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

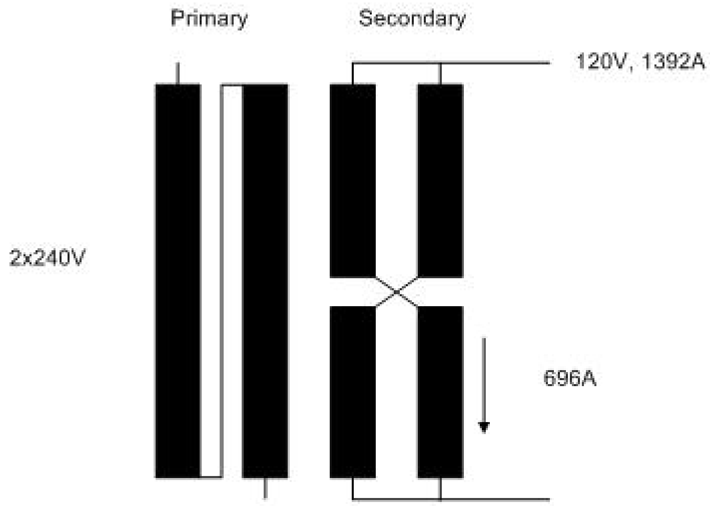
There are 4 input screens to set the input parameters for the designing of a transformer:

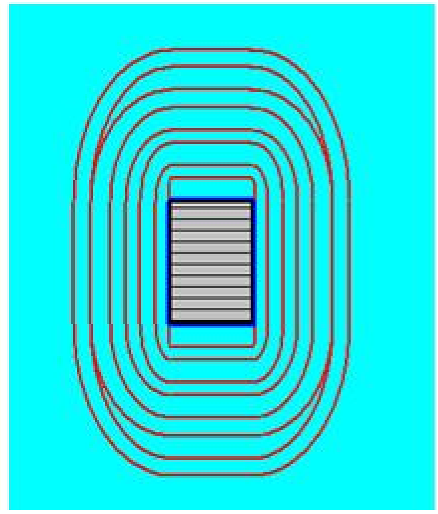
- Winding parameters per limb
- Core
- Environment
- Other parameters

and 3 screens for selection and set up of material :

- wires
- steels
- cores.

Windings parameters per limb





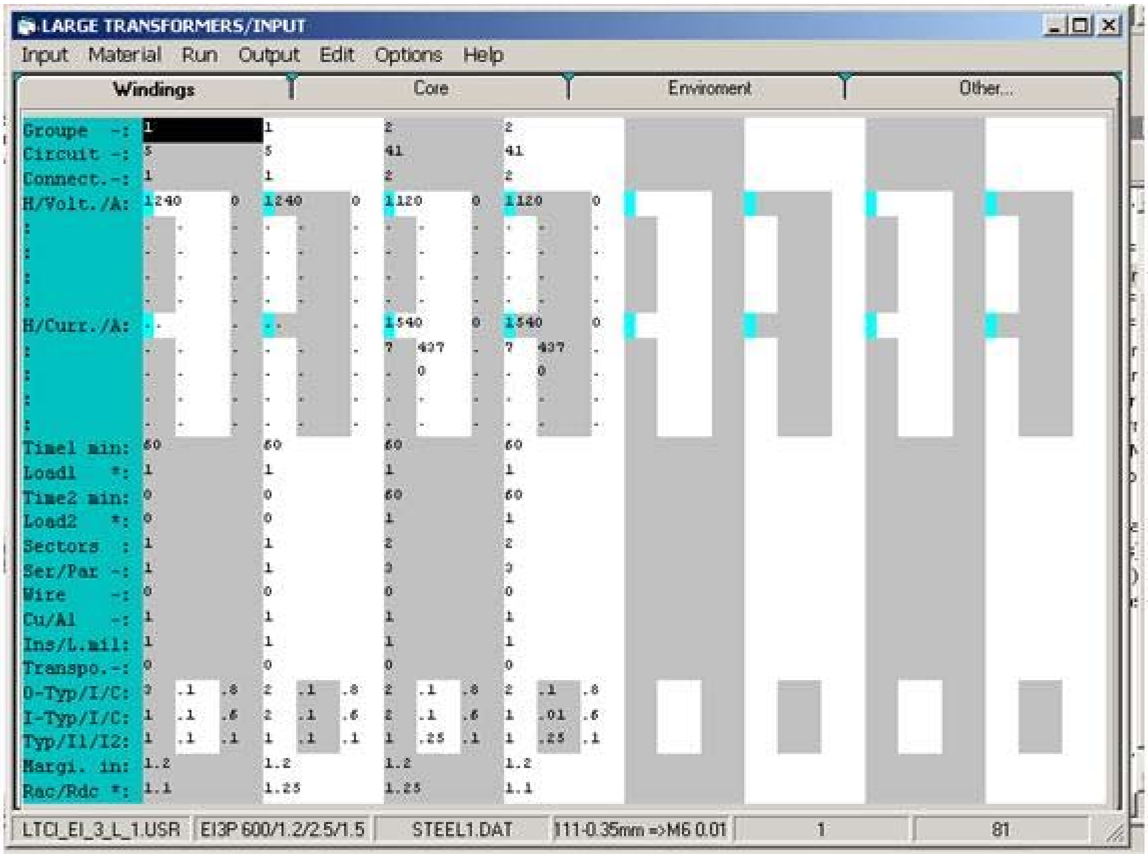
Primary

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

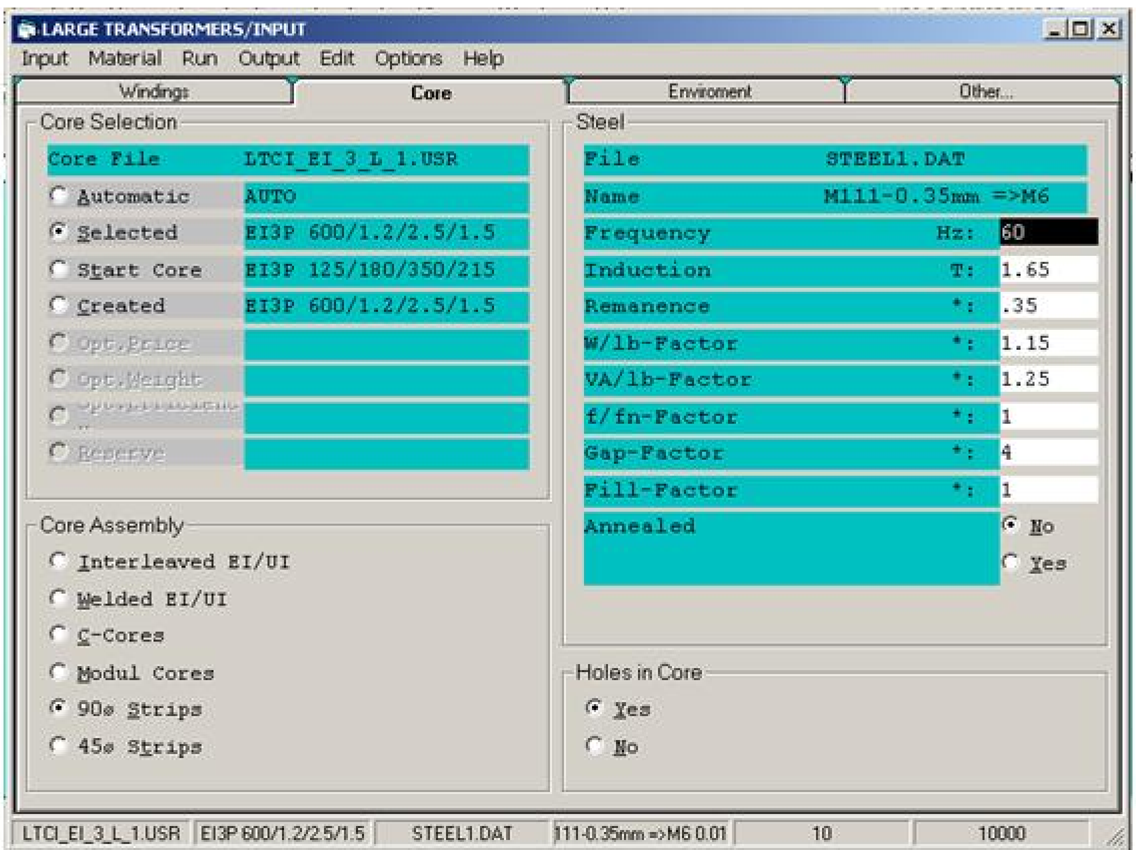
For Irms = 696Arms and K-factor = 20 the calculated current harmonics I1 and I7 are:
I1= 540Arms
I7 = 437Arms
Also there is no duty cycle operation mode on the secondary side.
In order to avoid the circulating current between 2 parallel connected secondary windings each of them is created with 2 cross 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

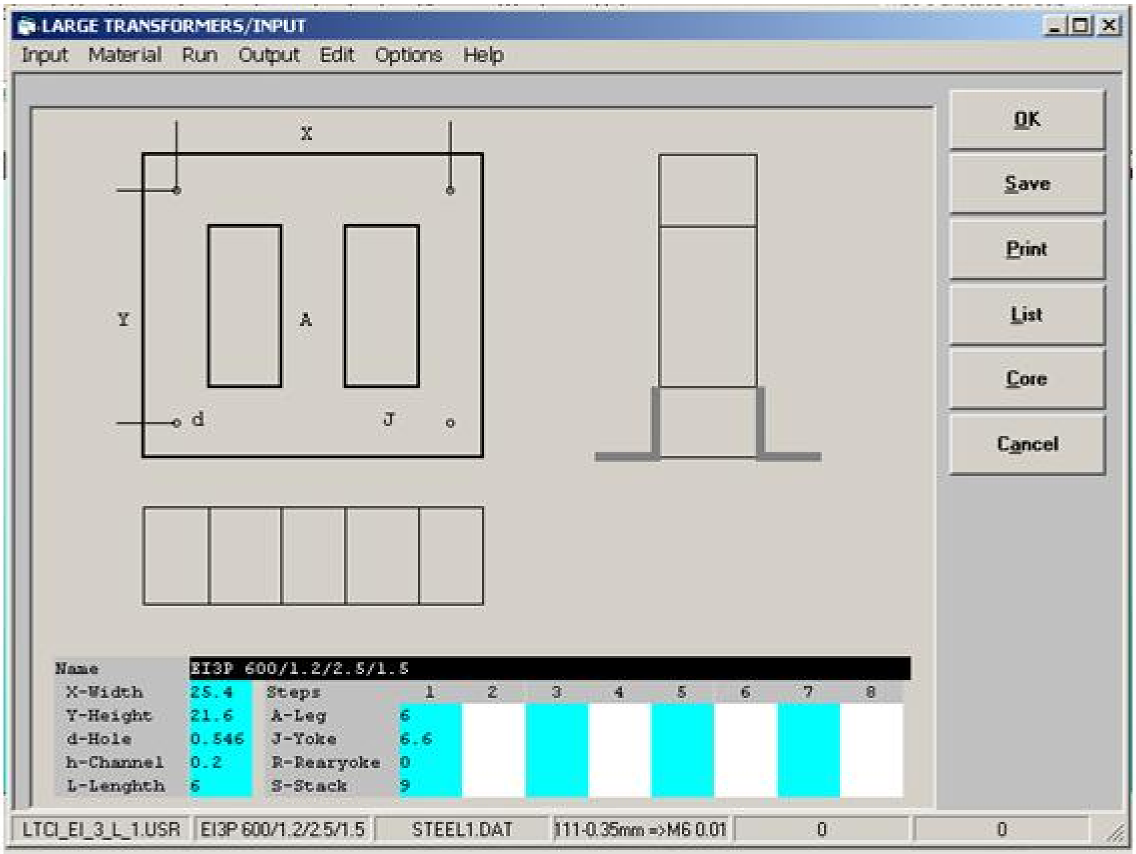
On this input screen you can :

- 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.

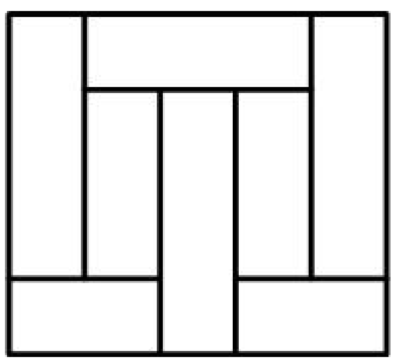


The core was created by program and by the designer in order to satisfy the following conditions:

- Ucc=5%
- Optimal price and weight

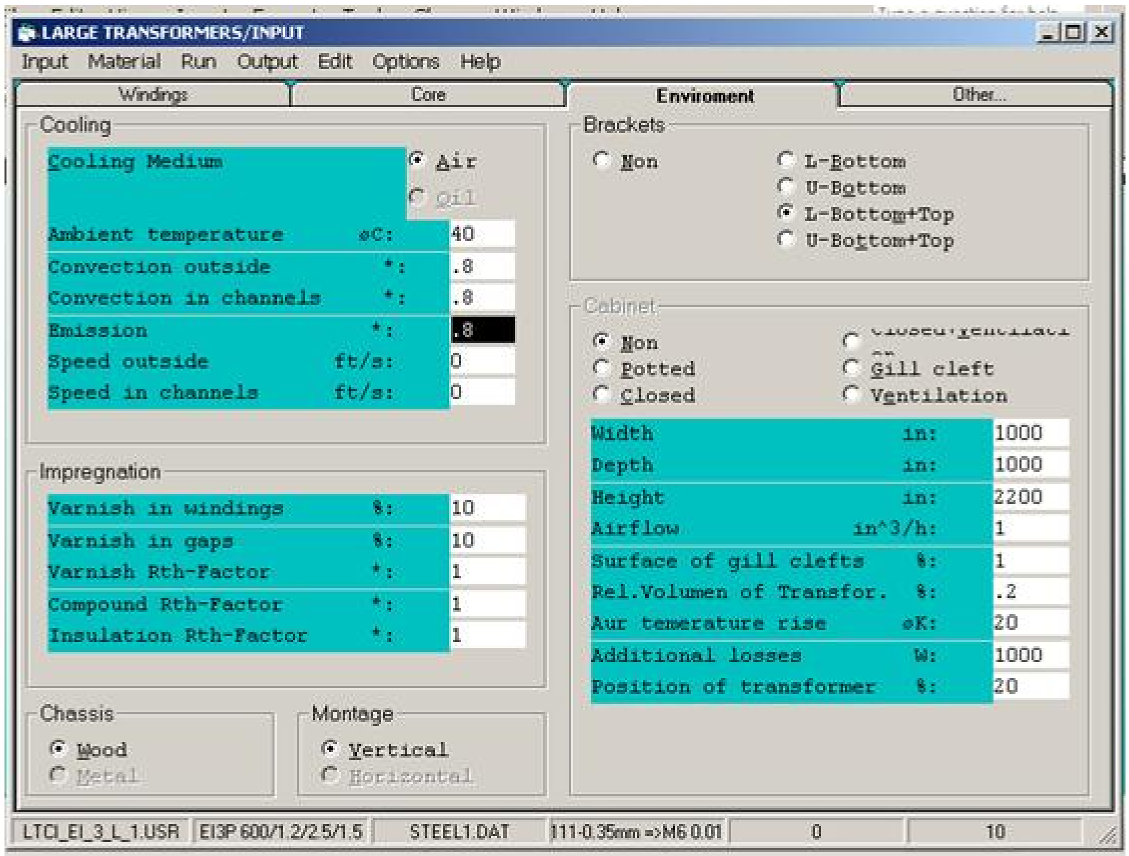


Normally for this application you use M6, 14mil, non annealed after stamping, grain oriented strips.

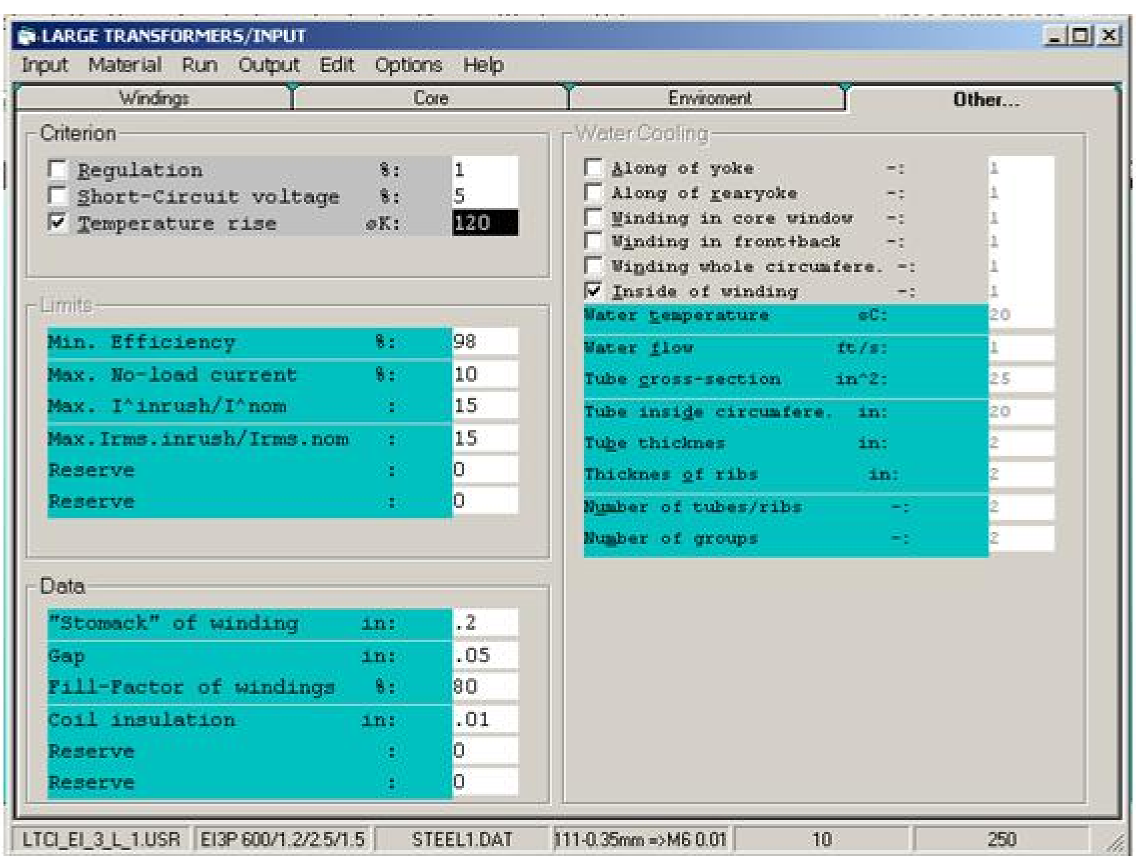


Environment

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


LARGE TRANSFORMERS/INPUT
Input Material Run Output Edit Options Help
Windings
Core
Enviroment
Other...
Cooling
Cooling Medium
Air
Oil
Ambient temperature øC: 40
Convection outside *: .8
Convection in channels *: .8
Emission *: .8
Speed outside ft/s: 0
Speed in channels ft/s: 0
Impregnation
Varnish in windings %: 10
Varnish in gaps %: 10
Varnish Rth-Factor *: 1
Compound Rth-Factor *: 1
Insulation Rth-Factor *: 1
Chassis
Wood
Metal
Montage
Vertical
Horizontal
Brackets
Non
L-Bottom
U-Bottom
L-Bottom+Top
U-Bottom+Top
Cabinet
Non
Potted
Closed
Gill cleft
Ventilation
Width in: 1000
Depth in: 1000
Height in: 2200
Airflow in^3/h: 1
Surface of gill clefts %: 1
Rel.Volumen of Transfor. %: .2
Aur temerature rise øK: 20
Additional losses W: 1000
Position of transformer %: 20
LTCI_EI_3_L_1.USR
EI3P 600/1.2/2.5/1.5
STEEL1.DAT
111-0.35mm =>M6 0.01
0
10

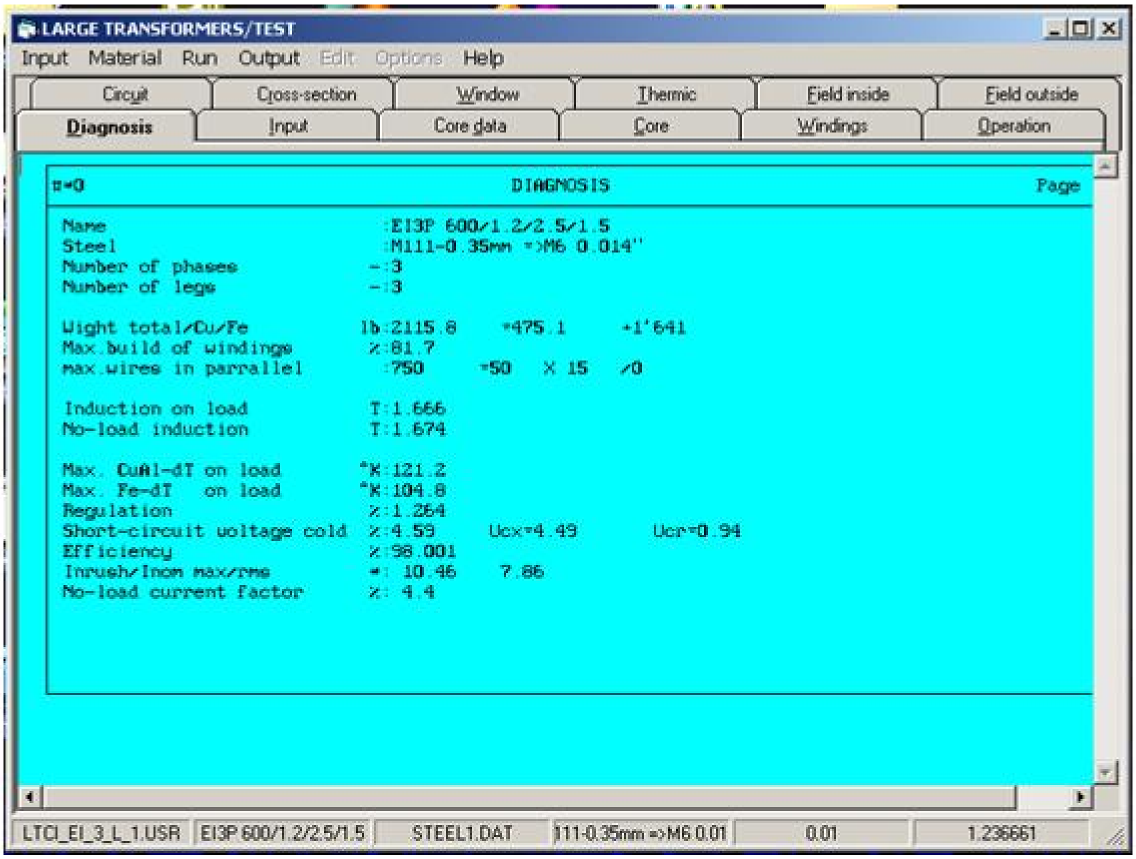
Other...


LARGE TRANSFORMERS/INPUT
Input Material Run Output Edit Options Help
Windings
Core
Enviroment
Other...
Criterion
Regulation %: 1
Short-Circuit voltage %: 5
Temperature rise øK: 120
Limits
Min. Efficiency %: 98
Max. No-load current %: 10
Max. I^inrush/I^nom : 15
Max.Irms.inrush/Irms.nom : 15
Reserve : 0
Reserve : 0
Data
"Stomack" of winding in: .2
Gap in: .05
Fill-Factor of windings %: 80
Coil insulation in: .01
Reserve : 0
Reserve : 0
Water Cooling
Along of yoke -: 1
Along of rearyoke -: 1
Winding in core window -: 1
Winding in front+back -: 1
Winding whole circumfere. -: 1
Inside of winding -: 1
Water temperature øC: 20
Water flow ft/s: 1
Tube cross-section in^2: 25
Tube inside circumfere. in: 20
Tube thicknes in: 2
Thicknes of ribs in: 2
Number of tubes/ribs -: 2
Number of groups -: 2
LTCI_EI_3_L_1.USR
EI3P 600/1.2/2.5/1.5
STEEL1.DAT
111-0.35mm =>M6 0.01
10
250

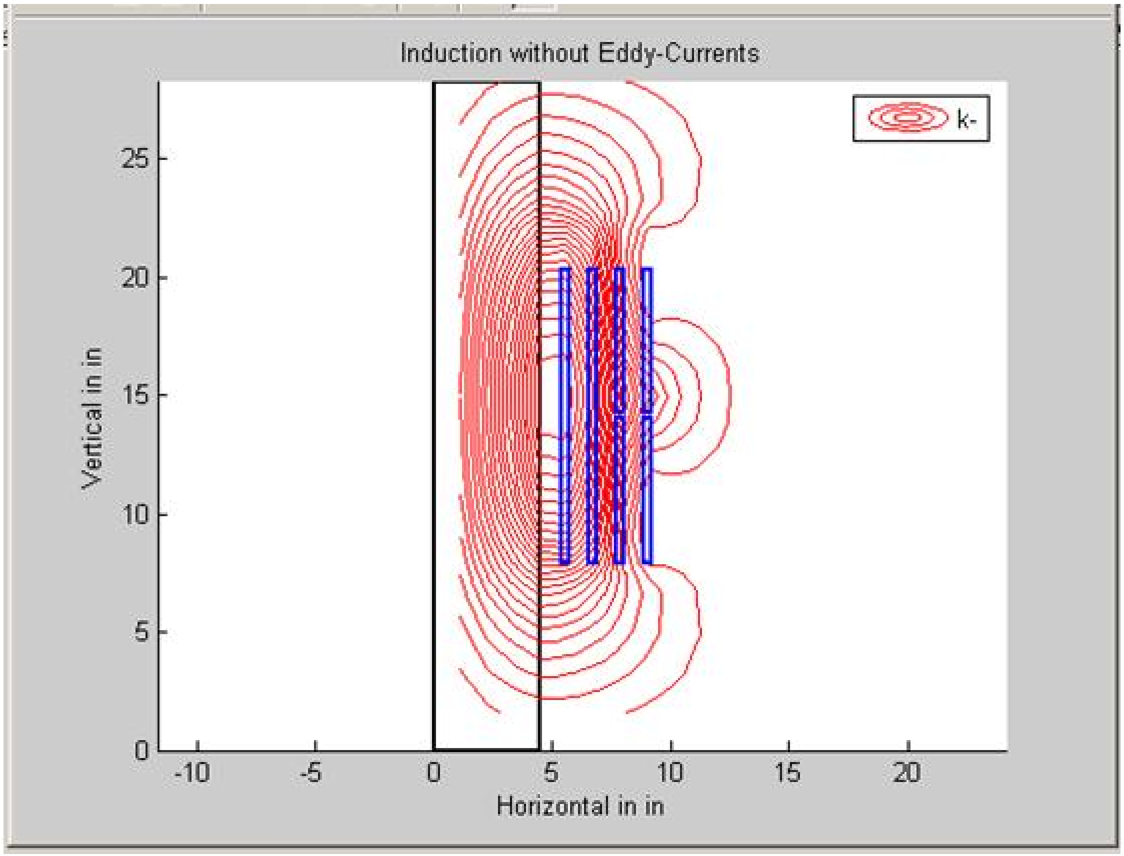
The selected criterion of the design is the temperature rise of 120°K for insulation class H. The oval space between the first winding and the tube (stomach), all gaps between the insulation, the windings and the varnish fill factor of the windings play very important roll from the thermal point of view.

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

	1	2	3	4	5	6	7	8
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

Criterion : dT
Regulation %: 1
Ucc-voltage %: 5
Temperat. rise °K: 120
Efficiency %: 98
No-load factor %: 10
I^in/I^nom : 15
Iinrms/Inomrms : 15

Core select. -: Selecte
Core file : LTCI_EI_3_L_
Core name : EI3P 600/1.2
Core assembly-: 90° &Strips
With hole -: No

Steel file : STEEL1.DAT
Steel name : M111-0.35mm
Induction T: 1.65
W/lb *: 1.15
VAr/lb *: 1.25
Airgap *: 4
f/fn-Factor *: 1
Fill factor : 1
Annealed -: No

Cooling medium : Air
Amb. temperature °C: 40
Convection outside *: 0.8
Convection inside *: 0.8
Emission *: 0.8
Airflowoutside ft/s: 0
Airflow inside ft/s: 0
Chassis -: Wood
Vertical -: Vertica
Horizontal -: L-TAB
:
Channel fill factor %: 80
Varnish in windings %: 10
Varnish in gaps %: 10
Rth-varnish *: 1
Rth-compound *: 1
Rth-insualtion *: 1
Coil insulation in: 0.01
Bauch in: 0.2
Gap in: 0.05

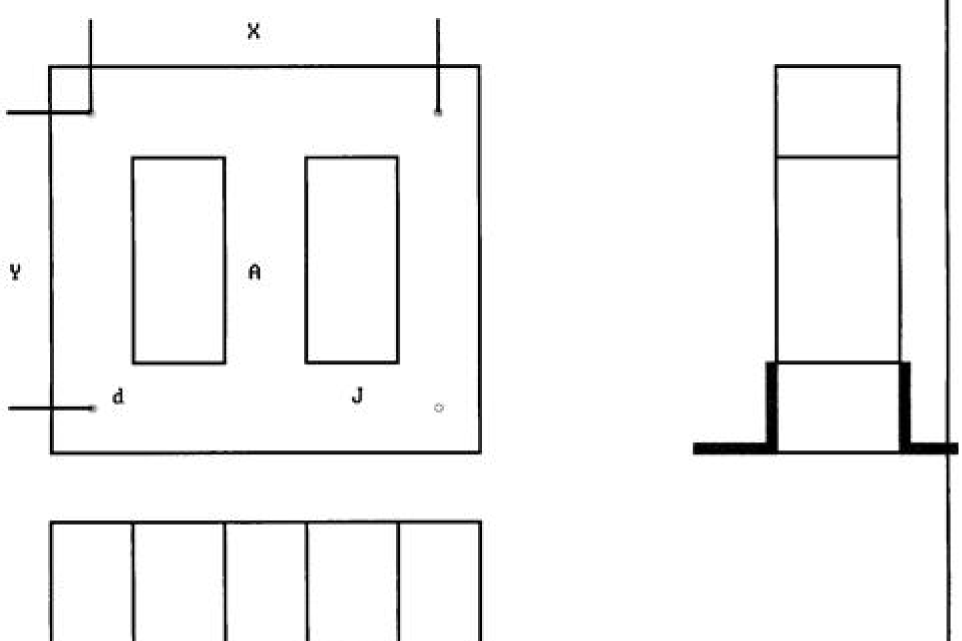
Core

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

Core file name	: LTCI_EI_3_L_1.USR		Fe-File name	: STEEL1.DAT
Core name	: EI3P 600/1.2/2.5/1.5		Fe-Name	: M111-0.35mm =>M6 0.014
Core type	: 3EI		Frequency	Hz: 60
Type of windings	: oval/rectangular		Remanence-Factor	*: 0.35
Number of legs	: 3		W/lb-Factor	*: 1.15
Core assembly	: 90° &Strips		VAr/lb-Factor	*: 1.25
Leg/Diameter	in: 6		Gap-Factor	*: 4
Window width	in: 6.7		f/fn-Factor	*: 1
Window height	in: 15		Fillfactor	*: 1
Stack	in: 9		Annealed	-: No
Cross section	in^2: 52.10			
Weight total	lb: 1640.			
With holes	-: Yes		Chassis	-:
Brackets	-: L-T&B		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:								

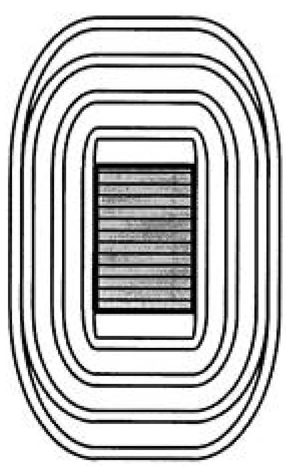


Windings

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								
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

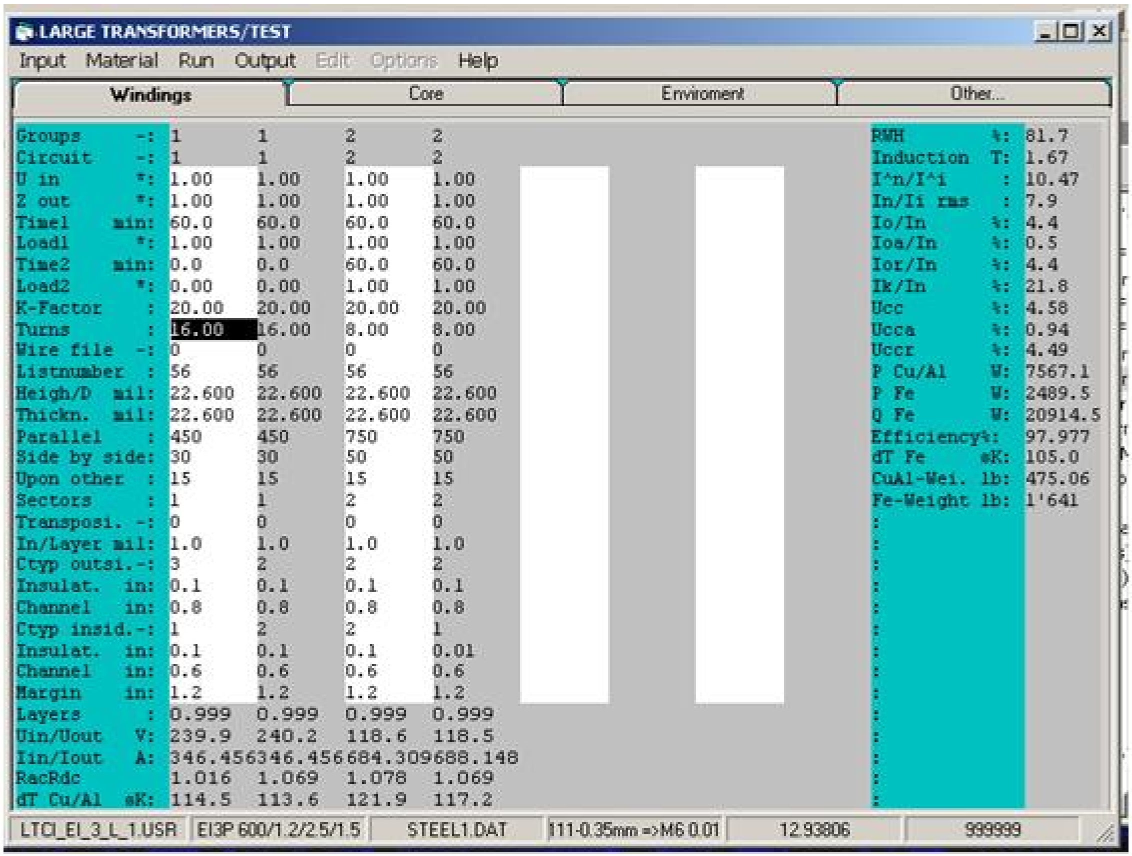
If you are not satisfied with the solution made by the program you can switch into the Test Mode and change your transformer manually:

- 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:

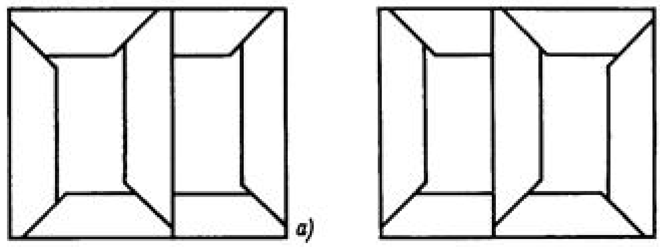
Impregnation

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