Advanced Softmagnetic Materials for EMI Filters in future Automotive Powernet Systems

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Dr. Martin Ferch, MAGNETEC GmbH
content of presentation

- introduction of MAGNETEC GmbH
- trends from MAGNETEC‘s point of view
- EMC basics
- EMI filters and current compensated chokes
- material comparison: NANOPERM® vs. Ferrite
- production process of nanocrystalline cores

MAGNETEC GmbH
Dipl. Phys. Dr. Martin Ferch
Managing Director
Industriestr. 7
D-63505 Langenselbold
Tel. +49 6184 9202 27
Fax +49 6184 9202 20
martin.ferch@magnetec.de
www.magnetec.de

Advanced Softmagnetic Materials for EMI Filters in future Automotive Powernet Systems
MAGNETEC GmbH was founded 1984 as a private company in Langenselbold near Frankfurt
specialized in development and production of softmagnetic tape wound cores
production facilities in Hungary since 1989
~ 280 employees, ISO 9001 certified
turnover 2001: 12 Mio € mainly in Europe
suppling ABB, Siemens, Schneider Group etc.
since many years with ~ 1 Mio products/month for earth-leakage circuit breakers and EMI filters
NANOPERM® cores were introduced 1999
New PWM-systems with IGBT technology (e.g. inverter drives) in tomorrow’s cars will increase radio-frequency-noise levels at the on-board-powernet.

- DC/DC converters (e.g. in 42/14V- systems)
- integrated starter/alternator (ISA)
- electrical brakes
- electrical steering (EPAS)
- electrical air conditioning systems
- engine fan control
- high intensity discharge lamps (HID) ....

In parallel, other new and highly sensitive systems, like advanced motor management and security systems (multiple Airbags, ABS, ESP...) require an even ‘cleaner’ powernet in order to exclude malfunctions!

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In this scenario, **EMC is essential** for a reliable and long term functionality of the whole vehicle system. (EMC = electromagnetic compatibility)

As a consequence, the requirements on EMI filtering will become **significantly more stringent**. State-of-the-art filter components may not be suitable, due to extended environmental boundary conditions like:

- operational temperature up to 180°C and higher
- increased functionality at smaller build volume
- extended shock resistance ...

Optimized solutions can be found on the basis of **new materials** – critical are in particular magnetic components like chokes and coils.

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EMC basics: inverter drive as rf-noise source

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EMC basics: sources of RF noise emissions

typical **voltage** and **harmonics** in a variable speed drive (inverter) – used in future Powernet systems. Those unwanted rf-signals are distributed over all connected wiring systems.

- **fundamental wave 4 kHz**
- **harmonics**

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EMC basics: typical noise spectra of inverter and converter

- a) inverter drive, continuous spectrum, unfiltered
- b) DC/DC converter, discrete spectrum of harmonics, with filter

Conducted common mode noise in 50Ω-system

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EMC basics

- Radiated noise distribution
- Capacitive and inductive coupling
- Conducted noise distribution

Scenario: propagation of rf-noise

EMC basics

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EMC basics: ways of distribution of RF noise

- Conducted emission ⇒ filtering
- Radiated emission ⇒ shielding

Typical distribution of emitted energy as a function of frequency:

- 0 kHz
- 1 kHz
- 1 MHz
- 10 MHz
- 100 MHz
- 1 GHz

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mains filter for conducted noise suppression

![Diagram](image)

- **240V mains**
- **L** \( L_1 \)
- **N** \( N \)
- **PE** \( PE \)
- **filter**
  - \( C_{x1} \)
  - \( C_{x2} \)
  - \( C_{y1} \)
  - \( C_{y2} \)
  - \( R \)
- **load**

### Components of EMI Filters

- \( C_{xn} \) X-capacitor
- \( C_{yn} \) Y-capacitor
- **L** current compensated choke
- **R** discharge resistor

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working principle of common mode chokes

the load current is not affected by a current compensated choke, but the rf-common mode noise is

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choice of softmagnetic material

**main requirement on an EMC filter choke:**

⇒ high impedance $Z$

$$Z(f) = \omega L(f) = 2\pi f L(f)$$

$$L(f) = A_L n^2 \quad \text{with} \quad A_L = \mu_0 \mu_r(f) \frac{A_{fe}}{l_f}$$
## Comparison of Materials: NANOPERM® vs. Ferrite

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Permeability $\mu_r$ (10 / 100kHz)</th>
<th>Saturation Induction $B_s$ [T] (25 / 100°C)</th>
<th>Curie-Temp. $T_c$ [°C]</th>
<th>Working Temp. $T_{max}$ [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrite 3E7</td>
<td>15.000 / 12.000</td>
<td>0.38 / 0.21</td>
<td>&gt;130</td>
<td>95</td>
</tr>
<tr>
<td>Ferrite T38</td>
<td>10.000 / 10.000</td>
<td>0.38 / 0.23</td>
<td>&gt;130</td>
<td>95</td>
</tr>
<tr>
<td>NANOPERM®</td>
<td>100.000 / 20.000</td>
<td>1.2 / 1.18</td>
<td>600</td>
<td>up to 180</td>
</tr>
<tr>
<td></td>
<td>80.000 / 28.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.000 / 20.000</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- Higher permeability - up to a factor of 10 (!)
- Higher saturation induction factor 3
- Extended working temperature - up to 180°C

⇒ advanced, smaller, lighter and cooler components

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comparison of materials: NANOPERM® vs. Ferrite

permeability as a function of temperature

max. for Ferrite: about 120°C
comparison of materials: NANOPERM® vs. Ferrite

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comparison of materials: NANOPERM® vs. Ferrite

permeability $\mu'$ as a function of frequency $f$

**NANOPERM®** vs. Ferrite

- Big advantage up to 100 kHz

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comparison of materials: NANOPERM® vs. Ferrite

Typical impedance curve for different core geometries

- NANOPERM®
  - \( \Omega = 40 \text{ mm} \)
- Ferrite
  - \( \Omega = 63 \text{ mm} \)

Volume reduction > 50%

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comparison of materials: **NANOPERM® vs. Ferrite**

![Attenuation Curve]

- **NANOPERM®** vs. Ferrite
- Improved attenuation below 500 kHz

**Typical impedance curve at same core geometry Ø=30mm, 22 turns**

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comparison of materials: NANOPERM® vs. Ferrite

NANOPERM®-choke

$I_N = 3 \times 25A @ 60°C$
$L_N = 3 \times 1.6 \text{ mH} @ 10\text{kHz}$
$m = 120g$

volume reduction 60%
weight reduction 65%

Ferrite-choke

$I_N = 3 \times 25A @ 40°C$
$L_N = 3 \times 1.3 \text{ mH} @ 10\text{kHz}$
$m = 350g$

volume reduction 60%
weight reduction 65%

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principle of production process of rapidly quenched ribbons

ribbon thickness: 17-24 µm

melted alloy
T = 1200°C

ceramic-nozzle

rotating Cu-wheel,
T = 20°C

amorphous ribbon
v = 100 km/h

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slitting of ribbons with high precision knives

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automatic winding process of tape wound cores

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furnace and batch of cores for magnetic-field treatment

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protective epoxy coating of tape wound cores

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available NANOPERM® products – cores and choke types

- Tape wound cores from 10 ... 200 mm Ø
- Single phase EMC chokes up to I = 60A
- Three phase EMC chokes up to I = 200A

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Conclusion / summary

- EMI/EMC will definitely become much more important in future vehicle powernet architectures.
- EMI/EMC will become essential for the functionality of future vehicles.
- Filter solutions based on state-of-the-art components may not work/not be optimal.
- There are new and advanced softmagnetic materials which are able to provide solutions.
- These new materials are available from several sources and their prices will come down as their market penetration actually grows rapidly.

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