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, manufactured, and tested. 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 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 is defined based on the measured results.
* The transformer 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),
  - tolerance for the secondary voltage at rated load and at working temperature is ± 5 %.

Notes

* All the decisions and conclusions made during the work have to be **written down and used in the report.**

Part 1: Core and winding calculation

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 (ratio between area of iron and area of core) — K_{fe} = 0,94
- The effective value of the current density — J_{cu} = 5,5 ... 6,5 A/mm^2
- The filling factor of the winding (ratio between insulated wire and winding cross-section) — 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.

Part 2: Production of transformer

* **Primary winding**
  - 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.

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Using extra force will damage the insulation of the sheets. From now on, the number 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 BH characteristics of the transformer will be measured and compared with the given rated value.

* **Secondary winding**
- **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.
- A layer of insulation tape should separate the primary windings, secondary windings, and the core.

REMARKS: Always the re-spooling has to be done using a new wire to avoid insulation breakdown.

* 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 fiber 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 centimeters. 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.

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2. TESTING OF THE TRANSFORMER

* The purpose of the measurements is to check that the transformer fulfils the given demands. The measured values are used to calculate the electrical equivalent circuit parameters for the transformer at open-circuit, short-circuit and rated conditions.

* **Test specifications**
  - BH characteristics of the transformer. (this is done during the primary winding design stage)
  - Open circuit test measurements
  - Short circuit test measurements
  - Rated load test measurements
  - **Temperature rise test measurements takes about 2 hours.**

* Measurement setup
  - 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.

3. TRANSFORMER DESIGN REPORT AND PRESENTATION

A final report including the design procedure, measurements results, and all necessary conclusion made will be submitted for review. The summary of the whole work will be presented by each group during the presentation session. The final report 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 P_{fe}-curve in Appendices)

These parameters should be compared with the parameters found based on measurements results.

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* 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, power factor, and the temperature rise using thermocouples and resistance measurement.
  - At short-circuit (rated primary current): the primary voltage, current, and power, and the short-circuit impedance of transformer.
  - Machine factor = power / volume.

* The thermal model of transformer: Definition of thermal equivalent circuit of the transformer for open circuit condition, and calculate the thermal resistance involved.
* The grading of the lab exercise is equally divided for:
  - The design and manufacturing of the transformer
  - The final report
  - The presentation/discussion

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 Enameled wires, data sheet

APPENDIX 1 RULES FOR THE REPORT

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List of symbols and abbreviations

Introduction

Design calculations, measurements and results

Discussions and conclusions

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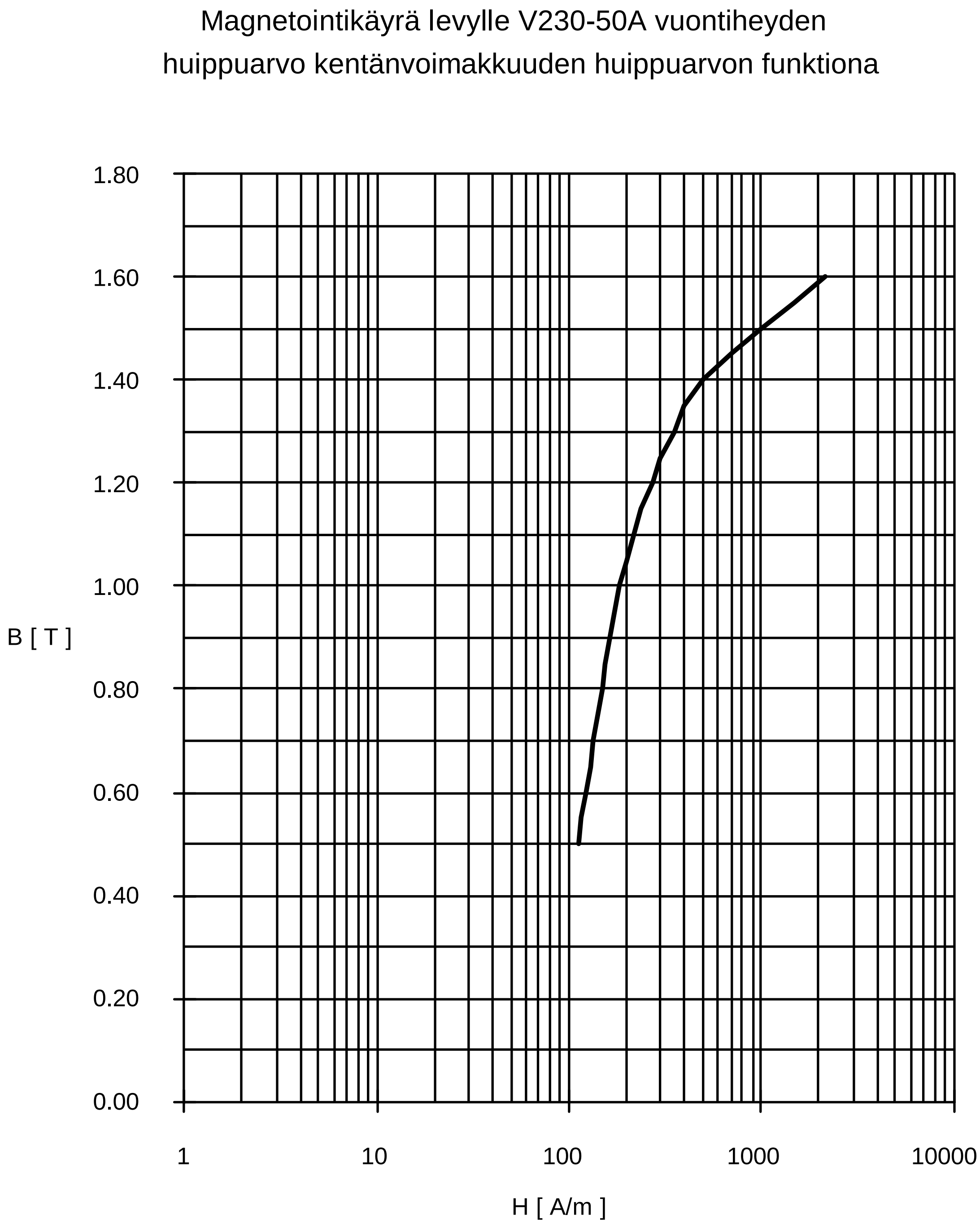
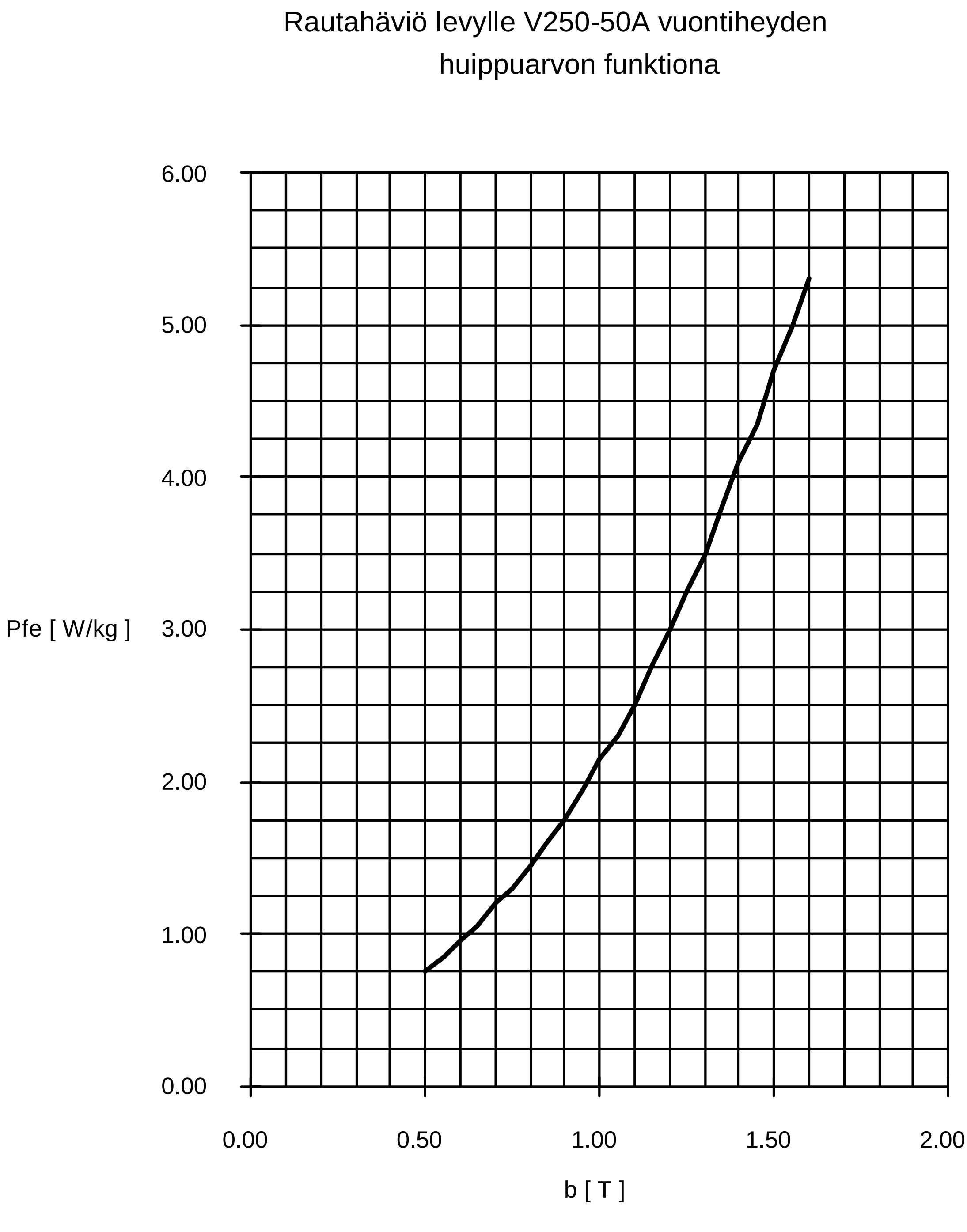
APPENDIX 2 *BH*-CURVE OF SHEET, 2,3 W/kg, 0.5 mm



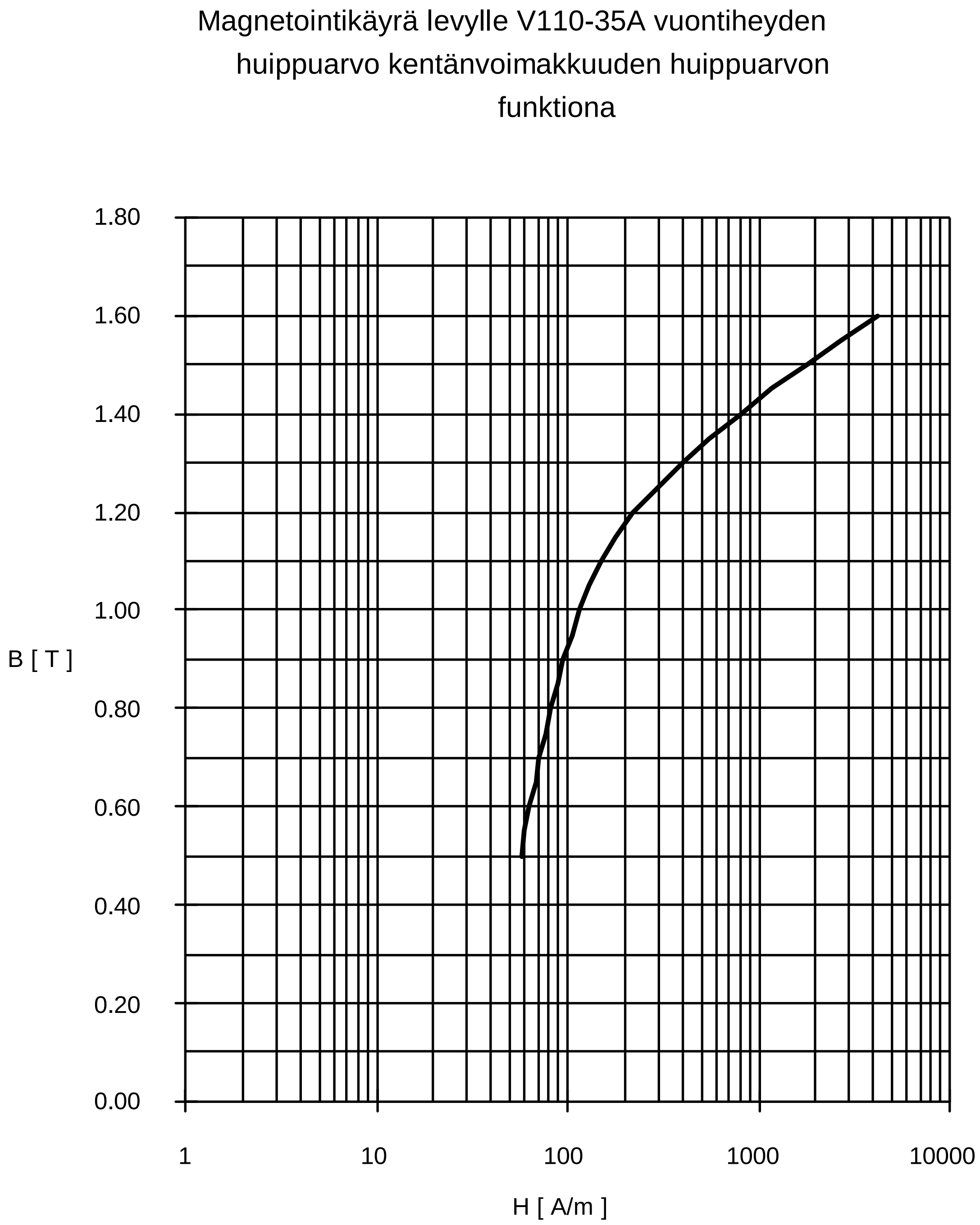
BH-curve for a core plate V230-50A
Peak value of flux density as a function of peak value of magnetic field strength

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



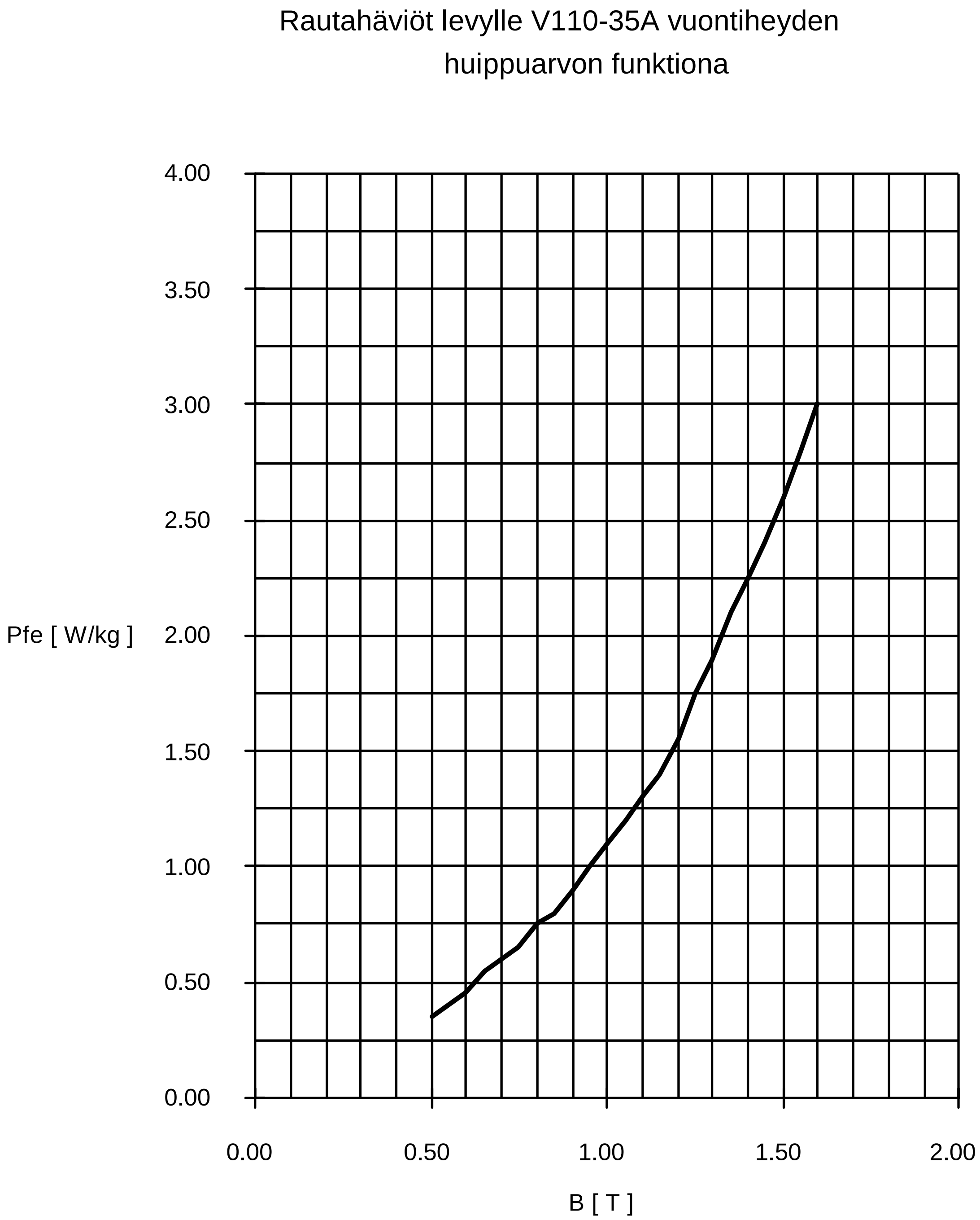
Iron losses for a core plate V230-50A
Iron losses as a function of peak value of flux density

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



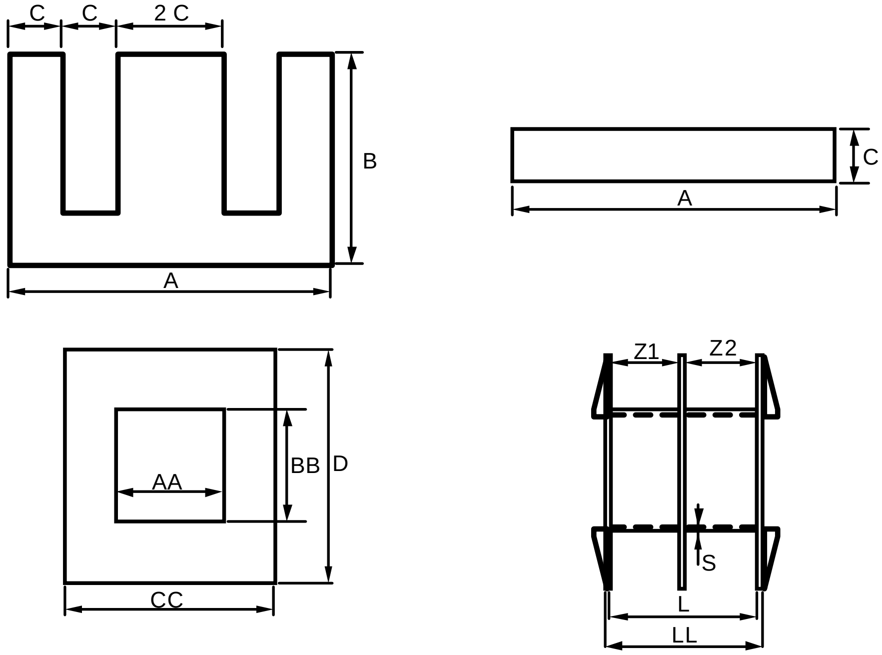
BH-curve for a core plate V110-35A
Peak value of flux density as a function of peak value of magnetic field strength

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



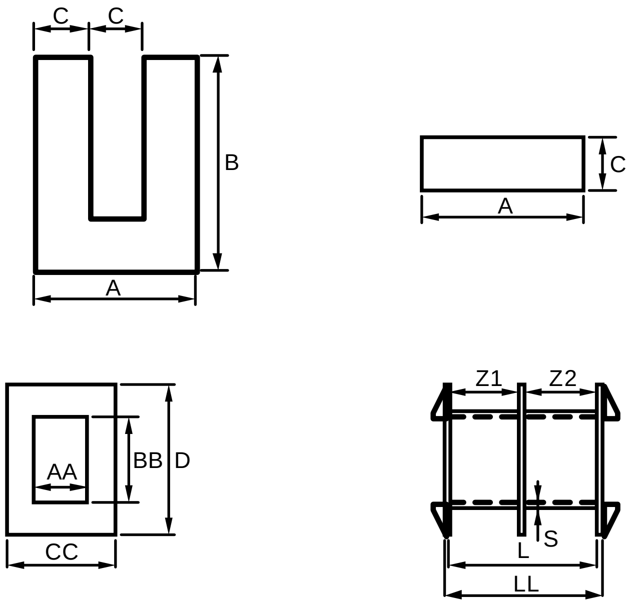
Iron losses for a core plate V110-35A
Iron losses as a function of peak value of flux density

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

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	-	-

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