

How should one design a low inrush current universal control transformer for 800VA continuous output power as per IEC 61558 ?

Technical specification relevant only to design

Electrical data and diagram

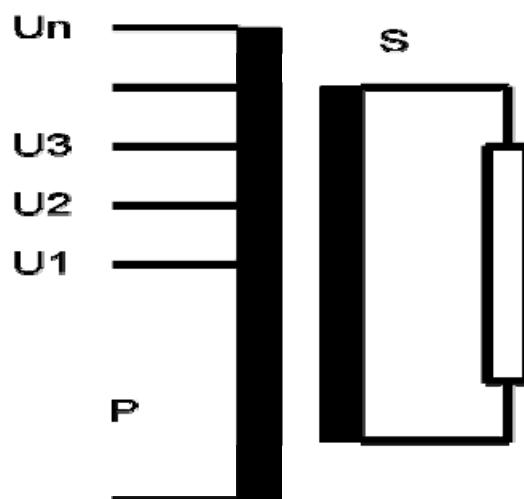
Input voltages sinusoidal	210V, 230V, 250V, 380V, 400V, 420V
Frequency	50Hz
Nominal output voltage	230V
Max. no-load voltage	253V at nominal input voltage
Nominal output current	3.47A (800VA)

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. Very often, we arrive at a combined protection solution consisting of a primary-side fuse and a thermal cutout. For this reason, short-circuit and overload are not design criteria. The criterion for design for purposes of IEC 61558 is only temperature θ **nominal** and the maximum permitted **regulation** (voltage increase), in relation to nominal output voltage at 10% nominal input voltage.

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 operating mode θ nominal (°C)	100	115	120	140	165
Max.voltage increase (%)	10	10	10	10	10

Insulation class

Max winding temperature in nominal operating mode =115°C

Max winding temperature in test mode = 215°C

Insulation class E is prescribed.

The criterion for design

The computer program employs two design criteria:

- Regulation (voltage increase)<10%
- Temperature rise <75°K at 40°C ambient temperature and insulation class E.

*Since we do not know which of these criteria is more important for design purposes, we enter **Criterion=0** and leave it to the computer program to decide.*

Bobbin unit

Control transformers have to be made with a low internal resistance and a low scatter impedance. For that reason, control transformers are constructed exclusively with single-chamber bobbin units.

Induction and Fe-quality

Low Inrush-current transformers are operated at a low induction (1.2T-1.5T). In the output range up to approximately 200VA, cold-rolled Fe quality 5.3W/kg is used at 1.5T, 50Hz. Over and above that, we find cold-rolled Fe-quality 4.00W/kg at 1.5T, 50Hz and grain-oriented Fe-quality 1.11W/kg at 1.5T,50Hz.

Inrush current

The peak value of the inrush current in the first period after switch-on at the zero-axis crossing point should not exceed a factor of 15 x the peak value for nominal input current. This can best be achieved if:

- The nominal induction is 1.2T-1.5T.
- The core is constructed with a defined gap of approx 0.05-0.10 mm, so as to reduce residual magnetism (remanence).
- The primary winding is routed to the outside.

Design procedure

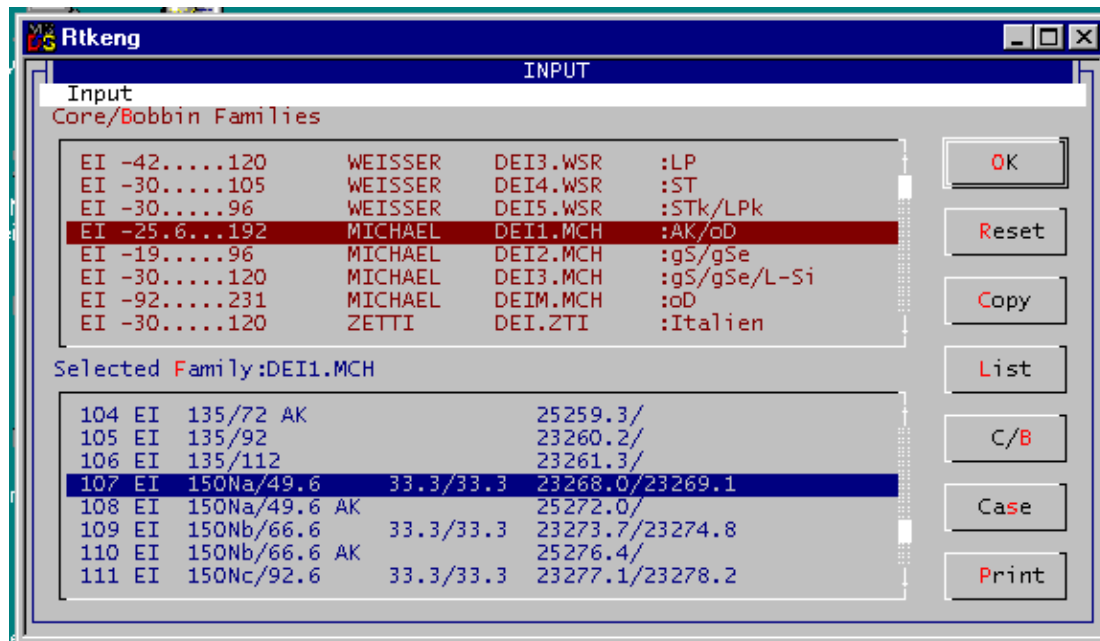
1. If you are not yet acquainted with Rale design software, please read the text "**How should I design a small transformer?**". Keep a copy of this text within convenient reach whenever performing design work.
2. Fill in the design input mask as follows. If you need any help, press function key F1.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

PRIMARY		SECONDARY	
U(V)	210	Circuit	:11
I(A)		Voltage V	:230
Circuit	:-1	Current A	:4.38
Overvolt.%	:1.06	Wire	:0
Wire	:-0	Ins/L	:0
Ins/L	:0	Ins/E	:0
Ins/E	:500		
Formfactor	:1.11		
Freque.Hz	:50		
dI/Io	:%100		

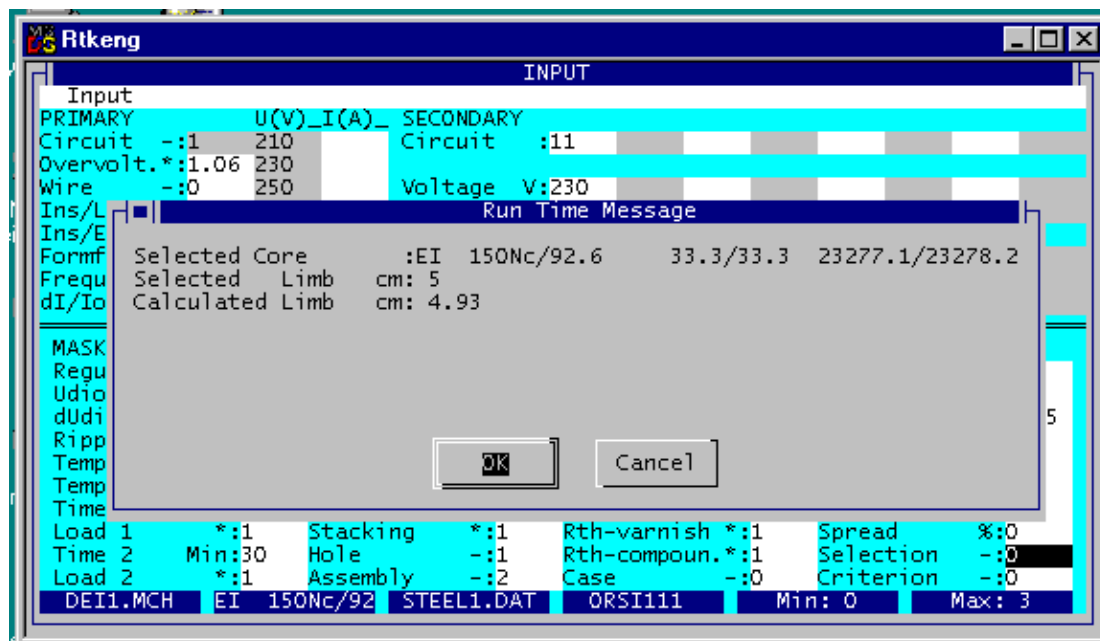
MASK							
Regulation	:%10	Steel	:-1	Cooling	*:1	Bobbin	:-1
Udiode	V:0.8	Induction	T:1.25	Force	m/s:0	P/S-Order	:-1
dUdiode	V:.05	Remanence	*:0.05	Bracket	:-1	Rac/Rdc	*:1.05
Ripple	:%5	W/kg	*:1	Radiator	:-0	Space	*:1.9
Temp.Amb.	:C:40	VAr/kg	*:1	Channel	cm:0	Vertical	:-1
Temp.rise	*K:70	Gap	*:2	Cu-Surface	*:1	Horizontal	:-1
Time 1	Min:30	Annealed	:-0	Rth-varnish	*:1	Impregnation	:-2
Load 1	*:1	Stacking	*:1	Rth-compoun.	*:1	Spread	:%0
Time 2	Min:30	Hole	:-1	Case	:-0	Selection	:-0
Load 2	*:1	Assembly	:-2			Criterion	:-0

DEI1.MCH EI 150Na/49 STEEL1.DAT ORSI111 Min: 1 Max: 5

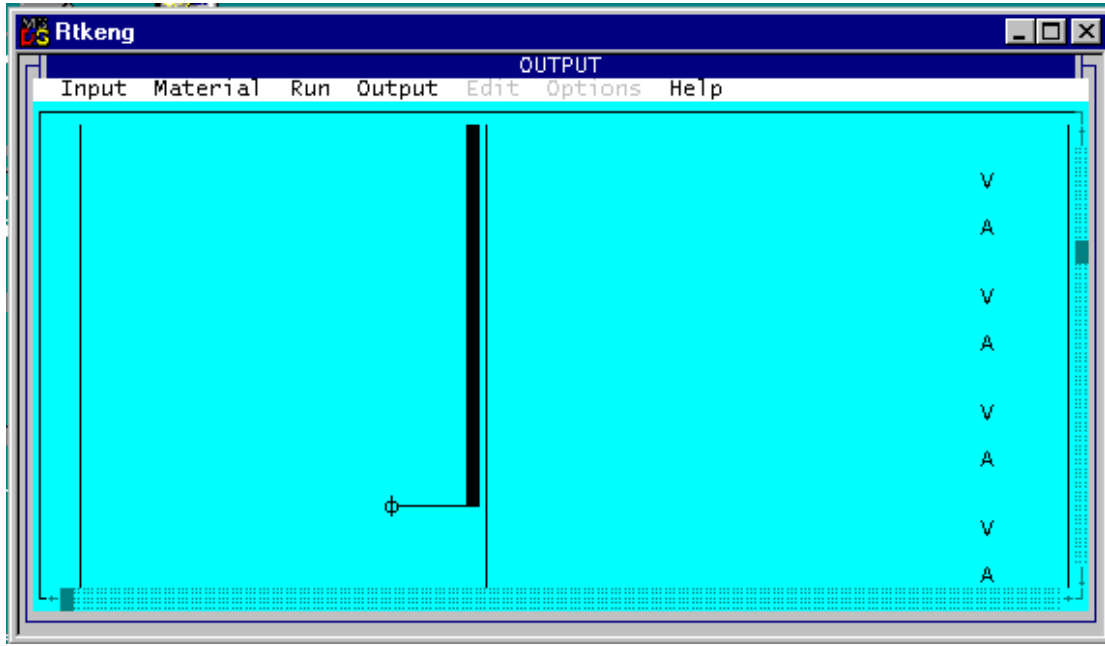
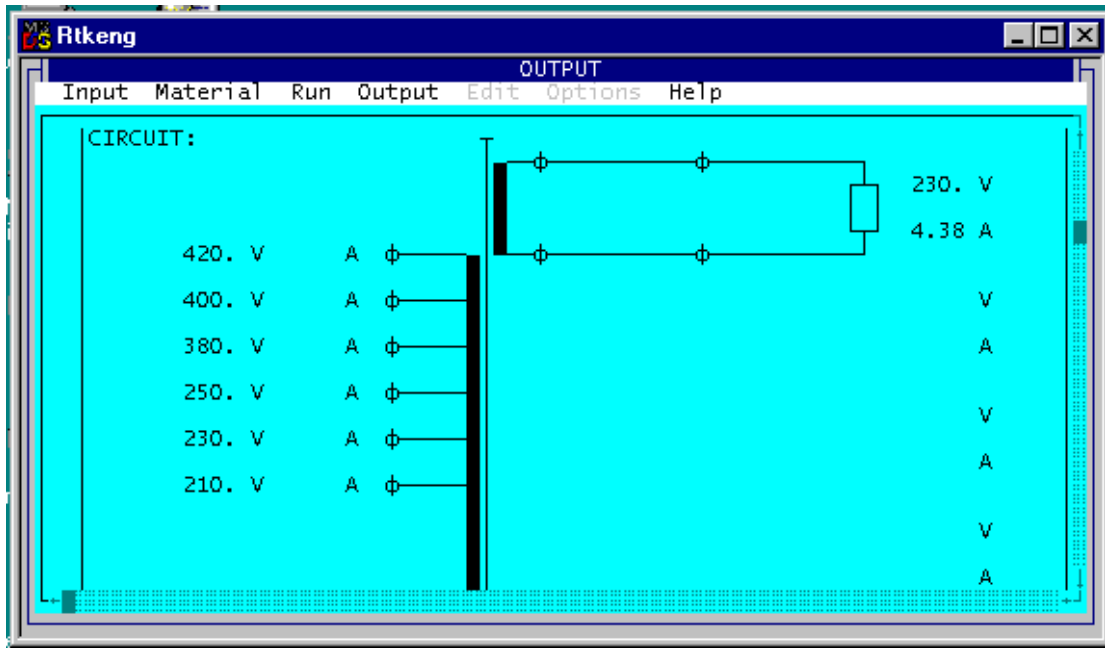
3. The **Selection** input field is set at **0**. This means that the program should search on-line for a suitable core for this application, from your selected core family.
4. Save your input data file. In this specimen design calculation, we saved the input data in input data file **CAL0007E.TK1**. This input data file was supplied together with this document. Copy it into the directory in which your Rale demo program is installed.
5. Connect up to the Rale design server.
6. Load up your input data file.
7. Now select the core family and the core from which a suitable core is to be searched by the computer program.



- Click on **OK**.
- Start your design work. In the system for automatic selection of the 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 be printed on the three pages:



Rtkeng OUTPUT

Input Material Run Output Edit Options Help

Name : 1XEI 150Nc/92.6 33.3/33.3 23277.1/23278.2
 Steel :ORSI111 /.35

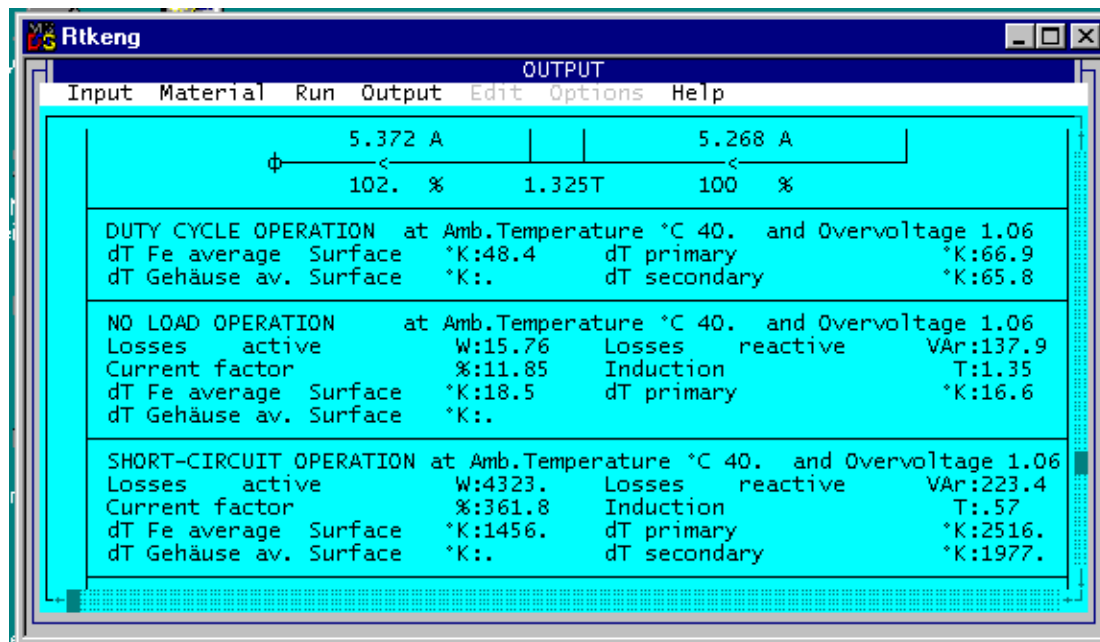
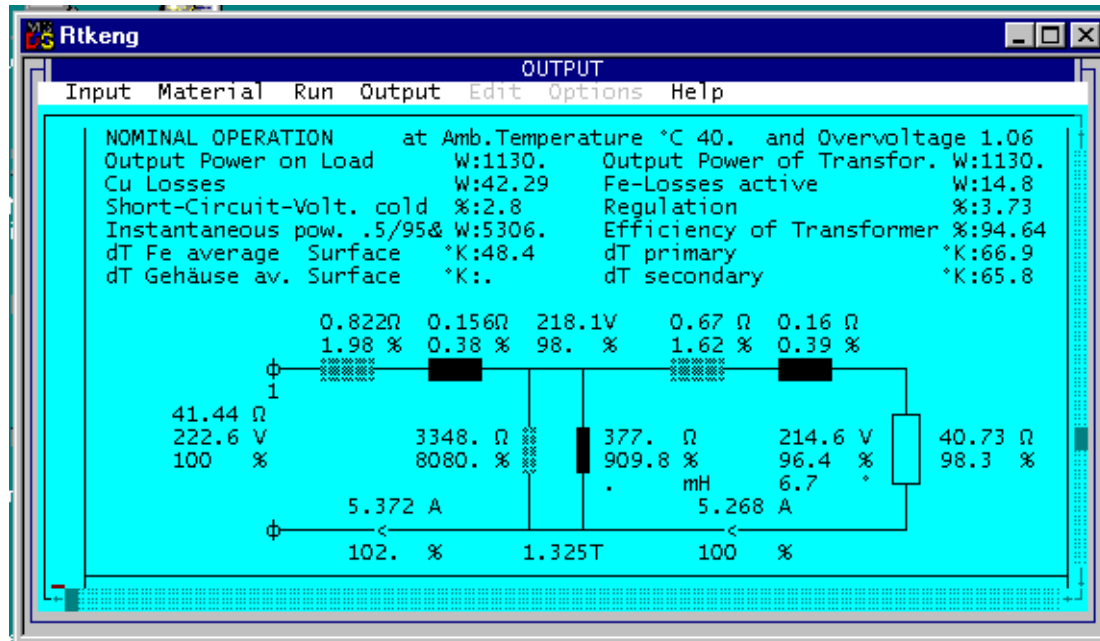
Weight gr:10242.
 Gap total cm:0.000
 A-Limb cm:5.00
 B-Width cm:2.50
 C-Height cm:7.50
 D-Stack cm:9.25
 E-Yoke 1 cm:2.50
 F-Yoke 2 cm:2.50
 G-Hole cm:0.80
 Radiator Fin :0
 Radiator Chan. :0

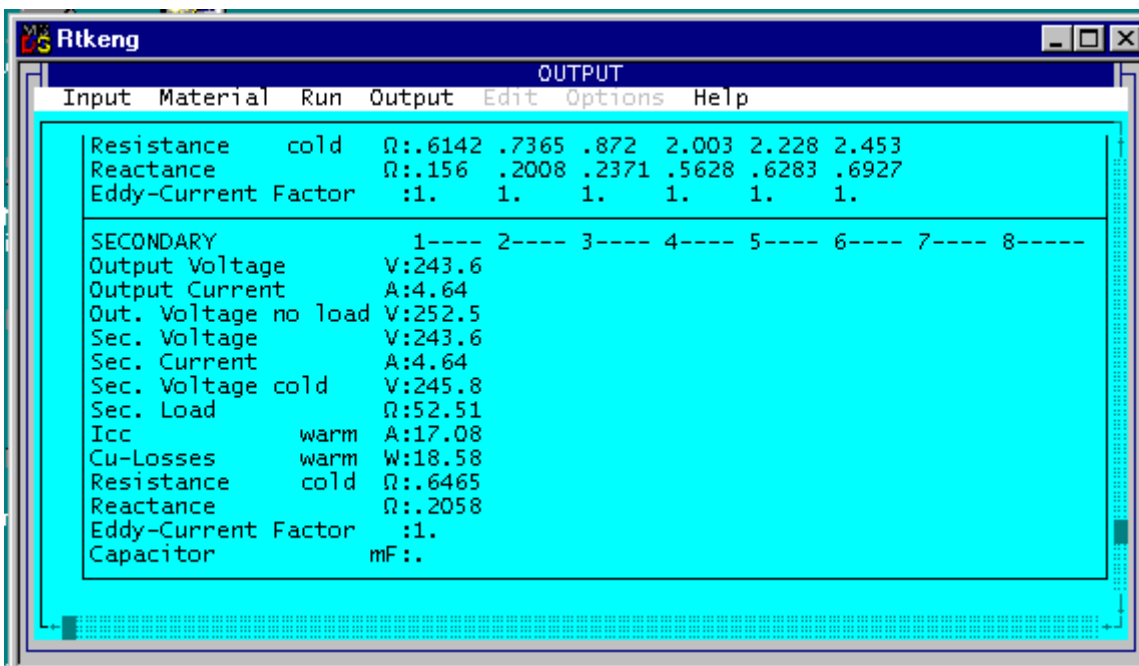
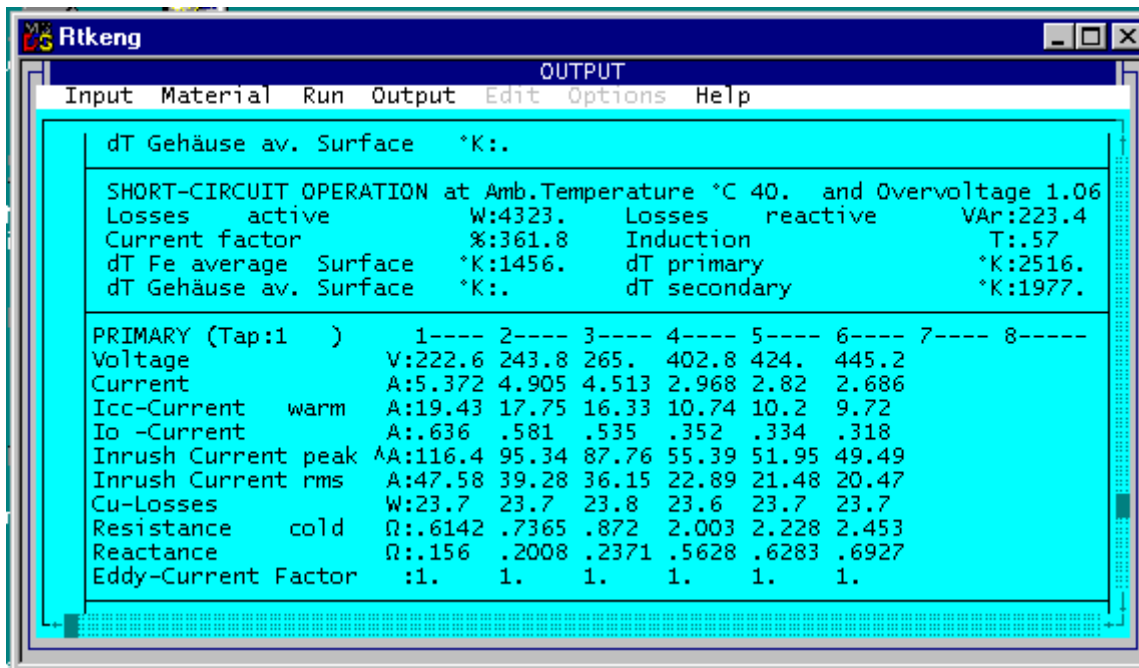
a1 cm:5.50
 a2 cm:9.70
 d1 cm 9.65
 d2 cm 15.00
 l cm:6.90
 lp cm:

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	166.2	0	88.0	88.0	1	1.4	1.4	44.48	3.74	.	500	722.97	30.
2	1	182.	0	82.0	82.0	1	1.	1.	61.9	.26	.	500	37.905	5.4
3	1	197.9	0	81.0	81.0	1	.95	.95	65.64	.24	.	500	34.158	5.1
4	1	300.8	0	79.0	79.0	1	.85	.85	72.71	1.42	.	500	182.83	9.3
5	1	316.6	0	77.0	77.0	1	.75	.75	82.16	.19	.	500	22.003	4.1
6	1	332.4	0	77.0	77.0	1	.75	.75	82.16	.19	.	500	22.049	4.1
7														
8														
1	11	188.7	0	90.0	90.0	1	1.6	1.6	39.07	4.83	.	100	1313.4	43.
2														
3														
4														
5														
6														
7														
8														





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

- We now check the winding data and the filling factor ($90.5 < 100\%$).
- The maximum temperature of the windings is $40^{\circ}\text{C} + 66.9^{\circ}\text{K} = 106.9^{\circ}\text{C} < 115^{\circ}\text{C}$.
- Regulation = $3.73\% < 10\%$.
- The inrush current factor is slightly more than $15 \times : 15.4 > 15$.

With a reduction in induction, there would be no problem in reducing the inrush current factor. In the test program, however, it is possible to set a lower primary winding wire size manually to increase the impedance of the primary winding. However, so that the temperature of the windings does not then exceed the prescribed limit values, we have to increase the secondary winding wire size at the same time.

- The primary windings' wire size, calculated by the program are not optimized for production. In the test program, only two wire sizes should be employed: 1.4mm to 240V and 0.85mm between 240 and 420V.

11. This is followed by checking of the output voltage at the nominal input voltage of 230V: $U_{in} = 1$

	Input	Material	Run	Output	Edit	Options	Help	
PRIMARY	1	2	3	4	5	6	7	8
Turns	: 166.2	182.3	198.4	301.1	317.	333.		
Family	: 0							
Number	: 88	88	88	79	79	79		
Parallel	: 1	1	1	1	1	1		
Ins/L	μ: 0.0							
φ-thic	mm: 1.4	1.4	1.4	0.85	0.85	0.85		
φ-wide	mm: 1.4	1.4	1.4	0.85	0.85	0.85		
Layers	: 3.74	0.36	0.36	1.41	0.22	0.22		
SECONDARY	1	2	3	4	5	6	7	8
Turns	: 188.7							
Family	: 0							
Number	: 90							
Parallel	: 1							
Ins/L	μ: 0.0							
Load s.	Ω: 52.51							
φ-thic	mm: 1.6							
φ-wide	mm: 1.6							
Layers	: 4.83							
U sec	V: 243.5							
U0 sec	V: 252.5							
I sec	A: 4.64							

12. 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.

13. 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, **CAL0007E.TK2**, is supplied together with this document. Copy it into the directory in which your Rale demo program is installed.

Tips & Tricks

Instantaneous output power

In accordance with IEC 61558, the instantaneous output power of a control transformer is measured as follows:

The transformer is connected to the nominal input voltage. At the output, there is selected an inductive load for which $\cos\phi = 0.5$, such that the output voltage is 95% of the nominal output voltage. In this context, the output voltage is measured as follows.

Instantaneous output power = 0.95*nominal output voltage* I_{measured}

In our case the instantaneous output power is 2991VA.

Supply Voltages Worldwide

100V 60Hz	Japan, Korea, Okinawa
100V 50Hz	Japan
105V 60Hz	Korea
110V 60Hz	Belize, Brazil, Colombia, Dominican Republic, Ecuador, Guam, Guyana, Haiti, Honduras, Panama, Peru, Philippines, Taiwan
110V 50Hz	Azores, Belgium, Bolivia, France, Guyana, Haiti, Jamaica, Lebanon, Somalia, Turkey
115V 60Hz	Brazil, El Salvador, Netherlands Antilles, Panama, Philippines, Surinam, Trinidad and Tobago, Barbados, Bolivia, France
115V 50Hz	Barbados, Bolivia, France
120V 60Hz	American Samoa, Bahamas, Bermuda, Brazil, Canada, Cayman Islands, Colombia, Costa Rica, Ecuador, Guam, Guatemala, Haiti, Liberia, Netherlands Antilles, Nicaragua, Okinawa, Puerto Rico, Venezuela, Virgin Islands (American)
120V 50Hz	Cambodia, France, Luxembourg, Venezuela, Vietnam
125V 60Hz	Brazil
125V 50Hz	France, Indonesia
126V 60Hz	Panama
127V 60Hz	Brazil, Ecuador, Mexico, Netherlands Antilles, Saudi Arabia, Tahiti
127V 50Hz	Algeria, Belgium, Brazil, Cameroon, Canary Islands, France, Italy, Libya, Madagascar, Mallorca Island,

	Monaco, Morocco, Netherlands Antilles, Senegal, Spain, Surinam, Togo, Tunisia, Vietnam
130V 50Hz	Belgium
150V 60Hz	Colombia
200V 50Hz	Hong Kong
220V 60Hz	Afghanistan, Belize, Brazil, Korea, Peru
220V 50Hz	Afghanistan, Algeria, Angola, Argentina, Austria, Azores, Bangladesh, Belgium, Benin, Bolivia, Botswana, Bulgaria, Burundi, Cambodia, Cameroon, Canary Islands, Cape Verde, Central African Republic, Chad, Chile, China (P.R.), Congo, Czech Republic, Denmark, Djibouti, Egypt, Equatorial Guinea, Ethiopia, Faeroe Islands, Finland, France, French Guiana, Gabon, Gambia, German D.R., Fed. Rep of Germany, Ghana, Greece, Greenland, Guadeloupe, Guinea, Guinea-Bissau, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Italy, Ivory Coast, Jerusalem, Jordan, Laos, Lebanon, Lesotho, Luxembourg, Macau, Madagascar, Madeira, Mallorca Island, Mali, Martinique, Monaco, Morocco, Mozambique, Nepal, Netherlands, Netherlands Antilles, New Caledonia, Niger, Paraguay, Peru, Poland, Portugal, Romania, Rwanda, Saudi Arabia, Somalia, South Africa, Spain, Sweden, Switzerland, Syria, Thailand, Togo, Tunisia, Turkey, the former USSR, United Arab Emirates, United Kingdom (Northern Ireland), Upper Volta, Uruguay, Vietnam, Yemen

	(Arab Rep.), Yugoslavia, Croatia, Slovenia, Macedonia, Bosna- Hercegovina, Zaire, Zambia, Zimbabwe
230V 60Hz	Antigua, Bahrain, Brazil, St. Kitts and Nevis, Trinidad and Tobago
230V 50Hz	Bahrain, Bolivia, Belgium, Burma, Cameroon, Channel Islands, Dominica, France, Grenada, India, Israel, Libya, Malawi, Malaysia, Maldives, Mauritius, Montserrat, New Zealand, Nigeria, Norway, Pakistan, St. Vincent, Saudi Arabia, Sierra Leone, Singapore, Somalia, South Africa, Sri Lanka, Swaziland, Tanzania, United Arab Emirates, United Kingdom (Northern Ireland), Western Samoa, Yemen (Aden), Zimbabwe
240V 60Hz	American Samoa
240V 50Hz	Australia, Channel Islands, Cyprus, Fiji, Gibraltar, Isle of Man, Kenya, Kuwait, Malaysia,, Malta, Oman, Papua, Qatar, St. Lucia, Seychelles, South Africa, Sudan, Tonga, Uganda, United Arab Emirates, United Kingdom (England, Scotland, Wales)
250V 50Hz	Australia, South Africa
380V 50Hz	France

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