.000							
Icc cold A:	435.6							
Cu-Losses warm W:	.004							
Resistance cold Ω:	.2129							
Reactance Ω:	.0979							
Eddy-Current Factor :	1.							
Capacitor mF:	.							

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Topic2 / Design1

Designing three phase autotransformer, for 3x400V/3x380V, 10kVA output power and 25% one phase unsymmetrical load

Input parameters

Input	Voltage	3 x 400V, +-10%, 50Hz, sine wave
	Wire	Cu, round, single insulated
	Layer insulation	No
	Final insulation	No
Output	Nominal output voltage	3 x 380V, star connection with 3 x 220V between phases and neutral line
	Nominal output current	3 x 15.15A and 1 x 3.78A UNSYMMETRICAL load
	Wire	Cu, round, single insulated
	Layer insulation	No
Core	Steel	M45, alternate stacking, not annealed
	Assembly	Gaped with 10 mil between E and I for limiting the magnetic flux of the unsymmetrical current.
Bobbin	Type	Single section
Design	Insulation class	B, max. operating temperature 120C,
	Ambient temperature	40C

Modifying the wire size from thermal point of view

Due to the fact that the program supports only the three phase symmetrical operation mode we need to compare the currents in both symmetrical and unsymmetrical operation mode, and modify the wire size by hand using the following pictures:

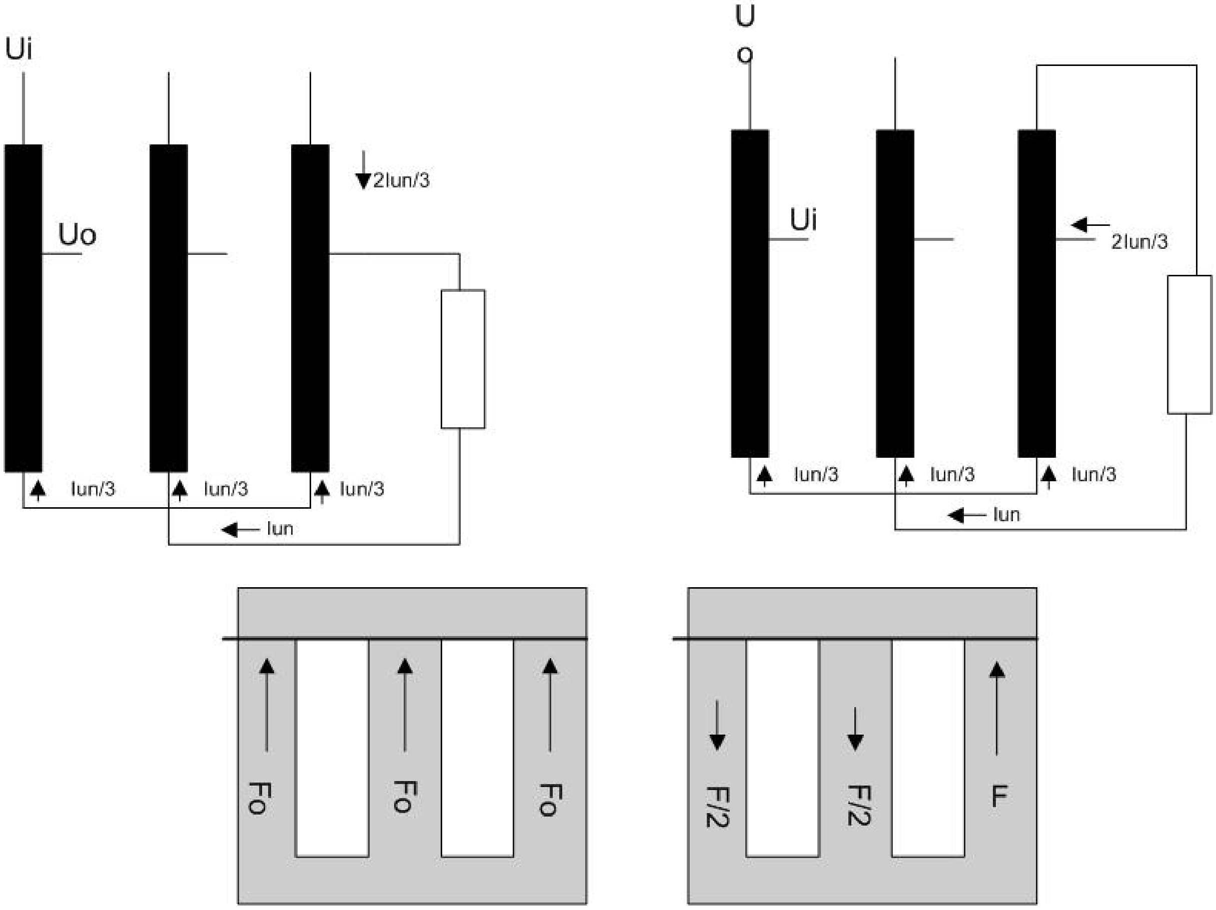
In the unsymmetrical operation mode the current between the neutral and Uo tap is Iun/3 = 3.78/3 = 1.26A. Between Ui and Uo taps the max current is 2Iun/3 = 2.52A

In the symmetrical operation mode the current between the neutral and Uo tap is (1-Uo/Ui)In= 0.635A (view the segment currents on the last page). Between Ui and Uo taps the max current is Ii = 14.6A.

If we compare the currents between the neutral and the Uo tap then we have to follow this procedure in order to design our autotransformer from thermal point of view properly:

1. Run the program in the symmetrical operation mode and select a bigger core in order to get the build approx. 40%

2. **Increase the wire cross section of the winding between the neutral and the Uo tap approx. by the factor (1.26/0.635)^2 = 3.93**



Calculating the induction during the unsymmetrical operation mode

Finally we need to check the size of the inductions Bo and B of the magnetic fluxes Fo and F.

1. The magnetic fluxes Fo are equal by size and phase. They flow through the legs and close their loops outside the core. They are normally very small and can be neglected.
2. Note that the ampere-turns of the no-load current Wi x Io = 845 x 0.268 = 226 excites over one legs the main induction of 1.3T (set on the input screen).
3. The magnetic flux F is driven by ampere-turns (on the leg with the unsymmetrical load) of the unsymmetrical current are:
   (2/3) x (Wi-Wo) x Iun = 0.666 x (845-812)x3.78 = 83
   Due to the fact that the phase delay between the main flux (driven by input voltage) and the flux F (driven by unsymmetrical current on the leg with the unsymmetrical load) is 90 degrees the max. induction in the leg during the unsymmetrical operation mode will be:
   Bmax = 1.3 x (1+(83/226)^2)^0.5 = 1.3 x 1.06 = 1.385T
4. **In order to get a very low influence of the unsymmetrical current the core has to be gaped by 10mil between the E and I part.**

```
#*0                          DIAGNOSE                          Page 0

 Name                          :3 X EI 3P120/(1_1/5)
 Steel                        -:M45 Gauge 24 / 0.0250"

 Number of Sections           -:1
 max.Cu-Fill Factor           %:88.9
 max. parallel Wires           :1

 Induction on Load            T:1.374
 Max. Induction               T:1.357

 Max.Cu-Temp.rise on load   °K:50.8
 Max.Cu-Temp.rise no-load   °K:18.3
 Regulation                   %:.4

 I^Inrush/I^nom-Factor        *:.9
 Input Current No-Load        %:1.8
```

***

08-06-2008/11:59:59/14.43 Input and Circuit Page 1

PRIMARY	U(V)	I(A)
Circuit-:1	220.	15.2
Overvlt*:1.00	230.	
Wire :0.0	.	
I/L. mil:0.	.	
I/E. mil:0.	.	
Formfac.:1.11	.	
Fre.Hz:50	.	
dI/Io :100	.	

SECOND.	1---	2---	3---	4---	5---	6---	7---	8---
Circuit-:								
Volta. V:								
Curre. A:								
Wire :								
I/L mil:								
I/E mil:								

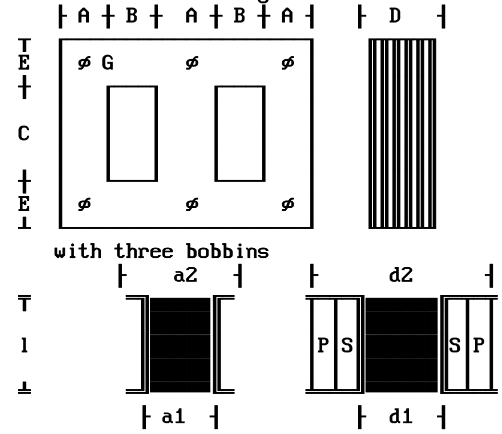
Regulat. %:7.0	Steel -:17	Cooling *:1.00	Bobbin -:1
Udiode V:0.8	Induction T:1.37	Force ft/s:0.00	P/S-Order -:2
dUdiode V:.1	Remanence *:0.35	Bracket -:1	Rac/Rdc *:1.05
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:2.00
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:60	Gap *:10.00	Channel in:0.00	Horizontal -:1
Time 1 Min:30.0	Annealed -:0	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:1.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:30.0	Hole -:1	Rth-comp. *:1.00	Selection -:2
Load 2 *:1.0	Assembly -:2	Case -:0	Criterion -:2

CIRCUIT:

***

08-06-2008/11:59:59 CORE / BOBBIN / STEEL / CASE   Page 2

Name   :3XEI 3P120/(1_1/5)
Steel   :M45 Gauge 24 / 0.0250"



		/25.59
Weight	lb	:8.27
Gap total	in	:0.000
A-Limb	in	:1.20
B-Width	in	:1.20
C-Height	in	:3.00
D-Stack	in	:1.20
E-Yoke 1	in	:1.20
F-Yoke 2	in	:1.20
G-Hole	in	:0.326
Radiator Fin		:0
Radiator Chan.		:0
a1	cm	:1.36
a2	cm	:2.35
d1	cm	1.36
d2	cm	2.35
l	cm	:2.88
lp	cm	:
ls	cm	:
Margin	cm	:0.06

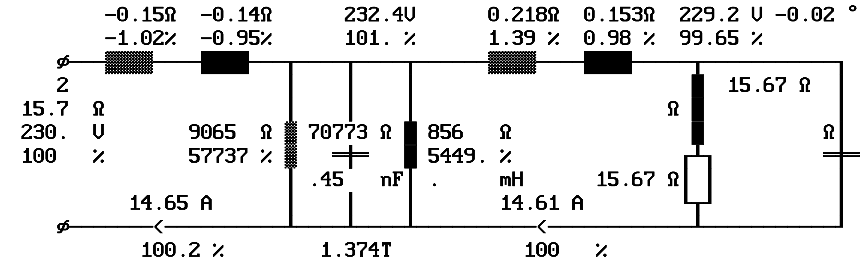
X- Length 1	in	:
Y- Width 1	in	:
Z- Height 1	in	:
x- Length 2	in	:
y- Width 2	in	:
z- Height 2	in	:
w- Thickness	in	:
Material		:
Potted		:

	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	1	812.4	C00	20.0	20.0	1	32.	32.	83	9.7	.	.	1.351	70.
2	1	845.6	C00	12.0	12.0	1	80.8	80.8	33	1.0	.	.	.444	36.
3														
4														
5														
6														
7														
8														
1														
2														
3														
4														
5														
6														
7														
8														
TOTAL													5.387	88.

***

08-06-2008/11:59:59 General Data Page 3

NOMINAL OPERATION at Temperature °C 90.4 and Overvoltage 1.00
Output Power on Load W:10051 Output Power of Transfor. W:10051
Cu Losses W:12.41 Fe-Losses active W:5.96
Short-Circuit-Volt. cold %:0.28 Regulation %:.35
Instantaneous pow. .5/95& W:80606 Efficiency of Transformer %:99.45
dT Fe average Surface °K:47.1 dT primary °K:50.9
dT Case aver. Surface °K:. dT secondary °K:



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
dT Fe average Surface °K:47.1 dT primary °K:50.8
dT Gehäuse av. Surface °K:. dT secondary °K:

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
Losses active W:6.19 Losses reactive VAr:61.27
Current factor %:1.83 Induction T:1.357
dT Fe average Surface °K:20.4 dT primary °K:18.3
dT Gehäuse av. Surface °K:. Rezonance frequency kHz:4.5

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
Losses active W:11903 Losses reactive VAr:90161
Current factor cold %:35427 Induction T:1.36
dT Fe average Surface °K:7461. dT primary °K:8768.
dT Gehäuse av. Surface °K:. dT secondary °K:

PRIMARY (Tap:2)		1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output	V:	220.2	230.						
Out. Voltage no load	V:	221.							
Current Input/Output	A:	15.21	14.65						
Load on output	Ω:	14.47							
Power factor of load	:	1.000							
Current in segment	A:	0.631	14.65						
Current density A/in^2	:	787.1	2856.						
Icc-Current cold	A:	5401.	5190.						
Io -Current	A:		0.268						
Inrush Current peak ^	A:		19.56						
Inrush Current rms	A:		9.02						
Cu-Losses	W:		12.4						
Resistance cold	Ω:	4.563	4.600						
Reactance	Ω:	.9902	.0017						
Eddy-Current Factor	:	1.	1.						

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

***

Topic: Inrush Current / Design1

Designing three phase, low inrush current universal autotransformer for 3x208V/120V, 50/60Hz, 9A

Input parameters

Input	Voltage	3 x 380/400/480/690V, +-6%, star connection, 50/60HzHz, sine wave
	Wire	Cu, round, single insulated
	Layer insulation	No
	Final insulation	Yes
Output	Nominal output voltage	3 x 208, star connection with 3 x 120V between phases and neutral line
	Nominal output current	3 x 9A
	Wire	Cu, round, single insulated
	Layer insulation	No
Core	Steel	M45, not annealed
	Assembly	Gaped with 5mil between E and I for limiting the remanence in the core.
Bobbin	Type	Single section
Design	Insulation class	B, max. operating temperature 120C,
	Ambient temperature	40C

About “low” inrush current

Note that you can not prescribe the value of the inrush current. But using the following rules you can easy limit it under the value you need:

1. If you use cold rolled or grain oriented steel set the induction between 0.9 and 1.3.
2. Use high temperature rise to increase the resistance of windings.
3. Unfortunately the remanence cannot be calculated in an alternated stacked core and vary between 20% and 70% of the operating induction. If you want to get a small and enough accurate amount of the calculated inrush current then use the gaped core assembly to reduce the remanence. Normally 3-5mil gap is big enough to reduce the remanence less than 5% of the operating induction and increase the accuracy of the inrush current calculation. The control parameter of the gap size is the amount of the no-load current. A good no-load current is smaller than 25% of the nominal primary current.
4. If you design a transformer set the primary outside. Reduce the primary wire cross section and increase the secondary wire cross section so that the temperature rise and the output voltage stay under the value you need. Due to the fact that the primary resistance is higher the inrush current will be smaller.

If you use cold rolled or grain oriented steel and you set the nominal operating induction at 0.8-0.9T then the inrush current will be very small and can be neglected. Normally, in order to save the material costs the used operating induction is 1.1-1.3T

If the relationship between the peak value of the inrush current and the peak value of the nominal current of an inverter is less than 8 then the transformer can be connected to the inverter and the inrush current is low enough.

If the relationship between the rms value of the inrush current within the first period and nominal value of a slow fuse current is less than 15 then the slow fuse can be used on the primary side of transformers. If you don't want to use the slow fuse you can use the calculated rms inrush current (view the last design page) during the first period and calculate I^2t. With the calculated I^2t you can select any fuse from catalogue.

```
#*0                        DIAGNOSE                        Page 0

 Name                          :3 X EI 3P180/(2.0)
 Steel                        -:M45 Gauge 24 / 0.0250"

 Number of Sections           -:1
 max.Cu-Fill Factor           %:87.9
 max. parallel Wires           :1

 Induction on Load            T:1.272
 Max. Induction               T:1.285

 Max.Cu-Temp.rise on load   °K:74.5
 Max.Cu-Temp.rise no-load   °K:24.2
 Regulation                   %:3.5

 I^Inrush/I^nom-Factor        *:6.9
 Input Current No-Load        %:6.5
```

***

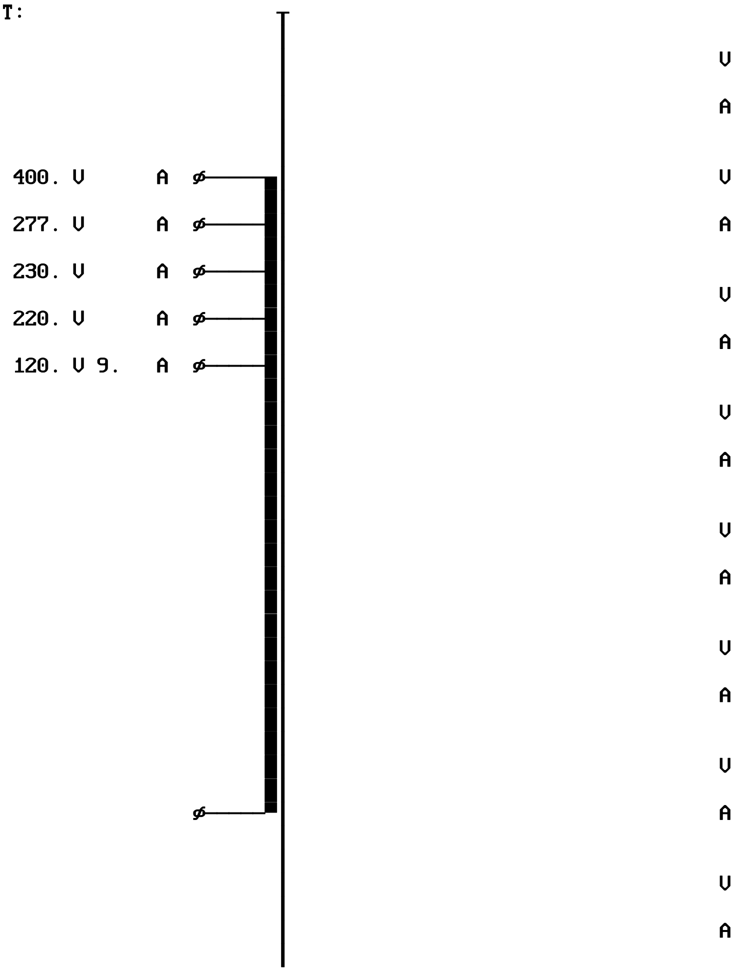
08-08-2008/14:50:56/14.43 Input and Circuit Page 1

PRIMARY	U(V)	I(A)
Circuit-:1	120.	9.
Overvlt*:1.06	220.	
Wire :0.0	230.	
I/L. mil:0.	277.	
I/E. mil:0.	400.	
Formfac.:1.11	.	
Fre.Hz:50	.	
dI/Io :100	.	

SECOND.	1---	2---	3---	4---	5---	6---	7---	8---
Circuit-:								
Volta. V:								
Curre. A:								
Wire :								
I/L mil:								
I/E mil:								

Regulat. %:50.0	Steel -:17	Cooling *:1.00	Bobbin -:1
Udiode V:0.8	Induction T:1.27	Force ft/s:0.00	P/S-Order -:2
dUdiode V:.1	Remanence *:0.05	Bracket -:1	Rac/Rdc *:1.05
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:0.95
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:75	Gap *:5.00	Channel in:0.00	Horizontal -:1
Time 1 Min:30.0	Annealed -:0	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:1.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:30.0	Hole -:1	Rth-comp. *:1.50	Selection -:2
Load 2 *:1.0	Assembly -:2	Case -:0	Criterion -:0

CIRCUIT:



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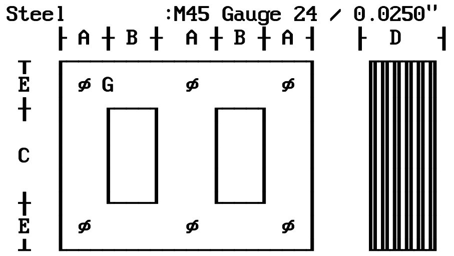
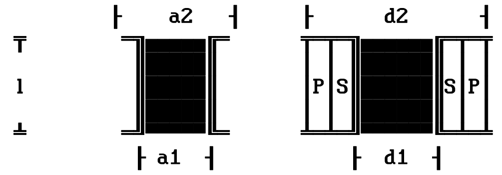
08-08-2008/14:50:56 CORE / BOBBIN / STEEL / CASE Page 2

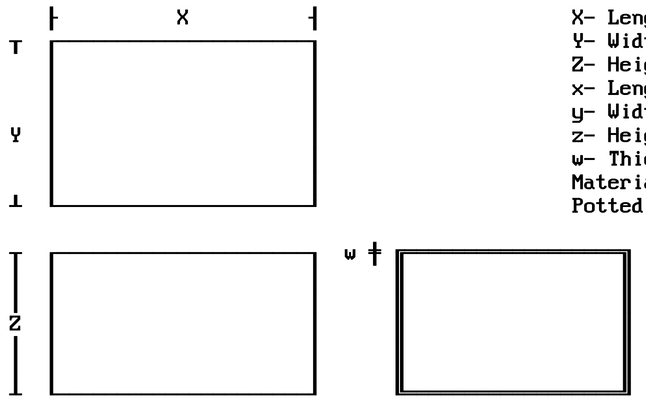
Name :3XEI 3P180/(2.0)
Steel :M45 Gauge 24 / 0.0250" /25.59



with three bobbins



Weight	lb:30.97
Gap total	in:0.000
A-Limb	in:1.80
B-Width	in:1.80
C-Height	in:4.50
D-Stack	in:2.00
E-Yoke 1	in:1.80
F-Yoke 2	in:1.80
G-Hole	in:0.49
Radiator Fin	:0
Radiator Chan.	:0
a1	cm:2.03
a2	cm:3.53
d1	cm 2.20
d2	cm 3.76
l	cm:4.25
lp	cm:
ls	cm:
Margin	cm:0.13



X- Length 1	in:
Y- Width 1	in:
Z- Height 1	in:
x- Length 2	in:
y- Width 2	in:
z- Height 2	in:
w- Thickness	in:
Material	:
Potted	:

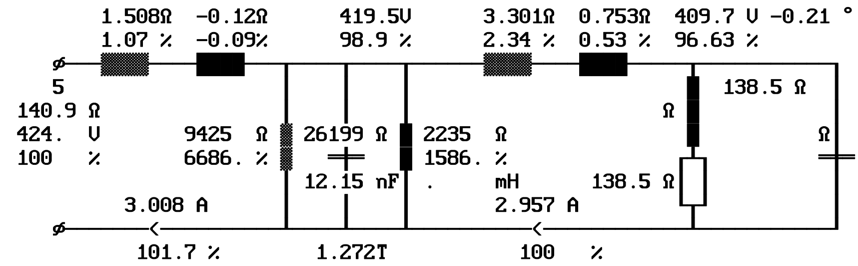
	Typ	Windun	MTI	DN	DN	Par	D/ø mil	B/ø mil	W/L	L	I/L mil	I/E mil	Weight lb	RWH %
1	1	204.7	C00	13.0	13.0	1	72.	72.	55	3.7	.	.	2.505	42.
2	1	364.6	C00	16.0	16.0	1	50.8	50.8	78	2.0	.	.	1.128	22.
3	1	377.7	C00	16.0	16.0	1	50.8	50.8	78	.17	.	.	.098	7.5
4	1	456.8	C00	16.0	16.0	1	50.8	50.8	78	1.0	.	.	.592	15.
5	1	660.2	C00	16.0	16.0	1	50.8	50.8	78	2.6	.	.	1.578	22.
6														
7														
8														
1														
2														
3														
4														
5														
6														
7														
8														
TOTAL													17.70	87.

***

08-08-2008/14:50:56 General Data Page 3

NOMINAL OPERATION at Temperature °C 113.5 and Overvoltage 1.06

Output Power on Load	W:3634.	Output Power of Transfor.	W:3634.
Cu Losses	W:41.64	Fe-Losses active	W:18.67
Short-Circuit-Volt. cold	%:2.46	Regulation	%:3.48
Instantaneous pow. .5/95&	W:4336.	Efficiency of Transformer	%:95.26
dT Fe average Surface	°K:65.6	dT primary	°K:74.5
dT Case aver. Surface	°K:.	dT secondary	°K:



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06

dT Fe average Surface	°K:65.6	dT primary	°K:74.5
dT Gehäuse av. Surface	°K:.	dT secondary	°K:

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06

Losses active	W:20.06	Losses reactive	VAr:80.56
Current factor	%:6.51	Induction	T:1.285
dT Fe average Surface	°K:29.3	dT primary	°K:24.2
dT Gehäuse av. Surface	°K:.	Rezonance frequency	kHz:.5

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06

Losses active	W:50944	Losses reactive	VAr:9319.
Current factor cold	%:4060.	Induction	T:.897
dT Fe average Surface	°K:1320.	dT primary	°K:1923.
dT Gehäuse av. Surface	°K:.	dT secondary	°K:

PRIMARY (Tap:5)		1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output	V:	127.1	233.2	243.8	293.6	424.			
Out. Voltage no load	V:	131.4							
Current Input/Output	A:	9.533				3.008			
Load on output	Ω:	13.33							
Power factor of load	:	1.000							
Current in segment	A:	6.536	3.005	3.006	3.007	3.008			
Current density A/in^2	:	1606.	1482.	1483.	1483.	1484.			
Icc-Current cold	A:	393.6				122.1			
Io -Current	A:					0.196			
Inrush Current peak	^A:					29.26			
Inrush Current rms	A:					12.29			
Cu-Losses	W:					41.6			
Resistance cold	Ω:	.328	.9236	.9751	1.287	2.120			
Reactance	Ω:	.0929	.0563	.0004	.0141	.0916			
Eddy-Current Factor	:	1.	1.	1.	1.	1.			

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

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Topic Battery Charger/ Design1

Designing rectifier transformer for battery charger 6Vdc, 40dc

Input parameters

Input	Voltage	120V, +-10%, 60Hz, sine wave
	Wire	Al, round, single insulated
Output	Nominal DC output voltage	6.3Vdc, via central tap, one phase rectifier with 2 diodes
	Nominal DC output current	40Adc, via central tap, one phase rectifier with 2 diodes
	Wire	Al, round, single insulated, wound bifilar
Core	Steel	M19, alternate stacking, not annealed
Bobbin	Type	Single section
Design	Insulation class	B, max. operating temperature 120C
	Criterion of design	16.6% regulation of the DC output voltage for battery charging between 2.45V/cell and 2.1V/cell
	Ambient temperature	40C

General rules

1. The cell voltage of an empty battery has amount of 2.1Vdc. If it is full then the voltage is between 2.35Vdc and 2.45Vdc per cell. The criterion of design has to be Regulation:
   Regulation = 100 x (2.45-2.1)/2.2 = 16.6%
2. Due to the fact that the allowed regulation is relatively low we have to use only single section bobbin.
3. The transformers with Al wires are bigger, cooler but cheaper.

```
#*0                          DIAGNOSE                          Page 0

 Name                          :1 X EI 150/(3_1/2) 8535-0
 Steel                        -:M19 Gauge 24 / 0.0250"

 Number of Sections           -:1
 max.Cu-Fill Factor           %:83.1
 max. parallel Wires           :2

 Induction on Load            T:1.354
 Max. Induction               T:1.386

 Max.Cu-Temp.rise on load    °K:58.3
 Max.Cu-Temp.rise no-load    °K:18.6
 Regulation                   %:5.9

 I^Inrush/I^nom-Factor        *:28.4
 Input Current No-Load        %:20.
```

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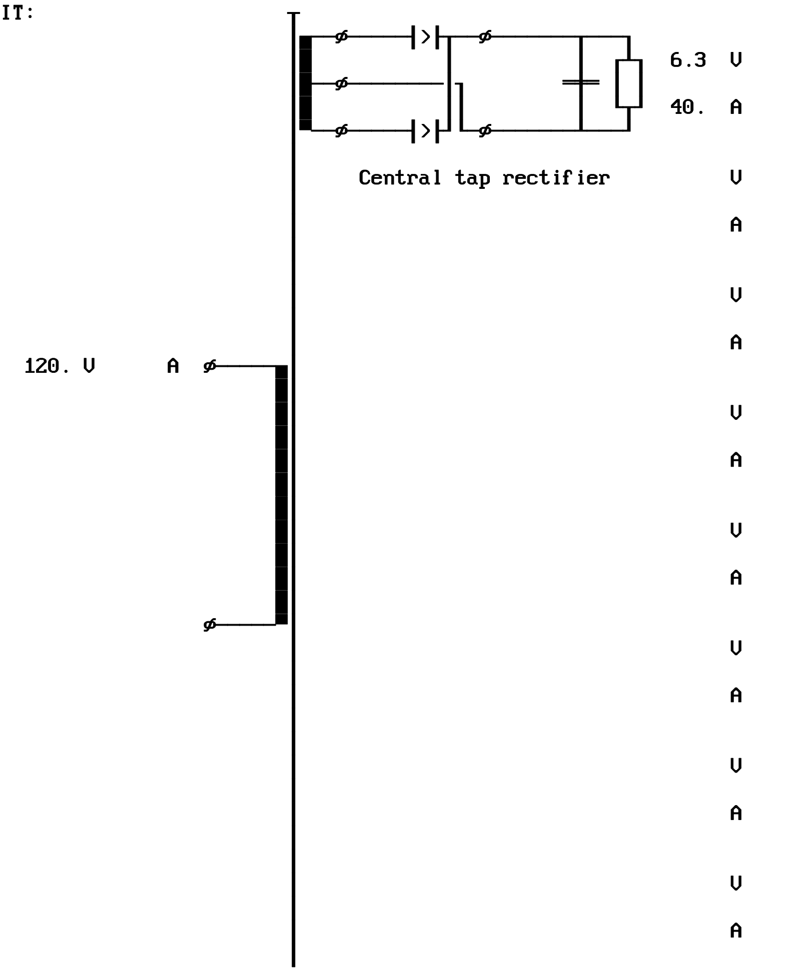
08-10-2008/15:02:42/14.43 Input and Circuit Page 1

PRIMARY U(V) I(A)	SECOND. 1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:1 120.	Circuit-:23
Overvlt*:1.00 .	Volta. V:6.3
Wire :-0.0 .	Curre. A:40.
I/L. mil:0. .	Wire :-0
I/E. mil:10. .	I/L mil:0.0
Formfac.:1.11 .	I/E mil:0.0
Fre.Hz:60 .	
dI/Io :100 .	

Regulat. %:-16.6	Steel -:22	Cooling *:1.00	Bobbin -:1
Udiode V:1.2	Induction T:1.35	Force ft/s:0.00	P/S-Order -:1
dUdiode V:.05	Remanence *:0.35	Bracket -:1	Rac/Rdc *:1.05
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:0.90
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:75	Gap *:1.00	Channel in:0.00	Horizontal -:1
Time 1 Min:30.0	Annealed -:0	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:1.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:30.0	Hole -:1	Rth-comp. *:1.00	Selection -:0
Load 2 *:1.0	Assembly -:1	Case -:0	Criterion -:0

CIRCUIT:



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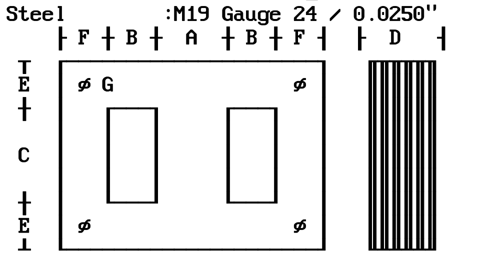
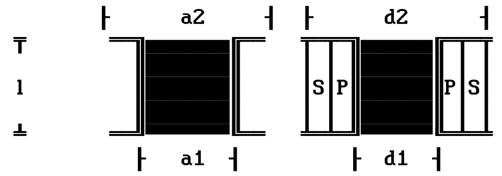
08-10-2008/15:02:42 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XEI 150/(3_1/2) 8535-0
Steel :M19 Gauge 24 / 0.0250"





/25.59
Weight lb:12.81
Gap total in:0.000
A-Limb in:1.50
B-Width in:0.75
C-Height in:2.25
D-Stack in:3.50
E-Yoke 1 in:0.75
F-Yoke 2 in:0.75
G-Hole in:0.233
Radiator Fin :0
Radiator Chan. :0
a1 cm:1.64
a2 cm:2.96
d1 cm 3.63
d2 cm 5.49
l cm:2.12
lp cm:
ls cm:
Margin cm:0.07

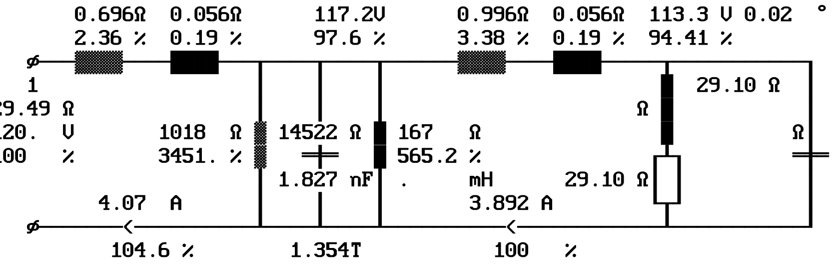
X- Length 1 in:
Y- Width 1 in:
Z- Height 1 in:
x- Length 2 in:
y- Width 2 in:
z- Height 2 in:
w- Thickness in:
Material :
Potted :

	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	99.	A00	15.5	15.5	1	53.9	53.9	36	2.7	.	10.	.241	27.
1 2 3 4 5 6 7 8	23	5.0 bifilar	A00	6.5	6.5	2	153.	153.	12	1.6	.	.	.456	54.
TOTAL													.698	83.

***

08-10-2008/15:02:42 General Data Page 3

NOMINAL OPERATION at Temperature °C 98.1 and Overvoltage 1.00
Output Power on Load W:252.5 Output Power of Transfor. W:440.9
Cu Losses W:26.63 Fe-Losses active W:13.49
Short-Circuit-Volt. cold %:6.02 Regulation %:5.92
Instantaneous pow. .5/95& W:1201. Efficiency of Transformer %:86.29
dT Fe average Surface °K:47.9 dT primary °K:57.9
dT Case aver. Surface °K:. dT secondary °K:58.4



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
dT Fe average Surface °K:47.9 dT primary °K:57.9
dT Gehäuse av. Surface °K:. dT secondary °K:58.3

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
Losses active W:13.05 Losses reactive VAr:96.77
Current factor %:20. Induction T:1.386
dT Fe average Surface °K:19.7 dT primary °K:18.6
dT Gehäuse av. Surface °K:. Rezonance frequency kHz:5.6

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
Losses active W:8096. Losses reactive VAr:519.5
Current factor cold %:1661. Induction T:.956
dT Fe average Surface °K:1110. dT primary °K:1527.
dT Gehäuse av. Surface °K:. dT secondary °K:1543.

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:4.07
Load on output Ω:
Power factor of load :
Current in segment A:4.07
Current density A/in^2:1783.
Icc-Current cold A:67.61
Io -Current A:0.814
Inrush Current peak ^A:163.0
Inrush Current rms A:70.63
Cu-Losses W:11.5
Resistance cold Ω:.5306
Reactance Ω:.0561
Eddy-Current Factor :1.

SECONDARY 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage V:6.28
Output Current A:40.23
Out. Voltage no load V:7.34
Sec. Voltage V:5.72
Sec. Current A:77.06
Current density A/in^2:2090.
Sec. Voltage cold V:5.8
Load on output Ω:.073
Power factor of load :1.000
Icc cold A:1335.
Cu-Losses warm W:15.09
Resistance cold Ω:.0019
Reactance Ω:.0001
Eddy-Current Factor :1.01
Capacitor mF:349.2

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Topic Welding/ Design1

Designing rectifier transformer for welding with 26Vdc, 200Adc

Input parameters

Input	Voltage	120V and 208V+-10%, 60Hz, sine wave
	Wire	Al, round, single insulated, wound outside
Output	Nominal DC output voltage	26Vdc, via one phase rectifier bridge and smoothing choke
	Nominal DC output current	200Adc during 1.5 minutes and 8.5 minutes pause
	Wire	Al, rectangular wire, wound inside
Core	Steel	M45, alternate stacking, not annealed
Bobbin	Type	Single section tube for EE 200/3” or EI long 150/75
Design	Insulation class	H, max. nominal g temperature 165°C at ambient temperature 40°C, ventilated with 3 ft/s airflow
	Criterion of design	Low price , high temperature rise

General rules

1. The welding transformers are normally forced cooled with airflow 0ver 3 ft/s
2. The welding transformers work in duty cycle operation mode and the winding losses are much higher than core losses. Due to this fact you can use cheap steel quality and relative high induction.
3. The welding transformers with Al wires are bigger, cooler but cheaper.
4. The welding transformers are always protected by a thermal fuse

```
#*0                      DIAGNOSE                         Page 0

Name                        :1 X EIL 200/(3)
Steel                      -:M45 Gauge 24 / 0.0250"

Number of Sections         -:1
max.Cu-Fill Factor         %:71.5
max. parallel Wires         :1

Induction on Load          T:1.456
Max. Induction             T:1.566

Max.Cu-Temp.rise on load  °K:118.3
Max.Cu-Temp.rise no-load  °K:40.8
Regulation                 %:15.2

I^Inrush/I^nom-Factor      *:8.7
Input Current No-Load      %:7.2
```

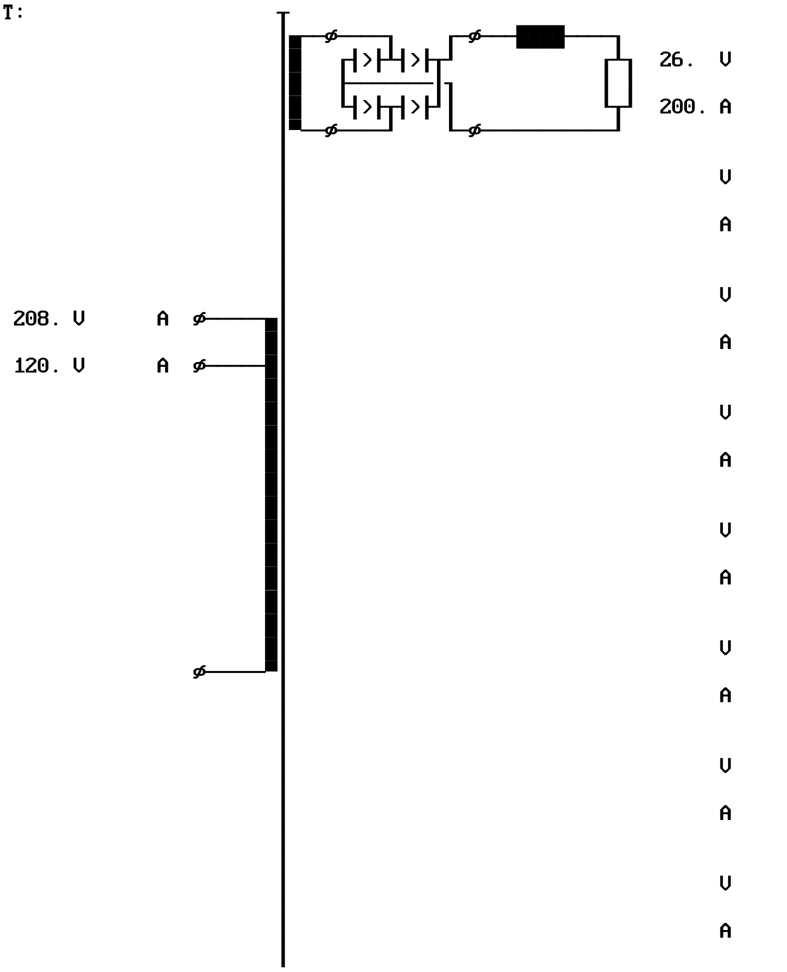
08-18-2008/23:24:34/14.43 Input and Circuit Page 1

PRIMARY	U(V)	I(A)
Circuit-:1	120.	
Overvlt*:1.00	208.	
Wire :-0.0	.	
I/L. mil:1.	.	
I/E. mil:1.	.	
Formfac.:1.11	.	
Fre.Hz:60	.	
dI/Io :100	.	

SECOND.	1---	2---	3---	4---	5---	6---	7---	8---
Circuit-:	32							
Volta. V:	26.							
Curre. A:	200.							
Wire :	-4							
I/L mil:	0.0							
I/E mil:	10.0							

Regulat. %:50.0	Steel -:17	Cooling *:1.00	Bobbin -:1
Udiode V:1.5	Induction T:1.46	Force ft/s:3.00	P/S-Order -:2
dUdiode V:.1	Remanence *:0.35	Bracket -:1	Rac/Rdc *:1.10
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:2.00
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:125	Gap *:1.00	Channel in:0.00	Horizontal -:1
Time 1 Min:1.5	Annealed -:0	Cu-Surface*:1.00	Impregnat. -:2
Load 1 *:1.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:8.5	Hole -:1	Rth-comp. *:1.00	Selection -:1
Load 2 *:.0	Assembly -:1	Case -:0	Criterion -:2

CIRCUIT:



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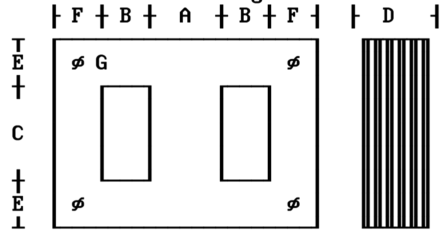
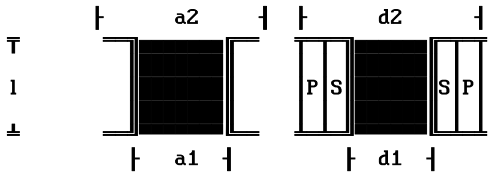
08-18-2008/23:24:34 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XEIL 200/(3)
Steel :M45 Gauge 24 / 0.0250"





	/25.59
Weight	lb:29.52
Gap total	in:0.000
A-Limb	in:2.00
B-Width	in:1.00
C-Height	in:6.00
D-Stack	in:3.00
E-Yoke 1	in:1.00
F-Yoke 2	in:1.00
G-Hole	in:0.31
Radiator Fin	:0
Radiator Chan.	:0
a1	cm:2.18
a2	cm:3.94
d1	cm 3.16
d2	cm 5.64
l	cm:5.78
lp	cm:
ls	cm:
Margin	cm:0.11

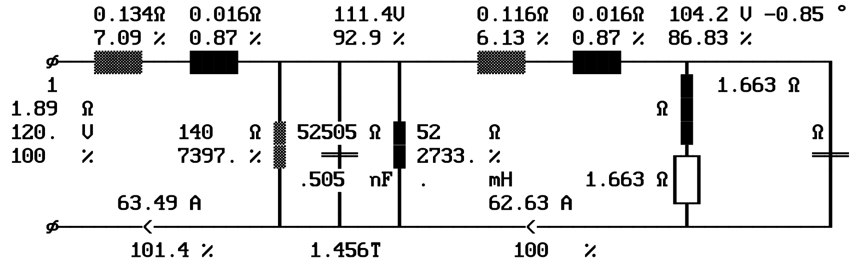
X- Length 1	in:
Y- Width 1	in:
Z- Height 1	in:
x- Length 2	in:
y- Width 2	in:
z- Height 2	in:
w- Thickness	in:
Material	:
Potted	:

	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	1	76.5	A00	8.0	8.0	1	128.	128.	42	1.8	1.	1.	1.254	33.
2	1	132.5	A00	12.0	12.0	1	80.8	80.8	67	.83	1.	1.	.398	10.
3														
4														
5														
6														
7														
8														
1	32	24	A11	10.0	97.0	1	102.	410.	13	1.8	.	10.	1.097	27.
2														
3														
4														
5														
6														
7														
8														
TOTAL													2.749	71.

***

```
08-18-2008/23:24:34          General Data                       Page 3

 NOMINAL OPERATION     at Temperature °C 158.2  and   Overvoltage 1.00
 Output Power on Load       W:5275.    Output Power of Transfor. W:6526.
 Cu Losses                  W:994.6    Fe-Losses active          W:88.79
 Short-Circuit-Volt. cold  %:9.15     Regulation                %:15.17
 Instantaneous pow. .5/95& W:11762    Efficiency of Transformer %:82.96
 dT Fe average  Surface    °K:210.9    dT primary               °K:337.4
 dT Case aver.  Surface    °K:.        dT secondary             °K:339.3
```




```
 DUTY CYCLE OPERATION  at Amb.Temperature °C 40.  and Overvoltage 1.00
 dT Fe average  Surface    °K:61.9     dT primary               °K:118.1
 dT Gehäuse av. Surface    °K:.        dT secondary             °K:118.3

 NO LOAD OPERATION     at Amb.Temperature °C 40.  and Overvoltage 1.00
 Losses    active           W:101.1    Losses    reactive      VAr:540.7
 Current factor             %:7.22     Induction                  T:1.566
 dT Fe average  Surface    °K:49.1     dT primary               °K:40.8
 dT Gehäuse av. Surface    °K:.        Rezonance frequency     kHz:19.1

 SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40.  and Overvoltage 1.00
 Losses    active           W:81731    Losses    reactive      VAr:15799
 Current factor cold        %:1092.    Induction                  T:.771
 dT Fe average  Surface    °K:1968.    dT primary               °K:2638.
 dT Gehäuse av. Surface    °K:.        dT secondary             °K:2696.

PRIMARY (Tap:1    )      1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Voltage Input/Output V:120.  208.
Out. Voltage no load V:
Current Input/Output A:63.49
Load on output       Ω:
Power factor of load  :
Current in segment   A:63.49 0.
Current density A/in^2:4898. 0.
Icc-Current   cold   A:693.7
Io -Current          A:4.584
Inrush Current peak ^A:782.0
Inrush Current rms   A:366.1
Cu-Losses            W:540.1
Resistance    cold   Ω:.0854 .2583
Reactance            Ω:.0164 .0088
Eddy-Current Factor   :1.01  1.

SECONDARY                1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage       V:26.2
Output Current       A:201.3
Out. Voltage no load V:30.59
Sec. Voltage         V:32.42
Sec. Current         A:201.3
Current density A/in^2:4814.
Sec. Voltage cold    V:32.4
Load on output       Ω:.16
Power factor of load  :1.000
Icc            cold  A:2228.
Cu-Losses      warm  W:454.5
Resistance     cold  Ω:.0072
Reactance            Ω:.0016
Eddy-Current Factor   :1.01
Capacitor          mF:.
```

***

Topic Audio/ Design1

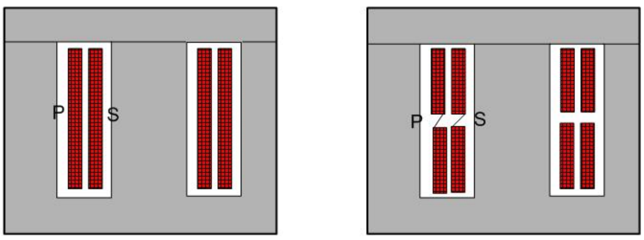
Designing the audio transformer for loudspeaker 25W, 16_Ohm

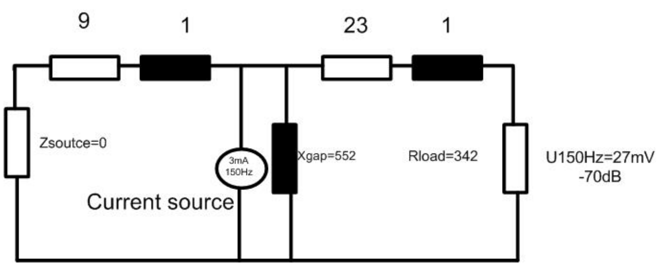
Input parameters

Input	Voltage	100V, 50-17000Hz, sine wave
	Wire	Cu, double insulated for small winding capacitance, wound outside
Output	Nominal output voltage	20V @ 50Hz, min 14.1V @ 17000Hz (-3dB)
	Nominal output current	1.25A @ 50Hz on 16 Ohm
	Wire	Cu, double insulated round wire for small winding capacitance, wound inside
Core	Steel	M6, annealed
	Assembly	Gaped EI core with 5 mil between E and I, for blocking amplifier DC bias current and the fine tuning of the resonance frequency
Bobbin	Type	Single section bobbin
Design	Criterion of design	<10% regulation

General rules

1. In order to keep the leaking reactance low normally you'll use a single section bobbin. If the resonance frequency is lower than the maxim operating frequency (in this design 17000Hz) then you can reduce the capacitance (and increase the resonance frequency) using a double section bobbin. In that case 50% of the primary and 50% of the secondary are wound in each section.£





2. For a low amount of the winding capacitance you'll use a double or heavy insulated round wire. In some cases you'll also need to use the layer insulation.
3. Typical core assembly of a loudspeaker audio transformer is gaped EI or C cores with annealed grain oriented steel. In order to avoid the output voltage distortion through the current harmonics of the magnetizing current the maximal induction should not exceed 1.3T in an annealed EI core or 1.7T in a C core. In that case the third harmonic of the magnetizing current (no load current) will not exceed 10%-15% (in our design approx. 3mA, view "Results at 50Hz without gap")
   With a gaped core assembly you can manipulate the resonance frequency changing the value of the no-load inductance. Additionally the gap will block the influence of the amplifier DC bias current.
4. At 17000Hz the output voltage is 15.85V (14.1V) and the phase delay 28.1°. If you would like to improve this operation mode then you need to reduce the eddy current losses (using litz wire) and the leaking reactance (using a long EI core with bigger Fe cross section). Note that the best results can be achieved using a toroidal core with minimum 8 sectors and one layer windings within each sector.

Results at 50Hz with gap

```
#*0                         DIAGNOSE                          Page 0

Name                          :1 X EI 75/(2)       1126-0
Steel                        -:M111-0.35mm =>M6 0.014"

Number of Sections           -:1
max.Cu-Fill Factor           %:73.4
max. parallel Wires           :1

Induction on Load            T:1.301
Max. Induction               T:1.333

Max.Cu-Temp.rise on load    °K:34.
Max.Cu-Temp.rise no-load    °K:22.7
Regulation                   %:9.8

I^Inrush/I^nom-Factor        *:14.1
Input Current No-Load        %:91.1
```

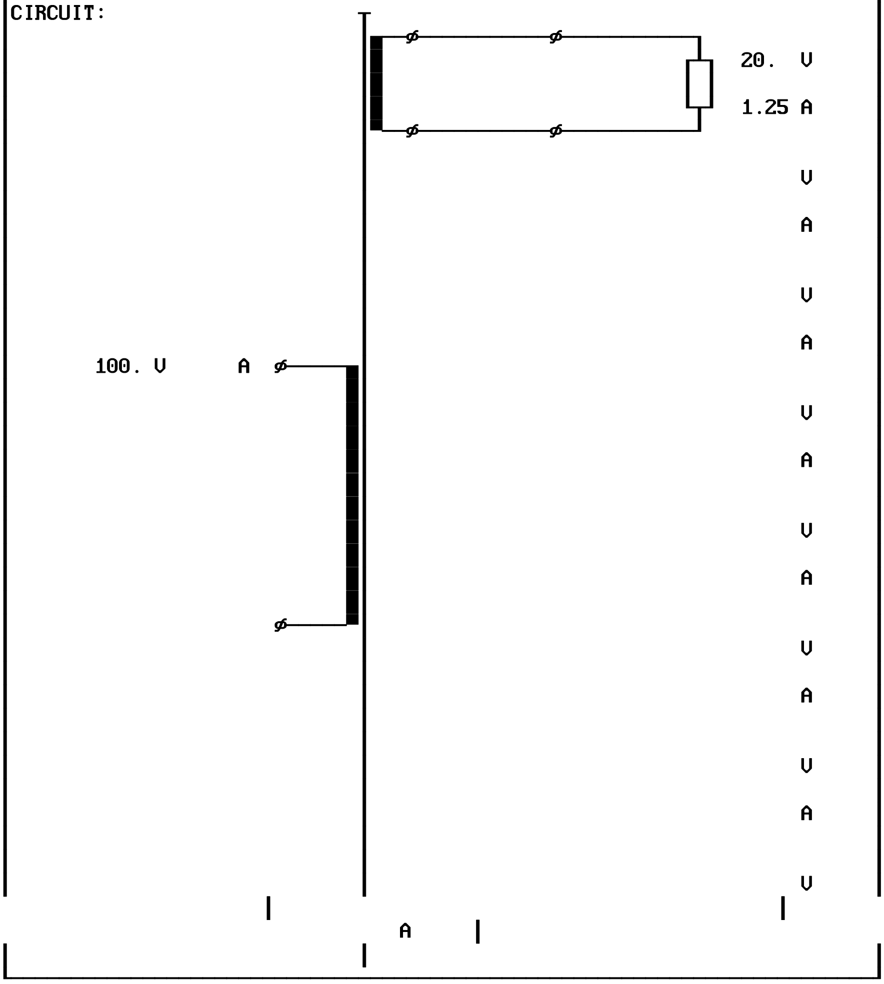
- -

08-22-2008/09:37:02/14.43 Input and Circuit Page 1

PRIMARY U(V) I(A)	SECOND. 1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:1 100.	Circuit-:11
Overvlt*:1.00 .	Volta. V:20.
Wire :2.0 .	Curre. A:1.25
I/L. mil:0. .	Wire :2
I/E. mil:10. .	I/L mil:0.0
Formfac.:1.11 .	I/E mil:5.0
Fre.Hz:50 .	
dI/Io :100 .	

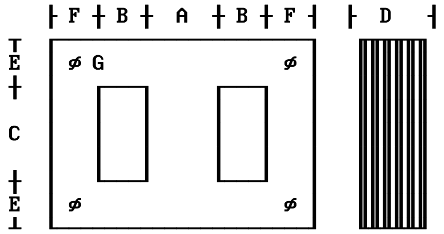
Regulat. %:8.0	Steel -:1	Cooling *:1.00	Bobbin -:1
Udiode V:1.5	Induction T:1.30	Force ft/s:0.00	P/S-Order -:2
dUdiode V:.1	Remanence *:0.35	Bracket -:1	Rac/Rdc *:1.05
Ripple %:5.	W/kg *:1.00	Radiator -:0	Space *:0.90
Tmp. Amb.°C:40	VAr/kg *:1.00	Chassis -:1.00	Vertical -:1
Tmp.rise °K:20	Gap *:5.00	Channel in:0.00	Horizontal -:1
Time 1 Min:30.0	Annealed -:1	Cu-Surface*:1.00	Impregnat. -:3
Load 1 *:1.0	Stacking *:1.00	Rth-varni.*:1.00	Spread %:0
Time 2 Min:30.0	Hole -:1	Rth-comp. *:1.00	Selection -:2
Load 2 *:1.0	Assembly -:2	Case -:0	Criterion -:1

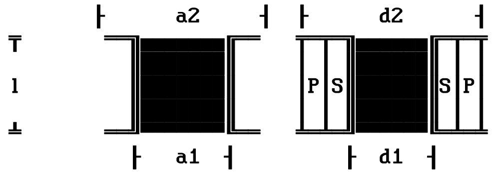
CIRCUIT:



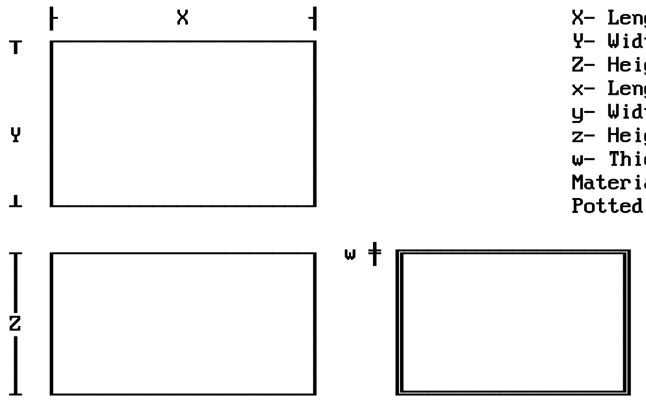
08-22-2008/09:37:02 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XEI 75/(2) 1126-0
Steel :M111-0.35mm =>M6 0.014" /13.78





Weight	lb:1.82
Gap total	in:0.000
A-Limb	in:0.75
B-Width	in:0.38
C-Height	in:1.13
D-Stack	in:2.03
E-Yoke 1	in:0.38
F-Yoke 2	in:0.38
G-Hole	in:0.00
Radiator Fin	:0
Radiator Chan.	:0
a1	cm:0.84
a2	cm:1.49
d1	cm 2.10
d2	cm 2.73
l	cm:1.03
lp	cm:
ls	cm:
Margin	cm:0.05



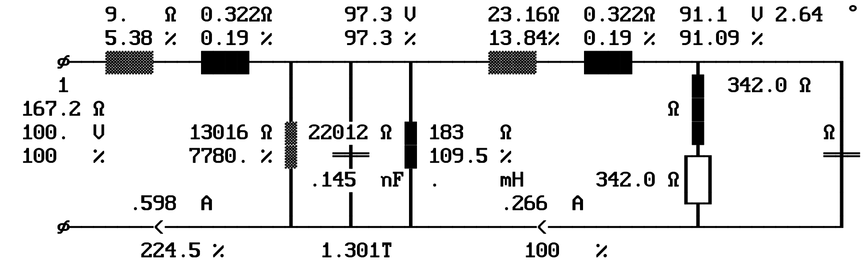
X- Length 1	in:
Y- Width 1	in:
Z- Height 1	in:
x- Length 2	in:
y- Width 2	in:
z- Height 2	in:
w- Thickness	in:
Material	:
Potted	:

	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	356.	C02	25.5	25.5	1	16.9	16.9	49	7.2	.	10.	.172	52.
1 2 3 4 5 6 7 8	11	77.0	C02	23.5	23.5	1	21.3	21.3	40	1.9	.	5.	.053	17.
TOTAL													.225	73.

08-22-2008/09:37:02 General Data Page 3

NOMINAL OPERATION at Temperature °C 72.2 and Overvoltage 1.00

Output Power on Load	W:24.26	Output Power of Transfor.	W:24.26
Cu Losses	W:4.86	Fe-Losses active	W:.73
Short-Circuit-Volt. cold	%:15.85	Regulation	%:9.79
Instantaneous pow. .5/95&	W:57.9	Efficiency of Transformer	%:81.29
dT Fe average Surface	°K:24.6	dT primary	°K:34.
dT Case aver. Surface	°K:.	dT secondary	°K:30.4



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

dT Fe average Surface	°K:24.5	dT primary	°K:34.
dT Gehäuse av. Surface	°K:.	dT secondary	°K:30.4

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

Losses active	W:3.4	Losses reactive	VAr:54.36
Current factor	%:91.11	Induction	T:1.333
dT Fe average Surface	°K:16.2	dT primary	°K:22.7
dT Gehäuse av. Surface	°K:.	Rezonance frequency	kHz:17.3

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

Losses active	W:375.2	Losses reactive	VAr:37.41
Current factor cold	%:630.9	Induction	T:.972
dT Fe average Surface	°K:267.2	dT primary	°K:410.2
dT Gehäuse av. Surface	°K:.	dT secondary	°K:448.3

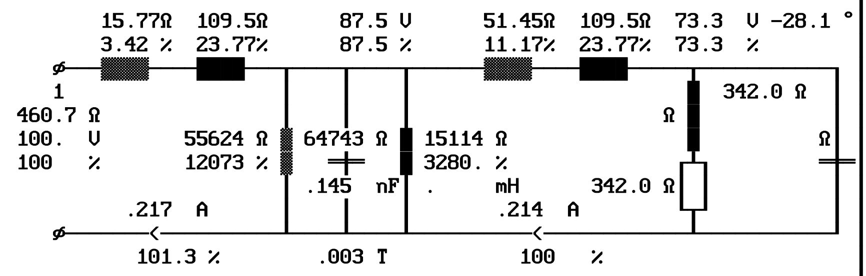
PRIMARY (Tap:1)	1----	2----	3----	4----	5----	6----	7----	8-----
Voltage Input/Output V:	100.							
Out. Voltage no load V:								
Current Input/Output A:	0.598							
Load on output Ω:								
Power factor of load :								
Current in segment A:	0.598							
Current density A/in^2:	2665.							
Icc-Current cold A:	3.77							
Io -Current A:	0.545							
Inrush Current peak ^A:	11.89							
Inrush Current rms A:	4.82							
Cu-Losses W:	3.2							
Resistance cold Ω:	7.406							
Reactance Ω:	.3221							
Eddy-Current Factor :	1.							

SECONDARY	1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage V:	19.7							
Output Current A:	1.231							
Out. Voltage no load V:	21.55							
Sec. Voltage V:	19.7							
Sec. Current A:	1.231							
Current density A/in^2:	3455.							
Sec. Voltage cold V:	19.7							
Load on output Ω:	16.							
Power factor of load :	1.000							
Icc cold A:	17.28							
Cu-Losses warm W:	1.643							
Resistance cold Ω:	.9024							
Reactance Ω:	.0151							
Eddy-Current Factor :	1.							
Capacitor mF:	.							

Results at 17000Hz

```
08-22-2008/09:38:43          General Data                   Page 3

NOMINAL OPERATION     at Temperature °C 59.9   and   Overvoltage 1.00
Output Power on Load       W:15.71    Output Power of Transfor. W:15.71
Cu Losses                  W:3.11     Fe-Losses active          W:.14
Short-Circuit-Volt. cold   %:47.66    Regulation                %:36.43
Instantaneous pow. .5/95& W:9.2       Efficiency of Transformer %:82.88
dT Fe average  Surface     °K:15.8    dT primary                °K:19.5
dT Case aver.  Surface     °K:.       dT secondary              °K:20.3
```




```
DUTY CYCLE OPERATION  at Amb.Temperature °C 40.  and Overvoltage 1.00
dT Fe average  Surface     °K:15.8    dT primary                °K:19.5
dT Gehäuse av. Surface     °K:.       dT secondary              °K:20.3

NO LOAD OPERATION     at Amb.Temperature °C 40.  and Overvoltage 1.00
Losses    active           W:.18      Losses    reactive      VAr:.44
Current factor             %:2.21     Induction                  T:.004
dT Fe average  Surface     °K:1.3     dT primary                °K:1.2
dT Gehäuse av. Surface     °K:.       Rezonance frequency      kHz:35.2

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40.  and Overvoltage 1.00
Losses    active           W:5.5      Losses    reactive      VAr:45.21
Current factor cold        %:209.8    Induction                  T:.002
dT Fe average  Surface     °K:29.2    dT primary                °K:37.7
dT Gehäuse av. Surface     °K:.       dT secondary              °K:38.8

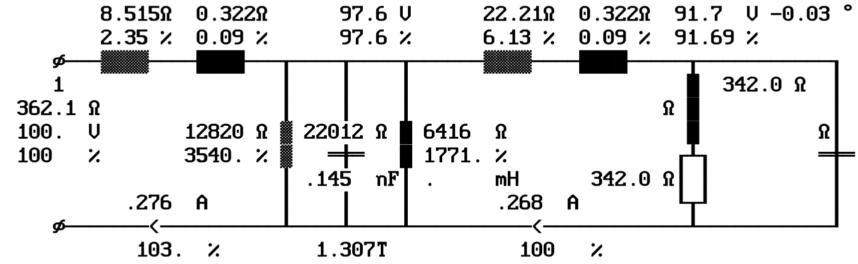
PRIMARY (Tap:1    )      1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Voltage Input/Output V:100.
Out. Voltage no load V:
Current Input/Output A:0.217
Load on output       Ω:
Power factor of load  :
Current in segment   A:0.217
Current density A/in^2:967.7
Icc-Current   cold   A:0.46
Io -Current          A:0.005
Inrush Current peak ^A:0.
Inrush Current rms   A:0.
Cu-Losses            W:.7
Resistance    cold   Ω:7.406
Reactance            Ω:109.5
Eddy-Current Factor   :1.84

SECONDARY                1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage       V:15.85
Output Current       A:0.991
Out. Voltage no load V:21.52
Sec. Voltage         V:15.85
Sec. Current         A:0.991
Current density A/in^2:2780.
Sec. Voltage cold    V:15.9
Load on output       Ω:16.
Power factor of load  :1.000
Icc            cold  A:2.08
Cu-Losses      warm  W:2.363
Resistance     cold  Ω:.9024
Reactance            Ω:5.123
Eddy-Current Factor   :2.3
Capacitor           mF:.
```

Results at 50Hz withot gap

08-22-2008/09:40:39 General Data Page 3

NOMINAL OPERATION at Temperature °C 57.7 and Overvoltage 1.00
Output Power on Load W:24.58 Output Power of Transfor. W:24.58
Cu Losses W:2.25 Fe-Losses active W:.74
Short-Circuit-Volt. cold %:7.36 Regulation %:9.06
Instantaneous pow. .5/95& W:60.6 Efficiency of Transformer %:89.16
dT Fe average Surface °K:14.9 dT primary °K:17.4
dT Case aver. Surface °K:. dT secondary °K:18.



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
dT Fe average Surface °K:14.9 dT primary °K:17.4
dT Gehäuse av. Surface °K:. dT secondary °K:18.

NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
Losses active W:.85 Losses reactive VAr:1.59
Current factor %:6.52 Induction T:1.337
dT Fe average Surface °K:5.1 dT primary °K:4.7
dT Gehäuse av. Surface °K:. Rezonance frequency kHz:2.9

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
Losses active W:374.8 Losses reactive VAr:9.59
Current factor cold %:1357. Induction T:.975
dT Fe average Surface °K:266.1 dT primary °K:403.7
dT Gehäuse av. Surface °K:. dT secondary °K:447.

PRIMARY (Tap:1) 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Voltage Input/Output V:100.
Out. Voltage no load V:
Current Input/Output A:0.276
Load on output Ω:
Power factor of load :
Current in segment A:0.276
Current density A/in^2:1231.
Icc-Current cold A:3.75
Io -Current A:0.018
Inrush Current peak ^A:11.89
Inrush Current rms A:4.82
Cu-Losses W:.6
Resistance cold Ω:7.406
Reactance Ω:.3221
Eddy-Current Factor :1.

SECONDARY 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage V:19.83
Output Current A:1.24
Out. Voltage no load V:21.61
Sec. Voltage V:19.83
Sec. Current A:1.24
Current density A/in^2:3478.
Sec. Voltage cold V:19.8
Load on output Ω:16.
Power factor of load :1.000
Icc cold A:17.31
Cu-Losses warm W:1.597
Resistance cold Ω:.9024
Reactance Ω:.0151
Eddy-Current Factor :1.
Capacitor mF:.

Topic Capacitor Charger / Design1

Designing flyback transformer for capacitor charger 10kVdc, 0.1 µF, 50W

In order to design a flyback C-charger transformer with the Rale Design Software you need the following inputs:

- Min. input voltage and the duty cycle (t_{on}&t_{off}) at this voltage
- DC-output voltages and DC-output currents
- The ripple of the ampere-turns (induction)
- Frequency

There are 2 typical operation modes:

- Continuous mode $t_s>t_{off}$
- Discontinuous mode $t_s<=t_{off}$ (typical for C-charging)

The charging & discharging of a capacitor is a dynamic procedure (view the next Figure). Due to the fact that there is no constant output voltage & current you need to determine by hand (from thermal point of view) the equivalent output voltage and the equivalent output current

Note that a flyback transformer is very suitable for charging a capacitor with constant power. In this operating mode the electronic has to control the constant frequency, the constant t_{on} time and the maximal capacitor output voltage U_c.
During the charging period T_p the capacitor C is empty ($U_c = 0$) and the secondary current will drop down with the formula:

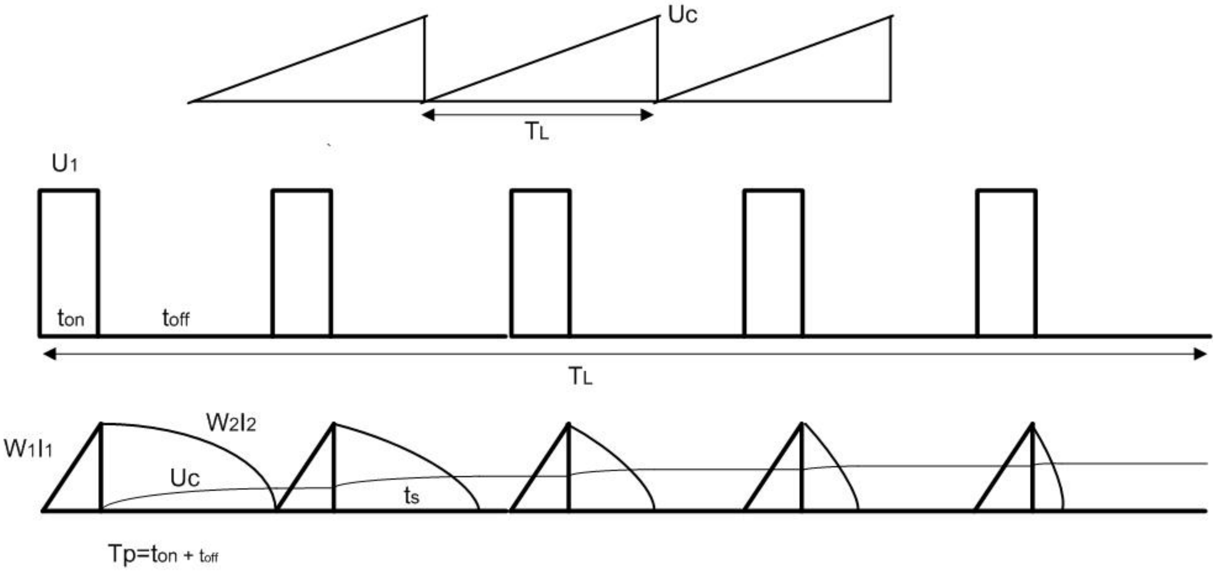
$$i_2 = Im \cos(□t)$$

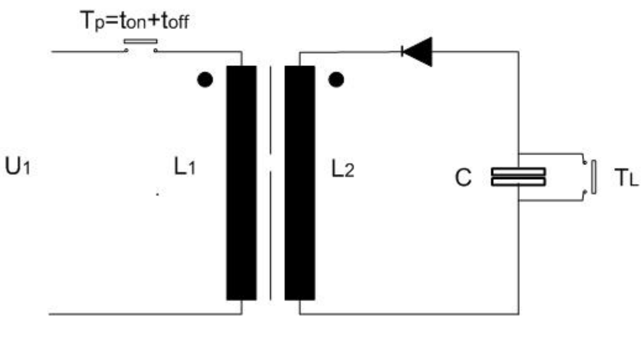
Where:

$$□ = (L_2C)^{-0.5}$$

For $i_2 = 0$, $□t_{off} = \pi/2$, $t_{off} = t_s = 900\mu s$, $t_{on} = 100\ \mu s$, $T_L = 0.1s$, $U_{cmax} = 10000V$ and $P = 50W$ we can calculate (without losses):

- The inductance of the secondary winding for the resonance frequency $1/4t_{off}$
  $L_2 = (2t_{off}/\pi)^2/C = (2\ 0.0009/3.14)^2/0.0000001 = 3.37H$
- The average value of the source current (without losses)
  $I_{1av} = P/U1 = 50/150 = 0.333A$
- The peak value of the source current
  $I_{1peak} = 2I_{1av}T_p/t_{on} = 2\ 0.333\ 1000/100 = 6.66A$
- The inductance of the primary winding
  $L_1 = U_1\ t_{on}/\ I_{1peak} = 2.25mH$
- The turns ration of the primary & secondary windings
  $W_1/W_2 = (L_1/L_2)^{0.5} = (0.00225/3.37)^{0.5} = 0.0258$
- The RMS value of the output current during the charging time T_L
  $I_{o.th} = (P\ C\ \ln(T_L/T_p)/2/T_L)^{0.5} = (50\ 0.0000001\ \ln(0.1/0.001)/2/0.1)^{0.5} = 34mA$
- The output voltage at the output current 34mA
  $U_{co.th} = P/I_{o.th} = 50/0.034 = 1470V$



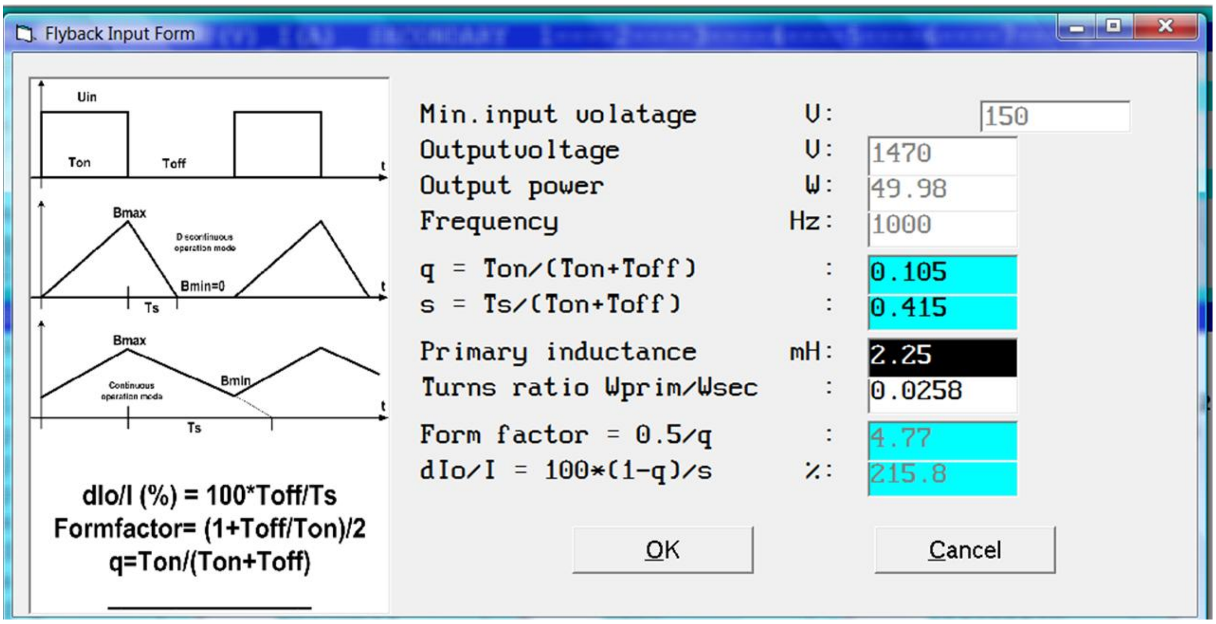


Input parameters

Input	Voltage	150V, 1000Hz, t_{on} =100µs, t_{off} = 900 µs
	Wire	Cu, round, single insulated
Output	Nominal DC output voltage	Nominal1470V, max. 10000V
	Nominal DC output current	Nominal 34mA, min. 5mA
	Wire	Cu, round, double insulated, wound outside
Core	Steel	Ferrite N27
Bobbin	Type	Single section, potted
Design	Insulation class	E, max. operating temperature 120C
	Criterion of design	Temperature rise
	Ambient temperature	40C

General rules

1. Before you start designing of the flybyck transformer with the above specified input parameters you have to set the **Form Factor** and the **dI/Io :**
   Form Factor = $T_p/2/t_{on}$
   dI/Io = 100 t_{off}/t_s
   These 2 input parameters can be calculated if you set q = ton/Tp & s = ts/Tp or L1 & W1/W2 in the following input mask:



2. Note that discharging time t_s varies during the time TL from 900 µs to 71µs. Due to this fact the operating flyback frequency can not be selected very high. If the output voltage is over the bobbin testing voltage and the transformer has to be potted then the flyback operating frequency has to be selected less than 2-3kHz.
3. If the commutating losses in the primary leaking inductance are too high then you need to increase t_{on} time.

Design at nominal operation mode 1470V @ 34mA

```
#*0                         DIAGNOSE                         Page 0

 Name                           :1 X ETD 59  B66397
 Steel                         -:N27         <SIEMENS 200k

 Number of Sections            -:1
 max.Cu-Fill Factor            %:85.3
 max. parallel Wires            :1

 Induction on Load             T:0.126
 Max. Induction                T:0.267

 Max.Cu-Temp.rise on load     °K:50.5
 Max.Cu-Temp.rise no-load     °K:.
 Regulation                    %:.

 I^Inrush/I^nom-Factor         *:.
 Input Current No-Load         %:.
```

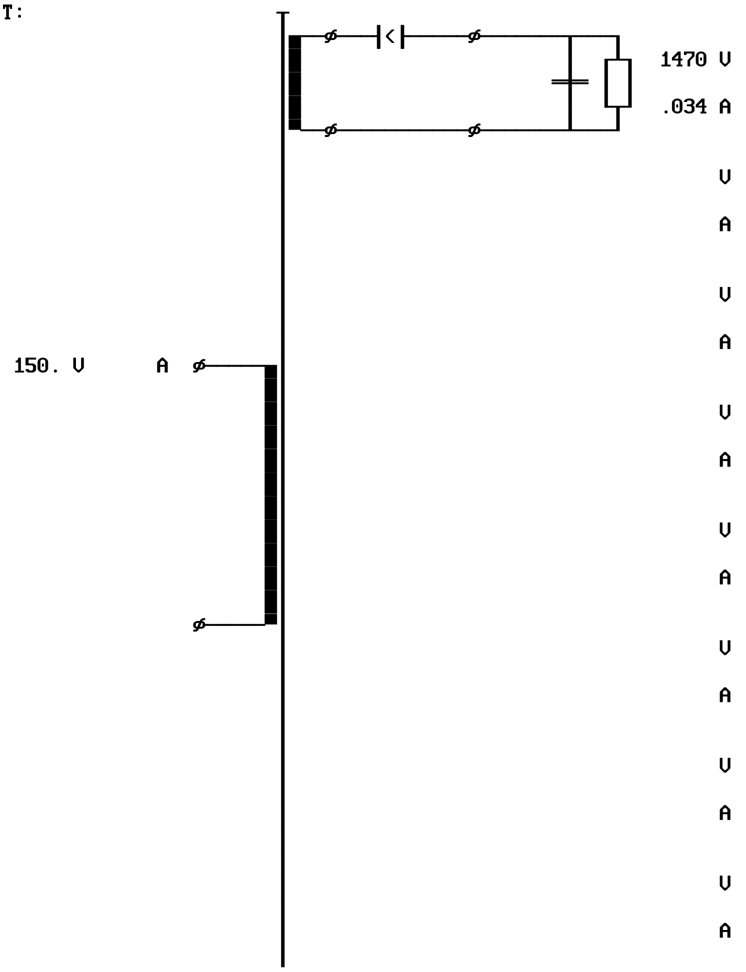
***

```
08-29-2008/20:12:28/14.43    Input and Circuit              Page 1

PRIMARY        U(V) I(A) SECOND.  1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:1     150.      Circuit-:35
Overvlt*:1.00  .         Volta. V:1470
Wire    :0.0   .         Curre. A:.034
I/L. mil:0.    .         Wire    :1
I/E. mil:10.   .         I/L  mil:2.0
Formfac.:4.76  .         I/E  mil:2.0
Fre.Hz:1000    .
dI/Io   :213   .

Regulat.  %:50.0  Steel      -:3     Cooling   *:1.00  Bobbin     -:1
Udiode    V:0.8   Induction T:0.27   Force ft/s:0.00   P/S-Order  -:1
dUdiode   V:.1    Remanence *:0.00   Bracket   -:1     Rac/Rdc    *:1.25
Ripple    %:5.    W/kg      *:1.00   Radiator  -:0     Space      *:0.90
Tmp. Amb.°C:40    VAr/kg    *:1.00   Chassis   -:1.00  Vertical   -:0
Tmp.rise °K:50    Gap       *:0.00   Channel  in:0.00  Horizontal -:1
Time 1  Min:30.0  Annealed  -:1      Cu-Surface*:1.00  Impregnat. -:4
Load 1    *:1.0   Stacking  *:1.00   Rth-varni.*:1.00  Spread     %:0
Time 2  Min:30.0  Hole      -:1      Rth-comp. *:1.00  Selection  -:2
Load 2    *:1.0   Assembly  -:2      Case      -:0     Criterion  -:2
```

CIRCUIT:



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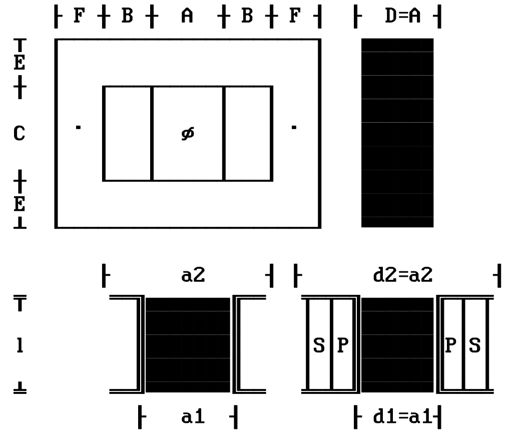
08-29-2008/20:12:28 CORE / BOBBIN / STEEL / CASE Page 2

Name :1XETD 59 B66397
Steel :N27 <SIEMENS 200k /39.37



Weight lb:.61
Gap total in:0.211
A-Limb in:0.87
B-Width in:0.42
C-Height in:1.73
D-Stack in:0.87
E-Yoke 1 in:0.36
F-Yoke 2 in:0.34
G-Hole in:0.00
Radiator Fin :0
Radiator Chan. :0
a1 cm:0.97
a2 cm:1.67
d1 cm 0.97
d2 cm 1.67
l cm:1.61
lp cm:
ls cm:
Margin cm:0.06

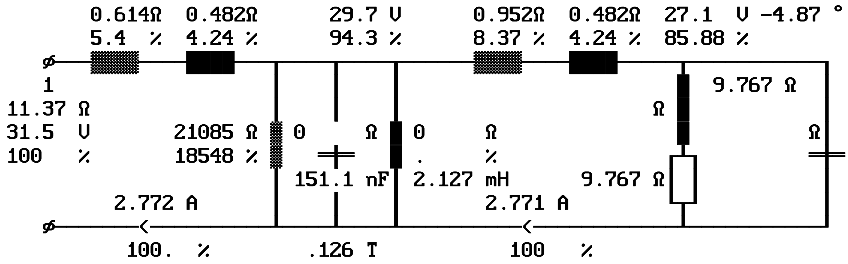
X- Length 1 in:
Y- Width 1 in:
Z- Height 1 in:
x- Length 2 in:
y- Width 2 in:
z- Height 2 in:
w- Thickness in:
Material :
Potted :

	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	154.1	C00	19.5	19.5	1	33.9	33.9	44	3.5	.	10.	.153	36.
1 2 3 4 5 6 7 8	35	7045.1	C01	37.5	37.5	1	4.2	4.2	303	23.	2.	2.	.137	46.
TOTAL													.29	85.

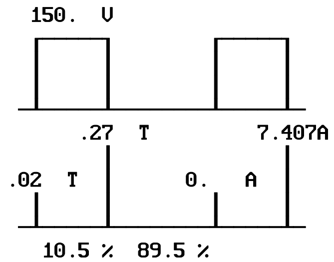
***

08-29-2008/20:12:28 General Data Page 3

NOMINAL OPERATION at Temperature °C 90.1 and Overvoltage 1.00
Output Power on Load W:58.31 Output Power of Transfor. W:74.99
Cu Losses W:8.49 Fe-Losses active W:.04
Short-Circuit-Volt. cold %: Regulation %:.
Instantaneous pow. .5/95& W:. Efficiency of Transformer %:82.85
dT Fe average Surface °K:46.3 dT primary °K:49.7
dT Case aver. Surface °K:. dT secondary °K:50.5



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00
dT Fe average Surface °K:46.3 dT primary °K:49.7
dT Case aver. Surface °K:. dT secondary °K:50.5



Frequency Hz:1000.
Rezonance frequency kHz:8.9
Input voltage V:150.
Relative turn on time %:10.5
Relative turn off time %:89.5
Rel.duty cycle s.current %:42.
Ripple (input current) %:100.
Min. Induction/Current T-A:.02 /0.
Max. Induction/Current T-A:.27 /7.407
No-load inductance mH:2.127
Ripple (output voltage) %:5.

PRIMARY (Tap:1) 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Input voltage V:150.
:
Input current rms. A:1.386
:
:
Current in segment A:1.386
Current dencity A/in^2:
:
:
Min. input current ^A:0.
Max. input current ^A:7.407
Cu-Losses W:1.2
Resistance cold Ω:.4069
Leaking reactance Ω:.4816
Eddy-Current Factor :1.18

SECONDARY 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage V:1713.
Output current dc A:0.034
:
Secondary curr. rms %:0.061
:
Current dencity A/in^2:
Secondary curr. min ^A:0.
Secondary curr. max ^A:0.162
:
:
Cu-losses warm W:7.307
Resistance cold Ω:1550.
Leaking reactance Ω:1006.
Eddy-current factor :1.
Capacitor mF:.
Capacitor curr. rms A:.05

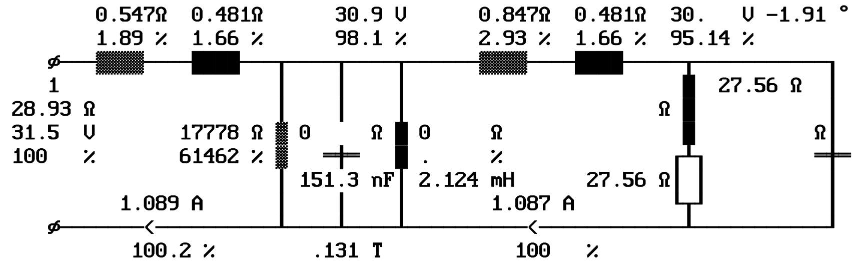
***

Design at maximal output voltage 10000V @ 5mA

08-29-2008/18:15:50 General Data Page 3

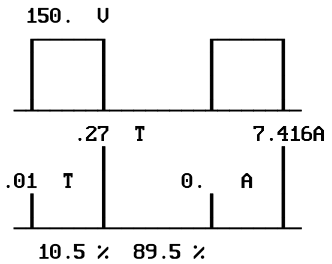
NOMINAL OPERATION at Temperature °C 54.6 and Overvoltage 1.00

Output Power on Load	W:55.56	Output Power of Transfor.	W:32.59
Cu Losses	W:1.96	Fe-Losses active	W:.05
Short-Circuit-Volt. cold	%:	Regulation	%:.
Instantaneous pow. .5/95&	W:.	Efficiency of Transformer	%:97.03
dT Fe average Surface	°K:13.7	dT primary	°K:14.6
dT Case aver. Surface	°K:.	dT secondary	°K:14.5



DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.00

dT Fe average Surface	°K:13.7	dT primary	°K:14.6
dT Case aver. Surface	°K:.	dT secondary	°K:14.5



Frequency	Hz:1000.
Rezonance frequency	kHz:8.9
Input voltage	V:150.
Relative turn on time	%:10.5
Relative turn off time	%:89.5
Rel.duty cycle s.current	%:7.1
Ripple (input current)	%:100.
Min. Induction/Current	T-A:.01 /0.
Max. Induction/Current	T-A:.27 /7.416
No-load inductance	mH:2.124
Ripple (output voltage)	%:5.

PRIMARY (Tap:1)		1----	2----	3----	4----	5----	6----	7----	8-----
Input voltage	V:	150.							
	:								
Input current rms.	A:	1.322							
	:								
	:								
Current in segment	A:	1.322							
Current dencity A/in^2	:								
	:								
	:								
Min. input current	^A:	0.							
Max. input current	^A:	7.416							
Cu-Losses	W:	1.							
Resistance cold	Ω:	.4066							
Leaking reactance	Ω:	.4808							
Eddy-Current Factor	:	1.18							

SECONDARY		1----	2----	3----	4----	5----	6----	7----	8-----
Output Voltage	V:	10111							
Output current dc	A:	0.005							
	:								
Secondary curr. rms	%:	0.024							
	:								
Current dencity A/in^2	:								
Secondary curr. min	^A:	0.							
Secondary curr. max	^A:	0.154							
	:								
	:								
Cu-losses warm	W:	1.001							
Resistance cold	Ω:	1550.							
Leaking reactance	Ω:	1006.							
Eddy-current factor	:	1.							
Capacitor	mF:	.							
Capacitor curr. rms	A:	.023							

Designing a 500 kVA, 60Hz, K-Factor, three phase dry transformer with cooling channels?

General Information

Technical Specification

Input voltage	3 x 480V, delta
Output voltage	3 x 208/120V, star
Output power	500kVA, K-Factor=20, continuous operating mode
Frequency	60Hz
Ambient temperature	40°C, in a cabinet
Temperature rise	Max. 120°K, insulation class H
°Short-circuit voltage	4-5%
Steel&core	M6, not annealed, strips for alternated stacking (90°)

Creating Input

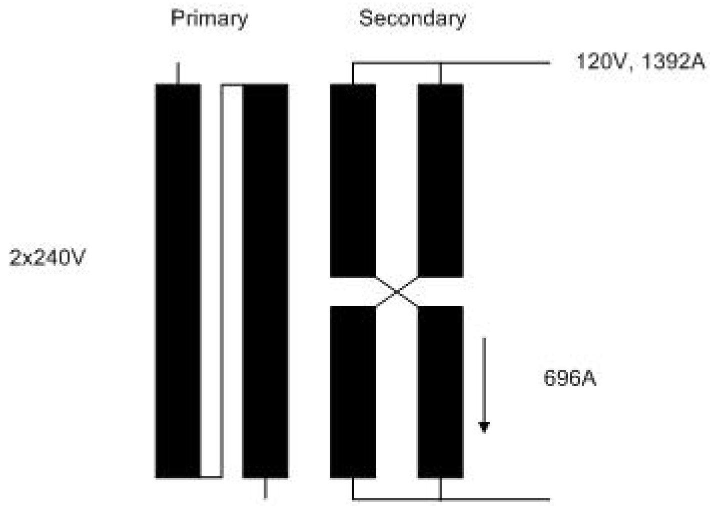
There are 4 input screens to set the input parameters for the designing of a transformer:

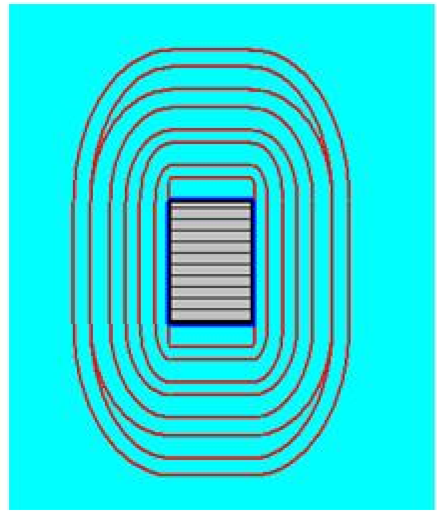
- Winding parameters per limb
- Core
- Environment
- Other parameters

and 3 screens for selection and set up of material :

- wires
- steels
- cores.

Windings parameters per limb





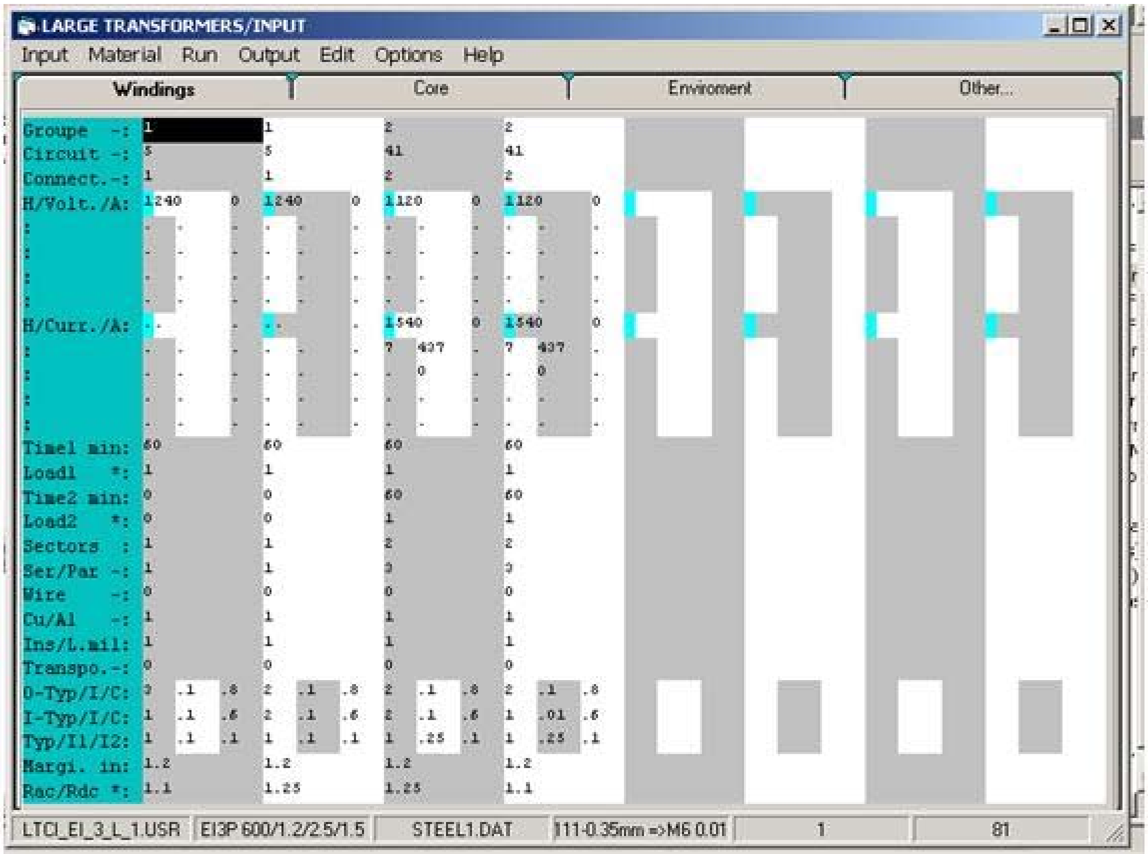
Primary

The primary is created with 2 windings connected in series . The sine wave input voltage is 480V (240V per winding).

There is no duty cycle operation mode and there are no sectors.

Note that a 500kVA transformer for K-factor=20 and the short-circuit voltage 5% can be optimal designed and manufactured only with litz wire. The round wires within the litz are not insulated but in transposition.

The first winding has the thermal contact with the center leg of the core within the core window via 0.1" tube thickness and 0.1" air gap (stomach). All other surfaces of the primary are cooled via the cooling channels of 0.6" (inside of the core window) and 0.8" (outside of the core window). The space between the yoke and the primary windings is 1.2" With the eddy current losses factor (RacRdc) 1.1 and 1.25 shell be limited the number of the round wires per litz.



Secondary

The secondary is created with 2 windings connected in parallel . The sine wave output voltage is 120V.
The rms current per winding is 696Arms. Normally there is no explicit information about the current harmonics in a K-factor transformers. The designer has to create a combination of the first current harmonic and 7. current harmonic in order to satisfy the following conditions:

I1^2 + I7^2 = Irms^2
1^1*I1^2 + 7^2*I7^2 = K-factor* Irms^2

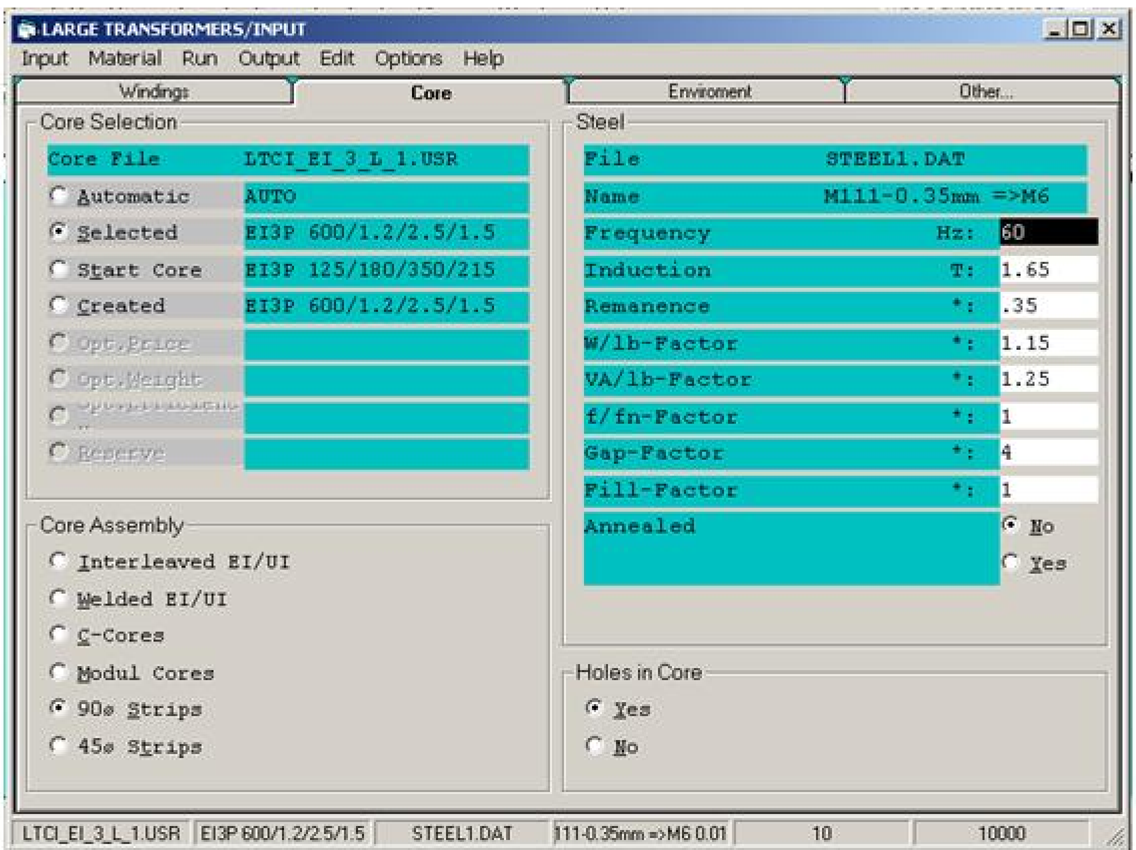
For Irms = 696Arms and K-factor = 20 the calculated current harmonics I1 and I7 are:
I1= 540Arms
I7 = 437Arms
Also there is no duty cycle operation mode on the secondary side.
In order to avoid the circulating current between 2 parallel connected secondary windings each of them is created with 2 cross connected sectors.
Once again, a 500kVA transformer for K-factor = 20 and the short-circuit voltage 5% can be optimal designed and manufactured only with litz wire. With the eddy current losses factor (RacRdc) 1.1 and 1.25 the number of the round wires per litz shall be limited. Note that at this point of design you can not prescribe the wire size. You can select only the wire family which the program has to use in order to select the suitable wires for your application.
The first secondary winding is cooled via the cooling channels of 0.6" (inside of the core window) and 0.8" (outside of the core window). The second secondary winding has only two 0.8" cooling channels outside of the core window. It is better cooled than the first secondary

winding and therefore it is in a good thermal connection within the core window with the first secondary winding.
The space between the yoke and the secondary windings is 1.2"

Core

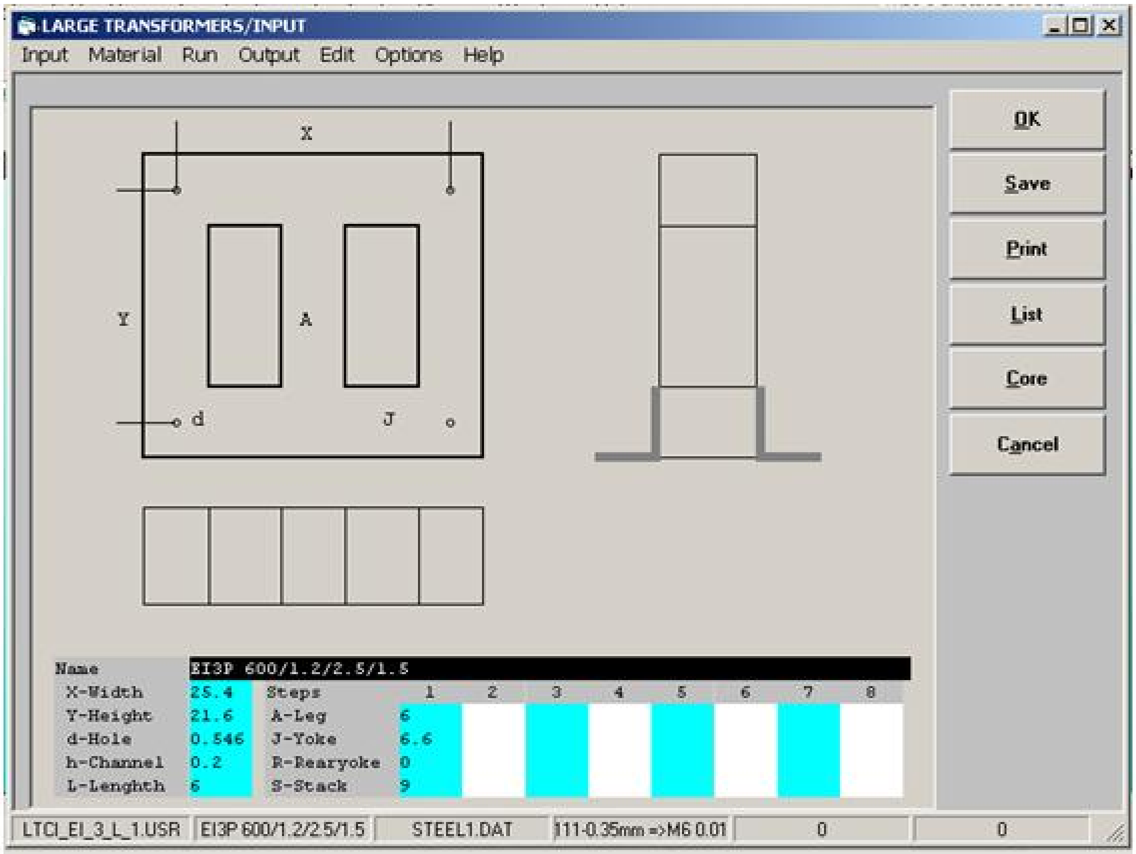
On this input screen you can :

- select and manipulate the selected steel M6, 14mil
- set the operating induction (1.65T) and the frequency (60Hz)
- select the core assembly
- and prescribe the core selection.

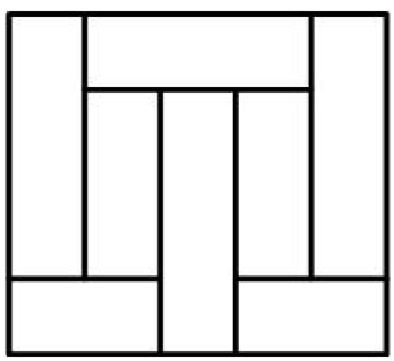


The core was created by program and by the designer in order to satisfy the following conditions:

- Ucc=5%
- Optimal price and weight

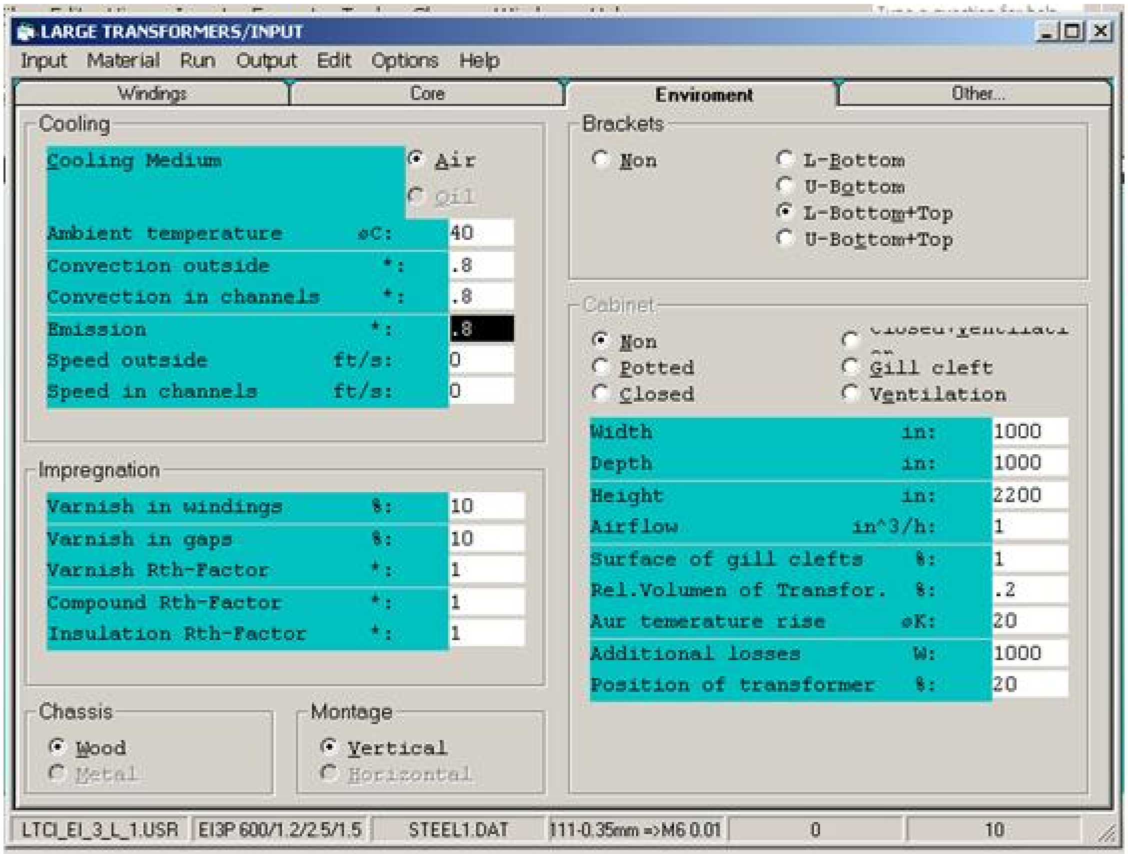


Normally for this application you use M6, 14mil, non annealed after stamping, grain oriented strips.

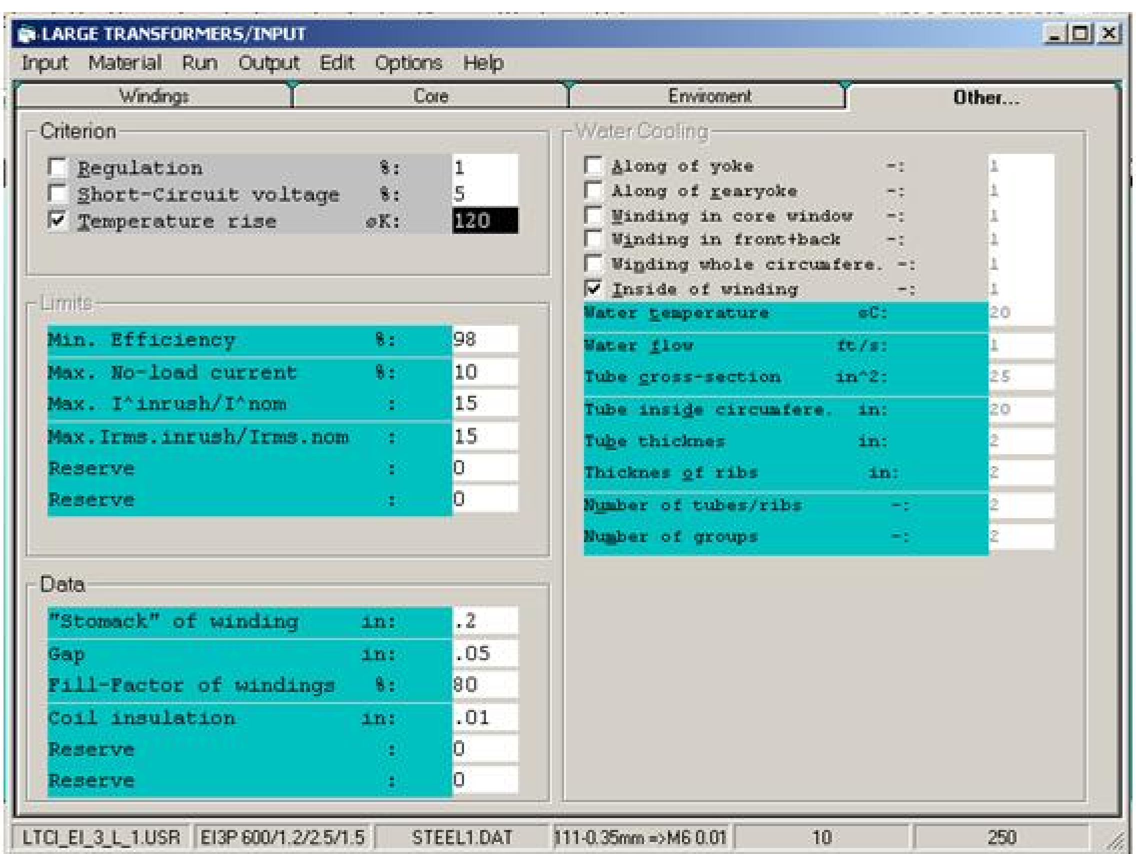


Environment

The cooling medium is air with the ambient temperature 40°C. The cooling factors for the convection and the emission are set to 80% because the transformer will be placed in a cabinet. The cooling surface of the core is increased by using 4 L-brackets on the core.
The impregnation is practically "dry" because there is only 10% varnish (90% air) in the windings and in all the gaps between the insulations and the layers of the windings



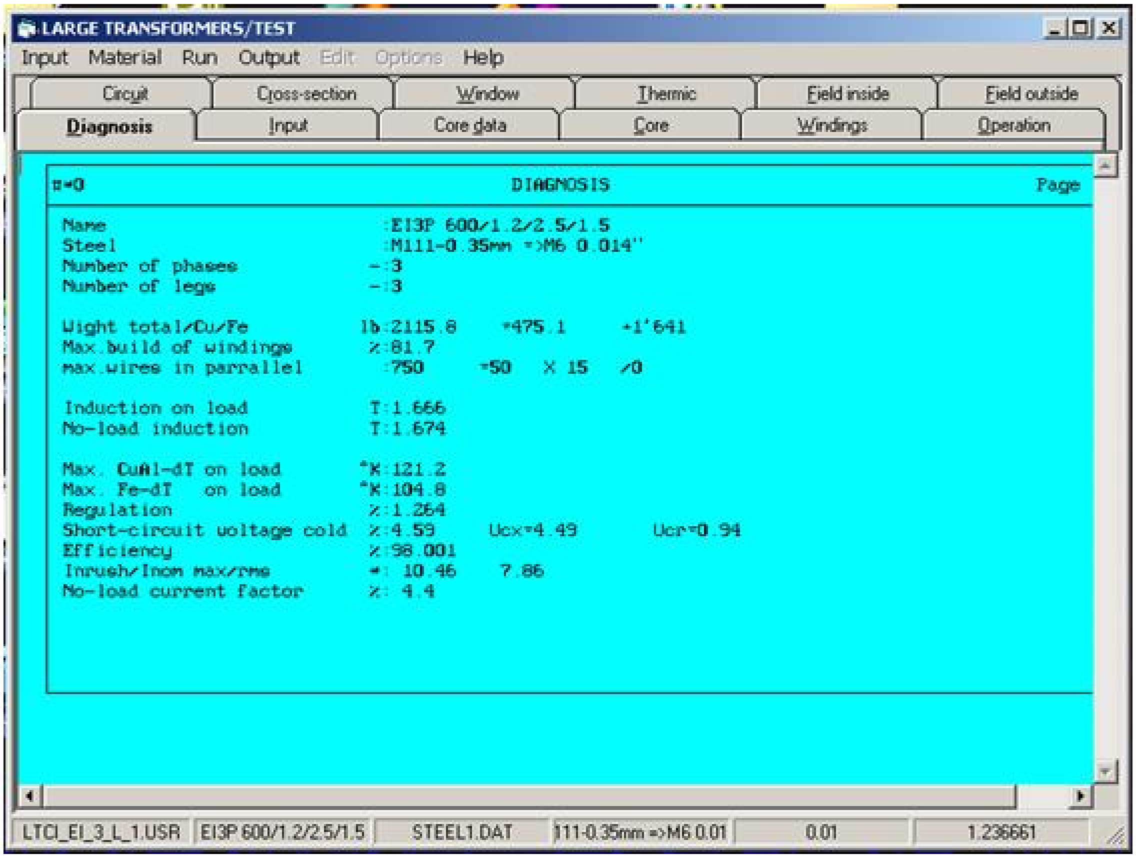
Other...



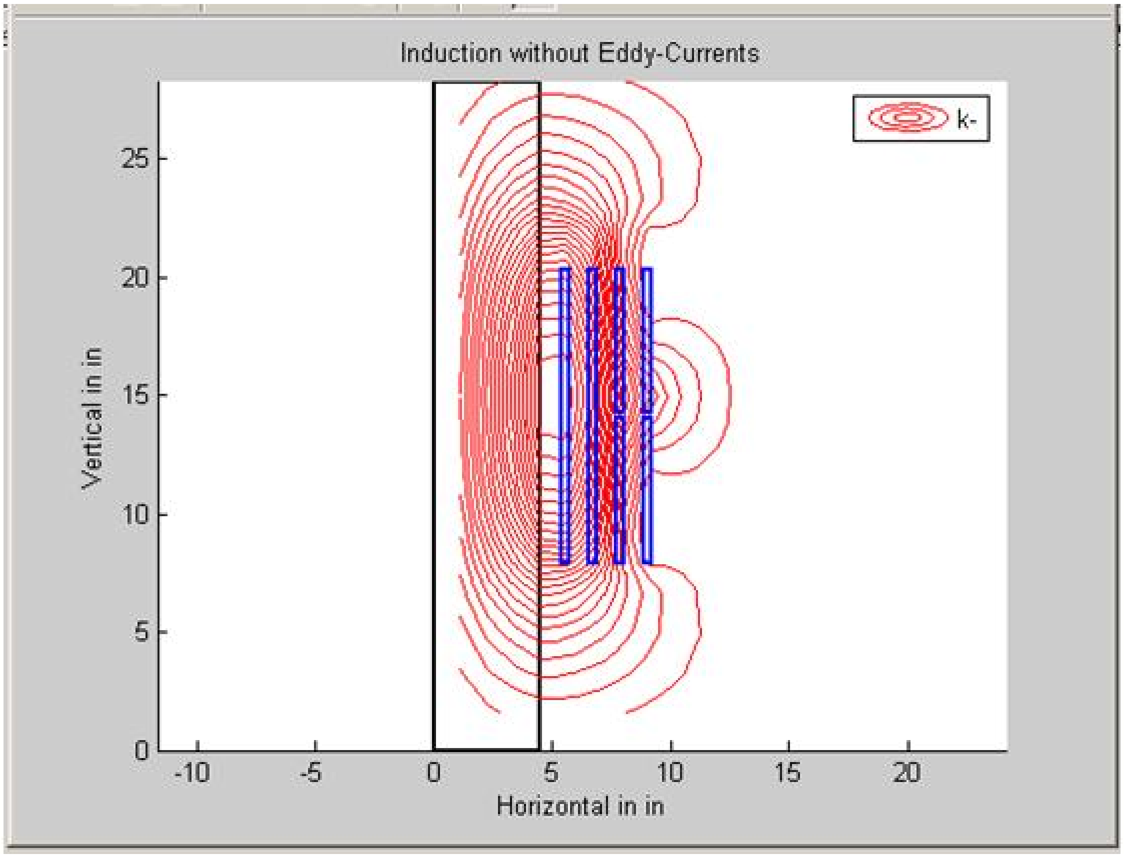
The selected criterion of the design is the temperature rise of 120°K for insulation class H. The oval space between the first winding and the tube (stomach), all gaps between the insulation, the windings and the varnish fill factor of the windings play very important roll from the thermal point of view.

Output

The first step is the presentation of the output screen DIAGNOSIS: it is the summery of the most important calculated parameters of your transformer.



Note that the program uses the numerical calculation of the magnetic fields and the temperature rises. Due to this technology the calculations of the eddy current losses, the steel losses, the short-circuit voltage, the circulating current and the transposition are very powerful.
In the following picture are presented the magnetic field outside of the core window.



Finally here are 4 printed pages with all the results of the design

Input

11-11-2005/12:14:37/ V:14 .13 INPUT Page 1

Windings	1	2	3	4	5	6	7	8
Groups	1	1	2	2				
Circuits	5	5	41	41				
Connection	1	1	2	2				
H/Voltag/A	1 240 0	1 240 0	1 120 0	1 120 0				
	. . .	. . .	. . .	. . .				
	. . .	. . .	. . .	. . .				
	. . .	. . .	. . .	. . .				
	. . .	. . .	. . .	. . .				
H/Curren/A	. . .	. . .	1 540 0	1 540 0				
	. . .	. . .	7 437 .	7 437 .				
	. . .	. . .	. 0 .	. 0 .				
	. . .	. . .	. . .	. . .				
	. . .	. . .	. . .	. . .				
Time1 min.	60	60	60	60				
Load1 *	1	1	1	1				
Time2 min.	0	0	60	60				
Load2 *	0	0	1	1				
Sectors	1	1	2	2				
Ser./Para.	1	1	3	3				
Wire file	0	0	0	0				
Cu/Al	1	1	1	1				
In/Lay.mil	1	1	1	1				
Transpos.	0	0	0	0				
Typ/1/C in	3 0.1 0.8	2 0.1 0.8	2 0.1 0.8	2 0.1 0.8				
Typ/1/C in	1 0.1 0.6	2 0.1 0.6	2 0.1 0.6	1 0.01 0.6				
Typ/1/I in	1 0.1 0.1	1 0.1 0.1	1 0.25 0.1	1 0.25 0.1				
Margin in	1.2	1.2	1.2	1.2				
RacRdc	1.1	1.25	1.25	1.1				

Frequency Hz: 60	Core select. -: Selecte	Cooling medium : Air	
	Core file : LTCI_EI_3_L_	Amb. temperature °C: 40	
Criterion : dT	Core name : EI3P 600/1.2	Convection outside *: 0.8	
Regulation %: 1	Core assembly-: 90° 4Strips	Convection inside *: 0.8	
Ucc-voltage %: 5	With hole -: No	Emission *: 0.8	
Temperat. rise °K: 120		Airflowoutside ft/s: 0	
Efficiency %: 98	Steel file : STEEL1.DAT	Airflow inside ft/s: 0	
No-load factor %: 10	Steel name : M111-0.35mm	Chassis -: Wood	
I^in/I^nom : 15	Induction T: 1.65	Vertical -: Vertica	
Iinrms/Inomrms : 15	W/lb *: 1.15	Horizontal -: L-T&B	
	VAr/lb *: 1.25	:	
	Airgap *: 4	Channel fill factor %: 80	
	f/fn-Factor *: 1	Varnish in windings %: 10	
	Fill factor : 1	Varnish in gaps %: 10	
	Annealed -: No	Rth-varnish *: 1	
		Rth-compound *: 1	
		Rth-insualtion *: 1	
		Coil insulation in: 0.01	
		Bauch in: 0.2	
		Gap in: 0.05	

Core

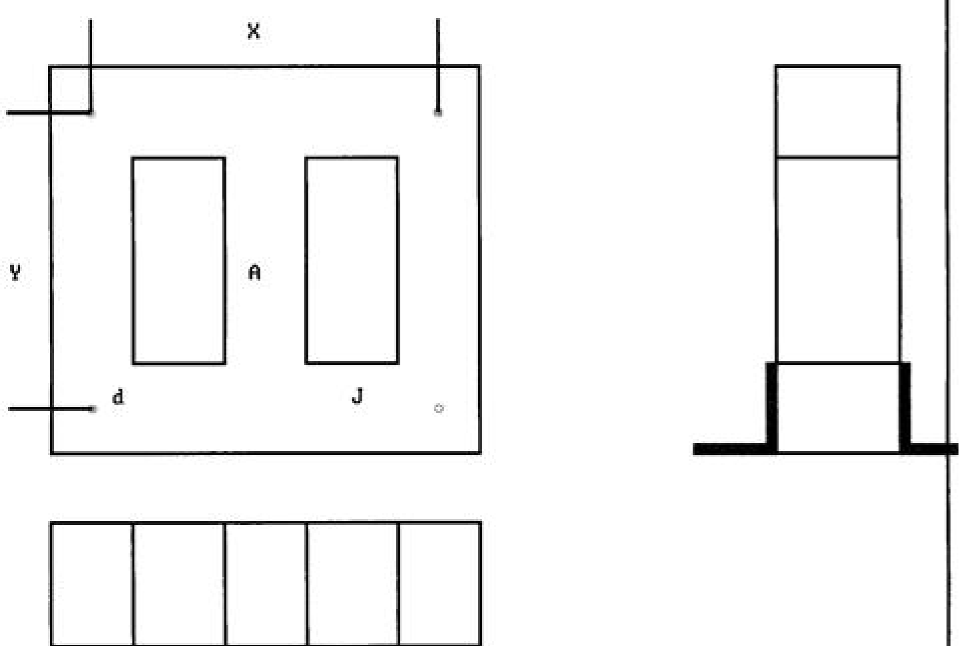
11-11-2005/12:14:37	CORE	Page 2

Core file name	: LTCI_EI_3_L_1.USR
Core name	: EI3P 600/1.2/2.5/1.5
Core type	: 3EI
Type of windings	: oval/rectangular
Number of legs	: 3
Core assembly	: 90° &Strips
Leg/Diameter	in: 6
Window width	in: 6.7
Window height	in: 15
Stack	in: 9
Cross section	in^2: 52.10
Weight total	lb: 1640.
With holes	-: Yes
Brackets	-: L-T&B

Fe-File name	: STEEL1.DAT
Fe-Name	: M111-0.35mm =>M6 0.014
Frequency	Hz: 60
Remanence-Factor	*: 0.35
W/lb-Factor	*: 1.15
VAr/lb-Factor	*: 1.25
Gap-Factor	*: 4
f/fn-Factor	*: 1
Fillfactor	*: 1
Annealed	-: No
Chassis	-:
Vertical/Horizontal	-:

X-Width	in: 25.40
Y-Height	in: 21.6
d_Hole	in: 0.546
h-Distance	in: 0.2
L-Laenght	in: 6

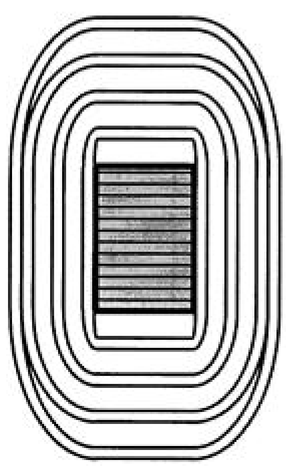
Stufen	1	2	3	4	5	6	7	8
A-Leg	in:6	0	0	0	0	0	0	0
J-Yoke	in:6.6	0	0	0	0	0	0	0
R-Rearyoke	in:0	0	0	0	0	0	0	0
S-Stack	in:9	0	0	0	0	0	0	0
Number lamin.	:							
Weight	lb:							



Windings

11-11-2005/12:14:37			WINDINGS					Page 3
Windings	1	2	3	4	5	6	7	8
Groups-Circuits	1-D	1-D	2-Yn	2-Yn				
Connection	ser.	ser.	par.	par.				
Turns	16.0	16.0	8.0	8.0				
Build %	13.64	42.20	70.77	81.73				
Weight lb	33.8	40.5	39.3	44.8				
WIRE								
Type	round	round	round	round				
Thicknes mil	22.60	22.60	22.60	22.60				
Width mil	22.60	22.60	22.60	22.60				
WG-thicknes	23	23	23	23				
WG-width	23	23	23	23				
Al/Cu	Cu	Cu	Cu	Cu				
STRANT/LITZ							7	
Thickne insula. mil	357.00	357.00	357.00	357.00				
Width insulata. mil	714.0	714.0	1190.0	1190.0				
Parallel wires	450	450	750	750				
side by side	30	30	50	50				
one upon the other	15	15	15	15				
Transposition	0	0	0	0				
Cross section mil^2	180598.	180598.	300997.	300997.				
SECTOR								
Number	1	1	2	2				
Serie/Parallel	ser.	ser.	mixed	mixed				
Turns	16	16	4	4				
Turns/Layer	16.01	16.01	4.002	4.002				
Layers	0.998	0.998	0.999	0.999				
Insul./Layer mil	1.0	1.0	1.0	1.0				
Transposition	0	0	1	1				
Thicknes in	0.357	0.357	0.357	0.357				
Width in	12.40	12.40	6.075	6.075				
Distance/Sector in	0.1	0.1	0.25	0.25				
SPACES/CHANNELS/INS.								
Outside in	WICW	WCW	WCW	WCW				
Insulation in	0.1	0.1	0.1	0.1				
Channel in	0.8	0.8	0.	0.8				
Inside in	WIW	WCW	WCW	WIW				
Insulation in	0.1	0.1	0.1	0.01				
Channel in	0.6	0.6	0.6	0.6				
Between sectors in	WIW	WIW	WIW	WIW				
Distance in	0.1	0.1	0.25	0.25				
Top/Bottom in	0.1	0.1	0.1	0.1				
Distance to yoke in	1.3	1.3	1.3	1.3				

Coil insulation in: 0.
D1i/D1e: 11.35 12.07
D2i/D2e: 13.67 14.38
D3i/D3e: 15.98 16.7
D4i/D4e: 18.3/ 19.01
D5i/D5e: /
D6i/D6e: /
D7i/D7e: /
D8i/D8e: /



Nominal operating mode

11-11-2005/12:14:37	IN OPERATION MODE	Page 4

Frequency	Hz: 60	Ventilation outsi.	ft/s: 0	Fillfactor/channels	%: 80
Ambient temperature	C: 40	Ventilation(chann.	ft/s: 0	Varnish in windings	%: 10
Convection outside	*: 0.8	Rth-Insulation	*: 1	Varnish in gaps	%: 10
Convection/channels	*: 0.8	Rth-Varnish	*: 1	Stomack	in: 0.20
Emission	*: 0.8	Rth-Epoxy	*: 1	Gap	in: 0.05

Output power	kVA: 488.3	Input power	kVA: 499.0	Core power	: 0.0
Fe-Losses	VA: 21062	Fe-active losses	W: 2489.	Fe-reactive losses	VAr: 20914
No-load curren	%: 4.4	No load curr. active	%: 0.5	No load curr. react.	%: 4.4
I^in/I^nom-Factor	: 10.46	Iinrms/Inomrms-Factor	: 7.86	No load induction	T: 1.674
I^in	kA: 8.87	Iin rms	kA: 4.72		
Icc cold	kA: 7.56	Iccr active cold	kA: 1.54	Iccx reactive cold	kA: 7.40
Ucc cold	%: 4.59	Uccr active cold	%: 0.94	Uccx inductive cold	%: 4.49
CuAl-losses	W: 7447.0	Efficiency	%: 98.001		
Max. dT Cu/Al	°K: 121.2	Max. dT Fe	°K: 104.8	Induction	T: 1.666

Windings		1	2	3	4	5	6	7	8
Groups-Circuits		1-D	1-D	2-Yn	2-Yn				
Connection		ser.	ser.	par.	par.				
Time1		60.0	60.0	60.0	60.0				
Load1		1.00	1.00	1.00	1.00				
Time2		0.0	0.0	60.0	60.0				
Load2		0.00	0.00	1.00	1.00				
Voltage rms	V	239.8	240.1	118.5	118.5				
U-Phasen delay	°	0.356	-0.35	-1.70	-2.22				
No-load voltage	V	239.9	240.0	120.0	120.0				
Regulation	%	0.0	0.0	1.2	1.3				
Current rms	A	346.53	346.53	685.37	687.37				
K-Factor		20.00	20.00	20.00	20.00				
Power	kVA	83.11	83.22	81.28	81.48				
I-Phase delay	°	-5.4	-4.7	-0.5	0.5				
Resistance cold	mOhm	2.245	2.688	0.939	1.073				
Losses warm	W	419.5	527.7	744.3	790.6				
RacRdc (total)		1.02	1.07	1.08	1.02				
Icc.all cold	kA	7.56	7.56	15.05	15.18				
Icc.group cold	kA	0.00	0.00	15.05	15.18				
Circ.losses	W	0.00	0.00	0.00	0.00				
Cur.density	A/in^2	1915.7	1915.7	2276.6	2276.6				
SECTORS									
1 RacRdc		1.02	1.07	1.07	1.02				
Current	A	346.5	346.5	685.3	687.3				
dT	°K	114.5	113.4	120.9	114.2				
2 RacRdc				1.08	1.02				
Current	A			687.37	685.37				
dT	°K			121.2	113.9				
3 RacRdc									
Current	A								
dT	°K								
4 RacRdc									
Current	A								
dT	°K								
5 RacRdc									
Current	A								
dT	°K								
6 RacRdc									
Current	A								
dT	°K								
7 RacRdc									
Current	A								
dT	°K								
8 RacRdc									
Current	A								
dT	°K								

Test Mode

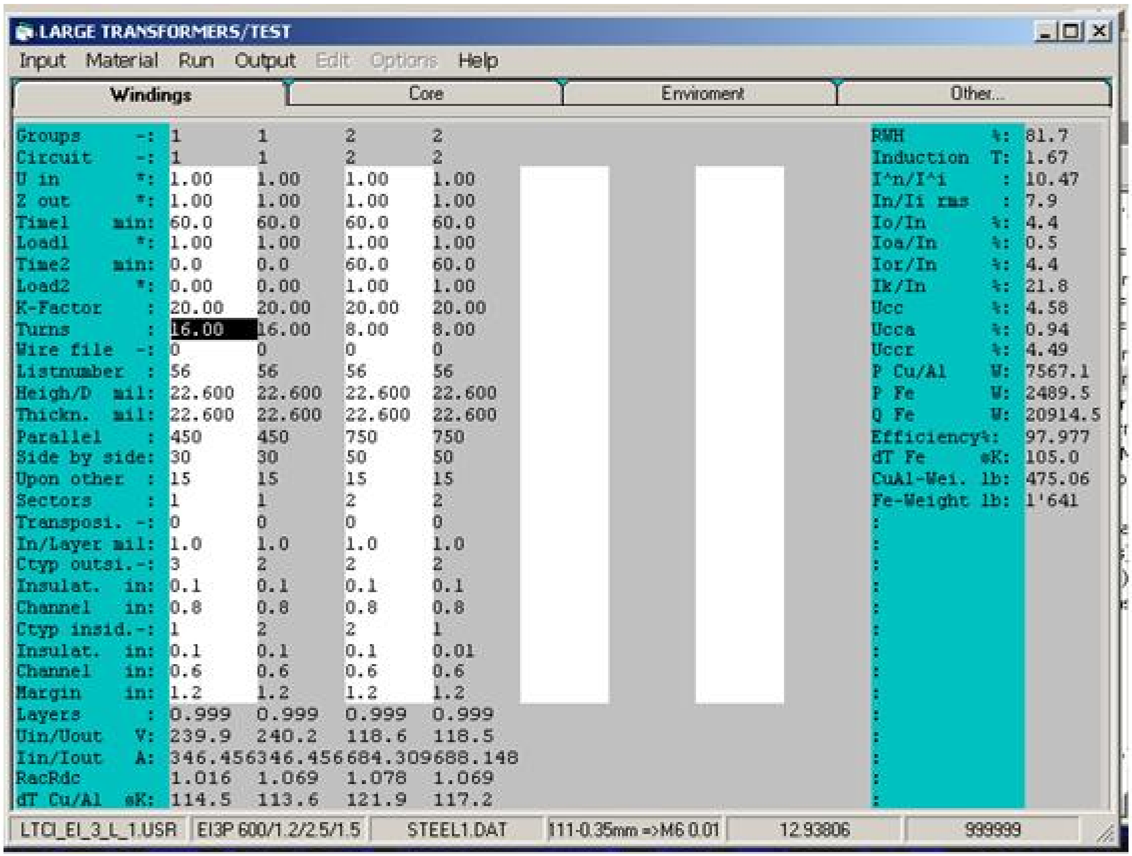
If you are not satisfied with the solution made by the program you can switch into the Test Mode and change your transformer manually:

- Turns
- Wire size
- Material (Cu or Al)
- Number parallel connected wires and their order in strand
- Cooling channels and insulations
- Margin
- Steel
- Technology parameter (impregnation, gaps,...)

and then you can set it under an operation mode changing:

- Input voltage
- Frequency
- Loads and their K-factors
- Duty cycle of each winding
- Ambient temperature
- Air flow

Note that the program could not create full layer windings at the prescribed temperature rise of 120°K. In order to get the full layer windings you have to select the wire size in the litz and the number in parallel connected wires manually.



Let us now change some technology parameters of this transformer:

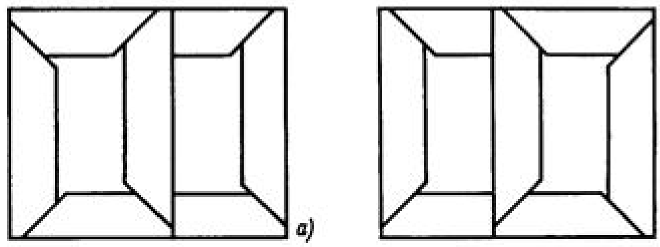
Impregnation

In the following table you can compare the temperature rise of our "dry" transformer and the full impregnated (no air in the windings, the gaps and the stomach) version.

	Core °K	Primary1 °K	Primary2 °K	Secondary1 °K	Secondary2 °K
Current version: 10% varnish	105	114	113	121	117
New version: 100% varnish	105	109	109	113	109

Core assembly

If you want to use 45° core assembly with the annealed M6 strips then:



	Core °K	Primary1 °K	Primary2 °K	Secondary1 °K	Secondary2 °K
Current version: 90° core assembly,non annealed strips	105	114	113	121	117
New version: 45° core assembly, annealed strips	90	107	109	120	116

Impregnation

In the following table you can compare the temperature rise of our "dry" transformer and the full impregnated (no air in the windings, the gaps and the stomach) version.

	Core °K	Primary1 °K	Primary2 °K	Secondary1 °K	Secondary2 °K
Current version: in the cabinet	105	114	113	121	117
New version: no cabinet	96	104	104	109	103

Designing a 3 phase, 50/60Hz rectifier transformer (YYD to supress 5. and 7. harmonics) with 2 parallel connected bridge rectifiers, for Udc = 400V and Idc = 1000A

General Information

Technical Specification

Input voltage	3 x 3 x 400, star
Transformer output voltage for Udc = 400Vdc	3 x 314/182V, star 3 x 314V, delta
Line output current per secondary: (Ia1,Ib1,Ic1,Ia2,Ib2,Ic2)	I1 = 388Arms I5 = 77.5Arms I7 = 55.5Arms I11 = 35Arms I13 = 30Arms continuous operating mode
Frequency	50Hz
Ambient temperature	40°C
Temperature rise	Max. 120°K, insulation class H
°Short-circuit voltage	Ucc = 3-4% Ucc_s1-s2/Ucc >= 2 for use with Ld1&Ld2 chokes
Steel & Core	M6, annealed, strips for alternated stacking (45°), Oval cross section

Creating Input

4 input screens are used to set the input parameters for the designing of a transformer:

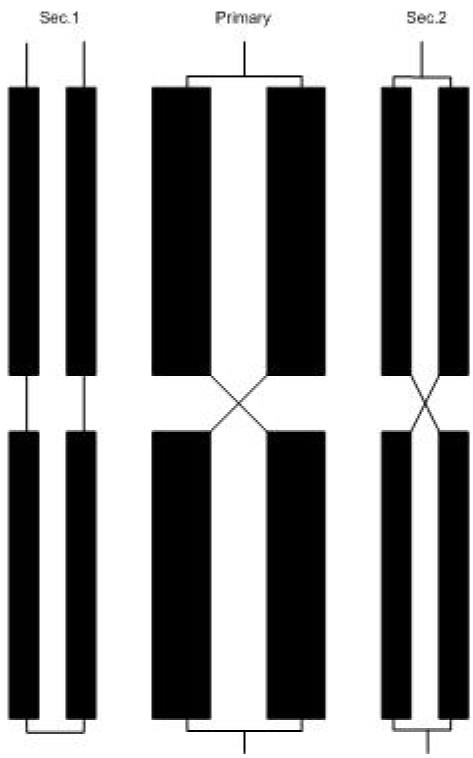
- Winding parameters per limb
- Core
- Environment
- Other parameters

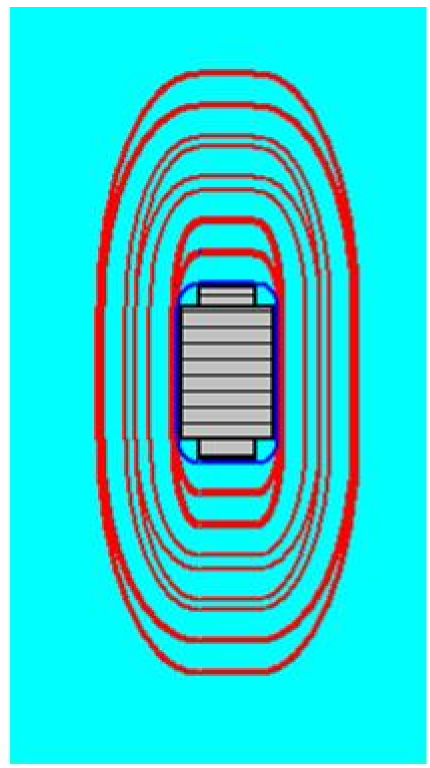
and 3 screens for selection and set up of material :

- wires
- steels
- cores.

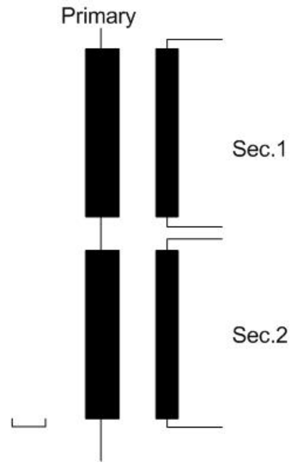
Windings parameters per limb

The following rectifier circuit is often used to compensate the 5. and 7. current harmonics on the primary side. The parallel connection of the rectifiers is normally used if the output current Id is over 500-1000Adc. For a good current distribution between 2 parallel connected rectifiers (with the chockes Ld1 and Ld2) the relationship Ucc_s1-s2/Ucc has to be bigger than 2; Ucc_s1-s2 is the short-circuit voltage between the secondary 1 and the secondary 2; Ucc is the short-circuit voltage of the transformer. For this condition the primary will be "sandwiched" between both secondaries.





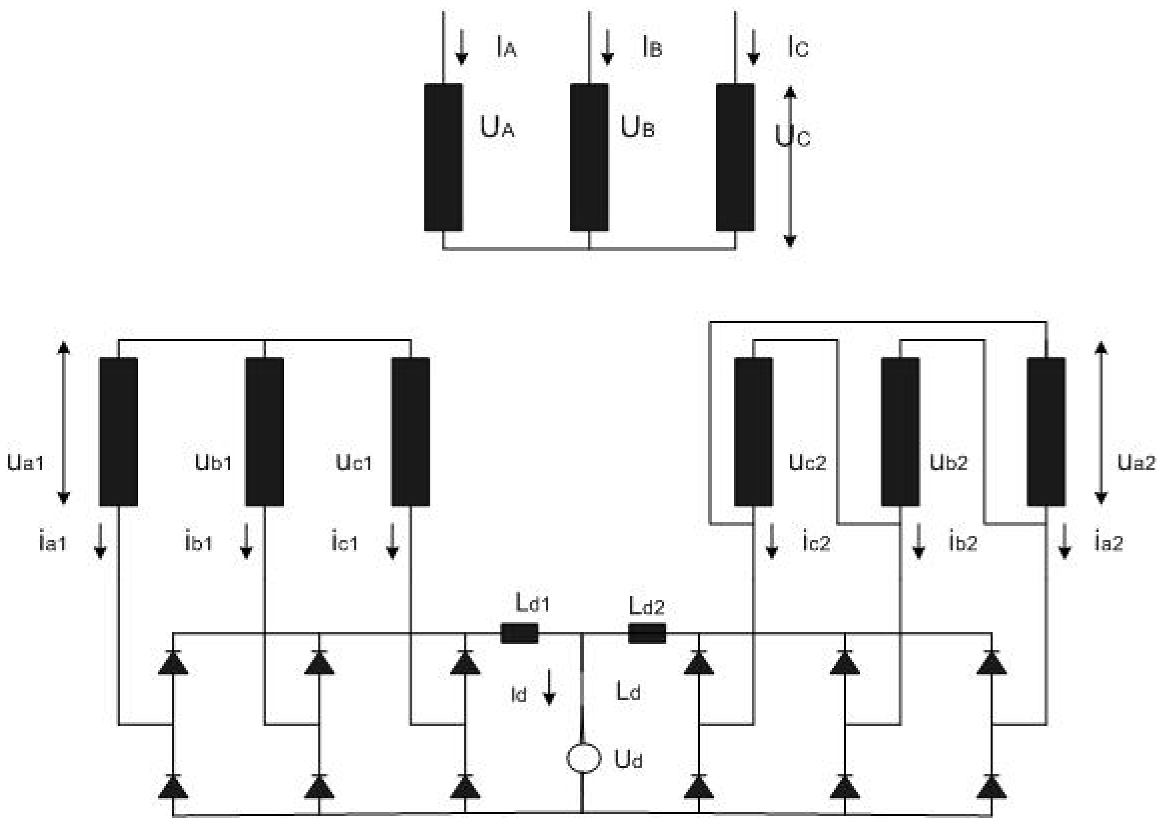
For equal current distribution between 2 parallel connected rectifiers (without the chockes Ld1 and Ld2) the relationship Ucc_s1-s2/Ucc has to be bigger or equal 4. For this condition you should use the following order of the windings:



Note that the short-circuit voltage of a rectifier transformer is a complex issue reflecting:

- the rectifier protection in a short circuit operation mode of all secondary winding, a group of windings or of only one winding.
- the commutation operation mode of a group of windings
- the voltage drop of the dc-output voltage
- the current distribution between the parallel connected rectifiers

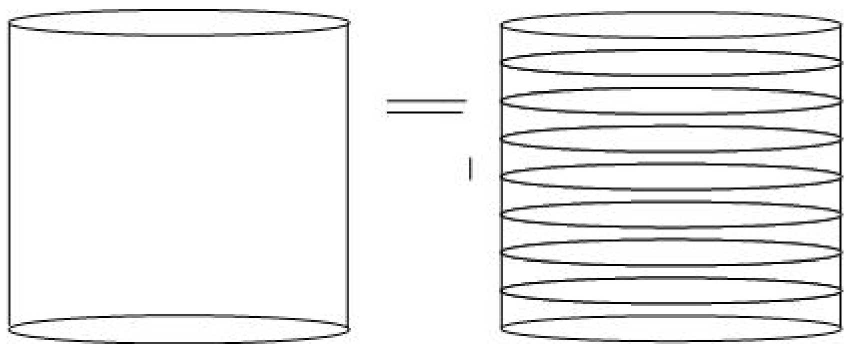
It has to be prescribed by the user of the transformer



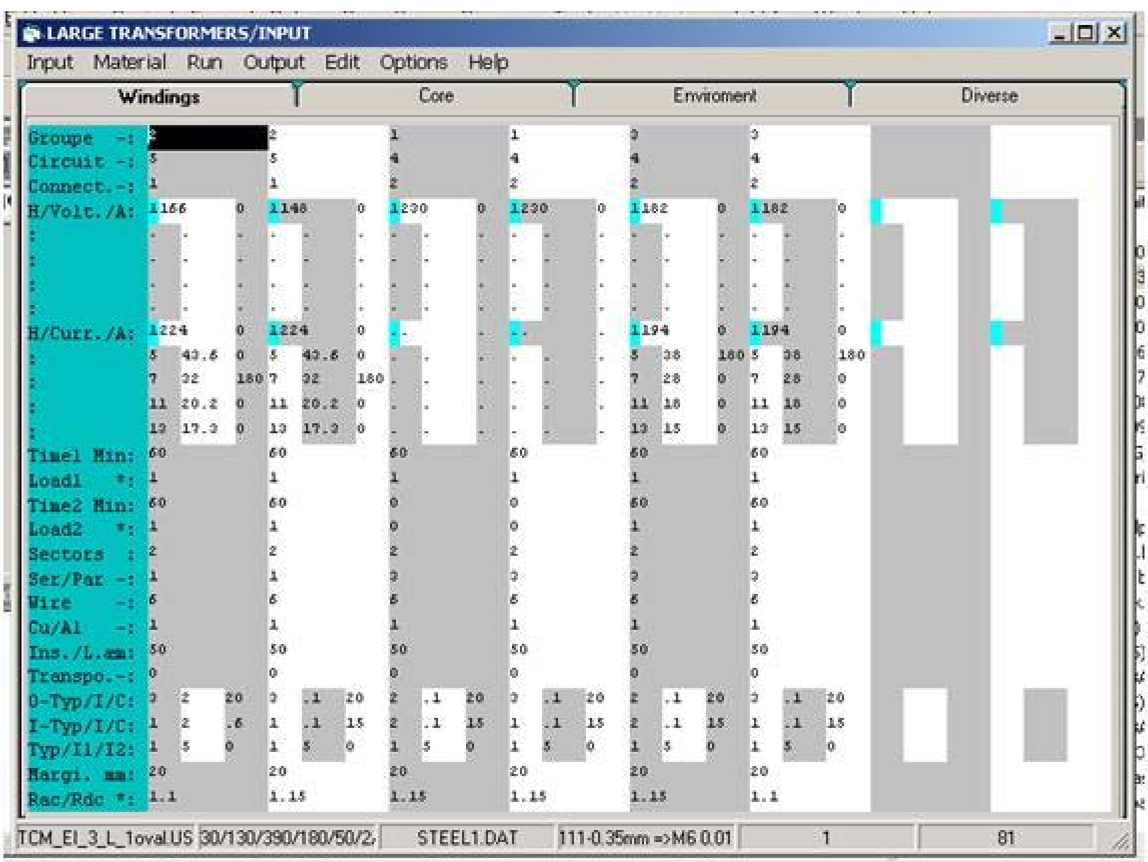
Primary

The primary is created with 2 parallel connected windings with 2 cross connected sectors. The sine wave input voltage (U_A,U_B,U_C)is 230V (230V per winding).
There is no duty cycle operation mode.

The primary sectors will be manufactured with Cu-foil with a layer insulation of 0.05omm. **Note that there no big difference from an electrical or magnetic point of view (if the distance between the sectors is small) between the winding made by foil with one sector and the winding made by foil with more (2-8) parallel connected sectors. The first and the last sector will be overloaded by a higher eddy & circulated current losses and due to the thermal insulation to the other sectors they wil normally be hotter .**



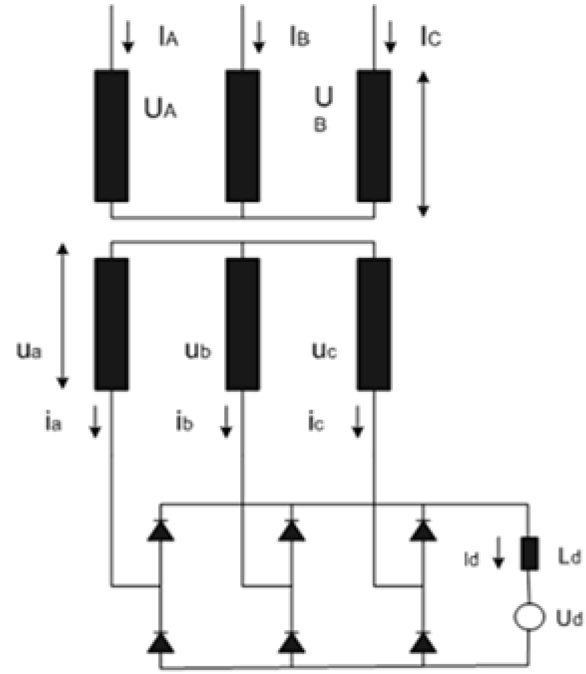
The primary lies between the secondary windings. All the surfaces of the primary are cooled via the cooling channels of 15mm (inside the core window) and 20mm (outside the core window). The space between the yoke and the primary windings is 20mm. With the eddy current losses factor (RacRdc) 1.15 shall be limited the number of the parallel connected foils per sector.



Secondary

The first secondary is connected in delta. It is created with 2 in series connected windings. Each winding has 2 in series connected sectors.
The sine wave output voltage is 314V = 166V + 148V.

The rms current through each winding (secondary) is 234Arms. The set current harmonics are calculated for the worst case: Ucc= 0 and Ld = ∞:



U = 1.05 x (0.741 x Ud + 3)/1.73						
Harmonic	i/Id	Angle				
1	0.777	0				
5	0.155	180				
7	0.111	0				
11	0.070	180				
13	0.060	0				

Also, there is no duty cycle operation mode on the secondary.
With the eddy current losses factor (RacRdc) 1.1 and 1.15 the use of parallel connected foils per sector shall be avoided . Note that at this point of the design you cannot prescribe the wire or foil size. You can select only the wire or family or foil which the program has to use in order to select the suitable wires or foils for your application.
The first secondary winding is cooled via the 20mm cooling channels (outside the core window) and via 2mm insulation to the core (inside the core window). The second secondary winding has only two 20mm cooling channels outside the core window. It is better cooled than the first secondary winding and therefore it is in a good thermal connection within the core window with the first secondary winding.
The space between the yoke and the secondary windings is 20mm

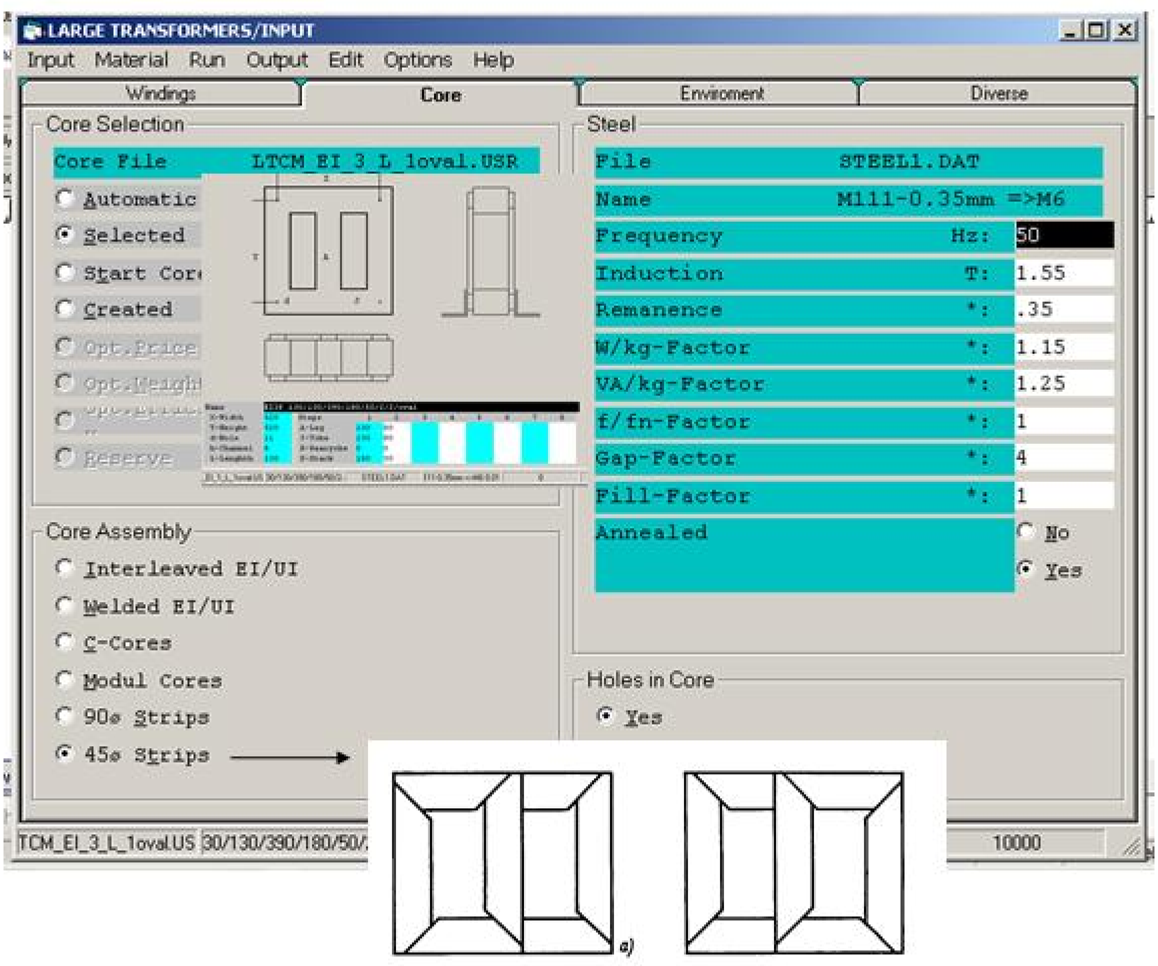
The second secondary is connected in star. It is created with 2 parallel connected windings. In order to avoid the circulating current between 2 parallel connected secondary windings, each of them is created with 2 cross connected sectors.

The sine wave output voltage is 182V.
The rms current through each parallel connected winding should be 205Aac (total output rms curren is 410Aac). The set current harmonics are calculated for the worst case: Ucc= 0 and Ld = ∞.
Also, there is no duty cycle operation mode on this secondary.
With the eddy current losses factor (RacRdc) 1.1 and 1.15 the use of the parallel connected foils per sector shall be avoided.
The first secondary winding is cooled via the 20mm cooling channels (outside the core window) and 20mm (inside the core window). The second secondary winding has only two 20mm cooling channels outside the core window. It is better cooled than the first secondary winding and therefore it is in a good thermal connection within the core window with the first secondary winding.
The space between the yoke and the secondary windings is 20mm

Core

On this input screen you can :

- select and manipulate the selected steel M111, 035mm (M6, 14mil)
- set the operating induction (1.55T) and the frequency (50Hz)
- select the core assembly
- and prescribe the core selection.

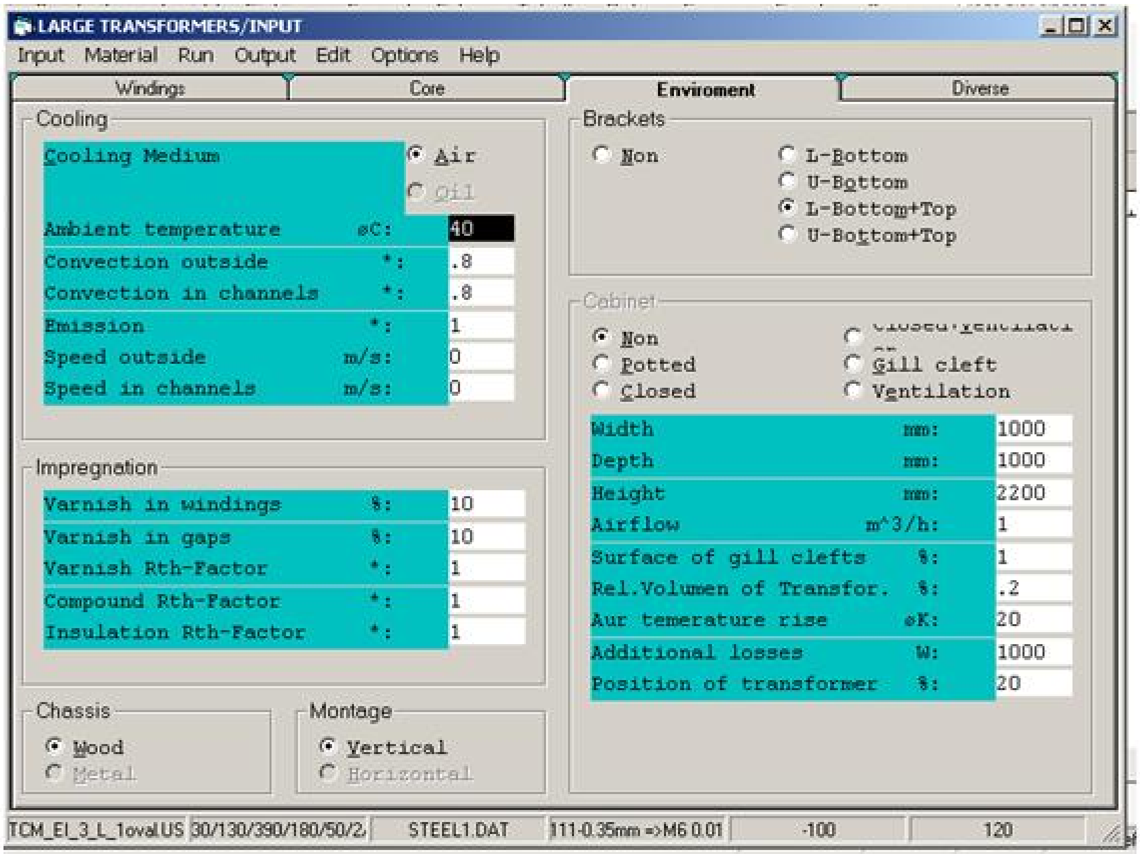


The oval core cross section was prescribed by the designer easier winding of the high current foil windings:

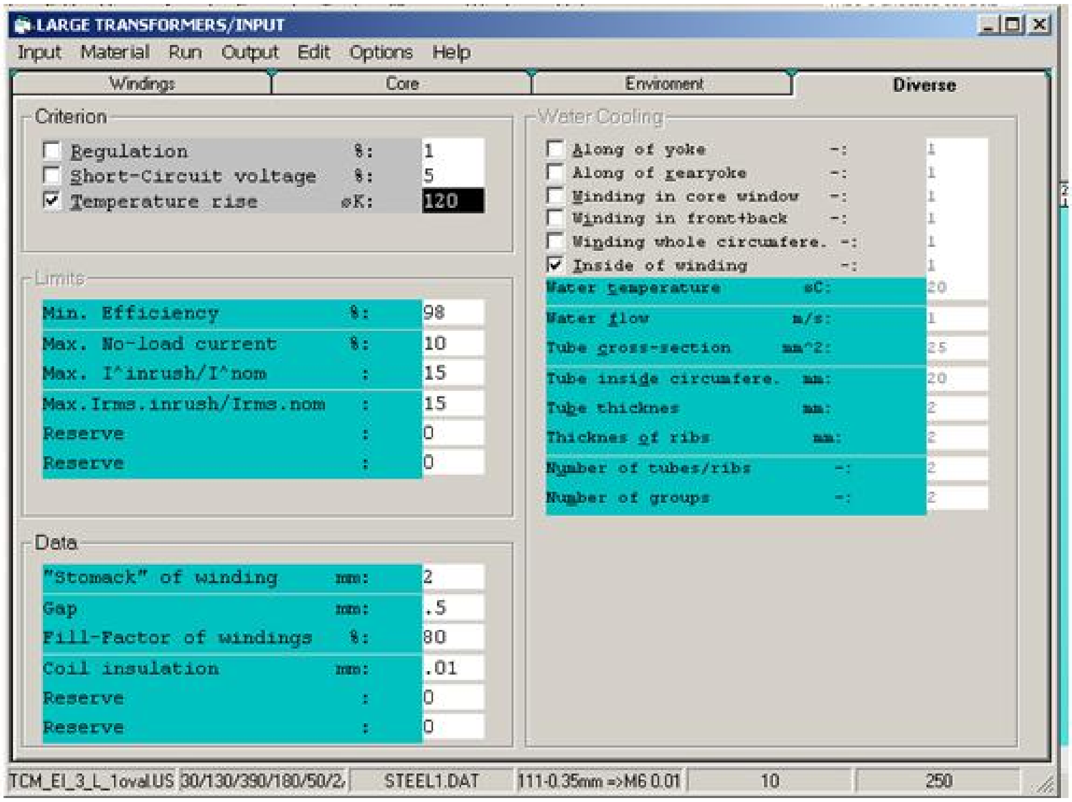
Normally you use for this application M111, 0.35mm (M6, 14mil), not annealed after stamping, grain oriented strips.

Environment

The cooling medium is air with the ambient temperature 40°C. The cooling factors for the convection. The cooling surface of the core is increased by using 4 L-brackets on the core.
The impregnation is practically "dry" because there is only 10% varnish (90% air) in the windings and in all the gaps between the insulations and the layers of the windings



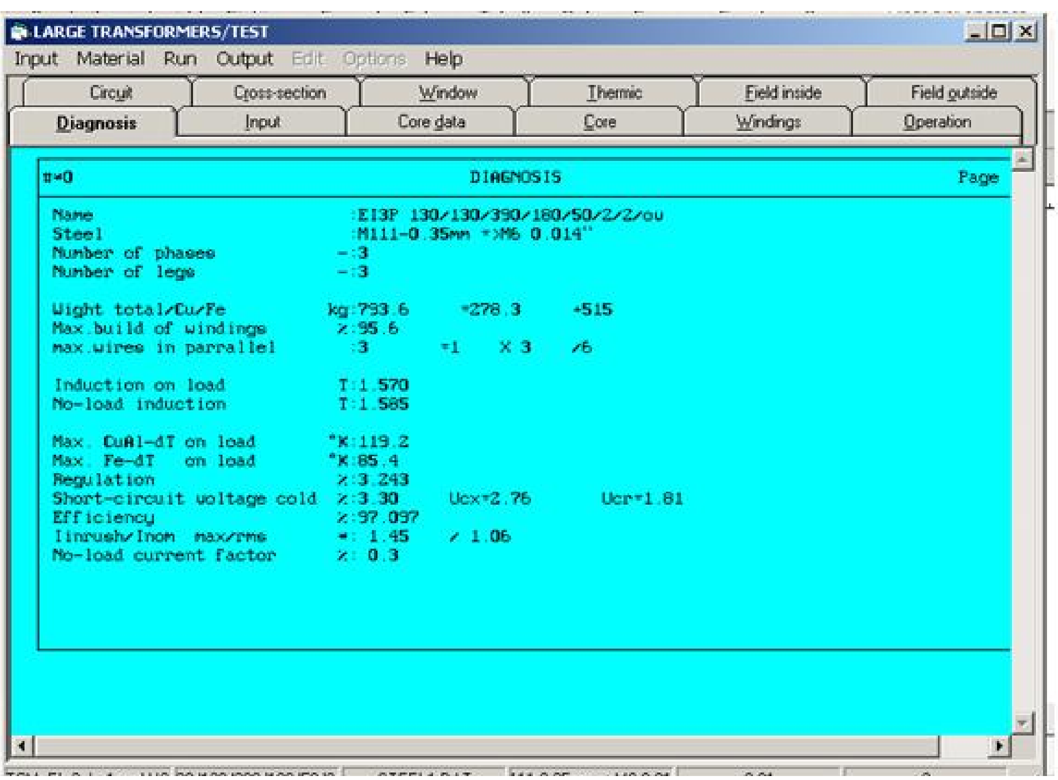
Other...



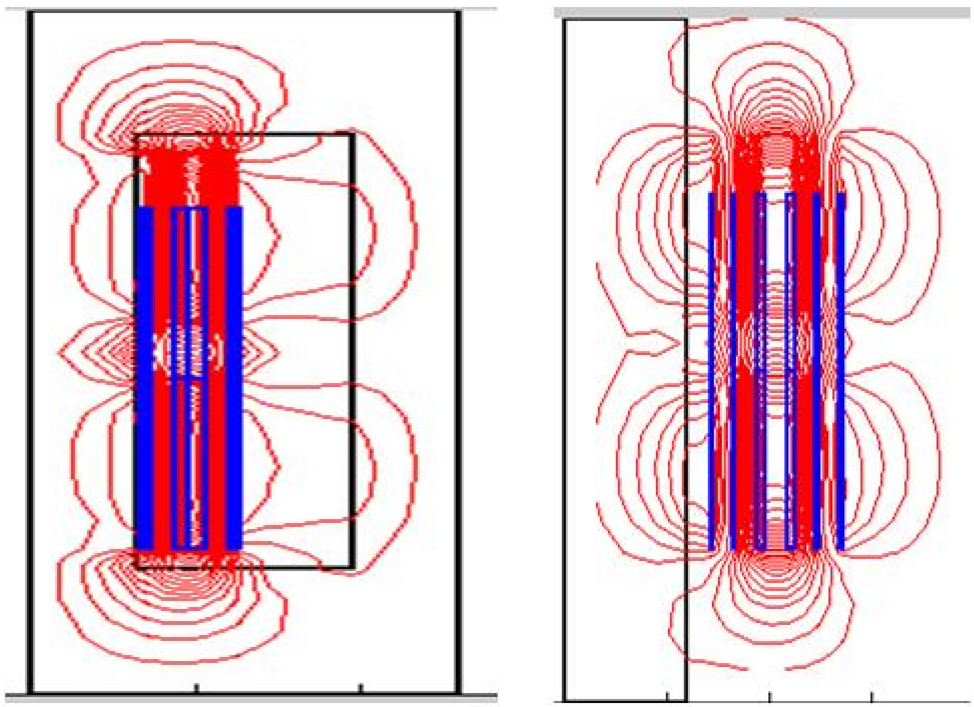
The selected criterion of the design is the temperature rise of 120°K for insulation class H. The oval space between the first winding and the tube (stomach), all gaps between the insulation, the windings and the varnish fill factor of them, play a very important roll from the thermal point of view.

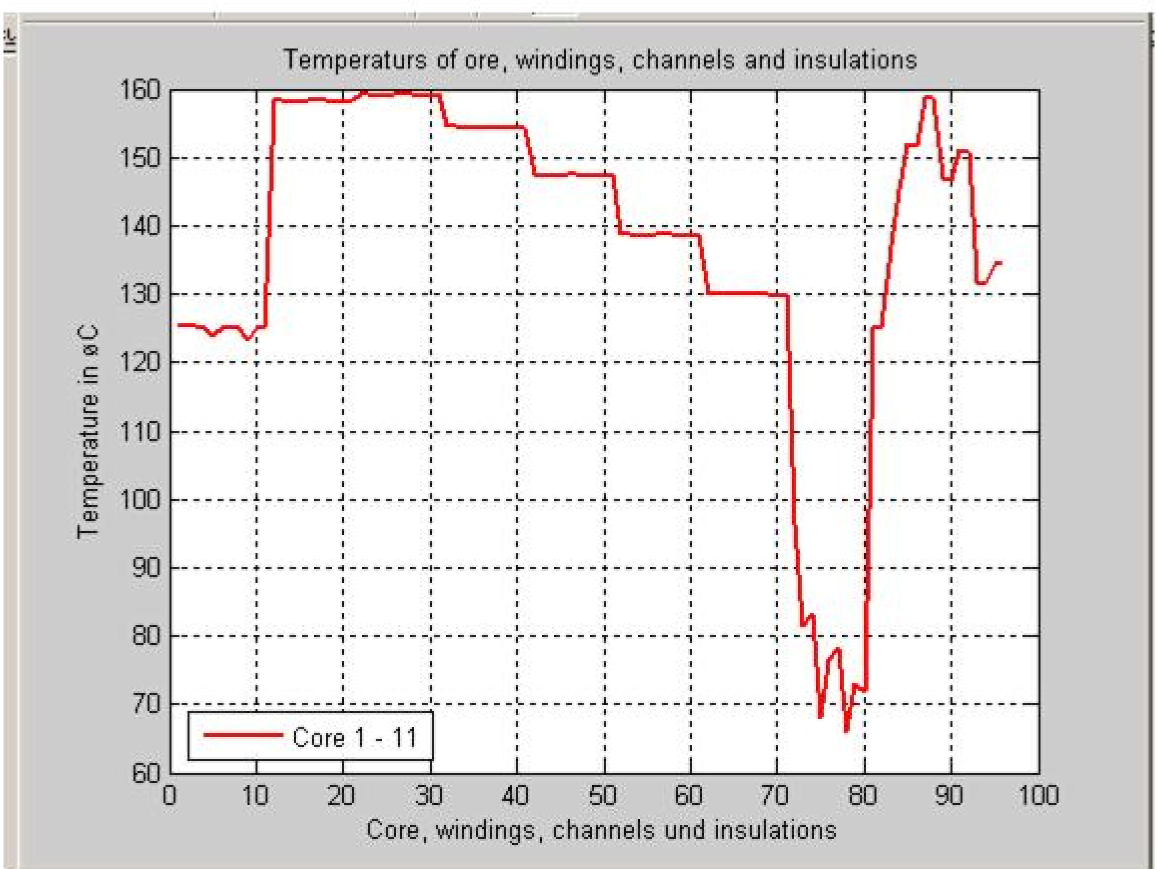
Output

The first step is the presentation of the output screen DIAGNOSIS: it is the summary of the most important calculated parameters of your transformer.



Note that the program uses the numerical calculation of the magnetic fields and the temperature rises. Due to this technology the calculations of the eddy current losses, the steel losses, the short-circuit voltage, the circulating current and the transposition are very powerful.
The following picture shows the magnetic field outside the core window.





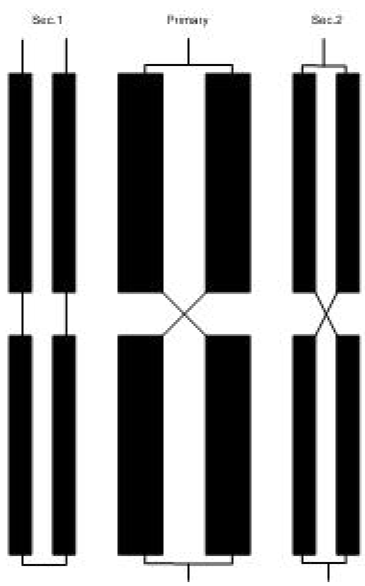
Finally here are 4 printed pages showing the design results

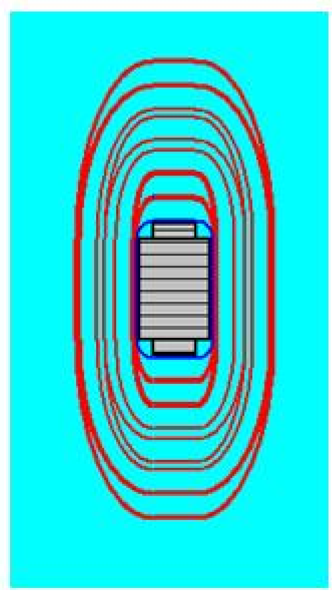
Input

12-17-2005/15:11:44/ V:14 .15 INPUT Page 1

Windings	1	2	3	4	5	6	7	8
Groups	2	2	1	1	3	3		
Circuits	5	5	4	4	4	4		
Connection	1	1	2	2	2	2		
H/Voltag/A	1 166 0	1 148 0	1 230 0	1 230 0	1 182 0	1 182 0		
	. . .	. . .	. . .	. . .	. . .	. . .		
	. . .	. . .	. . .	. . .	. . .	. . .		
	. . .	. . .	. . .	. . .	. . .	. . .		
	. . .	. . .	. . .	. . .	. . .	. . .		
H/Curren/A	1 224 0	1 224 0	. . .	. . .	1 194 0	1 194 0		
	5 43.6 0	5 43.6 0	. . .	. . .	5 38 180	5 38 180		
	7 32 180	7 32 180	. . .	. . .	7 28 0	7 28 0		
	11 28.2 0	11 28.2 0	. . .	. . .	11 18 0	11 18 0		
	13 17.3 0	13 17.3 0	. . .	. . .	13 15 0	13 15 0		
Time1 min.	60	60	60	60	60	60		
Load1 *	1	1	1	1	1	1		
Time2 min.	60	60	0	0	60	60		
Load2 *	1	1	0	0	1	1		
Sectors	2	2	2	2	2	2		
Ser./Para.	1	1	3	3	3	3		
Wire file	6	6	6	6	6	6		
Cu/Al	1	1	1	1	1	1		
In/Layer µ	50	50	50	50	50	50		
Transpos.	0	0	0	0	0	0		
Typ/I/C mm	3 2 20	3 0.1 20	2 0.1 20	3 0.1 20	2 0.1 20	3 0.1 20		
Typ/I/C mm	1 2 0.6	1 0.1 15	2 0.1 15	1 0.1 15	2 0.1 15	1 0.1 15		
Typ/I/I mm	1 0.1 0.1	1 0.1 0.1	1 0.1 0.1	1 0.1 0.1	1 0.1 0.1	1 0.1 0.1		
Margine mm	20	20	20	20	20	20		
RacRdc	1.1	1.15	1.15	1.15	1.15	1.1		

Frequency Hz: 50	Core select. -: Selecte	Cooling medium : Air	
	Core file : LTCM_EI_3_L_	Amb. temperature °C: 40	
Criterion : dT	Core name : EI3P 130/130	Convection outside *: 0.8	
Regulation %: 1	Core assembly-: 45° S&trips	Convection inside *: 0.8	
Ucc-voltage %: 5	With hole -: No	Emission *: 1	
Temperat. rise °K: 120		Airflow outside m/s: 0	
Efficiency %: 90	Steel file : STEEL1.DAT	Airflow inside m/s: 0	
No-load factor %: 10	Steel name : M111-0.35mm	Chassis -: Wood	
I^in/I^nom : 15	Induction T: 1.55	Vertical -: Vertica	
Iinrms/Inomrms : 15	W/kg *: 1.15	Horizontal -: L-T&B	
	VAr/kg *: 1.25	:	
	Airgap *: 4	Channel fill factor %: 80	
	f/fn-Factor *: 1	Varnish in windings %: 10	
	Fill factor : 1	Varnish in gaps %: 10	
	Annealed -: Yes	Rth-varnish *: 1	
		Rth-compound *: 1	
		Rth-insulation *: 1	
		Coil insulation mm: 0.01	
		Bauch mm: 2	
		Gap mm: 0.5	





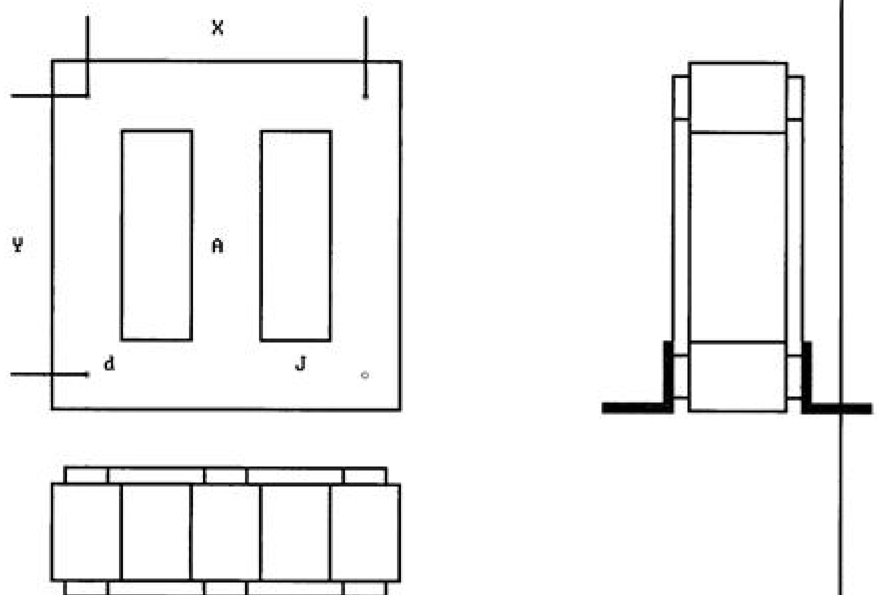
Core

12-17-2005/15:11:44 CORE Page 2

Core file name : LTCM_EI_3_L_1oval.USR	Fe-File name : STEEL1.DAT
Core name : EI3P 130/130/390/180/5	Fe-Name : M111-0.35mm =>M6 0.014
Core type : 3EI	Frequency Hz: 50
Type of windings : oval/rectangular	Remanence-Factor *: 0.35
Number of legs : 3	W/kg-Factor *: 1.15
Core assembly : 45° S&trips	VAr/kg-Factor *: 1.25
Leg/Diameter cm: 13	Gap-Factor *: 4
Window width cm: 13	f/fn-Factor *: 1
Window height cm: 39	Fillfactor *: 1
Stack cm: 24	Annealed -: Yes
Cross section in^2: 272.1	
Weight total kg: 515.3	
With holes -: Yes	Chassis -:
Brackets -: L-T&B	Vertical/Horizontal-:

X-Width cm: 52	
Y-Height cm: 52	
d_Hole cm: 1.1	
h-Distance cm: 0.8	
L-Laenght cm: 13	

Stufen		1	2	3	4	5	6	7	8
A-Leg	cm	13	8	0	0	0	0	0	0
J-Yoke	cm	13	8	0	0	0	0	0	0
R-Rearyoke	cm	0	0	0	0	0	0	0	0
S-Stack	cm	18	3	0	0	0	0	0	0
Number lamin. :									
Weight	kg:								

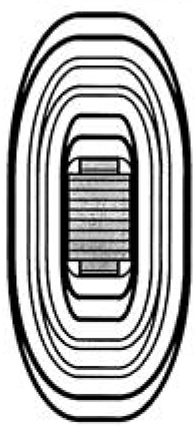


Windings

12-17-2005/15:11:44 WINDINGS Page 3

Windings	1	2	3	4	5	6	7	8
Groups-Circuits	2-D	2-D	1-Y	1-Y	3-Y	3-Y		
Connection	ser.	ser.	par.	par.	par.	par.		
Turns	18.0	16.0	24.0	24.0	20.0	20.0		
Build %	7.230	11.11	48.61	63.19	90.84	95.57		
Weight kg	5.1	5.3	28.1	32.7	10.2	11.2		
WIRE								
Type	Foil	Foil	Foil	Foil	Foil	Foil		
Thicknes mm	0.225	0.225	0.225	0.225	0.225	0.225		
Width mm	174.85	174.85	174.85	174.85	174.85	174.85		
WG-thicknes	0	0	0	0	0	0		
WG-width	0	0	0	0	0	0		
Al/Cu	Cu	Cu	Cu	Cu	Cu	Cu		
STRAND/LITZ								
Thickne insula. mm	0.23	0.23	0.68	0.68	0.23	0.23		
Width insulata. mm	174.9	174.9	174.9	174.9	174.9	174.9		
Parallel wires	1	1	3	3	1	1		
side by side	1	1	1	1	1	1		
one upon the other	1	1	3	3	1	1		
Transposition	0	0	0	0	0	0		
Cross section mm^2	39.3413	39.3413	118.023	118.023	39.3413	39.3413		
SECTOR								
Number	2	2	2	2	2	2		
Serie/Parallel	ser.	ser.	mixed	mixed	mixed	mixed		
Turns	9	8	12	12	10	10		
Turns/Layer	1	1	1	1	1	1		
Layers	9	8	12	12	10	10		
Insul./Layer µm	50.0	50.0	50.0	50.0	50.0	50.0		
Transposition	0	0	1	1	1	1		
Thicknes mm	2.70	2.425	9.375	9.375	2.975	2.975		
Width mm	174.85	174.85	174.85	174.85	174.85	174.85		
Distance/Sector mm	0.1	0.1	0.1	0.1	0.1	0.1		
SPACES/CHANNELS/INS.								
Outside mm	WICW	WICW	WCW	WICW	WCW	WICW		
Insulation mm	2.0	0.1	0.1	0.1	0.1	0.1		
Channel mm	20.0	20.0	0.	20.0	20.0	20.0		
Inside mm	WIW	WIW	WCW	WIW	WCW	WIW		
Insulation mm	2.0	0.1	0.1	0.1	0.1	0.1		
Channel mm	0.6	15.0	15.0	15.0	15.0	15.0		
Between sectors mm	WIW	WIW	WIW	WIW	WIW	WIW		
Distance mm	0.1	0.1	0.1	0.1	0.1	0.1		
Top/Bottom mm	0.1	0.1	0.1	0.1	0.1	0.1		
Distance to yoke mm	20.1	20.1	20.1	20.1	20.1	20.1		

Coil insulation mm: 0.
D1i/D1e: 259.3 264.7
D2i/D2e: 304.9 309.8
D3i/D3e: 349.8 368.5
D4i/D4e: 408.7 427.5
D5i/D5e: 467.5 473.4
D6i/D6e: 513.6 519.6
D7i/D7e: /
D8i/D8e: /



Nominal operating mode

12-17-2005/15:11:44	IN OPERATION MODE	Page 4

Frequency Hz:	50	Ventilation outsi. m/s:	0	Fillfactor/channels %:	80
Ambient temperature C:	40	Ventilation(chann. m/s:	0	Varnish in windings %:	10
Convection outside *:	0.8	Rth-Insulation *:	1	Varnish/gaps/stomack %:	10
Convection/channels *:	0.8	Rth-Varnish *:	1	Stomack mm:	2.00
Emission *:	1	Rth-Epoxy *:	1	Gap mm:	0.50

Output power kVA:	452.6	Input power kVA:	453.3	Core power :	0.0
Fe-Losses VA:	1190.	Fe-active losses W:	745.5	Fe-reactive losses VAr:	928.7
No-load curren %:	0.3	No load curr. active %:	0.2	No load curr. react. %:	0.2
I^in/I^nom-Factor :	1.45	Iinrms/Inomrms-Factor :	1.06	No load induction T:	1.585
I^in kA:	1.35	Iin rms kA:	0.70		
Icc cold kA:	19.91	Iccr active cold kA:	10.92	Iccx reactive cold kA:	16.64
Ucc cold %:	3.30	Uccr active cold %:	1.81	Uccx inductive cold %:	2.76
CuAl-losses W:	12763.6	Efficiency %:	97.097		
Max. dT Cu/Al °K:	119.2	Max. dT Fe °K:	85.4	Induction T:	1.570

Windings	1	2	3	4	5	6	7	8
Groups-Circuits	2-D	2-D	1-Y	1-Y	3-Y	3-Y		
Connection	ser.	ser.	par.	par.	par.	par.		
Time1	60.0	60.0	60.0	60.0	60.0	60.0		
Load1	1.00	1.00	1.00	1.00	1.00	1.00		
Time2	60.0	60.0	0.0	0.0	60.0	60.0		
Load2	1.00	1.00	0.00	0.00	1.00	1.00		
Voltage rms V	168.4	149.3	229.8	230.1	185.9	185.6		
U-Phasen delay °	-1.79	-1.32	1.070	-1.06	-1.32	-1.77		
No-load vo+tage V	172.4	153.3	229.9	230.0	191.6	191.6		
Regulation %	2.4	2.6	0.0	0.0	3.1	3.2		
Current rms A	234.76	234.76	329.09	327.89	205.14	205.27		
K-Factor	4.61	4.61	2.98	2.98	4.69	4.69		
Power kVA	39.54	35.06	75.64	75.46	38.14	38.10		
I-Phase delay °	0.2	-0.2	-1.7	-1.7	-0.2	0.2		
Resistance cold mOhm	6.588	6.869	4.013	4.672	13.143	14.432		
Losses warm W	565.3	590.1	674.8	765.6	800.5	858.0		
RacRdc (total)	1.00	1.00	1.02	1.02	1.00	1.00		
Icc.all cold kA	7.06	7.06	9.95	9.96	5.97	5.97		
Icc.group cold kA	6.55	6.55	0.00	0.00	5.44	5.45		
Circ.losses W	0.00	0.00	0.00	0.00	0.00	0.00		
Cur.density A/mm^2	5.97	5.97	2.77	2.77	5.16	5.16		
SECTORS								
1 RacRdc	1.00	1.00	1.02	1.02	1.00	1.00		
Current A	234.7	234.7	329.0	327.8	205.1	205.2		
dT °K	118.3	119.2	114.5	107.4	98.7	90.0		
2 RacRdc	1.00	1.00	1.02	1.02	1.00	1.00		
Current A	234.76	234.76	327.89	329.09	205.27	205.14		
dT °K	118.3	119.1	114.4	107.4	98.7	90.0		
3 RacRdc								
Current A								
dT °K								
4 RacRdc								
Current A								
dT °K								
5 RacRdc								
Current A								
dT °K								
6 RacRdc								
Current A								
dT °K								
7 RacRdc								
Current A								
dT °K								
8 RacRdc								
Current A								
dT °K								

Test Mode

If you are not satisfied with the solution made by the program you can switch into the Test Mode and change your transformer by hand:

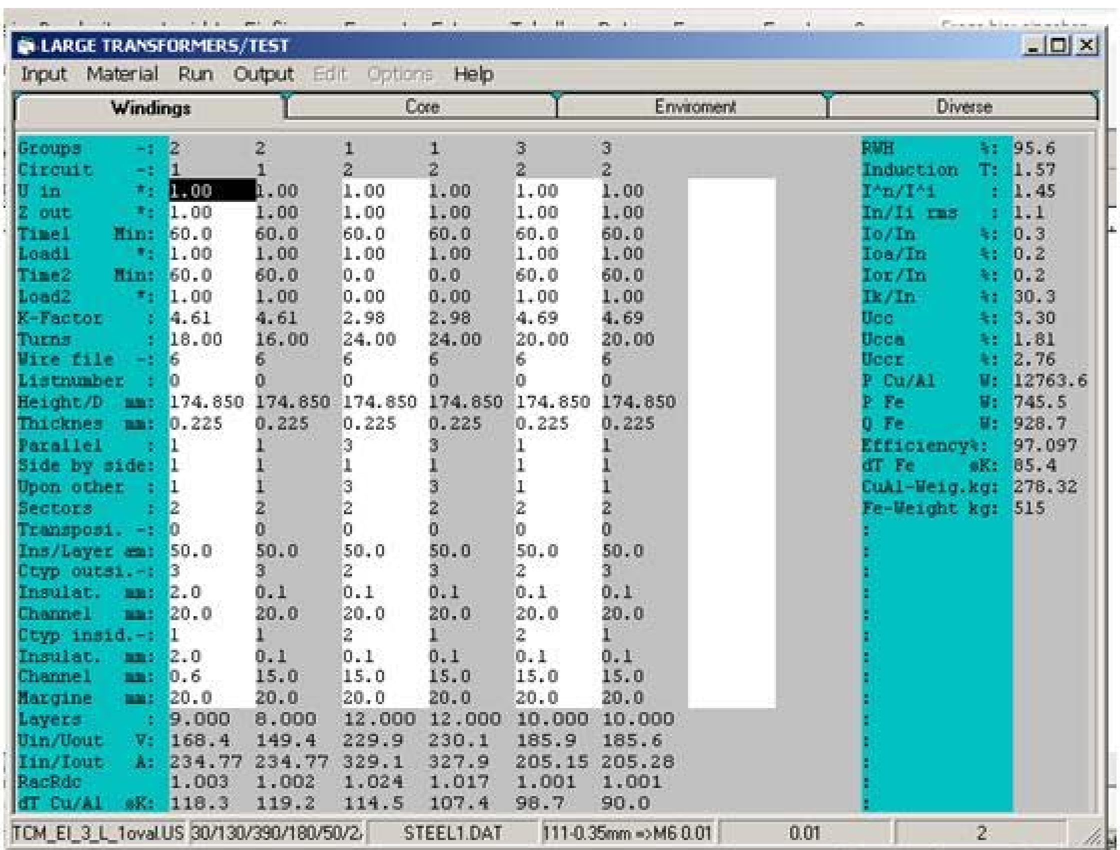
- Turns
- Wire size

- Material (Cu or Al)
- Number parallel connected wires and their order in strand
- Cooling channels and insulations
- Margin
- Steel
- Technology parameter (impregnation, gaps,...)

and then you can set it under an operation mode changing:

- Input voltage
- Frequency
- Loads and their K-factors
- Duty cycle of each winding
- Ambient temperature
- Air flow

Note that the program will calculate (not select from a data base) the thickness of the foil for the prescribed temperature rise of 120°K. In order to get an available foil you have to set the thickness of the foil by hand. Note that all the windings of this transformer will be manufactured with the same foil 175mm x 0.225mm



Designing a 12Vdc, 30kAdc Rectifier Transformer

General Information

Technical Specification

Input voltage	3 x 3 x 400/230, star
Transformer output voltages for Udc = 12Vdc	3 x 10.9Vac, star 3 x 10.9Vac, star
Line output current per secondary: (Ia1,Ib1,Ic1,Ia2,Ib2,Ic2)	I1 = 5850Arms I0 = 4980Arms (dc-comp.) I2 = 2880Arms I14 = 1590Arms I15 = 1170Arms continuous operating mode
Frequency	50Hz
Ambient temperature	40°C
Temperature rise	Max. 120°K, insulation class H
°Short-circuit voltage	Ucc_s1-s2/Ucc >= 2..4 for use with drainage choke
Steel & Core	M6, annealed, strips for alternated stacking (45°), "round" cross section

Creating Input

4 input screens are used to set the input parameters for the designing of a transformer:

- Winding parameters per limb
- Core
- Environment
- Other parameters

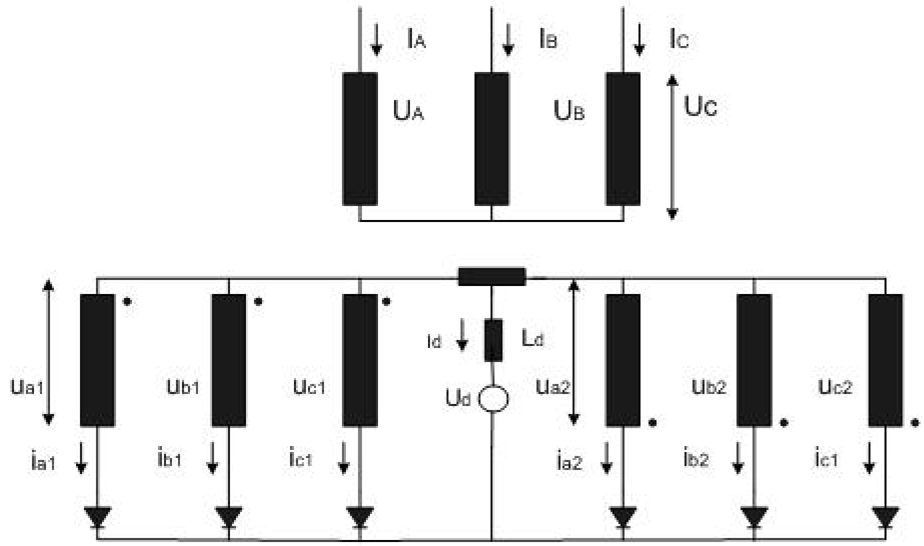
and 3 screens for selection and set up of material :

- wires
- steels
- cores.

Windings parameters per limb

The following rectifier circuit is often used for low voltage&high current output. For a good current distribution between 2 parallel connected rectifiers (with the drainage choke) the relationship Ucc_s1-s2/Ucc has to be bigger than 2; Ucc_s1-s2 is the short-circuit voltage between the secondary 1 and the

secondary 2; Ucc is the short-circuit voltage of the transformer. For this condition the primary will be "sandwiched" between both secondary.
The core cross section and the induction have to be set so that each secondary has only one turn. The form of the legs cross section have to be "round"



U = 1.05 x (0.855 x Ud + 1.5)

Harmonic	i1/Id	Angle	I2/Id	Angle		
1	0.195	0	0.195	0		
0	0.166	0	0.166	0		
2	0.096	0	0.096	180		
4	0.053	180	0.053	0		
5	0.039	0	0.039	0		

Legend:
u = rms value of the secondary voltages Ua1, Ub1 , Uc1, Ua2,Ub2 and Uc2
i1,2 = rms value of the secondary currents i_{a1}, i_{b1}, i_{c1}, i_{a2}, i_{b2} and i_{c2}
Ud = dc voltage
Id = dc current

Note:
The laeking inductance of the transformer Ls = 0 (worst case)
0 Harmonic = DC current

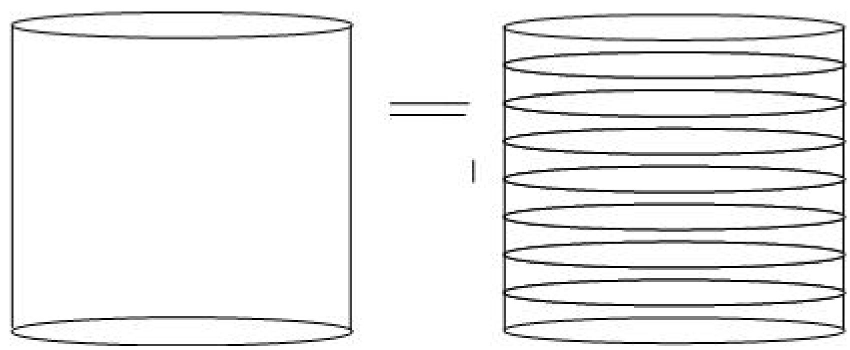
Note that the short-circuit voltage of a rectifier transformer is a complex issue reflecting:

- the rectifier protection in a short circuit operation mode of all secondary winding, a group of windings or of only one winding.
- the commutation operation mode of a group of windings
- the voltage drop of the dc-output voltage
- the current distribution between the parallel connected rectifiers

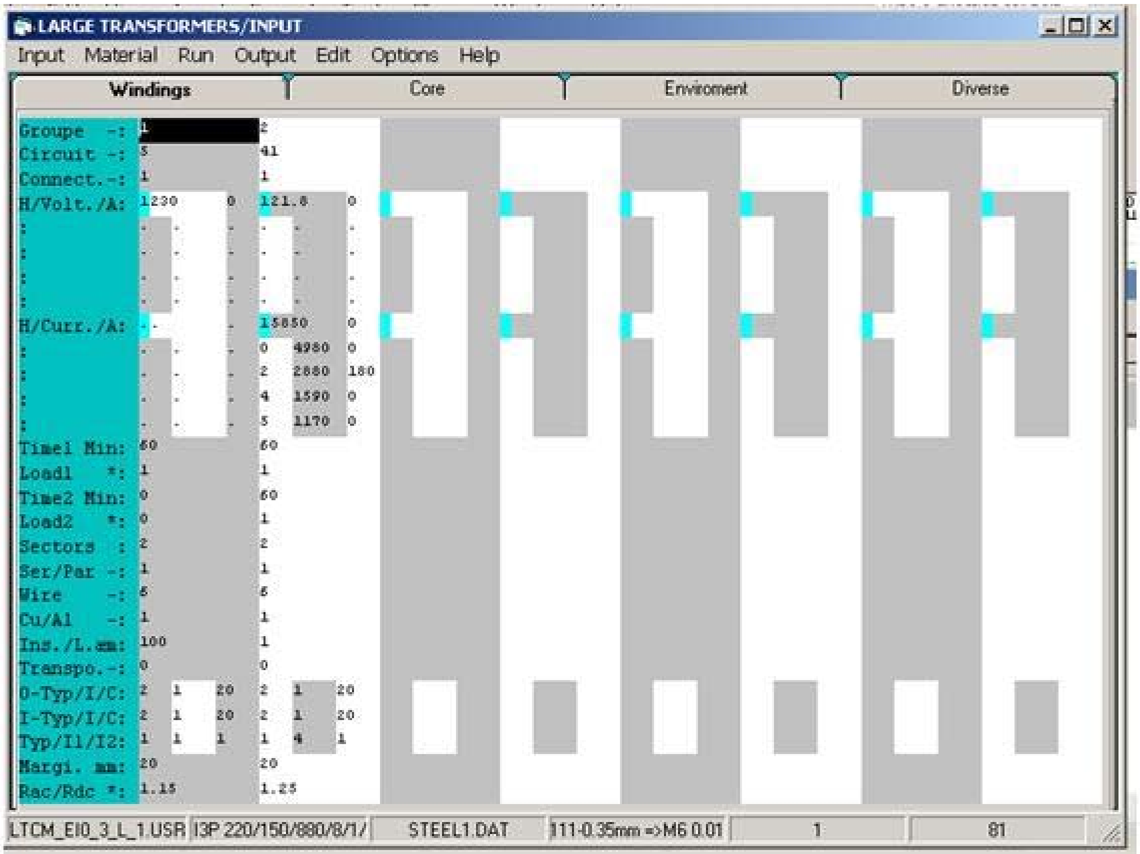
It has to be prescribed by the user of the transformer

Primary

The primary is created in star connection. The sine wave input voltage (U_A,U_B,U_C)is 230V (230V per winding).
There is no duty cycle operation mode.
The primary will be manufactured with Cu-foil with a layer insulation of 0.100mm. **Note that there no big difference from an electrical or magnetic point of view (if the distance between the sectors is small) between the winding made by foil with one sector and the winding made by foil with more (2-8) parallel connected sectors. The first and the last sector will be overloaded by a higher eddy & circulated current losses and due to the thermal insulation to the other sectors they will normally be hotter .**

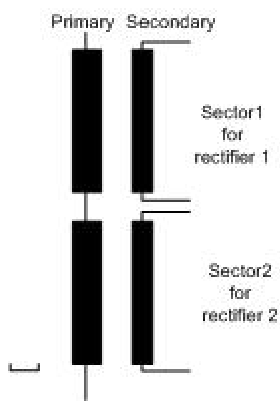


The primary lies between the secondary windings and the core. In order to avoid using very large foil with it is created with 2 in series connected sectors All the surfaces of the primary are cooled via the cooling channels of 20mm . The space between the yoke and the primary windings is 20mm. With the eddy current losses factor (RacRdc) 1.15 shall be limited the number of the parallel connected foils per sector.



Secondary

The both secondary windings are created with 2 in series connected **ONE ROUND TURN, BAR WOUND SECTORS**.



The sine wave output voltage per sector is 10.9V.
The rms current through each sector (secondary) is 8774Arms. The set current harmonics are calculated for the worst case: Ucc= 0 and Ld = ∞:

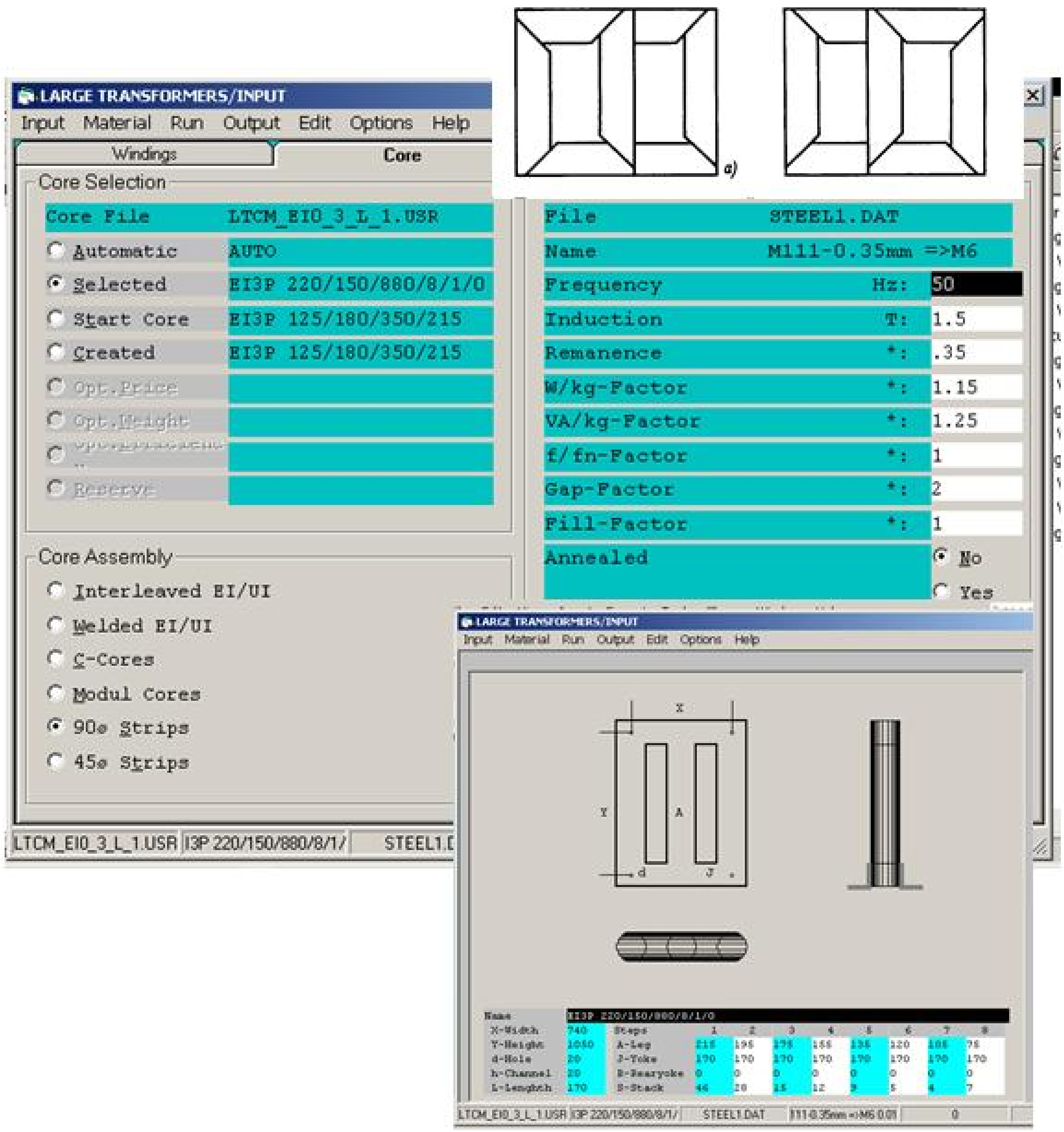
Also, there is no duty cycle operation mode on the secondary.
With the eddy current losses factor (RacRdc) 1.1 and 1.25 the use of parallel connected bars per sector shall be avoided . Note that at this point of the design you cannot prescribe the wire or foil (bar) size. You can select only the wire or family or foil (bar) which the program has to use in order to select the suitable wires or foils (bar) for your application.

The secondary winding has only 20mm cooling channels.
The space between the yoke and the secondary windings is 20mm

Core

On this input screen you can :

- select and manipulate the selected steel M111, 035mm (M6, 14mil)
- set the operating induction (1.55T) and the frequency (50Hz)
- select the core assembly
- and prescribe the core selection.

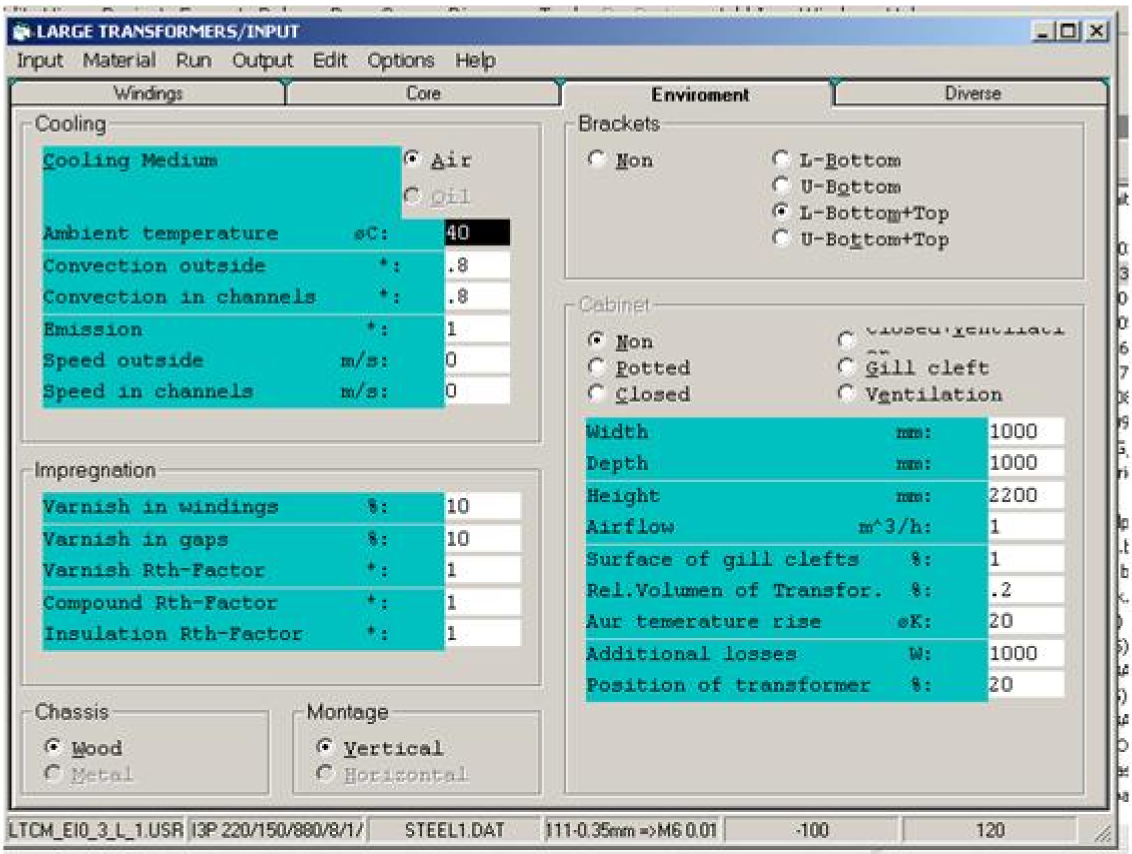


The "round" core cross section was prescribed by the designer for easier winding of the high current foil (bar) windings: The value of the cross section and the induction were set in order to get only one turn per sector
The window height was optimized for the low eddy current losses with a Cu-bar thickness between

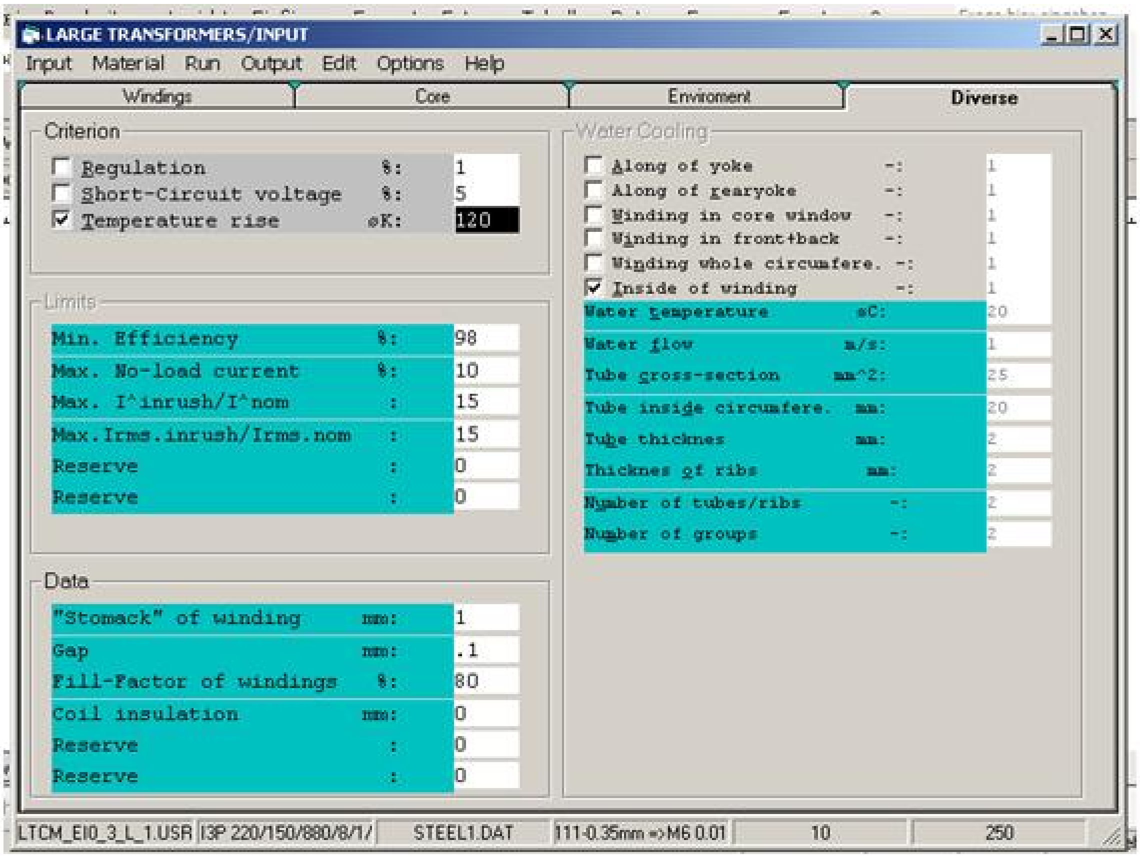
5mm and 6mm.
Normally you use for this application M111, 0.35mm (M6, 14mil), not annealed after stamping, grain oriented strips.

Environment

The cooling medium is air with the ambient temperature 40°C. The cooling surface of the core is increased by using 4 L-brackets on the core.
The impregnation is practically "dry" because there is only 10% varnish (90% air) in the windings and in all the gaps between the insulations and the layers of the windings



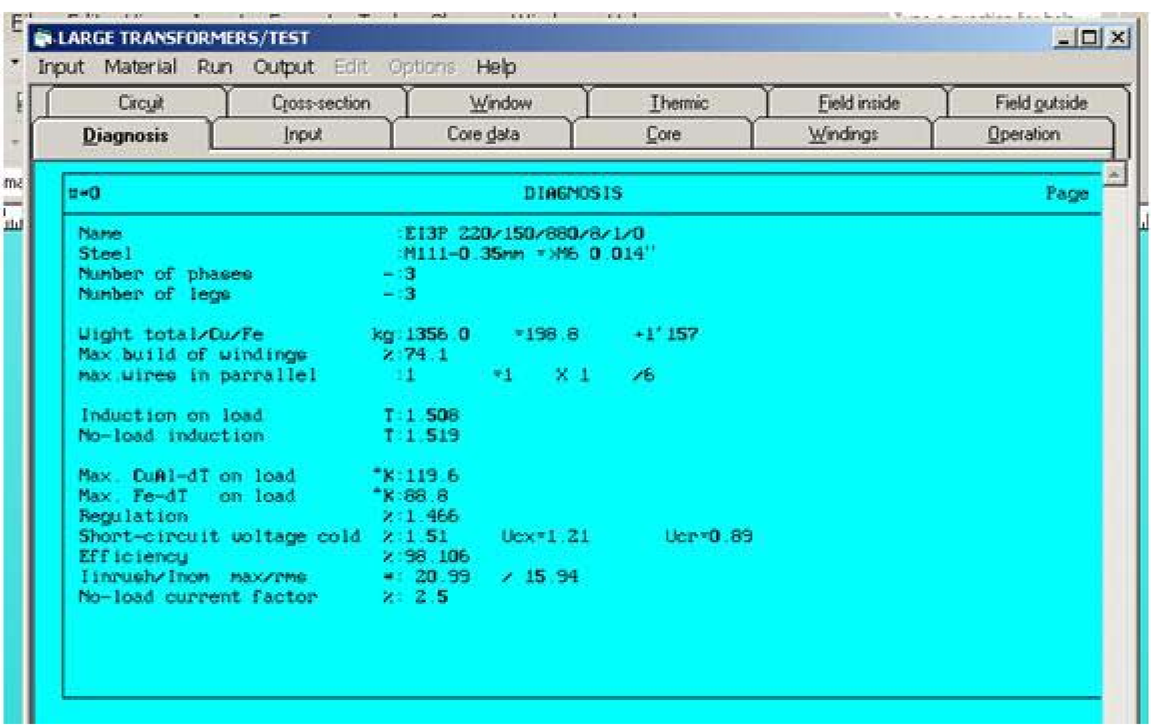
Other...



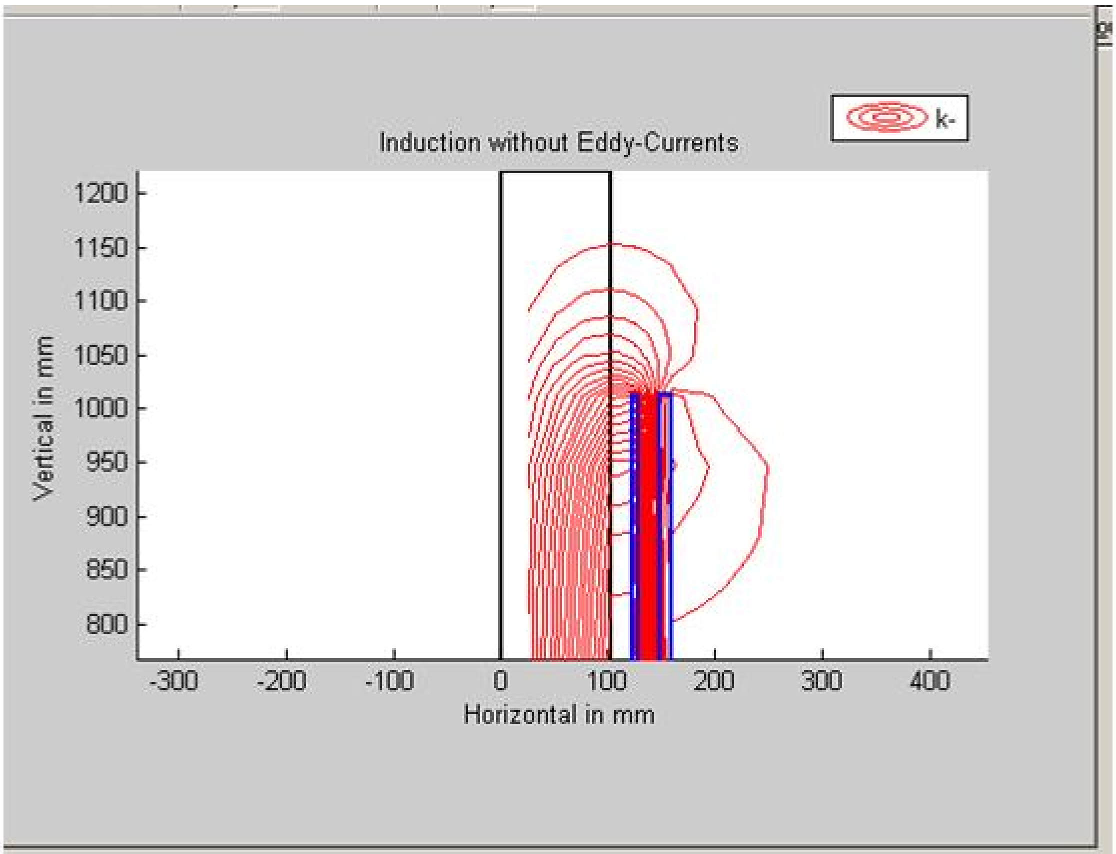
The selected criterion of the design is the temperature rise of 120°K for insulation class H. The oval space between the first winding and the tube (stomach), all gaps between the insulation, the windings and the varnish fill factor of them, play a very important roll from the thermal point of view.

Output

The first step is the presentation of the output screen DIAGNOSIS: it is the summary of the most important calculated parameters of your transformer.



Note that the program uses the numerical calculation of the magnetic fields and the temperature rises. Due to this technology the calculations of the eddy current losses, the steel losses, the short-circuit voltage, the circulating current and the transposition are very powerful.
The following picture shows the magnetic field outside the core window.
The ampere-turns of 1., 5., 7... current harmonics in the primary and in the secondary are compensated. They produce axial leakage magnetic field
The ampere-turns of the 0.(dc-current), 2., 4. ,... current harmonics do not exist in the primary. They exist only in the sectors of the secondary, are compensated too and produce radial leakage magnetic field.



Finally here are 4 printed pages showing the design results

Input

02-04-2006/12:24:08/ V:14 .17 INPUT Page 1

Windings	1	2	3	4	5	6	7	8
Groups	1	2						
Circuits	5	41						
Connection	1	1						
N/Voltag/A	1 230 0	1 21.8 0						
	. . .	. . .						
	. . .	. . .						
	. . .	. . .						
	. . .	. . .						
N/Curren/A	. . .	1 5850 0						
	. . .	0 4980 0						
	. . .	2 2880 180						
	. . .	4 1590 0						
	. . .	5 1170 0						
Time1 min.	60	60						
Load1 *	1	1						
Time2 min.	0	60						
Load2 *	0	1						
Sectors	2	2						
Ser./Para.	1	1						
Wire file	6	6						
Cu/Al	1	1						
In/Layer y	100	1						
Transpos.	0	0						
Typ/I/C mm	2 1 20	2 1 20						
Typ/I/C mm	2 1 20	2 1 20						
Typ/I/I mm	1 1 1	1 4 1						
Margins mm	20	20						
RacRdc	1.15	1.25						

Frequency Hz: 50	Core select. -: Selecte	Cooling medium : Air	
	Core file : LTCM_E10_3_L	Amb. temperature °C: 40	
Criterion : dT	Core name : EI3P 220/150	Convection outside *: 0.8	
Regulation %: 1	Core assembly-: 90° &Strips	Convection inside *: 0.8	
Ucc-voltage %: 5	With hole -: No	Emission *: 1	
Temperat. rise °K: 120		Airflow outside m/s: 0	
Efficiency %: 98	Steel file : STEEL1.DAT	Airflow inside m/s: 0	
No-load factor %: 10	Steel name : M111-0.35mm	Chassis -: Wood	
I^in/I^nom : 15	Induction T: 1.5	Vertical -: Vertica	
Iinrms/Inomrms : 15	W/kg *: 1.15	Horizontal -: L-T&B	
	VAr/kg *: 1.25	:	
	Airgap *: 2	Channel fill factor %: 80	
	f/fn-Factor *: 1	Varnish in windings %: 10	
	Fill factor : 1	Varnish in gaps %: 10	
	Annealed -: No	Rth-varnish *: 1	
		Rth-compound *: 1	
		Rth-insulation *: 1	
		Coil insulation mm: 0	
		Bauch mm: 1	
		Gap mm: 0.1	

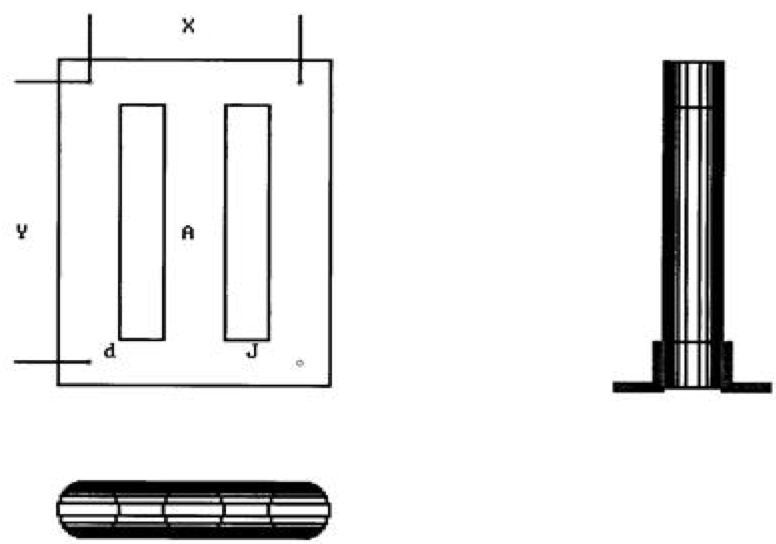
Core

02-04-2006/12:24:08 CORE Page 2

Core file name	: LTCM_EI0_3_L_1.USR	Fe-File name	: STEEL1.DAT
Core name	: EI3P 220/150/880/8/1/0	Fe-Name	: M111-0.35mm =>M6 0.014
Core type	: 3EI	Frequency	Hz: 50
Type of windings	: round	Remanence-Factor	*: 0.35
Number of legs	: 3	W/kg-Factor	*: 1.15
Core assembly	: 90° 8Strips	VAr/kg-Factor	*: 1.25
Leg/Diameter	cm: 21.98	Gap-Factor	*: 2
Window width	cm: 15.5	f/fn-Factor	*: 1
Window height	cm: 87.99	Fillfactor	*: 1
Stack	cm: 20.6	Annealed	-: No
Cross section	in^2: 340.6		
Weight total	kg: 1157.		
With holes	-: Yes	Chassis	-:
Brackets	-: L-T&B	Vertical/Horizontal	-:

X-Width	cm: 74
Y-Height	cm: 105
d_Hole	cm: 2
h-Distance	cm: 2
L-Laenght	cm: 17

Stufen		1	2	3	4	5	6	7	8
A-Leg	cm:	21.5	19.5	17.5	15.5	13.5	12	10.5	7.5
J-Yoke	cm:	17	17	17	17	17	17	17	17
R-Rearyoke	cm:	0	0	0	0	0	0	0	0
S-Stack	cm:	4.6	2.8	1.5	1.2	0.9	0.5	0.4	0.7
Number lamin.	:								
Weight	kg:								



Windings

02-04-2006/12:24:08 WINDINGS Page 3

Windings	1	2	3	4	5	6	7	8
Groups-Circuits	1-D	2-Yn						
Connection	ser.	ser.						
Turns	20.0	2.0						
Build %	32.77	74.06						
Weight kg	23.5	42.8						
WIRE								
Type	Foil	Foil						
Thicknes mm	0.40	6.00						
Width mm	400.00	400.00						
WG-thicknes	0	0						
WG-width	0	0						
Al/Cu	Cu	Cu						
STRAND/LITZ							7	
Thickne insula. mm	0.40	6.00						
Width insulata. mm	400.0	400.0						
Parallel wires	1	1						
side by side	1	1						
one upon the other	1	1						
Transposition	0	0						
Cross section mm^2	160.0	2400.0						
SECTOR								
Number	2	2						
Serie/Parallel	ser.	ser.						
Turns	10	1						
Turns/Layer	1	1						
Layers	10	1						
Insul./Layer μm	100.0	1.0						
Transposition	0	0						
Thicknes mm	5.40	12.001						
Width mm	400.00	400.00						
Distance/Sector mm	1.0	4.0						
SPACES/CHANNELS/INS.								
Outside mm	WCW	WCW						
Insulation mm	1.0	1.0						
Channel mm	20.0	20.0	0.					
Inside mm	WCW	WCW						
Insulation mm	1.0	1.0						
Channel mm	20.0	20.0						
Between sectors mm	WIW	WIW						
Distance mm	1.0	4.0						
Top/Bottom mm	1.0	1.0						
Distance to yoke mm	39.5	38.0						

Coil insulation mm: 0.
D1i/D1e: 259.8 270.6
D2i/D2e: 310.6 334.6
D3i/D3e: /
D4i/D4e: /
D5i/D5e: /
D6i/D6e: /
D7i/D7e: /
D8i/D8e: /

Nominal operating mode

02-04-2006/12:24:08	IN OPERATION MODE	Page 4

Frequency Hz	50	Ventilation outsi. m/s	0	Fillfactor/channels %	80
Ambient temperature C	40	Ventilation(chann. m/s	0	Varnish in windings %	10
Convection outside *	0.8	Rth-Insulation *	1	Varnish/gaps/stomack %	10
Convection/channels *	0.8	Rth-Varnish *	1	Stomack mm	1.00
Emission *	1	Rth-Epoxy *	1	Gap mm	0.10

Output power kVA	596.7	Input power kVA	430.4	Core power	0.0
Fe-Losses VA	10065	Fe-active losses W	2106.	Fe-reactive losses VAr	9842.
No-load curren %	2.5	No load curr. active %	0.5	No load curr. react. %	2.4
I^in/I^nom-Factor	20.99	Iinrms/Inomrms-Factor	15.94	No load induction T	1.519
I^in kA	32.01	Iin rms kA	17.24		
Icc cold kA	41.42	Iccr active cold kA	24.62	Iccx reactive cold kA	33.32
Ucc cold %	1.51	Uccr active cold %	0.89	Uccx inductive cold %	1.21
CuAl-losses W	9391.7	Efficiency %	98.109		
Max. dT Cu/Al °K	119.5	Max. dT Fe °K	88.7	Induction T	1.508

Windings	1	2	3	4	5	6	7	8
Groups-Circuits	1-D	2-Yn						
Connection	ser.	ser.						
Time1	60.0	60.0						
Load1	1.00	1.00						
Time2	0.0	60.0						
Load2	0.00	1.00						
Voltage rms V	230	22.66						
U-Phasen delay °	0	-0.66						
No-load vo÷tage V	230	22.99						
Regulation %	0.0	1.5						
Current rms A	623.74	8774.5						
K-Factor	1.92	1.99						
Power kVA	143.4	198.8						
I-Phase delay °	-2.0	0.0						
Resistance cold mOhm	1.822	0.015						
Losses warm W	1135.	1994.						
RacRdc (total)	1.00	1.14						
Icc.all cold kA	41.42	414.2						
Icc.group cold kA	0.00	414.2						
Circ.losses W	66.76	20.79						
Cur.density A/mm^2	3.89	3.65						
SECTORS								
1 RacRdc	1.00	1.13						
Current A	623.7	8774.						
dT °K	119.5	114.8						
2 RacRdc	1.00	1.14						
Current A	623.74	8774.5						
dT °K	119.4	115.4						
3 RacRdc								
Current A								
dT °K								
4 RacRdc								
Current A								
dT °K								
5 RacRdc								
Current A								
dT °K								
6 RacRdc								
Current A								
dT °K								
7 RacRdc								
Current A								
dT °K								
8 RacRdc								
Current A								
dT °K								

Test Mode

If you are not satisfied with the solution made by the program you can switch into the Test Mode and change your transformer by hand:

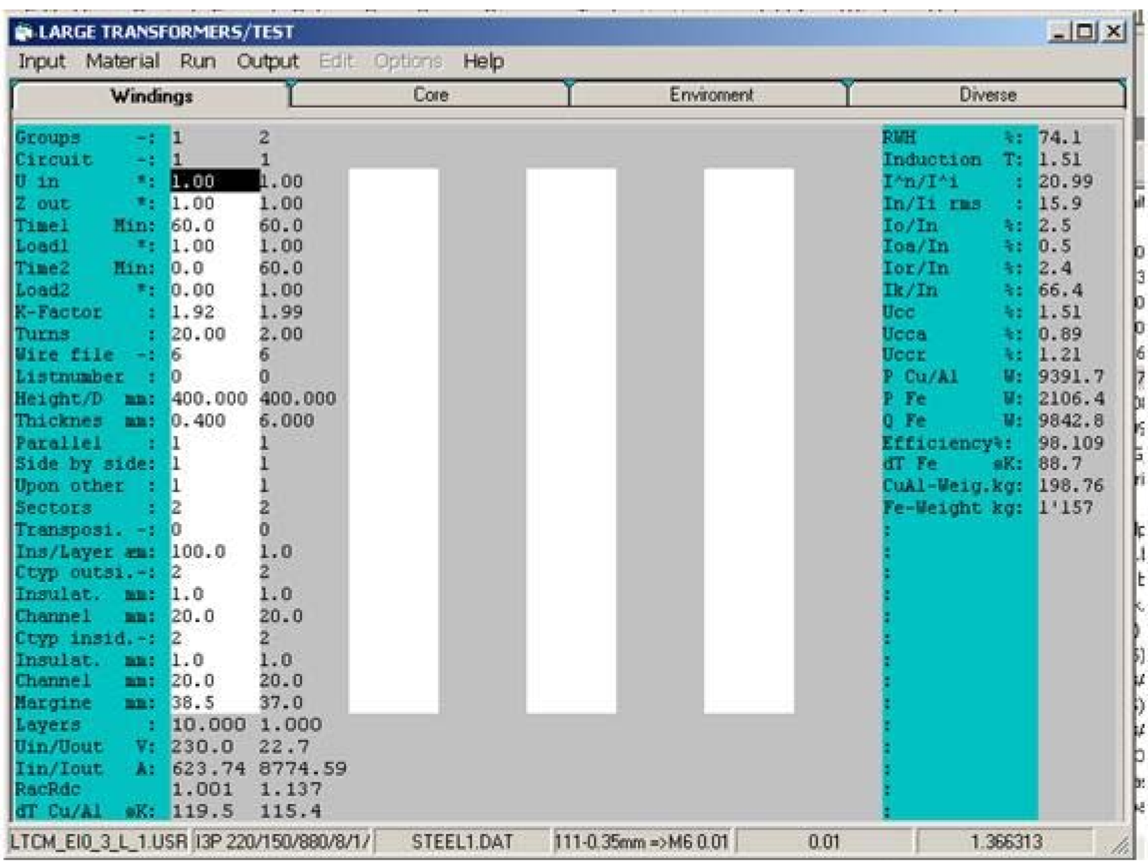
- Turns
- Wire size

- Material (Cu or Al)
- Number parallel connected wires and their order in strand
- Cooling channels and insulations
- Margin
- Steel
- Technology parameter (impregnation, gaps,...)

and then you can set it under an operation mode changing:

- Input voltage
- Frequency
- Loads and their K-factors
- Duty cycle of each winding
- Ambient temperature
- Air flow

Note that the program will calculate (not select from a data base) the thickness of the foil (bar) for the prescribed temperature rise of 120°K. In order to get an available foil (bar) you have to set the thickness of the foil by hand.



NOTE

If you would like to modify this transformer in order to use it for 12Vdc, 15kAdc then you need only to change the foil&bar width (200mm instead 400mm) and reduce the height of the core window for 400mm.

Designing a autotransformer for 400Vdc, 1000Adc with 2 parallel connected rectifiers in 12-pulse operating mode

General Information

Technical Specification

Input voltage	3 x 400/230V
Autotransformer output voltage for Udc = 400Vdc	3 x 314/182V, +15° 3 x 314/182V, -15°
Line output current per secondary: (Ia1,Ib1,Ic1,Ia2,Ib2,Ic2)	I1 = 388Arms I5 = 77.5Arms I7 = 55.5Arms I11 = 35Arms I13 = 30Arms continuous operating mode
Frequency	50Hz
Ambient temperature	40°C
Temperature rise	Max. 120°K, insulation class H
--Steel & Core	M6, annealed, strips for alternated stacking (45°), Oval cross section

Creating Input

4 input screens are used to set the input parameters for the designing of a transformer:

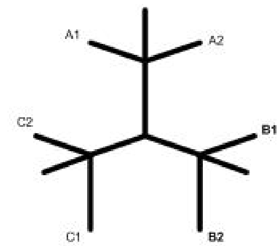
- Winding parameters per limb
- Core
- Environment
- Other parameters

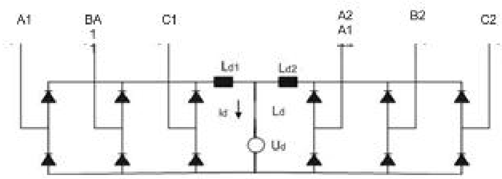
and 3 screens for selection and set up of material :

- wires
- steels
- cores.

Windings parameters per phase

The following 3 phase autotransformer circuit is often used to drive 2 parallel connected 6 pulse bridge rectifiers in order to compensate the 5. and 7. current harmonics on the input voltage side of the autotransformer. The parallel connection of the rectifiers is normally used if the output current Id is over 500-1000Adc.





For equal current distribution between 2 parallel connected rectifiers (without the chokes Ld1 and Ld2) the ratio Ucc_out1-out2/Ucc_in-out has to be bigger or equal 4 and Ucc_in-out > 4%. Normally this condition can be not realized by using the autotransformer and you need to consider using of Ld1&Ld2 chokes and/or 2 3-phase commutating chokes at the AC side between the rectifier and the autotransformer. Using of 2 3-phase commutating chokes is very effective for suppressing all current harmonics.

Note that the short-circuit voltage of a rectifier autotransformer is a complex issue reflecting:

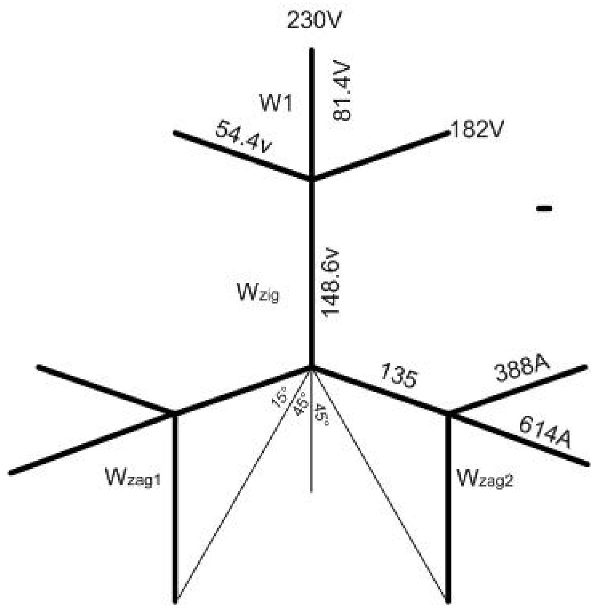
- the rectifier protection in a short circuit operation mode of all secondary winding, a group of windings or of only one winding.
- the commutation operation mode of a group of windings
- the voltage drop of the dc-output voltage
- the current distribution between the parallel connected rectifiers

It has to be prescribed by the user of the transformer

The following 50Hz vector diagram of the autotransformer was created as follows:

- Input voltage per phase is 230V
- The output voltage per phase for 400Vdc rectifier voltage is 182V
- The first current harmonic is 388A (for rectifier DC current 500Adc)
- The zag voltage is 182 x sin(45°)/sin(120°) = 148.6V
- The zig voltage is 182 x sin(15°)/sin(120°) = 54.4V
- The voltage on the W1 winding is 230-148.6 = 81.4V
- The input current is 2 x 388 x 182/230 = 614A

- The zig current is 2 x 388 x cos(15°) - 614 = 135A

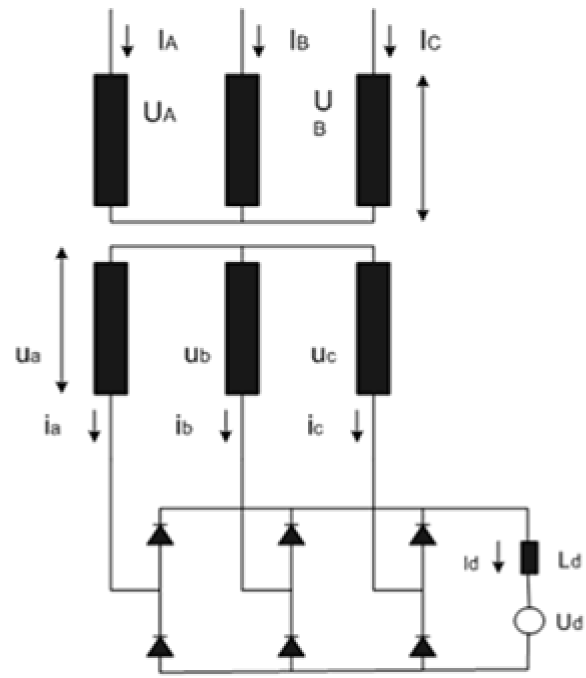


Windings parameters per leg

The Large Transformers Program supports the input per leg. You have to follow the following rules

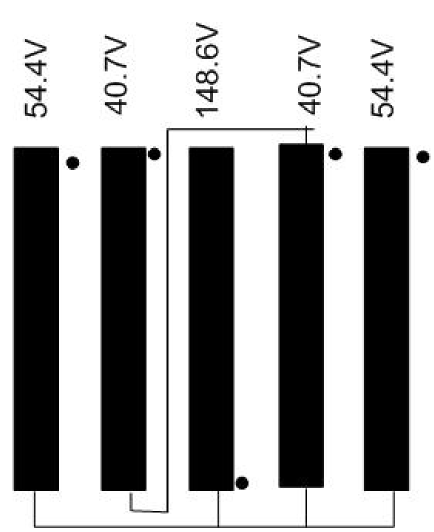
1. You need to declare min. one winding for primary. In this case it is zig winding with the input voltage 148.6V
2. Wzag1 is the first secondary winding with 54.4V and 388A(first harmonic). Note that the current angle is 135° to the primary zig-winding (view the diagram). Through this winding flow all current harmonics.
3. Wzag2 is the second secondary winding with 54.4V and 388A(first harmonic). Note that the current angle is 225° to the primary zig-winding (view the diagram). Through this winding flow all current harmonics. Note that the 5. and 7. harmonics flow in opposite direction to the 5. and 7. harmonics of the first zig winding (angle 180°)
4. W1 is the 3. secondary winding with 81.4V and 614A(first harmonic). Note that the 5. and 7. current harmonics do not exist in this winding. 11. and 13. harmonics are 2 x cos(15°) bigger than in the zag winding
5. For check in of your input you need to calculate "ampere-turns" of all winding per leg (without the primary no-load current)
   54.4 x 388 x sin(135°) + 54.4 x 388 x sin(225°) = 0
   81.4 x 614 -148.6 x 135 + 54.4x388 x (cos(135°) + cos(225°)) = 0

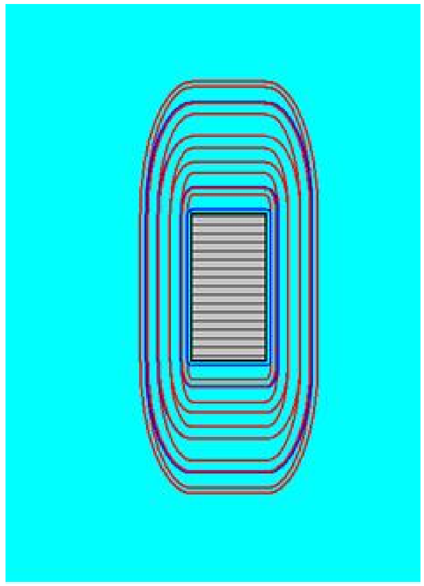
6. The set current harmonics are calculated for the worst case: Ucc= 0 and Ld = ∞ using the following table:



U = 1.05 x (0.741 x Ud + 3)/1.73						
Harmonic	i/Id	Angle				
1	0.777	0				
5	0.155	180				
7	0.111	0				
11	0.070	180				
13	0.060	0				

In order to get equal short-circuit voltage for both outputs and a good current distribution between 2 parallel connected rectifiers it is recommended to use the following winding configuration per leg





Output

06-22-2009/15:33:03/ V:14 .66 INPUT Page 1

Windings	1	2	3	4	5	6	7	8
Groups	2	3	1	3	4			
Circuits	4	4	5	4	4			
Connection	1	1	1	1	1			
H/Voltag/A	1 54.4 0	1 40.7 0	1 148.6053	1 40.7 0	1 54.4 0			
	. . .	. . .	. . .	. . .	. . .			
	. . .	. . .	. . .	. . .	. . .			
	. . .	. . .	. . .	. . .	. . .			
	. . .	. . .	. . .	. . .	. . .			
H/Curren/A	1 388 135	1 614 0	. . .	1 614 0	1 388 225			
	5 74 0	5 0 0	. . .	5 0 0	5 74 180			
	7 55.4 0	7 0 0	. . .	7 0 0	7 55.4 180			
	11 35 0	11 55.4 180	. . .	11 55.4 180	11 35 0			
	13 30 0	13 47.4 180	. . .	13 47.4 180	13 30 0			
Time1 min.	60	60	60	60	60			
Load1 *	1	1	1	1	1			
Time2 min.	60	60	0	60	60			
Load2 *	1	1	0	1	1			
Sectors	1	1	1	1	1			
Ser./Para.	1	1	1	1	1			
Wire file	6	6	3	6	6			
Cu/Al	1	1	1	1	1			
In/Layer μ	100	100	100	100	100			
Typ/Trans.	10	10	10	10	10			
Typ/I/C mm	3 3 10	3 1 10	3 0.1 10	3 0.1 15	3 1 10			
Typ/I/C mm	1 3 10	1 1 10	1 0.1 10	1 0.1 15	1 1 10			
Typ/I/I mm	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1			
Margin mm	15	15	15	15	15			
RacRdc	1.2	1.05	1.2	1.05	1.2			

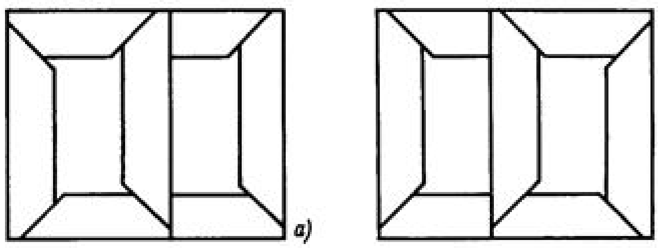
Frequency Hz: 50	Core select. -: Selecte	Cooling medium : Air	
	Core file : LTCM_EI_3_L_	Amb. temperature °C: 40	
Criterion : dT	Core name : EI3P 500/200	Convection outside *: 0.8	
Ucc-voltage act. %: 1	Core assembly-: (8) 6x45°+2x9	Convection inside *: 0.8	
Ucc-voltage tot. %: 5	With hole -: No	Emission *: 1	
Temperat. rise °K: 125		Airflow outside m/s: 0	
Max. Fe losses %: 0.2	Steel file : STEEL1.DAT	Airflow inside m/s: 0	
No-load factor %: 1.3	Steel name : M111-0.35mm	Chassis -: Wood	
I^in/I^nom : 10	Induction T: 1.55	Vertical -: Vertica	
Irms on/Irms nom : 10	W/kg *: 1	Horizontal -: L-T&B	
	VAr/kg *: 1	:	
Losses at temp.°C: 115	Airgap *: 1	Channel fill factor %: 70	
HV-Test volta. kV: 4	f/fn-Factor *: 1	Varnish in windings %: 10	
LV-Test volta. kV:	Fill factor : 1	Varnish in gaps %: 10	
HV-Nom.voltage kV: 0.4	Annealed -: No	Rth-varnish *: 1	
LV-Testvoltage kV:		Rth-compound *: 1	
Cu Price per kg : 2		Rth-insulation *: 1	
Al Price per kg : 2		Coil insulation mm: 0	
Fe Price per kg : 1		Bauch mm: 1	
		Bauch mm: 1	
		Min.distance W-W mm: 0	
		Flange mm: 0	

06-22-2009/15:33:03	CORE	Page 2

Core file name	: LTCM_EI_3_L_1.USR	Fe-File name	: STEEL1.DAT
Core name	: EI3P 500/200	Fe-Name	: M111-0.35mm =>M6 0.014
Core type	: 3EI	Frequency	Hz: 50
Type of windings	: oval/rectangular	Remanence-Factor	*: 0.35
Number of legs	: 3	W/kg-Factor	*: 1
Core assembly	: (8) 6x45°+2x9	VAr/kg-Factor	*: 1
Leg/Diameter	cm: 10	Gap-Factor	*: 1
Window width	cm: 10	f/fn-Factor	*: 1
Window height	cm: 30	Fillfactor	*: 1
Stack	cm: 20	Annealed	-: No
Cross section	in^2: 193.0		
Weight total	kg: 280.5		
With holes	-: Yes	Chassis	-:
Brackets	-: L-T&B	Vertical/Horizontal	-:

X-Width	cm: 40
Y-Height	cm: 40
d_Hole	cm: 1.5
h-Distance	cm: 0.5
L-Laenght	cm: 8
Z-Width	cm: 0

Stufen		1	2	3	4	5	6	7	8
A-Leg	cm:	10	0	0	0	0	0	0	0
J-Yoke	cm:	10	0	0	0	0	0	0	0
R-Rearyoke	cm:	0	0	0	0	0	0	0	0
S-Stack	cm:	20	0	0	0	0	0	0	0
Number lamin.	:								
Weight	kg:								



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06-22-2009/15:33:03 WINDINGS Page 3

Windings	1	2	3	4	5	6	7	8
Groups-Circuits	2-Y	3-Y	1-D	3-Y	4-Y			
Connection	ser.	ser.	ser.	ser.	ser.			
Turns	8.0	6.0	22.0	6.0	8.0			
Build %	14.8	32	47.8	63.2	74			
Weight kg	5.3	11.4	14.3	15.1	8.8			
WIRE								
Type	Foil	Foil	flat	Foil	Foil			
Thicknes mm	0.40	1.00	1.80	1.00	0.40			
Width mm	270.00	270.00	11.20	270.00	270.00			
WG-thicknes	0	0	68	0	0			
WG-width	0	0	1	0	0			
Al/Cu	Cu	Cu	Cu	Cu	Cu			
STRAND/LITZ							7	
Thickne insula. mm	0.40	1.00	7.80	1.00	0.40			
Width insulata. mm	270.0	270.0	11.4	270.0	270.0			
Parallel wires	1	1	4	1	1			
side by side	1	1	1	1	1			
one upon the other	1	1	4	1	1			
Transposition	Cyl	Cyl	Cyl	Cyl	Cyl			
Cross section mm^2	108.0	270.0	80.64	270.0	108.0			
SECTOR								
Number	1	1	1	1	1			
Serie/Parallel	ser.	ser.	ser.	ser.	ser.			
Turns	8	6	22	6	8			
Turns/Layer	1	1	22.21	1	1			
Layers	8	6	0.990	6	8			
Insul./Layer µm	100.0	100.0	100.0	100.0	100.0			
Transposition	None	None	None	None	None			
Thicknes mm	4.40	7.60	7.80	7.60	4.40			
Height mm	270.00	270.00	270.00	270.00	270.00			
Heights Wind/Sect	8	6	0.990	6	8			
SPACES/CHANNELS/INS.								
C/I Outside	WICW	WICW	WICW	WICW	WICW			
Insulation mm	3.0	1.0	0.1	0.1	1.0			
Channel mm	10.0	10.0		15.0	10.0			
C/I Inside	WIW	WIW	WIW	WIW	WIW			
Insulation mm	3.0	1.0	0.1	0.1	1.0			
Channel mm	10.0	10.0	10.0	15.0	10.0			
C/I Horizontal	II	II	II	II	II			
Sector-Sector mm	1.0	1.0	1.0	1.0	1.0			
Turn-Turn mm	1.0	1.0	1.0	1.0	1.0			
Distance to yoke mm	15.0	15.0	15.0	15.0	15.0			

Coil insulation mm: 0.00 Diatancw coil to coil : 26.00
D1i/D1e: 217.0 225.8
D2i/D2e: 247.8 263.0
D3i/D3e: 283.2 298.8
D4i/D4e: 329.0 344.2
D5i/D5e: 366.2 375.0
D6i/D6e: /
D7i/D7e: /
D8i/D8e: /

***

06-22-2009/15:33:03 IN OPERATION MODE Page 4

Frequency Hz:	50	Ventilation outsi. m/s:	0	Fillfactor/channels %:	70
Ambient temperature C:	40	Ventilation(chann. m/s:	0	Varnish in windings %:	10
Convection outside *:	0.8	Rth-Insulation *:	1	Varnish/gaps/stomack %:	10
Convection/channels *:	0.8	Rth-Varnish *:	1	Stomack mm:	1.00
Emission *:	1	Rth-Epoxy *:	1	Gap mm:	0.10
Output power kVA:	275.0	Input power kVA:	59.0	Core power :	0.0
Fe-Losses VA:	1038.	Fe-active losses W:	372.6	Fe-reactive losses VAr:	969.5
No-load curren %:	1.8	No load curr. active %:	0.6	No load curr. react. %:	1.7
I^in/I^nom-Factor :	17.67	Iinrms/Inomrms-Factor :	13.24	No load induction T:	1.575
I^in kA:	5.72	Iin rms kA:	3.04		
Icc cold kA:	20.25	Iccr active cold kA:	17.10	Iccx reactive cold kA:	10.84
Ucc cold %:	0.65	Uccr active at 115°C %:	1.819	Uccx inductive cold %:	0.35
CuAl-losses W:	3399.4	Efficiency %:	98.433		
Max. dT Cu/Al °K:	111.5	Max. dT Fe °K:	87.8	Induction T:	1.565

Windings	1	2	3	4	5	6	7	8
Groups-Circuits	2-Y	3-Y	1-D	3-Y	4-Y			
Connection	ser.	ser.	ser.	ser.	ser.			
Time1	60.0	60.0	60.0	60.0	60.0			
Load1	1.00	1.00	1.00	1.00	1.00			
Time2	60.0	60.0	0.0	60.0	60.0			
Load2	1.00	1.00	0.00	1.00	1.00			
Voltage rms V	54.58	40.17	148.6	39.63	53.71			
U-Phasen delay °	-0.28	-0.11	0	-0.16	0.722			
No-load vo÷tage V	54.02	40.52	148.6	40.52	54.03			
Regulation %	-1.0	0.9	0.0	2.3	0.6			
Current rms A	402.91	606.21	132.37	606.21	396.48			
K-Factor	4.58	2.95	1.29	2.95	4.58			
Power kVA	21.99	24.35	19.67	24.02	21.29			
I-Phase delay °	-45.1	0.0	-0.8	0.0	44.9			
Resistance cold mOhm	0.902	0.312	4.364	0.411	1.509			
Losses warm W	226.0	187.1	130.4	232.7	356.7			
RacRdc (total)	1.01	1.04	1.10	1.01	1.00			
Icc.all cold kA	9.99	27.97	20.25	27.97	8.00			
Radial tension N/mm2	35.66	64.86	193.2	81.61	28.38			
dTcc after 1.0 s °K	19518	2891.	770.0	2891.	15907			
Icc.group cold kA	22.29	35.84	0.00	35.84	18.41			
Circ.losses W	17.03	17.12	2.45	2.02	0.34			
Cur.density A/mm^2	3.73	2.25	1.64	2.25	3.67			
SECTORS								
1 RacRdc	1.01	1.04	1.10	1.01	1.00			
Current A	402.9	606.2	132.3	606.2	396.4			
dT °K	107.4	111.4	111.5	110.9	105.3			
2 RacRdc								
Current A								
dT °K								
3 RacRdc								
Current A								
dT °K								
4 RacRdc								
Current A								
dT °K								
5 RacRdc								
Current A								
dT °K								
6 RacRdc								
Current A								
dT °K								
7 RacRdc								
Current A								
dT °K								
8 RacRdc								
Current A								
dT °K								

Once again, the Large Transformers Program does not support full automatically design of autotransformers. In order to design an autotransformer you need to transform the autotransformer operation mode into the transformer operation mode. Due to this fact there is some calculated information on the page 4 for the transformer operation mode which is not valid for the autotransformer operation mode:

- The input and output power
- The no-load current (It is smaller for the factor 148.6/230)
- The short-circuit operation mode
- The inrush current (It is smaller approx. for the factor 148.6/230)

Due to the fact that the used transformer nominal operation mode simulates EXACT the autotransformer nominal operation mode (by equal losses, winding currents, form of magnetic fields, temperature rise, …) there is no problem to manufacture and use this autotransformer.

Designing a 1600kVA/35kVA, 50Hz Distribution Oil Transformer

General Information

Technical Specification

Input voltage	3 x 35000/20230V, star sine wave
Transformer output voltage	3 x 690/400V, star
Line output current	3 x 1340A, continuous operating mode
Frequency	50Hz
Average oil temperature	55°C
Max. temperature rise and/or max. Cu-winding losses at 75°C	25°K 18000W => 1.125%
Short-circuit voltage	6.5%
°Short-circuit voltage	6.5%
Max. core losses	3200W => 0.2%
Max. no-load current	1.3%
Test Voltage at 50Hz, 1 minute	Primary 85kV, outside Secondary 4kV, inside
Steel & Core Assembly	M5, annealed, strips for alternated stacking (4x45°+3x90° per shape), "round" cross section with 8 steps
Core Size	Optimized for minimal material price for: Cu_Price/Fe_Price = 2 with Cu-winding

Creating Input

4 input screens are used to set the input parameters for designing a transformer:

- Winding parameters per limb
- Core
- Environment
- Other

and 3 screens for selection and set up of material :

- wires
- steels
- cores.

Criteria and Parameters of Design

The design of a distribution transformer is always framed by 5 criteria which have to be put into effect simultaneously:

- Short-circuit voltage
- Winding losses at 75 °C
- Winding temperature rise
- Core losses
- No-load output current

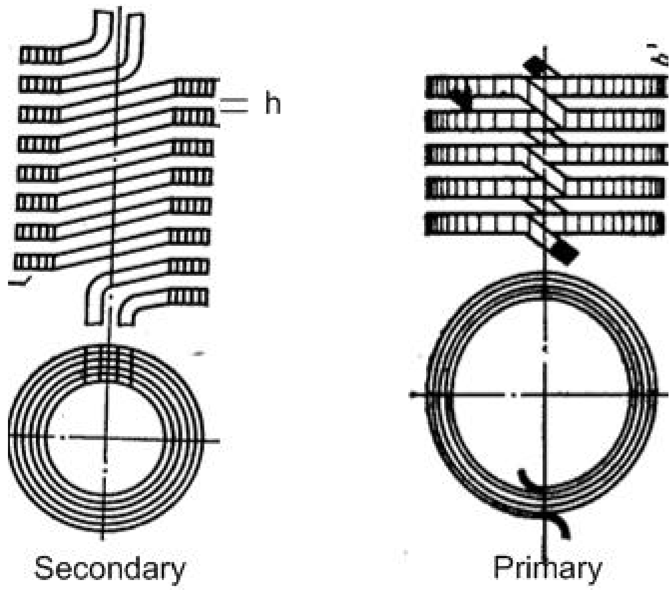
Under this condition the first step is the optimizing the core size to match the above mentioned prescribed design criteria for the optimal material price using some additional parameters such as:

- Cooling media
- Testing voltages
- Steel quality and core assembly
- Winding type and wire type & material
- Cu/Al and Fe price relationship

Normally the user of this software will create an optimized core family for a typical design criteria and parameters and select a desired core per click. In order to demonstrate the procedure for core optimization, note that the following parameters of optimization are a summery of 5-6 versions:

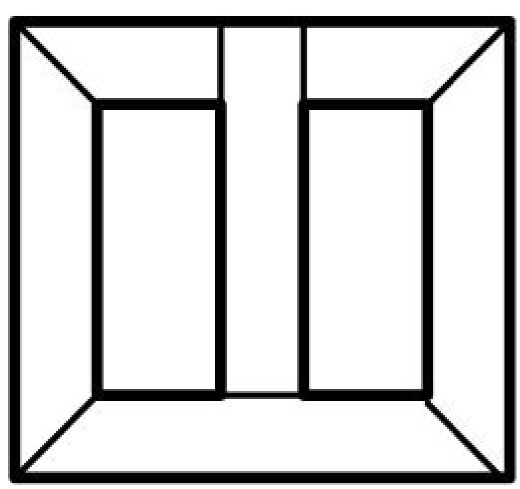
- **Max. winding losses at 75 °C = 18000W**
- **Inductive short-circuit voltage = 6.4 %**

- **Max. temperature rise 25 °K**
  For 18000W @ 25 °K you need a very big cooling surface using the vertical and horizontal cooling channels in both windings. The optimal windings construction is presented in the next picture. Note that the secondary winding can be realized by using foil with 4 cooling channels within the winding and approx. 40% more Cu material for the outside primary winding.

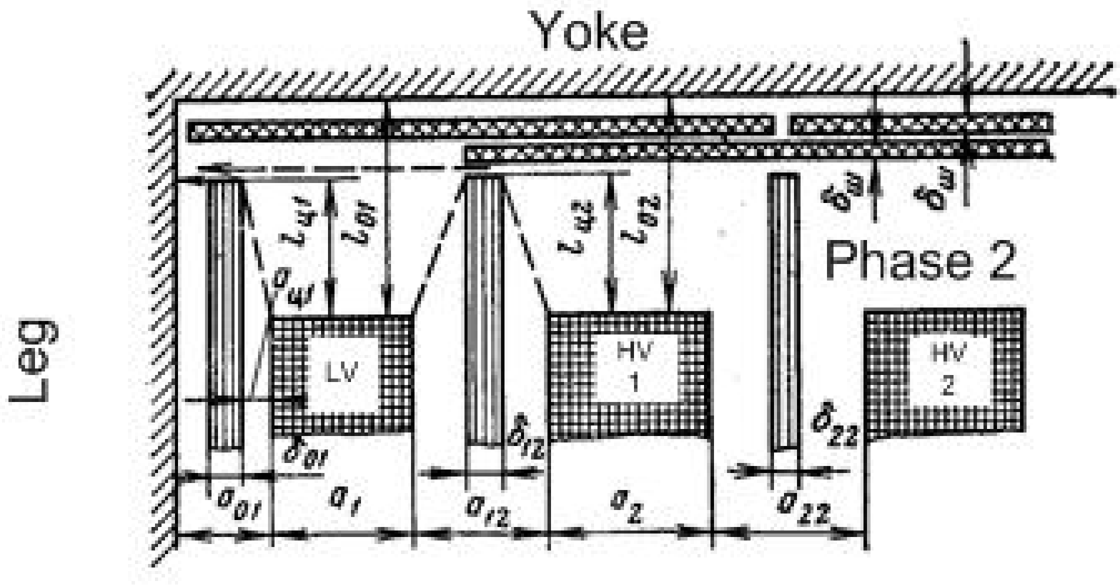


- **Max. core losses = 3200 W**

- **Max, no-load current = 1.3%**
  These 2 criteria of design can be easy realized with annealed strips of M111 (M6) grain oriented steel at the induction 1.6T with the following shape and 8 steps "round" cross-section:



- **For 85kV, 50Hz, 1 minute and the power 1600kVA test voltage the following min. spacing is recommended**:



a_{01}=17mm; a_{12}=27mm ;a_{22}=30mm

δ_{01}=δ_{12}=5mm (tubes)

δ_{22}=3mm ; $\delta_{ш}$=2mm (2 x overlaped to increase the creaping distance to the yoke)

l_{01}=l_{02}=75mm

$l_{ц1}$=$l_{ц2}$=50mm (tube width over the windings))

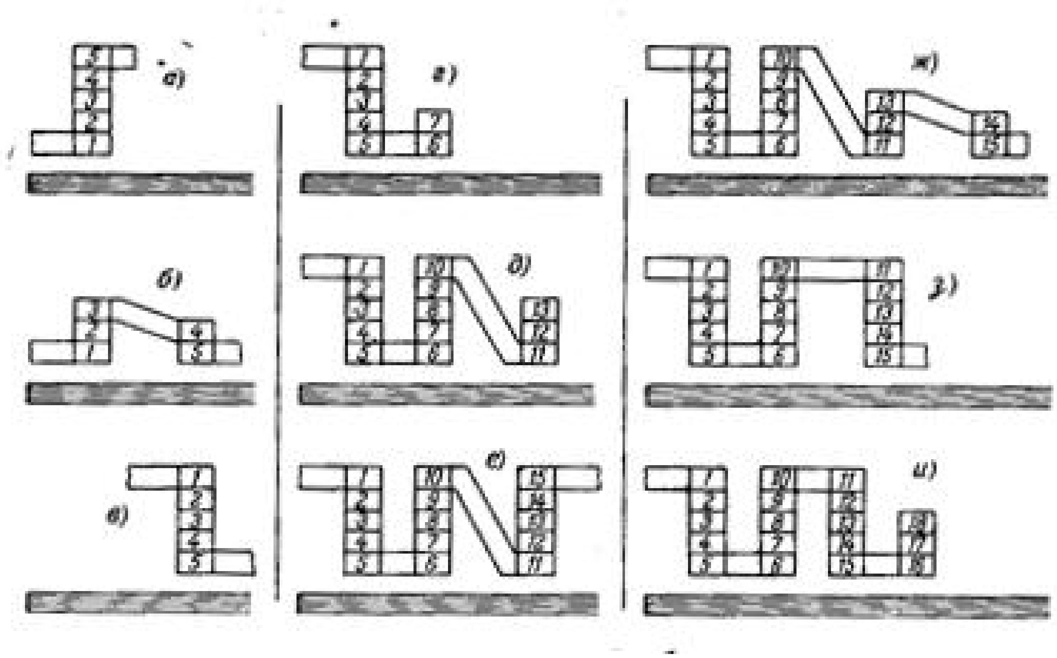
Note that the creeping distances between the windings and the HV-winding and the core have to be bigger than 125mm.

Windings parameters per limb

Primary

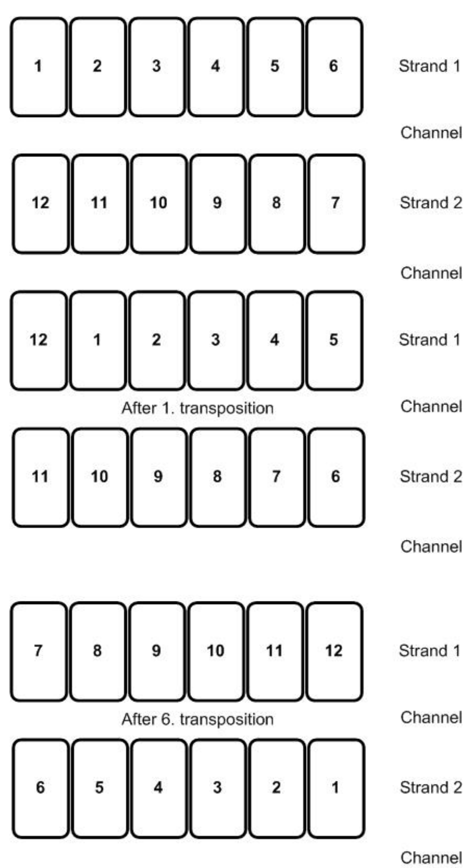
The primary is created in star connection. The sine wave input voltage is 20230V .
There are no voltage harmonics and there is no duty cycle operation mode.
The primary will be manufactured with Cu-flat wire in disc winding technology (view picture above) with the horizontal cooling channel of h=5mm. The advantage of the disc windings is low voltage per turn without any partial discharging problems. In order to suppress the high line voltage discharge the turns of the first and last disc can easily add stronger insulation.

The following picture describes the manufacturing of a continuous disc winding:

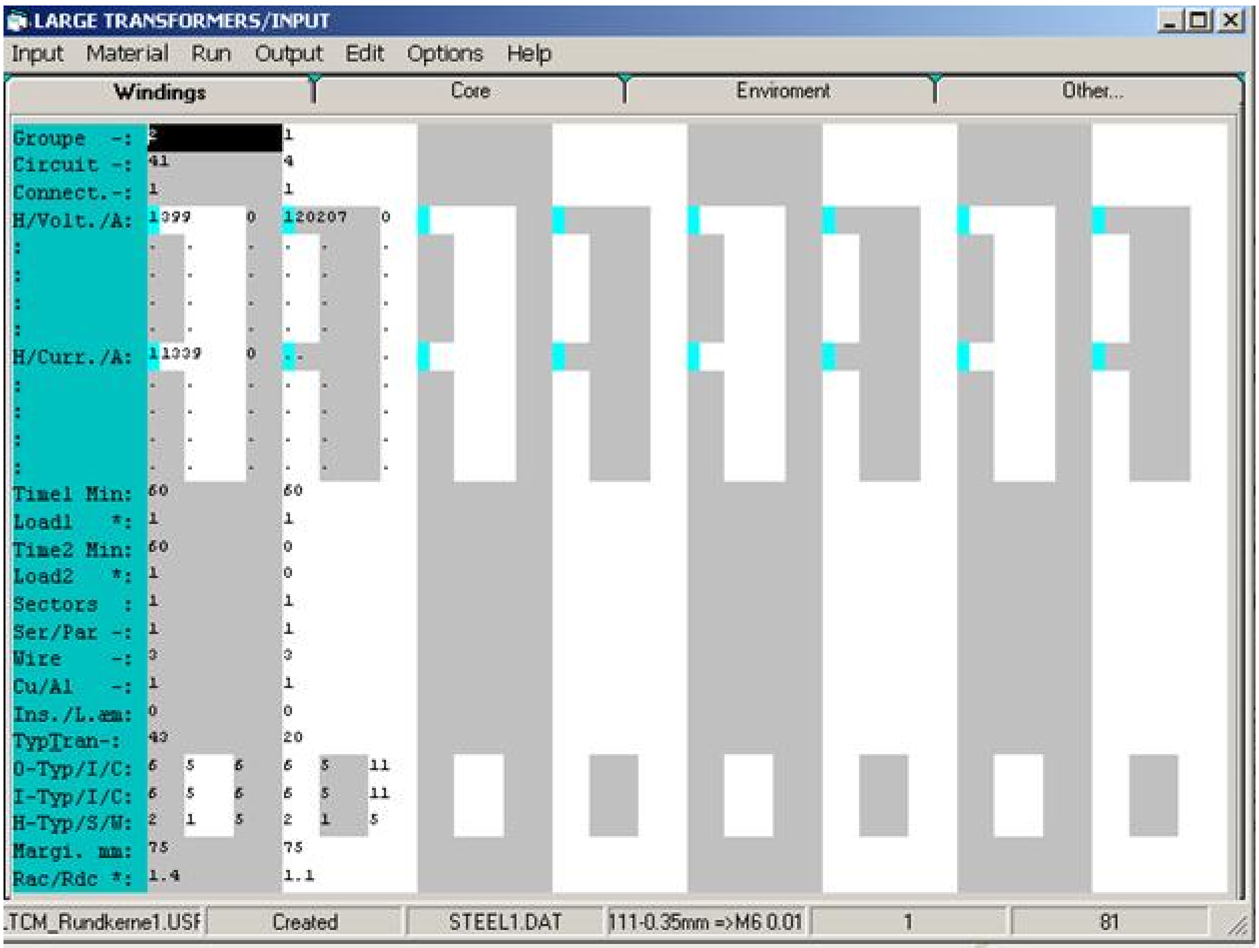


Secondary

The secondary winding is set inside. It is wound with 2 parallel connected "bifilar screw" strands (view picture above). Between each turn there are horizontal cooling channels. h=5mm. In order to avoid the circulating currents in parallel connected wires per strand you have to use the transposition through the rotation of the wire position in the strand in accordance with some rules:



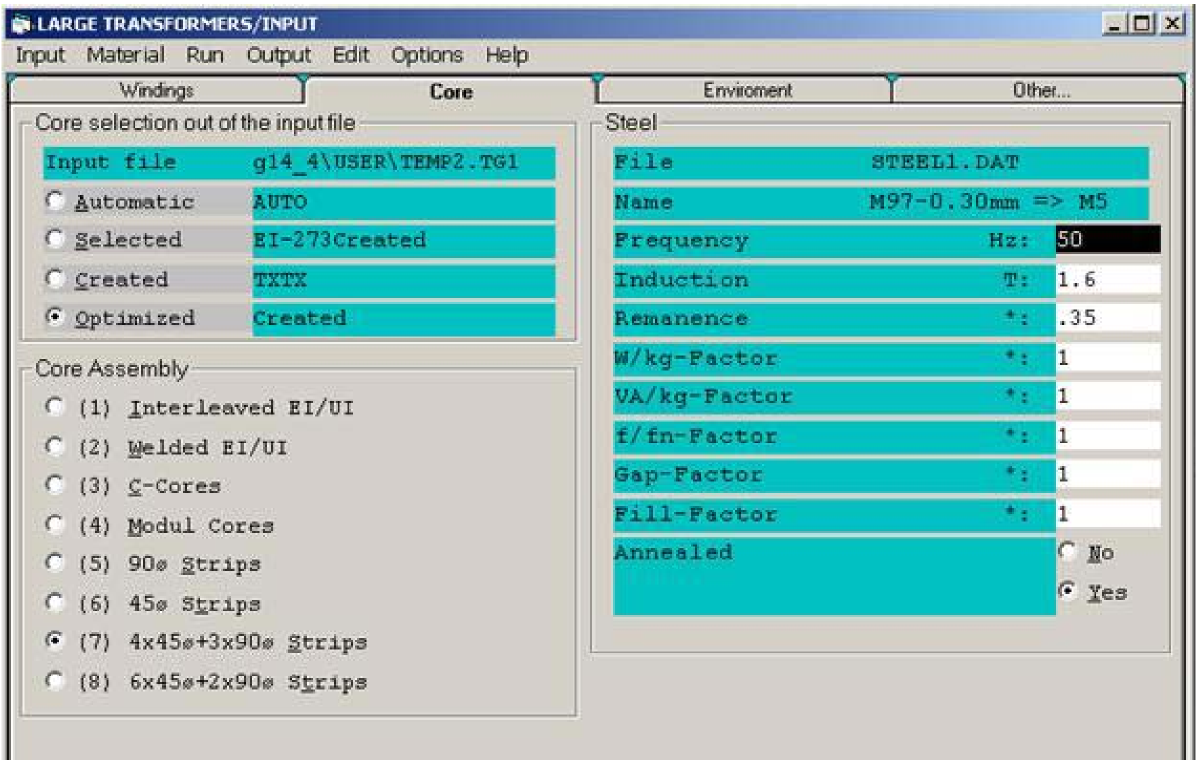
The sine wave output voltage is 399V.
The rms output current is 1336Arms. There are no current harmonics:
Also, there is no duty cycle operation mode on the secondary.
With the eddy current losses factor (RacRdc) 1.4 the number of parallel connected flat wires per strand will be limited . Note that at this point of the design you cannot prescribe the wire size . You can select only the wire or family which the program must use in order to select the suitable wires for your application.



Core

On this input screen you can :

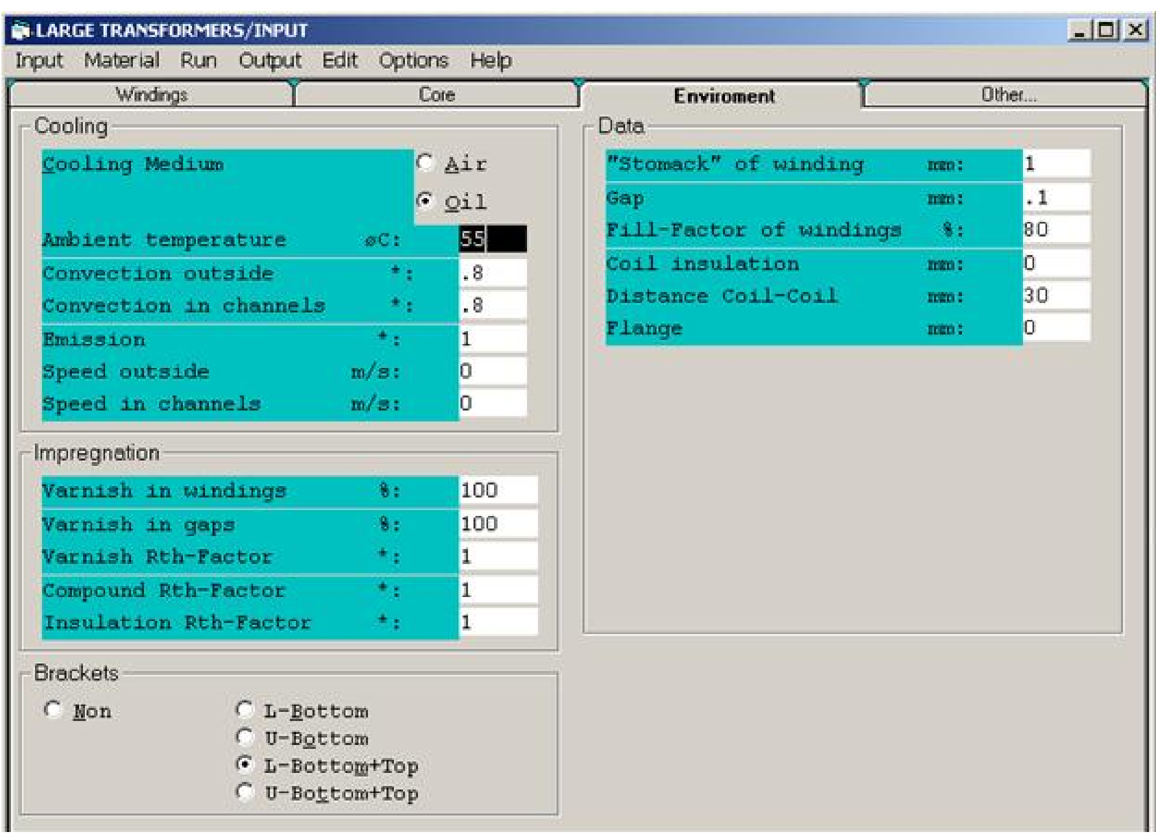
- select and manipulate the selected steel M97, 030mm (M5l)
- set the operating induction (1.6T) and the frequency (50Hz)
- select the core assembly
- and prescribe the core selection out of an input file. This option will not be used because the core size has to be optimized .



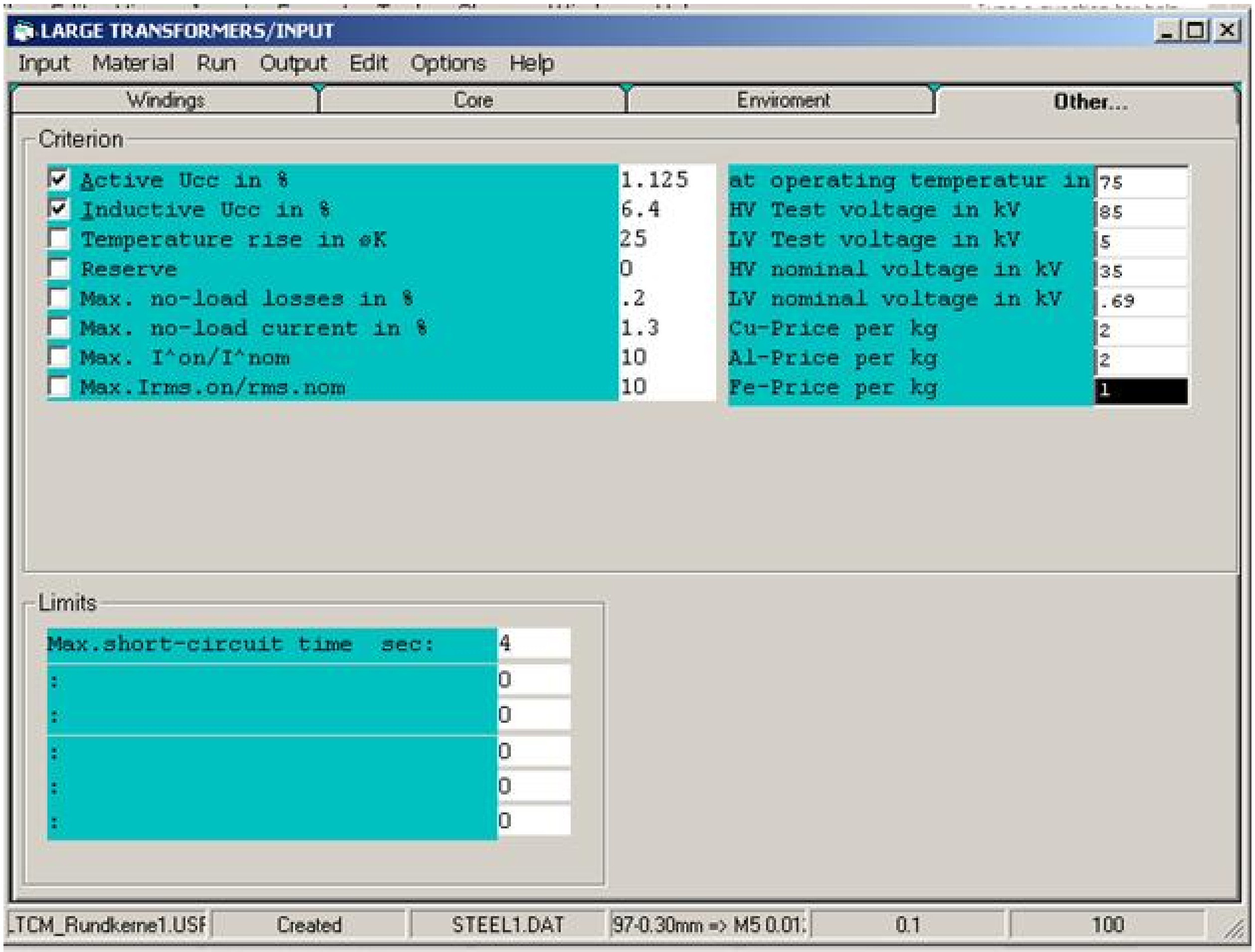
Environment

The cooling medium is oil with the **average** temperature 55°C. The cooling surface of the core is increased by using 4 L-brackets on the core. The minimum distance between the primary windings of 2 phases is 30mm. There is no flange but both windings have to be fixed in order to suppress the axial forces during the short circuit operation mode.

There is no air in the transformer!



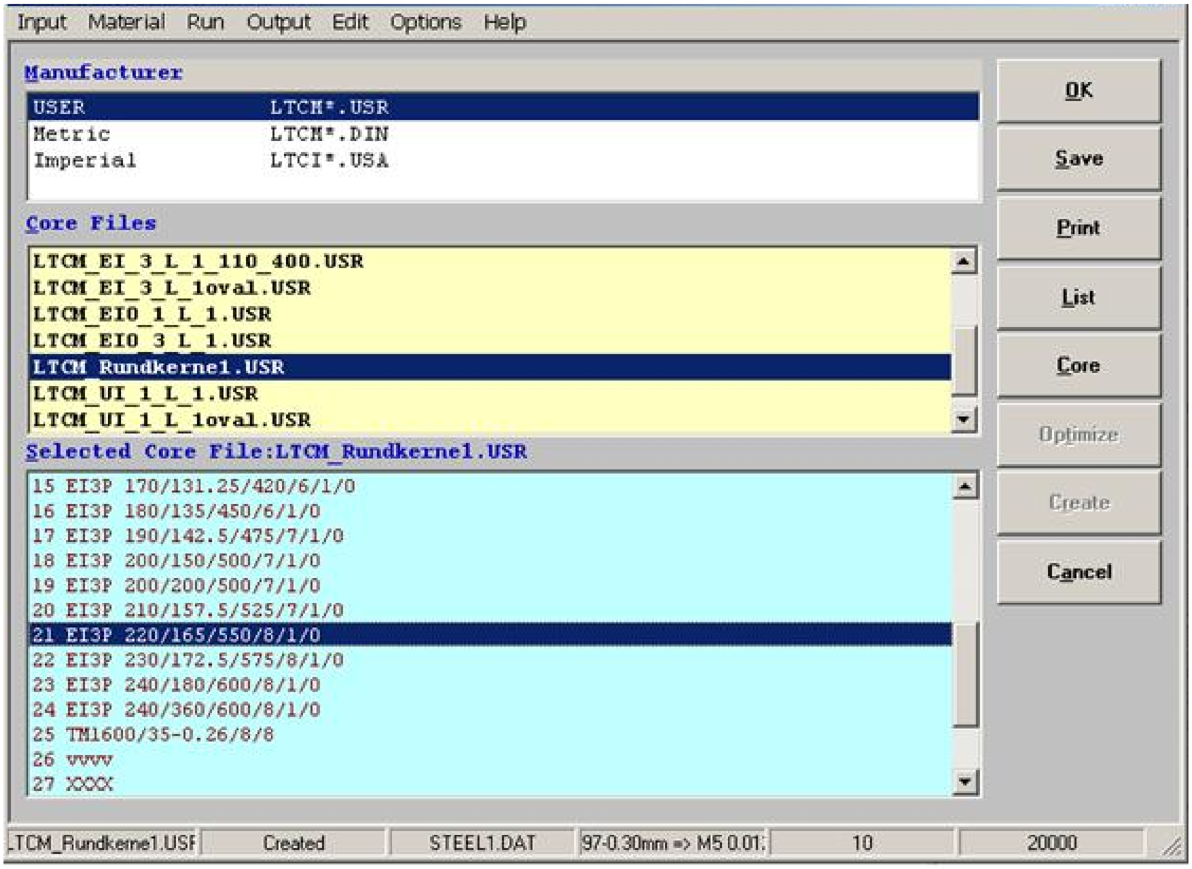
Other...



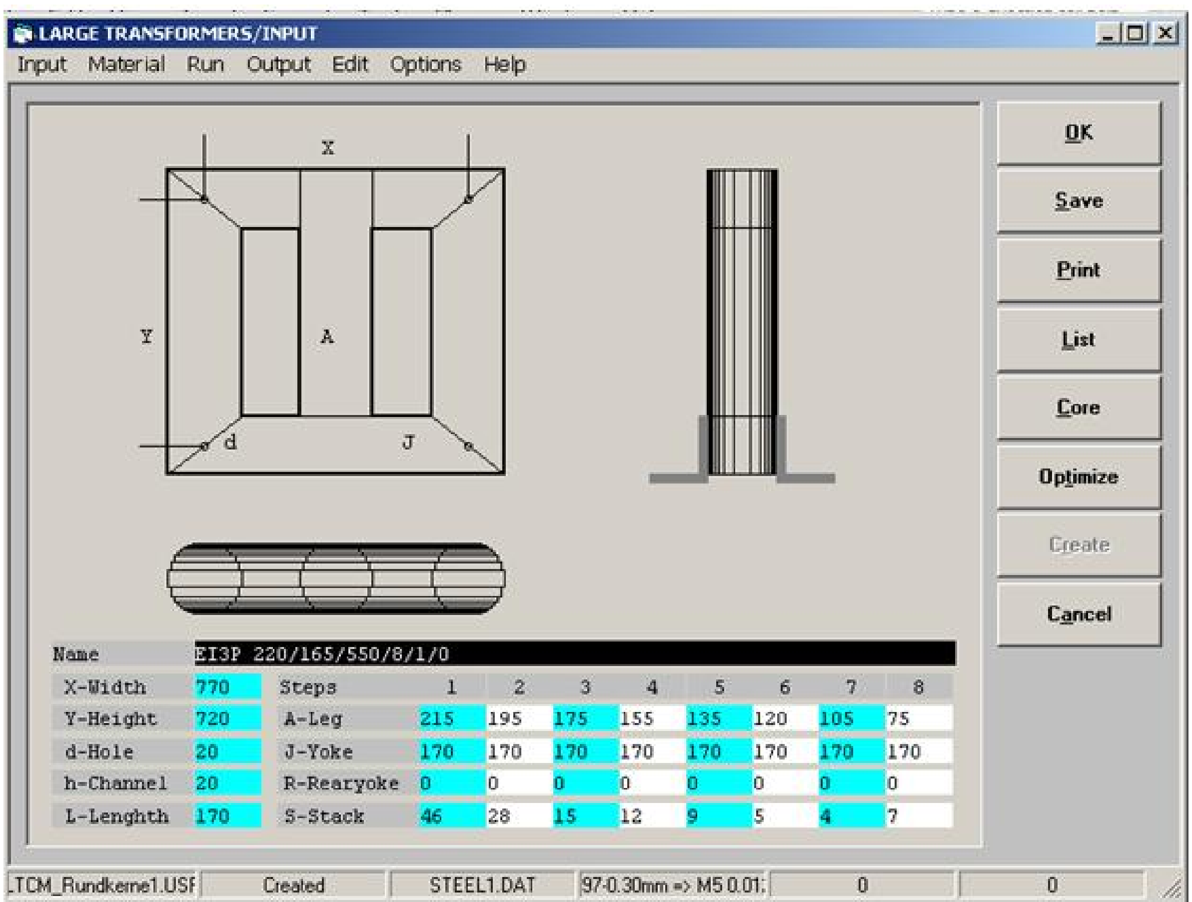
The selected criteria of the design and core optimization are the winding losses (18000W => 1.125%) at 75 °C and the inductive short-circuit voltage 6.4%. If you prescribe also the temperature rise then the program has to use the criterion which is more critical: either the winding losses or the temperature rise with the prescribed short circuit voltage.
The core losses and the no-load input current can be manipulated only with steel quality, core assembly and induction

Core optimization

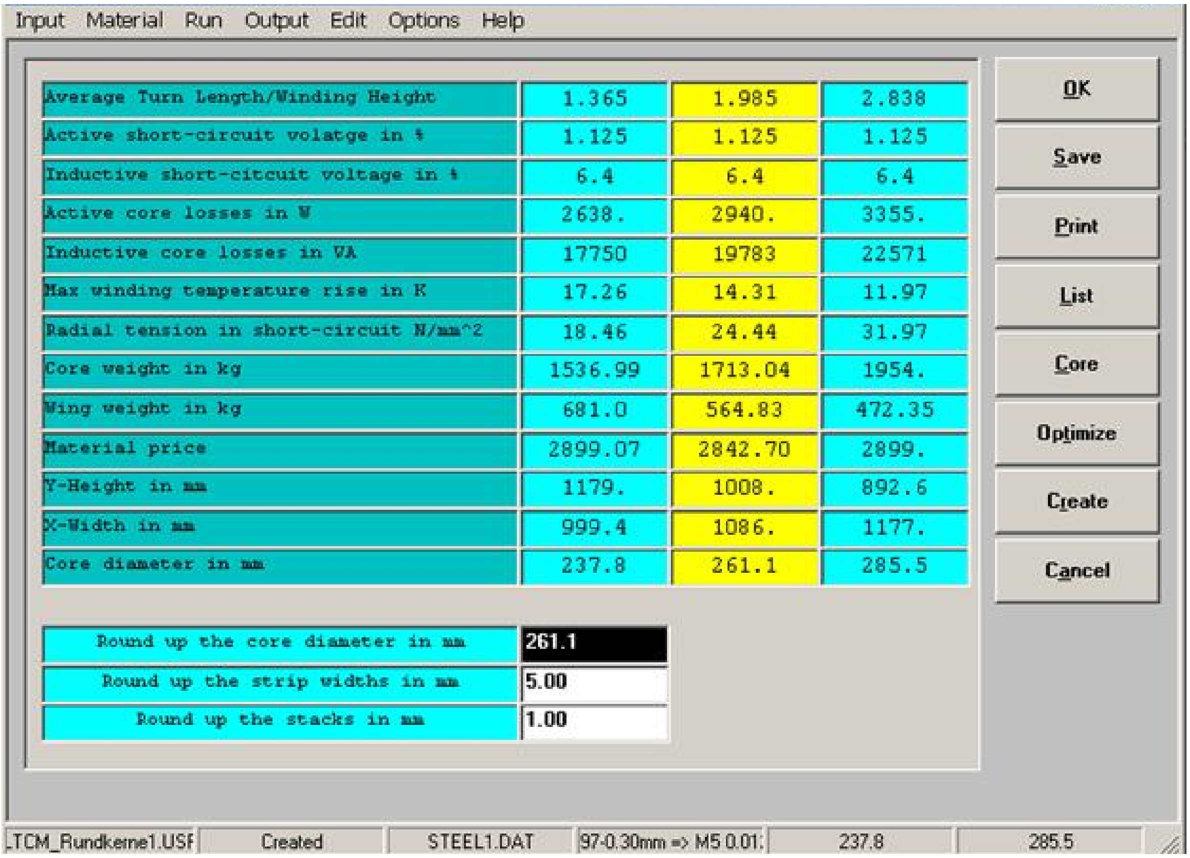
After you have set all input screens you need to select a core family and a core as template: 3 phase core family with 8 steps "round" cross section



Click **Core** to open the input screen for reading the parameters of the selected core



Click **Optimize** to optimize the core.

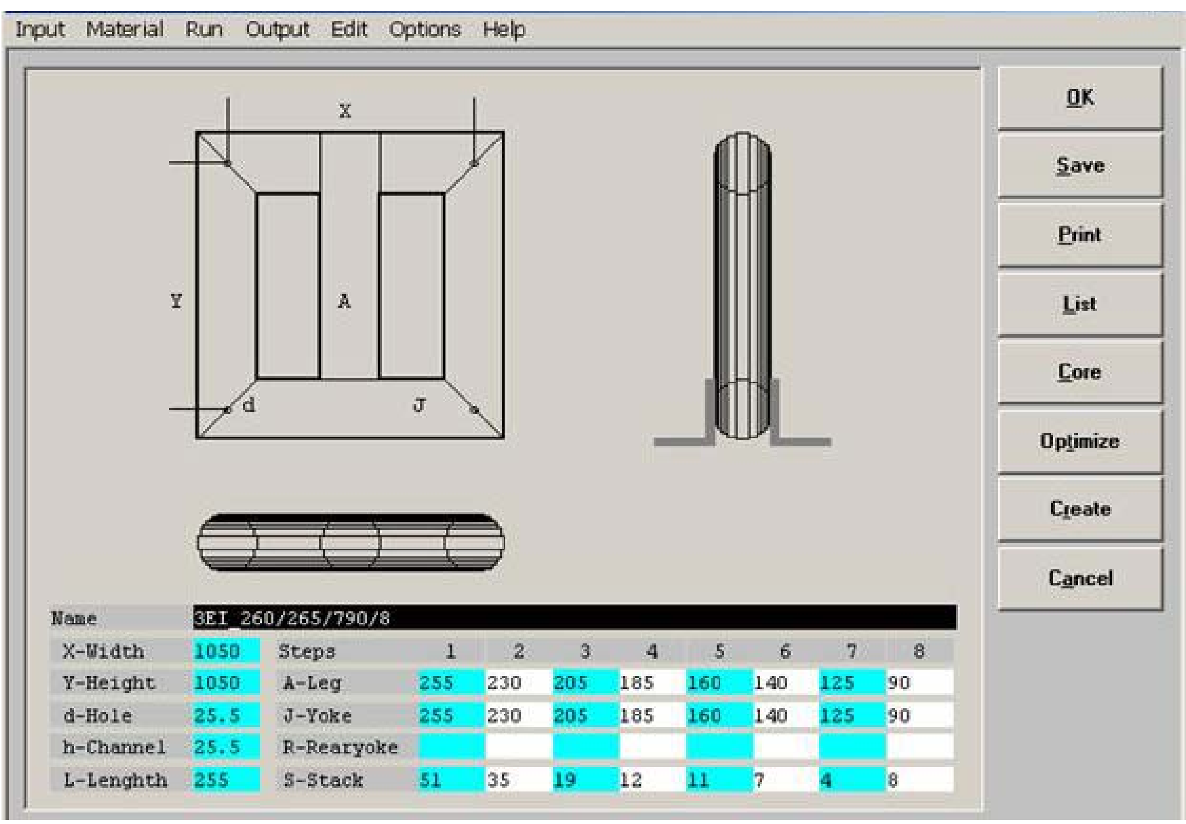


Average Turn Length/Winding Height	1.365	1.985	2.838
Active short-circuit volatge in %	1.125	1.125	1.125
Inductive short-citcuit voltage in %	6.4	6.4	6.4
Active core losses in W	2638.	2940.	3355.
Inductive core losses in VA	17750	19783	22571
Max winding temperature rise in K	17.26	14.31	11.97
Radial tension in short-circuit N/mm^2	18.46	24.44	31.97
Core weight in kg	1536.99	1713.04	1954.
Wing weight in kg	681.0	564.83	472.35
Material price	2899.07	2842.70	2899.
Y-Height in mm	1179.	1008.	892.6
X-Width in mm	999.4	1086.	1177.
Core diameter in mm	237.8	261.1	285.5

Round up the core diameter in mm	261.1
Round up the strip widths in mm	5.00
Round up the stacks in mm	1.00

TCM_Rundkerne1.USF	Created	STEEL1.DAT	97-0.30mm => M5 0.01:	237.8	285.5

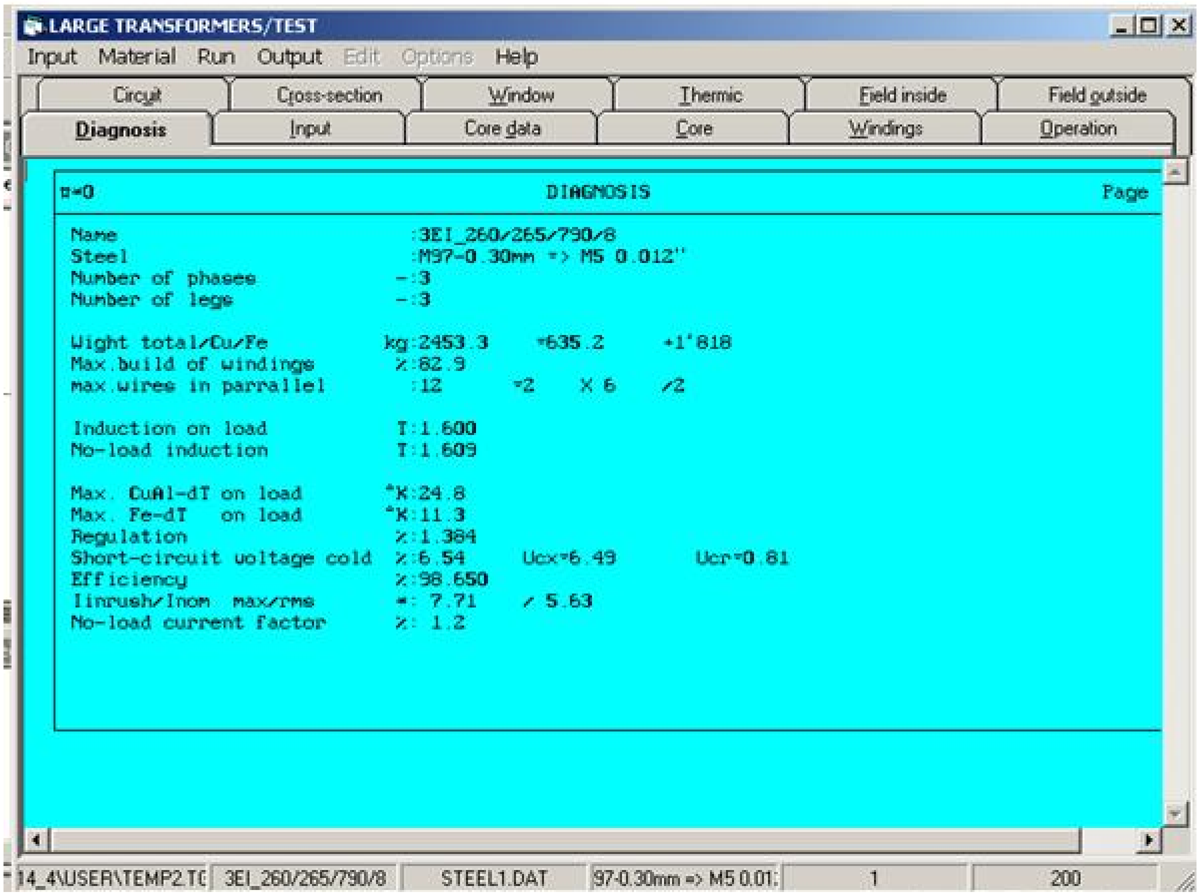
The yellow output fields are optimal results. Both other columns have a higher material price for 2%. Here you can round off the core diameter (260mm instead 261.1) and click **Create.** This is the optimized core after the setting X = Y = 1050 (in order to use only 3 strip sizes per shape).



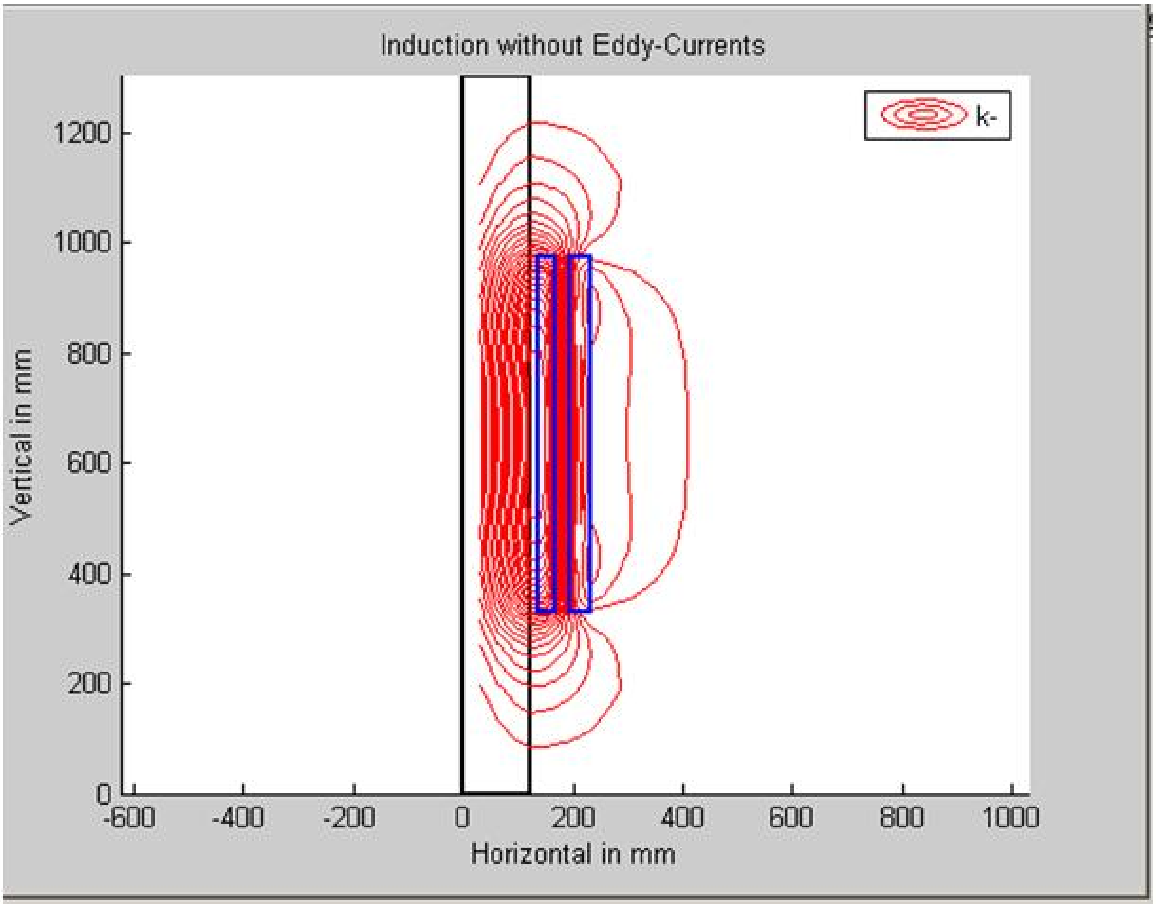
Name	3EI 260/265/790/8									
X-Width	1050	Steps	1	2	3	4	5	6	7	8
Y-Height	1050	A-Leg	255	230	205	185	160	140	125	90
d-Hole	25.5	J-Yoke	255	230	205	185	160	140	125	90
h-Channel	25.5	R-Rearyoke								
L-Lenghth	255	S-Stack	51	35	19	12	11	7	4	8

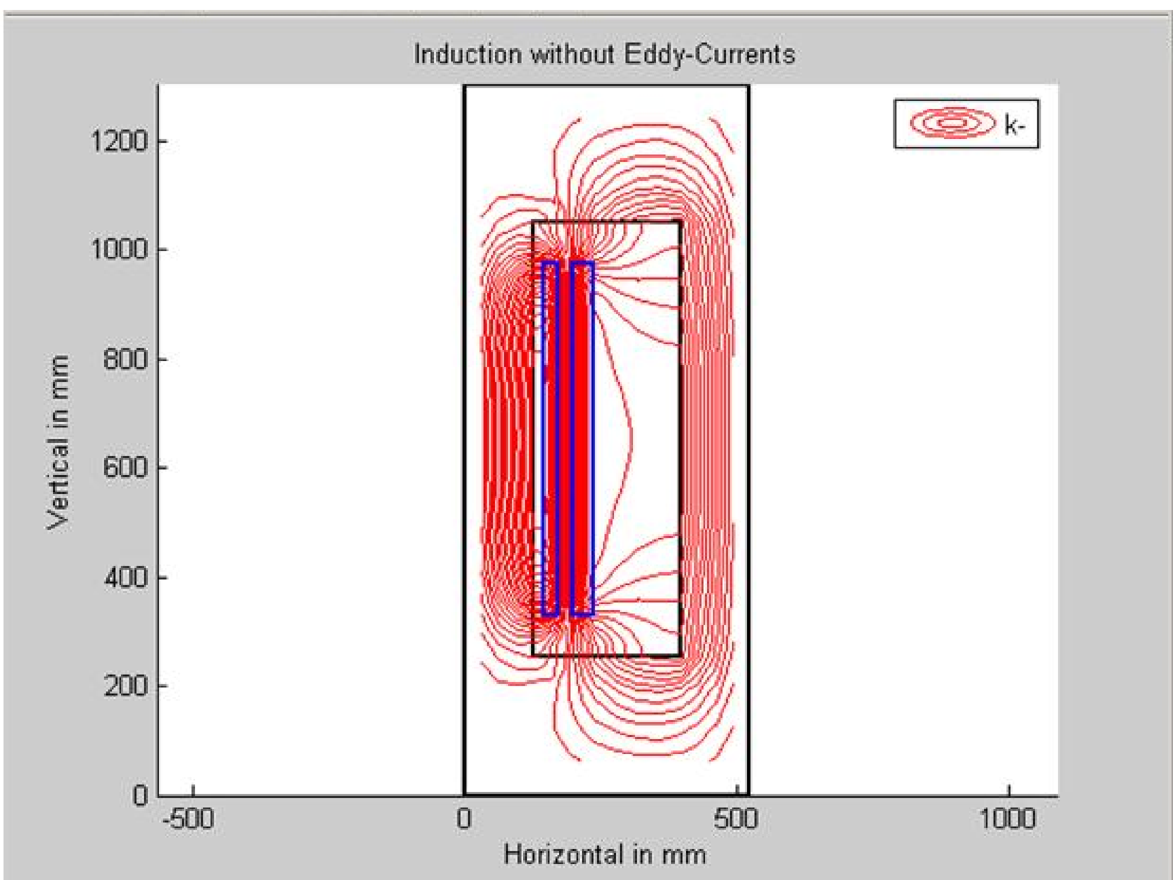
Output

The first step of the presentation of the output screen is DIAGNOSIS: it is the summary of the most important calculated parameters of your transformer.

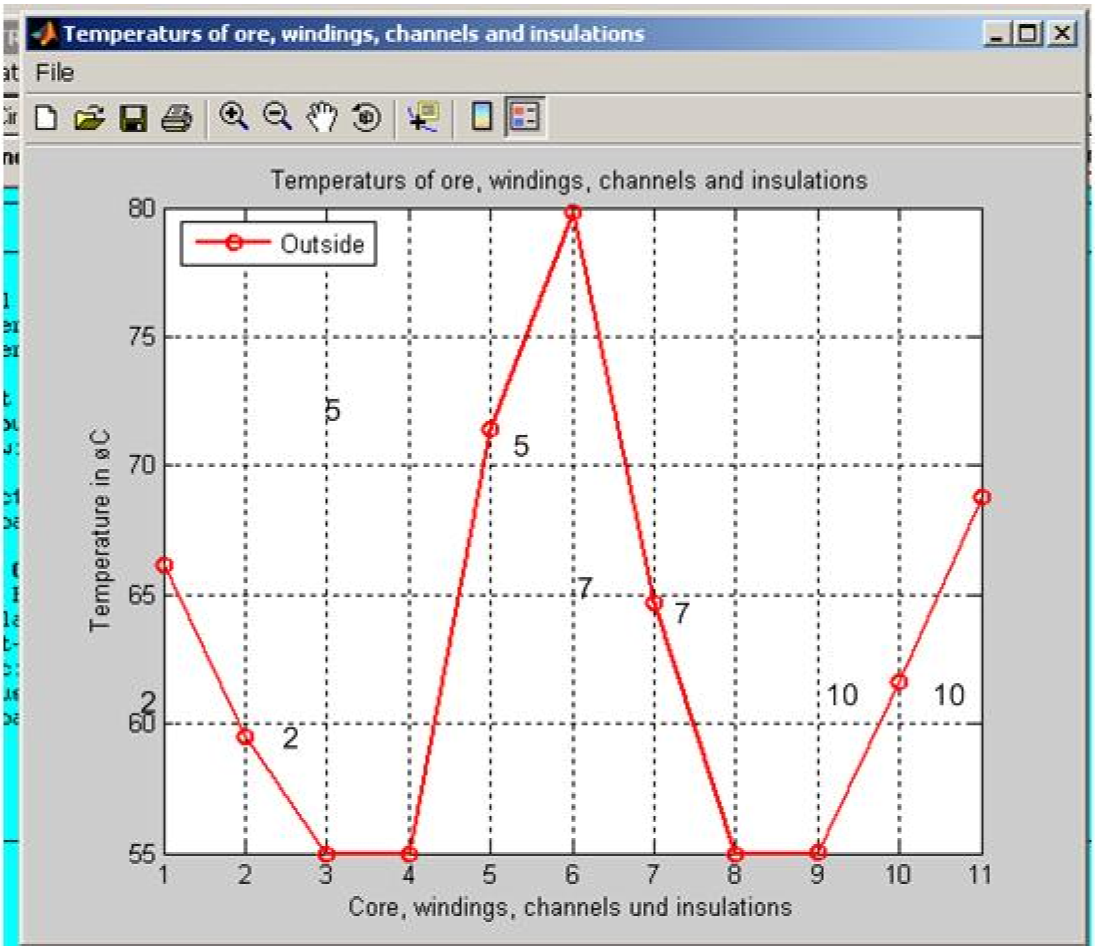


Note that the program uses the numerical calculation of the magnetic fields and the temperature rises. Due to this technology the calculations of the eddy current losses, the steel losses, the short-circuit voltage, the circulating current and the transposition are very powerful.
The following picture shows the magnetic field outside&inside the core window.


Induction without Eddy-Currents
k-
Vertical in mm
1200
1000
800
600
400
200
0
-600
-400
-200
0
200
400
600
800
1000
Horizontal in mm


Induction without Eddy-Currents
k-
Vertical in mm
1200
1000
800
600
400
200
0
-500
0
500
1000
Horizontal in mm

Note that the criterion of design is the winding losses. With this criterion, the program optimizes the relationship of the primary and secondary losses. Due to the higher eddy current losses in the secondary winding and better cooling of the primary winding the temperature rise of the secondary is higher than the temperature rise of the primary winding.
A very important detail is the max. oil temperature in the cooling channel (points 2 ,5, 7 and 10)



Finally here are 4 printed pages showing the design results

Input

03-11-2008/15:28:55/ V:14 .5				INPUT				Page 1
Windings	1	2	3	4	5	6	7	8
Groups	2	1						
Circuits	41	4						
Connection	1	1						
H/Voltag/A	1 399 0	1 20207052						
	. . .	. . .						
	. . .	. . .						
	. . .	. . .						
	. . .	. . .						
H/Curren/A	1 1339 0	. . .						
	. . .	. . .						
	. . .	. . .						
	. . .	. . .						
	. . .	. . .						
Time1 min.	60	60						
Load1 *	1	1						
Time2 min.	60	0						
Load2 *	1	0						
Sectors	1	1						
Ser./Para.	1	1						
Wire file	3	3						
Cu/Al	1	1						
In/Layer μ	200	200						
Typ/Trans.	43	20						
Typ/I/C mm	6 5 6	6 5 11						
Typ/I/C mm	6 5 6	6 5 11						
Typ/I/I mm	2 1 5	2 1 5						
Margin mm	75	75						
RacRdc	1.4	1.1						

Frequency Hz: 50	Core select. -: Created	Cooling medium : Oil
	Core file : LTCM_Rundker	Amb. temperature °C: 55
Criterion : Ucca	Core name : 3EI_260/265/	Convection outside *: 0.8
Ucc-voltage act. %: 1.125	Core assembly-: (7) 4x45°+3x9	Convection inside *: 0.8
Ucc-voltage tot. %: 6.4	With hole -: No	Emission *: 1
Temperat. rise °K: 25		Airflow outside m/s: 0
Max. Fe losses %: 0.2	Steel file : STEEL1.DAT	Airflow inside m/s: 0
No-load factor %: 1.3	Steel name : M97-0.30mm =	Chassis -: Wood
I^in/I^nom : 10	Induction T: 1.6	Vertical -: Vertica
Irms on/Irms nom : 10	W/kg *: 1	Horizontal -: L-T&B
	VAr/kg *: 1	:
Losses at temp.°C: 75	Airgap *: 1	Channel fill factor %: 80
HV-Test volta. kV: 85	f/fn-Factor *: 1	Varnish in windings %: 100
LV-Test volta. kV:	Fill factor : 1	Varnish in gaps %: 100
HV-Nom.voltage kV: 35	Annealed -: Yes	Rth-varnish *: 1
LV-Testvoltage kV:		Rth-compound *: 1
Cu Price per kg : 2		Rth-insulation *: 1
Al Price per kg : 2		Coil insulation mm: 0
Fe Price per kg : 1		Bauch mm: 1
		Bauch mm: 1
		Min.distance W-W mm: 30
		Flange mm: 0

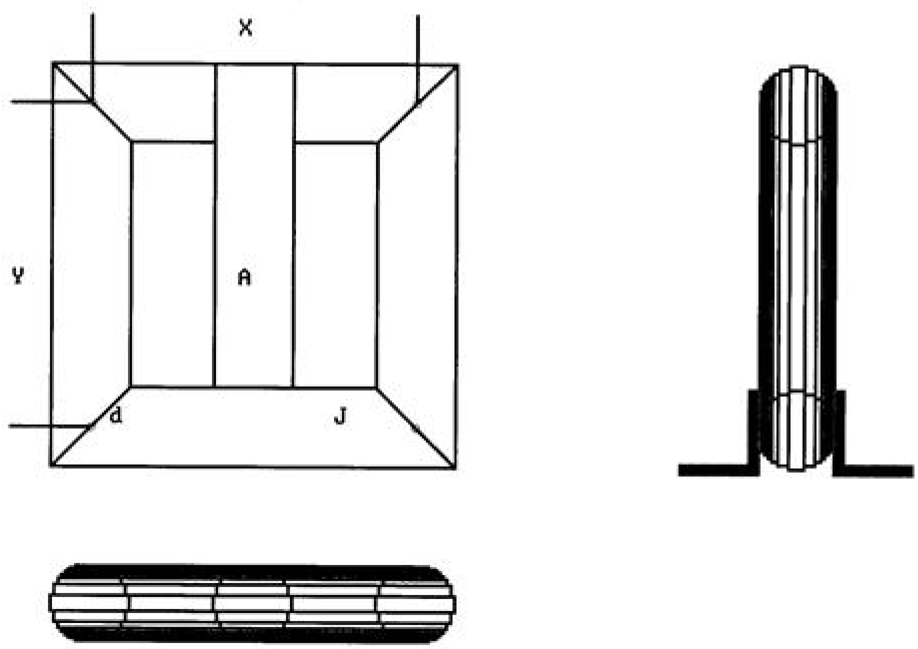
Core

03-11-2008/15:28:55	CORE	Page 2

Core file name : LTCM_Rundkerne1.USR		Fe-File name : STEEL1.DAT	
Core name : 3EI_260/265/790/8		Fe-Name : M97-0.30mm => M5 0.012	
Core type : 3EI		Frequency Hz: 50	
Type of windings : round		Remanence-Factor *: 0.35	
Number of legs : 3		W/kg-Factor *: 1	
Core assembly : (7) 4x45°+3x9		VAr/kg-Factor *: 1	
Leg/Diameter cm: 26.00		Gap-Factor *: 1	
Window width cm: 27		f/fn-Factor *: 1	
Window height cm: 79.49		Fillfactor *: 1	
Stack cm: 24.3		Annealed -: Yes	
Cross section in^2: 472.8			
Weight total kg: 1818.			
With holes -: Yes		Chassis -:	
Brackets -: L-T&B		Vertical/Horizontal-:	

X-Width	cm: 105
Y-Height	cm: 105
d_Hole	cm: 2.55
h-Distance	cm: 2.55
L-Laenght	cm: 25.5

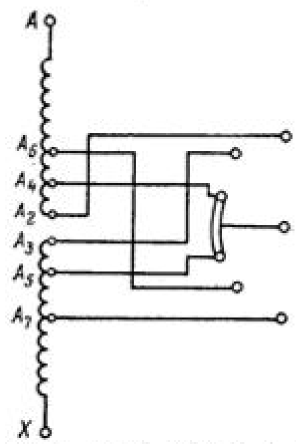
Stufen		1	2	3	4	5	6	7	8
A-Leg	cm:	25.5	23	20.5	18.5	16	14	12.5	9
J-Yoke	cm:	25.5	23	20.5	18.5	16	14	12.5	9
R-Rearyoke	cm:	0	0	0	0	0	0	0	0
S-Stack	cm:	5.1	3.5	1.9	1.2	1.1	0.7	0.4	0.8
Number lamin.	:								
Weight	kg:								



Windings

The secondary winding (2 x Scr) is wound with 2 parallel strands. Each strand has 6 parallel flat wires. The transposition (rotation) of the wires in these 2 strands has to be done after 1., 3., 5., 7., 9., 11., 13., 15., 17., 19., 21. and 23. turn. The horizontal cooling channel between these 2 strands is 5mm

The calculated number of the discs of the primary winding is 64 discs. In order to set the -5.0%, -2.5%, +2.5% and +5.0% taps for voltage regulation, the primary winding is normally cut in the middle. At this point there should be a horizontal cooling channel 12-15 mm instead 5mm.



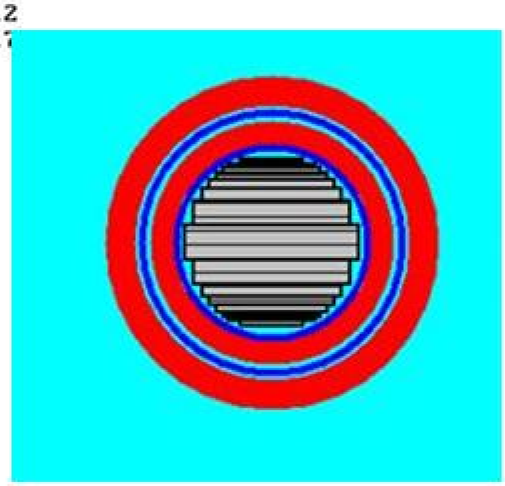
A6A4=A4A2=A3A5=A5A7 = 2 discs

Due to high voltage line discharge each turn in the 2 first and the 2 last discs have to be additionally insulated with approx 0.75 - 1.00mm one-side insulation. For these two reasons, the number of the discs should be set to 62, wound as follows:

- Discs 1&2 &61&62 => 10
- 28&29&30&31&32&33&34&35 => 15 turns
- Other =>20&21 turns

03-11-2008/15:28:55			WINDINGS					Page 3
Windings	1	2	3	4	5	6	7	8
Groups-Circuits	2-Yn	1-Y						
Connection	ser.	ser.						
Turns	24.0	1195.0						
Build %	34.14	82.85						
Weight kg	86.8	124.9						
WIRE								
Type	flat	flat						
Thicknes mm	4.50	1.70						
Width mm	7.50	5.00						
WG-thicknes	84	67						
WG-width	93	86						
Al/Cu	Cu	Cu						
STRAND/LITZ							7	
Thickne insula. mm	27.90	1.85						
Width insulata. mm	15.3	5.2						
Parallel wires	12	1						
side by side	2	1						
one upon the other	6	1						
Transposition	2xScr	Disc						
Cross section mm^2	405.12	8.5						
SECTOR								
Number	1	1						
Serie/Parallel	ser.	ser.						
Turns	24	1195						
Turns/Layer	24.88	64						
Layers	0.964	18.67						
Insul./Layer µm	200.0	200.0						
Transposition	Rotat	None						
Thicknes mm	29.10	38.75						
Width mm	645.00	645.00						
Distance/Sector mm	0.964	0.999						
SPACES/CHANNELS/INS.								
C/I Outside	WCICW	WCICW						
Insulation mm	5.0	5.0						
Channel mm	6.0	11.0	0.					
C/I Inside	WCICW	WCICW						
Insulation mm	5.0	5.0						
Channel mm	6.0	11.0						
C/I Horizontal	CC	CC						
Sector-Sector mm	1.0	1.0						
Turn-Turn mm	5.0	5.0						
Distance to yoke mm	75.0	75.0						

Coil insulation mm: 0.
D1i/D1e: 294.0 352.2
D2i/D2e: 406.2 483.7
D3i/D3e: /
D4i/D4e: /
D5i/D5e: /
D6i/D6e: /
D7i/D7e: /
D8i/D8e: /



Nominal operating mode

03-12-2008/11:00:08	IN OPERATION MODE	Page 4

Frequency	Hz: 50	Ventilation outsi.	m/s: 0	Fillfactor/channels	%: 80
Ambient temperature	C: 55	Ventilation(chann.	m/s: 0	Varnish in windings	%: 100
Convection outside	*: 0.8	Rth-Insulation	*: 1	Varnish/gaps/stomack	%: 100
Convection/channels	*: 0.8	Rth-Varnish	*: 1	Stomack	mm: 1.00
Emission	*: 1	Rth-Epoxy	*: 1	Gap	mm: 0.10

Output power	kVA: 1610.9	Input power	kVA: 1638.5	Core power	: 0.0
Fe-Losses	VA: 17589	Fe-active losses	W: 2942.	Fe-reactive losses	VAr: 17341
No-load curren	%: 1.2	No load curr. active	%: 0.2	No load curr. react.	%: 1.2
I^in/I^nom-Factor	: 7.71	Iinrms/Inomrms-Factor	: 5.63	No load induction	T: 1.609
I^in	kA: 0.29	Iin rms	kA: 0.15		
Icc cold	kA: 0.41	Iccr active cold	kA: 0.05	Iccx reactive cold	kA: 0.41
Ucc cold	%: 6.54	Uccr active at 75 °C	%: 0.99	Uccx inductive cold	%: 6.49
CuAl-losses	W: 18910.7	Efficiency	%: 98.650		
Max. dT Cu/Al	°K: 24.8	Max. dT Fe	°K: 11.3	Induction	T: 1.600

Windings		1	2	3	4	5	6	7	8
Groups-Circuits		2-Yn	1-Y						
Connection		ser.	ser.						
Time1		60.0	60.0						
Load1		1.00	1.00						
Time2		60.0	0.0						
Load2		1.00	0.00						
Voltage rms	V	400.0	20207						
U-Phasen delay	°	-3.71	0						
No-load vo÷tage	V	405.5	20207						
Regulation	%	1.4	0.0						
Current rms	A	1342.3	27.028						
K-Factor		1.00	1.00						
Power	kVA	536.9	546.1						
I-Phase delay	°	0.0	-4.3						
Resistance cold	mOhm	1.052	3437.7						
Losses warm	W	3257.	3046.						
RacRdc (total)		1.39	1.01						
Icc.all cold	kA	20.58	0.41						
Radial tension	N/mm2	18.22	10.67						
dTcc after 4.0 s	°K	59.99	54.85						
Icc.group cold	kA	20.58	0.00						
Circ.losses	W	0.00	0.00						
Cur.density	A/mm^2	3.31	3.18						
SECTORS									
1 RacRdc		1.39	1.01						
Current	A	1342.	27.02						
dT	°K	24.8	13.8						
2 RacRdc									
Current	A								
dT	°K								
3 RacRdc									
Current	A								
dT	°K								
4 RacRdc									
Current	A								
dT	°K								
5 RacRdc									
Current	A								
dT	°K								
6 RacRdc									
Current	A								
dT	°K								
7 RacRdc									
Current	A								
dT	°K								
8 RacRdc									
Current	A								
dT	°K								

On this page you can check the prescribed parameter:

- winding losses at 75 °C :0.99%<1.125%
- short voltage:6.49% (instead of 6.4%)
- core losses:2920W < 3200W
- No-load current : 1.2% < 1.3%
- Max temperature rise :24.8 °K < 25 °K
- Max.radial tension in short-circuit: 18.22N/mm^2 < 60 N/mm^2
- Max temp. rises during 4s in short-circuit:59.99°K

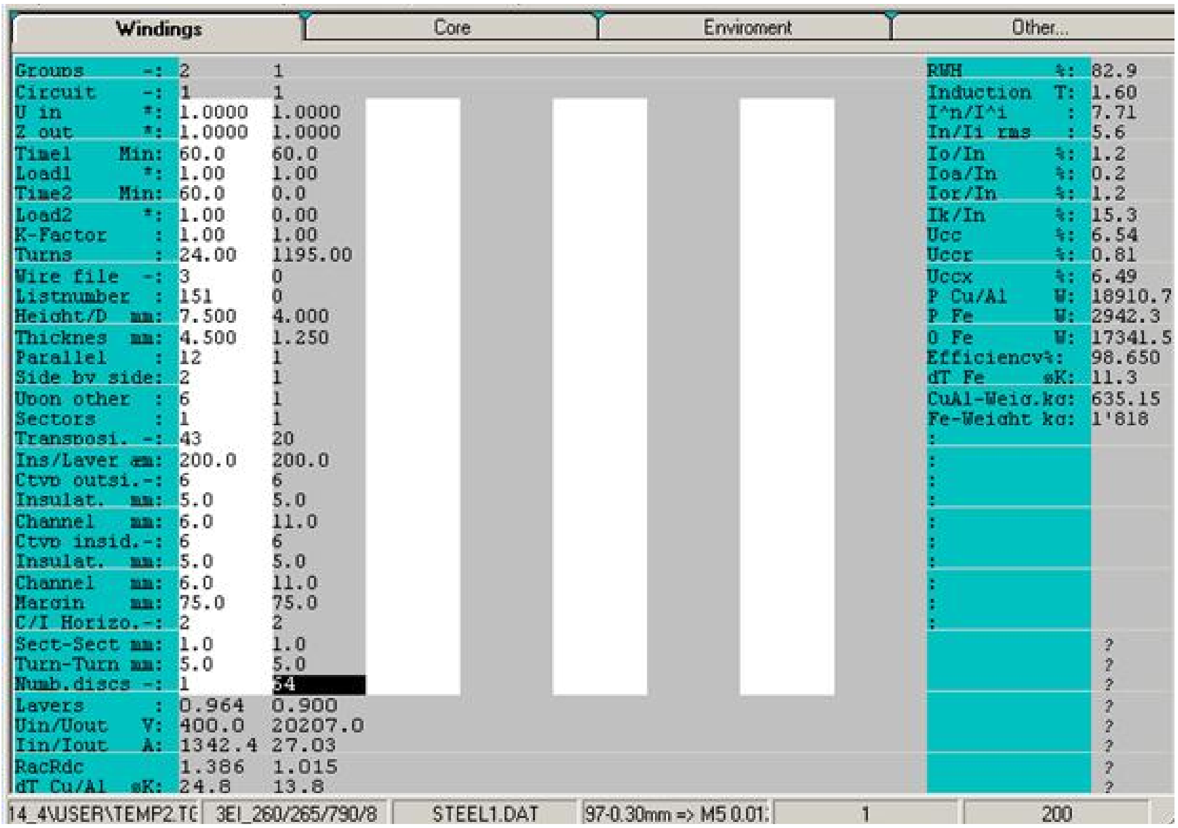
Test Mode

If you are not satisfied with the solution made by the program you can switch into the Test Mode and change your transformer by hand:

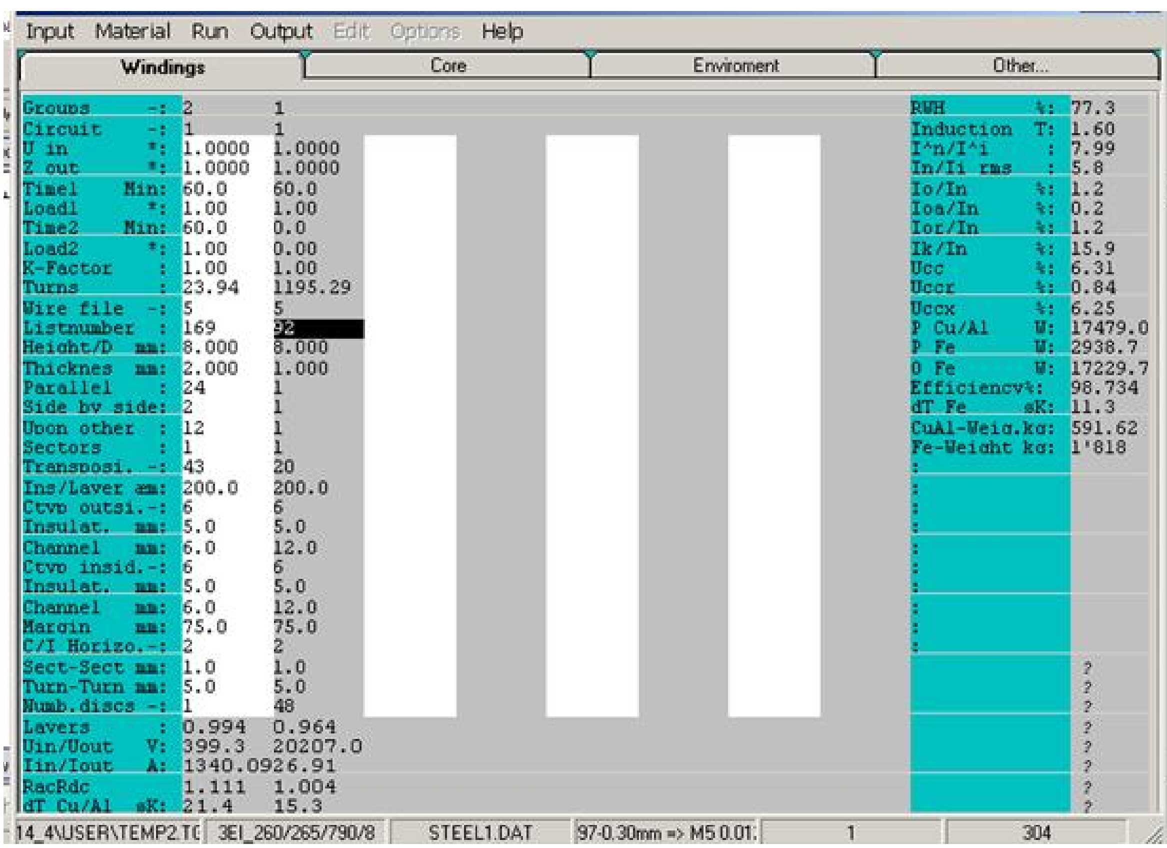
- Turns 24.8
- Wire size
- Material (Cu or Al)
- Number parallel connected wires and their order in strand
- Cooling channels and insulations
- Margin
- Steel
- Technology parameter (impregnation, gaps,...)

and then you can set it under an operation mode changing:

- Input voltage
- Frequency
- Loads and their K-factors
- Duty cycle of each winding
- Ambient temperature
- Air flow



In order to optimize the material costs you need to reduce the very high eddy current losses. From a material costs point of view, here is a better version with secondary 2 x 12 flat wires 8mm x 2mm and primary wires 1mm x 8mm in only 48 discs.



Designing Water Cooled Inverter Filter Choke, 0.5mH, 600Arms, 60Hz

General about inverter filter choke

Fig.1 illustrates the main circuit diagram of a three-phase inverter. The 3-phase mains **Uin** supplies the controlled rectifier **R** through the 3-phase commutation choke **CC**. The DC voltage **Udc** is regulated by the rectifier and smoothed with the capacitor **C**. The 3-phase AC voltage **Uout** is produced at the inverter outputs. The amplitude, frequency and form of this 3-phase AC voltage are regulated with the inverter and rectifier.

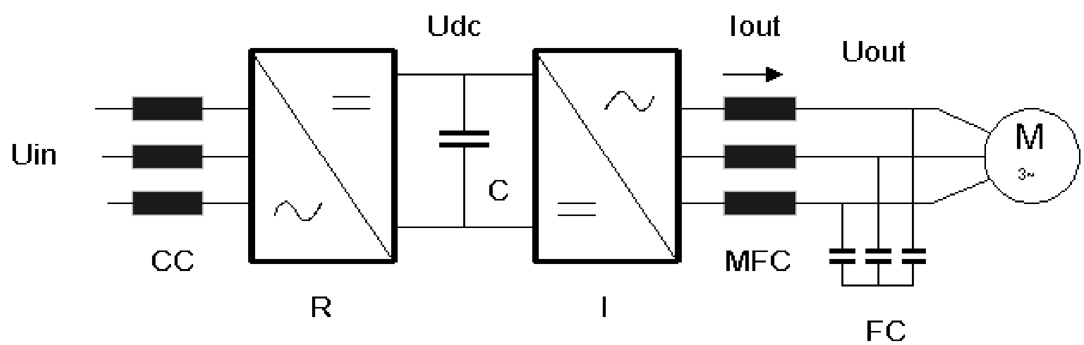


Fig. 1

The typical form of the inverter output voltage per phase is illustrated in **Fig.2**.

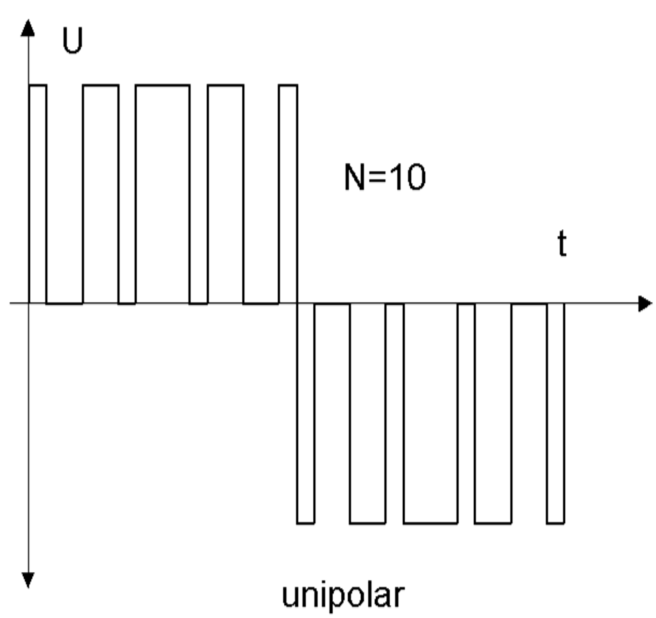


Fig. 2

At an inverter modulation frequency **N*f**, the output voltage **Uout** essentially consists of three components:

- Fundamental frequency **U** with the frequency f (50Hz or 60Hz)
- First harmonic **U1=0.45*U** with the frequency **(N-1)*f.**
- Second harmonic **U2=0.45*U** with the frequency **(N+1)*f**

Accordingly, the current through the inverter filter choke **Iout** essentially comprises of 3 components:

- Fundamental frequency **I** with the frequency **f.** This current is "impressed" and its amplitude depends on the inverter power.
- First harmonic **I1** with the frequency **(N-1) * f.** The amplitude of this current depends on the voltage **U1,** the modulation frequency **N*f** and the inductance **L** of the inverter filter choke:
  I1=U1/(2* ¶*f*(N-1)*L).
- Second harmonic **I2** with the frequency **(N+1) * f.** The amplitude of this current depends on the voltage **U2,** the modulation frequency **N*f** and the inductance **L** of the inverter filter choke:
  I2=U2/(2* ¶*f*(N+1)*L)

About input parameters

Inductance at 1000Hz and 900Apeak	0.5mH
Inverter frequency	60Hz
Modulation frequency (N=18)	1080Hz
RMS current at main frequency	600Arms at 60Hz
RMS currents at 1020Hz and 1140Hz	30Arms
Maximal total losses (warm)	10kW
Insulation clas	H
Indirect water cooling	20°C incoming 55°C, maximal outcoming 1.5at max. pressure drop 1.5 m/s, max. speed
Test voltage winding-cooler, winding-core	4kV, 1minute, 60Hz

About indirect water cooling

The indirect water cooling of the three phase inverter filter choke will be ralized with accordance to the construction in the Fig.3.

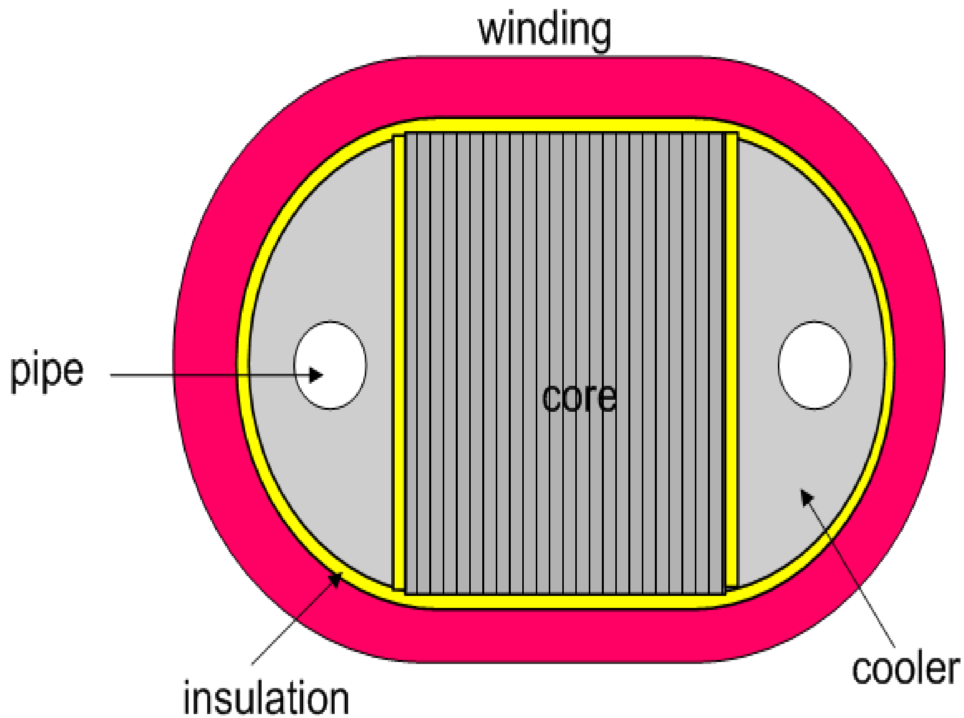


Fig.3

Note that the Small Chokes Program does not support water cooling. I selected this design example in order to transfer the know-how for water cooling design to my users.

Power per cooler in W and kcal/s

1. **Pc = K*Ptot/Nc**
2. **Qc = Kd*Ptot/4180/Nc**

- Kd => Factor of the losses distribution between cooler and air (0.8-0.9)
- Ptot => Choke total losses in W
- Nc => Number of coolers
- Pc => Power per cooler in W
- Qc => Power per cooler in kcal/s

Amount of water in l/s

q = Qc/dTw

- Qc => Power per cooler in kcal/s
- dTw => maximal temperature rise of water in °K
- q => Amount of water in l/s

Water speed in m/s

$$v = 10q/Apcs$$

- q => Amount of water in l/s
- Apcs => Cross section of pipe in cm^2
- v => Water speed in m/s (It must not be higher tan 1.5 m/s)

Equivalent pipe diameter

If the pipe cross section is rectangular then the equivalent pipe diameter can be calculated

$$Dk = 2ab/(a+b)$$

- a, b => Sides of the rectangular pipe
- Dk => Equivalent pipe diameter

Factor of the convection between water and pipe in W/°K/cm^2

$$\alpha = 0.313v^{0.87}Dk^{-0.13}$$

- V => Water speed in m/s
- Dk => pipe diameter in m
- Al => Factor of the convection in $W/°K/cm^2$

Temperature drop between cooler and water in °K

$$dTcw = Pc/\alpha/Apw$$

- Pc = 1000Ptot/Nc => Losses per cooler in W
- α => Factor of convection in $W/°K/cm^2$
- Apw => Contact surface cooler-water in cm^2
- dTcw => Temperature drop between the cooler and water in the pipe in °K

Temperature drop between the pipe and the cooler surface in °K

$$dTcc = 2\ Pc\ Lcp/(Ac+Apw)/\lambda c$$

- Pc = => Losses per cooler in W
- Lcp => Equivalent distance cooler surface-pipe in cm
- Apw => Contact surface cooler-water in cm^2
- Ac => Surface between the cooler and winding in cm^2
- λc=> Thermal conductivity of cooler material (normally Al) 1.8 W/°K/cm
- dTcc = Temperature drop between the pipe and cooler surface in °K

Temperature drop within the cooler insualtion in °K

dTci = Pc Lci/Ac/λci

- Pc => Losses per cooler in W
- Lci => Thickness of the cooler insulation cm
- Ac => Surface between the cooler and winding in cm^2
- λci => Thermal conductivity of cooler insulation in W/°K/cm
- dTci = Temperature drop within the cooler insulation in °K

Temperature drop within the wire insualtion in °K

dTwi = Pc Lwi/Ac/λwi

- Pc => Losses per cooler in W
- Lwi => Thickness of the wire insulation cm
- Ac => Surface between the cooler and winding in cm^2
- λwi => Thermal conductivity of wire insulation in W/°K/cm
- dTwi = Temperature drop within the wire insulation in °K

Temperature drop within the winding in °K

dTw = Pc Lw/Aw/λw/16

- Pc = => Losses per cooler in W
- Lw => Average turn length in cm
- Aw => Winding cross section (all turns) in cm^2
- λw=> Thermal conductivity of winding material (normally Cu) 3.5 W/°K/cm
- dTw = Temperature drop within the winding in °K

Water pressure drop in the pipe in at

dp = 0.01 K v^2 Lt/Dk

- **Lp => Pipe length in cm**
- **Dk => Pipe diameter in cm**
- **K => Factor**

Dk (m)	0.0.004	0.006	0.006	0.007	0.008	0.009	0.010	0.011	0.012
K	0.094	0.087	0.083	0.080	0.075	0.073	0.070	0.068	0.066

Provisional "core selection"

Before you start coke design you need approximately to know how big has to be the cooler. Due to the fact that the cooler fits tightly over the leg along the window height its cooling surface to the winding is approximately equal with the leg surface along the window height.

Pc = Kd Ptot/Nc = 0.9x10000/6 = 1500 W
Qc = Pc/4180 = 0.358 kcal

dTw = 3.58°K
q = Qc/dTw = 0.358/3.58 = 0.1 l/s

Dk = 0.4 " = 0.1.016 cm
Apcs = $\pi Dk^2/4 = 3.14x1.016^2/4 = 0.81cm^2$
v = 10q/Apcs = 10x0.1/0.81 = 1.23 m/s

$\alpha = 3.13v^{0.87}Dk^{-0.13} = 0.313x1.23^{0.87}x1.016^{-0.13} = 0.374$ W/°K/ cm^2

Lp = 12in = 30.48 cm
Apw = πDkLp = 3.14x1.016x30.48 = 97.23 cm^2
dTcw = Pc/α/Apw = 1500/0.374/97.23 = 41 °K

dp = 0.01 K v^2 Lp/Dk = 0.01x0.070x1.23^2x30.48/1.016 = 0.03at per cooler

Lcp= 0.75"=1.9cm
Ac = 12"x3" = 1.06x 232 = 246 cm^2 (Leg Width x Height), Factor 1.06 due to the oval form
λc=1.8 W/°K/cm
dTcc = 2 Pc Lcp/(Ac+Apw)/λc = 2 x 1500 x 1.9 /(97+ 246)/1.8 = 9.2°K

λci = 0.015 W/°K/cm (Huntsman XB 2710+XB 271, 20kV/mm, Tmax=120°C)
Lci = 0.1cm (Insulation thicknes of the coated coole))
dTci = Pc Lci/Ac/λci = 1500x0.1/0.015/246 = 40°K

λwi = 0.004 W/°K/cm
Lwi = 0.01 cm
dTwi = Pc Lwi/Ac/λwi = 1500x0.01/0.004/246 = 15°K

Lw = 13" = 33cm
Aw= 40 x 0.46" x 0.182 = 3.34 in^2 = 21.5 cm^2
λw = 3.5 W/°K/cm
dTw = Pc Lw/Aw/λw/16 = 1500 x 33/ 21.5/3.5/16 = 42°K

Winding teperature rise will be 2+41+40+15 +9.2 + 42 =149.2°K. Due to the fact that the winding losses are lower than 3000W (view the design results) the temperature rise will be approx. 20% lower (125°K instead 149°K)

This provisional thermal design of the cooler shows that the core with the leg sizes 3" x 12" is, from thermal point of view, big enough.

General design rules

- The cooler size is H=12", W=3" T=1.2". In order to avoid any gaps between the cooler and the winding the contact form has to be oval (see the Fig3). The cooler has to be coated with 1.5mm resin from Huntsman XB 2710+XB2711. This resign has very high thermal conductivity (0.015W/°K/cm) and relative high break down voltage (>20kV/mm).
- Due to the fact that the water cooled are small the amperturns are very high and the gap size very big. For a "good" gap of approx <0.1" the choke has to be made by more than 10 gaps per leg and with the high induction
- The criterion of the design is Q-factor:at the max. temperature 165°C:
  Qf = $L\omega/Irms^2$/Ptot/Kd/(Nc/2) = 0.0005x376/600^2/10000/3/0.9 >24 =2
- The insulation in the gaps and around the gaps has to be class H.
- From thermal point of view the optimal construction is one layer winding with Cu rectangular wire

Design page 1

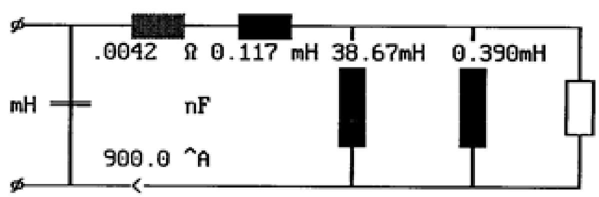
10-06-2008/15:17:16/14.44 INPUT and OUTPUT Seite 1

	L(mH)	I(A)
Schema :1.	0.5	900.
L-Type *:4.		
Wire -:4.		
In/L mil:0.		
In/E mil:0.		
Al/Cu -:1.		
Fre.Hz:60		
Ripple %:10.		

	1---	2---	3---	4---	5---	6---	7---	8---
Harmo. -	:1	17	19					
Curre. A	:600	30	30					
Angle °	:0.	0.	189.					

Q-Factor :26	Steel -:1	Cooling *:7	Bobbin -:3
Cal.Freq.Hz:60	Induction T:1.44	Ventil. m/s:0	Stomach *:1
L@Freq. .Hz:1080	Plate -:0	Brackets -:1	Rac/Rdc *:1.2
:0	W/kg *:1	Radiator -:0	Space Fac. *:2
Amb.Temp.°C:20	VAr/kg *:1	Chassis -:1	Force -:1
Tmp.rise °K:145	Gap posit.*:8	Channel in:0.	Windintech.-:1
Time 1 Min:30	Annealed -:1	Cu-Surfac.*:1	Impregnat. -:1
Load 1 *:1	Stack.Fac.*:.96	Rth-Varn. *:2	Full Layer -:0
Time 2 Min:30	Hole -:0	Rth-Comp. *:1	Selection -:1
Load 2 *:1	Core Asse.-:4	Case -:0	Criteriom -:1

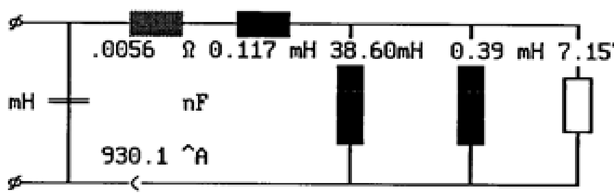
Type of the Inductance L=dU/dI/Ω1



Bave T: 1.296
Bgap T: 1.513
Bmax T: 1.414

Nominal operation mode at the temperature °C 110.1

Nominal current Inom rms A:601.4	Peak current of Inom ^A:930.1
Al/Cu Losses/phase W:2477.	Steel Losses/phase(activ) W:1070.
Addy current losses factor :1.213	Q-Factor :33.68
dT Fe (average) °K:36.98	dT Winding (hot spot) ^°K:90.15
dT Case (average) °K:0.0	dT Windig (average) °K:83.51



Bave T: 1.337
Bgap T: 1.561
Bmax T: 1.460
Bx T: 0.055
By T: 0.078

Harmonics	:1.	17.	19.	0.	0.	0.	0.	0.
Current rms	A:600.	30.	30.	.	.	.	.	.
Al/Cu Losses	W:2365.	52.80	58.90	.	0.	.	.	.
Fe-Losses	W:762.0	141.2	167.0	.	.	.	.	.

Duty cycle operation mode at the amboent temperature °C 110.1

dT Steel (average) °K:36.98	dT Winding (hot spot) °K:90.15
dT Case (average) °K:0.0	dT Winding (average) °K:83.51

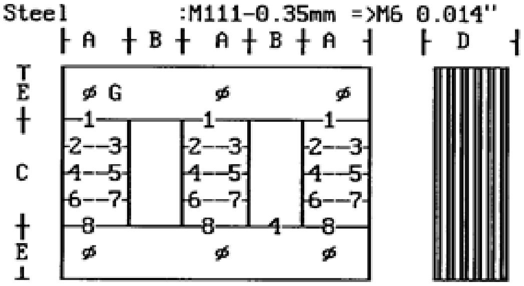
Inductance and induction at the impressed peak current

Current	^A	90.	900.	.	.	.	1350.	.	1800.	.
Induction	^T	.13	1.297	.	.	.	.507	.	.614	.
L=U1/Ω1/I1	mH									
L=U1/Ω1/Ieff	mH									
L=ΣU*t/^I	mH									
L=dU/Ω1/dI	mH	0.506	0.504	0.	0.	0.	0.204	0.	0.187	0.
Leaking Ind.	mH	0.118	0.117	0.	0.	0.	0.168	0.	0.158	0.
Gap-Induct.	mH	0.393	0.391	0.	0.	0.	0.114	0.	0.101	0.

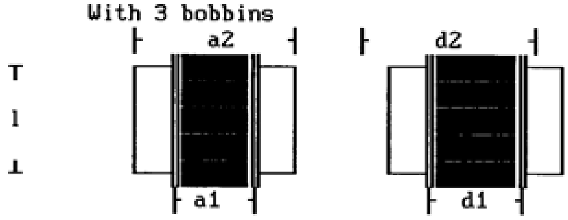
Design page 2

10-06-2008/15:17:16 / BOBBIN / STEEL / CASE / WINDING Seite 2

Name :3XEI 3P 3x3/1.5x12
Steel :M111-0.35mm =>M6 0.014"



With 3 bobbins



	/13.78
Weight	lb:138.26
A-Limb(Dia.)	in:3.00
B-Width	in:1.50
C-Height	in:12.00
D-Stack/Dia.	in:3.00
E-Yoke	in:3.00
F-Rearyoke	in:3.00
G-Hole	in:0
Radiator Ribs	:0
Radiator Chann.	:0
a1	cm:3.24
a2	cm:4.44
d1	cm 3.24
d2	cm 4.44
l	cm:11.58
p	cm:
ls	cm:
Margin	cm:0.21

X- Lenght 1	in:
Y- Width 1	in:
Z- Height 1	in:
x- Lenght 2	in:
y- Width 2	in:
z- Height 2	in:
w- Thicknes	in:
SPK Material	:
Compound	in^3:
Chann./Wind.	in:0.00
Chann.=>core	in:0.00

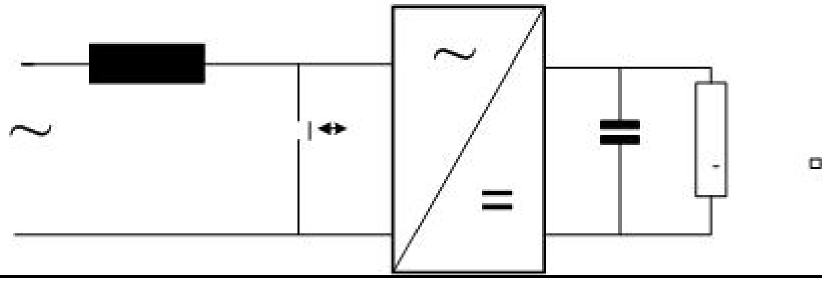
	Windng	T	AWG	AWG	Para	D/ø mil	B/ø mil	Pitch mil	T/L	L	I/L mil	I/E mil	Weight lb	RWH %
1 2 3 4	40.	2	5.	98.	1	188.	500.		21.2	1.89	0.	0.	17.231	82.

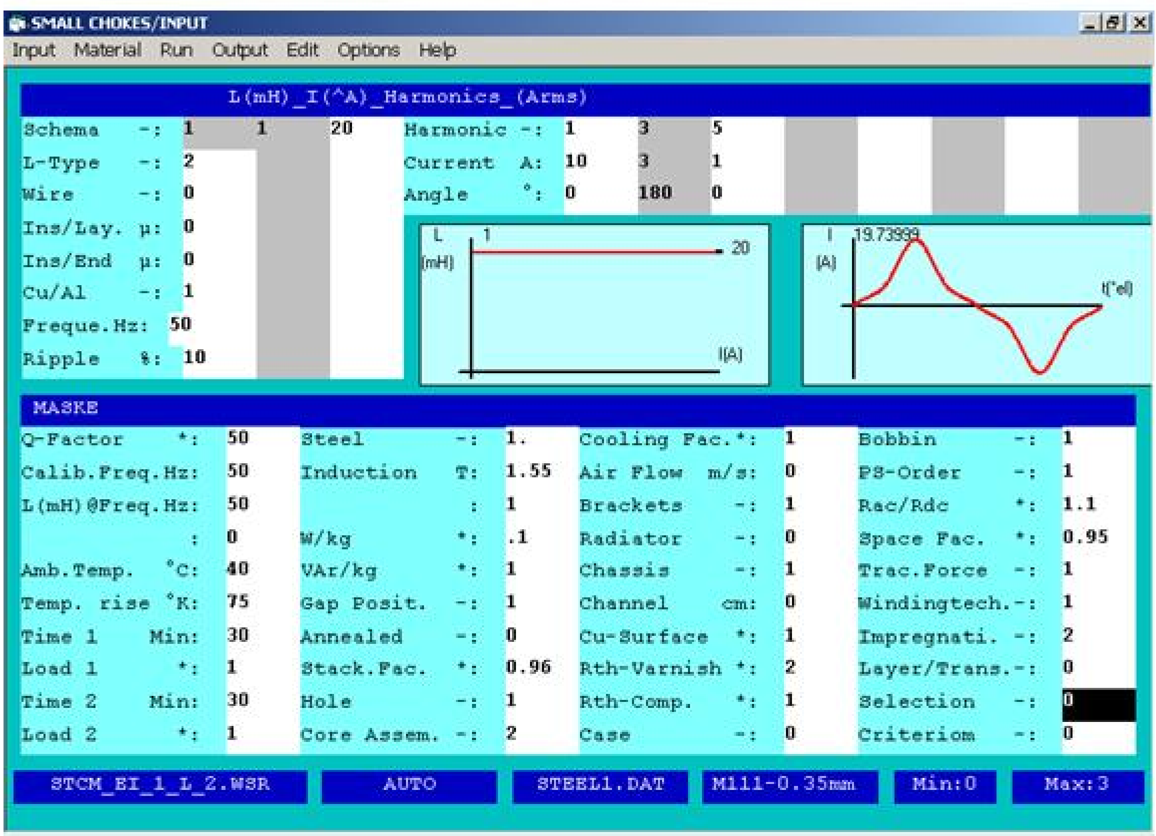
Order Layers Turns								
Position Gap in	1 0.161	2 0.161	3 0.161	4 0.161	5 0.161	6 0.161	7 0.161	8 0.161
Voltag.V Curren.A	12.21 63.82	122.2 638.2	0. 0.	0. 0.	0. 0.	171.4 957.4	0. 0.	224.5 1276.

Order :
Customer :
Remarks :

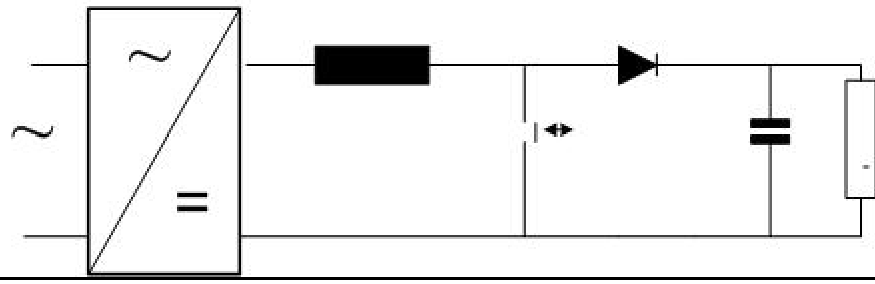
Date :10-06-2008
Time :15:17:16

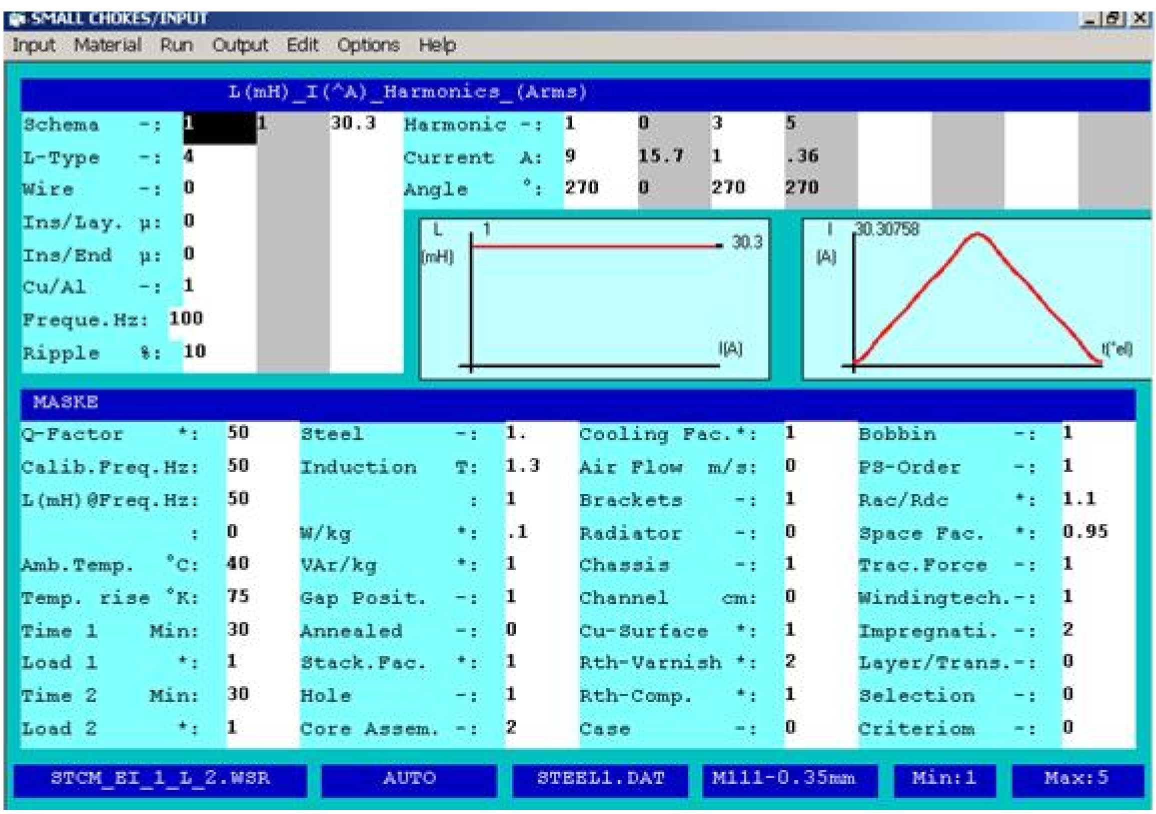
Power Factor Correction Chokes

Title	**One-Step Power Factor Correction Choke, connected before rectifier bridge with switching transistor, diode and RC-Load** 
Input	• Set inductance at peak current (View the peak value on the current diagram) • Select the AC inductance : L-Type = 2 • Select Cu round wire: Wire = 0 • The frequency of the first harmonic is 50Hz • Set the rms values of harmonics of the thermal current: • Set the temperature rise • Select grain oriented steel. Note that the induction will be optimized by program in order to get optimal relationship between core losses and winding losses • Set Gap = 1 and Core Assembly = 2 or better • Select suitable core family

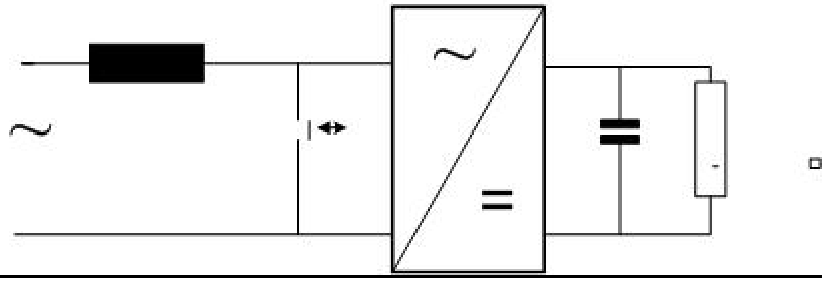


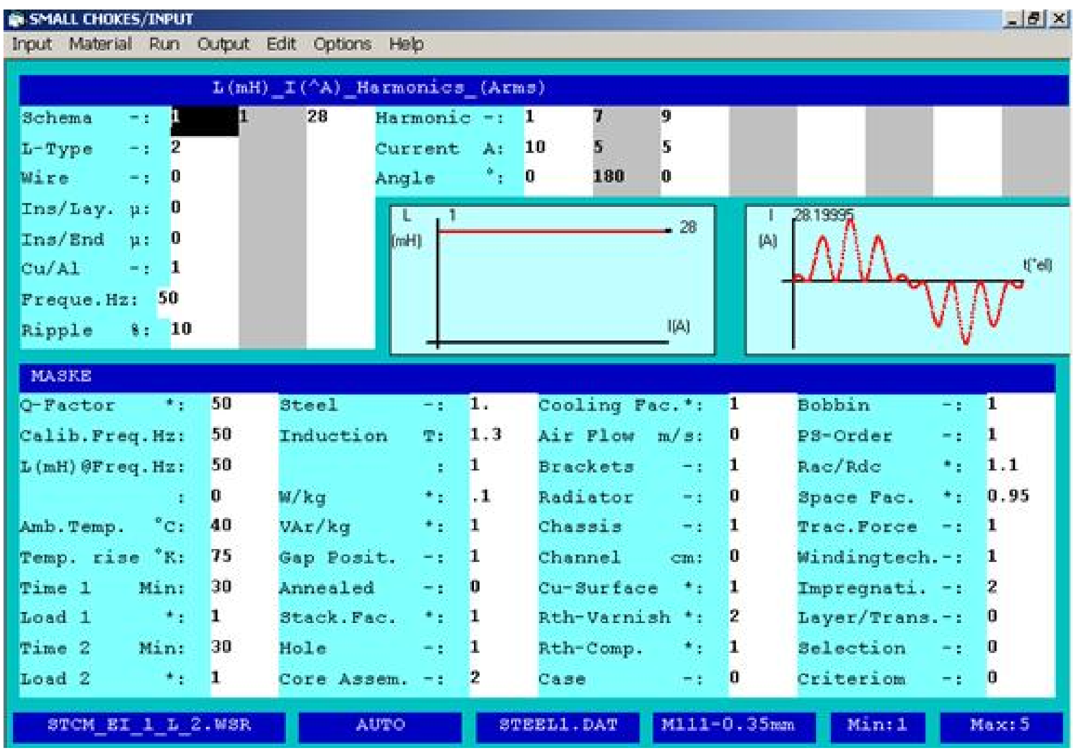
Output	• Control the value of induction, gap and connected wires in parallel
Test	• Round the number of turns
Note	• In order to calibrate the choke, connect it on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current

	(rms value).
Title	**One-Step Power Factor Correction Choke, connected between rectifier bridge and switching transistor with diode and RC-Load** 
Input	• Set inductance at peak current (View the peak value on the current diagram) • Select the differential inductance : L-Type = 4 • Select Cu round wire: Wire = 0 • The frequency of the first harmonic is 60Hz • Set the rms values of harmonics of the thermal current: • Set the temperature rise • Select grain oriented steel. Note that the induction will be optimized by program in order to get optimal relationship between core losses and winding losses • Set Gap = 1 and Core Assembly = 2 or better • Select suitable core family

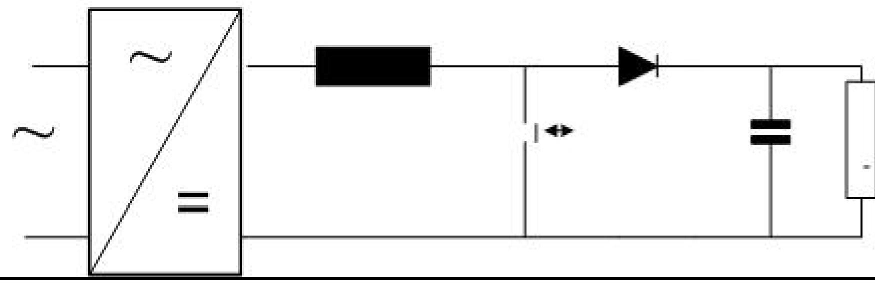


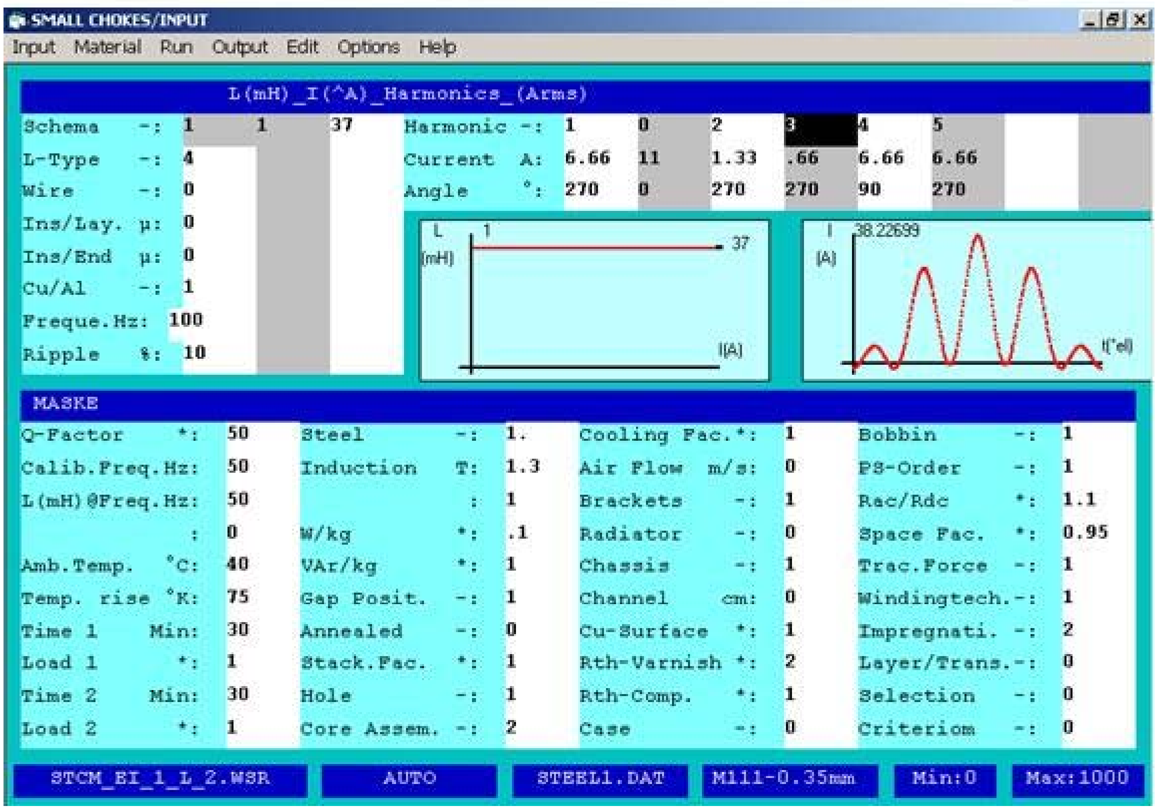
Output	• Control the value of induction, gap and wires connected in parallel
Test	• Round the number of turns
Note	• In order to calibrate the choke, connect it on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

Title	**5-Step Power Factor Correction Choke, connected before rectifier bridge with switching transistor, diode and RC-Load** 
Input	• Set inductance at peak current (View the peak value on the current diagram) • Select the AC inductance : L-Type = 2 • Select Cu round wire: Wire = 0 • The frequency of the first harmonic is 50Hz • Set the rms values of harmonics of the thermal current: • Set the temperature rise • Select grain oriented steel. Note that the induction will be optimized by program in order to get optimal relationship between core losses and winding losses • Set Gap = 1 and Core Assembly = 2 or better • Select suitable core family



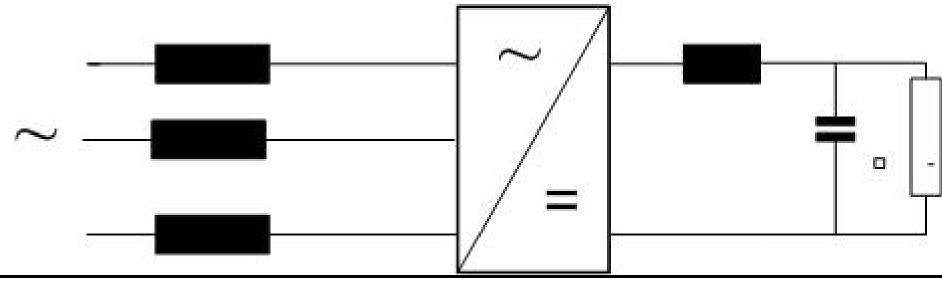
Output	• Control the value of induction, gap and connected wires in parallel
Test	• Round the number of turns
Note	• In order to calibrate the choke, connect it on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

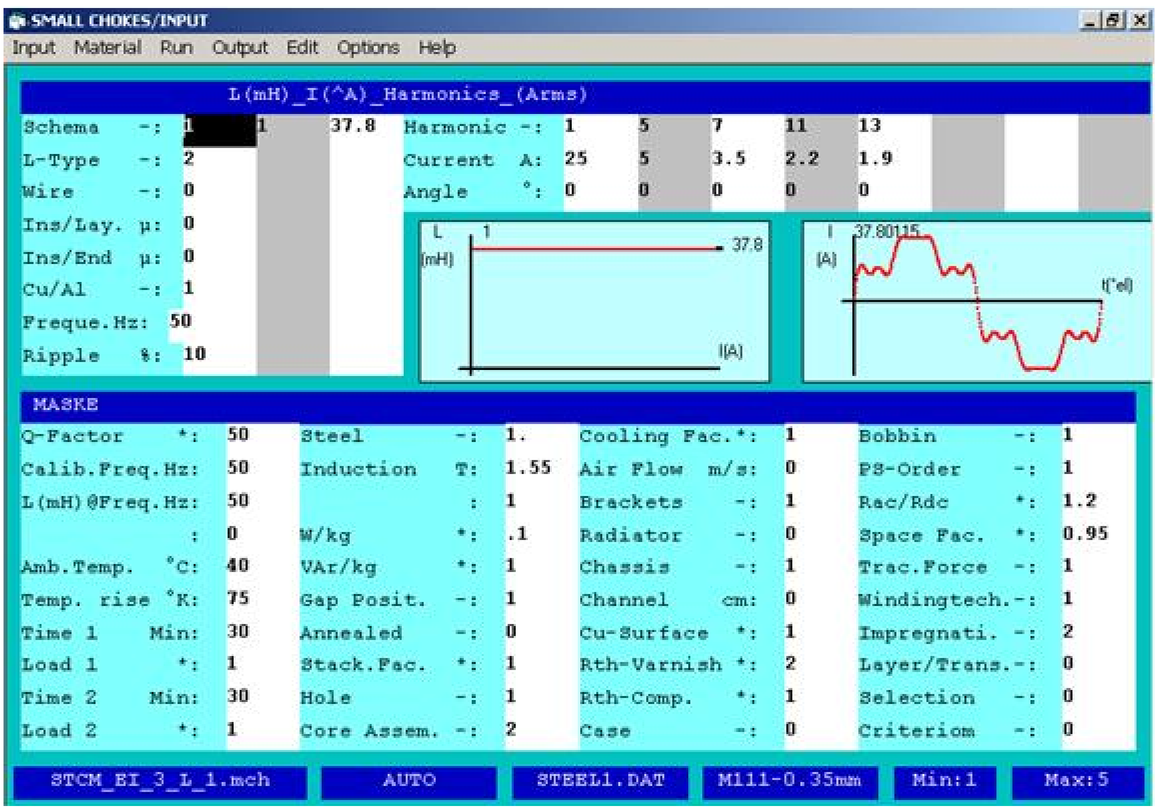
Title	**5-Step Power Factor Correction Choke, connected between rectifier bridge and switching transistor with diode and RC-Load** 
Input	• Set inductance at peak current (View the peak value on the current diagram) • Select the differential inductance : L-Type = 4 • Select Cu round wire: Wire = 0 • The frequency of the first harmonic is 50Hz • Set the rms values of harmonics of the thermal current: • Set the temperature rise • Select grain oriented steel. Note that the induction will be optimized by program in order to get optimal relationship between core losses and winding losses • Set Gap = 1 and Core Assembly = 2 or better • Select suitable core family



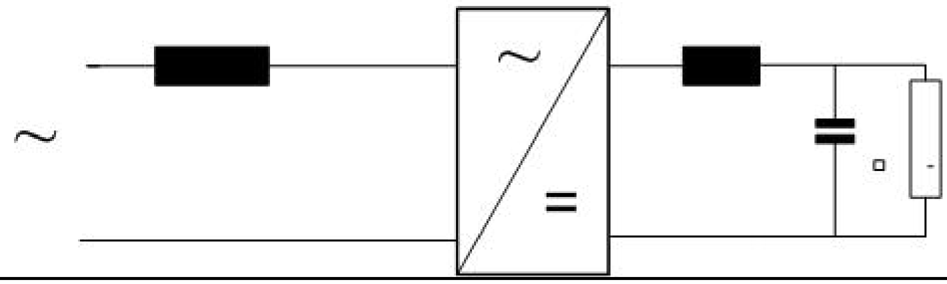
Output	• Control the value of induction, gap and connected wires in parallel
Test	• Round the number of turns
Note	• In order to calibrate the choke, connect it on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

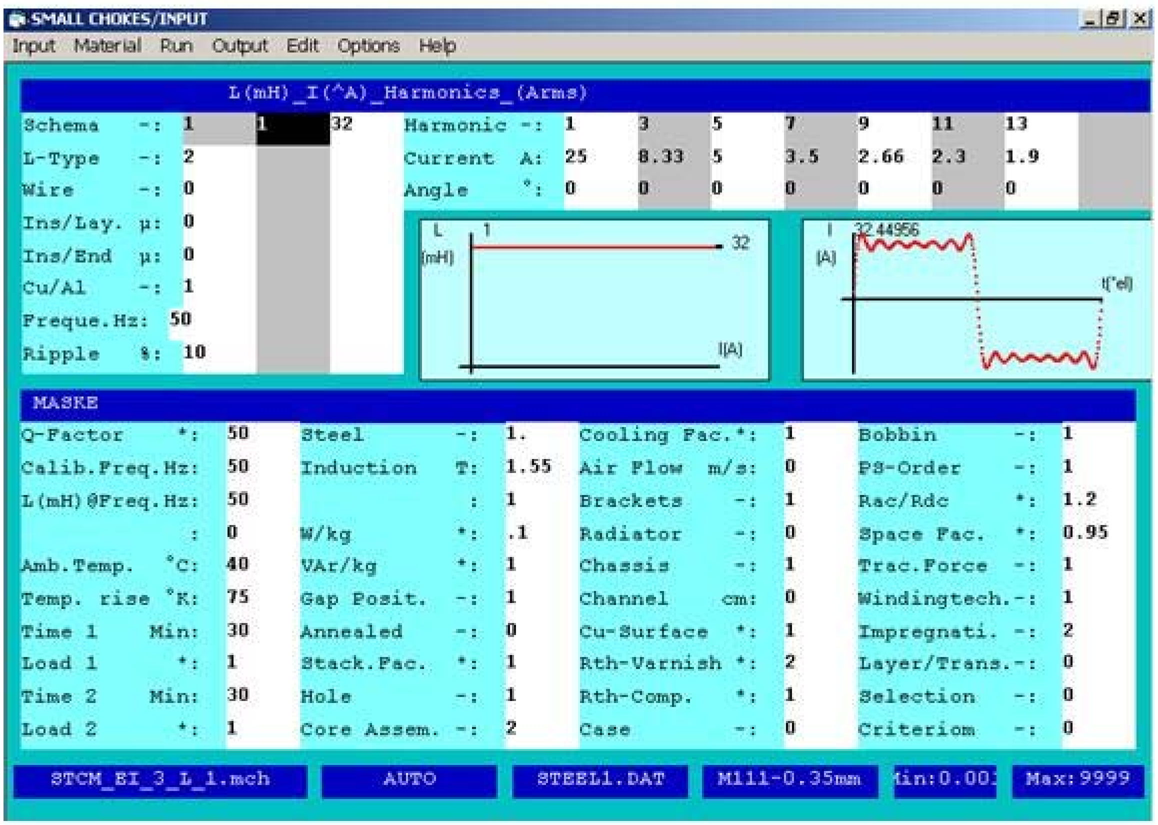
Commutation Chokes

Title	**Three-Phase Commutation Choke, connected before rectifier bridge with smoothing choke** 
Input	• Set inductance at peak current (View the peak value on the current diagram) • Select the AC inductance : L-Type = 2 • Select Cu round wire: Wire = 0 • The frequency of the first harmonic is 50Hz • Set the rms values of harmonics of the thermal current: typical values In=I1/n, without 3rd and 9th harmonic • Set the temperature rise • Select grain oriented steel. Note that the induction will be optimized by program in order to get optimal relationship between core losses and winding losses • Set Gap = 1 and Core Assembly = 2 or better • Select suitable 3 phase core family



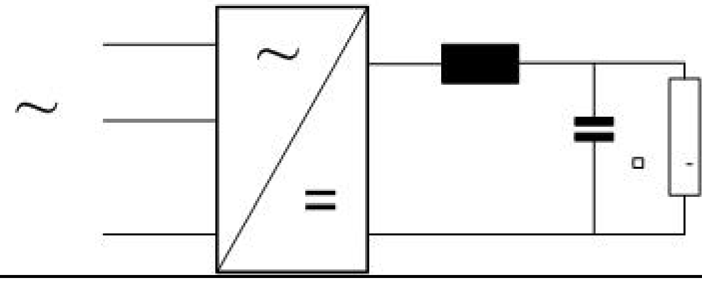
Output	• Control the value of induction, gap and connected wires in parallel
Test	• Round the number of turns
Note	• In order to calibrate the choke, connect it on the calculated calibration 3 phase AC-voltages (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration 3 phase AC-currents (rms value).

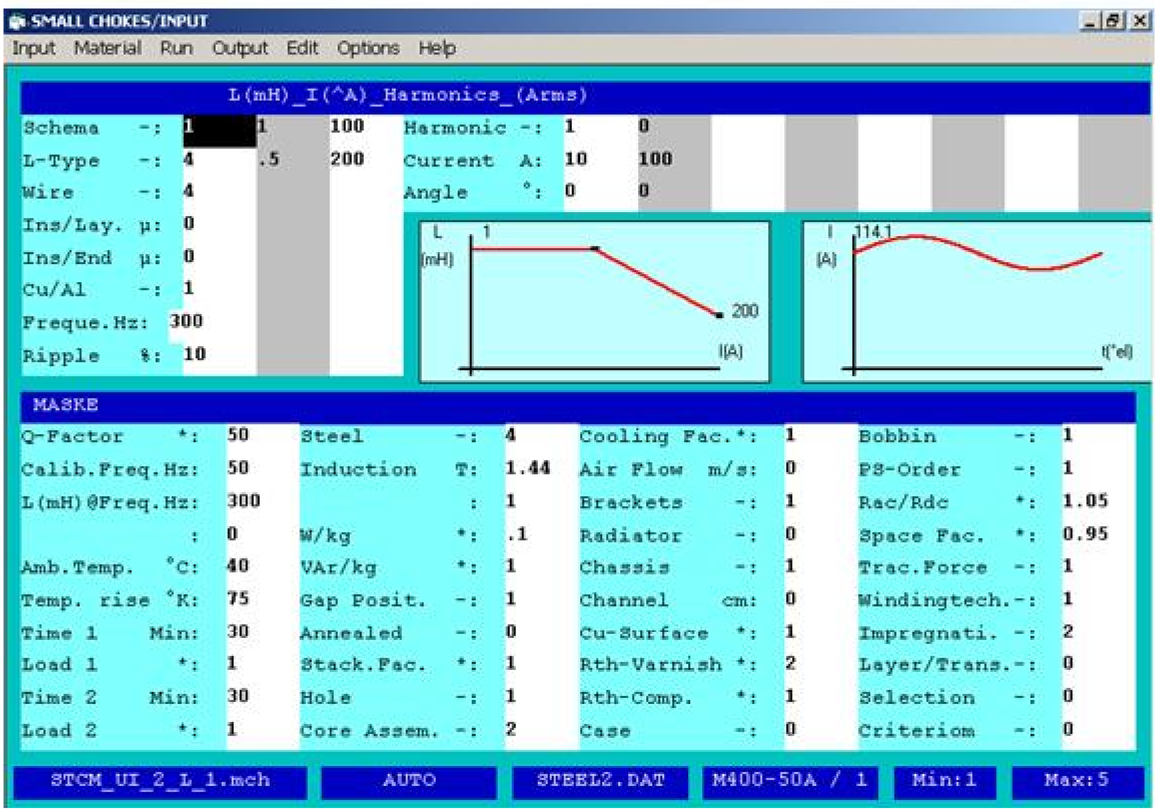
Title	**One-Phase Commutation Choke, connected before rectifier bridge with smoothing choke** 
Input	• Set inductance at peak current (View the peak value on the current diagram) • Select the AC inductance : L-Type = 2 • Select Cu round wire: Wire = 0 • The frequency of the first harmonic is 60Hz • Set the rms values of harmonics of the thermal current: typical values In=I1/n • Set the temperature rise • Select grain oriented steel. Note that the induction will be optimized by program in order to get optimal relationship between core losses and winding losses • Set Gap = 1 and Core Assembly = 2 or better • Select suitable one phase core family



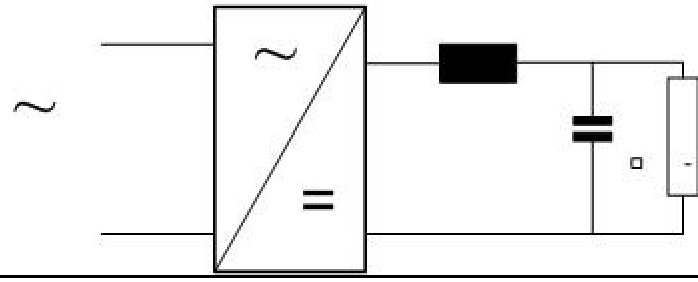
Output	• Control the value of induction, gap and connected wires in parallel
Test	• Round the number of turns
Note	• In order to calibrate the choke, connect it on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

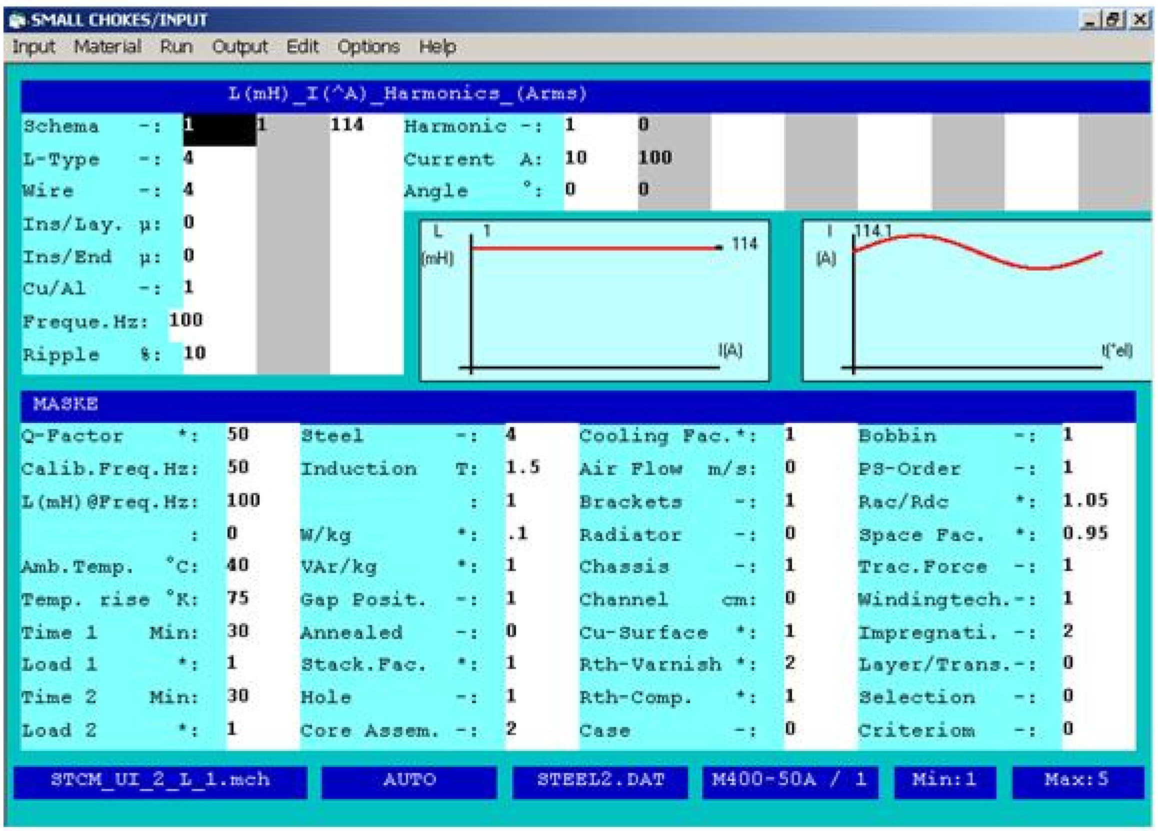
Smoothing Chokes

Title	**Swinging Smoothing Choke for 3 Phase Rectifier Bridge** 
Input	• Set two LI-points: 2 inductance at 2 peak currents. Note that the induction corresponds to the first current • Select the differential inductance : L-Type = 4 • Select Cu flat wire: Wire = 4 • The frequency of the first harmonic is 300Hz • Set the harmonics of the thermal current: the rms-values of the first harmonic and of the DC-current • Set the temperature rise • Select cheap steel. Note that the induction will be optimized by program in order to get 2 prescribed inductance at 2 prescribed currents • Set Gap = 1 and Core Assembly = 2 • Select suitable core family



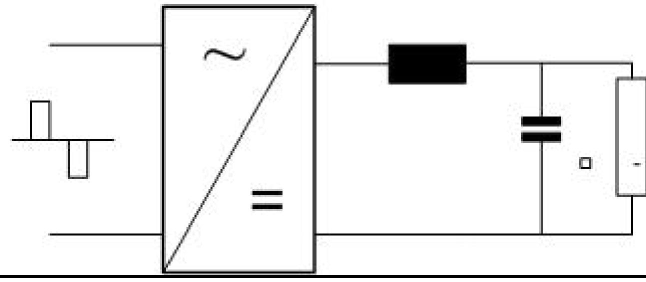
Output	• Press Ctrl+L in order see the diagram Inductance vs. Current
Test	• Round the number of turns • Change the peak value of the second LI-point in order to increase the current range of the diagram Inductance vs. Current
Note	• In order to calibrate the choke, connect it on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

Title	Smoothing Choke for 1 Phase Rectifier Bridge
	
Input	• Set the LI-point of the inductance, the induction at the peak current. • Select the differential inductance : L-Type = 4 • Select Cu flat wire: Wire = 4 • The frequency of the first harmonic is 100Hz • Set the harmonics of the thermal current: the rms-values of the first harmonic and of the DC-current • Set the temperature rise • Select cheap steel. • Set Gap = 1 and Core Assembly = 2 • Select suitable core family



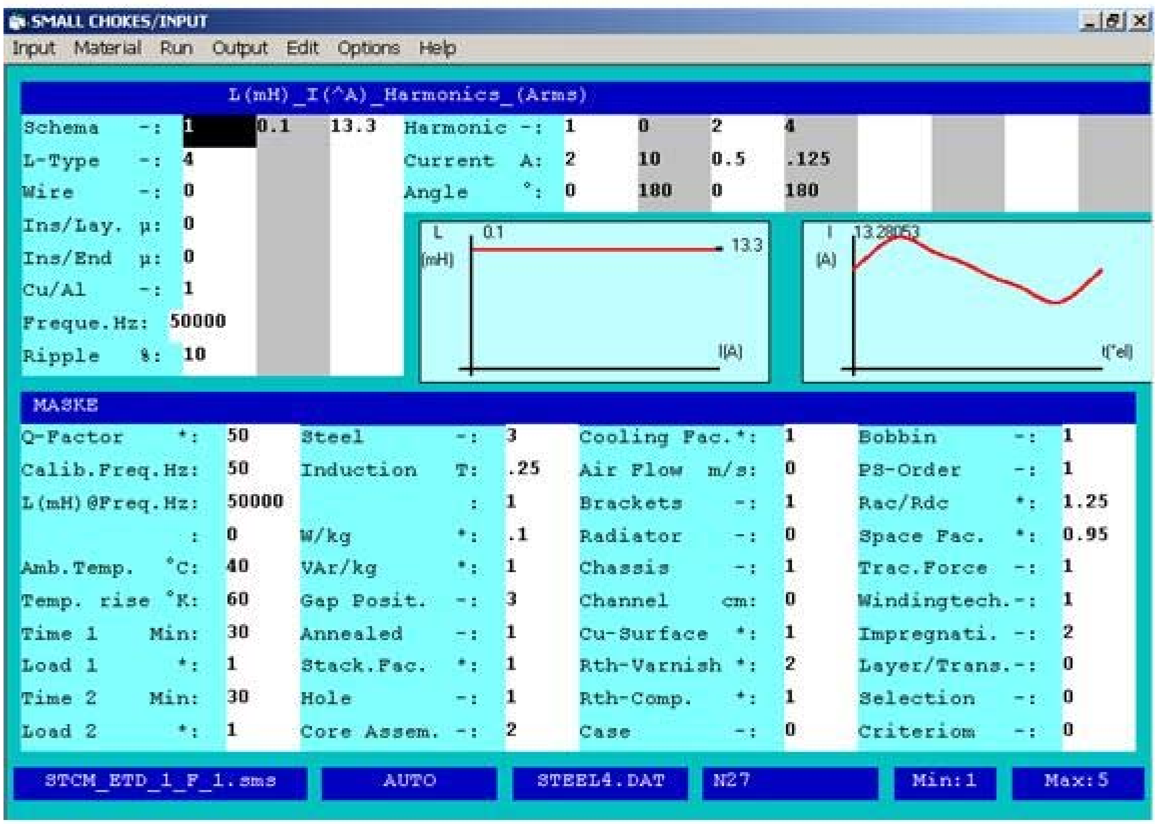
Output	• Press Ctrl+L in order see the diagram Inductance vs. Current
Test	• Round the number of turns • Change the peak value in order to increase the current range of the diagram Inductance vs. Current
Note	• In order to calibrate the choke, connect it on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

Title — **High Frequency Smoothing Choke for 1 Phase Rectifier Bridge**



Input

- Set the LI-point of the inductance, the induction at the peak current.
- Select the differential inductance : L-Type = 4
- Select Cu flat wire: Wire = 0
- Select core material: ferrite or powder
- The frequency of the first harmonic is 50000Hz
- Set the harmonics of the thermal current: the rms-values of the first harmonic and of the DC-current
- Set the temperature rise
- Select suitable core family and the gap position



Output

- Press Ctrl+L in order see the diagram Inductance vs. Current

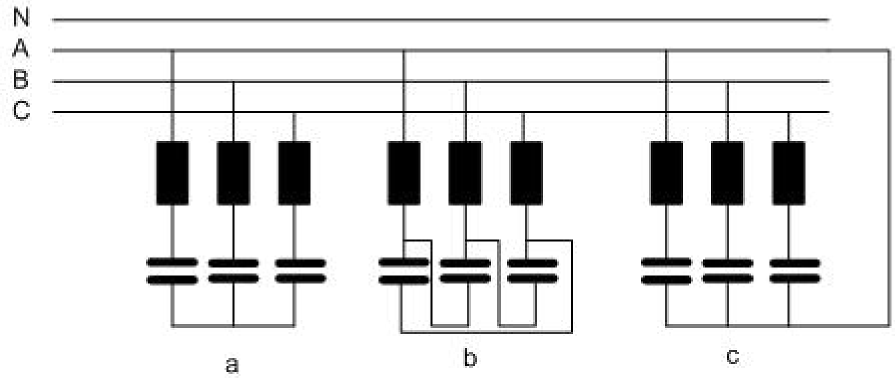
Test

- Round the number of turns
- Change the peak value in order to increase the current range of the diagram Inductance vs. Current

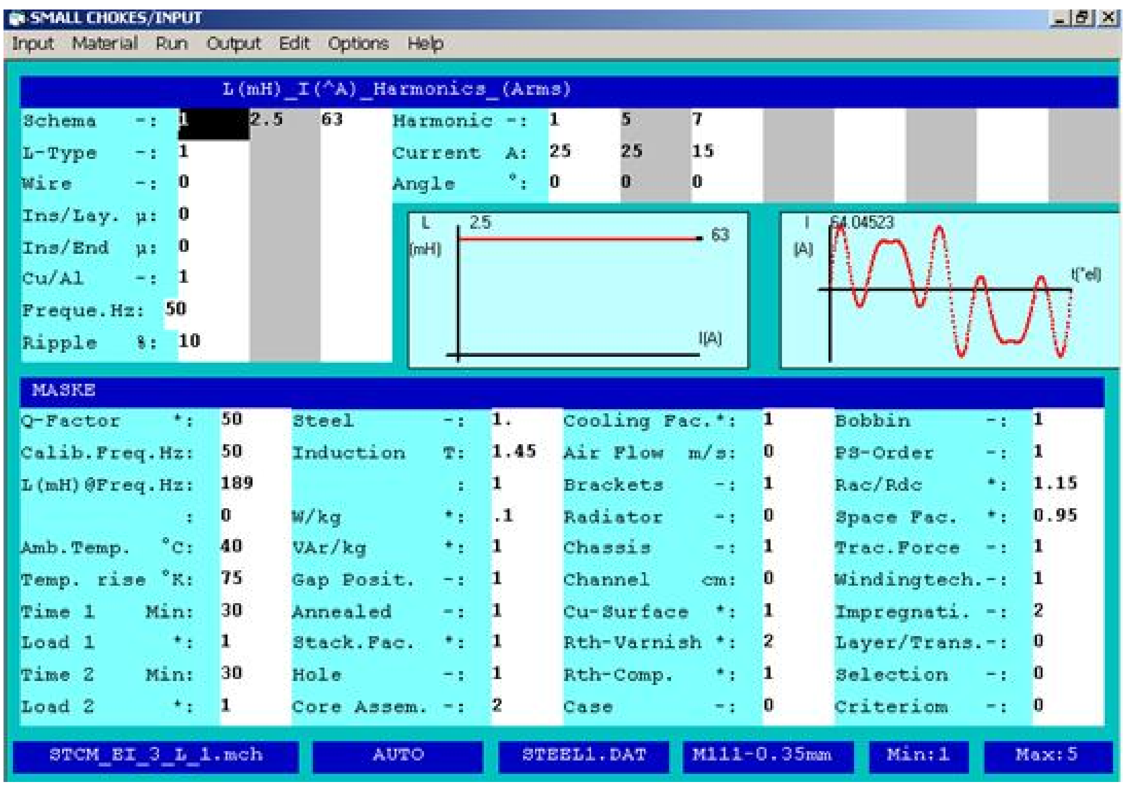
Note

- In order to calibrate the choke, connect it on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

LC-Filter Chokes

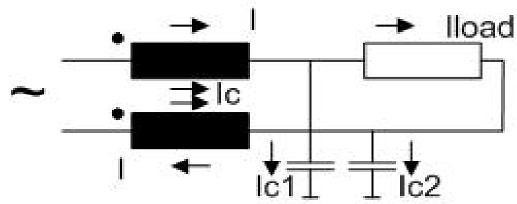
<table>
<tr><td>Title</td><td>Three-Phase LC-Resonance Filter Choke, connected in series with capacitor

</td></tr>
<tr><td>Input</td><td>

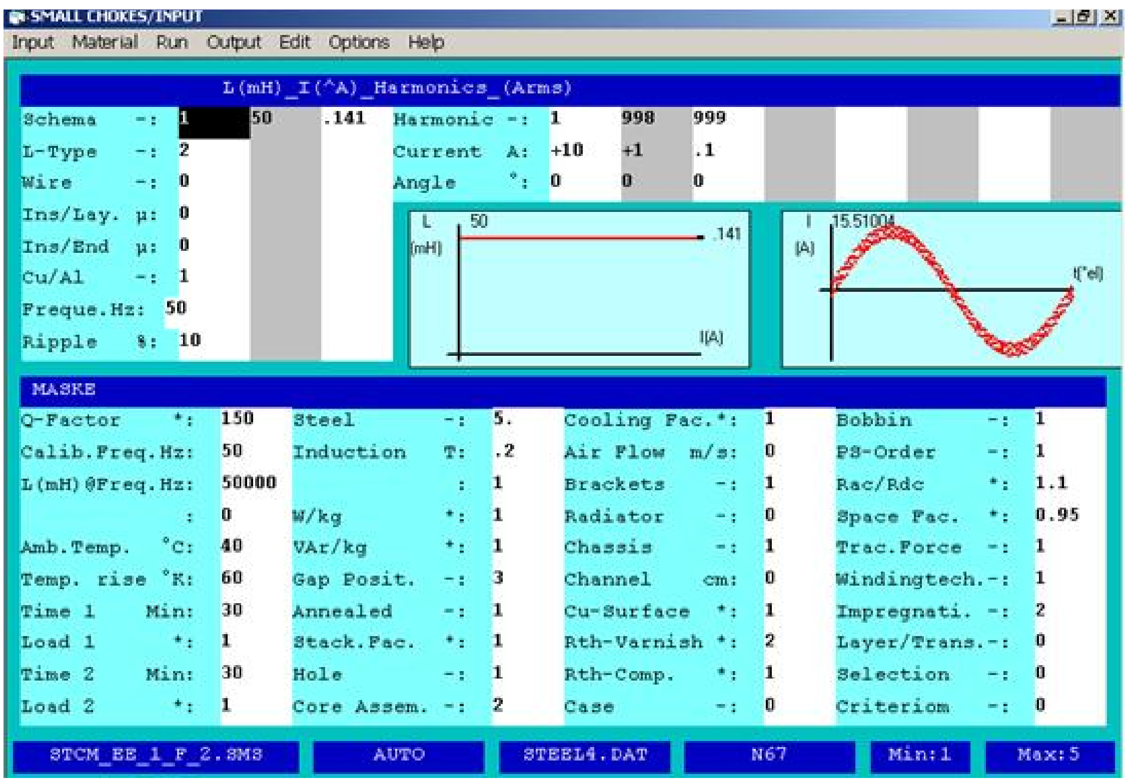
Set inductance at peak current (View the peak value on the current diagram). The resonance frequency is 189Hz for Ul/Uc=7%
Select the AC inductance : L-Type = 1
Select Cu round wire: Wire = 0
The frequency of the first harmonic is 50Hz
Set the rms values of harmonics of the thermal current. These harmonics have to be prescribed by your customer!
Set the temperature rise
Select grain oriented steel. Note that the induction will be optimized by program in order to get optimal relationship between core losses and winding losses
Set Gap = 1 and Core Assembly = 2 or better
Select suitable 3 phase core family. If there are 3. and 9. harmonics (circuit c) then you need to use 3 one phase cores.
</td></tr>
</table>



Output	• Control the value of induction, gap and connected wires in parallel
Test	• Round the number of turns
Note	• In order to calibrate the choke, connect it on the calculated calibration 3 phase AC-voltages (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration 3 phase AC-current (rms value).

Current Compensated Chokes

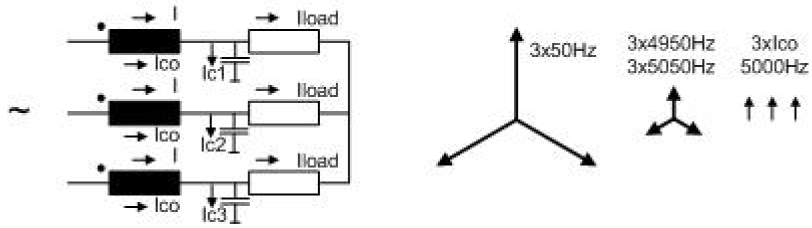
Title	**One Phase Common Mode Choke in a 50Hz net for suppressing 50kHz current harmonic** 
Input	• Set inductance of both in series connected windings at the peak value of the current Ic (Ic = (Ic1 - Ic2)/2 ~ (0.01-0.05) x Iload • Set the compensated harmonics of the thermal current .Note that the sign "+" marks the compensated current harmonics. • Set the other harmonics of the thermal current which are not compensated without the sign "+". • Select the differential inductance : L-Type = 4 • Select Cu round wire: Wire = 0 • The frequency of the first harmonic is 50Hz • Set the Q-factor in order to limit the resistive voltage drop of the compensated current, the temperature rise and the criterion = 0 • Select ferrite with a good reverse permeability. • Select suitable core family and the gap positions



Output	• Control the value of inductance • Manufacture 2 insulated, full layer windings, each with 50% of the calculated turns. Do not use double section bobbin
Test	• Check the core construction with Gap=0 • Set the current in the LI-point higher and Press Ctrl+L to see the diagram Inductance vs. Current
Note	• In order to calibrate the choke, connect both windings in series on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

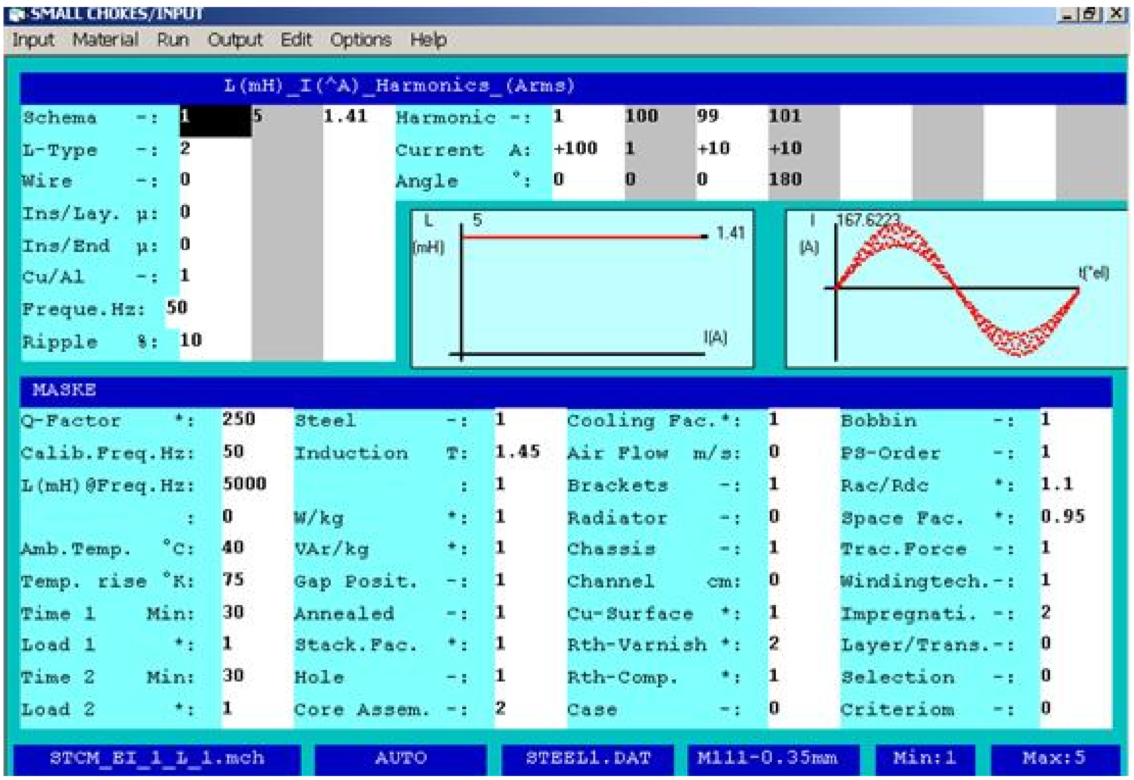
Title

Three Phase Common Mode Choke with a one phase core in a 50Hz symmetrical net for suppressing 5000Hz unsymmetrical current harmonics



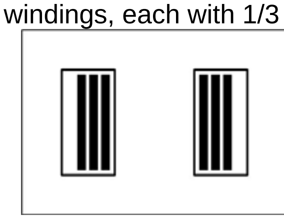
Input

- Set inductance of three in series connected windings at the peak value of the current 2 x Ico (Ico ~ (0.01-0.05) x Iload)
- Set the compensated harmonics of the thermal current .Note that the sign "+" marks the compensated current harmonics.
- Set the other harmonics of the thermal current which are not compensated without the sign "+".
- Select the differential inductance : L-Type = 4
- The frequency of the first harmonic is 50Hz
- Set the Q-factor in order to limit the resistive voltage drop of the compensated current, the temperature rise and the criterion = 0
- Select grain oriented steel.
- Select suitable one phase core family and the gap positions



Output

- Control the value of inductance
- Manufacture 3 insulated, full layer windings, each with 1/3 of the calculated turns.

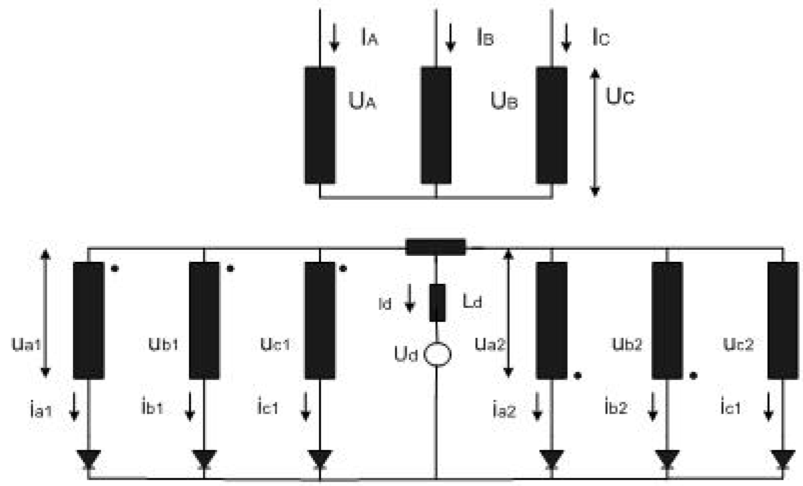


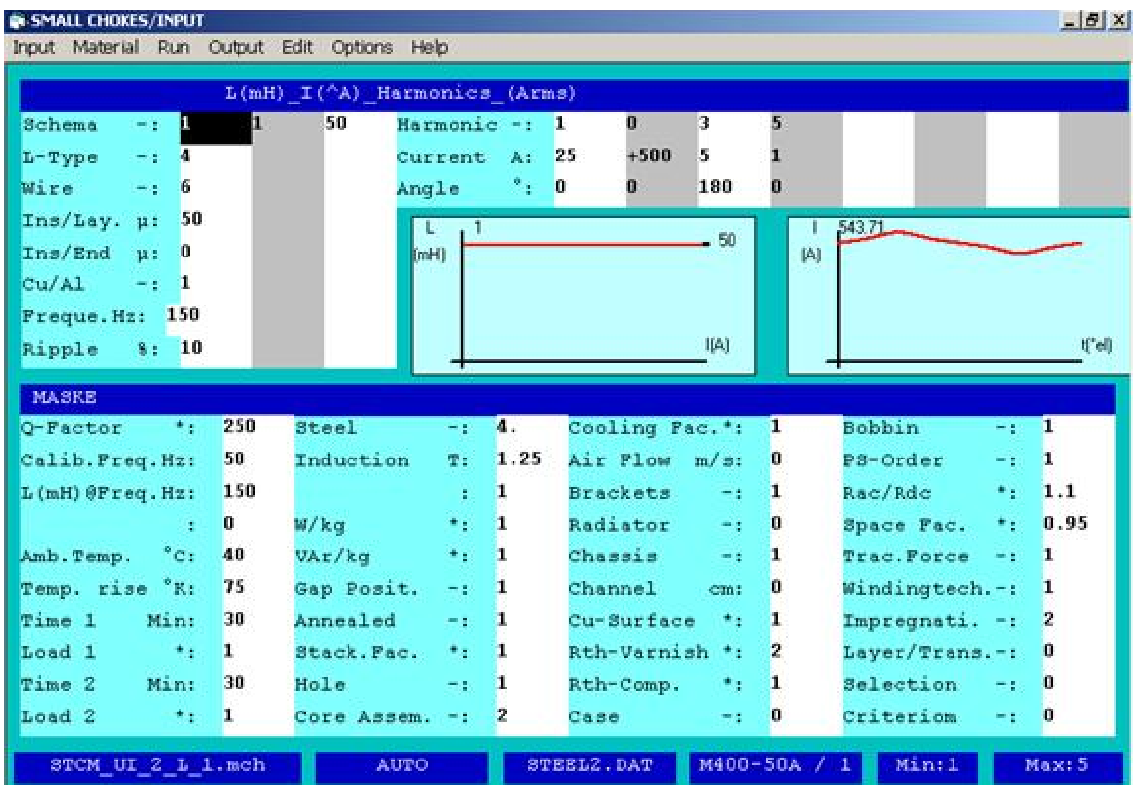
Test

- Check the core construction with Gap=0
- Set the current in the LI-point higher and Press Ctrl+L to see the diagram Inductance vs. Current

Note

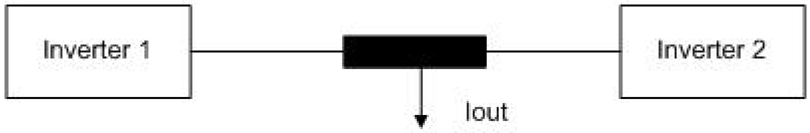
- In order to calibrate the choke, connect all windings in series on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

Title	**Drainage Choke between 2 rectifiers**
	
Input	• Set inductance of both windings in series at approx. 5-10% of the nominal current Id/2 • Select the differential inductance : L-Type = 4 • Select Cu flat wire or foil with layer insulation: Wire = 3 or 6 • The frequency of the first harmonic is 150Hz • Set the rms values of the harmonics of the thermal current: Note that the sign "+" marks the compensated current harmonics. • Set the temperature rise • Select cold rolled steel. • Set Gap = 1 and Core Assembly = 2 or better • Select suitable core family (UI)

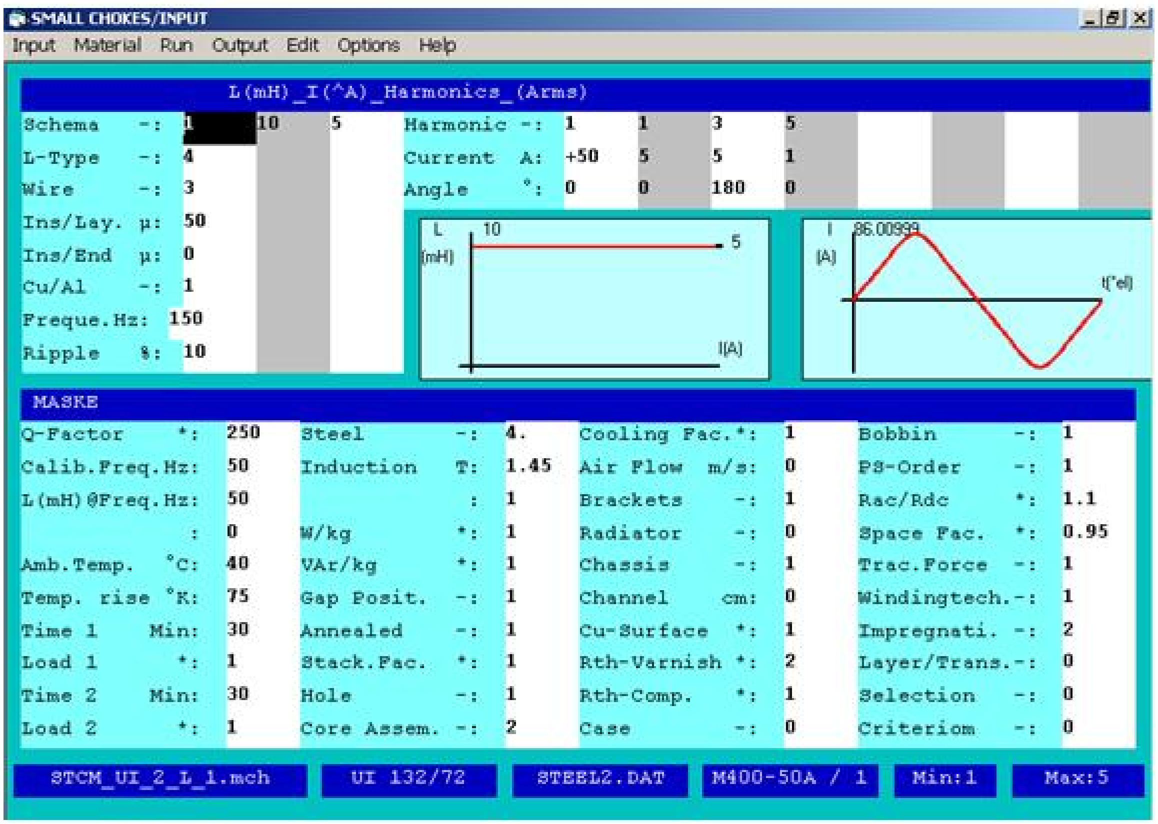


Output	• Control the value of inductance
Test	• Set the current in the LI-point higher and Press Ctrl+L to see the diagram Inductance vs. Current
Note	• In order to calibrate the choke, connect both in series windings on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

Title	**Drainage Choke between 2 phases of inverters**



Input	• Set inductance of both windings in series at approx. 5-10% of the nominal current Iout/2 • Select the differential inductance : L-Type = 4 • Select Cu flat wire or foil with layer insulation: Wire = 3 or 6 • The frequency of the first harmonic is 50Hz • Set the rms values of the harmonics of the thermal current: Note that the sign "+" marks the compensated current harmonics. • Set the temperature rise • Select cold rolled steel. • Set Gap = 1 and Core Assembly = 2 or better • Select suitable core family (UI)



Output	• Control the value of inductance
Test	• Set the current in the LI-point higher and Press Ctrl+L to see the diagram Inductance vs. Current
Note	• In order to calibrate the choke, connect both in series windings on the calculated calibration AC-voltage (rms value) with the calibration frequency (normally 50Hz or 60Hz) and then vary the gap until you get the calculated calibration AC-current (rms value).

How do we design a "current transformer" for 100A/0.1A, 10V , class1%?

Technical specification relevant only to design

Electrical data

Nominal input Current	100A, sine wave, impressed
Frequency	50Hz
Nominal output voltage	10V
Nominal output current	0.1A@100A input current
Current class	1% @ 100A, 40°C max. +-2%@200A,40°C
	+-0.8%@40°C+-40C°, 100A
Angle class	NO CRITERION OF DESIGN

Environment and operating conditions:

Ambient temperature	0°-70°C, class E
Primary turns	1, NOT wound
Core & Bobbin	Gaped 2 legs C core with double section bobbin

General rules

Note that the Small Transformers Program does not support the classic current transformer design where you can prescribe the impressed input & output current, the current & angle accuracy, power, … But if you need an impressed output voltage (not impressed output current) proportional to an impressed input current and the angle accuracy is no criterion of design then you can use the Small Transformers Program to design a "current transformers" as a magnetic shunt with galvanic isolation (Fig.2). For this operation mode you need to use a gaped core with constant permeability in the wide range of the induction. Additionally for using one-turn primary it is optimal to design this "current transformer" with a 2 legs core and double section bobbin.

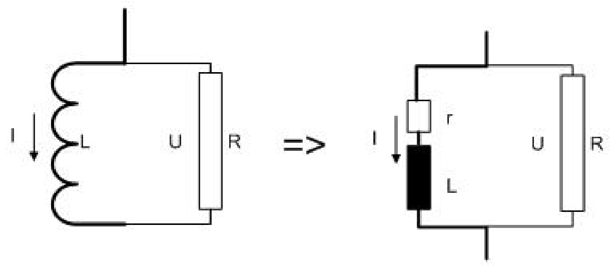


Fig. 1

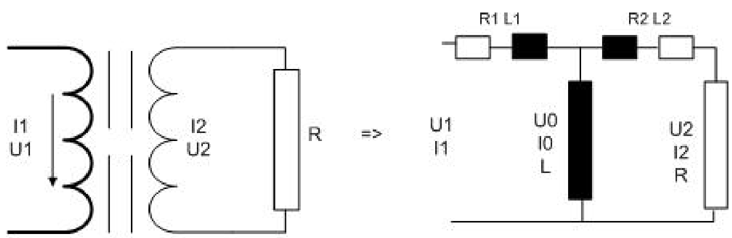


Fig. 2

Design criteria

Input voltage and Gap

Once again you can not set the nominal primary current 100A as parameter of the design. You have to set the primary voltage. It is recommended to set

U1 = U2*(1+Regulation/100) = 1.1*U2 **= 11V**

If the ampere-turns of the calculated primary winding are 100 then you can use the primary with one turn at 100A.

W1*I1 = 87 x 1.149A = 100

In order to reach this condition you need to manipulate the size of the 2 gaps in the 2 legs C-core.

Total gap size = 2*4.6mil = 9.2mil = 0.233mm

Ambient temperature and Regulation

For the impressed primary current the no-load output voltage and its linearity & accuracy depends only on the inductance L, better said, on the steel permeability.

$$U20 = (W2/W1)*I1*L$$

Using air gaps in the core you can limit sufficiently the non linear influence of the steel permeability. The output voltage can be calculated:

$$U2 = U20*R/((X2^2+(R+r2)^2)^0.5$$

For $X2<<R$:

$$U2 = U20*R/(R+r2) \text{ and } dU2/U2 = dr2/(R+r2)$$

If the nominal ambient temperature is 40°C and the winding temperature varies between 10°C and 80°C then the resistance r2 will vary max 16%. Now you can calculate the regulation:

$$\text{Regulation} = 100*(r1+r2)/R=100*2*r2/R =100*2*0.008/0.16 = 10\%$$

Due to the fact that the regulation has to be limited you have to use the regulation as the criterion of design

$$\text{Criterion} = 1$$

Core, Steel and Induction

For current accuracy around 1% acceptable results can be achieved with 2 legs C-core and M5 steel. Using 2 double sections bobbin without the primary you will get the free space in the core window to realize one-turn primary “winding” with an insulated cable.
In order to stay in the “linear” part of the magnetizing curve at 200A the nominal operating induction at 100A is set at 0.75T

Design procedure

1. Normally you do not know the gap size that you need to get the prescribed ampere-turns of the primary winding. Due to this fact you have to start with a value between 5 and 10 (5-10mil=0.125-0.25mm per gap)

2. Run the program. Note that the secondary bobbin section will be “empty”.

3. Switch to the Test Mode. Round up the primary turns

4. Increase the cross section of the secondary winding to get the build 80%-90%. The output voltage & current will increase

5. Reduce the turns of the secondary winding to get the nominal voltage & current

6. Check the primary ampere-turns and then press F2 to switch to the input screen
7. Set Criterion = 3 (the wire size and the turns will be not be changed after you run the program again)
8. Change the gap and press F4 to run the program
9. Repeat 6 and 8 until you get the primary ampere-turns 100

Test procedure

1 In order to check the current accuracy switch to the Test Mode and vary the input voltage from 10% to 200% of the nominal value.

2 In order to check the influence of the ambient temperature open the Test Mode and vary the ambient temperature from 0°c to 70°C

Output

Calibration

In the following table you can see that the current accuracy is better than 1% for the input current range 10A to 200A

Input Ampere Turns A	Output Voltage V	Error to 100A %
10.78	1.02	0.78
100	10.2	0
201.75	20.4	0.75

For optimal calibration of the “current transformer” you have to use the following procedure:

1 Connect to the secondary high precision resistance of 100 Ohm

2 Supply the one-turn primary winding with impressed current of 99.7A.

3 Change the gaps in order to get the output voltage 10V

Note that such a calibrated “current transformer” will be good enough for the current accuracy +-

0.5%

Nominal operation mode

```
#*0                         DIAGNOSE                         Page 0

 Name                         :2 X SU 48/2x25.5         M
 Steel                       -:M97-0.30mm => M5 0.012"

 Number of Sections          -:2
 max.Cu-Fill Factor          %:75.9
 max. parallel Wires          :1

 Induction on Load           T:0.756
 Max. Induction              T:0.758

 Max. Cu-Temp.rise on load  °K:2.5
 Max. Cu-Temp.rise no-load  °K:2.5
 Regulation                  %:1.6

 I^Inrush/I^nom-Factor       *:.
 Input Current No-Load       %:99.7
```

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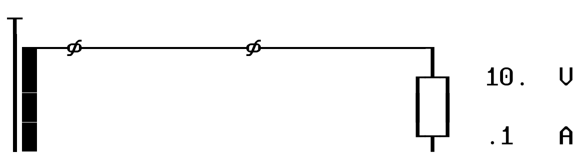
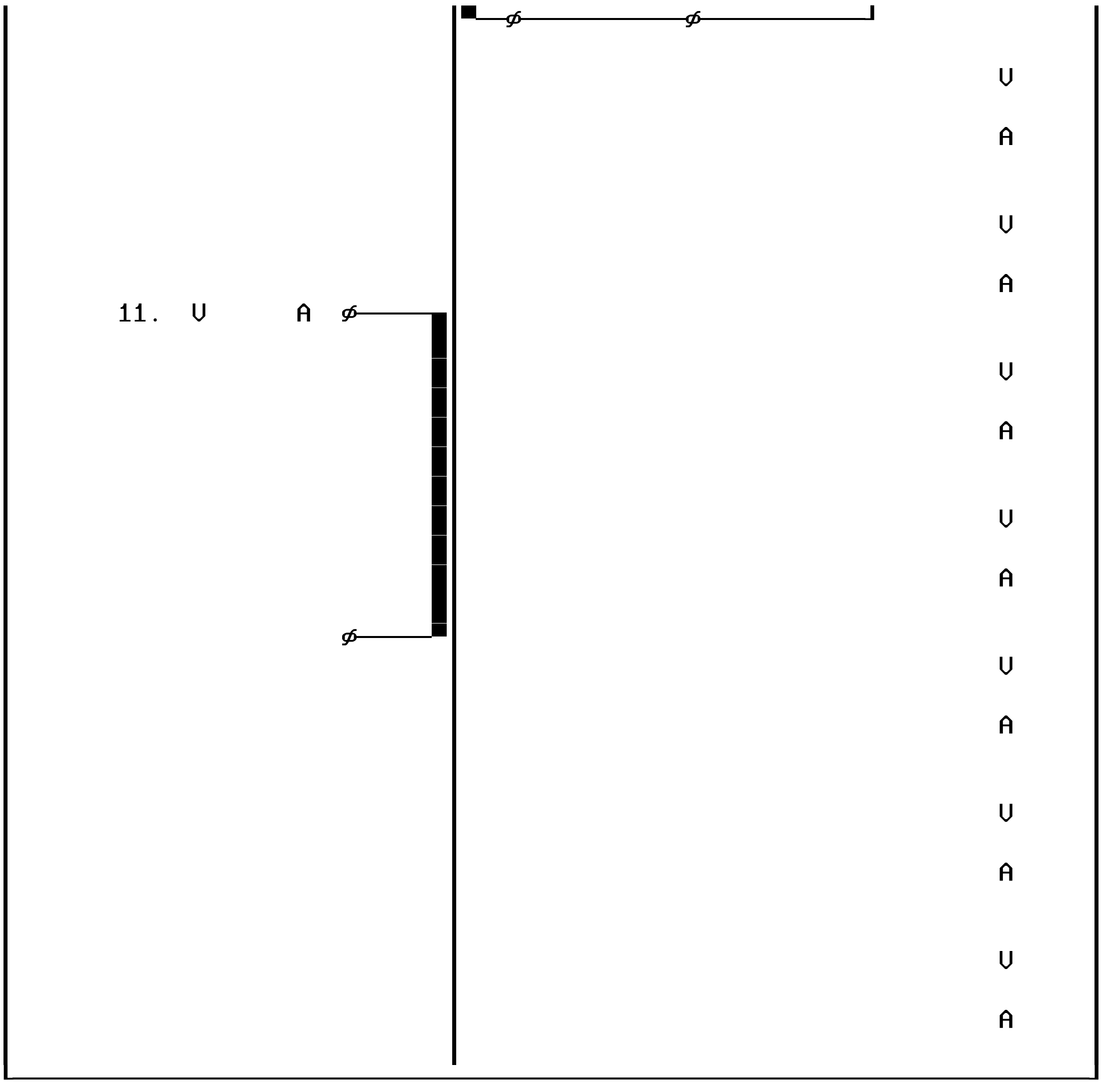
```
07-03-2009/11:25:49/14.59   Input and Circuit                Page 1

PRIMARY       U(V) I(A) SECOND.  1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:1    11.       Circuit-:11
Overvlt*:1.00 .         Volta. V:10.
Wire    :0.0  .         Curre. A:.1
I/L.   µ:0.   .         Wire    :0
I/E.   µ:300. .         I/L    µ:0.0
Formfac.:1.11 .         I/E    µ:0.0
Fre.Hz:50     .
dI/Io  %:100  .           1     1    1    1    1    1

Regulat.  %:10.0 Steel      -:2    Cooling    *:1.00 Bobbin     -:2
Udiode    V:0.8  Induction T:0.76  Force    m/s:0.00 P/S-Order  -:1
dUdiode   V:.1   Remanence *:0.35  Bracket    -:1    Rac/Rdc    *:1.25
Ripple    %:5.   W/kg      *:1.00  Radiator   -:0    Space      *:0.90
Tmp. Amb.°C:40   VAr/kg    *:1.00  Chassis    -:1.00 Vertical   -:1
Tmp.rise °K:75   Gap       *:4.60  Channel  cm: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. *:1.50  Selection  -:2
Load 2    *:1.0  Assembly  -:1     Case       -:0    Criterion  -:3

CIRCUIT:
```





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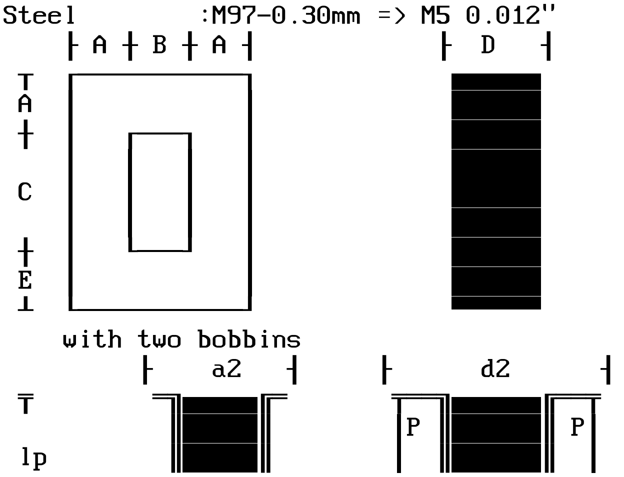
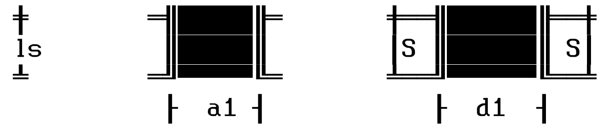
07-03-2009/11:25:49 CORE / BOBBIN / STEEL / CASE Page 2

Name :2XSU 48/2x25.5 M
Steel :M97-0.30mm => M5 0.012"

/.3



Weight	gr	:1041.5
Gap total	cm	:0.000
A-Limb	cm	:1.60
B-Width	cm	:1.60
C-Height	cm	:5.06
D-Stack	cm	:5.09
E-Yoke 1	cm	:1.60
F-Yoke 2	cm	:0.00
G-Hole	cm	:0.00
Radiator Fin		:0
Radiator Chan.		:0
a1	cm	:1.87
a2	cm	:3.09
d1	cm	5.34
d2	cm	7.10



l cm:
lp cm:2.21
ls cm:2.21
Margin cm:0.26

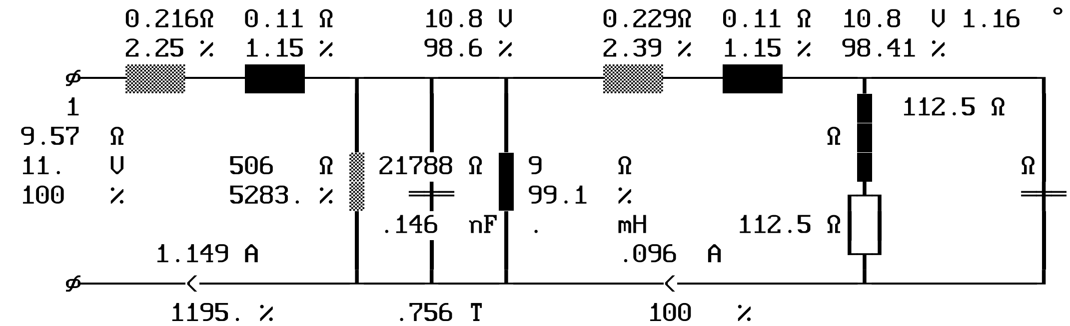
X- Length 1 cm:
Y- Width 1 cm:
Z- Height 1 cm:
x- Length 2 cm:
y- Width 2 cm:
z- Height 2 cm:
w- Thickness cm:
Material :
Potted :

	Typ	Windun	MTI	DN	DN	Par	D/ø mm	B/ø mm	W/L	L	I/L µ	I/E µ	Weight gr	RWH %
1 2 3 4 5 6 7 8	1	87.	C00	86.0	86.0	1	1.25	1.25	15	2.8	.	300	147.46	71.
1 2 3 4 5 6 7 8	11	82.0	C00	86.0	86.0	1	1.25	1.25	15	2.6	.	.	138.98	71.
TOTAL													286.4	75.

***

07-03-2009/11:25:49 General Data Seite 3

NOMINAL OPERATION at Temperature °C 42.4 and Overvoltage 1.00
Output Power on Load W:1.04 Output Power of Transfor. W:1.04
Cu Losses W:.29 Fe-Losses active W:.23
Short-Circuit-Volt. cold %:4.79 Regulation %:1.62
Instantaneous pow. .5/95& W:14.3 Efficiency of Transformer %:66.7
dT Fe average Surface °K:2.4 dT primary °K:2.5
dT Gehäuse av. Surface °K:. dT secondary °K:2.3



DUTY CYCLE OPERATION	at Amb.Temperature °C 40.	and Overvoltage 1.00	
dT Fe average Surface	°K:2.4	dT primary	°K:2.5
dT Gehäuse av. Surface	°K:.	dT secondary	°K:2.3

NO LOAD OPERATION	at Amb.Temperature °C 40.	and Overvoltage 1.00	
Losses active	W:.52	Losses reactive	VAr:12.59
Current factor	%:99.67	Induction	T:.758
dT Fe average Surface	°K:2.4	dT primary	°K:2.5
dT Gehäuse av. Surface	°K:.	Rezonance frequency	kHz:75.8

SHORT-CIRCUIT OPERATION	at Amb.Temperature °C 40.	and Overvoltage 1.00	
Losses active	W:230.5	Losses reactive	VAr:128.0
Current factor cold	%:2086.	Induction	T:.392
dT Fe average Surface	°K:210.5	dT primary	°K:247.8
dT Case aver. Surface	°K:.	dT secondary	°K:249.2

PRIMARY (Tap:1) 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Voltage Input/Output V:11.
Out. Voltage no load V:
Current Input/Output A:1.149
Load on output Ω:
Power factor of load :
Current in segment A:1.149
Current dencity A/mm^2:0.94
Icc-Current cold A:23.98
Io -Current A:1.145
Inrush Current peak ^A:0.
Inrush Current rms A:0.
Cu-Losses W:.3
Resistance cold Ω:.197
Reactance Ω:.1098
Eddy-Current Factor :1.

SECONDARY 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage V:10.2
Output Current A:0.102
Out. Voltage no load V:10.24
Sec. Voltage V:10.2
Sec. Current A:0.102
Current dencity A/mm^2:0.08
Sec. Voltage cold V:10.2
Load on output Ω:100.
Power factor of load :1.000
Icc cold A:25.13
Cu-Losses warm W:.002
Resistance cold Ω:.1857

```
Reactance            Ω:.0976
Eddy-Current Factor   :1.
Capacitor           mF:.
```

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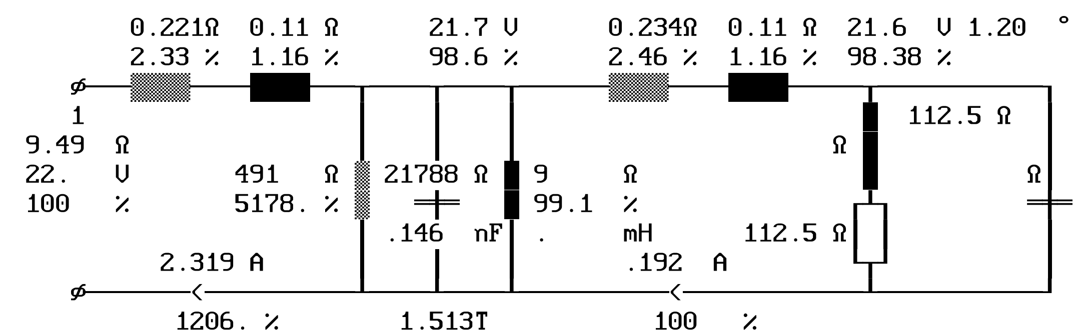
200% operation mode

```
07-03-2009/11:28:47          General Data                        Seite 3

NOMINAL OPERATION   at Temperature °C 48.7   and   Overvoltage 2.00
Output Power on Load       W:4.16      Output Power of Transfor. W:4.16
Cu Losses                  W:1.2       Fe-Losses active          W:.96
Short-Circuit-Volt. cold  %:4.84      Regulation                %:1.64
Instantaneous pow. .5/95& W:56.7      Efficiency of Transformer %:65.89
dT Fe average  Surface   °K:8.7       dT primary               °K:9.1
dT Gehäuse av. Surface   °K:.         dT secondary             °K:8.3
```




```
DUTY CYCLE OPERATION  at Amb.Temperature °C 40.  and Overvoltage 2.00
dT Fe average  Surface   °K:8.7       dT primary               °K:9.1
dT Gehäuse av. Surface   °K:.         dT secondary             °K:8.3

NO LOAD OPERATION    at Amb.Temperature °C 40.  and Overvoltage 2.00
Losses    active           W:2.14      Losses    reactive      VAr:50.81
Current factor            %:99.69     Induction                 T:1.515
dT Fe average  Surface   °K:8.7       dT primary               °K:9.1
dT Gehäuse av. Surface   °K:.         Rezonance frequency     kHz:76.1

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40.  and Overvoltage 2.00
Losses    active           W:922.2     Losses    reactive      VAr:512.1
Current factor cold       %:2067.     Induction                 T:.784
dT Fe average  Surface   °K:552.6     dT primary               °K:644.1
dT Case aver.  Surface   °K:.         dT secondary             °K:647.2

PRIMARY (Tap:1   )     1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Voltage Input/Output V:22.
Out. Voltage no load V:
Current Input/Output A:2.319
Load on output       Ω:
Power factor of load  :
Current in segment   A:2.319
```

```
Current dencity A/mm^2:1.9
Icc-Current   cold   A:47.95
Io -Current          A:2.312
Inrush Current peak ^A:101.8
Inrush Current rms   A:43.
Cu-Losses            W:1.2
Resistance    cold   Ω:.197
Reactance            Ω:.1098
Eddy-Current Factor   :1.
```

```
SECONDARY              1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage       V:20.4
Output Current       A:0.204
Out. Voltage no load V:20.48
Sec. Voltage         V:20.4
Sec. Current         A:0.204
Current dencity A/mm^2:0.17
Sec. Voltage cold    V:20.4
Load on output       Ω:100.
Power factor of load  :1.000
Icc            cold  A:50.26
Cu-Losses      warm  W:.009
Resistance     cold  Ω:.1857
Reactance            Ω:.0976
Eddy-Current Factor   :1.
Capacitor           mF:.
```

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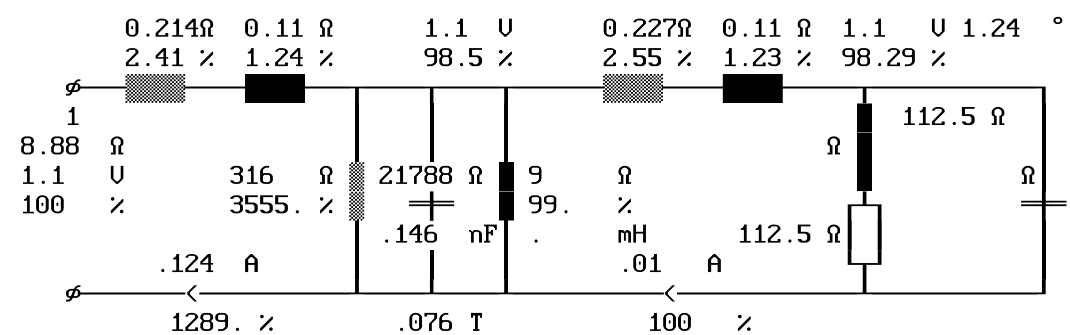
10% operation mode

```
07-03-2009/11:36:34         General Data                    Seite 3
```

```
NOMINAL OPERATION   at Temperature °C 40.    and   Overvoltage 0.10
Output Power on Load      W:.01      Output Power of Transfor. W:.01
Cu Losses                 W:.        Fe-Losses active          W:.
Short-Circuit-Volt. cold  %:5.16     Regulation                %:1.74
Instantaneous pow. .5/95& W:.1       Efficiency of Transformer %:59.68
dT Fe average  Surface   °K:.        dT primary               °K:.
dT Gehäuse av. Surface   °K:.        dT secondary             °K:.
```




```
DUTY CYCLE OPERATION  at Amb.Temperature °C 40.  and Overvoltage 0.10
dT Fe average  Surface   °K:.        dT primary               °K:.
dT Gehäuse av. Surface   °K:.        dT secondary             °K:.
```

```
NO LOAD OPERATION     at Amb.Temperature °C 40.  and Overvoltage 0.10
Losses    active           W:.01      Losses    reactive      VAr:.14
Current factor             %:99.64    Induction                 T:.076
dT Fe average  Surface    °K:.        dT primary               °K:.
dT Gehäuse av. Surface    °K:.        Rezonance frequency     kHz:78.7

SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40.  and Overvoltage 0.10
Losses    active           W:2.31     Losses    reactive      VAr:1.29
Current factor cold        %:1938.    Induction                 T:.039
dT Fe average  Surface    °K:8.4      dT primary               °K:9.1
dT Case aver.  Surface    °K:.        dT secondary             °K:9.1

PRIMARY (Tap:1   )      1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Voltage Input/Output V:1.1
Out. Voltage no load V:
Current Input/Output A:0.124
Load on output       Ω:
Power factor of load  :
Current in segment   A:0.124
Current dencity A/mm^2:0.1
Icc-Current   cold   A:2.4
Io -Current          A:0.123
Inrush Current peak ^A:0.
Inrush Current rms   A:0.
Cu-Losses            W:.
Resistance    cold   Ω:.197
Reactance            Ω:.1098
Eddy-Current Factor   :1.

SECONDARY               1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Output Voltage       V:1.02
Output Current       A:0.01
Out. Voltage no load V:1.02
Sec. Voltage         V:1.02
Sec. Current         A:0.01
Current dencity A/mm^2:0.01
Sec. Voltage cold    V:1.
Load on output       Ω:100.
Power factor of load  :1.000
Icc           cold   A:2.51
Cu-Losses     warm   W:.
Resistance    cold   Ω:.1857
Reactance            Ω:.0976
Eddy-Current Factor   :1.
Capacitor           mF:.
```

***