

**How should one design
a 250kHz, 120W forward transformer with voltage controller,
for input voltage range 200V to 350V,
as per IEC 61558?**

Technical specification relevant only to design

Electrical data and diagram:

Input voltages range	200Vdc - 350Vdc (bridge rectifier with RC-load, for input voltage 230Vac+10%-20%, 50Hz)
Frequency	70kHz
Nominal output voltage	2 x 12Vdc, automatic controlled on the primary side
Nominal output current	2 x 5Adc, -50%
Ripple of the input current	Max. 50% at the maximal input voltage and the nominal load

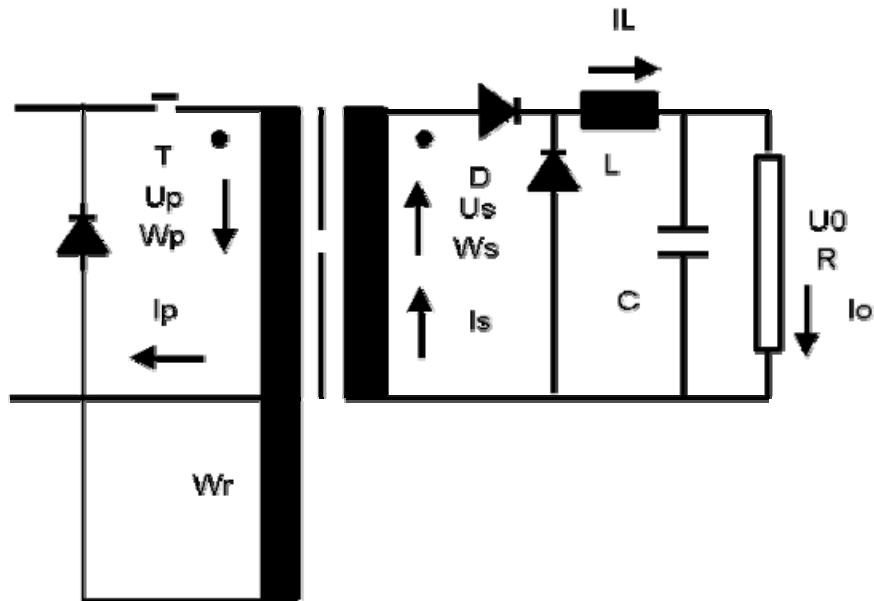
Ambient and operating conditions:

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

Specification

Insulation class E

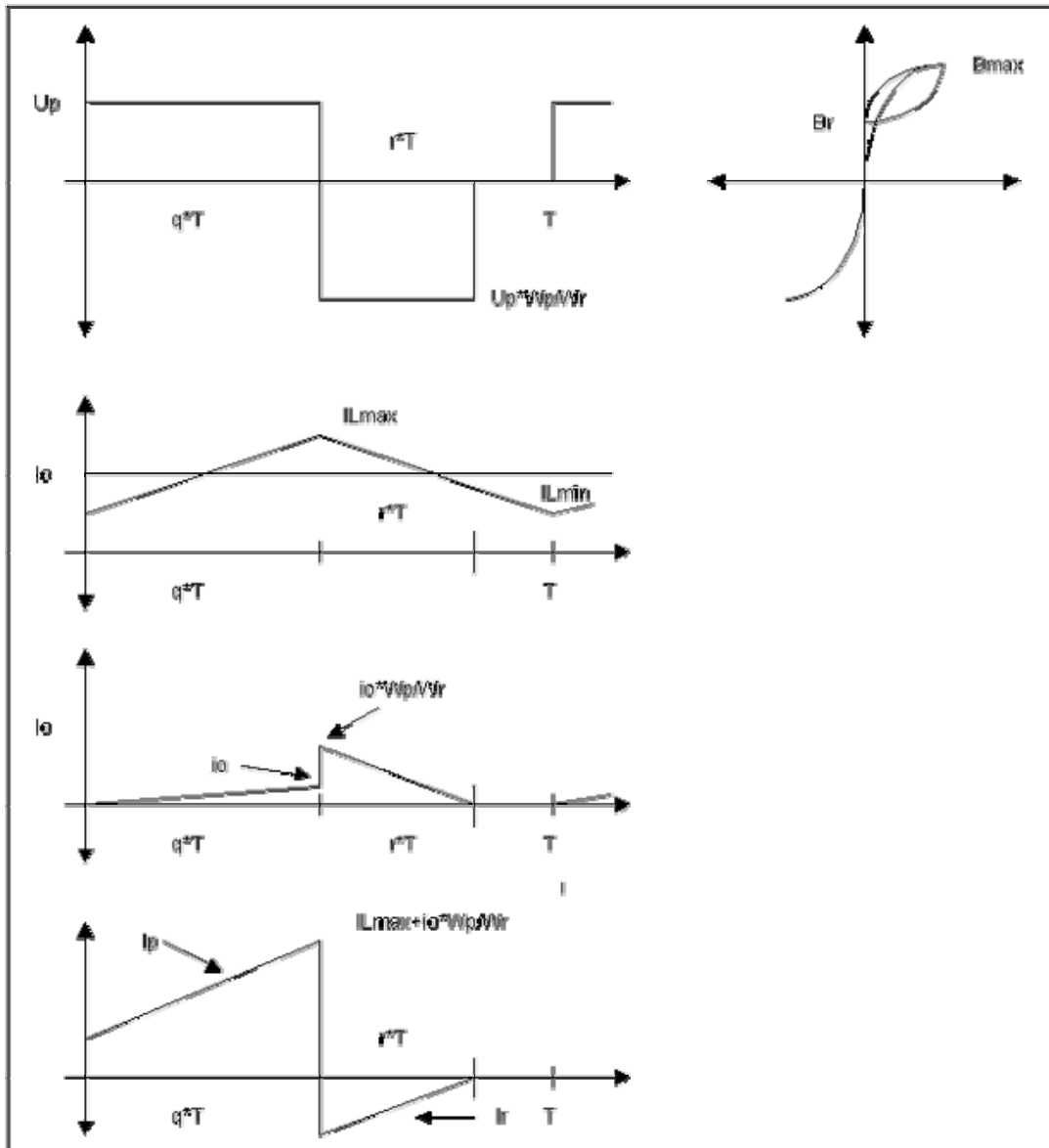
The following forward transformer diagram illustrates only parameters relating to design. The windings for rekuperation and for measurement cannot be calculated by program.



During the initial half period a normal AC transformer is powered by positive voltage, and during the second half period by negative voltage. The values of the voltage-time surfaces of both voltages are the same. This changes the induction in the core of the AC transformer from $-B_{max}$ to $+B_{max}$.

In the case of a forward transformer, the start of the primary development W_p during the initial switching period $q \cdot T$, which is not necessarily the same as the second switching period, is fed to the input voltage U_p . In this time the induction rises from B_r to B_{max} . During the second switching period the end of the recuperation development W_r is fed to the same input voltage. In this time the induction falls from B_{max} to B_r .

In this frequently-used forward transformer switch, magnetic energy stored during the switch-on phase $q \cdot T$ is returned to the feed source via the feed source recuperation development W_r . There are several layouts which can be used to realize the recuperation. For this reason, and because the structural performance of this winding is normally only approx. 10%-20% of the structural performance of the winding W_p , this winding is not calculated with the program. The user calculates it manually.



In the case of forward transformers, one distinguishes between 2 main phases during a switching period: during the first phase the primary voltage **Up** is fed to the primary winding **Wp**. The primary voltage increases in direct proportion to the voltage **IL** through the choke **L**. In addition comes the magnetizing voltage **io**. The voltage lies in the secondary winding:

$$U_s = (U_o + U_{diode}) / q.$$

During the second phase the primary winding **WP** is separated from the primary voltage. The magnetic energy which is stored in this is returned via the winding **Wr**. The number of windings **Wr** in this winding is chosen to ensure that the conditions:

$$q + r < 0.8-0.9$$

and

$$r = q * (W_r / W_p)$$

are constantly fulfilled. The relative switch-on duration **q** is chosen to be between **0.40** and **0.60** at minimum input voltage. This produces:

$$r < 0.3 - 0.6$$

or

$$W_r = (0.5 - 0.66) * W_p$$

During the switching period **T**, the induction changes by pulsing between **Br** and **Bmax**. The choice of **Bmax** depends on the ferrite type and on the operating temperature. The residual induction **Br** can be set practically at a value between 5% and 10% of the **Bmax** induction by an air gap in the core. With an external source or a permanent magnet it would be possible to set a negative residual induction.

The ripple of the voltage through the choke **L** affects the effective value of the transformer voltage.

$$\text{Ripple} = 100 * (I_{lmax} - I_{lmin}) / (I_{lmax} + I_{lmin})$$

This value must be notified by the user.

Criteria for design

IEC 61558

A high-frequency transformer with non-inherently short-circuit proof as per IEC 61558 is equipped with a safety. Very often we arrive at a combined protection solution consisting of a thermal cutout in the transformer and cutout electronics in the cycled mains power unit to protect against overload and short-circuit. For this reason, short-circuit and overloads are not design criteria. The criterion for design with regard to IEC 61558 is only temperature θ **nominal**.

Insulation class	A	E	B	F	H
Max winding temperature in nominal operating mode θ nominal (° C)	100	115	120	140	165

Insulation class

Max winding temperature in nominal operating mode = 115°C

Insulation class E is prescribed.

Criterion for design

Normally, high-frequency transformers have very low regulation and are designed according to the prescribed temperature rise.

Since these transformers are manufactured almost exclusively using ferrites, the optimum operating temperature is around 100°C.

Bobbin unit

In order to protect the transistors, high-frequency transformers should be manufactured for low leaking reactance, with single-chamber bobbin units. For this reason, we very often arrive at bifilar or interleaved windings.

Ferrite quality

Since the optimum operating temperature of ferrite for high-frequency transformers over 100VA is around 100°C and their ambient temperature is between 40°C and 70°C, our design assumption must be for a temperature rise of between 30°K and 60°K. If the core losses in relation to temperature rise are not economically acceptable, then the computer program will optimize or reduce the AC-component of the induction automatically. But this does indicate that the selected ferrite quality is not optimized.

Induction and ferrite quality

High-frequency transformers are equipped almost exclusively with ferrites. The program calculates both the active and the reactive core losses by hypothesizing the ferrite type, the frequency, the form of input voltage, induction and core temperature. The induction should be selected such that the transformer does not saturate at maximum input voltage and maximum core temperature.

Copper additional losses

With a high-frequency transformer, the distinctions are drawn between the following additional losses in a winding, over and above the dc-current losses:

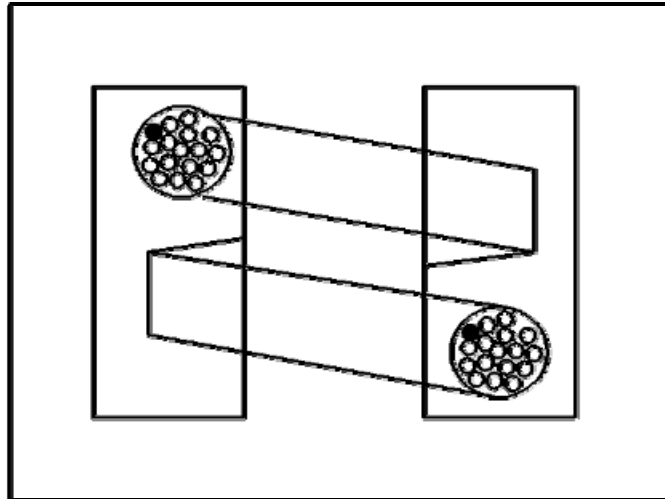
1. Eddy current losses
1. Displacement losses
1. Proximity effect losses
1. Losses due to circulating currents through the parallel-connected wires.

Additional losses are smaller in the case of a winding that takes up only 30-60% of the available winding space. For that reason, one should always set the input for the **filling factor** between 0.3 and 0.6 for purposes of automatic core selection.

The input for **Rac/Rdc** will limit the extent of additional losses (eddy current losses and displacement losses). The computer program selects a high enough number of parallel-connected wires for the eddy current losses and displacement losses to fall short of the prescribed value for **Rac/Rdc**. For that reason, the input for **Rac/Rdc** is also used for monitoring of parallel-connected wires. The value is normally set between 1.5 and 5.

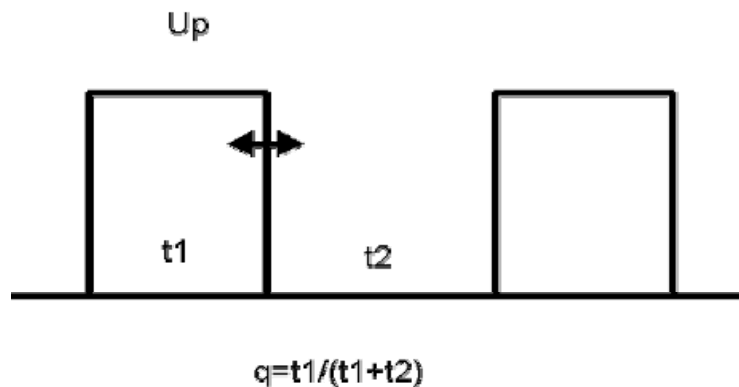
Proximity effects can be reduced by means of the **Spread** input. Another option for reducing proximity effects is to select wires with thicker insulation.

Losses of circulating currents through the parallel-connected wires are not calculated. It is assumed that these additional losses have been eliminated by suitable design precautions. In particular, it should be ensured, for a given litz, that the twisting for the winding is done such that a given wire has the same position at the input and at the output of the winding.



Nominal input voltage and relative switch-on period

The relative primary voltage switch-on period is defined as follows:



In the design of a forward transformer, the duration of the relative switch-on period ($q = t1 / (t1 + t2)$) is taken into account indirectly via the input mode of the **form factor**:

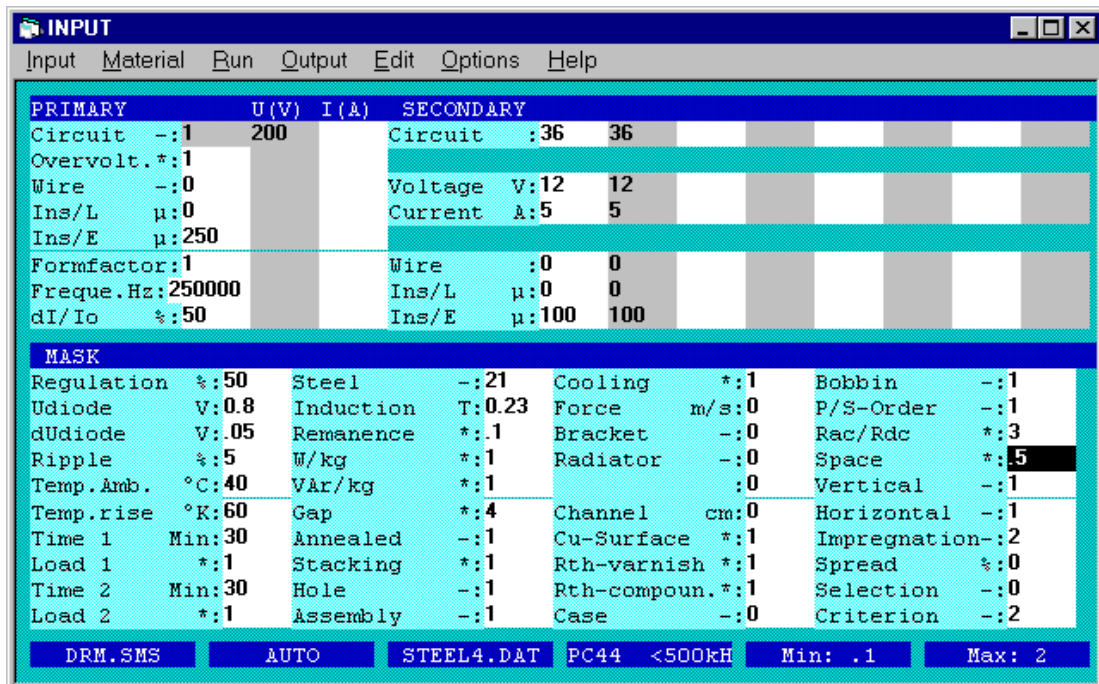
$$\text{Form factor} = 1 / (2 * q)$$

A forward transformer with an automatic controller of output voltage is normally designed with the following parameters:

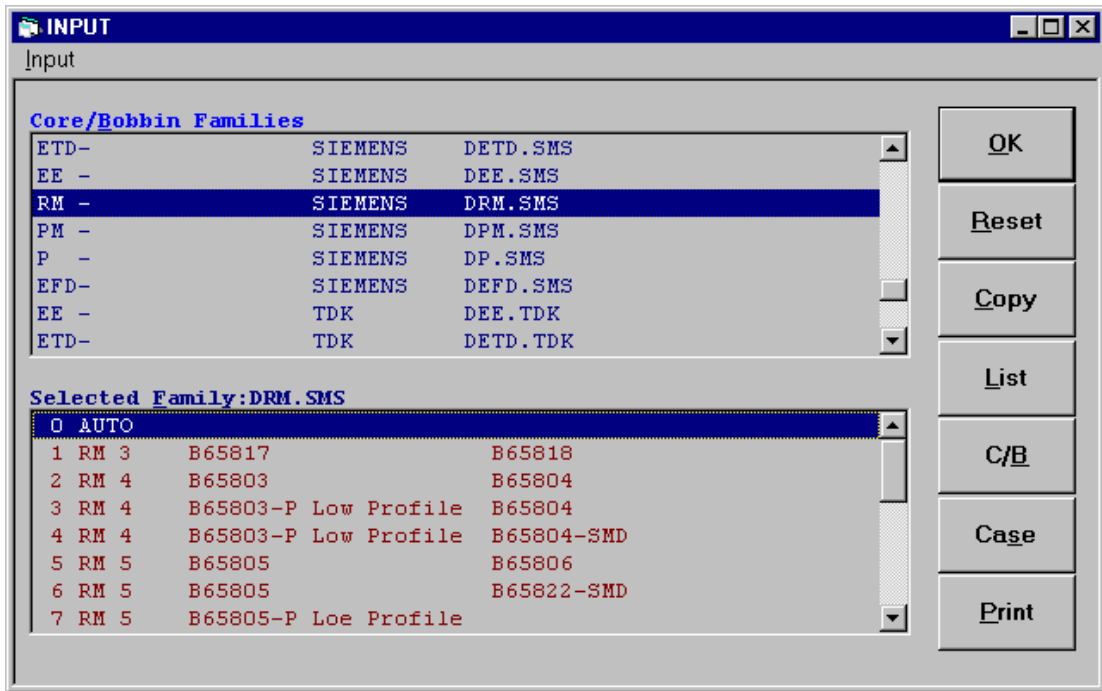
- "Nominal" input voltage $U_{pmin} = 200V$.
- At this input voltage the relative switch-on period q_{max} will be 0.5 and the relative recuperation period $r_{min} = 0.35$.
- The form factor $= 1 / (2 * q_{max}) = 1 / (2 * 0.5) = 1$
- The relative switch-on period at the input voltage $U_{pmax} = 350V$ will be:
 $q_{min} = q_{max} * U_{pmin} / U_{pmax} = 0.5 * 200 / 350 = 0.285$

Procedure for design

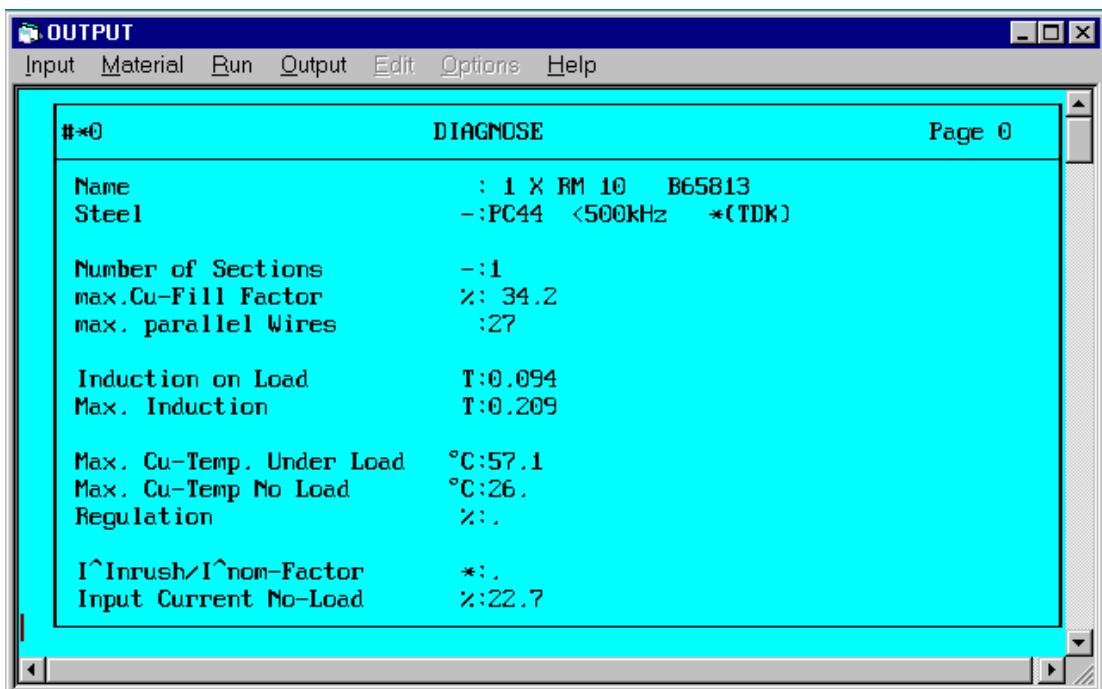
1. If you are not yet acquainted with Rale design software, please read the text "**How should I design a small transformer?**". Keep a copy of this text within convenient reach whenever performing design work.
2. Fill in the design input mask as follows. If you need any help, press function keys F1.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



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 **CAL0011E.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 for automatic search by the computer program.

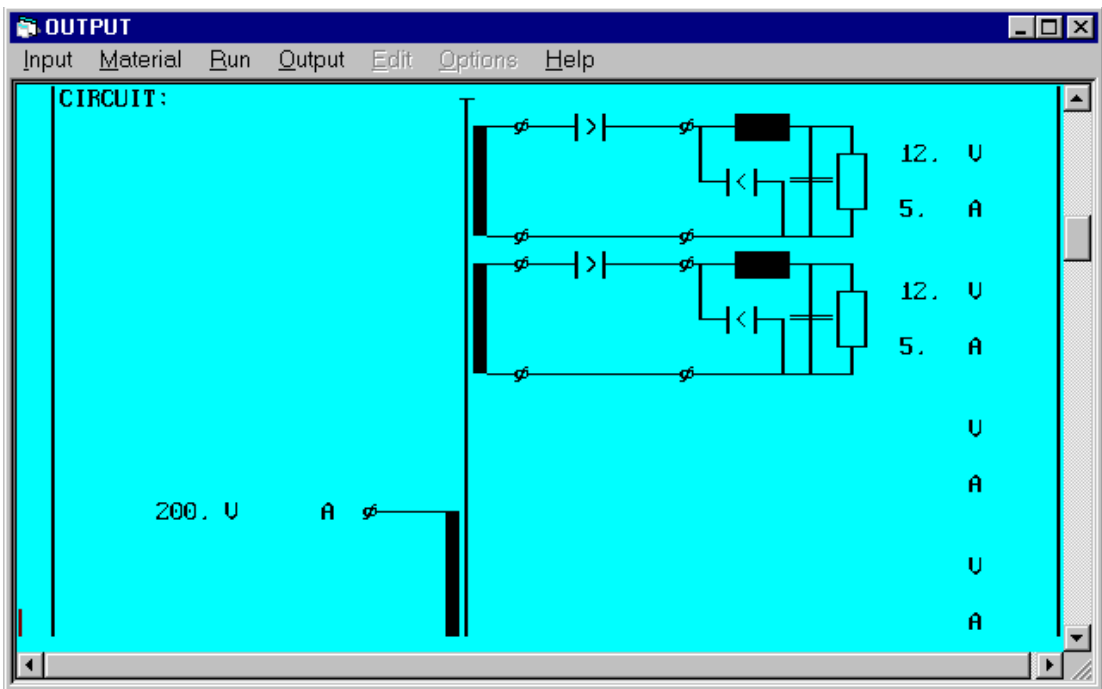


8. Click on **OK**.
9. Start your design work. In the system for automatic selection of the core from your prescribed core family, the program will offer you an adequately sized core for your application. Click on OK in order to accept the core.
10. On completion of your design work, the following design data is available. We must not omit to mention at this point that the calculated data for **short-circuit** is not applicable to the forward transformer (and cannot be used for that context).
11. On completion of the design work, the following design data will be available, which can be printed on 3 pages.



PRIMARY		SECOND.		1	2	3	4	5	6	7	8
Circuit-:	1	U(U)	I(A)	Circuit-:	36	36					
Overvolt*:	1.00			Volta. U:	12.	12.					
Wire	:0.0			Curre. A:	5.	5.					
I/L	μ:0.			Wire	:0	0					
I/E	μ:250.			I/L	μ:0.0	0.0					
Formfac.:	1.00			I/E	μ:100.	100.					
Fre.Hz:	250000										
dI/Io	%:50										
Regulat.	%:50.0	Steel	-:21	Cooling	*:1.00	Bobbin	-:1				
Udiode	U:0.8	Induction	T:0.21	Force	m/s:0.00	P/S-Order	-:1				
dUdiode	U: .05	Remanence	*:0.10	Bracket	-:0	Rac/Rdc	*:3.00				
Ripple	%:5.	W/kg	*:1.00	Radiator	-:0	Space	*:0.50				
Tmp. Amb.	°C:40	UAr/kg	*:1.00		:0.00	Vertical	-:1				
Tmp.rise	°K:60	Gap	*:4.00	Channel	cm:0.00	Horizontal	-:1				
Time 1	Min:30.0	Annealed	-:1	Cu-Surface*	:1.00	Impregnat.	-:2				
Load 1	*:1.0	Stacking	*:1.00	Rth-varni.:	*:1.00	Spread	%:0				
Time 2	Min:30.0	Hole	-:1	Rth-comp.	*:1.00	Selection	-:0				
Load 2	*:1.0	Assembly	-:1	Case	-:0	Criterion	-:2				

12.

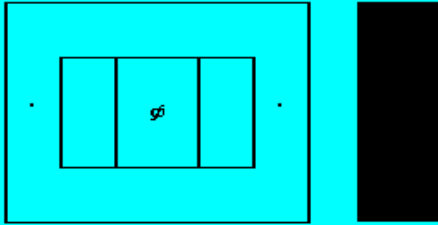


OUTPUT

Input Material Run Output Edit Options Help

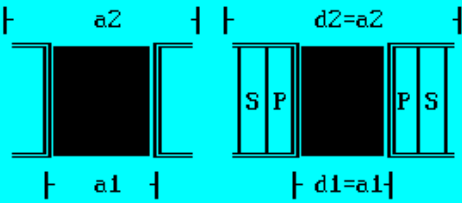
Name : 1XRM 10 B65813 B65814
 Steel : PC44 <500kHz S(TDK) /1.

| F | B | A | B | F | | D=A |



Weight gr:23.289
 Gap total cm:0.000
 A-Limb cm:1.09
 B-Width cm:0.51
 C-Height cm:1.23
 D-Stack cm:1.48
 E-Yoke 1 cm:0.31
 F-Yoke 2 cm:0.31
 G-Hole cm:0.00
 Radiator Fin :0
 Radiator Chan. :0

| a2 | | d2=a2 |

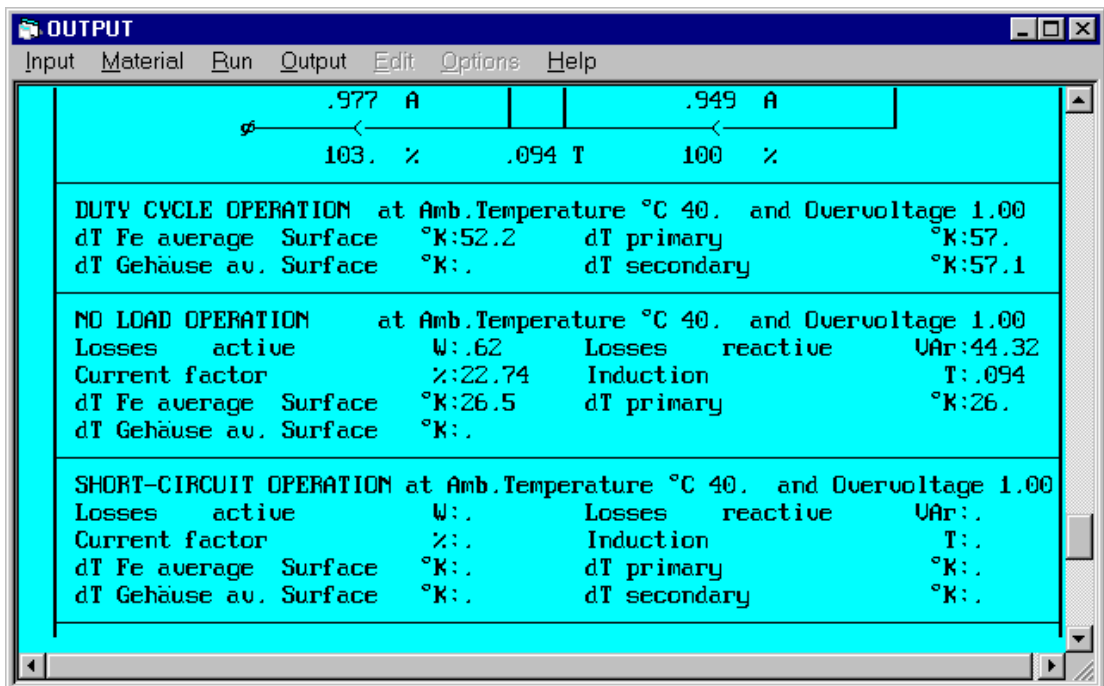
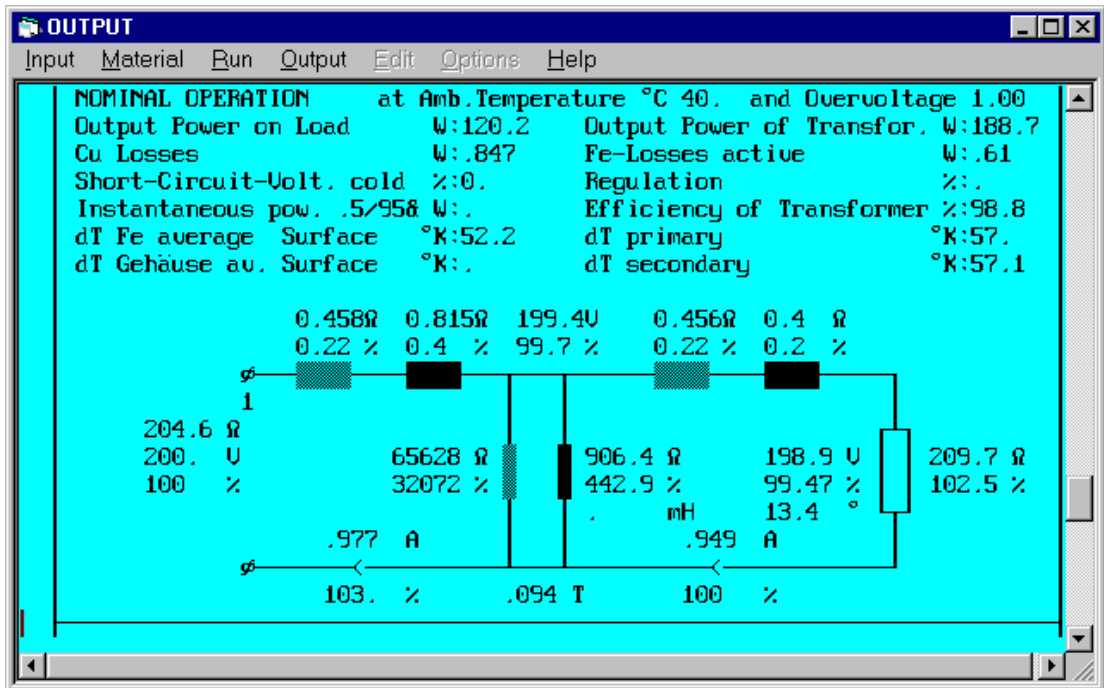


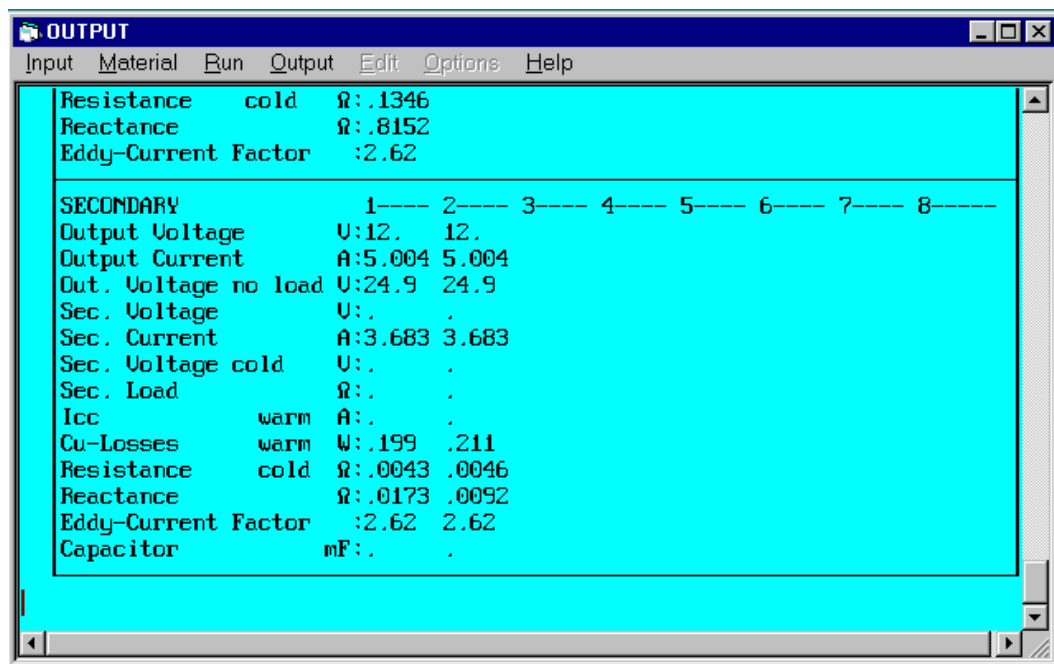
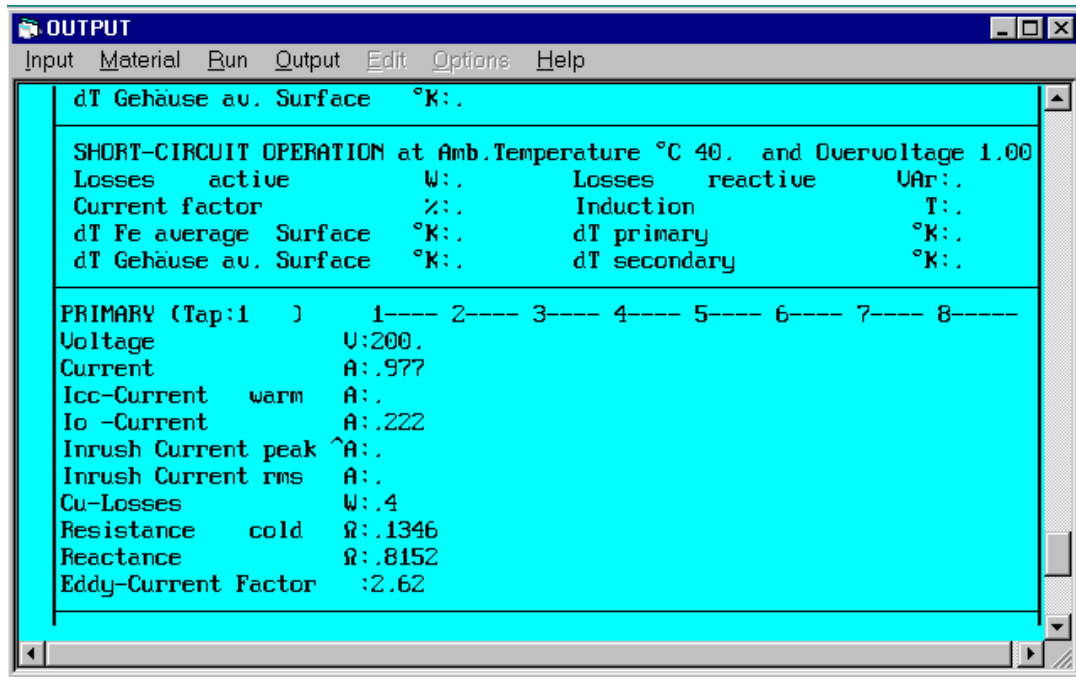
a1 cm:1.24
 a2 cm:2.09
 d1 cm:1.24
 d2 cm:2.09
 l cm:1.06
 lp cm:

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	22.8	0	48.0	48.0	6	.16	.16	55	2.48	.	250	.985	13.
2														
3														
4														
5														
6														
7														
8														
1	36	2.9	0	48.0	48.0	27	.16	.16	55	1.43	.	100	.637	11.
2	36	2.9	0	48.0	48.0	27	.16	.16	55	1.43	.	100	.679	11.
3														
4														
5														
6														
7														
8														





13. Checking of the design data follows this.

- We now check the winding data and the filling factor (34.2% < 100%).
- The maximum temperature of the windings is 40°C + 57.1°K = 97.1°C < 115°C.
- The number of parallel-connected wires with 0.16 mm diameter is 6 and 27. Commercial considerations prompt us to select a litz of 5 wires of 0.16 mm diameter for the primary and a litz of 30 wires of 0.16 mm for both secondary windings. This operation must be performed manually in the test mode.
- There now follows the configuration of the recuperation winding W_r :

$$W_r = W_p * r_{min} / q_{max} = 23 * 0.285 / 0.5 = 13 \text{ windings}$$
 The number of parallel-switched wires is smaller than the number of parallel-switched wires in the primary winding W_p by the factor $I_{p\text{rms}} / I_{r\text{rms}}$.

$5 * 0.218/0.99 = 1$ wire

Ip rms => No-load voltage

Ip rms => Primary nominal voltage

13. This is followed by checking of the output voltage for the maximal input voltage of 350V and the relative switch-on period of 0.285: $U_{in} = 350/200 = 1.75$ and form factor = $1/(2*0.285) = 1.754$.

Note that the program controls your input in order to avoid the operation in the saturation of the core. If you get any problem with your input, follow these procedures.

- Increase the form factor to 1.754 ($q = 0.285$)
- Press F6 to recalculate
- Increase the input voltage to 350V : $U_{in} = 1.75$
- Press F6 to recalculate

or

- Decrease the input voltage to 200V : $U_{in} = 1$
- Press F6 to recalculate
- Decrease the form factor to 1.0 ($q = 0.5$)
- Press F6 to recalculate

	1	2	3	4	5	6	7	8		
PRIMARY									FormFact.:	1.75
Turns :	23.								U input *:	1.75
Family :	0								FREQ. Hz:	250000
Number :	48								T amb. °C:	40.0
Parallel :	5								t1 on Min:	30.0
Ins/L μ:	0.0								Load 1 *:	1.00
f-thic mm:	0.16								t2 on Min:	30.0
f-wide mm:	0.16								Load 2 *:	1.00
Layers :	2.10								STEEL -:	21
SECONDARY									Margin cm:	0.09
Turns :	3.	3.							Case -:	0
Family :	0	0							RWH %:	38.6
Number :	48	48							dT-rise°K:	54.3
Parallel :	30	30							dU %:	.6
Ins/L μ:	0.0	0.0							IO %:	28.27
Load s. O:	2.556	2.556							Ii^/In^ :	24.
f-thic mm:	0.16	0.16							P Fe W:	.59
f-wide mm:	0.16	0.16							P Cu W:	.78
Layers :	1.64	1.64							Bn T:	.093
U sec V:	25.93	25.93							BO T:	.207
UO sec V:	26.06	26.06							Br T:	.021
I sec A:	2.82	2.82							RM 10	B658

The following table shows the summary of the most important parameters, calculated by program in the test mode. Note that the relative switch-on period (q) was changed in order to get the nominal input voltage as by a voltage controller.

Ui V	Iprms A	2xIsrms A	2xUodc V	2xIodc A	Pcu W	Pfe W	q	Ripple %	dTcu °K
200	0.999	3.72	12.2	5.06	1.04	0.57	0.5	50	62.6
350	0.77	2.82	12.2	5.07	0.73	0.60	0.28	50	53

11. 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.

12. 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, **CAL0011E.TK2**, is supplied together with this document. Copy it into the directory in which your Rale demo program is installed.

Tips & Tricks

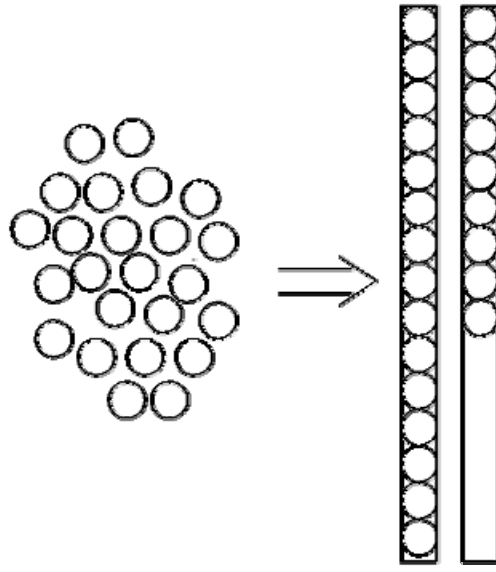
Rounding off the number of windings

With a flyback transformer, the procedure for rounding off the number of windings differs from that employed with a "normal" transformer.

- Next, we correct the nominal primary voltage until the desired number of primary windings is reached.
- In the test program, finally, the number of windings is rounded off manually.

Copper strip instead of litz

A copper strip can replace a litz. The strip thickness should correspond to the wire diameter of the litz. Strip width should be matched to the width of the bobbin. The number of strips connected in parallel is determined in accordance with the following illustration.



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