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:

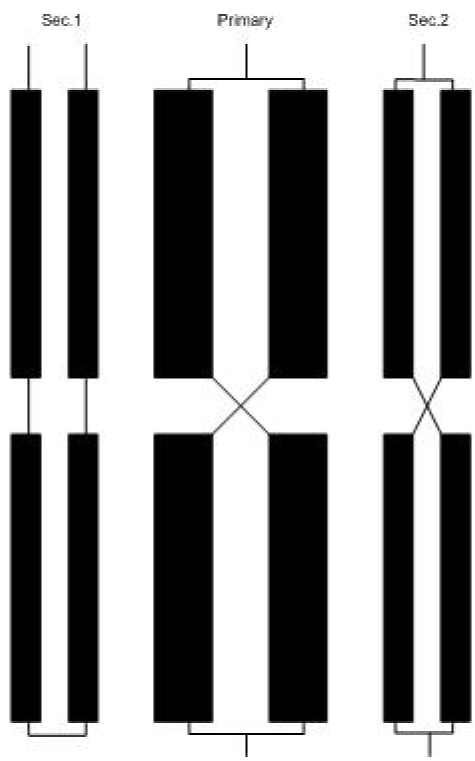
- Winding parameters per limb
- Core
- Environment
- Other parameters

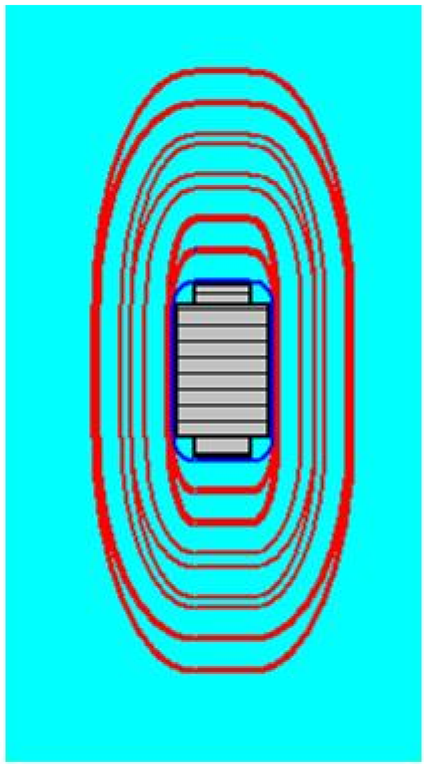
and 3 screens for selection and set up of material :

- wires
- steels
- cores.

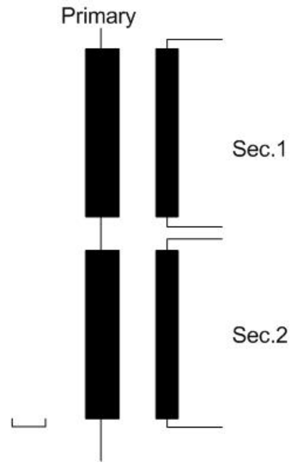
Windings parameters per limb

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.





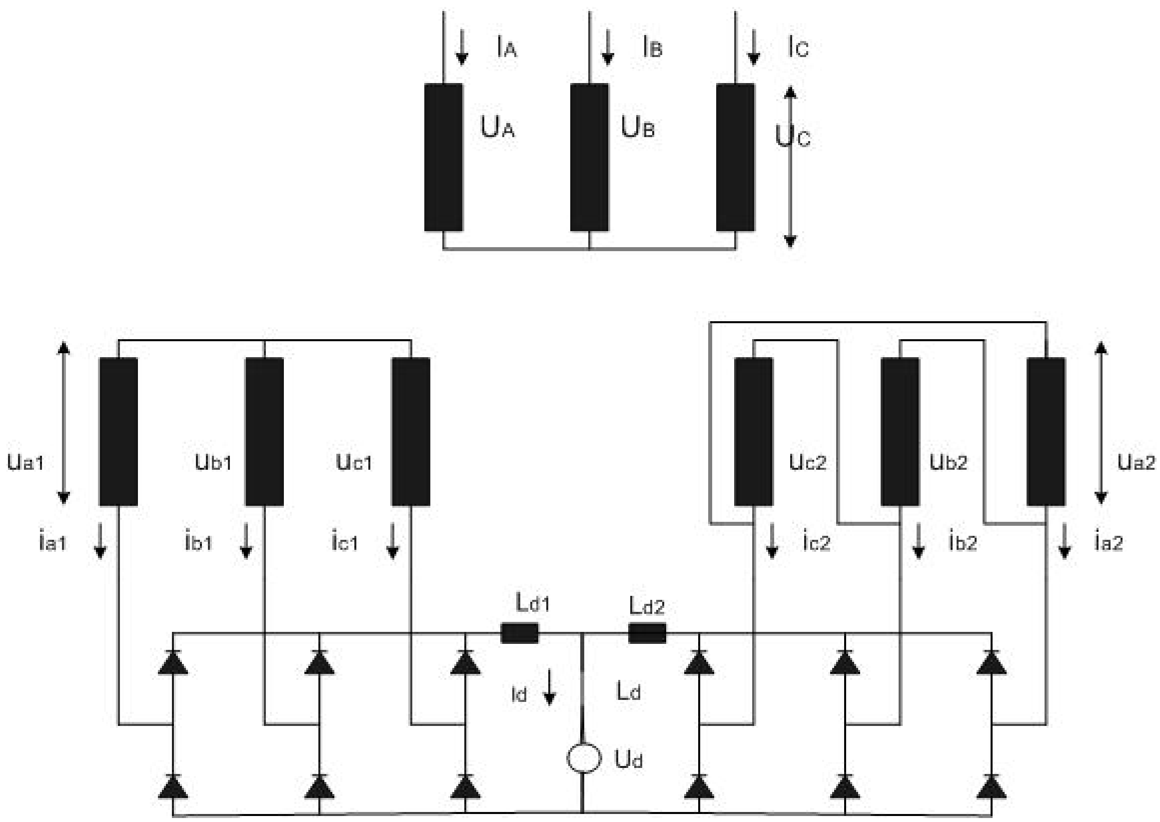
For equal current distribution between 2 parallel connected rectifiers (without the chockes Ld1 and Ld2) the relationship Ucc_s1-s2/Ucc has to be bigger or equal 4. For this condition you should use the following order of the windings:



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

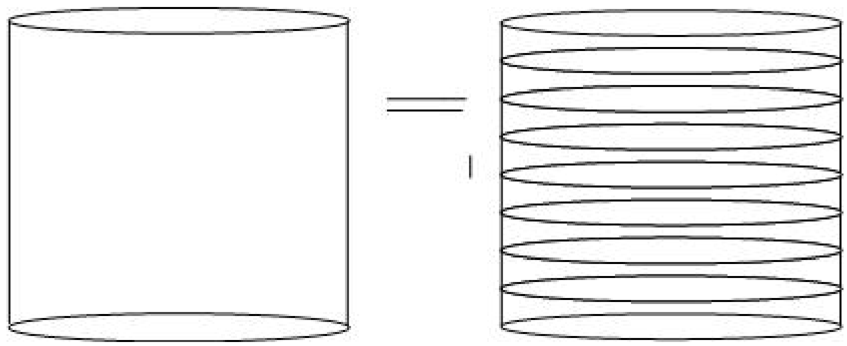
It has to be prescribed by the user of the transformer



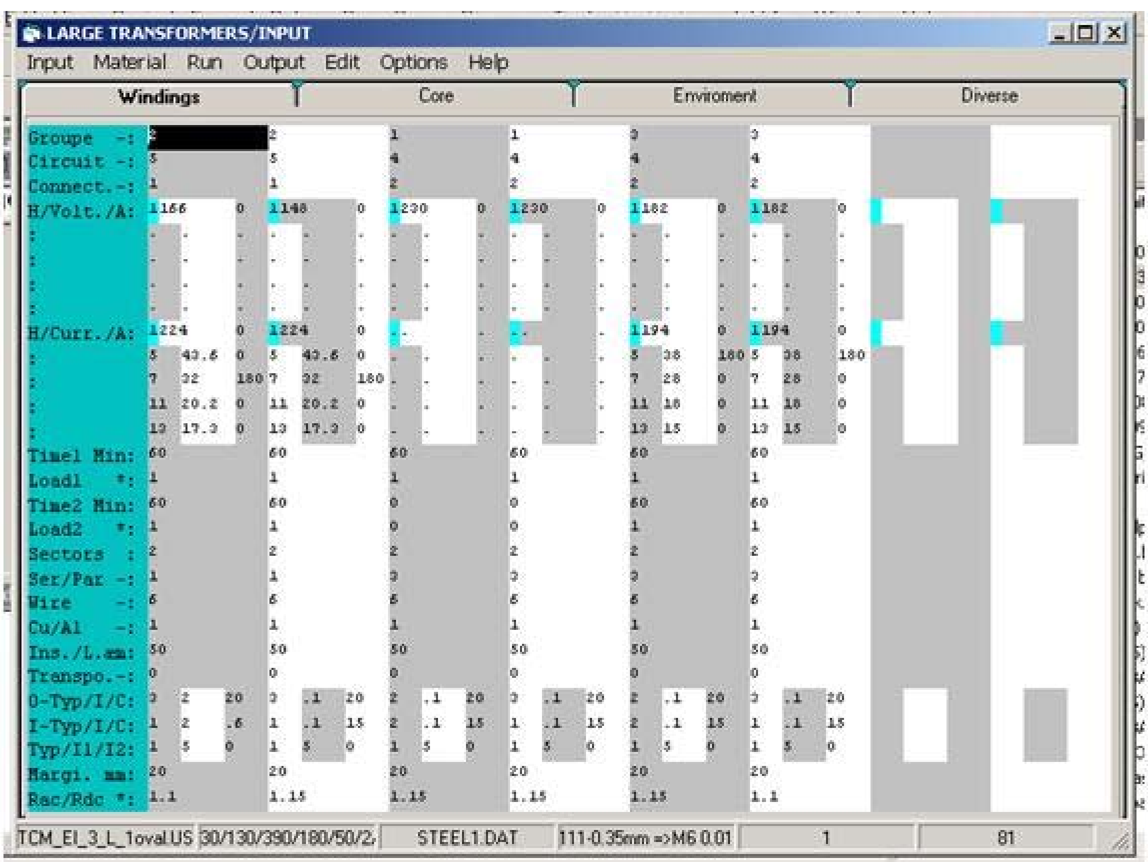
Primary

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 .**



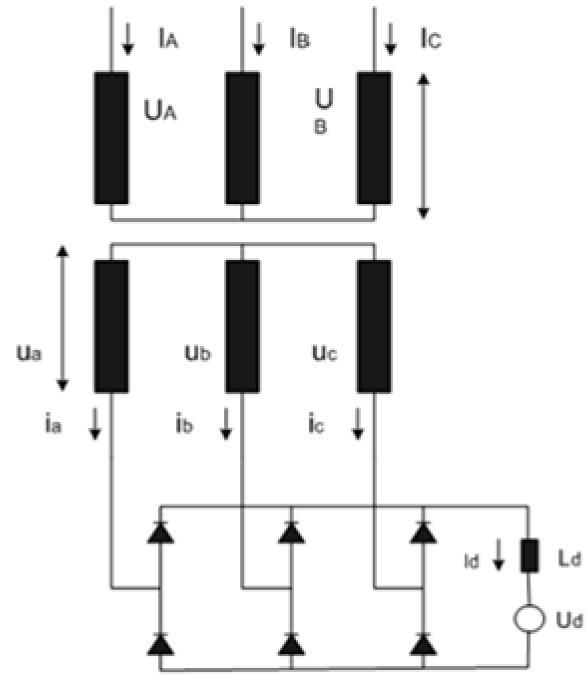
The primary lies between the secondary windings. All the surfaces of the primary are cooled via the cooling channels of 15mm (inside the core window) and 20mm (outside the core window). The space between the yoke and the primary windings is 20mm. With the eddy current losses factor (RacRdc) 1.15 shall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

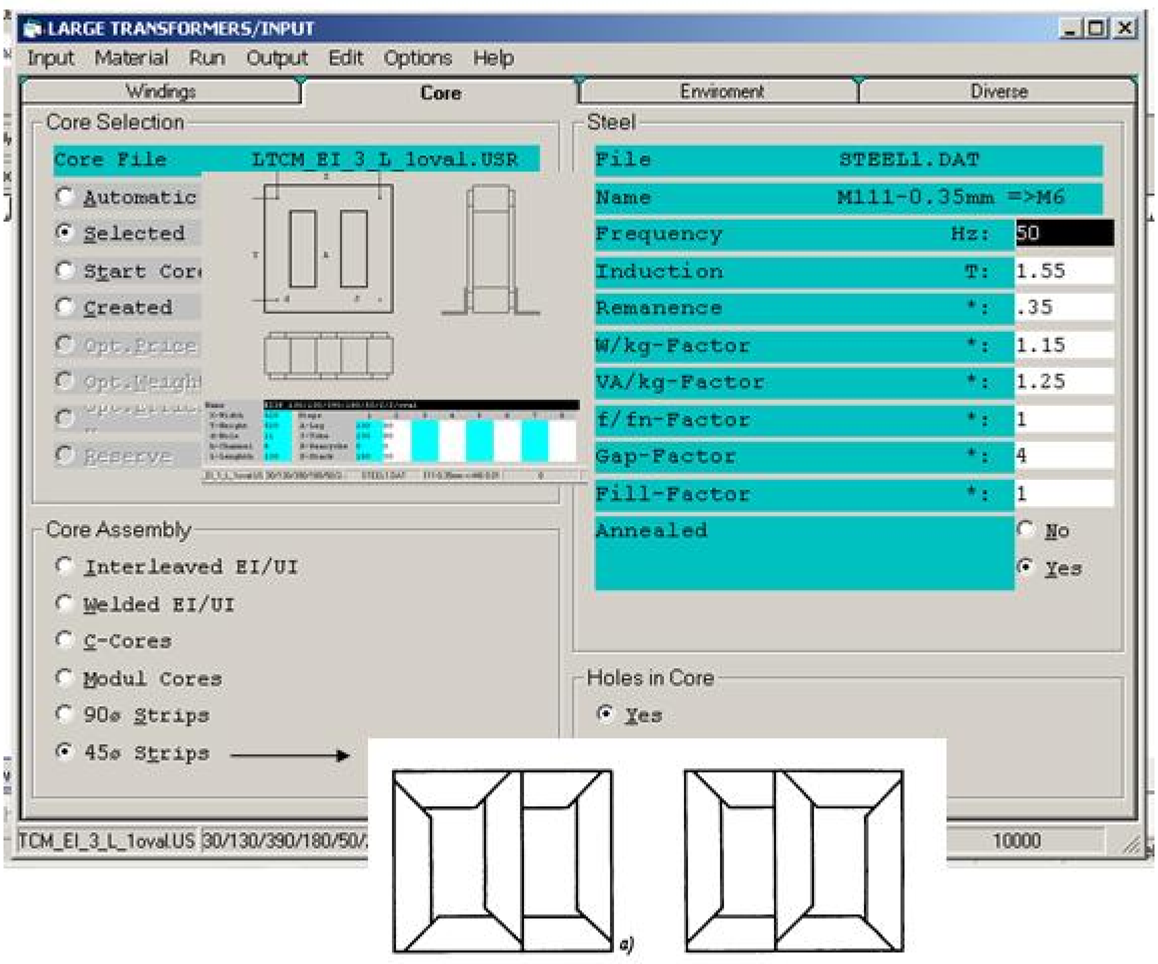
The second secondary is connected in star. It is created with 2 parallel connected windings. In order to avoid the circulating current between 2 parallel connected secondary windings, each of them is created with 2 cross connected sectors.

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.

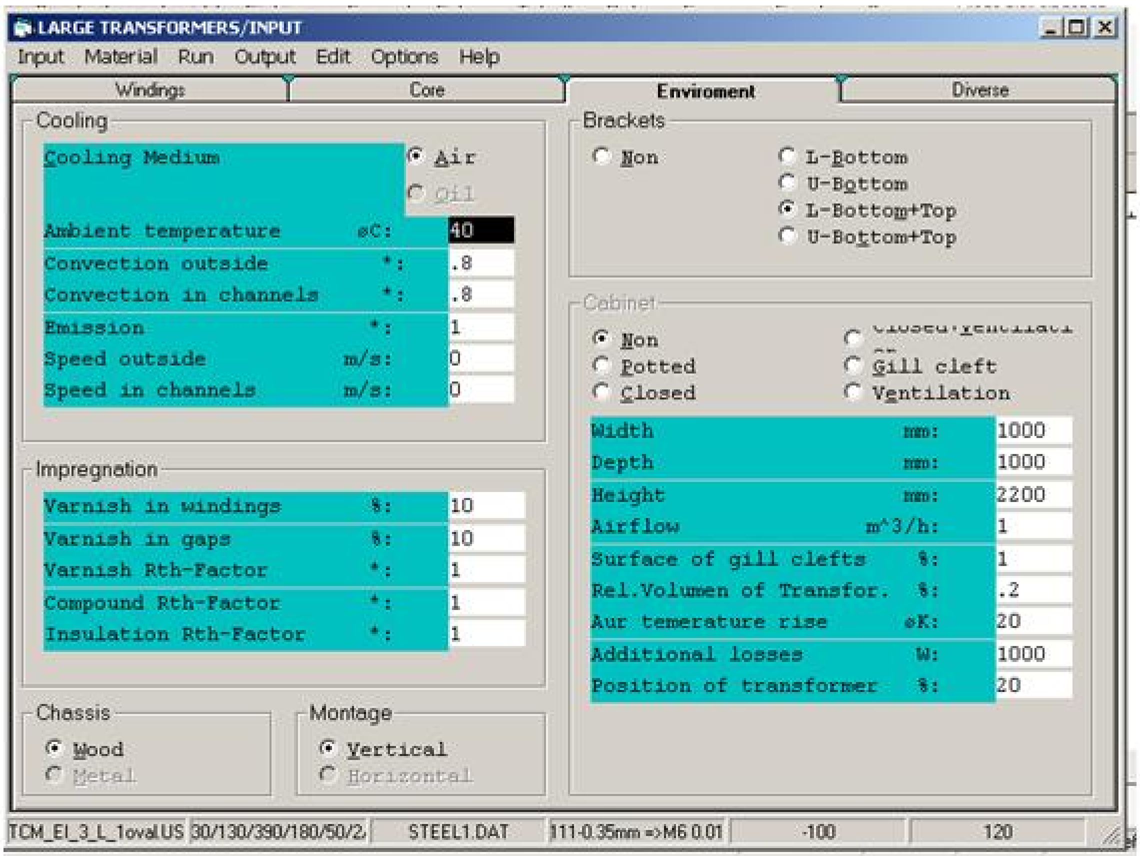


The oval core cross section was prescribed by the designer easier winding of the high current foil windings:

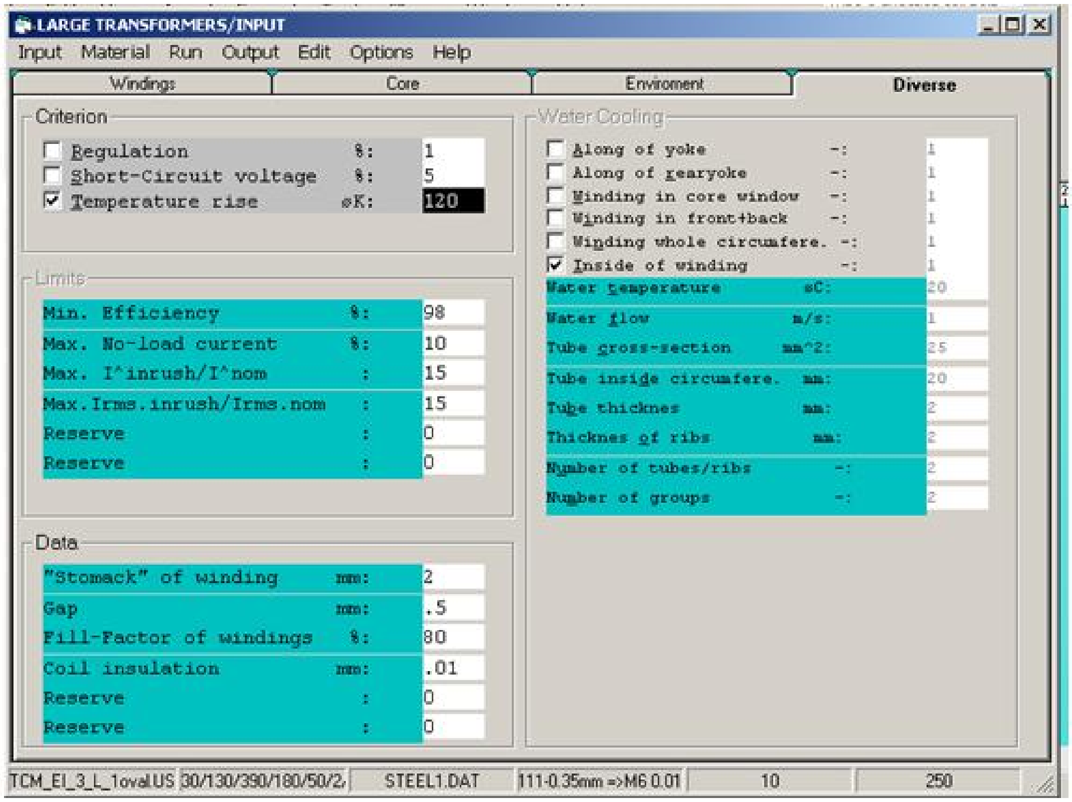
Normally you use for this application M111, 0.35mm (M6, 14mil), not annealed after stamping, grain oriented strips.

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



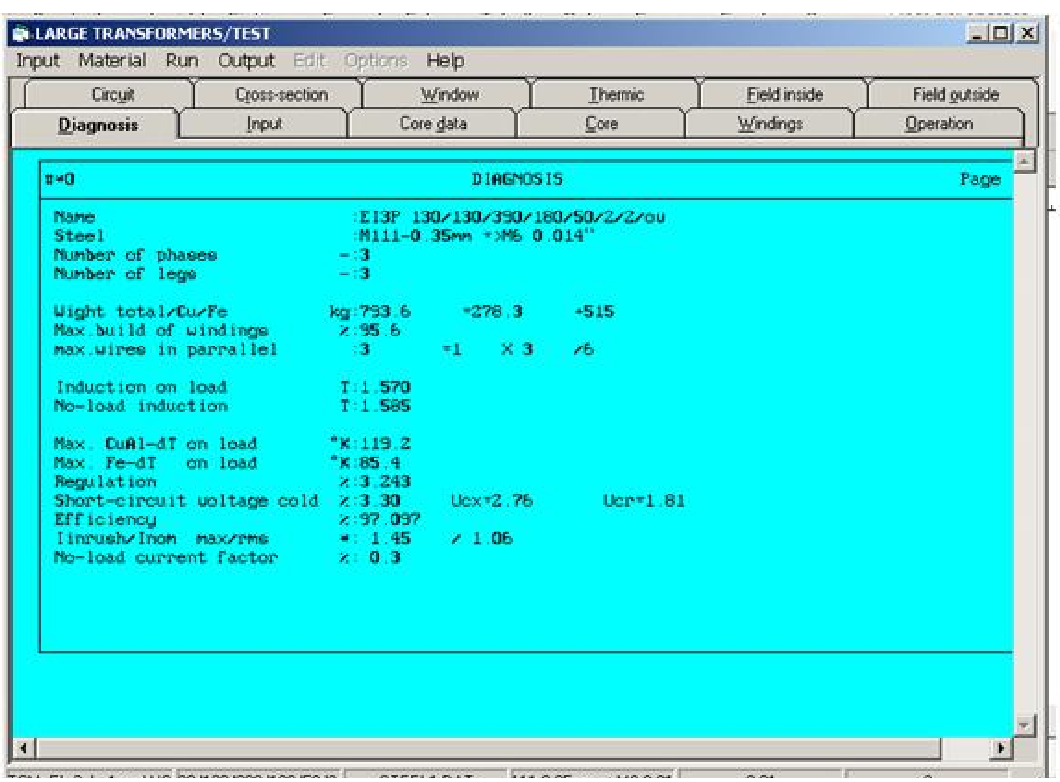
Other...



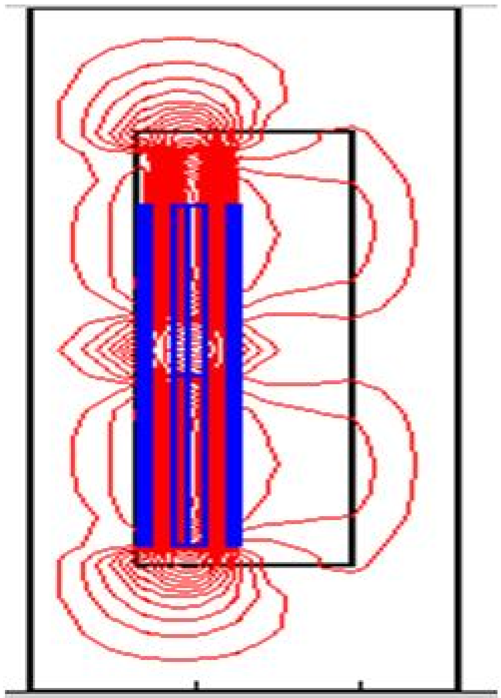
The selected criterion of the design is the temperature rise of 120°K for insulation class H. The oval space between the first winding and the tube (stomach), all gaps between the insulation, the windings and the varnish fill factor of them, play a very important roll from the thermal point of view.

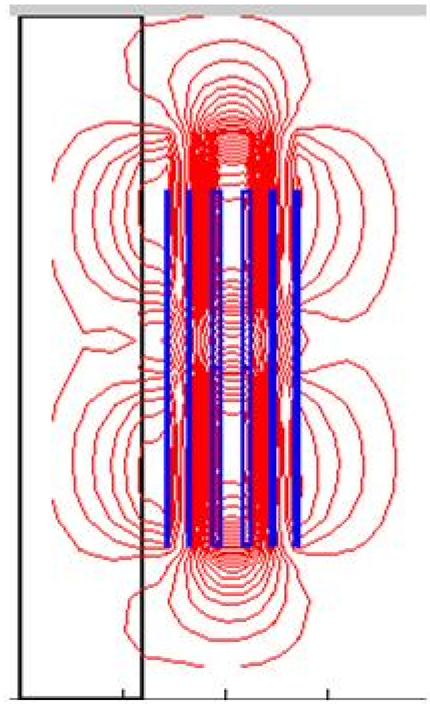
Output

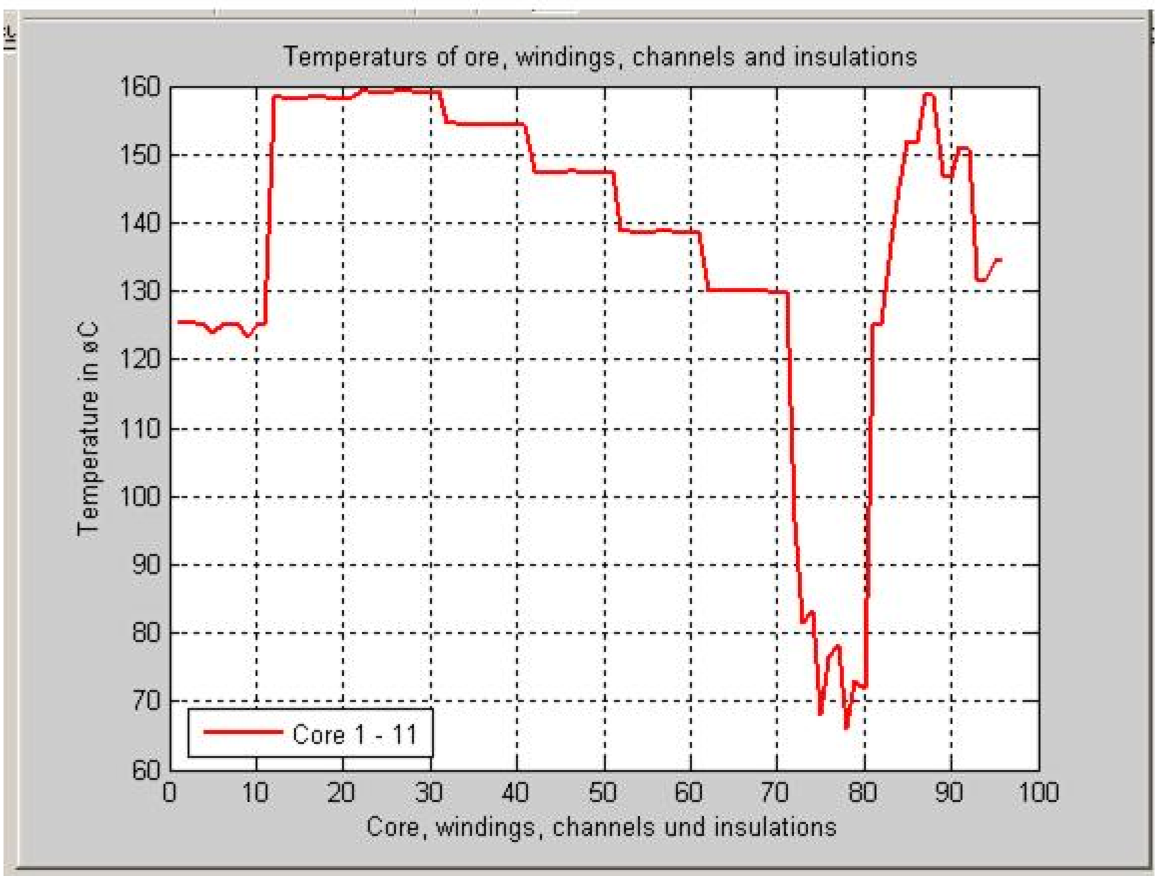
The first step is the presentation of the output screen DIAGNOSIS: it is the summary of the most important calculated parameters of your transformer.



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

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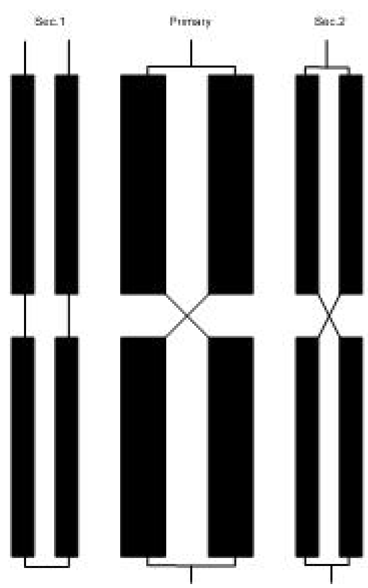
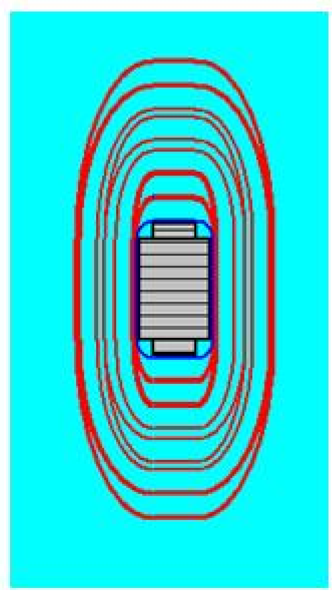
Windings	1	2	3	4	5	6	7	8
Groups	2	2	1	1	3	3		
Circuits	5	5	4	4	4	4		
Connection	1	1	2	2	2	2		
H/Voltag/A	1 166 0	1 148 0	1 230 0	1 230 0	1 182 0	1 182 0		
	. . .	. . .	. . .	. . .	. . .	. . .		
	. . .	. . .	. . .	. . .	. . .	. . .		
	. . .	. . .	. . .	. . .	. . .	. . .		
	. . .	. . .	. . .	. . .	. . .	. . .		
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		
Margins 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

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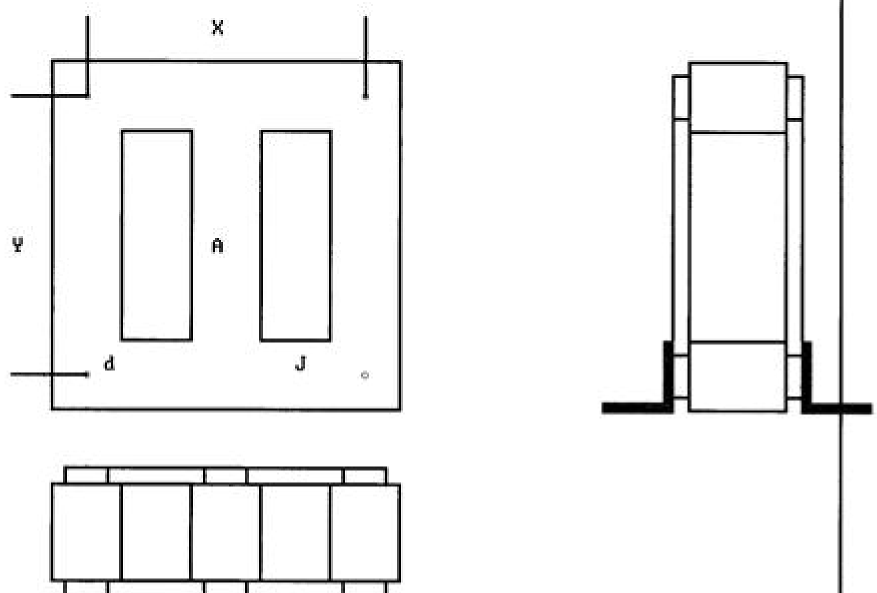
Core file name	: LTCM_EI_3_L_1oval.USR	Fe-File name	: STEEL1.DAT
Core name	: EI3P 130/130/390/180/5	Fe-Name	: M111-0.35mm =>M6 0.014
Core type	: 3EI	Frequency	Hz: 50
Type of windings	: oval/rectangular	Remanence-Factor	*: 0.35
Number of legs	: 3	W/kg-Factor	*: 1.15
Core assembly	: 45° S&trips	VAr/kg-Factor	*: 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:								

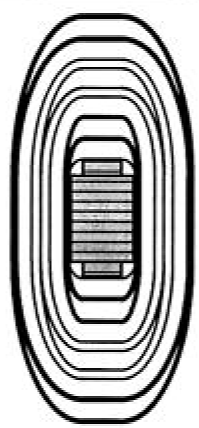


Windings

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

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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