BROCKHAUS ACADEMY

Current status of standardization work single sheet test, magnetostriction, material standards

Stefan Siebert, Coiltech 2023

BROCKHAUS ACADEMY

- Material Standard IEC60404-8-7
- Single Sheet Tester SST500 IEC60404-3
- Introduction into measurment technique
- Magnetostriction IEC60404-17
- Franklin Tester IEC60404-11
- Other IEC-Work
- Discussion

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Material Standard IEC60404-8-7

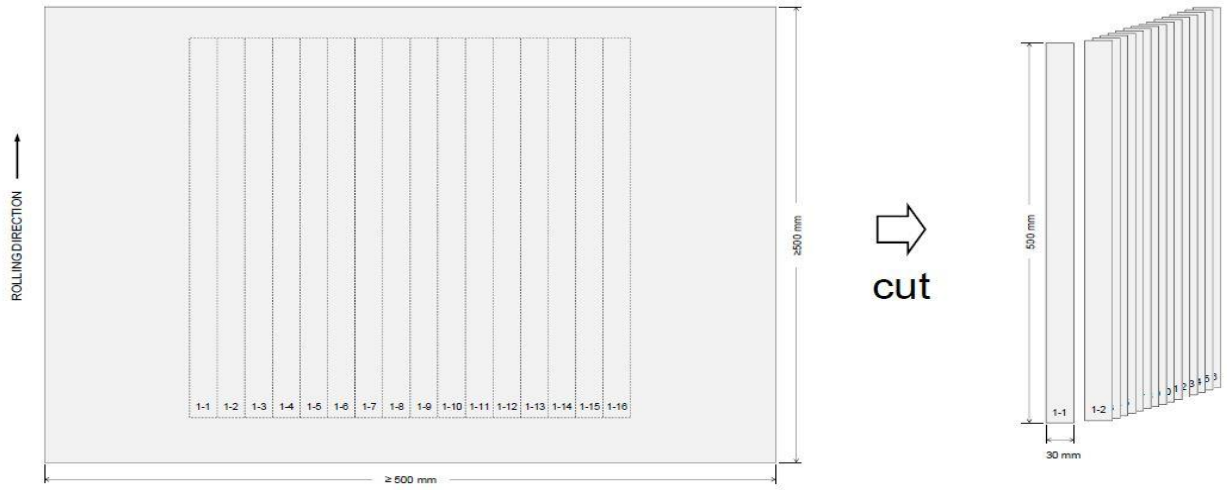
Situation before revision of IEC60404-8-7

- Epstein measurements (IEC 60404-2) was the only basis of values in the material standard (IEC 60404-8-7) for oriented electrical steel

- This method was not applicable to modern domain-refined materials

- Domain–Refined materials was not fully described in the material standard

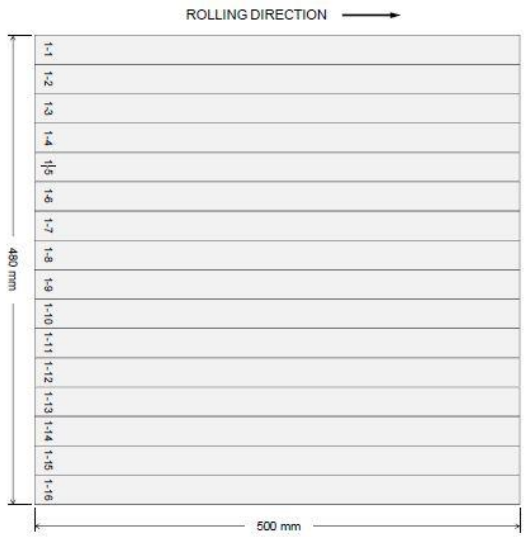
SST-Epstein Calibration failed

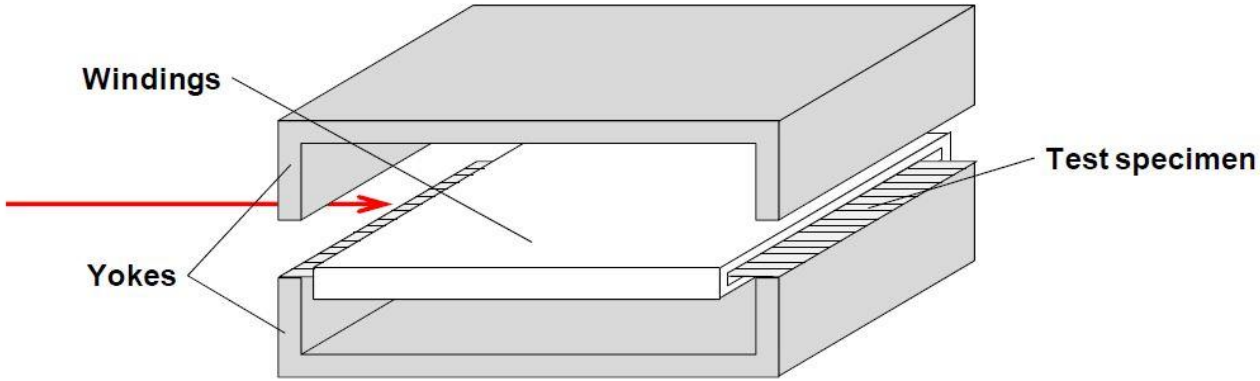


- 16 test strips of 500 mm (RD) x 30 mm (TD) shall be cut side by side from a sample sheet of GO materials [3,4]
- Stress-relief heat treatment [3,4]
- Domain-refining process [3,4]
- Measurement in the Epstein frame [3,4]

Reference to: [3] IEC 60404-3 Annex B
[4] Dr. Masao Yabumoto, The Japanese National Committee for IEC/TC68, 2013/09/30

SST-Epstein Calibration

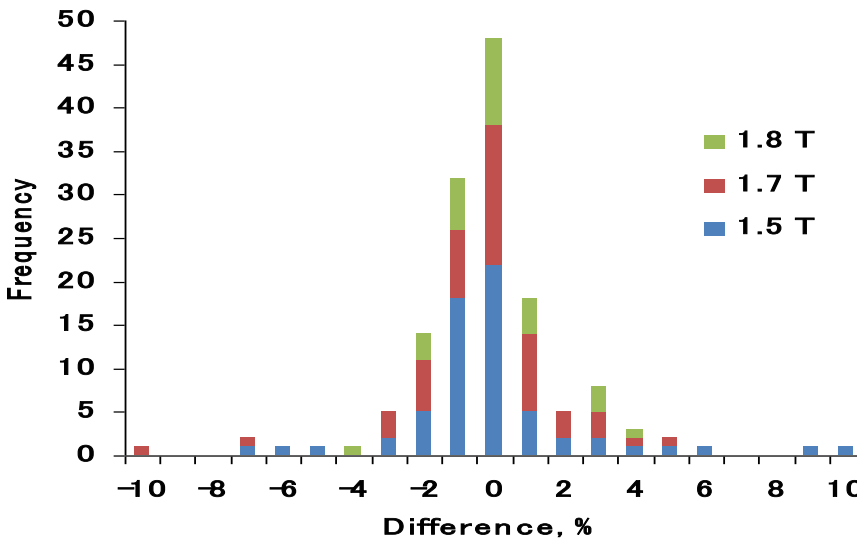


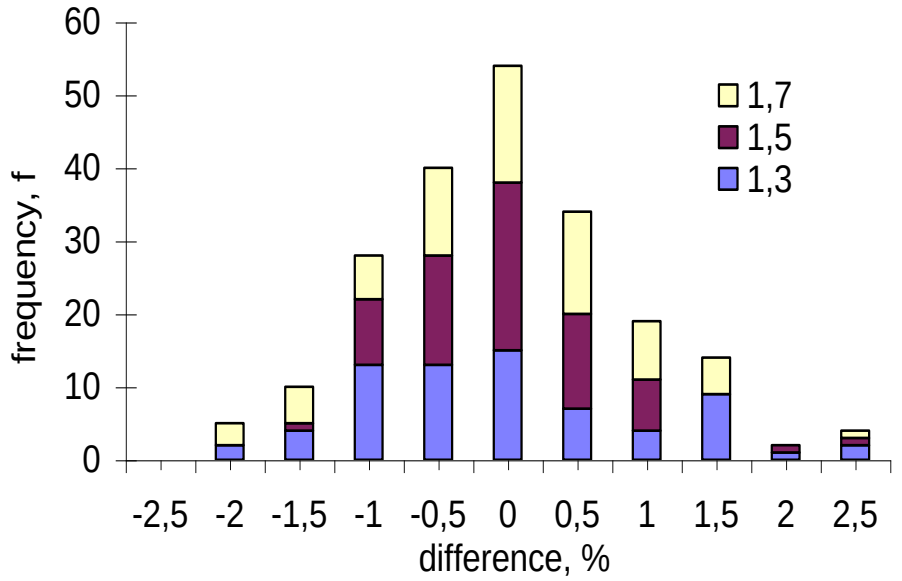


- Strips to be inserted in SST92 apparatus
- The same specific total losses and magnetic polarization with Epstein to be measured
- Calculation of path length or power loss

Reference to: [3] IEC 60404-3 Annex B
[4] Dr. Masao Yabumoto, The Japanese National Committee for IEC/TC68, 2013/09/30

SST-Epstein Calibration

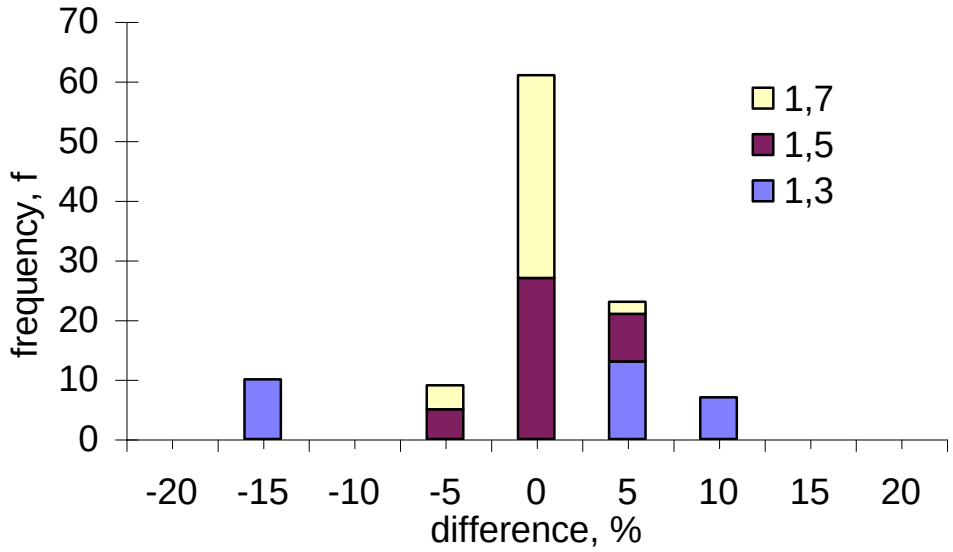




Comparison of Epstein measurements [1] Comparison of SST measurements [2]

Reference to: [1] Drake, A.E.;. EU-report No. EUR 10233, Brussels 1985
[2] Girgis, R, K. Gramm , J. Sievert and M.G. Wickramasekara: SMM 12 Conference, Grenoble 1997; Journal de Physique IV France **8** (1998), p.Pr2-729 – Pr2-232

SST-Epstein Calibration



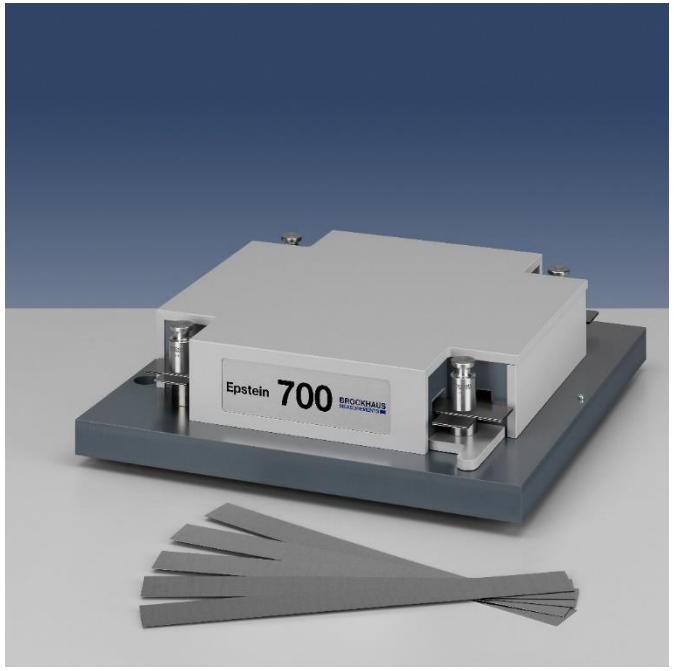
Comparison of SST82 measurements [2]

Reference to: [2] Girgis, R, K. Gramm , J. Sievert and M.G. Wickramasekara: SMM 12 Conference, Grenoble 1997; Journal de Physique IV France **8** (1998), p.Pr2-729 – Pr2-232

Solution for IEC 60404-8-7

- Calibration SST to Epstein values fails
- TC 68 of IEC has finished new work item in 2021
- Adding domain-refined electrical steel to the material standard in a new Class 3
- SST92 as the basis of material classification
- Adding SST(92) measuring values to this material standard for domain-refined electrical steel
- Only one Conversion factor for Ps at 1.7T (0.925 confirmed)
- SST 500 more important in the future
- Osaka 2022: Discussion about Transition from Epstein to SST

Solution for IEC 60404-8-7



Published Revision for IEC 60404-8-7

Table 3 – Technological and magnetic properties of magnetic domain refined high permeability grades of grain-oriented electrical steel strip and sheet (magnetic properties are measured using the Single Sheet Test method* according to IEC 60404-3).

Steel name	Nominal thickness	Maximum specific total loss at 1,7 T* W/kg		Minimum magnetic polarization at H = 800 A/m [a]	Minimum stacking factor
	mm	at 50 Hz	at 60 Hz	T	
M70-20R5	0,20	0,70	0,92	1,85	0,940
M75-20R5		0,75	0,99	1,85	
M75-23R5	0,23	0,75	0,99	1,85	0,945
M80-23R5		0,80	1,05	1,85	
M85-23R5		0,85	1,12	1,85	
M90-23R5		0,90	1,18	1,85	
M85-27R5	0,27	0,85	1,12	1,85	0,950
M90-27R5		0,90	1,18	1,85	
M95-27R5		0,95	1,25	1,85	

[a] It has been common practice for many years to give values of magnetic flux density instead of values of magnetic polarization (intrinsic flux density) which is defined as:

$J = B - \mu_0 H$

where

J is the magnetic polarization;

B is the magnetic flux density;

μ_0 is the magnetic constant: $4\ \pi \times 10^{-7}$ H·m^{-1};

H is the magnetic field strength.

The difference between B and J at H = 800 A/m is equal to 0,001 T.

* The values of the specific total loss are given by the results of the SST measurements multiplied by the conversion factor, Fc, as described in 7.1.4. In the case of heat-proof DR materials, when the Epstein method is to be applied (7.1.4), the listed values are to be considered as the grade limit loss values as measured directly by the Epstein method.

- Discussion:
  - 0,925 only for 1.7T
  - B800?
  - Use SST also for conventional GO material?
- Next meeting in Osaka TC 68 08.10.2022

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What is your experience with this new standard?

What are your expectations?

Revision: Single Sheet Tester IEC60404-3

Revision: Single Sheet Tester IEC60404-3

- Revision started 2019

- more than 600 comments

- Main Changes:
  - Annex A: Requirements concerning the manufacture of yokes
    - Yoke power loss of 1 mW/kg at 40 mT or of 0,1 mW/kg at 10 mT
    - Yoke resistivity: over the full length of 50 cm > 100 Ω

  - Annex B: Performance test by the use of reference samples
  - Small strip specimens can be measured using this SST placing them side by side

- Revision approved 2022

Revision: Single Sheet Tester IEC60404-3

BROCKHAUS ACADEMY

68/710/RVC

RESULT OF VOTING ON CDV (RVC)

PROJECT NUMBER: **IEC 60404-3 ED3**
DATE OF CIRCULATION: **2022-06-03**
REFERENCE NUMBER OF THE CDV: **68/699/CDV**

IEC TC 68 : MAGNETIC ALLOYS AND STEELS

SECRETARIAT:	SECRETARY:	CHAIR:
Germany	Mr Richard Daniel Knobloch	Mr Carlo Stefano Ragusa

OF INTEREST TO THE FOLLOWING COMMITTEES:	HORIZONTAL STANDARD:
	☐

FUNCTIONS CONCERNED:

☐ EMC ☐ ENVIRONMENT ☒ QUALITY ASSURANCE ☐ SAFETY

☒ SUBMITTED FOR CENELEC PARALLEL VOTING	☐ NOT SUBMITTED FOR CENELEC PARALLEL VOTING

The CDV document was distributed to National Committees with a request that voting take place for circulation as a FDIS or publication as an International Standard.

P-MEMBERS VOTING

MEMBERS VOTING	P-MEMBERS IN FAVOUR	IN FAVOUR %	CRITERIA	RESULT
10	10	100	≥66,7 %	**APPROVED**

ALL VOTES

TOTAL VOTES CAST	TOTAL AGAINST	AGAINST %	CRITERIA	RESULT
14	0	0	≤25 %	**APPROVED**

BROCKHAUS ACADEMY

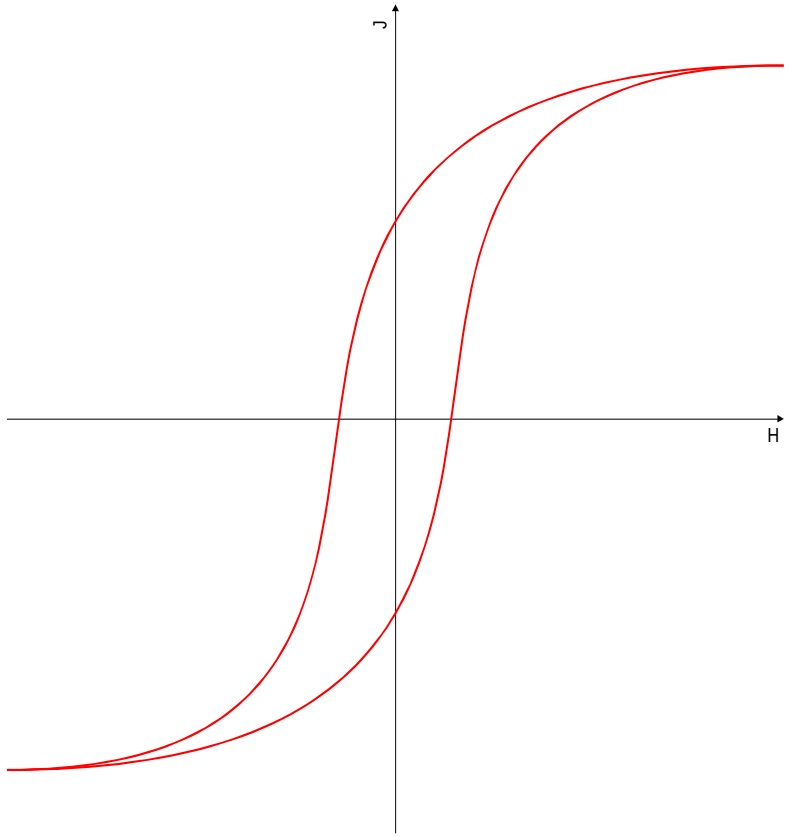
Introduction into measuring technology

Introduction

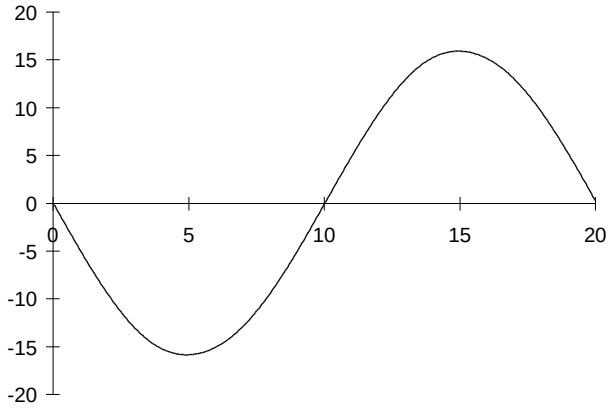
Determination of Magnetic Properties of Electrical Steel with very well known methods:

- Epstein or Single Sheet
- IEC 60404-2 ff. or ASTM 343 ff.
- Secondary Voltage/Polarisation sinusoidal
- Transformer principle

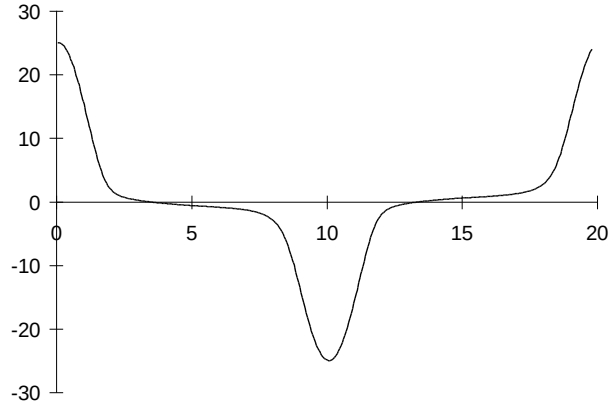
Hysteresisloop



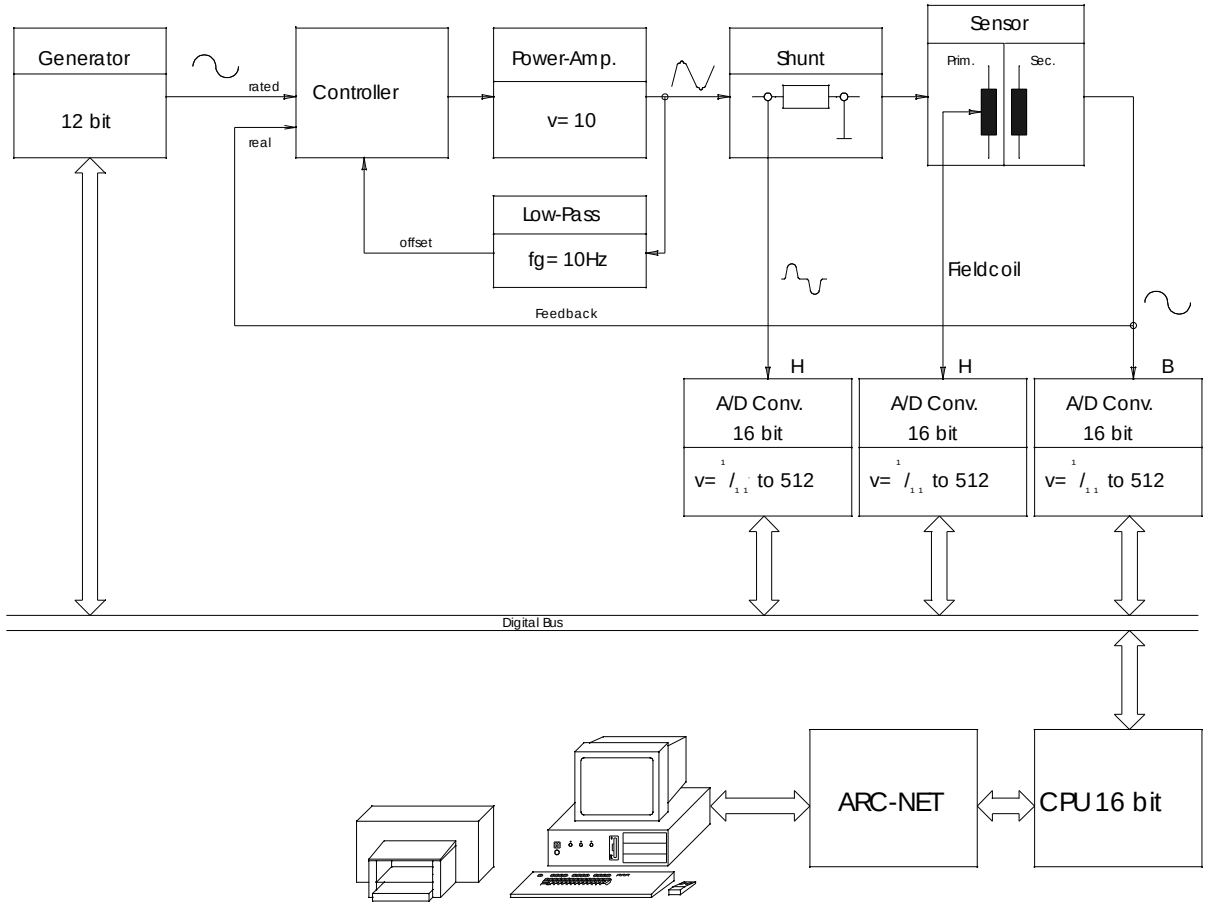
Secondary Voltage/Polarisation J



Primary Current/Field Strength H



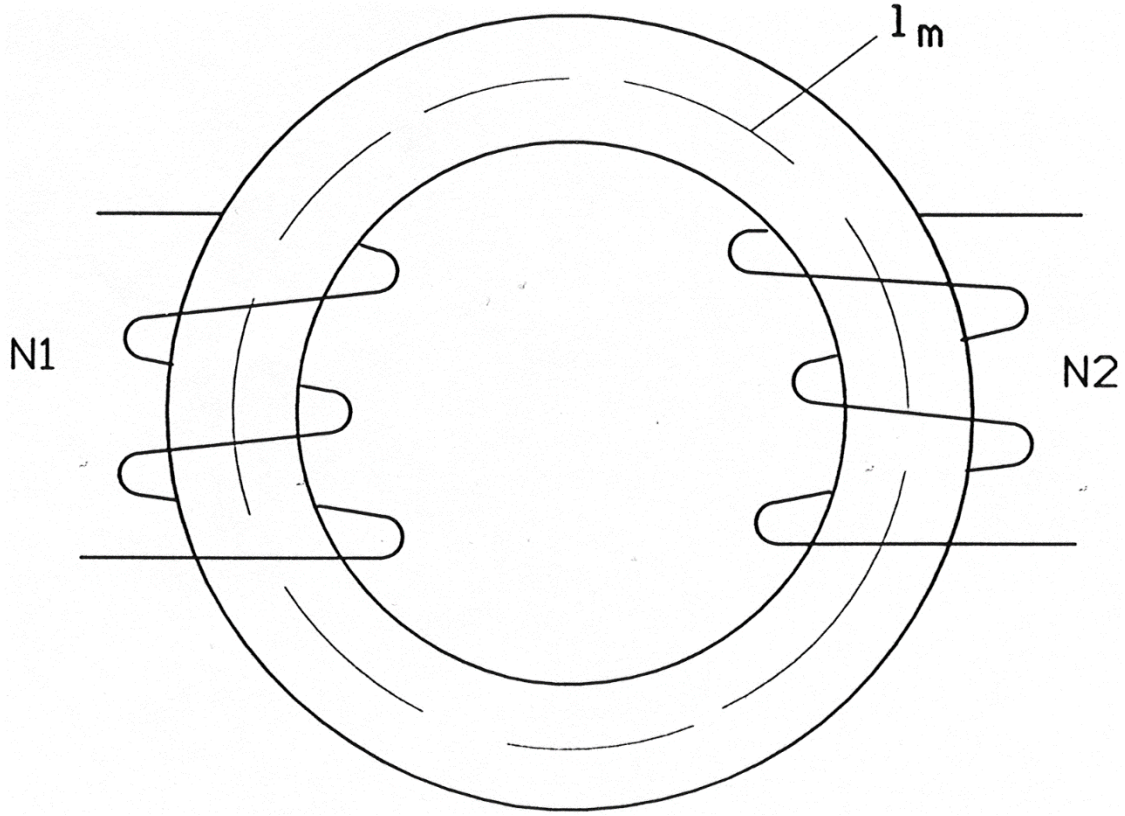
Equipment


Generator
12 bit
rated
real
Controller
Power-Amp.
v= 10
Shunt
Sensor
Prim.
Sec.
Low-Pass
fg= 10Hz
offset
Fieldcoil
Feedback
H
H
B
A/D Conv.
16 bit
v= 1/11 to 512
A/D Conv.
16 bit
v= 1/11 to 512
A/D Conv.
16 bit
v= 1/11 to 512
Digital Bus
ARC-NET
CPU 16 bit

Data of Interest

- Polarisation J, Induction B
- Field strength H
- Permeability μ
- Total Power Loss

Transformer (Principle)



Transformer (Principle)

Measuring principle:

•Transformer principle

• Alternating current on the primary winding is proportional to the magnetizing field strength:

$$H = \frac{I \bullet N_1}{l_m}$$

• Secondary voltage integrated to get the induction/polarisation:

$$B = -\frac{1}{NA}\int_{t_1}^{t_2} U(t) \bullet dt$$

The integral of the secondary voltage represents the polarisation of the material and is displayed versus the magnetizing current so that a typical hysteresis loop is created.

Transformer (Principle)

Area of hysteresis loop is proportional to the total power loss P_s

$$P_s = \frac{f}{\delta} \sum_{i=1}^{n} (dB_i \cdot H_i)$$

With: δ

f = Measuring frequency

= Material density

Epstein Frame

IEC 60 404-2

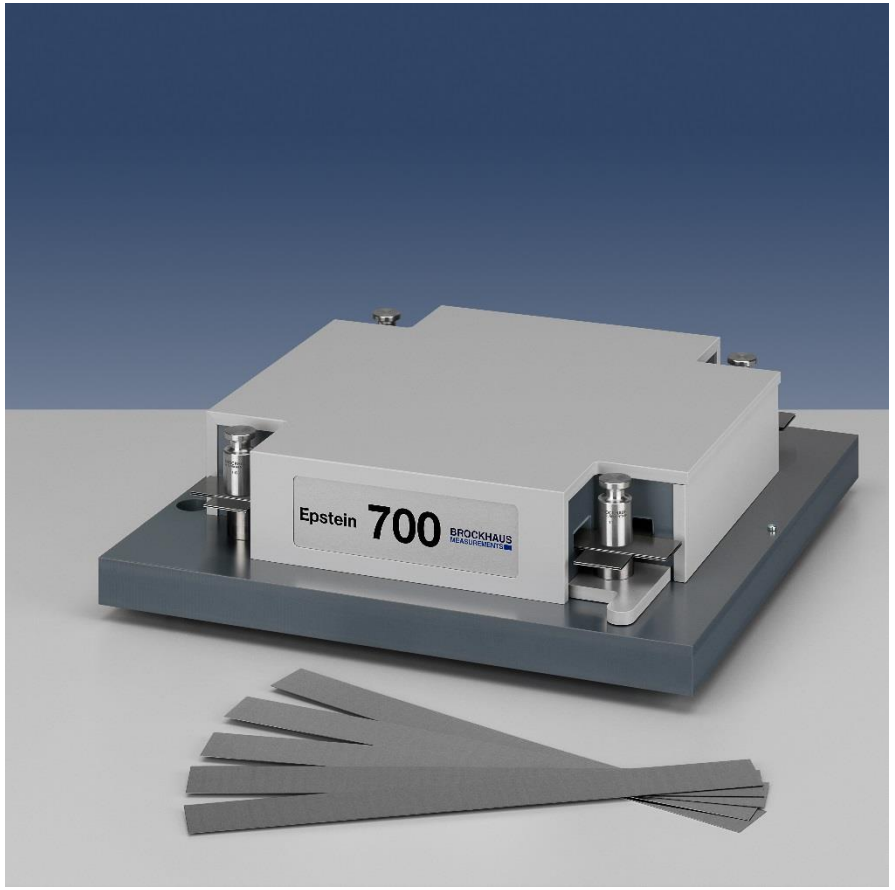
Sample: Weight: 0,5 Kg

Number of Strips: 8, 12, 16, 24, 28

Width: 30 mm

Length: >280 mm

Epstein Frame



Single Sheet Tester

IEC 60 404-3

Frequency Range: 50 Hz – 400 Hz

Form Factor: 1.11 ± 1%

Path Length: 450 mm

Sample Weight: 0,5 Kg

Number of Sheets: 1

Width: 500 mm, Length: 500 mm

Single Sheet Tester

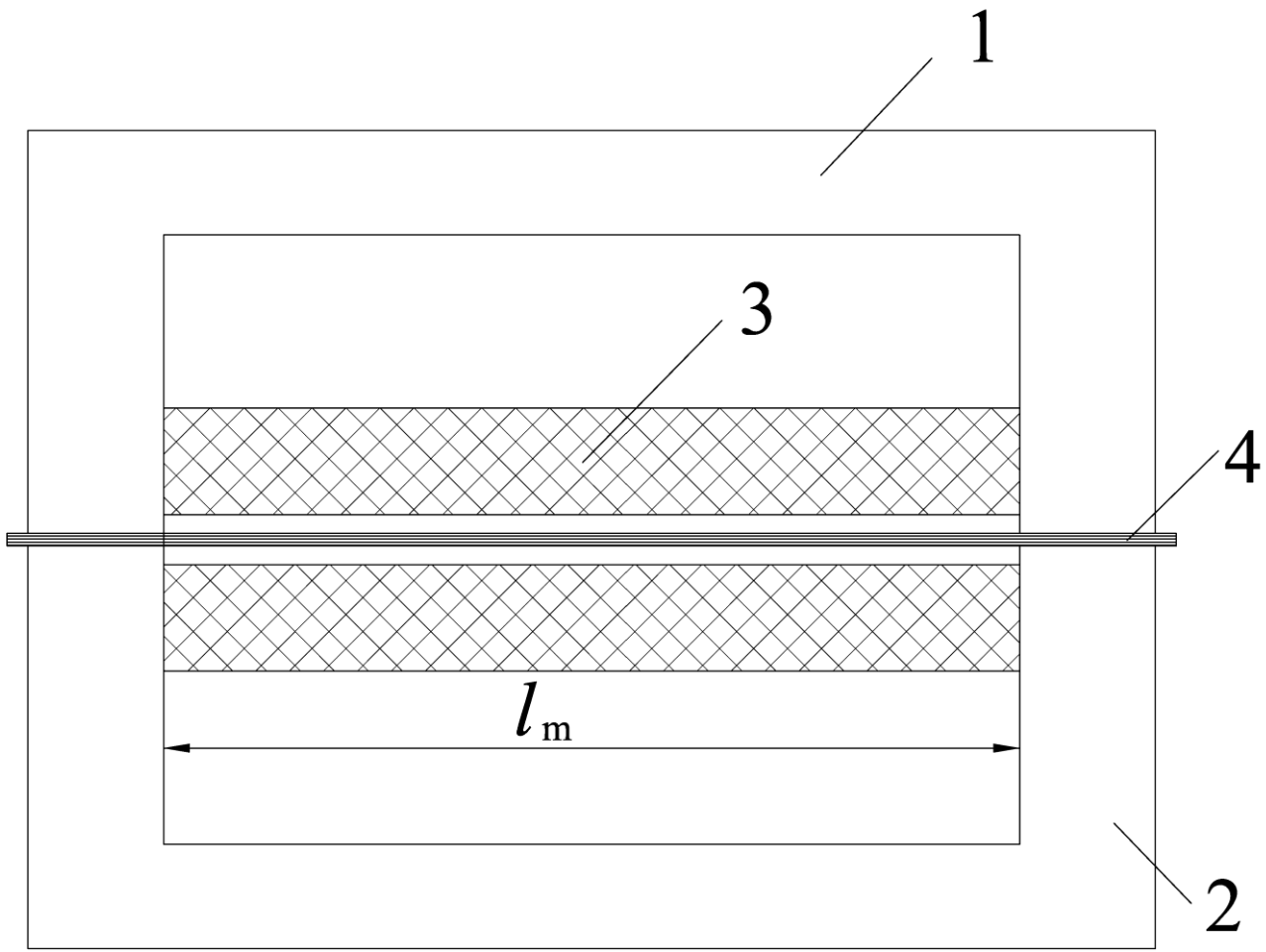
Sample Weight: 0,5 Kg

Number of Strips: 1

Width: 500 mm

Length: 500 mm

Single Sheet Tester



Single Sheet Tester

Single Sheet Tester

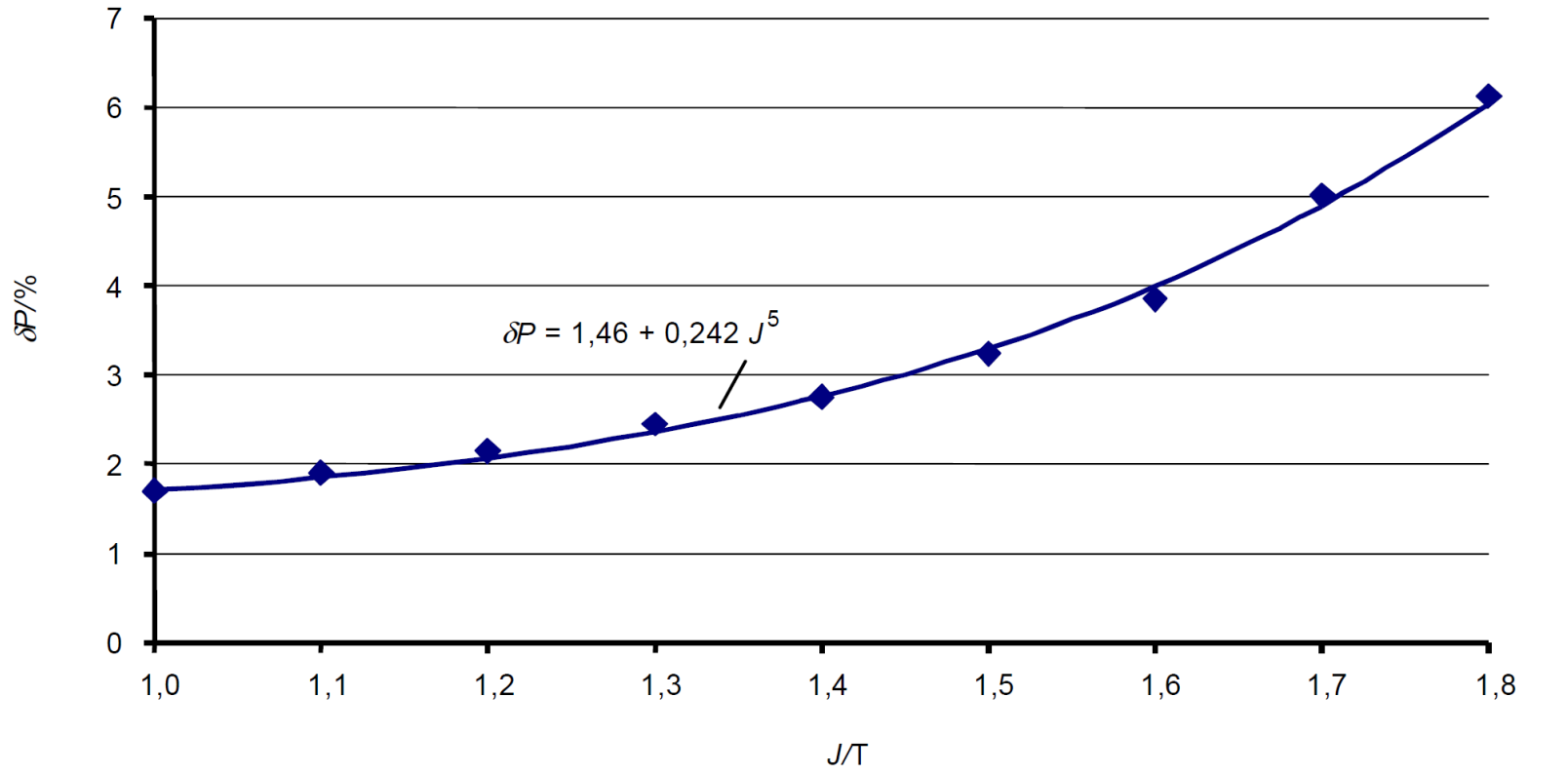
Advantages:

- High Reproducibility (< 2% for different Equipment)
- Simple Sample Preparation
- Information about processing influences

Disadvantages:

- Different results compared with Epstein values
- Expensive coil system

SST-Epstein Problem



Difference IEC to ASTM Standard

- ASTM 343-ff: Uses the real density for cross section calculation
- IEC 60404-2, -3: Use density as defined in the material standard IEC60404-8 for cross section calculation

- Due to different density different loss values

Revision: Single Sheet Tester IEC60404-3

Revision: Single Sheet Tester IEC60404-3

- Revision started 2019

- more than 600 comments

- Main Changes:
  - Annex A: Requirements concerning the manufacture of yokes
    - Yoke power loss of 1 mW/kg at 40 mT or of 0,1 mW/kg at 10 mT
    - Yoke resistivity: over the full length of 50 cm > 100 Ω

  - Annex B: Performance test by the use of reference samples
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Franklin Tester IEC60404-11

Franklin Tester

IEC 60 404-11

Contacts: 10 x 64,5 mm^2

Pressure: 2 N/mm^2 total 1290 N

Test Voltage: 0,5 V

Drills: 2

Difference IEC to JIS Standard

- JIS C2550-4: 64,5 mm² or 100 mm² contact size
- IEC 60404-11: 64,5 mm² contact size

- JIS C2550-4: 2 N/mm² total 1290 N or 2000 N pressure
- IEC 60404-11: 2 N/mm² total 1290 N pressure

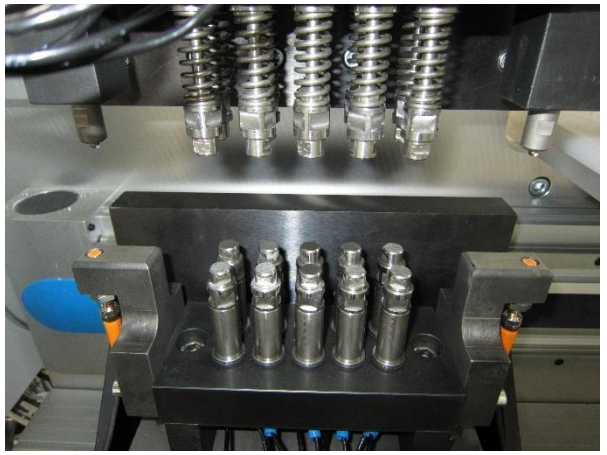
- Due to different size of contacts different resistance values

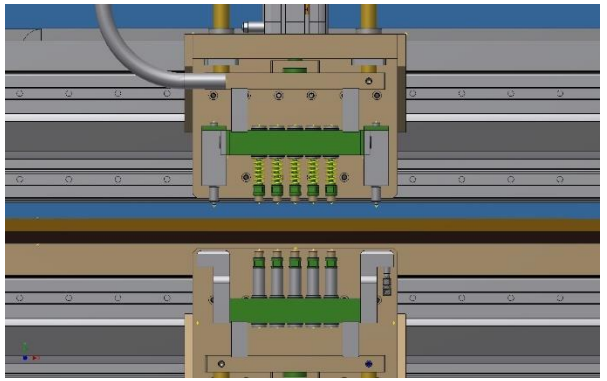
- In the future Japan will eliminate 100 mm² contacts

Single Side / Double Side

Standard Franklin Tester

Double Side Franklin Tester





Franklin Tester

- Double side measurement is now standard, too

- BROCKHAUS supplies double side systems:
  - Auto-SST
  - Inline Franklin Tester
  - Manual Franklin Tester

- Standard has been printed 2021

Difference IEC to ASTM Standard

- ASTM A717: surface insulation resistance, in Ω·mm2 / lamination
- IEC 60404-11: surface insulation resistance, in Ω·mm2/side

- Confusion due to : per side versus per lamination
- ASTM-values approx. 2 x IEC-values

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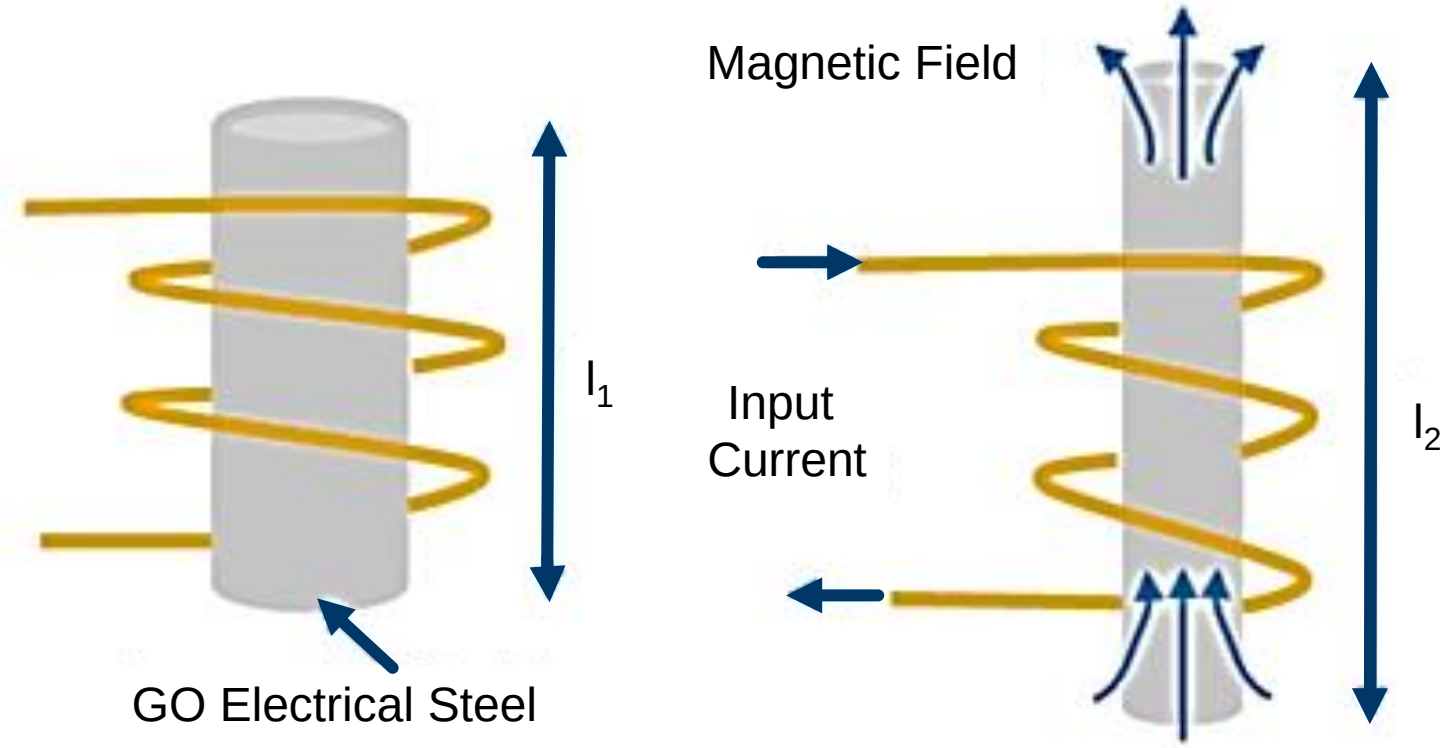
Magnetostriction

IEC60404-17

IEC Magnetostriction System

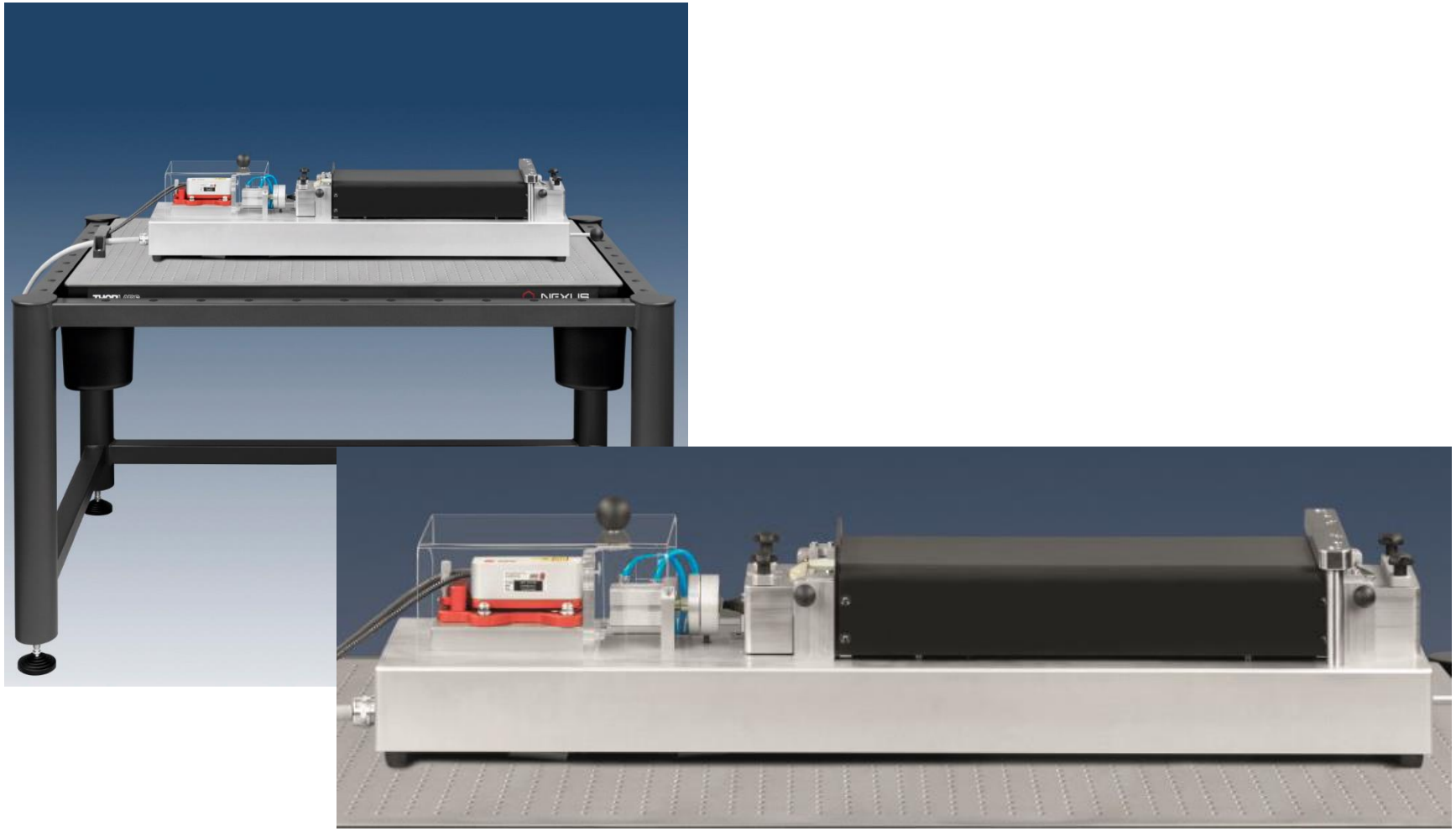
Magnetostriction I



Elongation of steel under the influence of a magnetic field

Ref: https://www.researchgate.net/figure/a-Joule-Effect-Direct-Magnetostrictive-Effect-b-Villari-Effect-Inverse_fig1_331115151

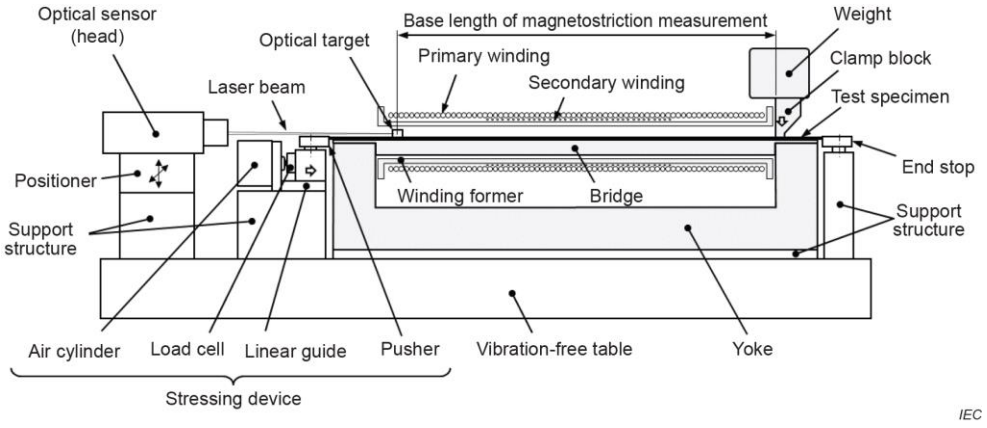
IEC Magnetostriction System



IEC Magnetostriction System

IEC Standard 60404-17

Magnetic materials – Part 17: Methods of measurement of the magnetostriction characteristics of grain-oriented electrical steel strip and sheet by means of a single sheet tester and an optical sensor



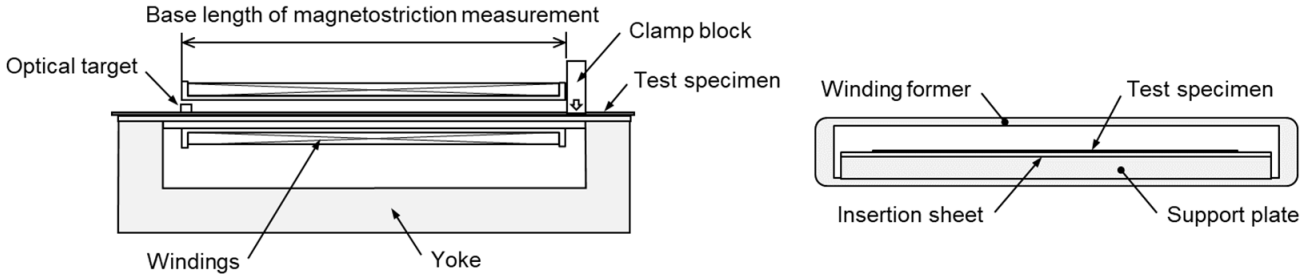
IEC Magnetostriction System: Conclusion

Round Robin Tests reproducibility
2017: 2nd RRT until 2019
- 8 laboratories
- Double yoke systems
- Relative standard deviation: 20% with weight on the sample (at 1.7 T)
- Relative standard deviation: 9% without weight on the sample (at 1.7 T)

2019: 3nd RRT
- 9 laboratories
- Single yoke systems
- Relative standard deviation: 5% without weight on the sample (at 1.7 T)

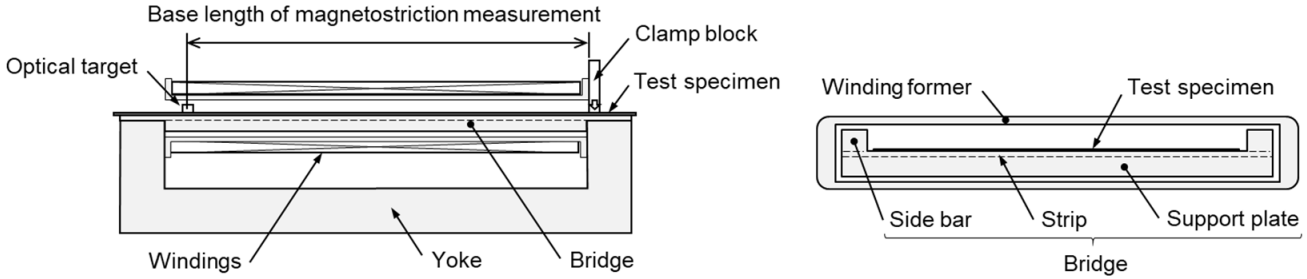
2020: 4th RRT
- 8 laboratories
- Single yoke systems
- Relative standard deviation: 2% without weight on the sample (at 1.7 T)

IEC Magnetostriction System: Main Improvements



(a) Longitudinal cross-section (b) Transversal cross-section

Figure 1 – Schematic diagram of the test apparatus before the improvement



(a) Longitudinal cross-section (b) Transversal cross-section

Figure 2 – Schematic diagram of the test apparatus after the improvement

IEC Magnetostriction System: Conclusion

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2020: 4th RRT
- 8 laboratories
- Single yoke systems
- Relative standard deviation: 2% without weight on the sample (at 1.7 T)

IEC Magnetostriction System: Main Improvements

Main Modifications:

- No upper yoke
- Laser mirror inside yoke construction path approx. 10 mm from the yoke pole
- Clamp inside the magnetic path
- Friction reduction by PTFE thin film along the length of bottom yoke placed below the sample
- Accurate sinusoidal waveform control (ff = 1.1107 ±0.2 %)

IEC Magnetostriction System: Main Improvements (Target position and clamping)

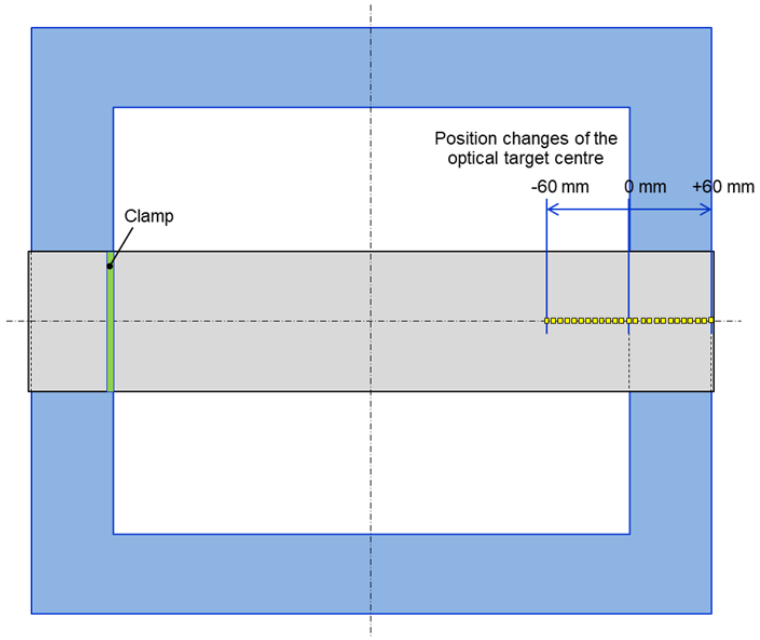
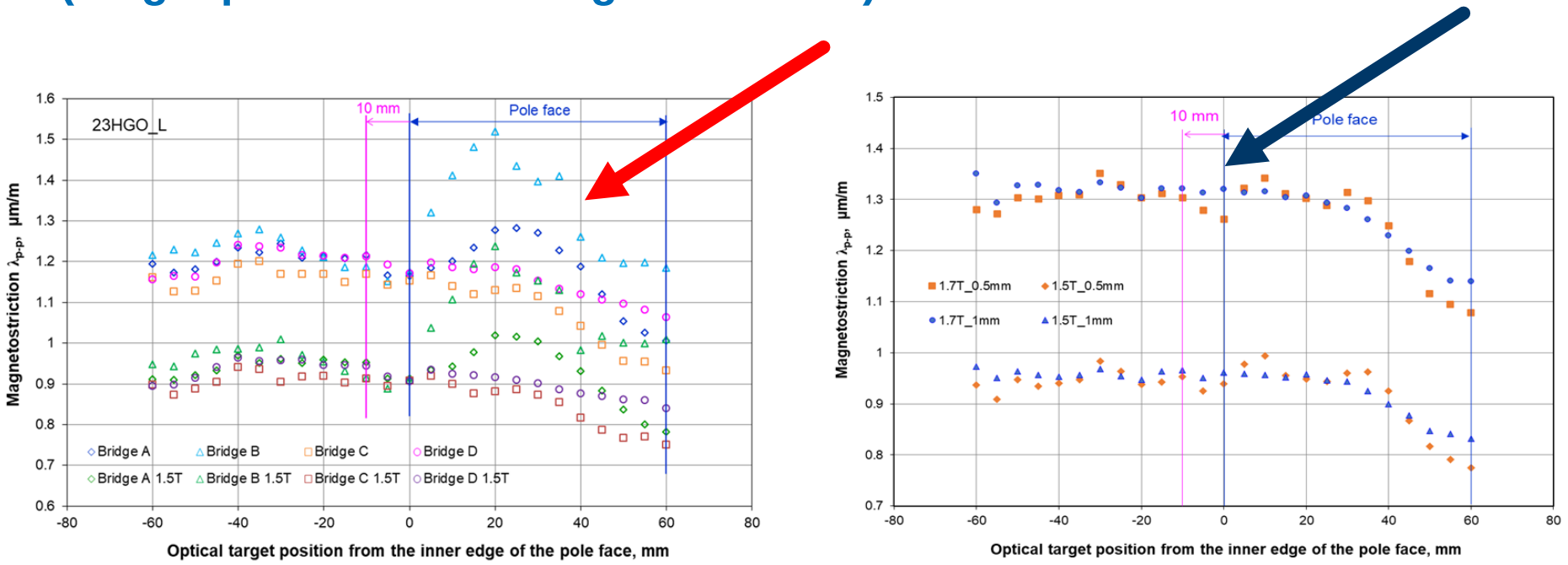


Figure 3 – Range of the positions of the optical target (specified position is -10 mm)

IEC Magnetostriction System: Main Improvements (Target position and Bridge thickness)



(a) Comparison between Bridges A to D

(b) Comparison between strip thickness of 0.5 mm and 1.0 mm in Bridge D

Figure 4 – The peak-to-peak values λ_{p-p} as a function of the optical target position

IEC Magnetostriction System:Additional Improvements

- Protrusions on the top surface of the bridge strip have to be removed
- The bridge strip surface and the back side of the test specimen are wiped with a solvent before measurement. Experiments have shown that contamination of grease on the surface of the bridge strip or the back surface of the test specimen significantly reduces the magnetostriction value;
- The test specimen is grounded to release the electrostatic charge through the end stop to reduce friction by electrostatic artraction
- Accurate clamping (no deformation/tilting of the sample). Confirmed by experiment that the magnetostriction value does not change with the clamping weight between 17.6 N and 46.8 N

IEC Magnetostriction System: 4th Round Robin Test

- 8 laboratories
- The test specimen size was again 100 mm x 500 mm
- 5 sheets of 35CGO in the L direction (hereafter 35CGO_L)
- 5 sheets of 23HGO in the L direction (hereafter 23HGO_L)
- 3 sheets of 23HGO in the C direction (hereafter 23HGO_C)
- Measurements are made under stress free conditions
- No weight placed on the test specimen except the optical target and the clamp block;
- Magnetizing frequency: 50 Hz.
- Measurements in the L direction: Jp = 1.5 T and 1.7 T;
- Measurements in the C direction: Jp = 1.3 T and 1.4 T.

IEC Magnetostriction System: 4th Round Robin Test

Table 5 – Reproducibility of measurements as the results of the 4th RRT

		35CGO_L		23HGO_L		23HGO_C	
		1.5 T	1.7 T	1.5 T	1.7 T	1.3 T	1.4 T
λ_{p-p} [µm/m]	average	0.94	1.31	0.69	1.17	16.6	17.6
	rel.stdev	1.6%	1.6%	1.8%	1.5%	1.4%	1.2%
λ_{0-p} [µm/m]	average	-0.94	-1.20	-87.1	-1.11	16.6	17.6
	rel.stdev	1.4%	1.8%	1.6%	1.1%	1.4%	1.1%

IEC Magnetostriction System: Conclusion

Round Robin Tests reproducibility
2017: 2nd RRT until 2019
- 8 laboratories
- Double yoke systems
- Relative standard deviation: 20% with weight on the sample (at 1.7 T)
- Relative standard deviation: 9% without weight on the sample (at 1.7 T)

2019: 3nd RRT
- 9 laboratories
- Single yoke systems
- Relative standard deviation: 5% without weight on the sample (at 1.7 T)

2020: 4th RRT
- 8 laboratories
- Single yoke systems
- Relative standard deviation: 2% without weight on the sample (at 1.7 T)

IEC Magnetostriction System: Conclusion

IEC 60404-17

Edition 1.0 2021-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Magnetic materials –
Part 17: Methods of measurement of the magnetostriction characteristics of grain-oriented electrical steel strip and sheet by means of a single sheet tester and an optical sensor

Matériaux magnétiques –
Partie 17: Méthodes de mesure des caractéristiques de magnétostriction des bandes et tôles magnétiques en acier à grains orientés au moyen d'un essai sur tôle unique et d'un capteur optique

IEC Normen (New)

IEC 60404-8-11:	**Specifications for individual materials - Fe-based amorphous strip delivered in the semi-processed state.**
IEC 60404-16:	**Methods of measurement of the magnetic properties of Fe-based amorphous strip by means of a single sheet tester**
IEC 60404-6:	**Methods of measurement of the magnetic properties of magnetically soft metallic and powder materials at frequencies in the range 20 Hz to 100 kHz by the use of ring specimens**
IEC 60404-17:	**Methods of measurement of the magnetostriction characteristics of electrical steel strip and sheet by means of a single sheet tester and an optical sensor**

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Revised Standards

IEC Normen

IEC 60404-1:	Magnetic materials. Part 1: Classification
IEC 60404-2:	Magnetic materials. Part 2: Methods of measurement of the magnetic properties of electrical steel sheet and strip by means of an Epstein frame.
IEC 60404-3:	**Magnetic materials. Part 3: Methods of measurement of the magnetic properties of magnetic sheet and strip by means of a single sheet tester.**
IEC 60404-4:	Magnetic materials. Part 4: Methods of measurement of d.c. magnetic properties of magnetically soft materials.
IEC 60404-5:	**Magnetic materials. Part 5: Permanent magnet (magnetically hard) materials - Methods of measurement of magnetic properties.**

IEC Normen

IEC 60404-7:	**Magnetic materials. Part 7: Methods of measurement of the coercivity of magnetic materials in an open magnetic circuit.**
IEC 60404-8-1:	Magnetic materials. Part 8-1: Specifications for individual materials - Standard specifications for magnetically hard materials. Amendment 2: 1992
IEC 60404-8-2:	Magnetic materials. Part 8-2: Specifications for individual materials - Cold-rolled electrical alloyed steel sheet and strip delivered in the semi-processed state.
IEC 60404-8-3:	Magnetic materials. Part 8-3: Specifications for individual materials - Cold-rolled electrical non-alloyed steel sheet and strip delivered in the semi-processed state.
IEC 60404-8-4:	Magnetic materials. Part 8-4: Specifications for individual materials - Cold-rolled non-oriented electrical steel sheet and strip delivered in the fully-processed state.

IEC Normen

IEC 60404-8-8:	Magnetic materials. Part 8-8: Specifications for individual materials - Specification for thin magnetic steel strip for use at medium frequencies.
IEC 60404-8-9:	Magnetic materials. Part 8-9: Specifications for individual materials - Standard specification for sintered soft magnetic materials.
IEC 60404-8-10:	Magnetic materials. Part 8-10: Specifications for individual materials - Specification for magnetic materials (iron and steel) for use in relays.
IEC 60404-9:	Magnetic materials. Part 9: Methods of determination of the geometrical characteristics of magnetic steel sheet and strip.
IEC 60404-10:	**Magnetic materials. Part 10: Methods of measurement of magnetic properties of magnetic sheet and strip at medium frequencies.**

IEC Normen

IEC 60404-11:	**Magnetic materials. Part 11: Method of test for the determination of surface insulation resistance of magnetic sheet and strip.**
IEC 60404-12:	**Magnetic materials. Part 12: Guide to methods of assessment of temperature capability of interlaminar insulation coatings.**
IEC 60404-13:	**Magnetic materials. Part 13: Methods of measurement of density, resistivity and stacking factor of electrical steel sheet and strip.**
IEC 61807-TR:	**Magnetic properties of magnetically hard materials at elevated temperatures - Methods of measurement.**

Additional New work proposals:

- Use of non standard SST (TR)
- For GO material: SST to substitutes Epstein
- Pulsfield Magnetometer (J. Duding)
- Measurement with higher harmonics content (TR)
- Add new permanent magnet materials to the material standards

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What are your expectations for new standards?

Which standard is needed?

Thank you very much for your attention!

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