How should one design an 8000VA transformer for medical premises in accordance with IEC 61558 ?

Technical specification relevant only to design

Electrical data and diagram

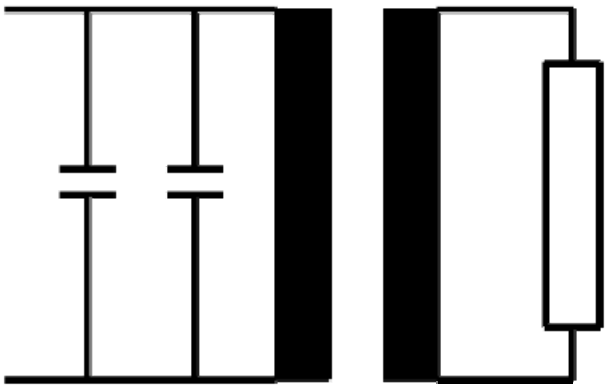
Input voltages	230Vac, sinusoidal
Frequency	50Hz
Nominal output voltage	230Vac
Nominal output current	34.8A (8000VA)
Short-circuit voltage	3% (cold, +-20%)
Inrush current factor	max 8 x I^nominal
No-load current	max 3%

Ambient and operating conditions:

Ambient temperature	40°C
Mode of operation	Continuous operation
Test conditions	Non iherently short-circuit proof

Specification

- Insulation class B



Criteria for design

IEC 61558
A non inherently short-circuit proof transformer as per IEC 61558 is equipped with a safety. Very often, we arrive at a combined protection solution, which consists of a primary-side fuse and a thermal cut-out. For this reason, short-circuit and overload are not design criteria. The design criteria for purposes of IEC 61558 are temperature θ **nominal**, the maximum permitted short-circuit voltage of **3%** and the inrush current, whose maximum level is eight times the peak value of the primary nominal current. Since IEC 61558 permits utilization of two condensers for compensation of the reactive no-load current, we should limit the active no-load current and iron losses to approximately 2%, which is not usually a problem.

Insulation class	A	E	B	F	H
Max winding temperature in test θ **max** (° C)	200	215	225	240	260
Max winding temperature in nominal operation θ **nominal** (° C)	100	115	120	140	165
Short-circuit voltage (%)	<3	<3	<3	<3	<3
Inrush current factor	<8	<8	<8	<8	<8
No-load current (%)	<3	<3	<3	<3	<3

Insulation class

- Max winding temperature in nominal operating mode = **120°C**
- ax winding temperature in test mode = **225°C**

Insulation class B is prescribed.

Design criteria
Computer program employs two design criteria:

- Regulation **<3%**
- Temperature rise **<80°K** for 40°C ambient temperature and insulation class B.

Note that short-circuit voltage for a single-chamber bobbin unit is very closed to the regulation.

*Since we do not know which of these criteria will be the more relevant to our design, we shall enter **Criterion = 0** and leave it to the computer program to decide.*

Bobbin unit and core.
Control transformers have to be produced with a low internal resistance and with low scatter impedance. For this reason, transformers for medical purposes are constructed exclusively with single-chamber bobbin units. For practical purposes, there is only one choice of UI core form to select for the 3kVA to 10kVA output range.

Inrush current
The peak value of the inrush current, cold, in the first period after switch-on at the zero-axis crossing point, should not exceed a factor of **8** x the peak value for nominal input current. This can best be achieved if:

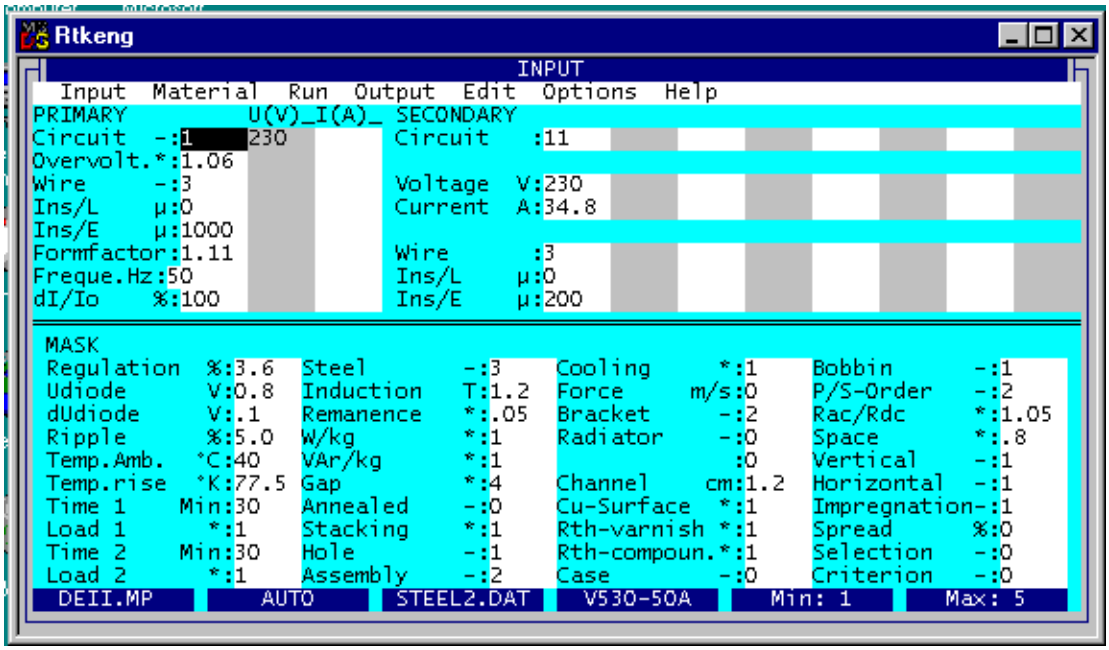
- The nominal induction is **1.1T-1.2T**.
- The transformer is constructed with a defined creep distance of approx **0.05-0.10** mm, so as to reduce residual magnetism.
- The primary winding is routed to the outside.

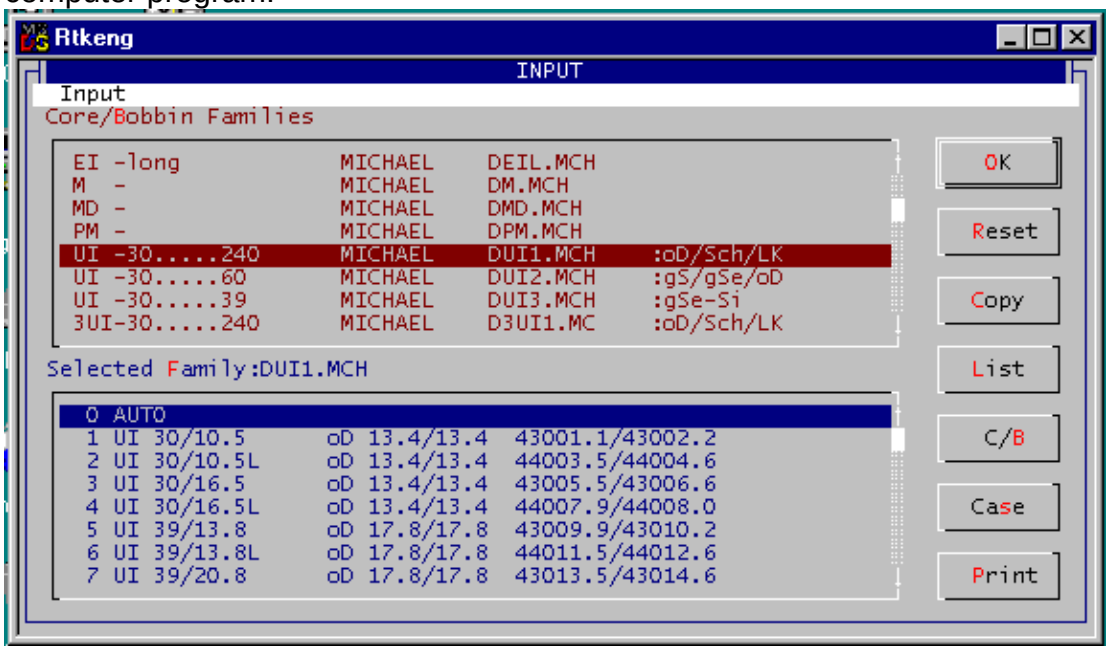
Induction and iron quality
Inrush-current transformers with a inrush factor of <8 are operated with a low induction (**1.0T-1.2T**). For this reason, we use virtually nothing but cold-rolled iron quality of **5.3W/kg at 1.5T, 50Hz**.

Short-circuit voltage
The maximum permitted short-circuit voltage is **3%**. In accordance with IEC 61558, a transformer's short-circuit voltage is measured in the cold state at 20°C. The permitted tolerance is **+-20%**.
The computer program calculates short-circuit voltage. However, this cannot be used as a design criterion. We shall use regulation, since a single-chamber transformer's regulation is practically identical to its short-circuit voltage.
In the design process, regulation of **3.3%** to **3.6%** is used, on account of the permitted short-circuit tolerance of **+/-20%**.

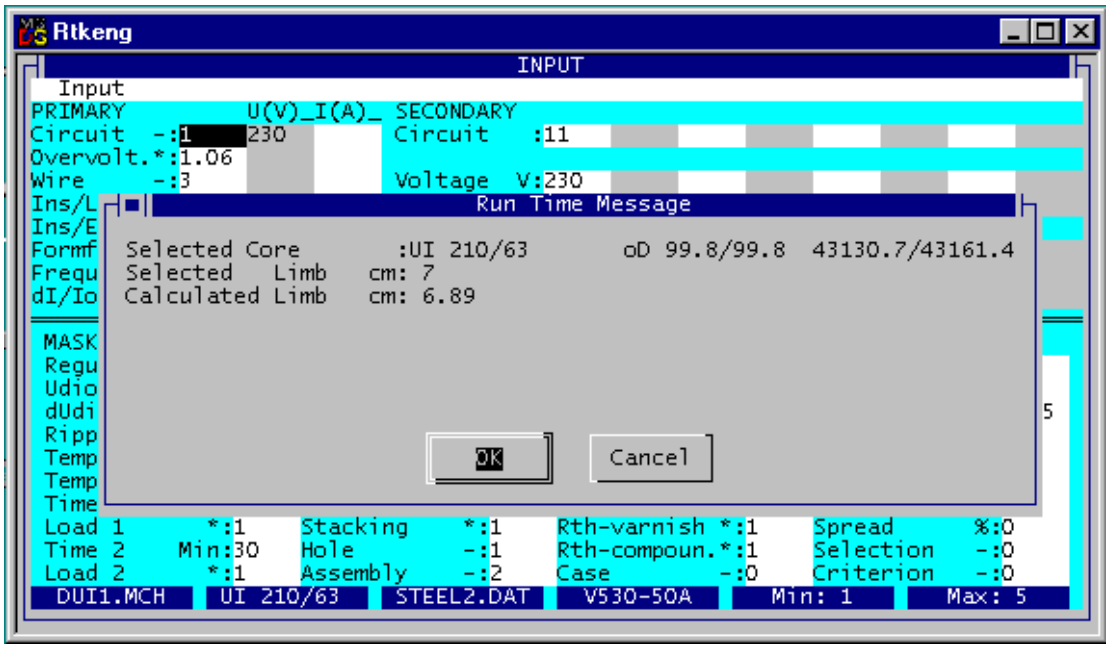
Procedure for design

1. If you are not yet acquainted with Rale design software, please read the **text "How should I design a small transformer?**". Keep a copy of this text within convenient reach whenever performing design work.
2. Fill in the design input mask as follows. If you need any help, press function key F1. There is extensive description for each input field.

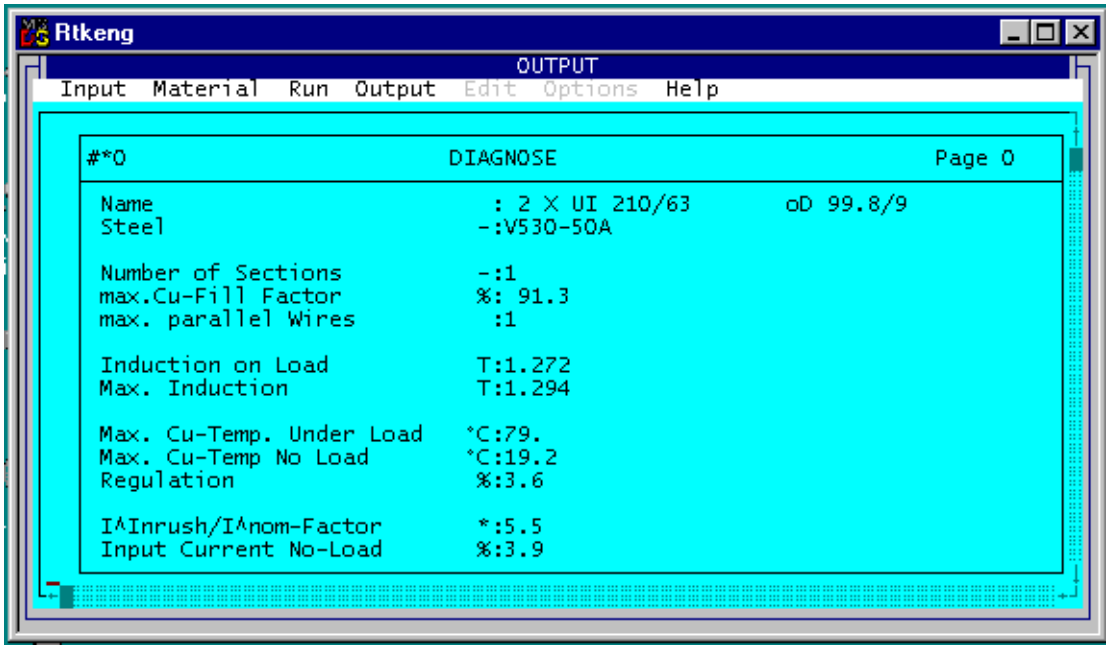
3. 

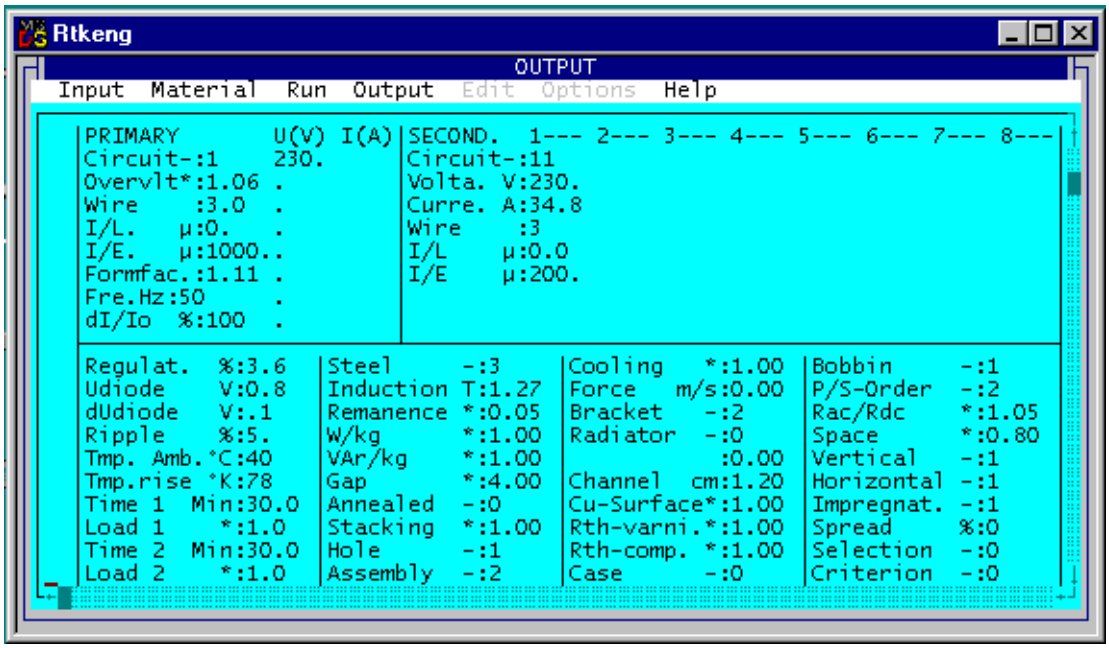
4. The **Selection** input field is set at **0**. This means that the program should search on-line for a suitable core for this application, from your selected core family.
5. Save your input data file. In this specimen design calculation, we saved the input data in input data file **CAL0008E.TK1**. This input data file was supplied together with this document. Copy it into the directory in which your Rale demo program is installed.
6. Connect up to the Rale design server.
7. Load up your input data file.
8. Now select the UI core family and the core for automatic search by the computer program.
9. 

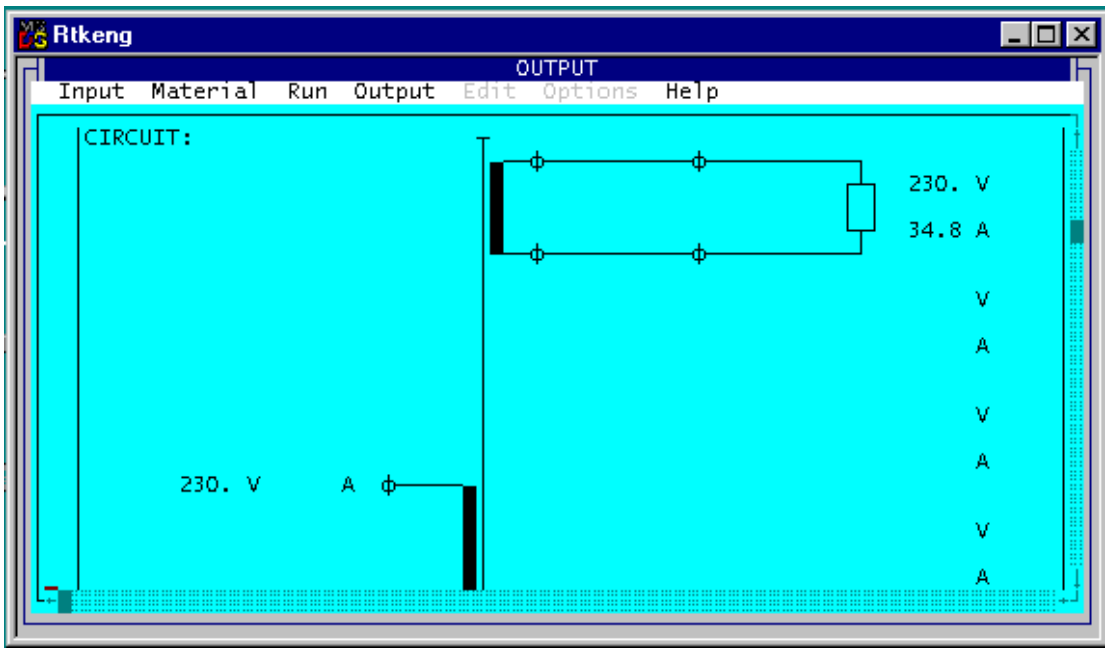
10. Click on **OK.**
11. Start your design work. In the system for automatic selection of the UI core from your prescribed core family, the program will offer you an adequately sized core for your application. Click on OK in order to accept the core.

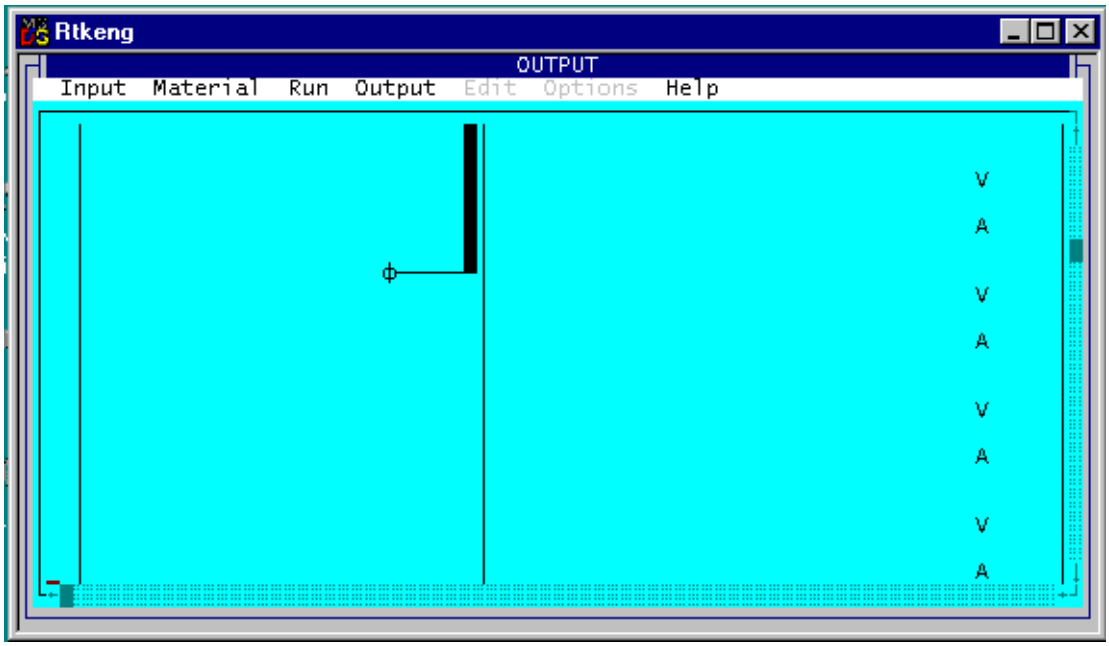


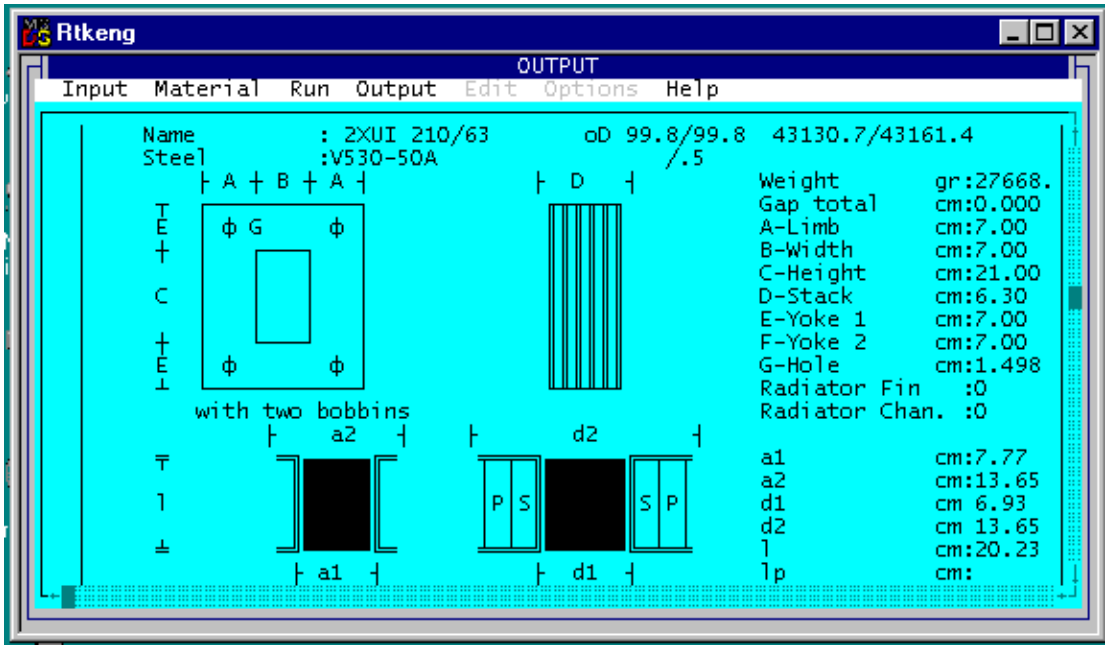
On completion of the design work, the following design data will be available and can bprinted on three pages:

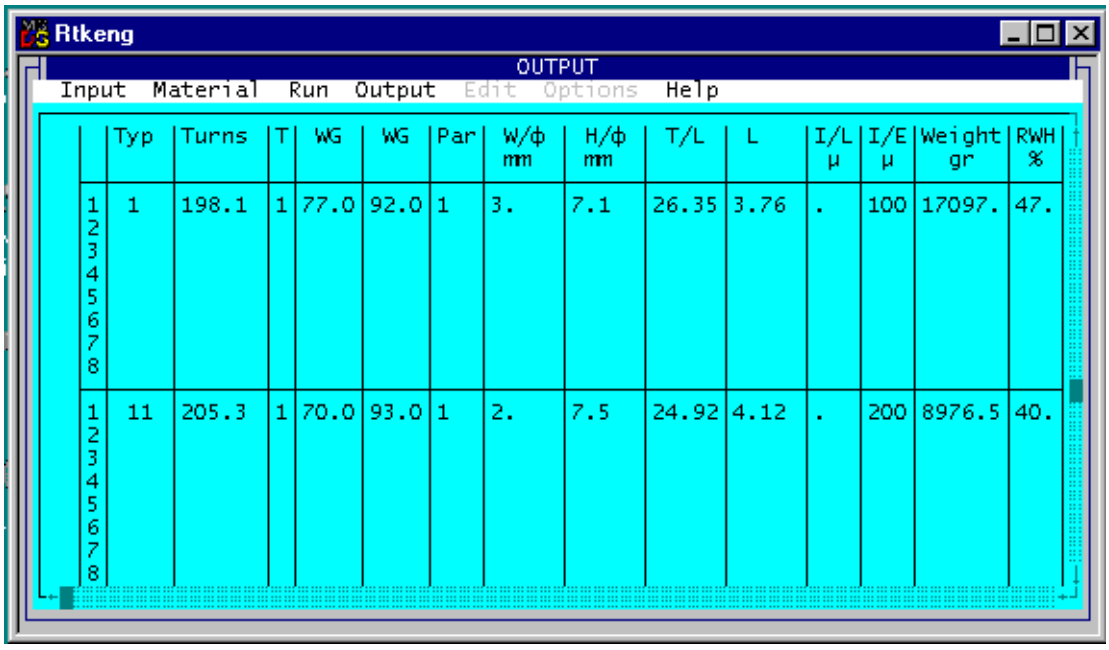


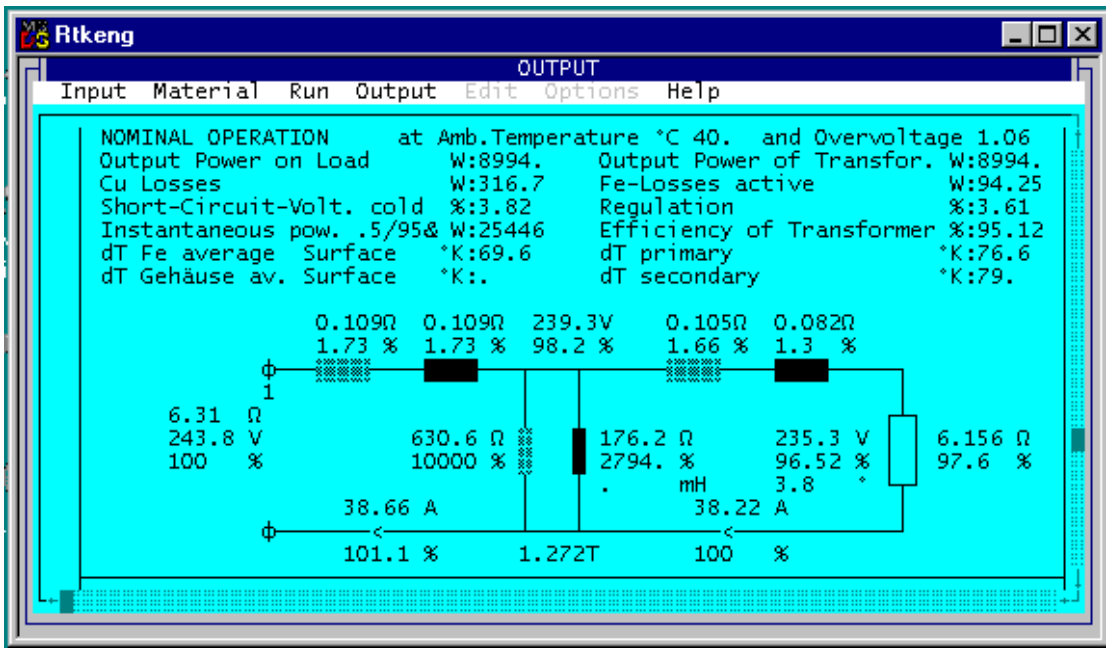

Rtkeng
OUTPUT
Input Material Run Output Edit Options Help
PRIMARY U(V) I(A)
Circuit-:1 230.
Overvlt*:1.06 .
Wire :3.0 .
I/L. µ:0. .
I/E. µ:1000..
Formfac.:1.11 .
Fre.Hz:50 .
dI/Io %:100 .
SECOND. 1--- 2--- 3--- 4--- 5--- 6--- 7--- 8---
Circuit-:11
Volta. V:230.
Curre. A:34.8
Wire :3
I/L µ:0.0
I/E µ:200.
Regulat. %:3.6
Udiode V:0.8
dUdiode V:.1
Ripple %:5.
Tmp. Amb.°C:40
Tmp.rise °K:78
Time 1 Min:30.0
Load 1 *:1.0
Time 2 Min:30.0
Load 2 *:1.0
Steel -:3
Induction T:1.27
Remanence *:0.05
W/kg *:1.00
VAr/kg *:1.00
Gap *:4.00
Annealed -:0
Stacking *:1.00
Hole -:1
Assembly -:2
Cooling *:1.00
Force m/s:0.00
Bracket -:2
Radiator -:0
:0.00
Channel cm:1.20
Cu-Surface*:1.00
Rth-varni.*:1.00
Rth-comp. *:1.00
Case -:0
Bobbin -:1
P/S-Order -:2
Rac/Rdc *:1.05
Space *:0.80
Vertical -:1
Horizontal -:1
Impregnat. -:1
Spread %:0
Selection -:0
Criterion -:0

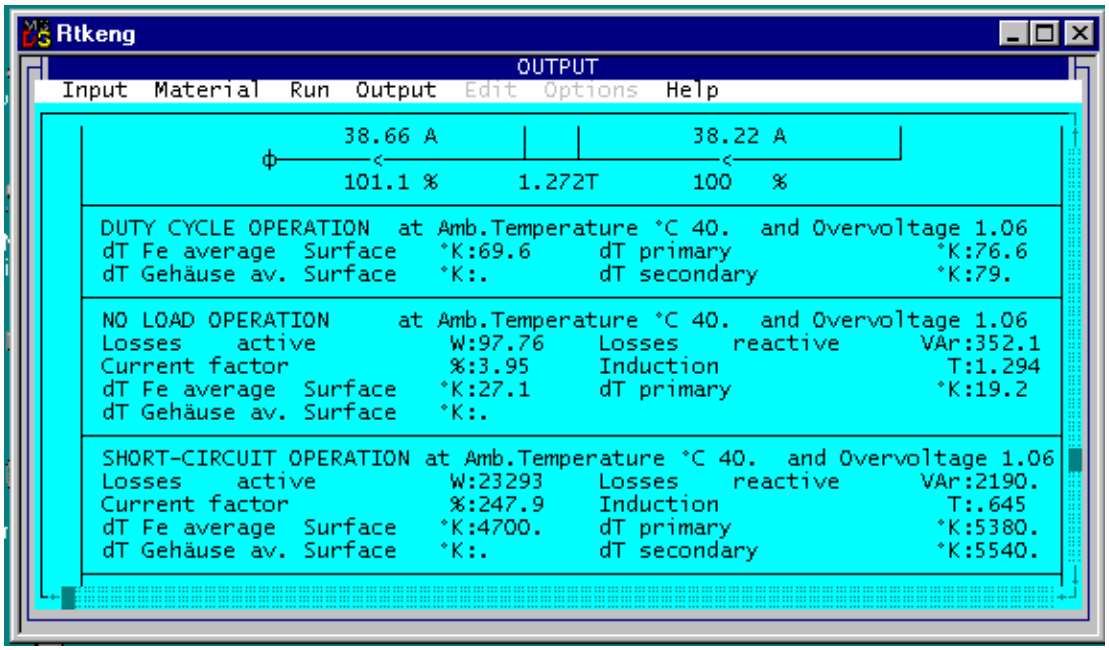

Rtkeng
OUTPUT
Input Material Run Output Edit Options Help
CIRCUIT:
230. V
34.8 A
V
A
V
A
V
A
230. V
A

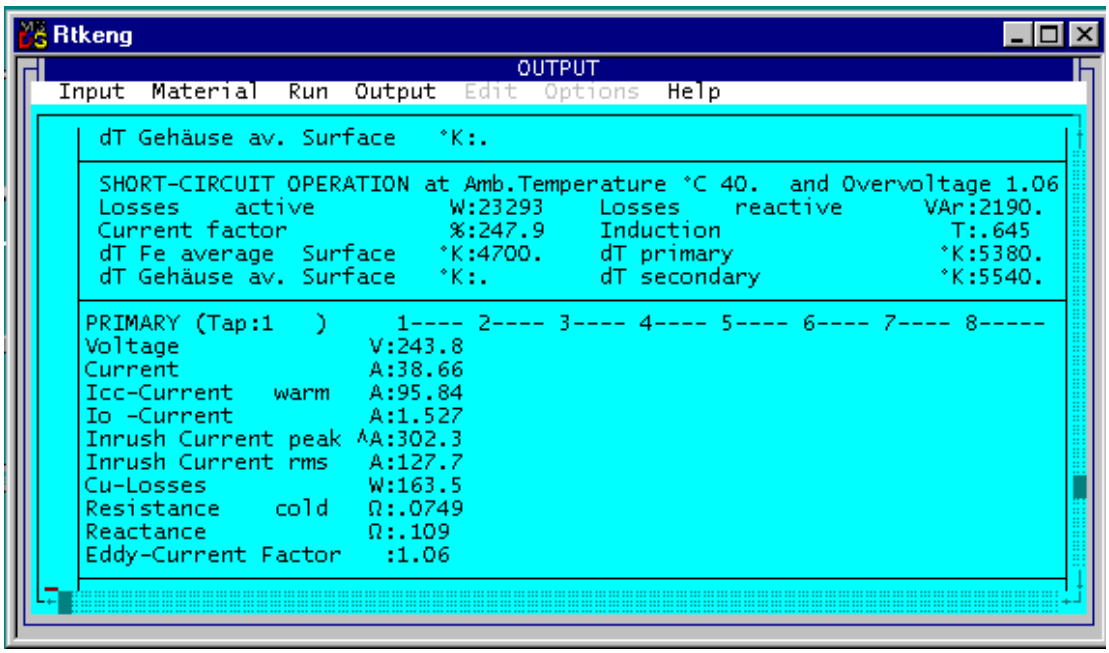

Rtkeng
OUTPUT
Input Material Run Output Edit Options Help
V
A
V
A
V
A
V
A

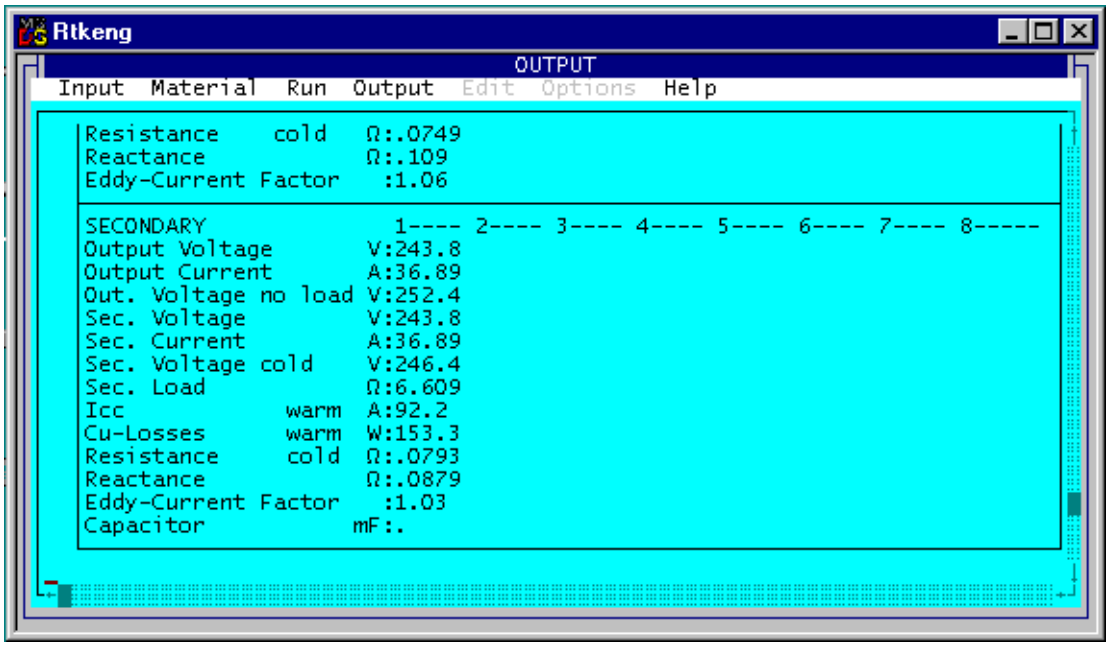

Rtkeng
OUTPUT
Input Material Run Output Edit Options Help
Name : 2XUI 210/63 oD 99.8/99.8 43130.7/43161.4
Steel :V530-50A /.5
A B A
D
G
with two bobbins
a2
d2
P S
S P
a1
d1
Weight gr:27668.
Gap total cm:0.000
A-Limb cm:7.00
B-Width cm:7.00
C-Height cm:21.00
D-Stack cm:6.30
E-Yoke 1 cm:7.00
F-Yoke 2 cm:7.00
G-Hole cm:1.498
Radiator Fin :0
Radiator Chan. :0
a1 cm:7.77
a2 cm:13.65
d1 cm 6.93
d2 cm 13.65
l cm:20.23
lp cm:


Rtkeng
OUTPUT
Input Material Run Output Edit Options Help
Typ Turns T WG WG Par W/ϕ mm H/ϕ mm T/L L I/L µ I/E µ Weight gr RWH %
1 1 198.1 1 77.0 92.0 1 3. 7.1 26.35 3.76 . 100 17097. 47.
11 205.3 1 70.0 93.0 1 2. 7.5 24.92 4.12 . 200 8976.5 40.


Rtkeng
OUTPUT
Input Material Run Output Edit Options Help
NOMINAL OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06
Output Power on Load W:8994.
Output Power of Transfor. W:8994.
Cu Losses W:316.7
Fe-Losses active W:94.25
Short-Circuit-Volt. cold %:3.82
Regulation %:3.61
Instantaneous pow. .5/95& W:25446
Efficiency of Transformer %:95.12
dT Fe average Surface °K:69.6
dT primary °K:76.6
dT Gehäuse av. Surface °K:.
dT secondary °K:79.
0.109Ω 0.109Ω 239.3V 0.105Ω 0.082Ω
1.73 % 1.73 % 98.2 % 1.66 % 1.3 %
ϕ
1
6.31 Ω
243.8 V
100 %
630.6 Ω
10000 %
176.2 Ω
2794. %
. mH
235.3 V
96.52 %
3.8 °
6.156 Ω
97.6 %
38.66 A
38.22 A
ϕ
101.1 %
1.272T
100 %


Rtkeng
OUTPUT
Input Material Run Output Edit Options Help
38.66 A
38.22 A
101.1 %
1.272T
100 %
DUTY CYCLE OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06
dT Fe average Surface °K:69.6
dT primary °K:76.6
dT Gehäuse av. Surface °K:.
dT secondary °K:79.
NO LOAD OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06
Losses active W:97.76
Losses reactive VAr:352.1
Current factor %:3.95
Induction T:1.294
dT Fe average Surface °K:27.1
dT primary °K:19.2
dT Gehäuse av. Surface °K:.
SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06
Losses active W:23293
Losses reactive VAr:2190.
Current factor %:247.9
Induction T:.645
dT Fe average Surface °K:4700.
dT primary °K:5380.
dT Gehäuse av. Surface °K:.
dT secondary °K:5540.

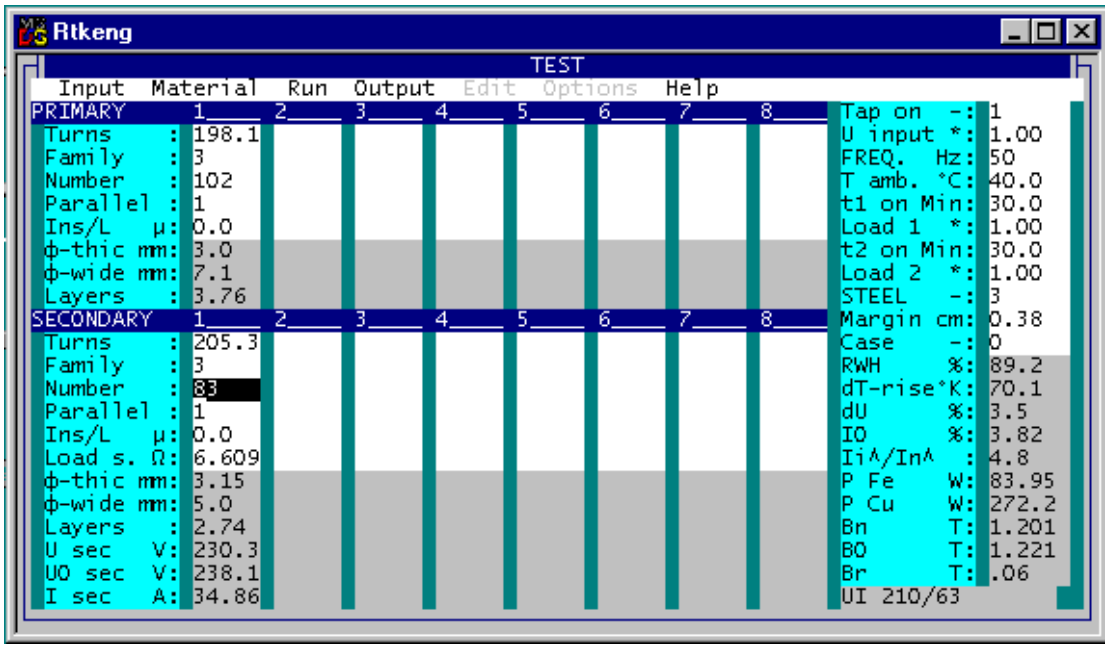

Rtkeng
OUTPUT
Input Material Run Output Edit Options Help
dT Gehäuse av. Surface °K:.
SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06
Losses active W:23293
Losses reactive VAr:2190.
Current factor %:247.9
Induction T:.645
dT Fe average Surface °K:4700.
dT primary °K:5380.
dT Gehäuse av. Surface °K:.
dT secondary °K:5540.
PRIMARY (Tap:1) 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8-----
Voltage V:243.8
Current A:38.66
Icc-Current warm A:95.84
Io -Current A:1.527
Inrush Current peak ^A:302.3
Inrush Current rms A:127.7
Cu-Losses W:163.5
Resistance cold Ω:.0749
Reactance Ω:.109
Eddy-Current Factor :1.06



12. This is followed by checking of the design data.

- We now check the winding data and the filling factor **(91.3%<100%)**.
- The maximum temperature of the windings is **40°C+79.0°K = 119°C < 120°C**.
- Short-circuit voltage = **3.82% > 3.6%** (see the corrections in the test mode)**.**
- The inrush current factor is somewhat less than 8:
  302.3A^/38.49A/1.41=5.7<8. We could use a higher induction.
  In the test program, we could manually select a lower wire thickness in the primary winding and increase the primary winding resistance so as to reduce the inrush current. At the same time, however, we should increase the wire thickness of the secondary winding so that the temperature of the windings will not exceed the prescribed limits.
- Iron losses should not exceed approximately 2% of the nominal output **(100*94.25W/8994VA=1.08% < 2%)**.
  The reactive component of the no-load current is **100*352.1VA/230V/38.59A= 3.95%**. For complete compensation, we should connect **two** condensers to the primary winding terminals, and the two condensers together should compensate the transformer's no-load reactance of **176.2 Ohm**: The capacitance value is **Ctotal = 1/176.2/314=18µF**. At approximately **6-7µF**, we would be safely below 3%.

13. This is followed by checking of the output voltage for a nominal input voltage of 230V: Uin = 1. Note that the wire size of the secondary winding was changed manually in order to get a better number of layers and to reduce the short-circuit voltage from 3.8% to 3.6%



14. If the design data is not satisfactory, then there are two ways by which we can implement the desired correction:

- You can return to the input mask (function key F2), correct the input data and redesign the transformer.
- Or you can access the test program (function key F5), modify the designed transformer manually and redesign the transformer by that means.

15. On completion of the design work, you can print out the design data on-line, or save it on your local PC and print it out off-line. The output data file from this design example, **CAL0008E.TK2**, is supplied together with this document. Copy it into the directory in which your Rale demo program is installed.

Tips & Tricks

The optimum solution
The optimum solution features the maximum permitted temperature and the maximum permitted short-circuit voltage at the same time. This also means that you can use the maximum induction in relation to the inrush current factor.

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