Measurement Technologies for Evaluation of Magnetic Properties of Stator Cores

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Outline:

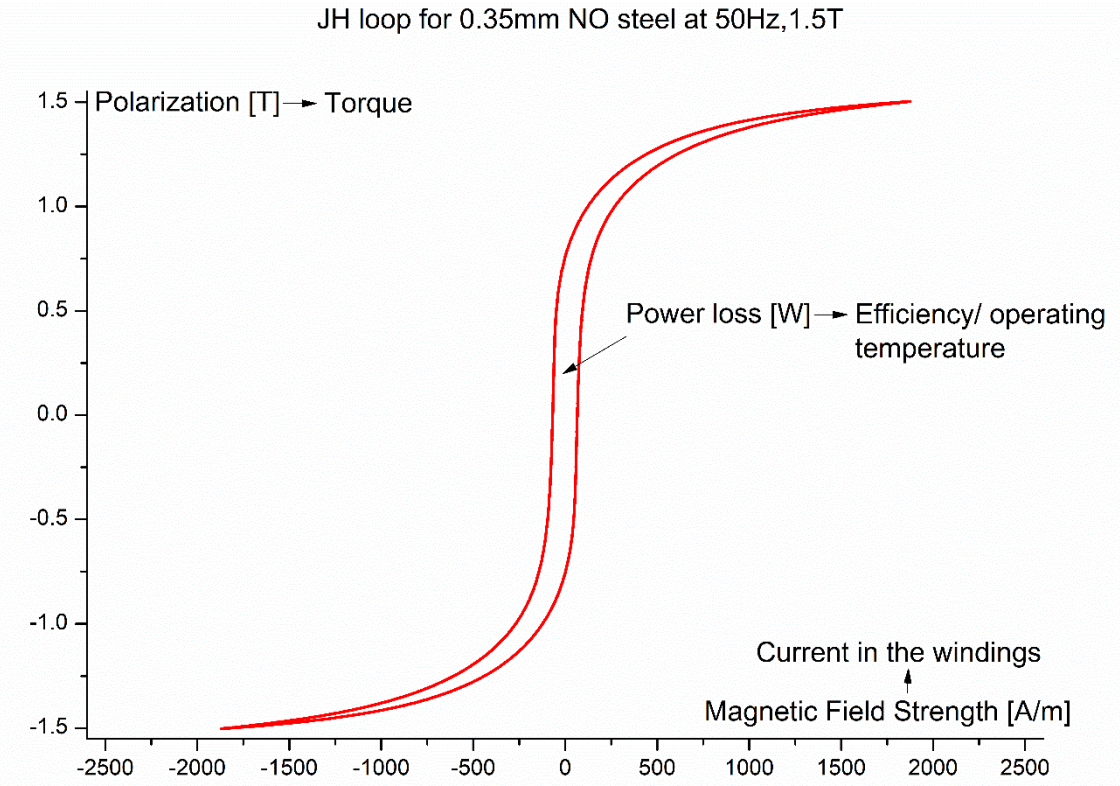
- Introduction to Brockhaus Measurements
- Characterisation of soft magnetic materials
- Effects of manufacturing processes on magnetic properties of motor components
- Brockhaus measurement systems for stators of electric motors
- Summary

About us:

- One of the leading manufacturers of measurement equipment for magnetic materials
- Our customers:

- Electrical steel manufacturers
- Transformer manufacturers
- Motor manufacturers
- Permanent magnet manufacturers
- Research laboratories
- Academic partners

Link between magnetic properties and motor performance



Characterisation of soft magnetic materials – Epstein frame

Measurement conditions specified in the international standard IEC 60404-2:

- Shape of polarization J waveform should be sinusoidal
- Measurement temperature should be 23°C (+/-5 °C)
- No external stress exerted on the specimens

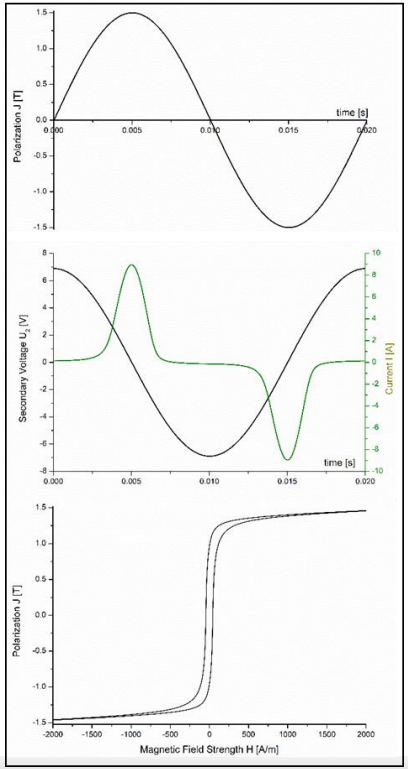
- Epstein measurements under standard conditions are **insufficient** for proper power loss characterisation of magnetic materials used in automotive applications
- The measurement conditions should include the following main factors:

➢ **Non-sinusoidal magnetisation conditions due to PWM excitation and harmonic distortion**
➢ **Elevated temperatures**
➢ **Stress sensitivity of magnetic properties**

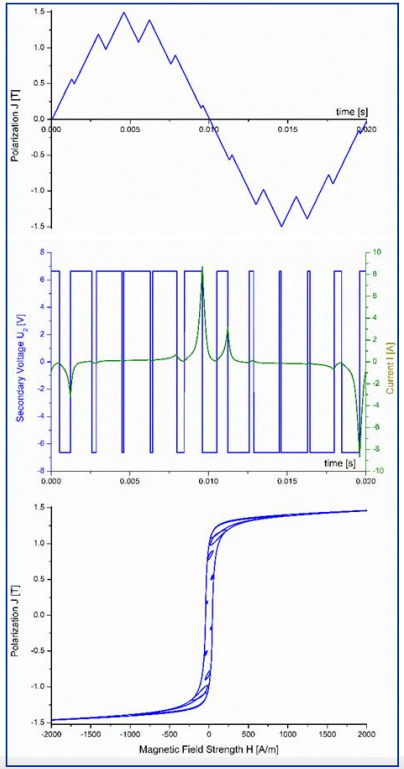
❑ **Brockhaus developed a range of measurement systems to meet the above criteria**

Characterisation of soft magnetic materials - different magnetisation conditions

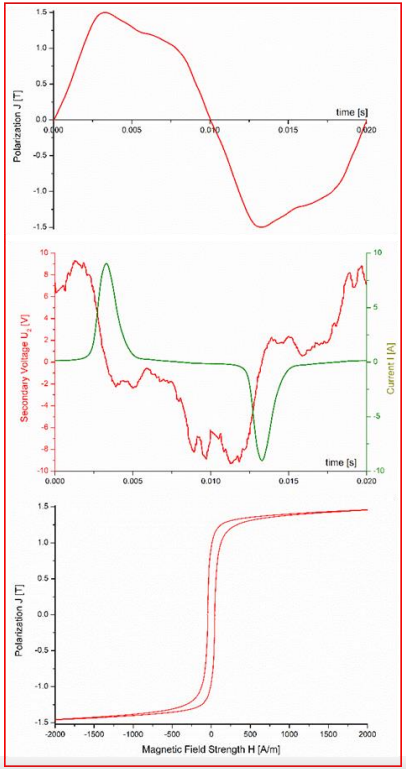
sinusoidal



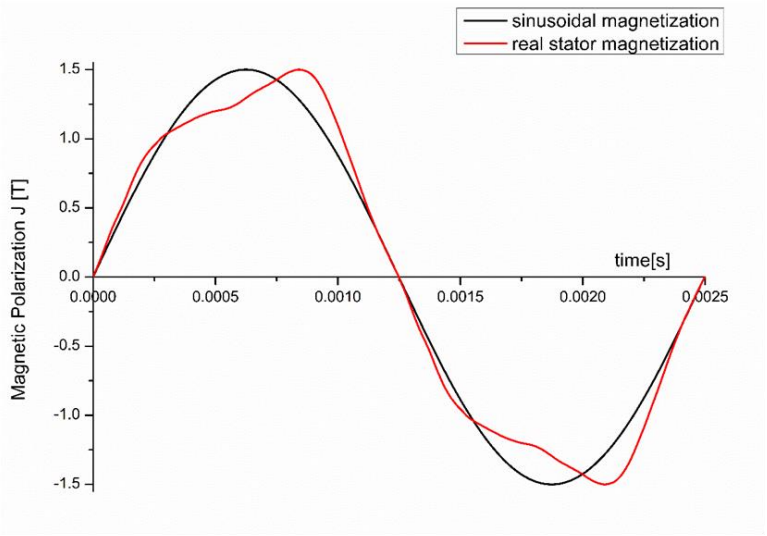
PWM

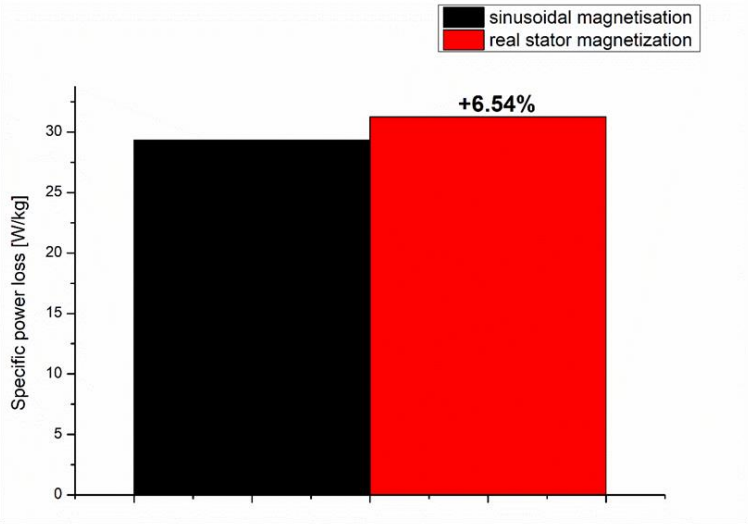


Free-curve



Characterisation of soft magnetic materials – measurements under standard and real operating conditions for NO20 steel at 1.5T, 400Hz.

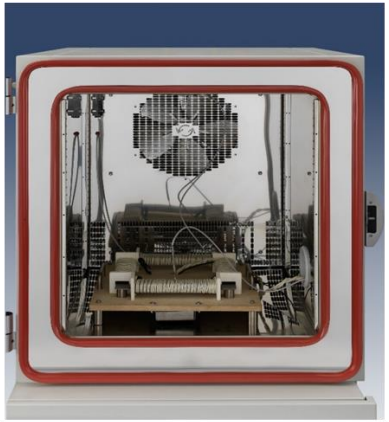


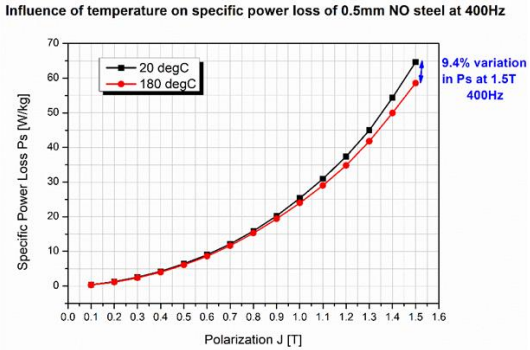


Overview:

- Material suppliers provide power loss data from standard IEC 60404 measurements under sinusoidal magnetization
- In the real applications, such as electric motors and generators, stator material is subject to distorted non-sinusoidal magnetization where magnetization upper harmonics lead to additional power loss

Characterisation of soft magnetic materials – measurements at high temperatures

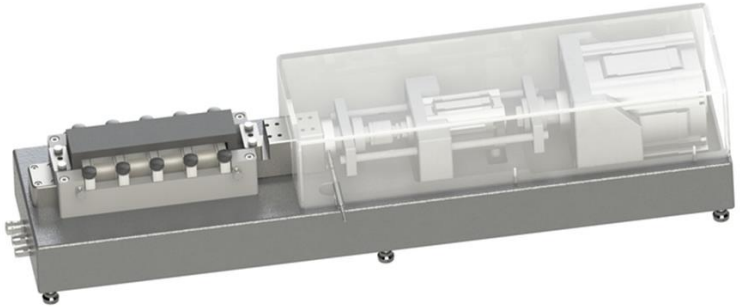




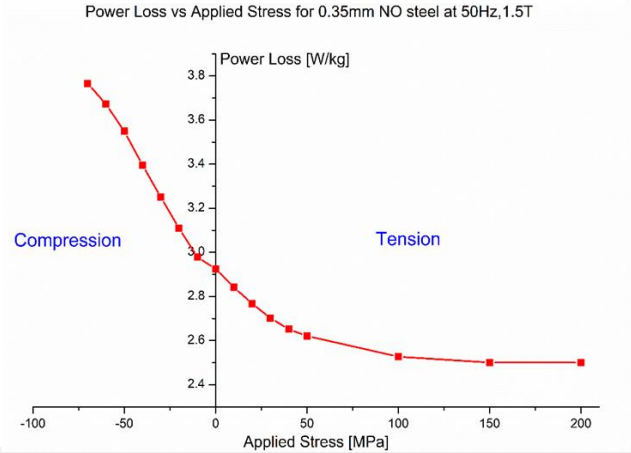
Main features:

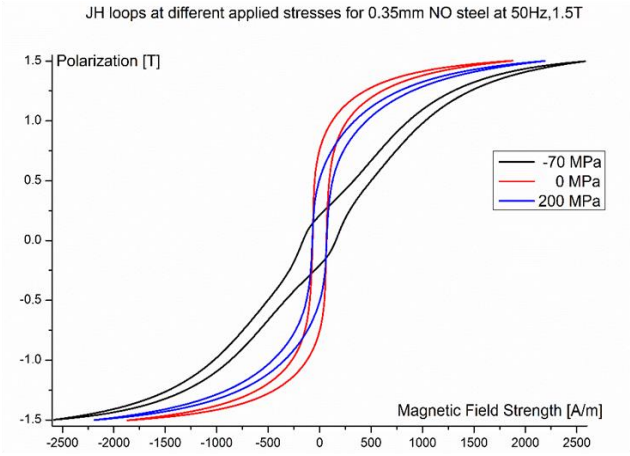
- Heat resistant ceramic Epstein frame
- High temperature windings
- 100 primary turns
- 100 secondary turns
- Magnetising frequency up to 20kHz
- Max magnetising field H=6000A/m
- Programmable temperature range from **-40°C to +180°C**
- Magnetisation under B,H control, PWM or user-defined arbitrary conditions
- Variation in temperature affects resistivity and consequently dynamic eddy current loss in magnetic materials
- This temperature effect becomes more pronounced with increasing magnetising frequency

Characterisation of soft magnetic materials – measurements under applied stress

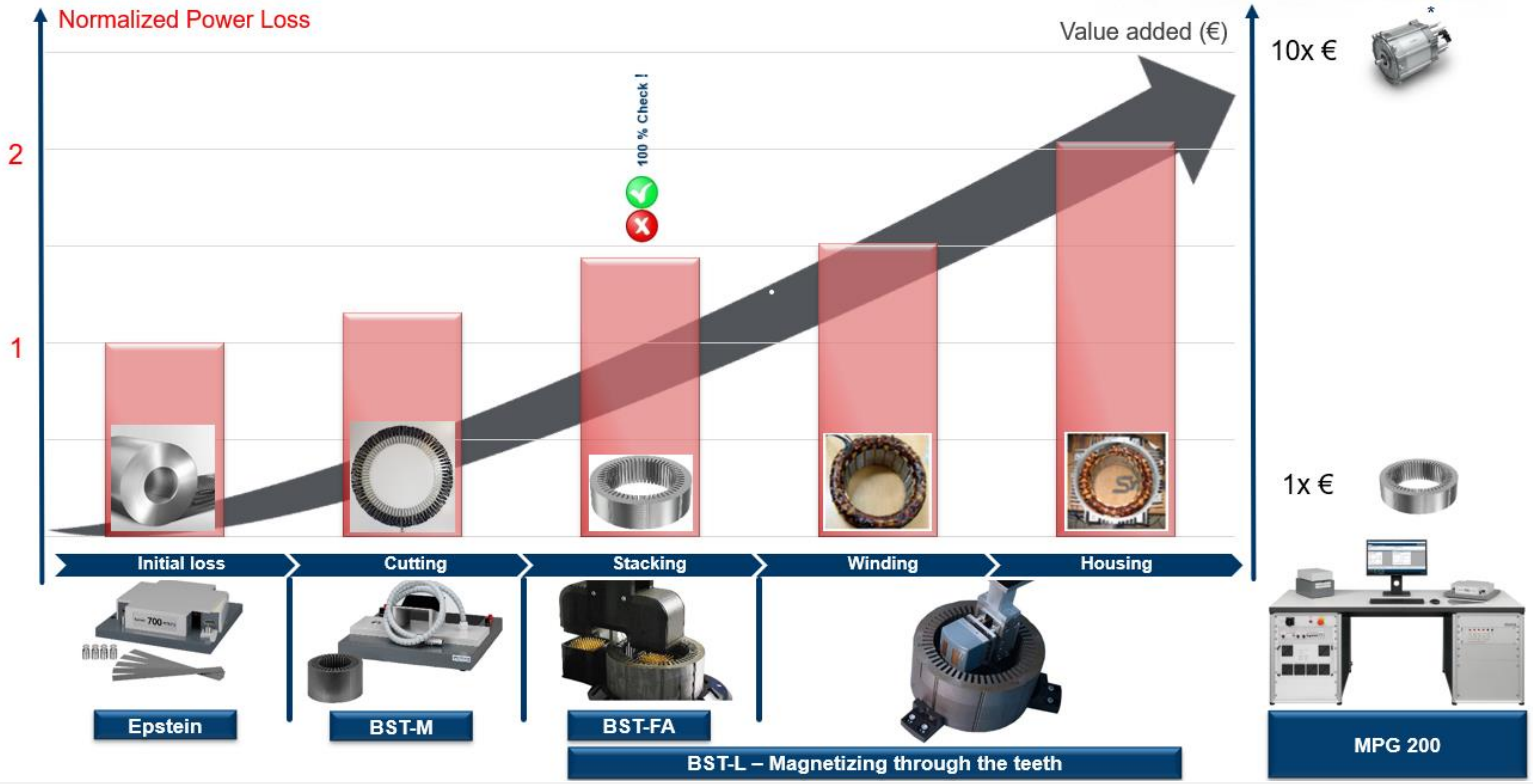


- Pneumatic cylinders for application of uniaxial load up to 6500N tension and 1500N compression
- Cylindrical guides for uniform load application
- Embedded potentiometer for load regulation
- Embedded load cells for real-time force measurements
- Magnetisation under B,H control, PWM or user-defined arbitrary conditions



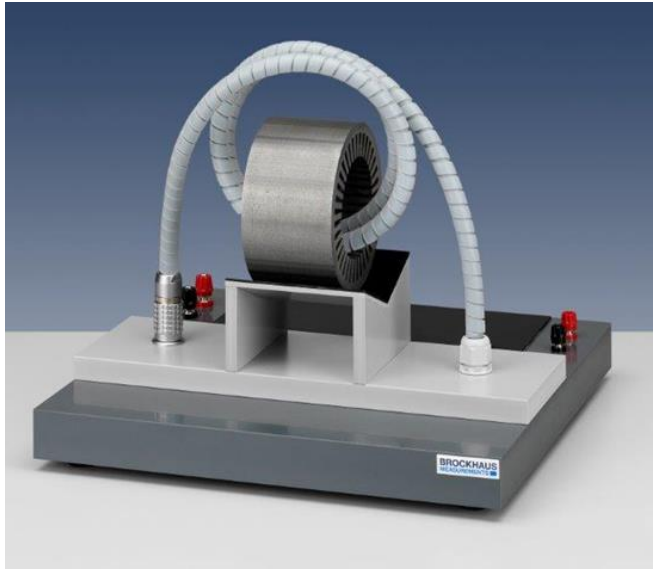


Brockhaus measurement systems for stators – effects of manufacturing on magnetic properties of stator laminations



* Source: Bosch mobility solutions

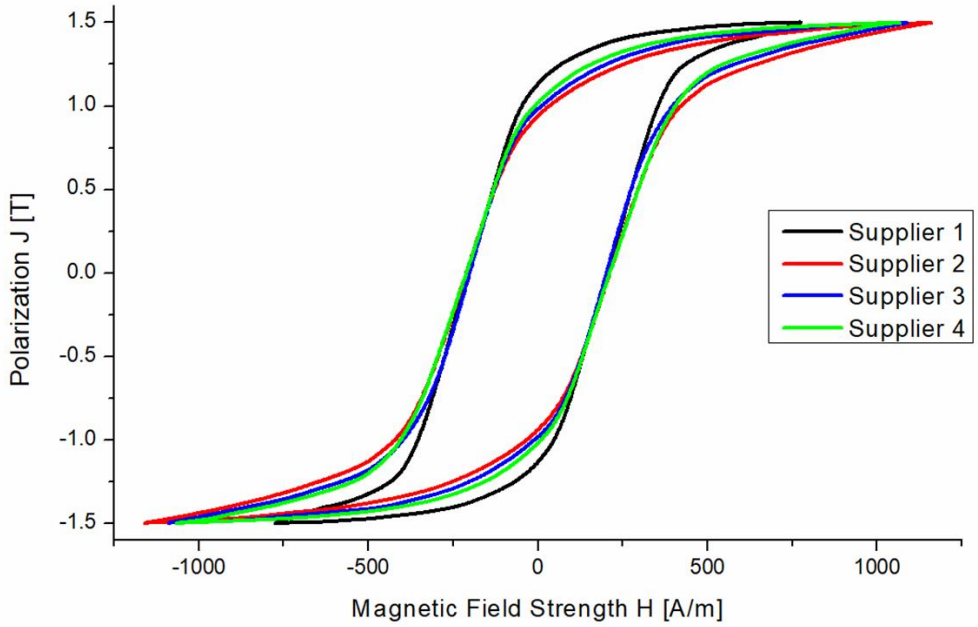
Brockhaus measurement systems for stators – Brockhaus Stator Tester BST-M



Main features:

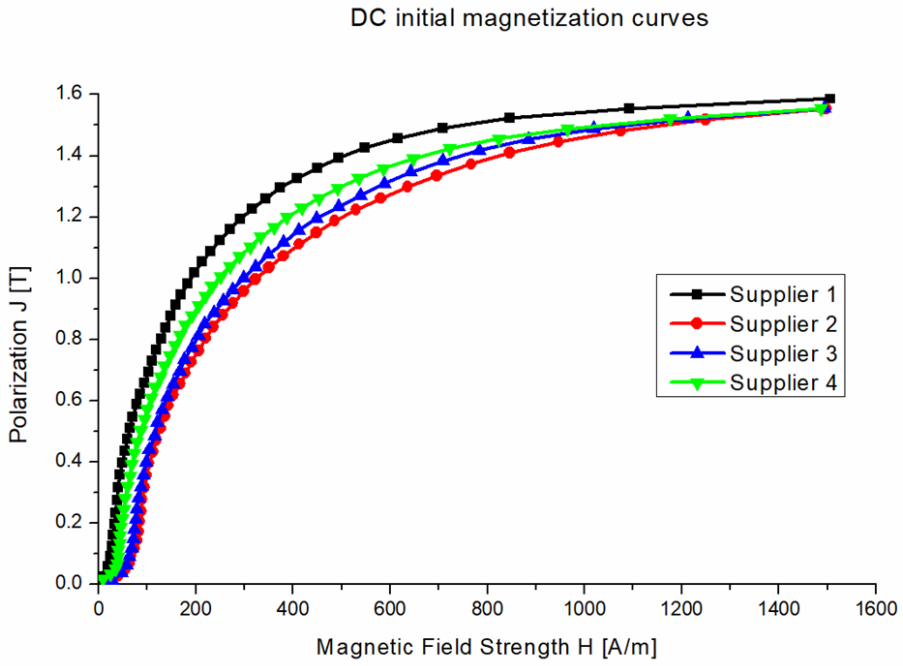
- Compatible with Brockhaus MPG systems
- Measurement with direct windings on stator back-iron or with flexible cable
- Each flexible cable winding is equivalent to 5 primary and 5 secondary turns
- Magnetisation under B,H control, PWM or user-defined arbitrary conditions
- Magnetising frequency up to 20kHz
- Effective for comparison of stators to detect variations in magnetic properties
- Suitable for quality control

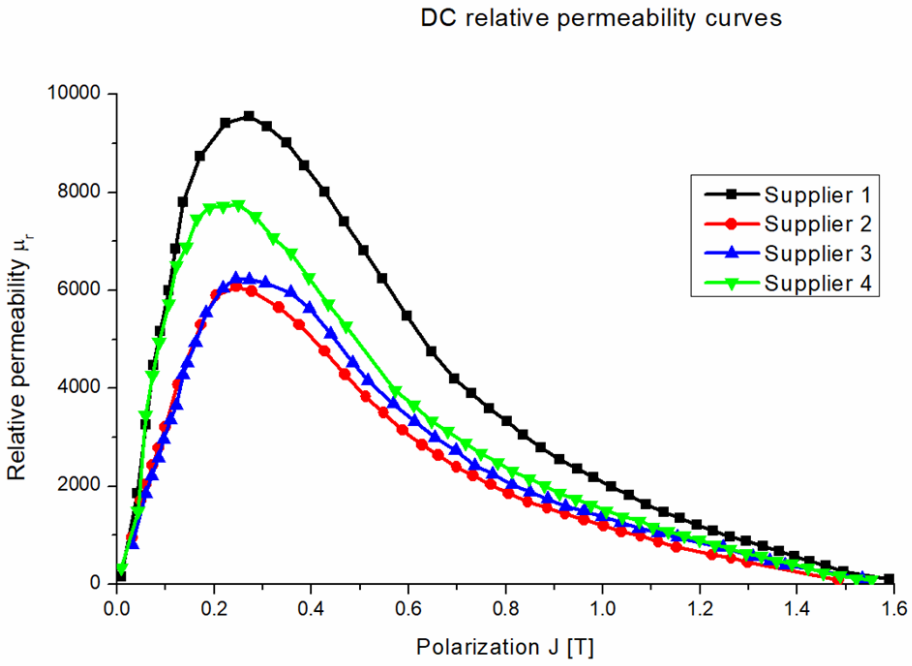
Brockhaus measurement systems for stators – Customer Case Study No. 1 – different material suppliers



- Same Grade of NO electrical steel
- 4 different suppliers of the steel
- 4 different stator characteristics
- Similar power losses
- Differences in permeability
- Lower permeability = Lower torque (higher current required)
- Higher Losses = Lower efficiency

Brockhaus measurement systems for stators – Customer Case Study No. 1 – different material suppliers

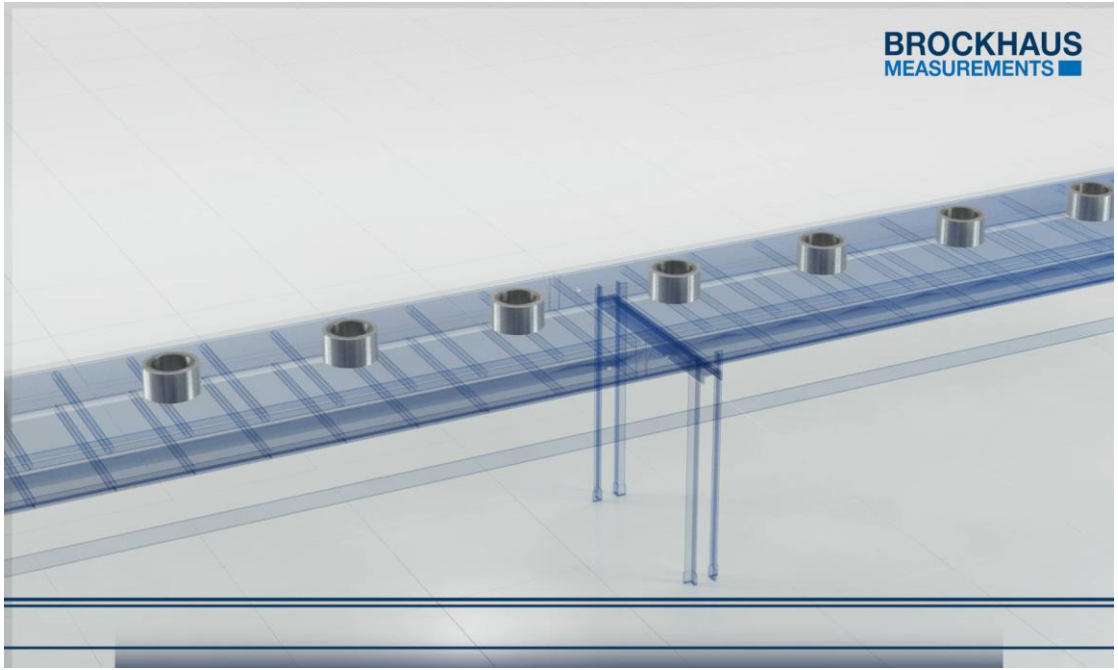




Brockhaus measurement systems for stators – Brockhaus automatic stator tester BST-FA

Video available on BROCKHAUS Group channel on YouTube

Brockhaus measurement systems for stators – Brockhaus fully-automatic stator tester for production lines BST-FA

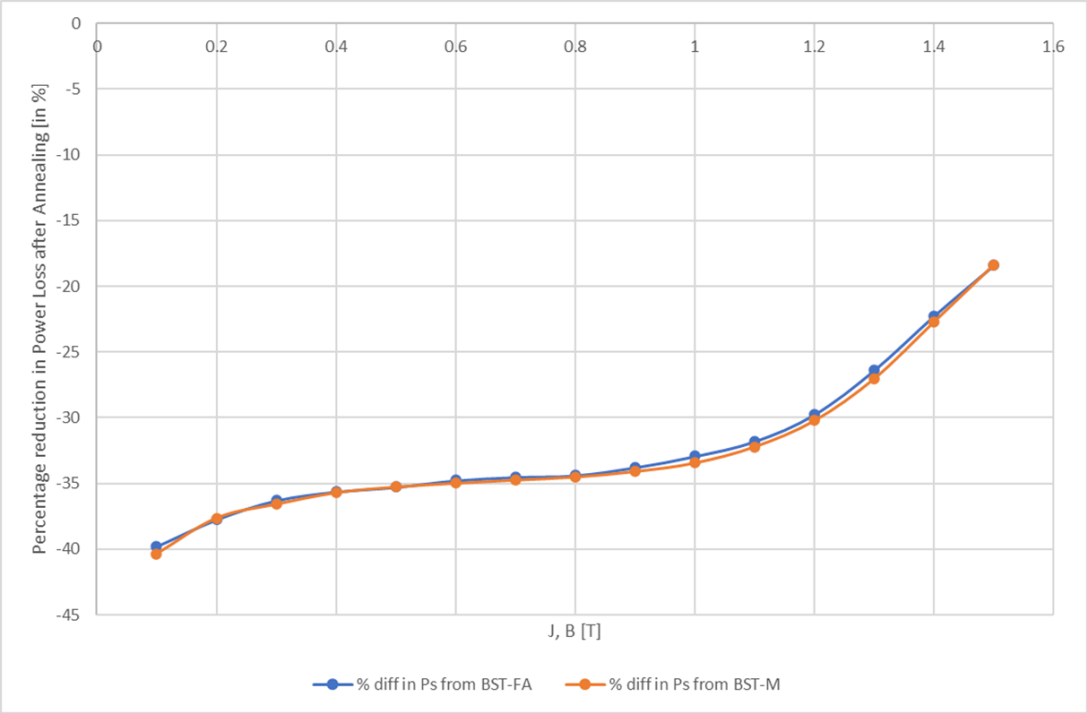


High performance and fast measuring unit for stator quality control prior to motor assembly

- Power loss measurement
- Permeability measurement
- Magnetizing frequency: DC – 2,5 kHz
- Advanced measurement options:
  - Free curves
  - Pulse-width modulation
  - Higher harmonics
  - DC measurement
  - DC bias offset
  - Digital Feedback Control

Video available on BROCKHAUS Group channel on YouTube

Brockhaus measurement systems for stators – Customer Case Study No. 2 – evaluation of annealing effect on magnetic properties of stators with BST-FA and BST-M systems

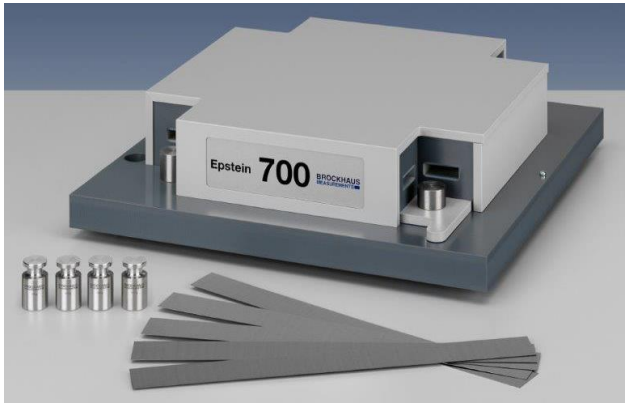


Brockhaus measurement systems for stators – Brockhaus BST-L system for testing teeth and back iron section

Video available on BROCKHAUS Group channel on YouTube

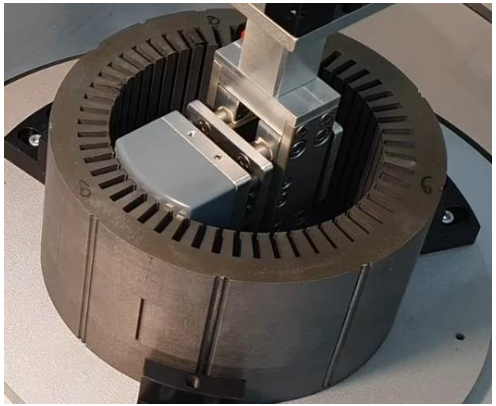
Brockhaus measurement systems for stators – Customer Case Study No. 3 – evaluation of stamping and welding on magnetic properties of stators with BST-M and BST-L

Characterisation of initial magnetic properties of steel samples in Epstein frame



Characterisation of magnetic properties of stator back iron after stamping and welding

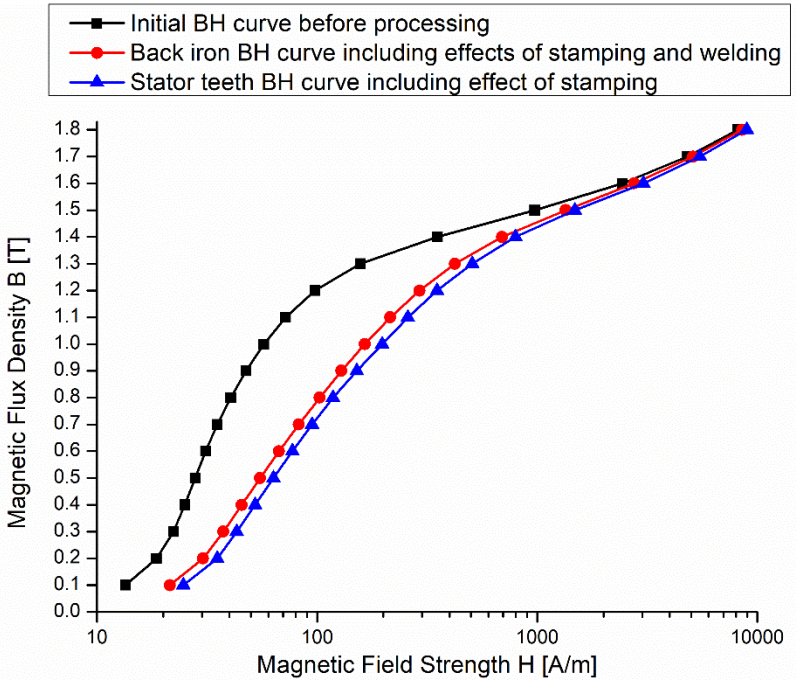
Characterisation of magnetic properties of stator teeth after stamping



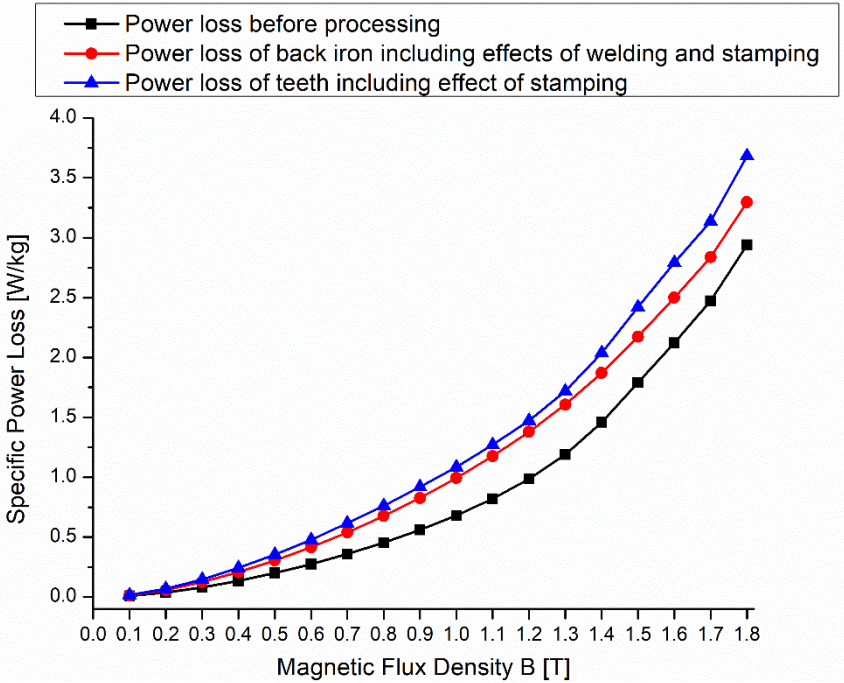
- Initial and post-processing magnetic properties were characterised for B27AHV1400 steel laminations
- Power loss and magnetisation BH curves were measured for Epstein strips, stator back iron and teeth at multiple frequencies within range 50Hz – 20kHz
- The obtained measurement data was suitable for direct implementation into FEM models of electric motor

Brockhaus measurement systems for stators – Customer Case Study No. 3 – evaluation of stamping and welding on magnetic properties of stators with BST-M and BST-L

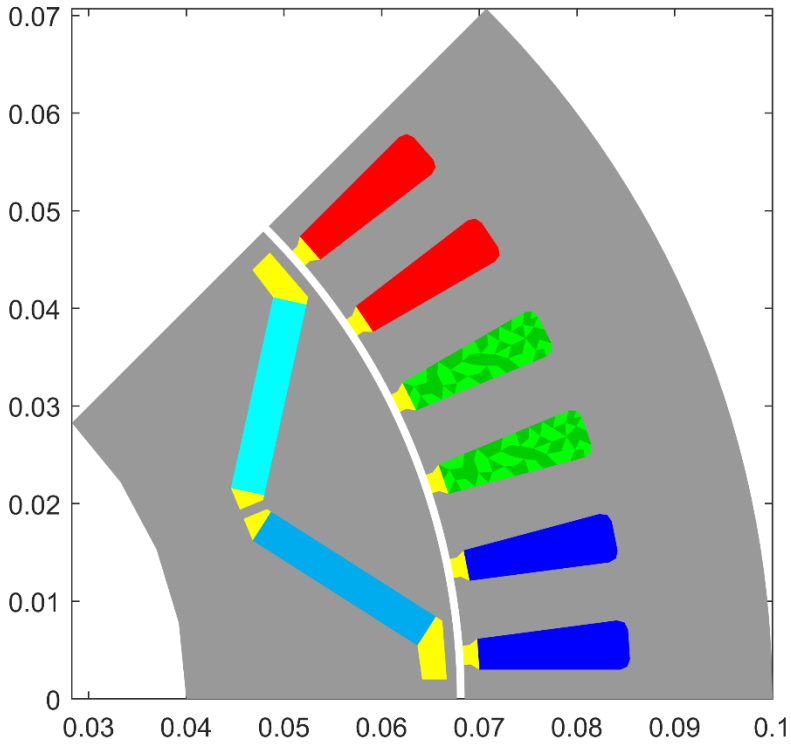
BH magnetisation curves



Power loss at 50Hz



Influence of deteriorated stator core properties on motor performance

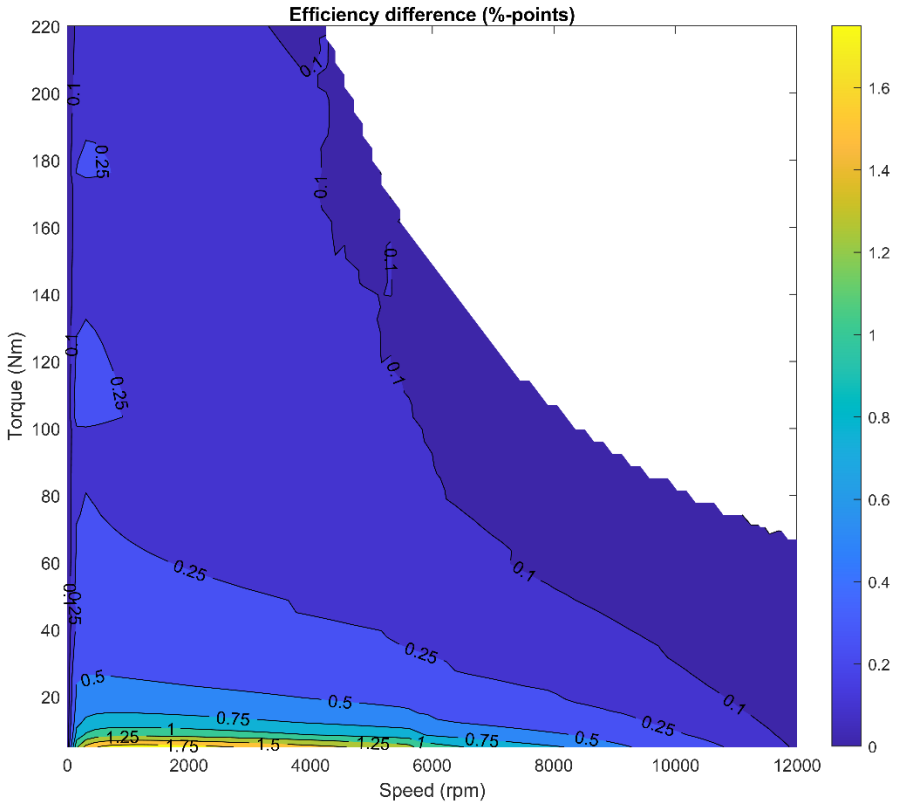


Simulated motor parameters:

- Type: IPM with V-shaped magnets
- Number of slots: 48
- Number of poles: 8
- Stator OD: 200 mm
- Stator ID: 137.8 mm
- Stack length: 100 mm
- Air gap: 0.8 mm
- Continuous power: 53 kW
- Magnet thickness: 3.5 mm
- Magnet type: N42SH

In collaboration with Dr. Antti Lehikoinen, Smeklab Ltd.

Influence of deteriorated stator core properties on motor performance



Main conclusions:

- After incorporating effects of **only stamping and welding** the efficiency of motor decreased by **as much as 1.75% in the city driving range (low torque, low-medium speeds)**
- In the next phase **the effects of housing and elevated temperatures** will be added which **multiply this efficiency reduction (currently estimated by 3% to 5%)**
- In traction motors this decrease in efficiency in order of few percent is **considerable**
- In case of induction motors and synchronous reluctance motors the effect of manufacturing is even more significant
- Decreased efficiency of motors reduces the driving range of electrified vehicles

In collaboration with Dr. Antti Lehikoinen, Smeklab Ltd.

Summary:

- Manufacturing processes, such as stamping, welding and housing have a detrimental impact on magnetic properties of stator cores
- Deterioration of magnetic properties due to manufacturing can significantly affect the efficiency of electric motors
- Continuous monitoring of stators quality is necessary for assurance of expected motor performance and driving range of electric vehicles

Thank You