Design of transformer series

DESIGN TARGET:

* **Design a series of three transformers** consisting of three consecutive core sizes of dimension A (see Appendices 6 and 7). The middle one of the three transformers will be designed, manufactured and tested. The other two sizes will not be manufactured but their designs should be reported. These designs should follow the same design rules as applied to the tested transformer.

* The rated primary voltage of the transformer series is U_1 = 24 V, f = 50 Hz.

* There are two secondary windings of rated voltage $U_{21} = U_{22}$ = 12 V.

* The rated output of the transformer series is defined based on the measured results.

* The transformer series has to fulfil the following special demands:

  - the ambient temperature for the transformer is 35 °C,
  - the temperature rise is between 60 ... 80 °C,
  - no-load current < 33 % I_N (I_N is the rated current), and
  - the tolerance for the secondary voltage at rated load and at working temperature is ± 5 %.

* All the decisions and conclusions made during the work have to be **written down to notes**. Using the notes it is easy to write the work report. Also, if some decision or conclusion is not correct - checking from the notes helps to find the correction.

Design of transformer series

Part 1: Basis for the calculation of core and winding values

* Initial design of the transformer

Design the transformer using the initial values:

- The peak value of the flux density at no-load $\hat{b}_{fe}$ = 1,4 T
- The filling factor of the core η_{fe} = 0,94
  (ratio between area of iron and area of core)
- The effective value of the current density J_{cu} = 5,5 ... 6,5 A/mm^2
- The filling factor of the winding η_{cu} = 0,65
  (ratio between insulated wire and winding cross-section)

REMARKS: The nominal value of the wire 0,315 means the value of diameter of the copper. The diameter of the insulated wire is in table of the standard wires in Appendices.

* Define the components for the electrical equivalent circuit of the transformer using the initial design values

- Excitation reactance (using the *BH*-curve in Appendices)
- Winding resistance (by calculation)
- Leakage reactance (by calculation)
- Iron-loss resistance (using the P_{fe}-curve in Appendices)

* Check that the transformer fulfils the demands by calculus.

***** Define the properties of the transformer core by measuring the excitation and the iron loss characteristics.

- Produce the designed initial primary winding on the winding frame, bobbin, and construct the core to **measure** the *BH*-curve (excitation curve) of the core material.
- The wound frame operates as an assembly stand for the core packing.
- The setting of the core sheets is made from both sides of the frame in turn. The number of the sheets has to be limited setting only those sheets which go without any violence. Using extra force will damage the insulation of the sheets. From now on, the amount of sheets should be the same.
- The auxiliary measuring winding is spooled over the yoke of the core. The number of turns for the auxiliary winding is 10 turns.
- The characteristics will be measured.
- **Producing of transformer and the measurement will take about 2 hours.**

* The calculations of transformer must be checked taking into account the measurements.

* The demand on the temperature rise can be checked only after the temperature rise test using the thermal equivalent circuit of the transformer.

Design of transformer series

Part 2: Production of transformer

* Spooling in the winding frame

  - **In one chamber frame**, the primary winding is on the bottom. Both the secondary windings are spooled on the same chamber over the primary winding.
  - **In two-chamber frame**, the primary and the secondary windings are spooled in their own chambers.
  - The primary winding used in the core measurement may be used also.
  - There have to be a clear air gap between the wire and the core. Otherwise, the wound chamber has to be insulated by a foil iovercoateing the upper-most winding.

  - REMARKS. The spooling is damaging the insulation of the wire.
    Always the re-spooling has to be done using a new wire to avoid insulation problems.

* Packing of the core around the winding frame
  - The wound frame operates as a tool for the core packing.
  - The setting of the core sheets is made from both sides of the frame in turn.
  - The auxiliary measuring winding is spooled over the yoke of the core.
  - In the final check of the core, a special attention has to be put on the joints between the sheets. There has to be no air gaps in the joints.

* Tightening of the core
  The core sheets are pressed using the screws through the holes in the sheets. If there are no holes in the sheets, the tightening has to be done e.g. by fibre tape.

* Winding connections
  For the testing, the ends of all the windings (also of the measuring coil) have to be cleaned of length about two centimetres. The ends of the windings are connected to the measuring tool using a screw-connection.

* Inspection of the isolation structure
  - Make a visual check over the insulation between the core and the winding, and over the air gap between the core and the upper wire layer.
  - Check the cleanness of the winding ends.
  - **Producing of transformer will need about 3 hours.**

Design of transformer series

Part 3: Testing of the transformer

* Test program

- The working group should have the test program and the test diary when coming to the testing. These documents include the necessary measurements, the tables for the target variables and the list of the testing equipment.

- The meaning of the measurements is to check that the transformer fulfils the given demands. The measured values are used to calculate the electrical equivalent circuit components for the transformer at no-load, at rated load and in secondary short-circuit.

- The test program should include at least

  * Measuring of the no-load current and losses
  * Measuring the primary current and the secondary voltage at the rated load
  * Measuring of the temperature rise after the transformer has succeeded in all the other demands.
    The temperature rise test takes about 2 hours.
  * Measuring of the short-circuit impedance at rated secondary current.

  *Definition of thermal equivalent circuit of transformer
    - A model for current supply without flux supply.
    - A model for flux supply without current supply.
    - A model for current and flux supply together.

* **The measurement will need about 4 hours.**

* Measuring connection

  - The testing arrangement is made ready and has all the supply facilities, measuring instruments, and loading resistors on the working place. All the changes to the arrangement are made according to the orders of the working group. The working group makes the measurements by them-self.
  - The testing arrangement is isolated from the supply network by isolation transformer!

* Approval of the transformer or the corrections because of the demands
  - The working group decides by reason of the measuring results about the approval or the correction of the transformer.
    For the course degree the validation of the work bases on how well the transformer fulfils the given demands on its operation and the production quality.

Design of transformer series

Part 4: The design report of the series of transformers

A research report will be done after the transformer has been approved. The report will be reviewed. The report is the summary of the whole work and a design rule for the transformer series. The writing rules are in Appendix 1.

The report should include:

- the design material of the target transformer with calculations,
- the measuring connection and facilities, and measuring results,
- comparison between measured and calculated results,
- correction factors defined by measurements, if any,
- the design calculations for transformer series based on the measured results,
- the technical data of the transformer:
  * At no-load and at rated voltage: the secondary voltage, the primary current and power
  * At rated load and at rated primary voltage: the secondary voltage, output power, the primary current and power, efficiency, power factor, and the temperature rise using thermocouples and resistance measurement.
  * At short-circuit and at rated secondary current: the primary voltage, current, and power, and the short-circuit impedance of transformer.
  * Machine factor = power / volume.
  * The thermal model of transformer.

Appendices

Appendix 1 Writing rules of report
Appendix 2 *BH*-curve of sheet, 2,3 W/kg, 0,5 mm
Appendix 3 P_{fe}-curve of sheet, 2,3 W/kg, 0,5 mm
Appendix 4 *BH*-curve of sheet, 1,1 W/kg, 0,35 mm
Appendix 5 P_{fe}-curve of sheet, 1,1 W/kg, 0,35 mm
Appendix 6 EI-core dimensions and winding frames
Appendix 7 UI-core dimensions and winding frames
Appendix 8 Enamelled wires, data sheet

APPENDIX 1 RULES FOR THE REPORT

1. Contents

There have to be a list of contents in the report. It should be in the beginning. In the list, there should be the headers of the chapters and of the appendices with page number of the starting point.

2. List of symbols

In this list, all the symbols, abbreviations, terms etc. have to be collected. This list should be in alphabetical order; first the Latin, then the Greek symbols, last the abbreviations. The list follows the list of contents.

3. Introduction

The report starts with an introduction. There You explain shortly the back-ground, the limits and the aim of the work. Also You have to tell the contents of the report, not in details of theory, methods, or results.

4. Methods

The target of the report is that a professional reader may repeat the whole work by following Your report. Get the same equations and measure results.

The report should include the following parts::

4.1 Theory

In the theory part, You present the basis from where You started to work. Please, no useless writings to increase the number of pages.

4.2 Explanation of basic material, remarks and the results of work

The way of working procedure should be explained carefully and all the measuring and calculation results should be in original form so that the reader gets the whole information. All long equation deductions and lists of computer programs should be included in appendix. The appendices should be numbered and they should have a header, too.

Deductions for the equations picked from the literature are not necessary, but You have to check the equations are in the right form. The new equations should be introduced deep enough with deduction.

The equations and formulas should be written clearly on their own rows and separated from the text. Consecutive numbering either over whole report or according to the chapters should number the equations. The numbering should be in ( )-parentheses on the right end of the row of the column. Consecutive numbering either over whole report or according to the chapters should number the figures and the tables. They should also have a self-explaining text, for tables over the table and for figures under the figure.

In mathematical presentation, You should use the standardised symbol, when there is a one. Or if there is no such a symbol, You should use other established symbols, and if there is no such a symbol either, You may use Your own symbols. You should introduce the quantity (the name of symbol, e.g. current *I*) always in the text when it comes at the first time and later if You think it is necessary. All the quantities and variables should be written in italics. The constants and numbers should be written in normal. The same style rules also for index, e.g. the primary voltage U_1, induced voltage U_i, voltage of *i*:th winding U_i.

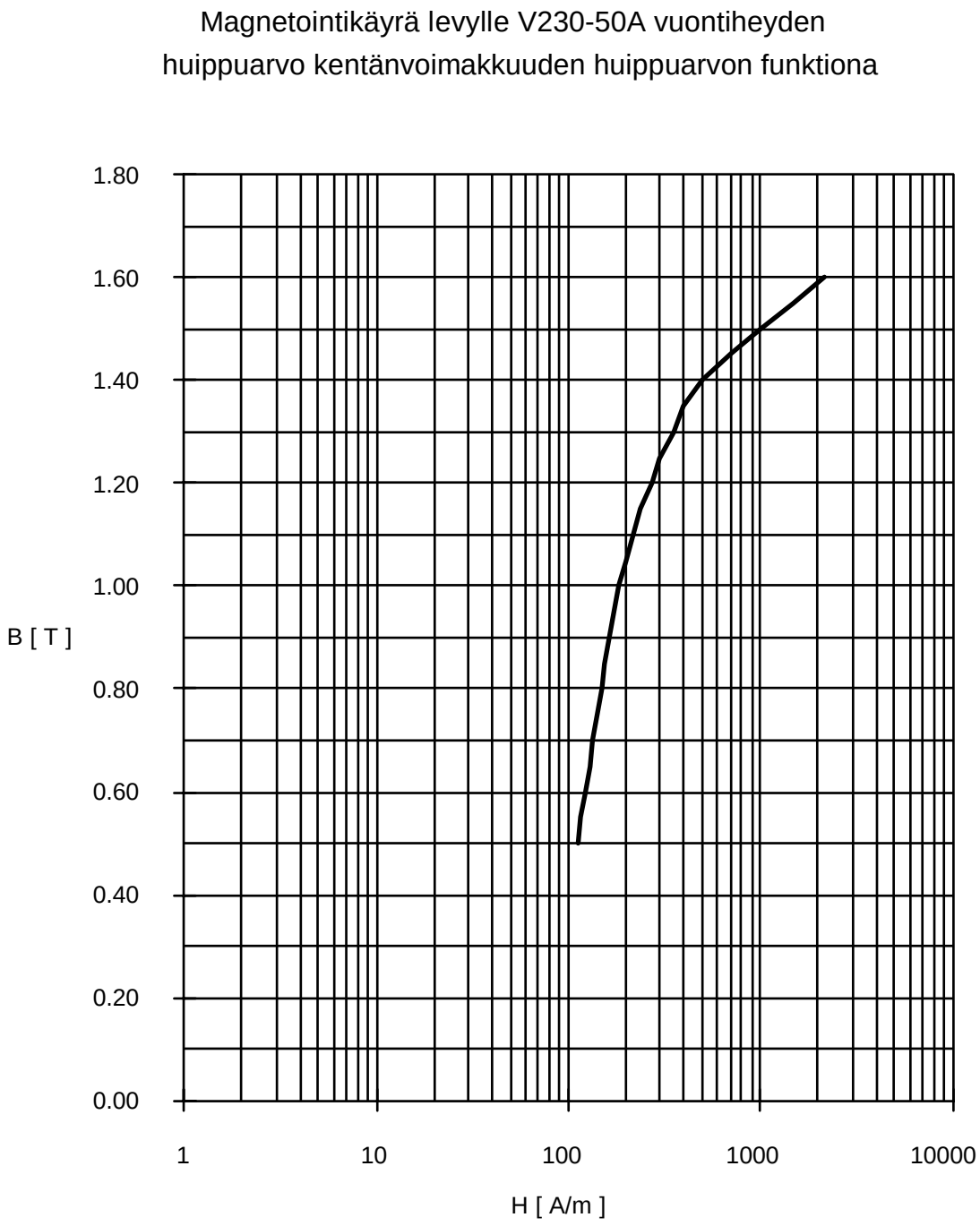
5. Discussions and conclusions

In the end of the report, You should have two separate chapters, e.g. "Discussions" and "Conclusions". In the discussions, You should compare the result according to the theory and measurement, how they differ on each other if any, what are the reasons for that. In the conclusions, You have to present mainly the main results, what are You own benefits or remarks from Your own research and how they are in comparison with the literature. The results should be compared especially to the earlier studies on the subject.

6. Appendices

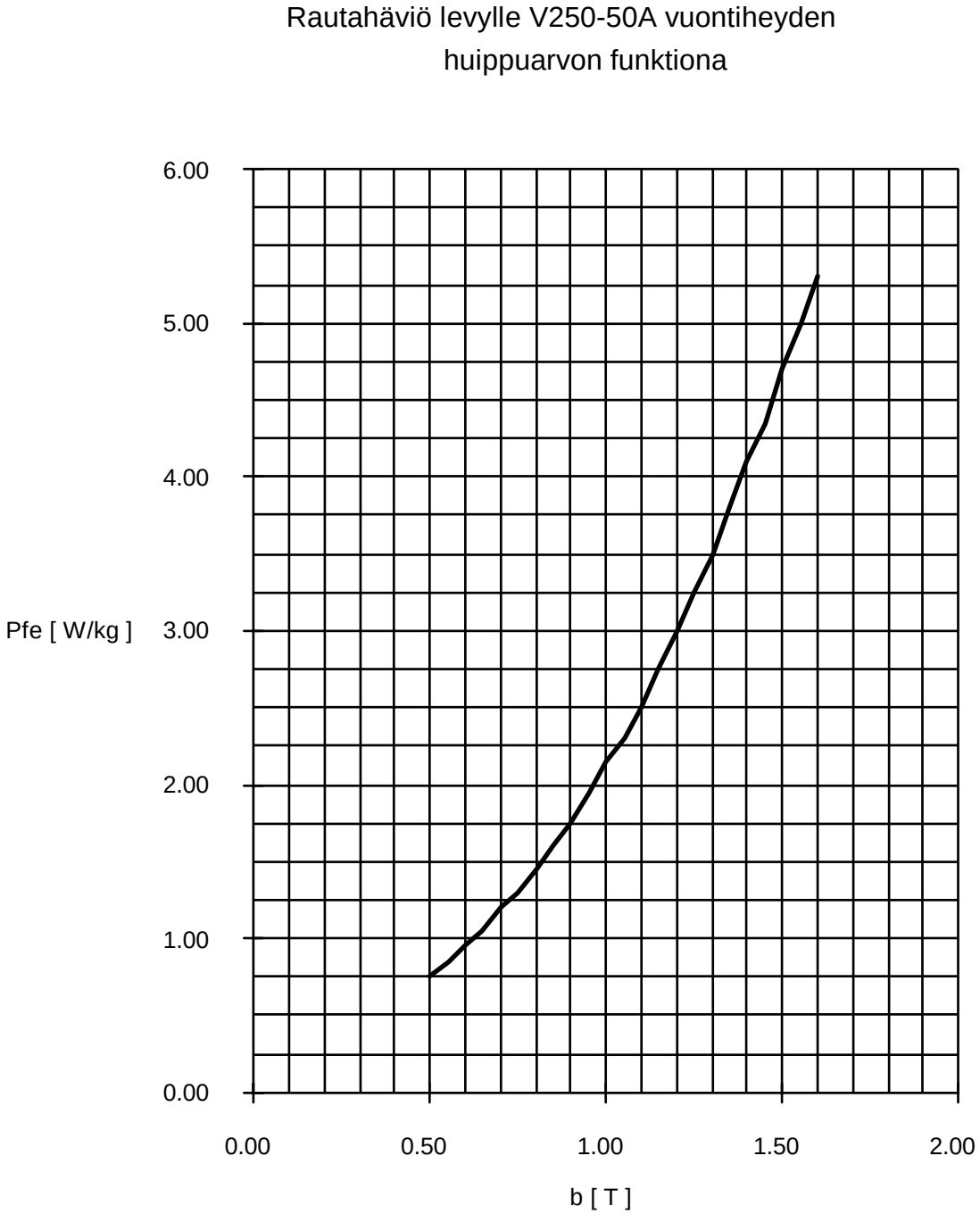
The appendices are for the extra material supporting the text, e.g. figures, tables, computer programs, measurement data, and deduction of formulas. The appendix should be numbered and formed so that they operate as an independent text. The page numbering of appendix may be consecutive from the beginning of the report or every appendix may be separated as an own unit of text.

APPENDIX 2 *BH*-CURVE OF SHEET, 2,3 W/kg, 0.5 mm



BH-curve for a core plate V230-50A
Peak value of flux density as a function of peak value of magnetic field strength

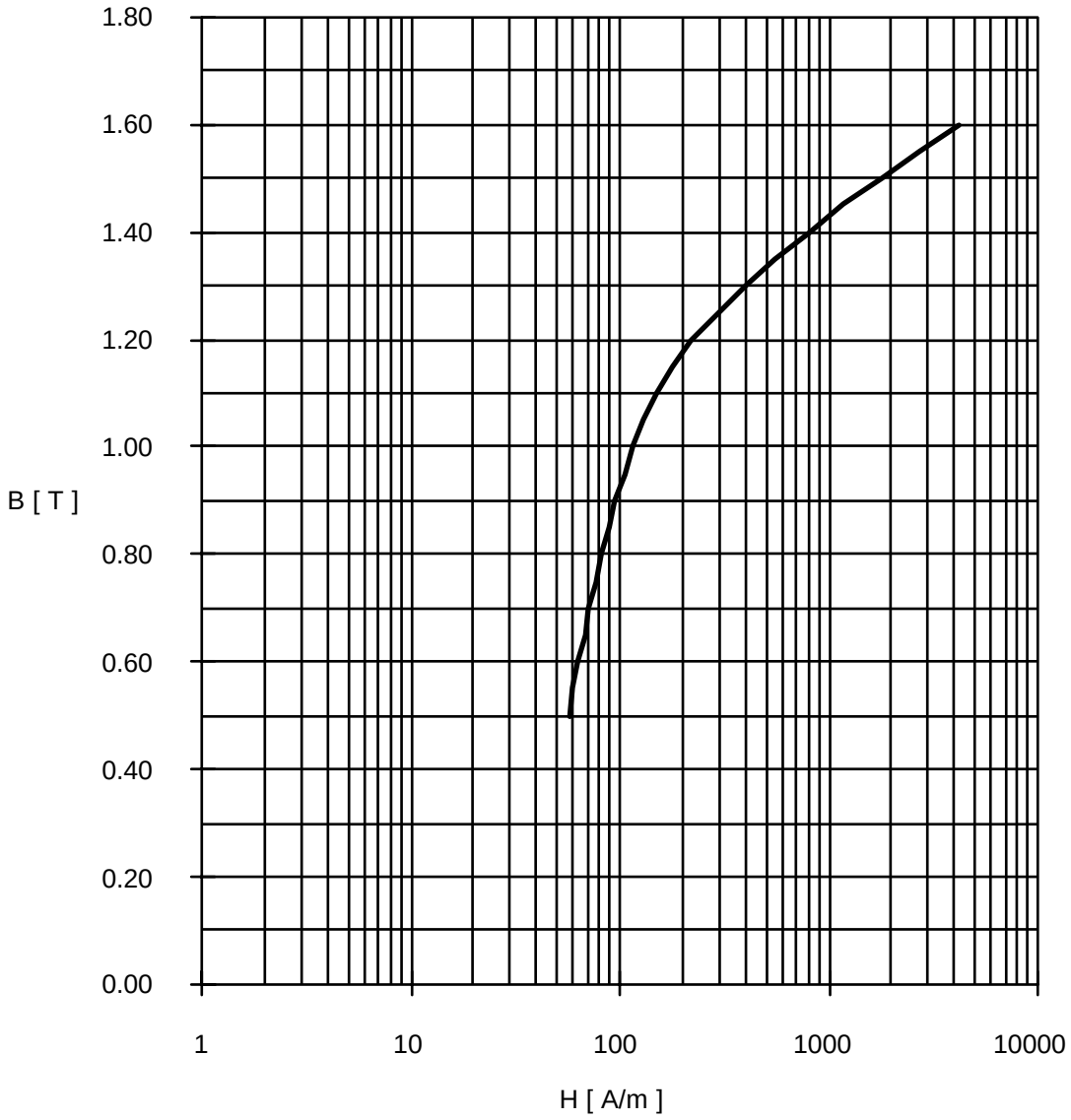
APPENDIX 3 P_{fe}-CURVE OF SHEET, 2.3 W/kg, 0.5 mm



Iron losses for a core plate V230-50A
Iron losses as a function of peak value of flux density

Design of transformer series

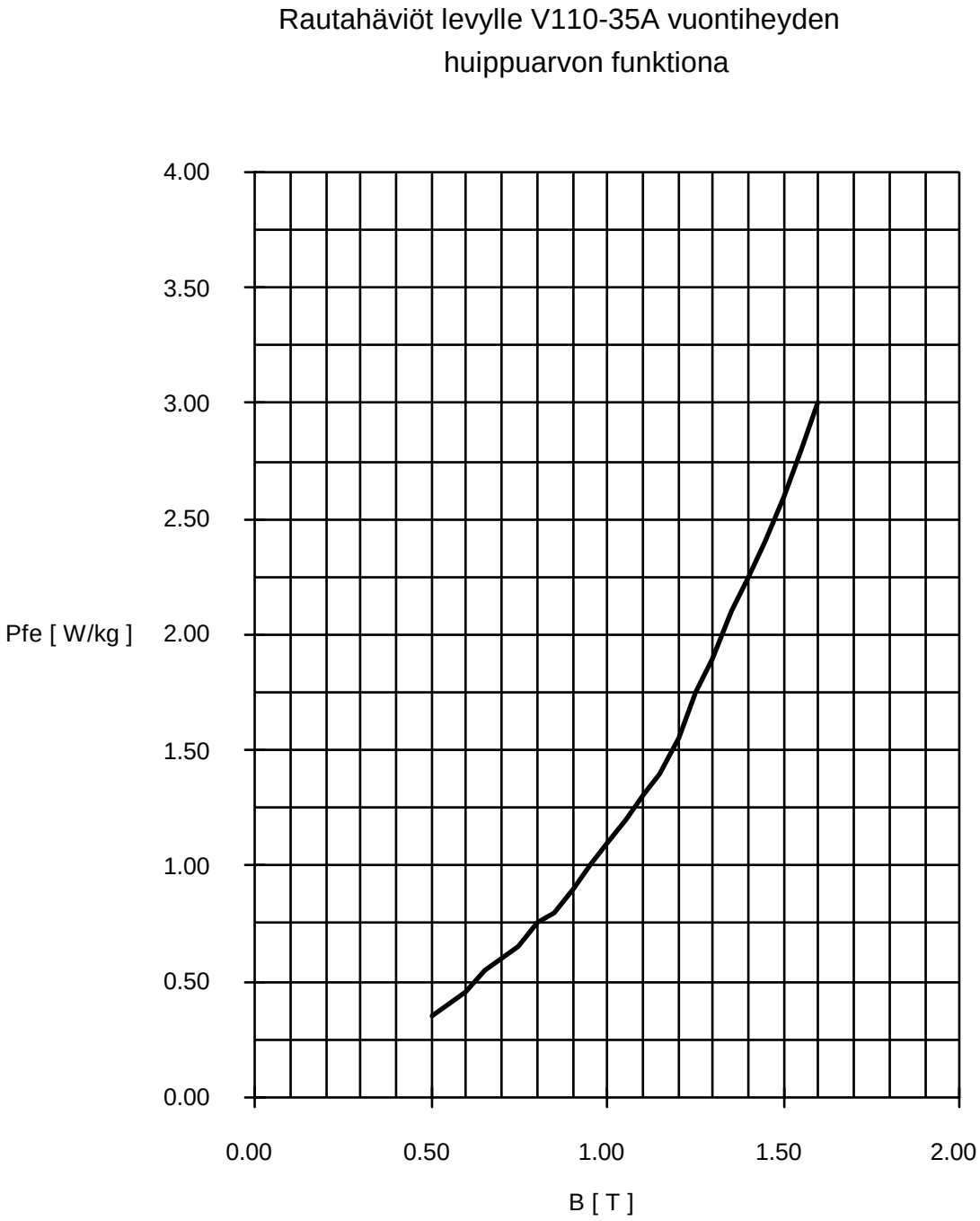
APPENDIX 4 *BH*-CURVE OF SHEET, 1.1 W/kg, 0.35 mm



BH-curve for a core plate V110-35A
Peak value of flux density as a function of peak value of magnetic field strength

Design of transformer series

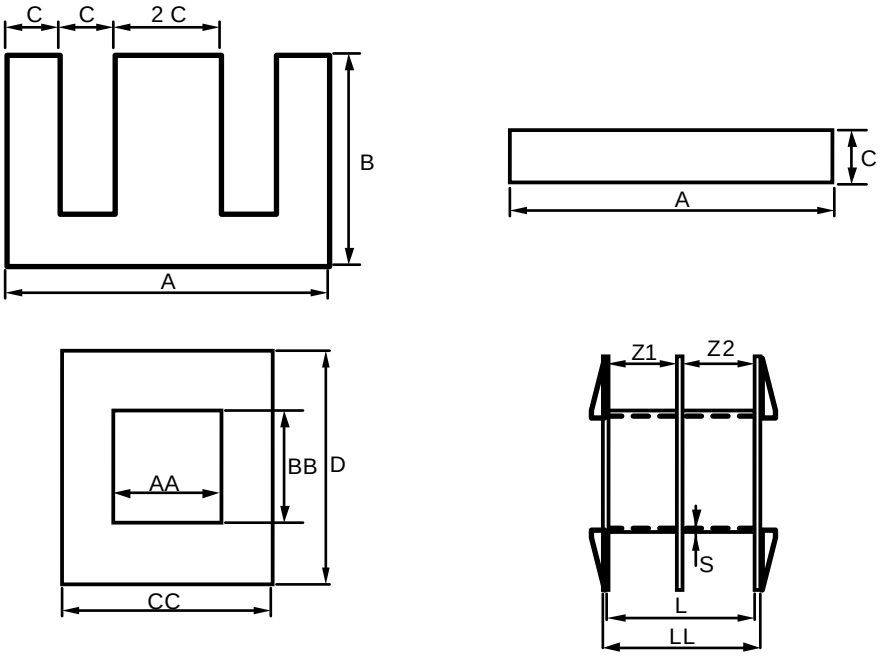
APPENDIX 5 P_{fe}-CURVE OF SHEET, 1.1 W/kg, 0.35 mm



Iron losses for a core plate V110-35A
Iron losses as a function of peak value of flux density

Design of transformer series

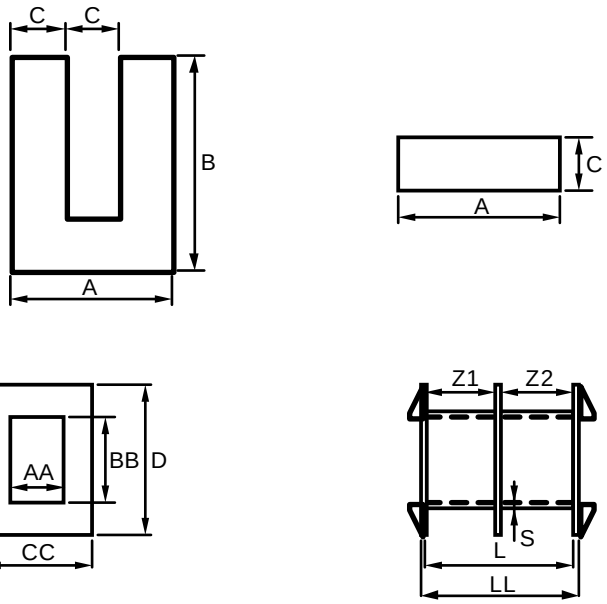
APPENDIX 6 DIMENSIONS OF EI-PLATES AND COIL FORMERS



	A mm	B mm	C mm	AA mm	BB mm	CC mm	D mm	L mm	LL mm	S mm	Z1 mm	Z2 mm
EI 30	30.0	20.0	5.0	10.4	15.5	19.6	24.8	13.0	14.8	1.0	6.7	5.0
EI 38	38.4	25.6	6.4	13.4	13.7	25.3	28.0	16.5	18.9	1.0	-	-
EI 42	42.0	28.0	7.0	14.5	14.8	27.2	31.0	18.5	20.5	1.0	8.8	8.8
EI 48	48.0	32.0	8.0	16.5	16.8	31.0	38.9	21.5	23.5	1.0	9.8	9.8
EI 54	54.0	36.0	9.0	18.5	18.8	35.2	38.2	24.5	26.5	1.0	11.7	11.7
EI 60	60.0	40.0	10.0	20.6	21.0	39.0	42.5	27.0	29.0	1.1	12.9	12.9
EI 66a	66.0	44.0	11.0	22.6	23.0	43.1	46.5	30.0	32.0	1.0	14.4	14.4
EI 66b	66.0	44.0	11.0	22.6	34.7	43.0	58.0	30.0	32.0	1.0	14.4	14.4
EI 78	78.0	52.0	13.0	26.6	27.5	51.0	56.2	35.4	38.0	1.3	17.2	17.2
EI 84a	84.0	56.0	14.0	28.6	29.5	55.0	60.2	38.2	41.0	1.5	18.4	18.4
EI 84b	84.0	56.0	14.0	28.6	43.5	55.0	74.2	38.2	41.0	1.5	18.4	18.4
EI 96a	96.0	64.0	16.0	32.6	35.7	62.4	70.0	44.0	47.0	1.5	21.0	21.0
EI 96b	96.0	64.0	16.0	32.6	45.7	62.4	80.0	44.0	47.0	1.5	21.0	21.0
EI 96c	96.0	64.0	16.0	32.6	59.7	62.4	94.0	44.0	47.0	1.5	21.0	21.0
EI 120a	120.0	80.0	20.0	40.8	41.7	77.5	84.0	55.2	59.0	1.5	26.7	26.7
EI 120b	120.0	80.0	20.0	40.8	55.7	77.5	98.0	55.2	59.0	1.5	26.7	26.7
EI 120c	120.0	80.0	20.0	40.8	73.7	77.5	116.0	55.2	59.0	1.5	26.7	26.7
EI 150a	150.0	100.0	25.0	51.1	49.6	97.0	107.0	68.9	73.5	1.9	33.3	33.3
EI 150b	150.0	100.0	25.0	51.1	66.6	97.0	124.0	68.9	73.5	1.9	33.3	33.3
EI 150c	150.0	100.0	25.0	51.1	92.6	97.0	150.0	68.9	73.5	1.9	33.3	33.3

Design of transformer series

APPENDIX 7 DIMENSIONS OF UI-PLATES AND COIL FORMERS



	A mm	B mm	C mm	AA mm	BB mm	CC mm	D mm	L mm	LL mm	S mm	Z1 mm	Z2 mm
UI 30a	30.0	40.0	10.0	10.6	10.5	17.0	21.5	27.7	29.5	0.8	13.4	13.4
UI 30b	30.0	40.0	10.0	10.6	16.5	17.0	27.5	27.7	29.5	0.8	13.4	13.4
UI 39a	39.0	52.0	13.0	13.6	13.8	25.0	28.6	36.5	38.5	0.9	17.8	17.8
UI 39b	39.0	52.0	13.0	13.6	20.8	25.0	35.6	36.5	38.5	0.9	17.8	17.8
UI 48a	48.0	64.0	16.0	16.6	17.0	31.0	36.7	45.5	47.5	0.9	22.2	22.2
UI 48b	48.0	64.0	16.0	16.6	26.0	31.0	45.7	45.5	47.5	0.9	22.2	22.2
UI 60a	60.0	80.0	20.0	20.6	21.0	39.0	45.7	56.6	59.0	1.3	27.7	27.7
UI 60b	60.0	80.0	20.0	20.6	31.0	39.0	55.7	56.6	59.0	1.3	27.7	27.7
UI 75a	75.0	100.0	25.0	25.6	26.5	49.0	57.8	71.6	74.0	1.3	35.2	35.2
UI 75b	75.0	100.0	25.0	25.6	41.5	49.0	72.8	71.6	74.0	1.3	35.2	35.2
UI 90a	90.0	120.0	30.0	30.6	31.5	58.0	66.8	86.2	89.0	1.5	42.4	42.4
UI 90b	90.0	120.0	30.0	30.6	51.5	58.0	86.8	86.2	89.0	1.5	42.4	42.4
UI 114a	114.0	152.0	38.0	38.8	40.0	73.8	80.1	108.6	112.0	1.8	53.5	53.5
UI 114b	114.0	152.0	38.0	38.8	64.0	73.8	104.1	108.6	112.0	1.8	53.5	53.5
UI 132a	132.0	176.0	44.0	44.8	46.0	85.0	94.3	126.0	130.0	2.4	62.0	62.0
UI 132b	132.0	176.0	44.0	44.8	72.0	85.0	120.3	126.0	130.0	2.4	62.0	62.0
UI 150a	150.0	200.0	50.0	51.3	52.0	96.5	106.0	143.4	148.0	2.6	70.6	70.6
UI 150b	150.0	200.0	50.0	51.3	77.0	96.5	131.0	143.4	148.0	2.6	70.6	70.6
UI 180a	180.0	240.0	60.0	61.5	63.0	117.0	132.0	173.0	178.0	2.5	85.3	85.3
UI 180b	180.0	240.0	60.0	61.5	78.0	117.0	147.0	173.0	178.0	2.5	85.3	85.3
UI 180c	180.0	240.0	60.0	61.5	93.0	117.0	162.0	173.0	178.0	2.5	85.3	85.3
UI 210a	210.0	280.0	70.0	71.5	73.0	137.0	150.0	202.4	208.0	2.9	99.8	99.8
UI 210b	210.0	280.0	70.0	71.5	103.0	137.0	180.0	202.4	208.0	2.9	99.8	99.8
UI 210c	210.0	280.0	70.0	71.5	133.0	137.0	210.0	202.4	208.0	2.9	99.8	99.8
UI 240a	240.0	320.0	80.0	81.7	83.0	155.0	184.0	224.0	237.0	4.0	-	-
UI 240b	240.0	320.0	80.0	81.7	110.0	155.0	211.0	224.0	237.0	4.0	-	-

Design of transformer series

APPENDIX 8 DIMENSIONS OF ENAMELLED COPPER WIRES

	copper diameter mm	enamelled diameter mm	copper cross-section mm^2	resistance at 20 °C Ω / m
x	0,100	0,129	0,00785	2,228
x	[0,150]	0,188	0,01767	0,990
x	0,160	0,199	0,0201	0,870
x	0,250	0,301	0,0491	0,357
x	[0,300]	0,355	0,0707	0,248
x	0,315	0,371	0,0779	0,225
x	[0,335]	0,394	0,0881	0,1985
x	0,355	0,414	0,0990	0,1768
x	[0,375]	0,435	0,1104	0,1584
x	0,400	0,462	0,1257	0,1393
x	0,450	0,516	0,1590	0,1100
x	0,500	0,569	0,1963	0,0891
x	0,560	0,632	0,246	0,0711
x	[0,600]	0,674	0,283	0,0619
x	0,630	0,706	0,312	0,0561
x	0,710	0,790	0,396	0,0442
x	[0,750]	0,833	0,442	0,0396
x	0,800	0,885	0,503	0,0348
x	0,850	0,937	0,568	0,0308
x	0,900	0,990	0,636	0,0275
x	1,000	1,093	0,785	0,0223
x	1,320	1,423	1,369	0,01279
x	1,500	1,608	1,767	0,00990
x	1,700	1,813	2,27	0,00771
x	1,800	1,916	2,55	0,00688

[non-standardised dimensions in parenthesis]

x available to use