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

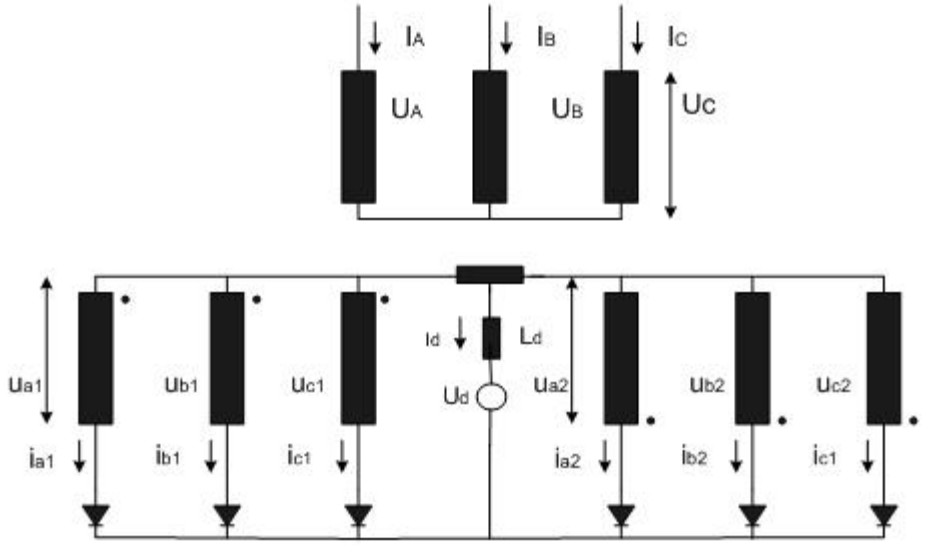
and 3 screens for selection and set up of material :

- 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

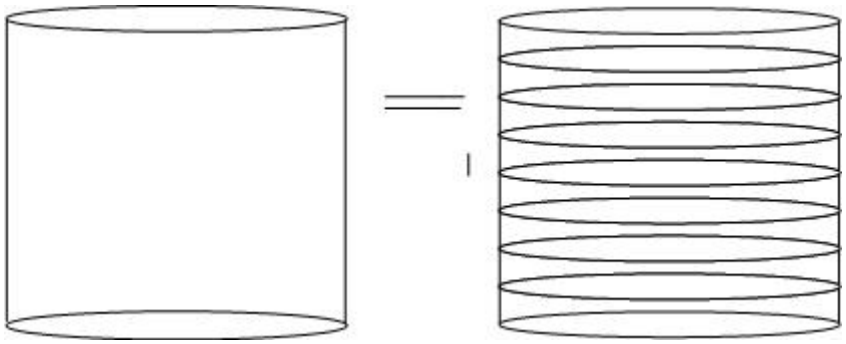
Note that the short-circuit voltage of a rectifier transformer is a complex issue reflecting:

- 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

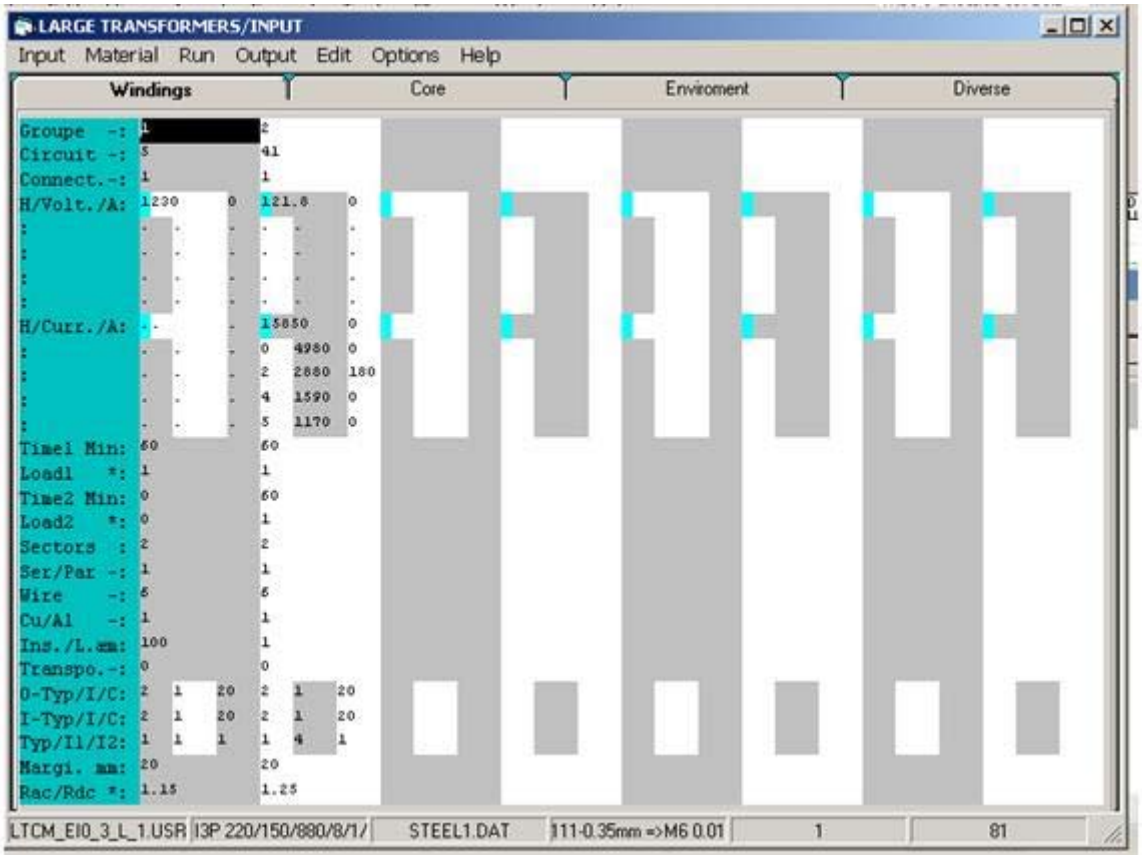
It has to be prescribed by the user of the transformer

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 .**

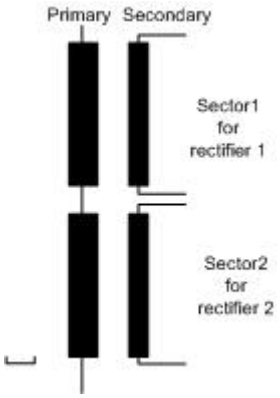


The primary lies between the secondary windings and the core. In order to avoid using very large foil with it is created with 2 in series connected sectors All the surfaces of the primary are cooled via the cooling channels of 20mm . The space between the yoke and the primary windings is 20mm. With the 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 = ∞:

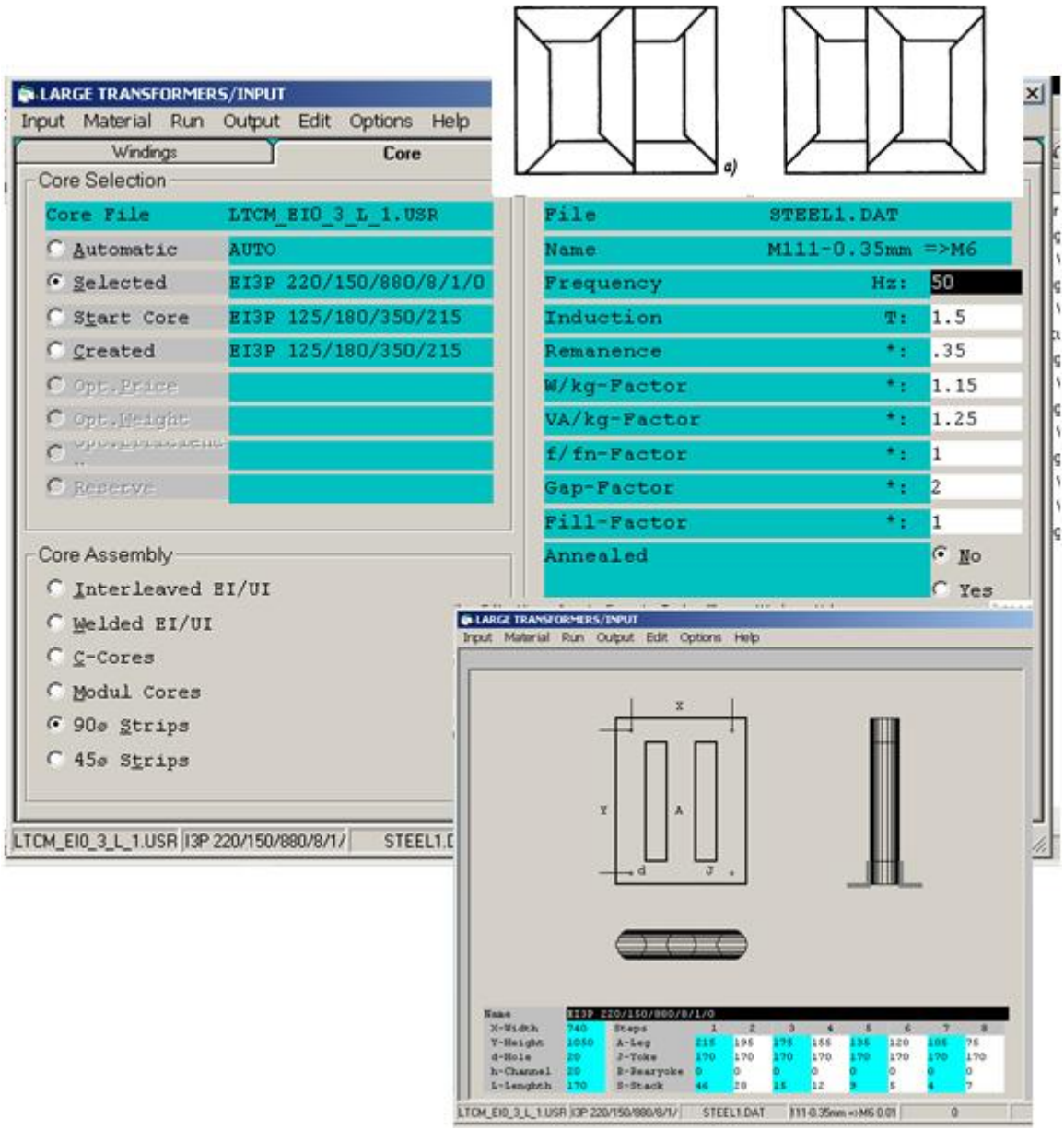
Also, there is no duty cycle operation mode on the secondary.
With the eddy current losses factor (RacRdc) 1.1 and 1.25 the use of parallel connected bars per sector shall be avoided . Note that at this point of the design you cannot prescribe the wire or foil (bar) size. You can select only the wire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

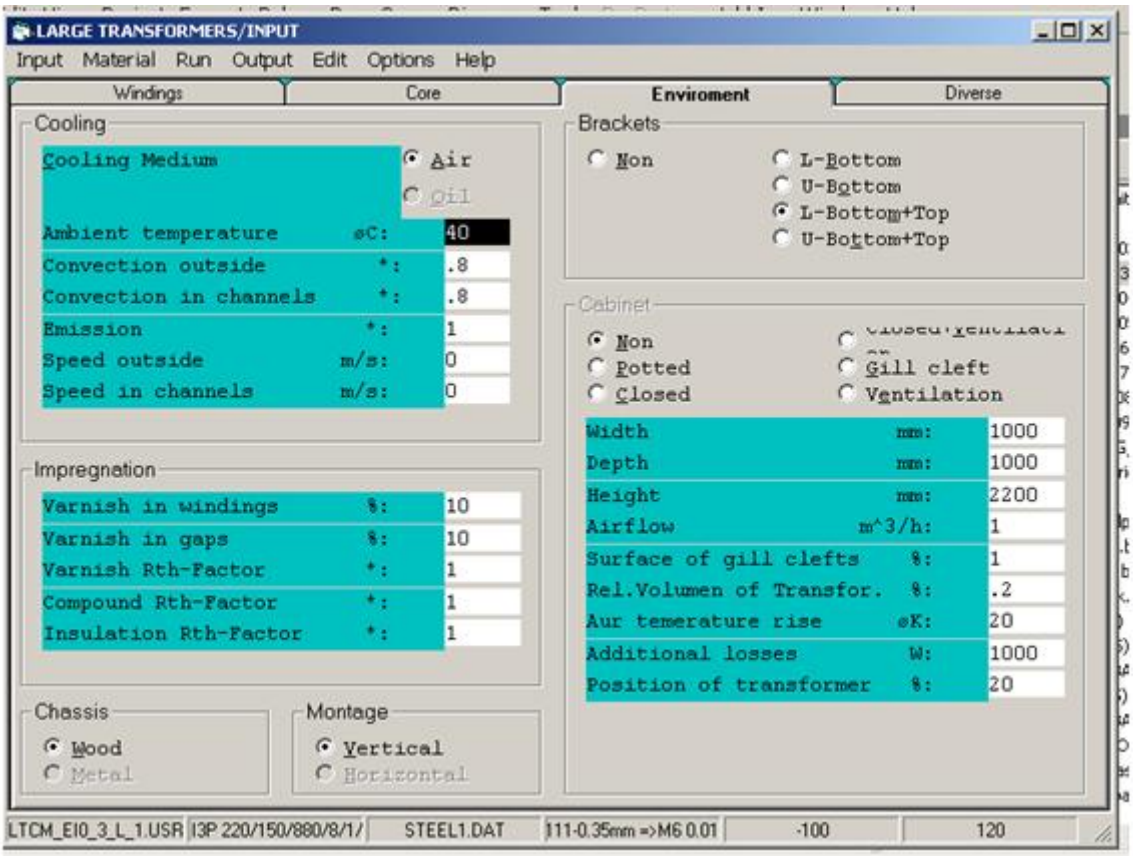


The "round" core cross section was prescribed by the designer for easier winding of the high current foil (bar) windings: The value of the cross section and the induction were set in order to get only one turn per sector
The window height was optimized for the low eddy current losses with a Cu-bar thickness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

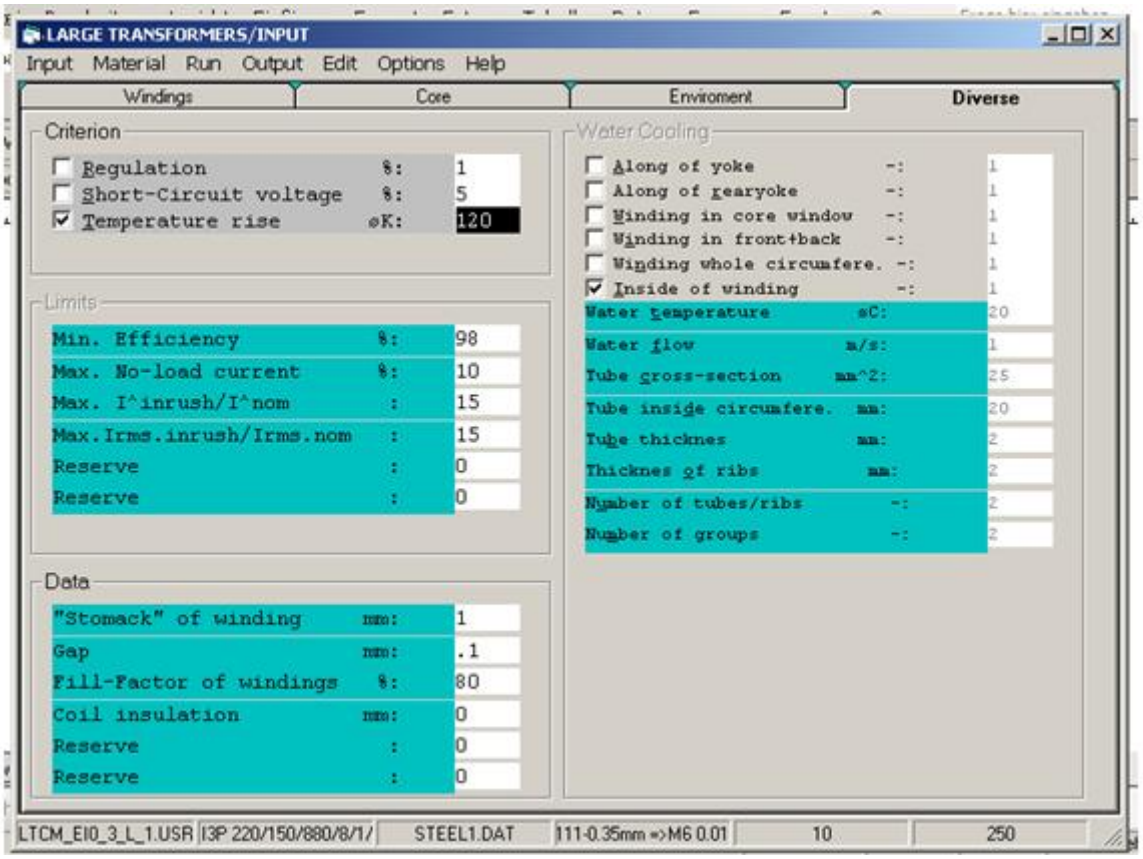
5mm and 6mm.
Normally you use for this application M111, 0.35mm (M6, 14mil), not annealed after stamping, grain oriented strips.

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



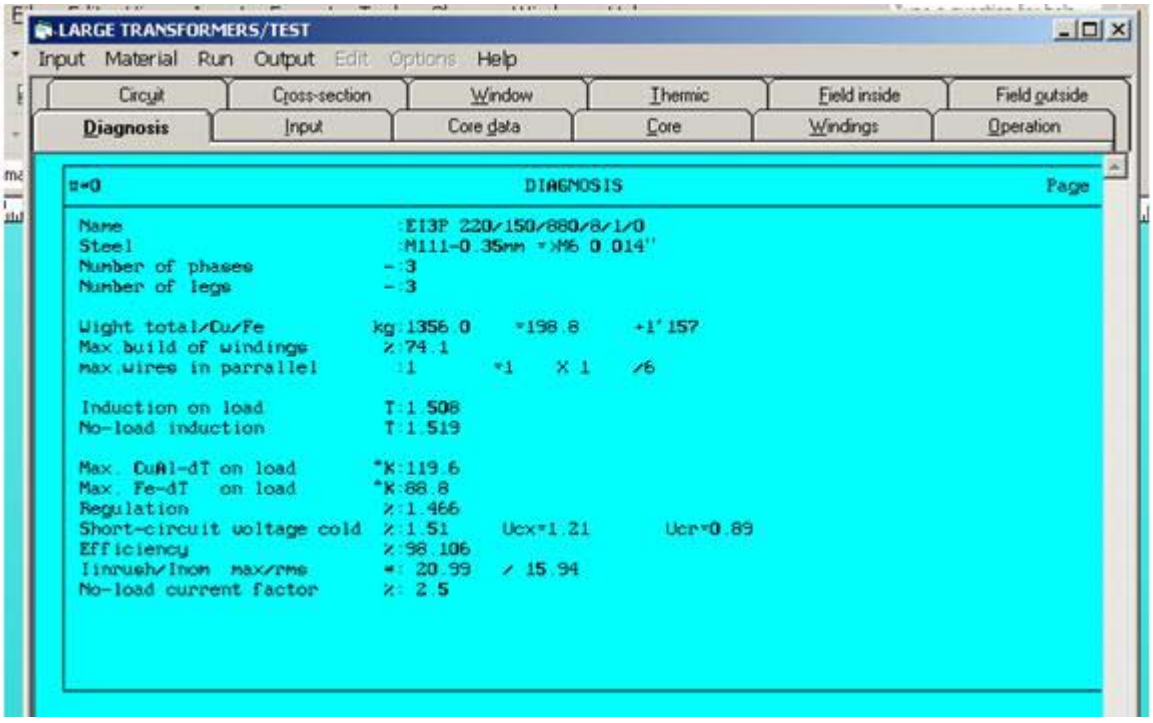
Other...



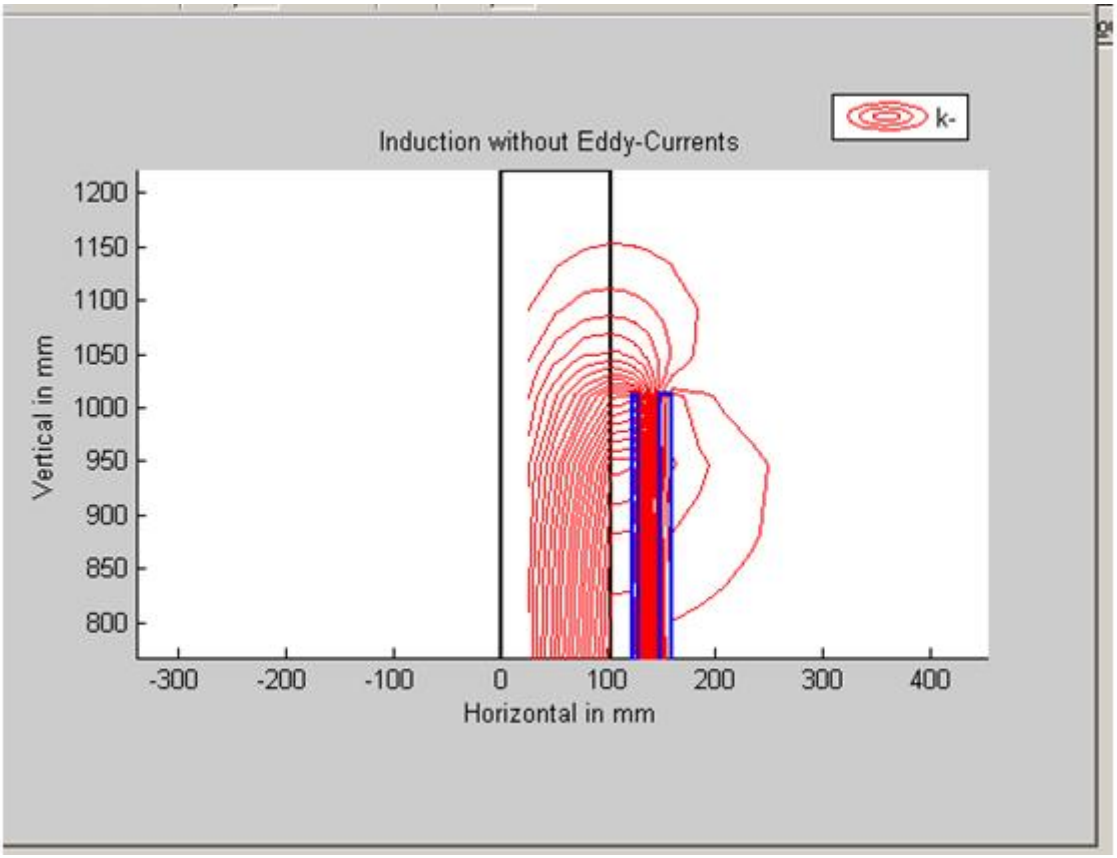
The selected criterion of the design is the temperature rise of 120°K for insulation class H. The oval space between the first winding and the tube (stomach), all gaps between the insulation, the windings and the varnish fill factor of them, play a very important roll from the thermal point of view.

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

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Windings	1	2	3	4	5	6	7	8
Groups	1	2						
Circuits	5	41						
Connection	1	1						
H/Voltag/A	1 230 0	1 21.8 0						
	. . .	. . .						
	. . .	. . .						
	. . .	. . .						
	. . .	. . .						
H/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 µ	100	1						
Transpos.	0	0						
Typ/l/C mm	2 1 20	2 1 20						
Typ/l/C mm	2 1 20	2 1 20						
Typ/l/l mm	1 1 1	1 4 1						
Margine 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 : E13P 220/150	Convection outside *: 0.8	
Regulation %: 1	Core assembly-: 90° 8Strips	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

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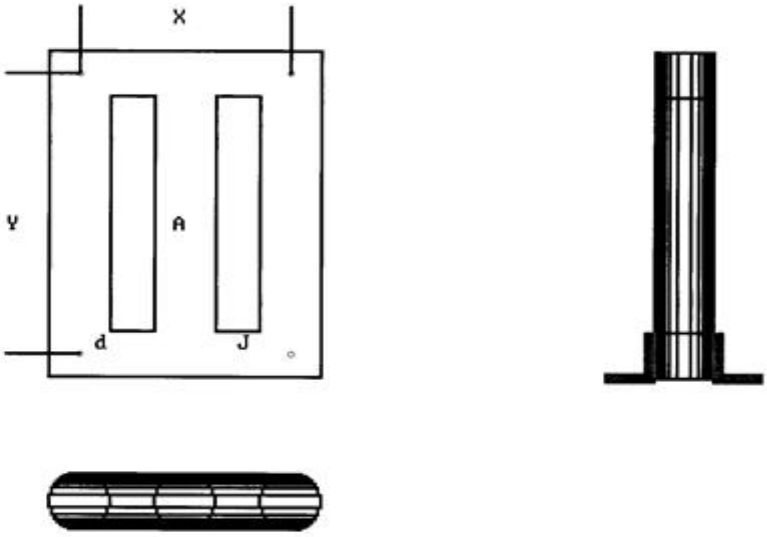
Core file name	: LTCM_EI0_3_L_1.USR	Fe-File name	: STEEL1.DAT
Core name	: EI3P 220/150/880/8/1/0	Fe-Name	: M111-0.35mm =>M6 0.014
Core type	: 3EI	Frequency Hz	: 50
Type of windings	: round	Remanence-Factor *:	0.35
Number of legs	: 3	W/kg-Factor *:	1.15
Core assembly	: 90° &Strips	VAr/kg-Factor *:	1.25
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	Stufen		1	2	3	4	5	6	7	8
Y-Height	cm: 105	A-Leg	cm:	21.5	19.5	17.5	15.5	13.5	12	10.5	7.5
d_Hole	cm: 2	J-Yoke	cm:	17	17	17	17	17	17	17	17
h-Distance	cm: 2	R-Rearyoke	cm:	0	0	0	0	0	0	0	0
L-Laenght	cm: 17	S-Stack	cm:	4.6	2.8	1.5	1.2	0.9	0.5	0.4	0.7
		Number lamin.	:								
		Weight	kg:								



Windings

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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

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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: 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 voltage	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:

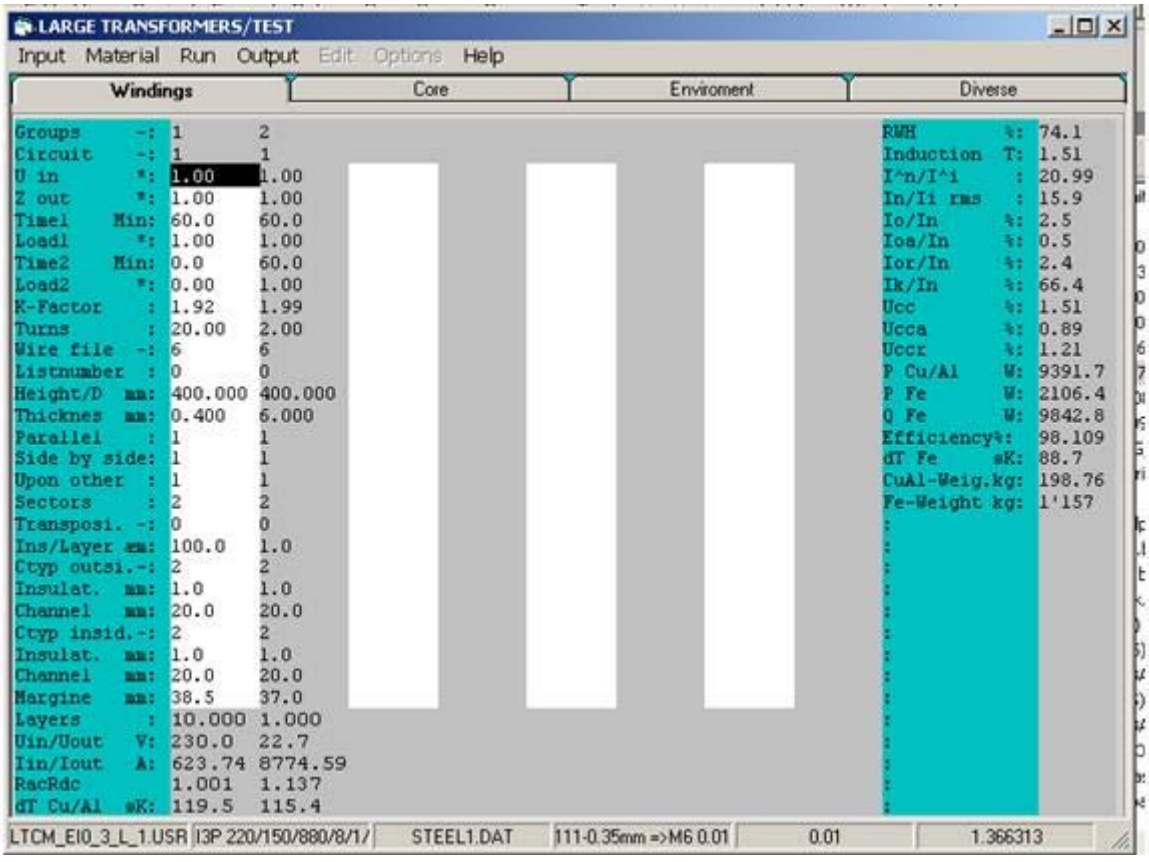
- Turns
- Wire size

- 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.