

# How should one design a three-phase rectifier/safety transformer for 24Vdc, 80A dc supply with RC load, as per IEC 38 and IEC 61558 ?

## Technical specification relevant only to design

### Electrical data and diagram

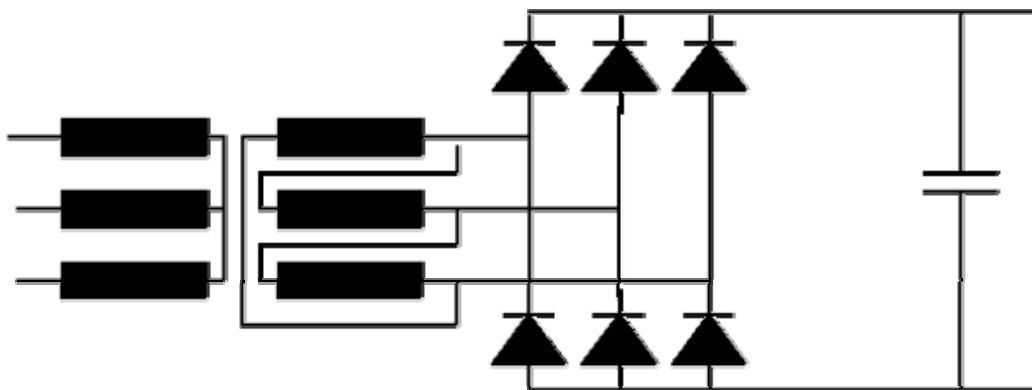
Input voltage	3 x 230V per phase , +6%, -10%, sinusoidal
Frequency	50Hz
Min. output voltage	20.4Vdc, at -10% input voltage
Nominal output voltage	24Vdc, at nominal input voltage
No-load voltage	28.8Vdc, at +6% input voltage
Nominal output current	80A dc, RC load
Voltage ripple	max 5%

### Ambient and operating conditions:

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

### Specification

- Safety transformer as per IEC 61558
- Insulation class E



## ***Design criteria***

### **IEC 61558**

A transformer with non-inherently short-circuit protection as per IEC 61558 is equipped with a safety. Normally, we try to provide effective protection both for the transformer and for the rectifier. Very often, we arrive at a combined protection solution consisting of three fuses matched to the rectifier and a thermal cutout. For these reasons, short-circuit and overload are not design criteria. The design criterion for purposes of IEC61558 is only temperature  $\theta$  **nominal**

Insulation class	A	E	B	F	H
Max. winding temperature in test $\theta$ <b>max</b> (° C)	200	215	225	240	260
Max. winding temperature in nominal operating mode $\theta$ <b>nominal</b> (° C)	100	115	120	140	165

### **Insulation class**

Max. winding temperature in nominal operating mode = 115°C

Max. winding temperature in test mode = 215°C

*Insulation class E is prescribed.*

### **IEC 38**

The above-prescribed limit values for voltages and for the ripple of a 24V dc supply are laid down by IEC 38. A rectifier/transformer with RC load, for which the minimum and maximum output voltages are prescribed, is designed in accordance with the regulation criterion (**Criterion = 1**).

### **Note 0:**

Rectifier/transformers with RC load can be designed **ONLY** in accordance with the **regulation** criterion. For that reason, we have to select a **regulation** solution such that the prescribed limit values for output voltage and temperature of the windings do not exceed  $\theta$  **nominal**.

### **Regulation (voltage increase)**

For purposes of designing the transformer in accordance with the **regulation** criterion (voltage increase), we have to input the value for the increase in the secondary voltages. This is calculated as follows, on the basis of the DC voltage information:

The transformer is calculated for an input voltage of 207Vac. In this context, the output voltage under load - in the hot state - must not fall short of 20.4Vdc. The maximum no-load voltage must not exceed the level of 28.8 at 243.8Vac input voltage.

At the input voltage of 207Vac, the no-load voltage must be below the values of

$28.8 \cdot 207 / 243.8 = 24.59 \text{Vdc}$ . This corresponds to a DC voltage increase of  $100 \cdot (24.5 - 20.4) / 20.4 = <20\%$ . The secondary voltage increase should be  $<10\%$  in accordance with the following table.

Regulation of secondary voltage %	Regulation of the DC voltage of a single-phase shunt rectifier with RC load %	Regulation of the DC voltage of a triple-phase shunt rectifier with RC load %
1	8-12	5-6
2.5	12-14	7-8
5	14-17	9-10
10	20-25	18-22
15	30-33	24-26

**Note 1:**

The first design calculation was performed with 10% regulation. At that level, the temperature of the windings was too high in operation at 243.8V. Only at 3.5% regulation who were satisfactory results obtained.

**Output voltage ripple**

$$\text{Ripple} = 100 \cdot (U_{dcmax} - U_{dcmin}) / (U_{dcmax} + U_{dcmin})$$

The program calculates the magnitude of the required capacity on the part of the smoothing condensers for the prescribed DC ripple.

*5% ripple is prescribed in accordance with IEC 38*

**Bobbin unit**

Our calculation was performed with a single-chamber bobbin unit. With a double-chamber bobbin unit, the transformer is somewhat larger. For this purpose, for however, we can use smoothing condensers of three to five times smaller capacity, and thus achieve the same ripple. In order to find the optimum solution, we have to perform one calculation with a single-chamber bobbin unit and one calculation with a double-chamber bobbin unit.

**Induction and Fe quality**

The choice of induction is selected at a voltage below the input voltage of minus 10% between 1.2 and 1.4.

The rectifier/transformer is very often installed together with the rectifier in a case or in a cabinet. For that reason, the loss output of the transformer should be sized low and the grain-related Fe quality should be used: M6X, ORSI 111,...

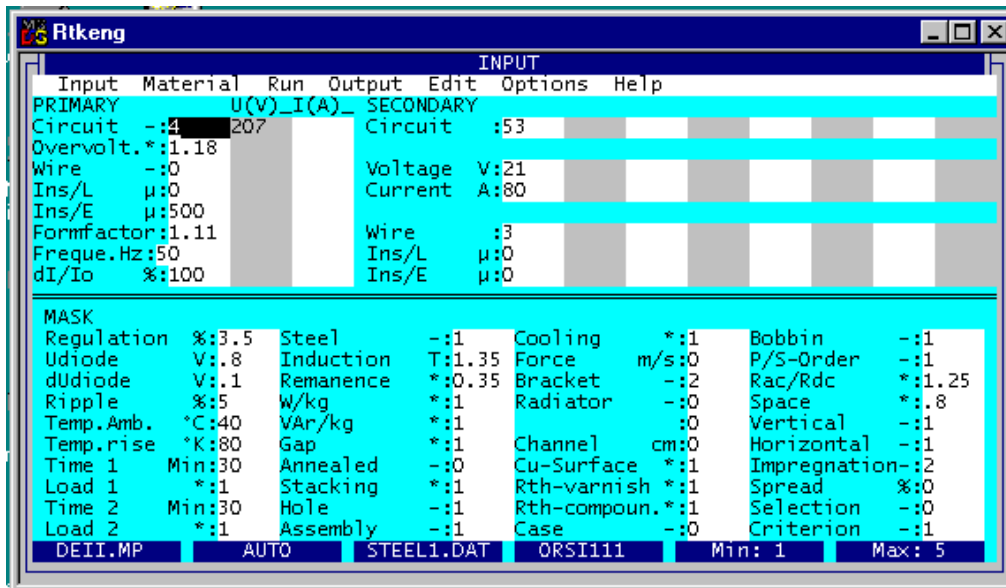
**Connection of transformer windings**

The primary winding is connected in a star circuit. The secondary is used in "Delta", so that the current through the winding is less and the application of

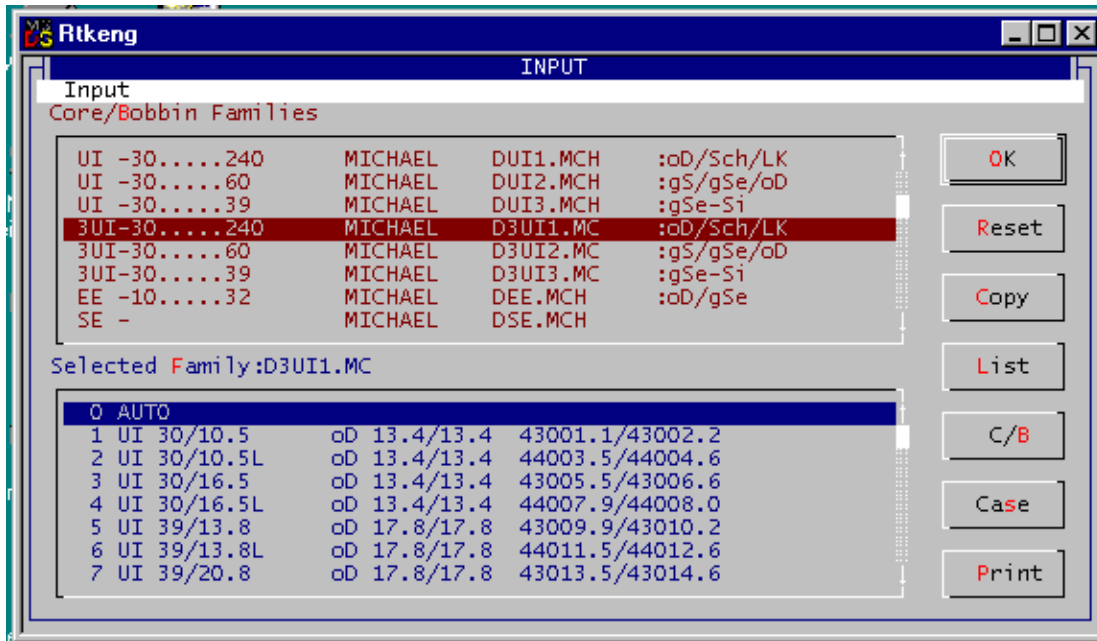
parallel-connected flat wires can be avoided.

### Procedure for design

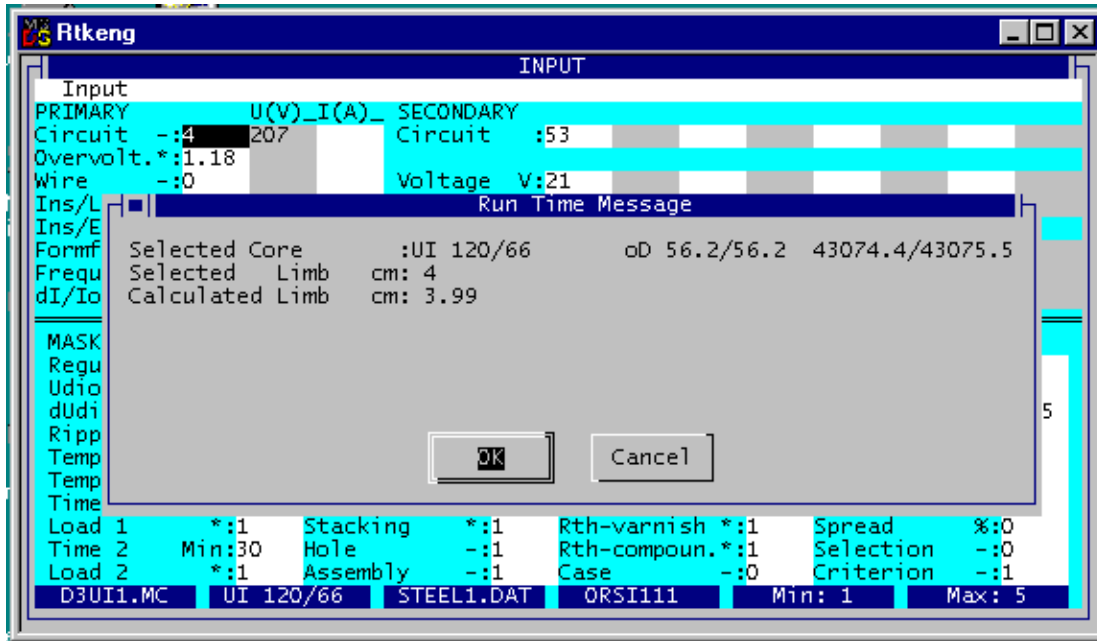
1. If you are not yet acquainted with Rale design software, please read the text "**How should I design a small transformer?**". Keep a copy of this text within convenient reach whenever performing design work.
2. Fill in the design input mask as follows. If you need any help, press function key F1.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



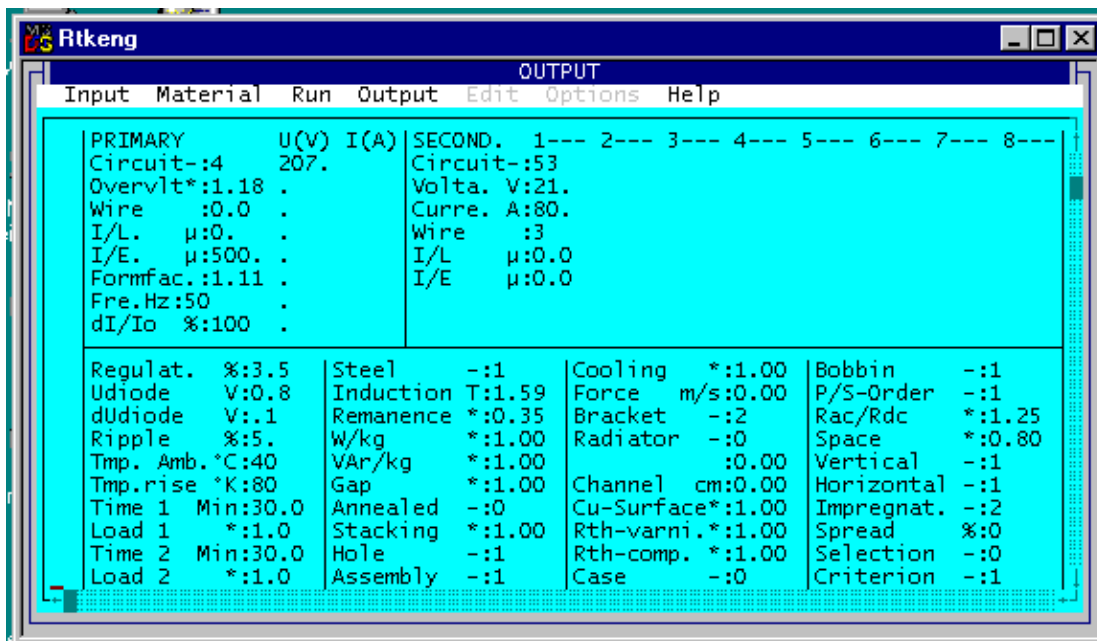
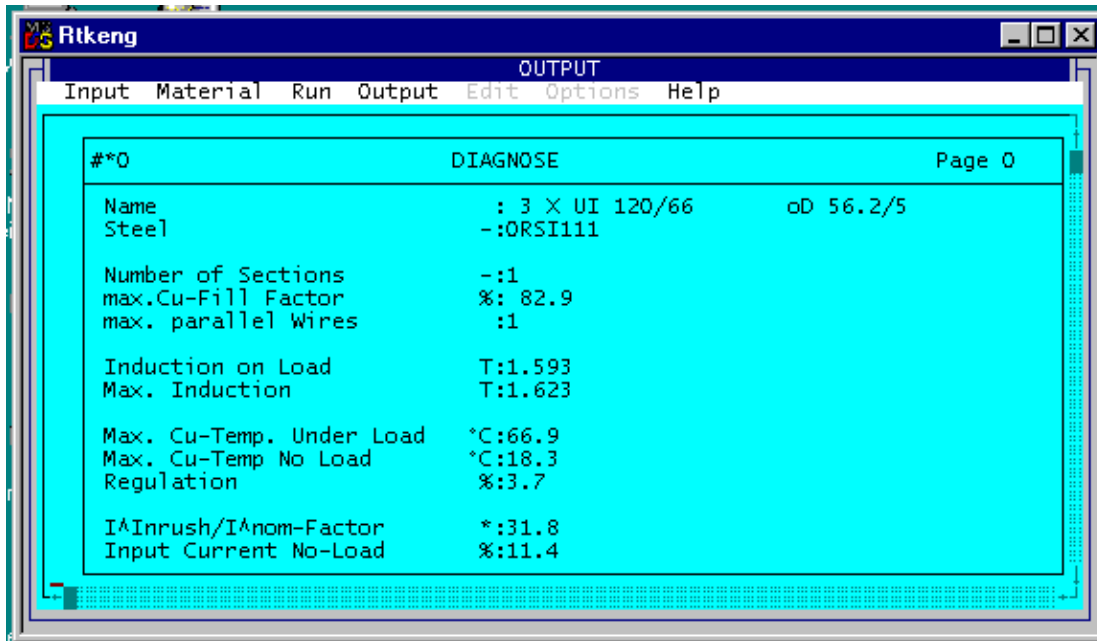
- The output **voltage** of 21Vdc at 80Adc is ensured at the under-voltage for the 207V input voltage. Temperature is designed simultaneous with the over-value of 243.8V for input voltage of 207V.
  - **Regulation = 3-5% <10%** was selected such that the maximum temperature of the windings does not exceed the value of  $\theta$  **nominal** and the output voltage is within the limits prescribed by IEC 38.
  - **Rac/Rdc = 1.25** was increased such that the program uses no parallel-connected flat wires.
  - **Winding space = 0.8** should be used for automatic selection of the core (**Selection=0**) with thick wires.
  - 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 triple-phase core family.
3. Save your input data file. In this specimen design calculation, we saved the input data in input data file **CAL0006E.TK1**. This input data file was supplied together with this document. Copy it into the directory in which your Rale demo program is installed.
  4. Connect up to the Rale design server.
  5. Load up your input data file.
  6. Now select the **three-phase** core family from which a suitable core is to be searched for your application. Ensure that the marked core is **AUTO**.

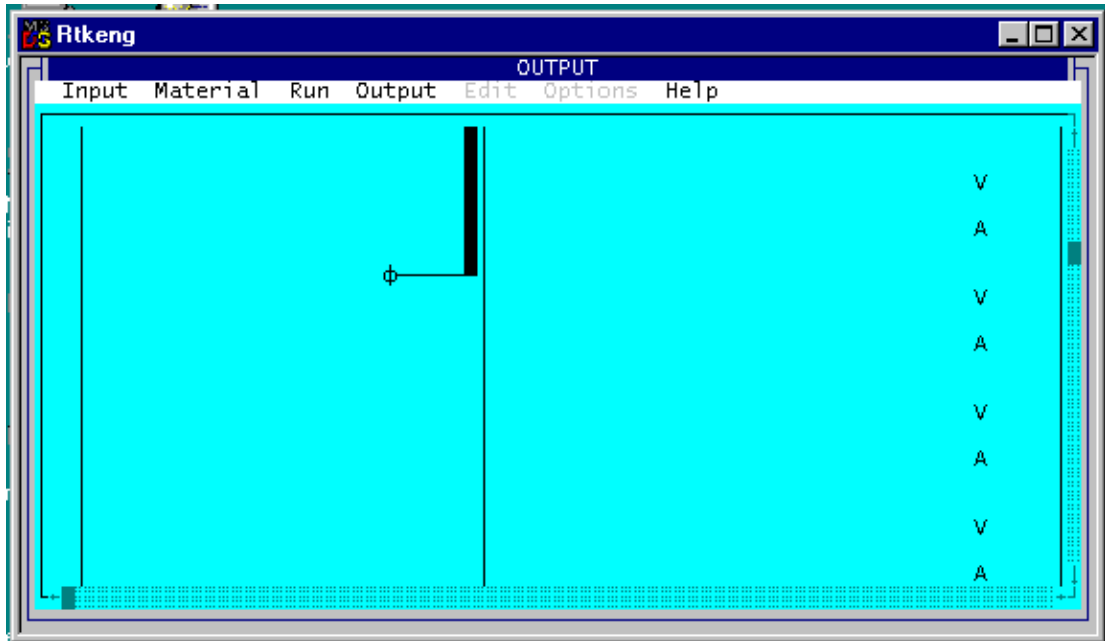
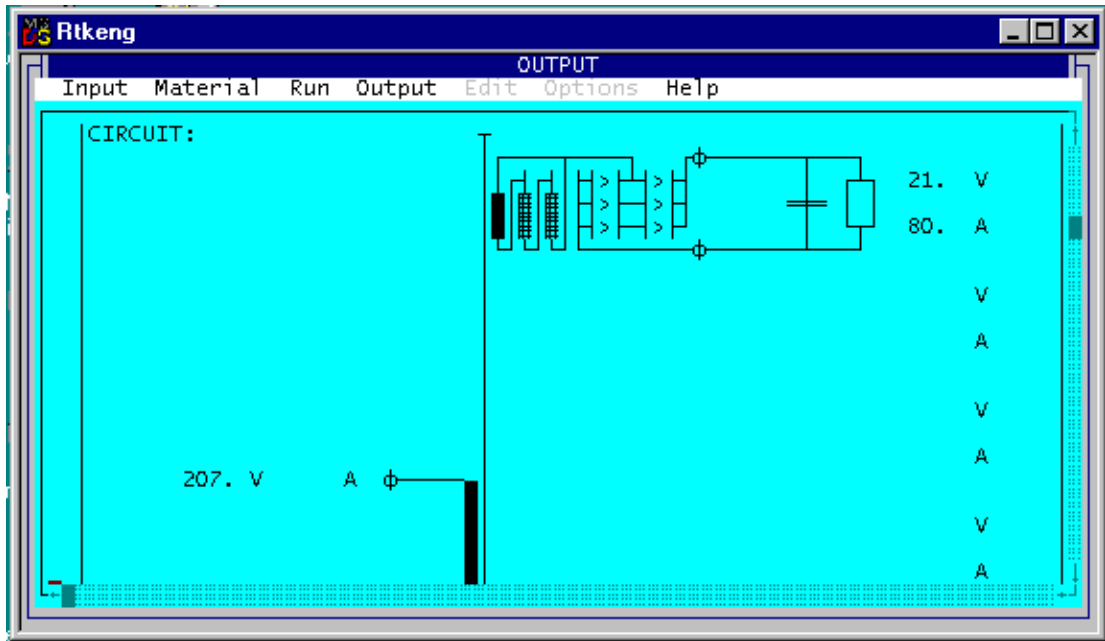


7. Click on **OK**.
8. Start your design work. In the system for automatic selection of the core from your prescribed three-phase core family, the program will offer you an adequately sized core for your application. Click on OK in order to accept the core.



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





**Rtkeng** OUTPUT

Input Material Run Output Edit Options Help

Name : 3XUI 120/66 oD 56.2/56.2 43074.4/43075.5  
 Steel :ORSI111 / .35

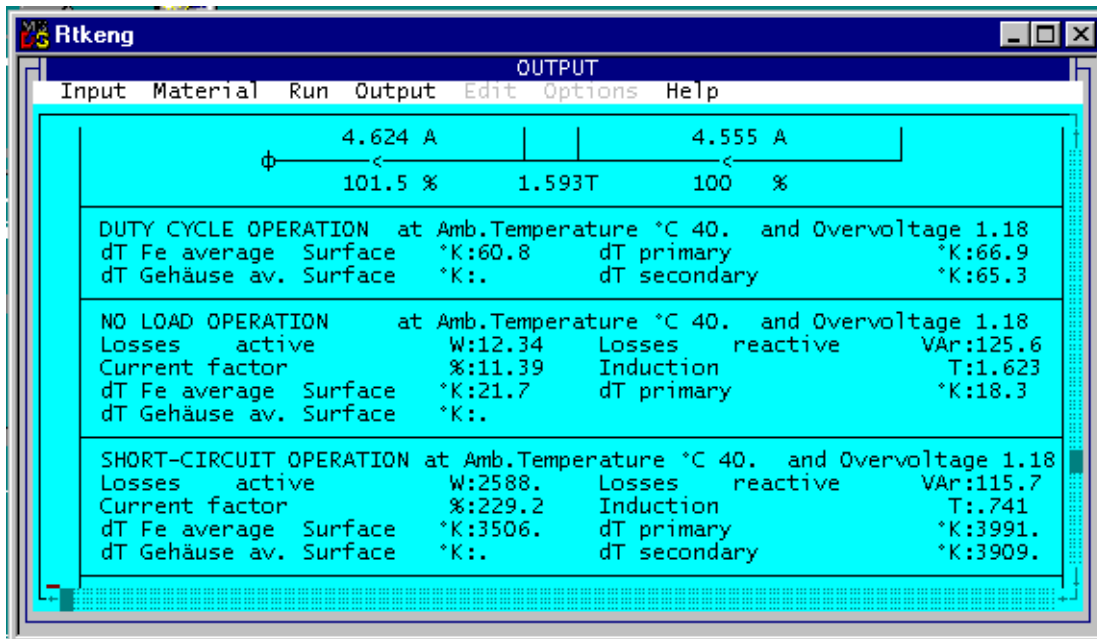
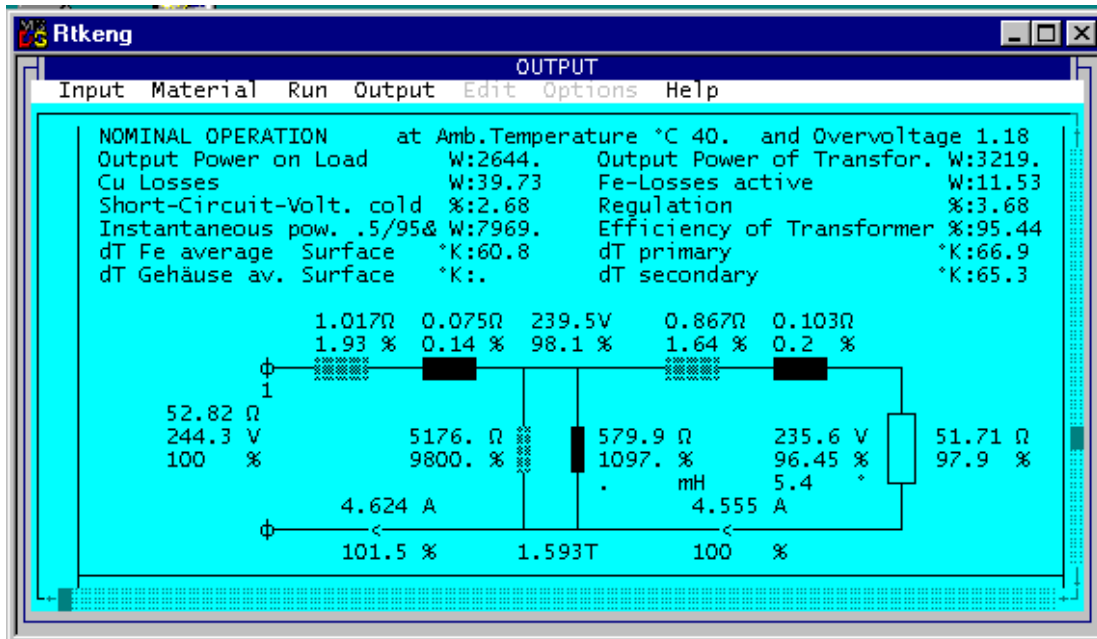
A B A B A D  
 φ G φ φ  
 φ φ φ  
 with two bobbins  
 a2 d2  
 a1 d1  
 1p

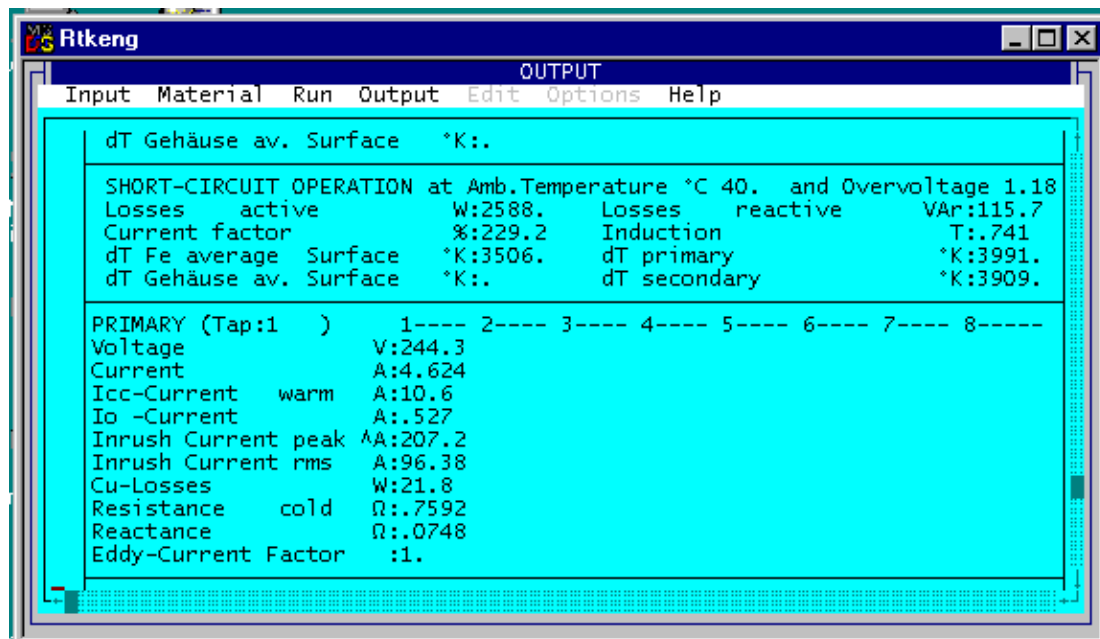
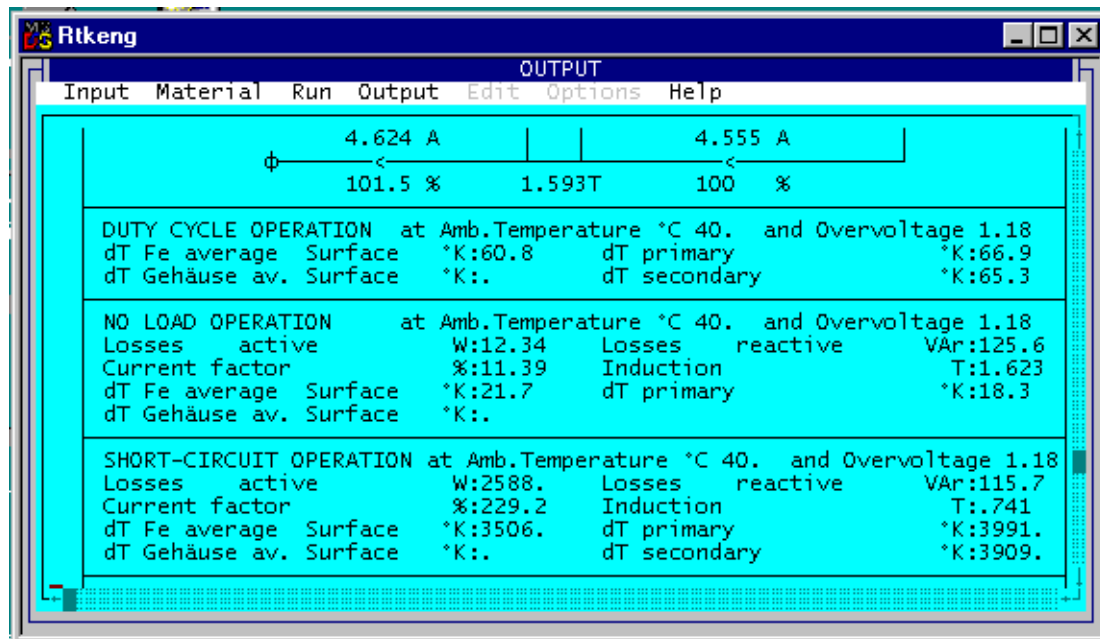
Weight gr:14811.  
 Gap total cm:0.000  
 A-Limb cm:4.00  
 B-Width cm:4.00  
 C-Height cm:12.00  
 D-Stack cm:6.60  
 E-Yoke 1 cm:4.00  
 F-Yoke 2 cm:4.00  
 G-Hole cm:1.156  
 Radiator Fin :0  
 Radiator Chan. :0  
 a1 cm:4.48  
 a2 cm:7.84  
 d1 cm 7.00  
 d2 cm 11.00  
 1 cm:11.44  
 1p cm:

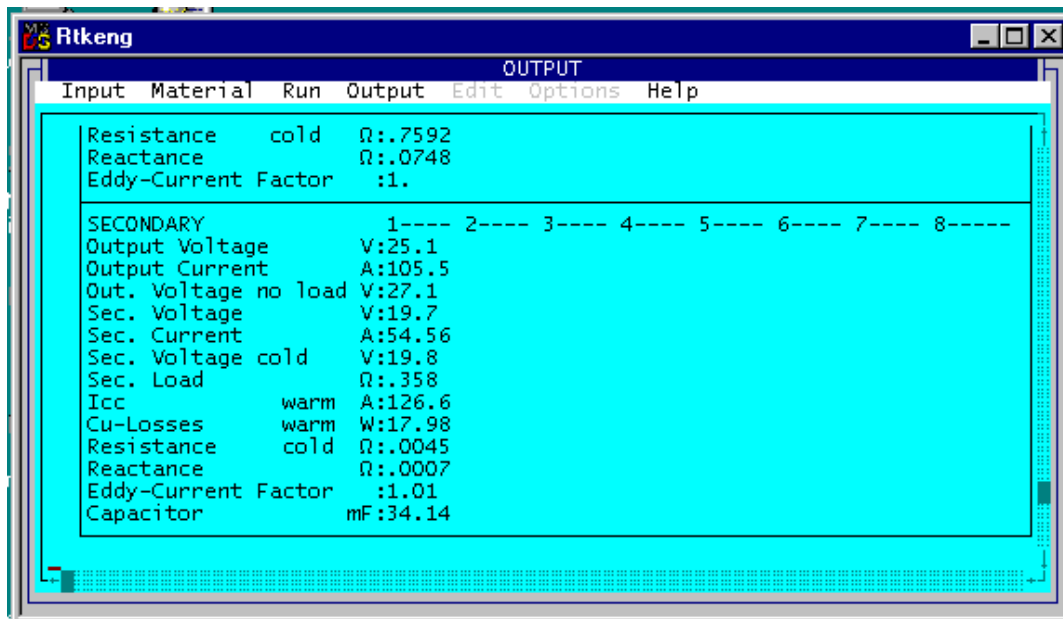
**Rtkeng** OUTPUT

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	4	265.9	0	88.0	88.0	1	1.4	1.4	74.41	3.57	.	500	893.71	38.
2														
3														
4														
5														
6														
7														
8														
1	53	22.2	1	77.0	95.0	1	3.	8.5	11.96	1.86	.	.	1469.2	41.
2														
3														
4														
5														
6														
7														
8														



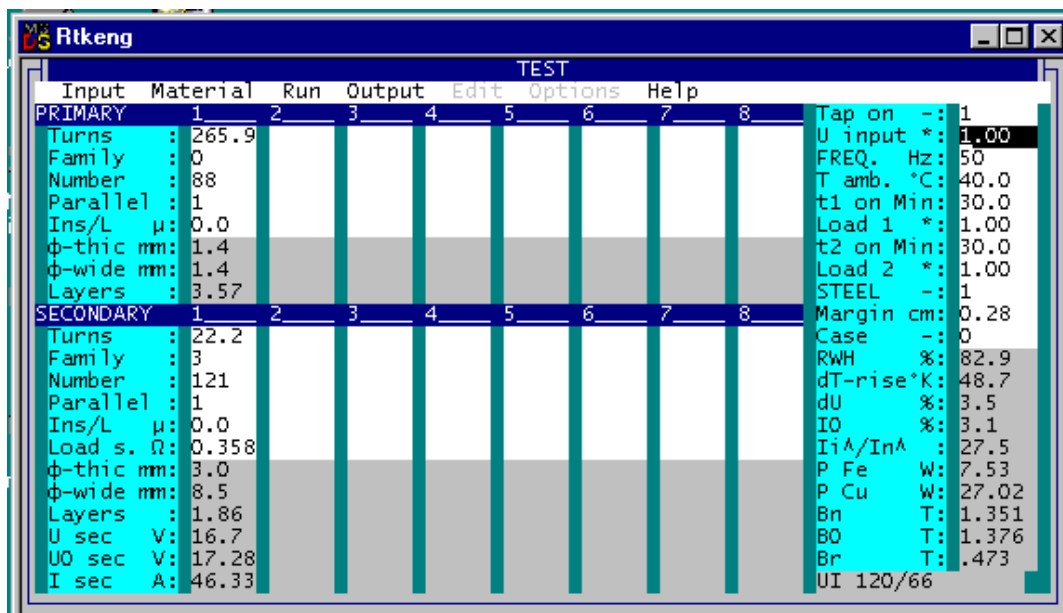




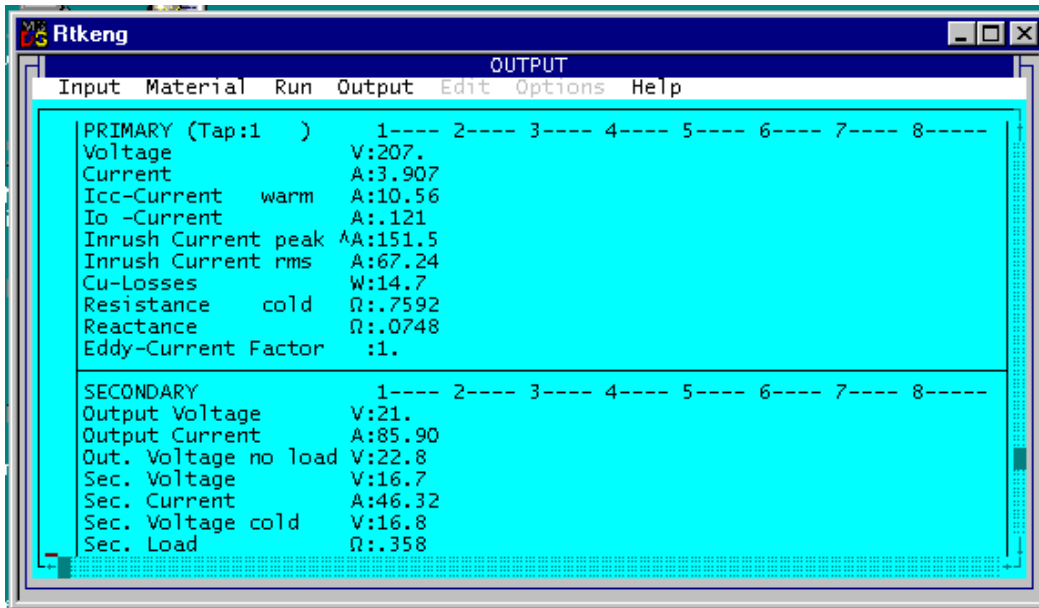
9. This is followed by checking of the design data.

- Firstly, we check the DC output voltages in no-load mode for input voltage of 244.3Vac:  $27.1\text{Vdc} < 28.8\text{Vdc}$
- We then check the winding data and the filling factor ( $82.0 < 100\%$ ).
- The maximum temperature of the windings is  $40^\circ\text{C} + 66.9^\circ\text{K} = 106.9^\circ\text{C} < 115^\circ\text{C}$ .

This is followed by checking of the output voltage for an input voltage of 207V:  $U_{in} = 1$ .



On the third page of the winding datasheet we should check the output voltages for an input voltage of 207V:  $21\text{Vdc} > 20.4\text{Vdc}$ .



10. 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.

11. 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, CAL0006E.TK2, is supplied together with this document. Copy it into the directory in which your Rale demo program is installed.

### ***Tips & Tricks***

#### **Temperature in nominal operating mode is too high**

- Reduce your regulation and increase your induction.
- Employ a better iron quality
- Increase your cooling surface area. In the case of 3UI cores, the base angles are very effective for this purpose. You can reduce the windings' temperature rise by approximately 10%-15%.

#### **Smoothing condenser**

For the prescribed DC ripple of 5%, the program has calculated the value of **33000μF+20%**.

For the same output voltage ripple, a 2-chamber transformer requires only **6700μF!**

## Regulation

We selected **regulation = 3.5%**, so that the overtemperature would not be too high. In the case of a double-chamber transformer which has a higher scatter inductance, a higher degree of regulation is permissible. In our case, **regulation = 5%** is perfectly suitable.

[Home](#)