Design of a Single-Phase Transformer

1. DESIGN SECTION

Design Target: Design a single-phase transformer based on the specification allocated to your group. The transformer should be designed and simulate the operating condition with COMSOL Multiphysics FEM software. The standard dimension of the core sizes is given in Appendices 6 and 7. The design procedure is based on the lectures on transformer.

Transformer design specifications

- The rated primary voltage of the transformer is U1 = 24 V, f = 50 Hz.
- The rated secondary voltage of the transformer is U2 = 12 V.
- The rated output of the transformer is defined based on the load current.
- The transformer must fulfill 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 % IN (IN is the rated current),
  - tolerance for the secondary voltage at rated load and at working temperature is ± 5 %.

Notes

- All the decisions and conclusions made during the work must be written down and used in the report.

Core and winding design parameter

Design the transformer using the initial values:

- The peak value of the flux density at no-load **b_{fe} = 1,4 T**
- The filling factor of the core **K_{fe} = 0.95**
- The effective value of the current density **J_{Cu} = 5,5 ... 6,5 A/mm2**
- The filling factor of the winding **K_{Cu}= 0,65**

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.

2. Transformer model Simulation

The simulation exercise aims to present typical setups for the estimation of electrical quantities in power transformers to create a better understanding of the basic operating principles of a power transformer. The transformer model is implemented using the commercial finite element software COMSOL Multiphysics. The primary winding of the transformer is connected to a primary resistor, R_P and the AC voltage source, V_{ac} while the secondary winding is connected to the secondary load resistor, R_s as shown in Figure 1 below. The model is solved in frequency domain for a line frequency of 50 Hz.

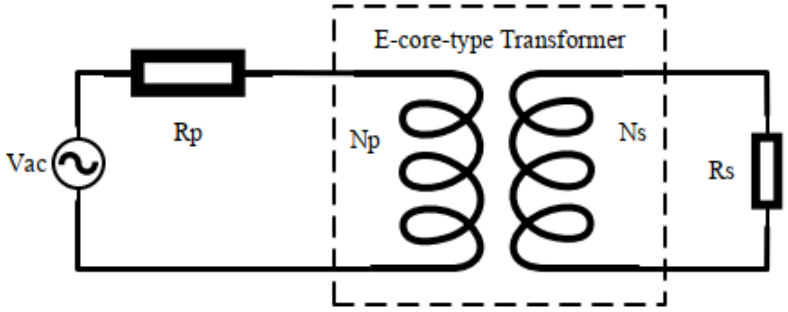


Figure 1: Transformer supply setup

Note: To simulate your design see the simulation instructions pdf file.

Simulation specifications

The purpose of the simulations is to check that the transformer fulfils the given design requirements and calculate the electrical equivalent circuit parameters for the transformer from the open circuit and short-circuit simulation results.

- Open circuit test measurements
- Short circuit test measurements
- Rated load test measurements

3. TRANSFORMER DESIGN REPORT AND PRESENTATION

A final report including the analytical design procedure and simulation results will be submitted for review. The summary of the whole work will be presented by each group during the presentation session. The writing rules are in Appendix 1.

➢ Determine the parameters of the electrical equivalent circuit of the transformer based on theoretical calculations

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

These parameters should be compared with the parameters found based on simulation results

➢ The technical data of the transformer

- At no-load (rated primary voltage): the secondary voltage, the primary current and power.
- At rated load (rated primary current): the secondary voltage, output power, the primary voltage and input power, efficiency and power factor.

- At short-circuit (rated primary current): the primary voltage, current, and power, and the short-circuit impedance of transformer.
- Machine factor = power / volume.

Appendices

Appendix 1 Writing rules of report

Appendix 2 BH-curve of sheet, 2,3 W/kg, 0,5 mm Appendix 3 $\boldsymbol{P_{fe}}$-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 $\boldsymbol{P_{fe}}$--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 Enameled wires, data sheet

APPENDIX 1 RULES FOR THE REPORT

Table of Contents

List of symbols and abbreviations

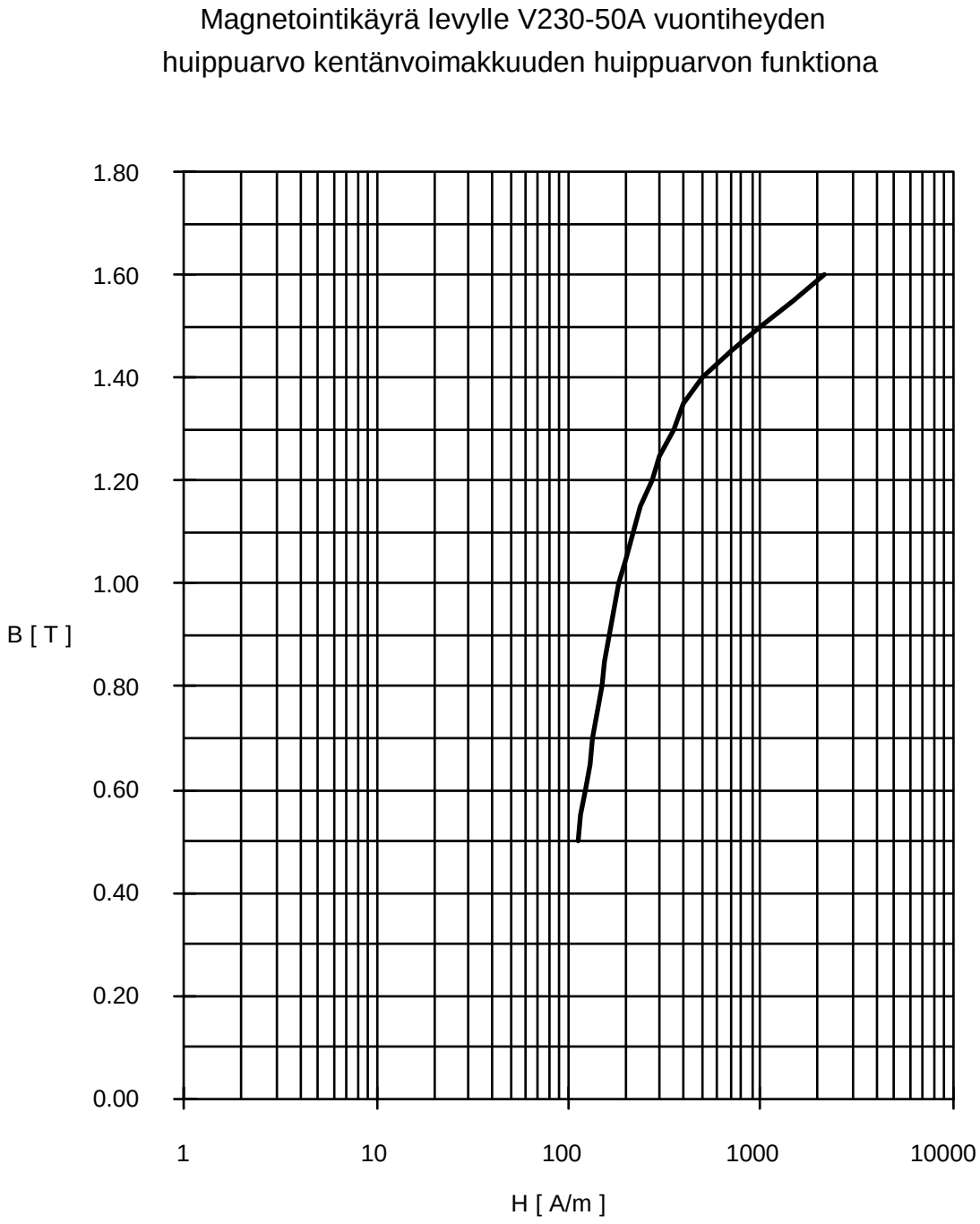
Introduction

Design calculations and simulation results

Discussions and conclusions

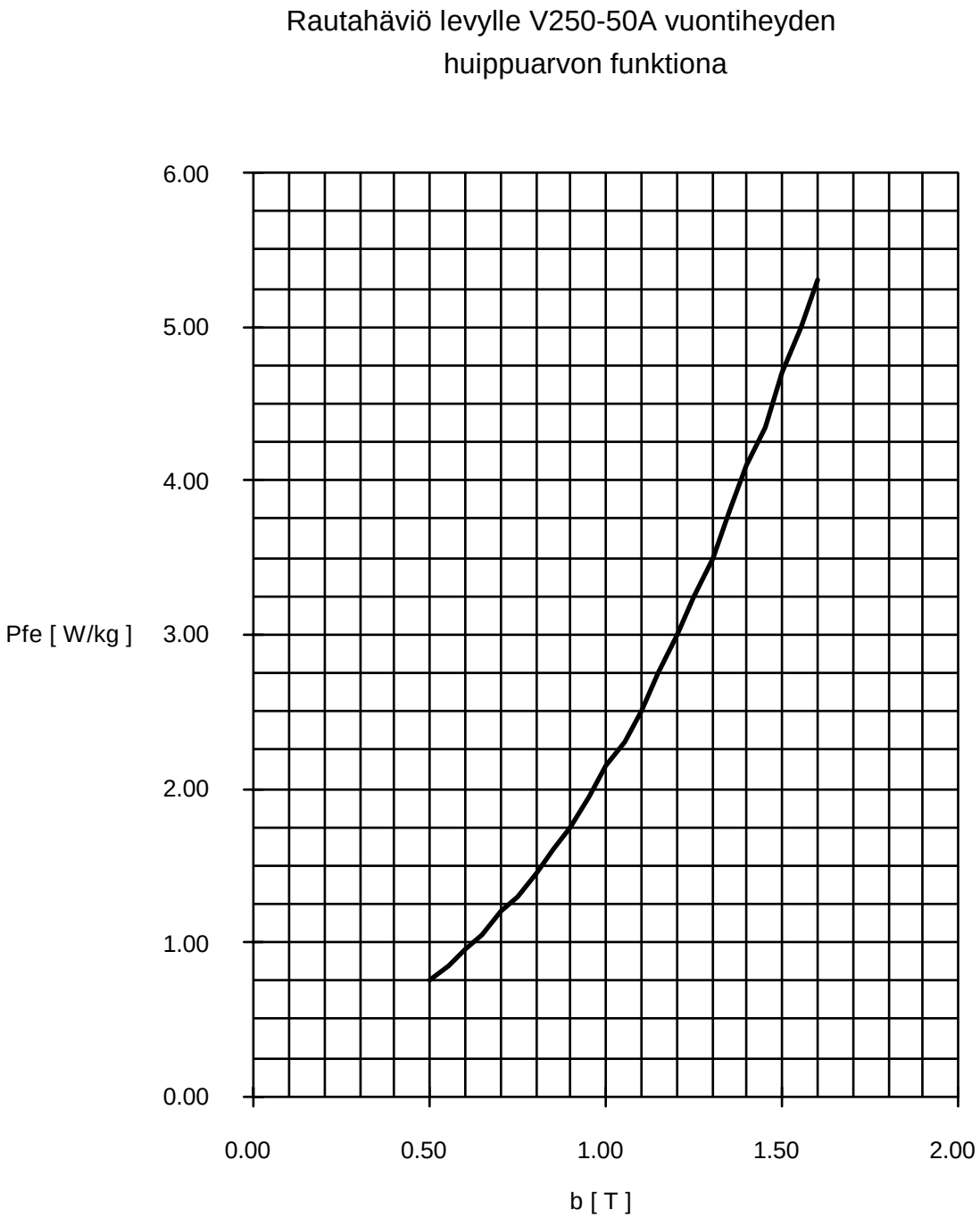
Appendices

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



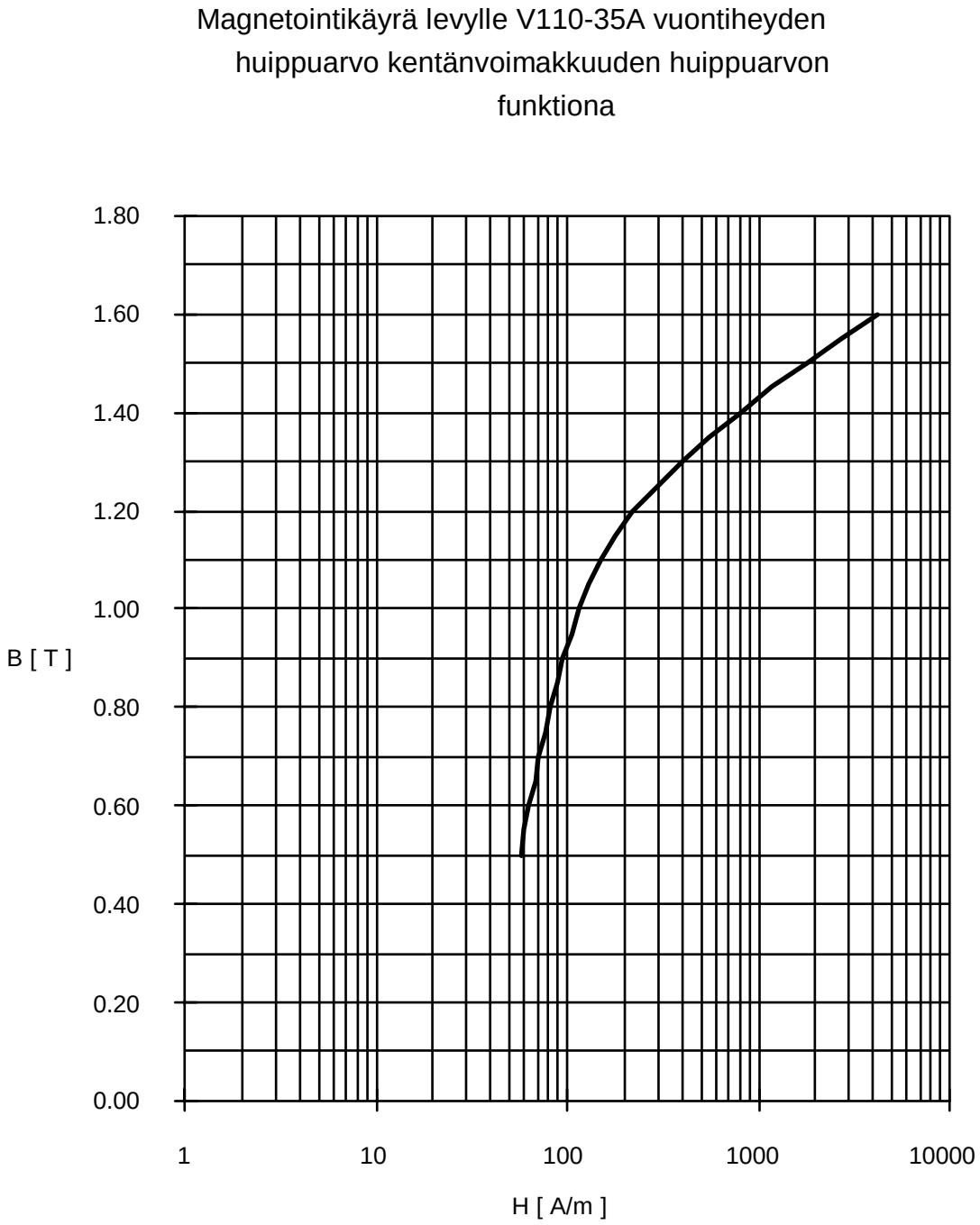
BH-curve for a core plate V230-50A
Peak value of flux density as a function of peak value of magnetic field strength

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



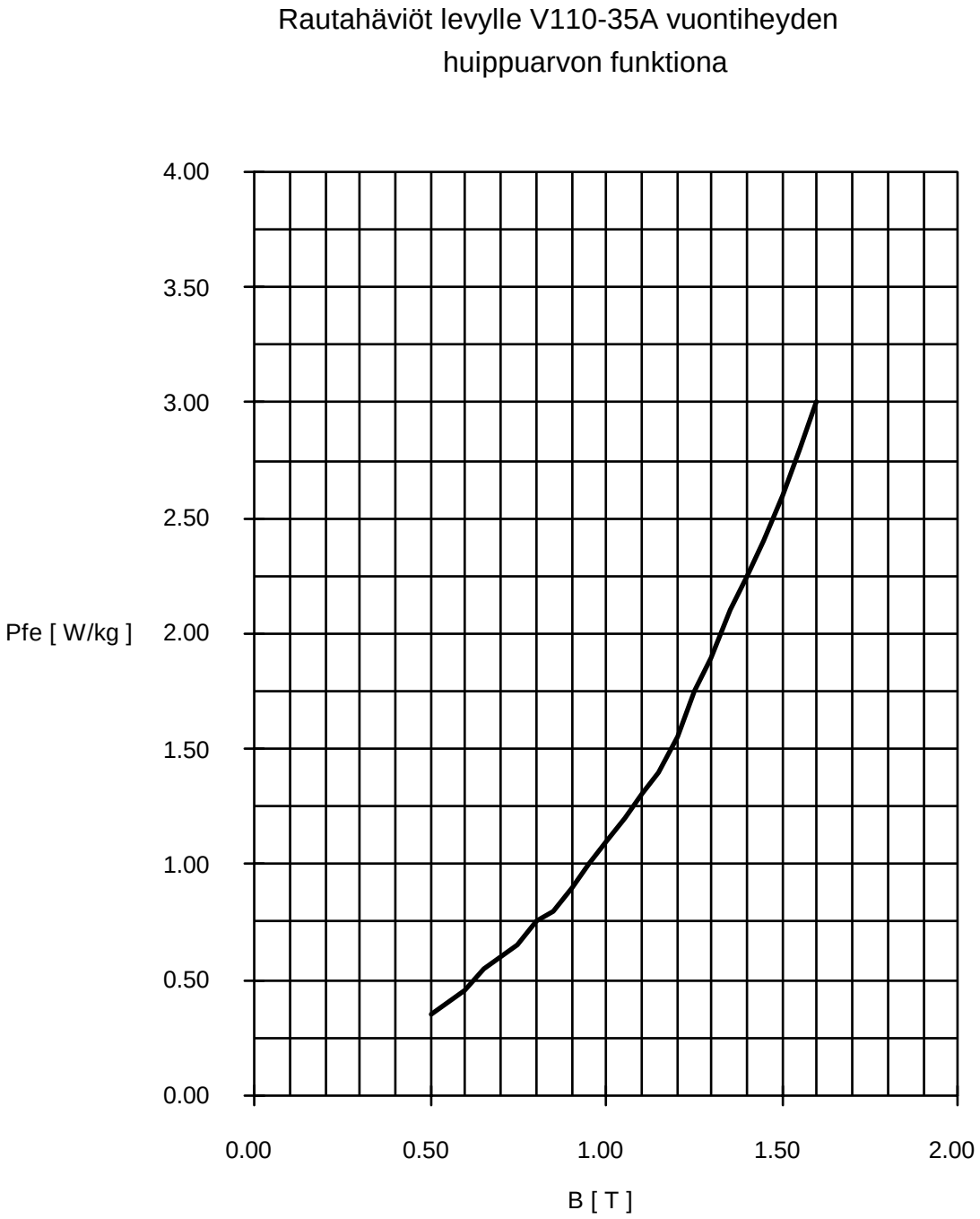
Iron losses for a core plate V230-50A
Iron losses as a function of peak value of flux density

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

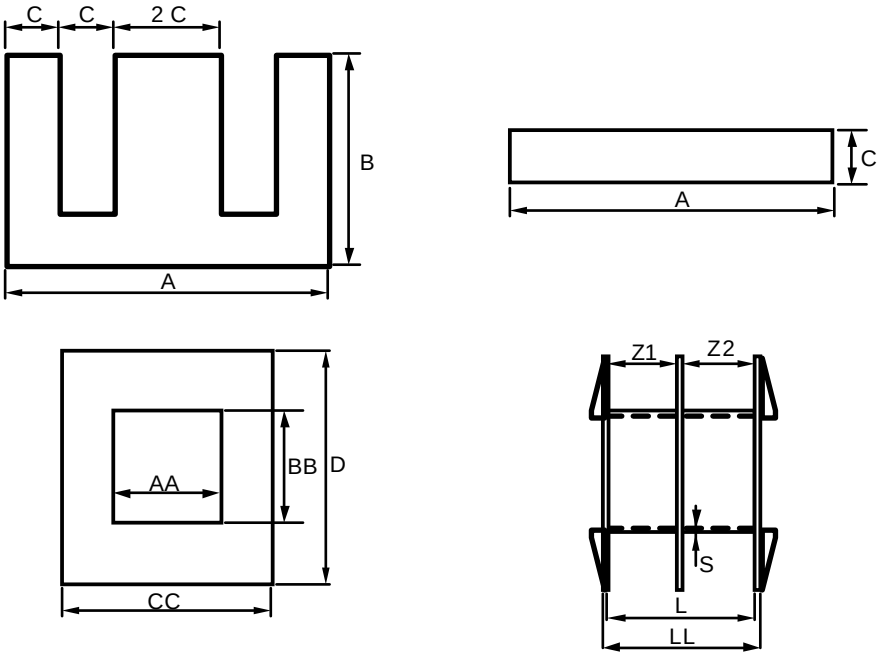
APPENDIX 5 P_{fe}-CURVE OF SHEET, 1.1 W/kg, 0.35 mm



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

Design of transformer series

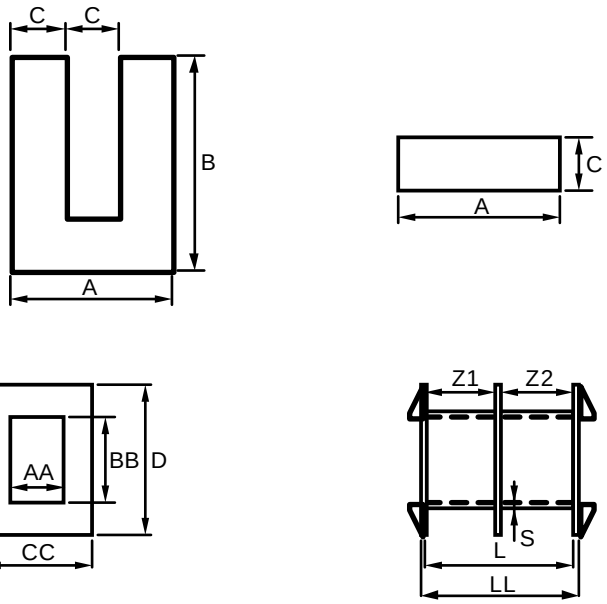
APPENDIX 6 DIMENSIONS OF EI-PLATES AND COIL FORMERS



	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