Experience and procurement of ferrites and alternative materials

Agenda

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  - Facts & Figures
  - Main usage of Ferrite at CERN
- Main Challenges
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  - Potential alternative materials replacing Ferrite.
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Supply Demand market for Ferrite at CERN

- Strategic CERN certified suppliers
    - Ferroxcube - Europe
    - National Magnetics - North America
- More than fifty [50] known worldwide suppliers, but mainly for small formats.
- Who are main market players using special Ferrites : **Particles accelerators**
- No lack of production capacity worldwide, *but* lack of production capacity as per CERN's specs.

Facts & Figures at CERN

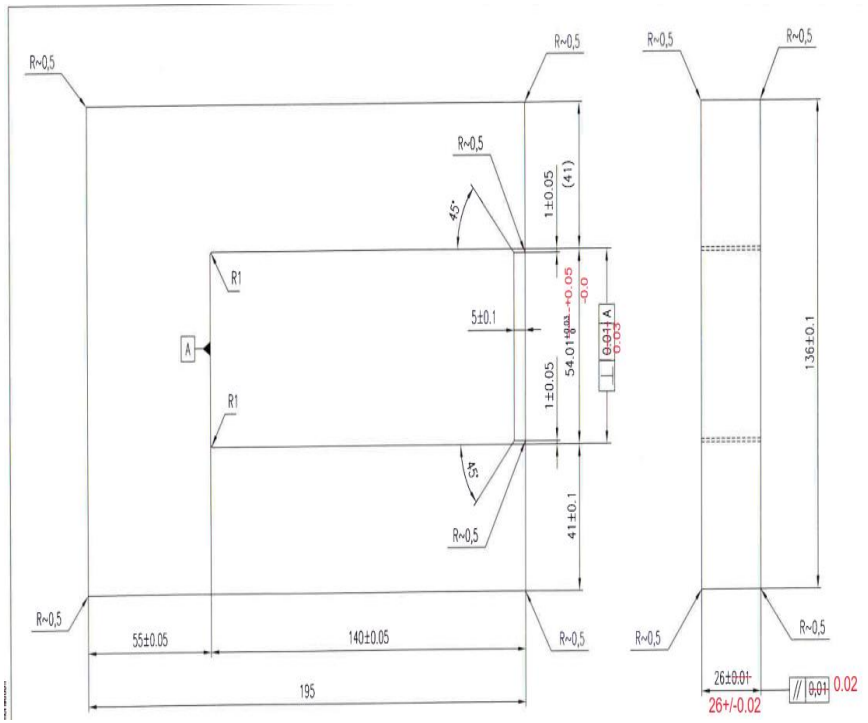
- The market share between both suppliers has been equally distributed for the past 10 years: 51% for Ferroxcube and 49% for National magnetics.

- Other European companies were invited to tender, but all refused mainly because they lack the technical knowledge for the required dimensions.

- Conversations started with procurement with the objective of launching a market survey outside Europe.

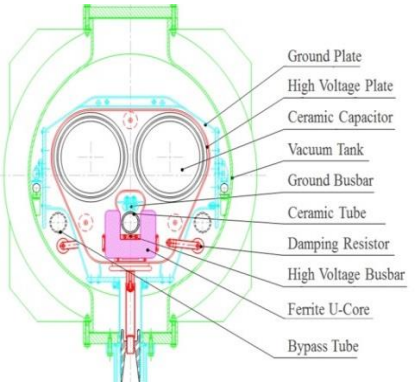
Facts & Figures at CERN

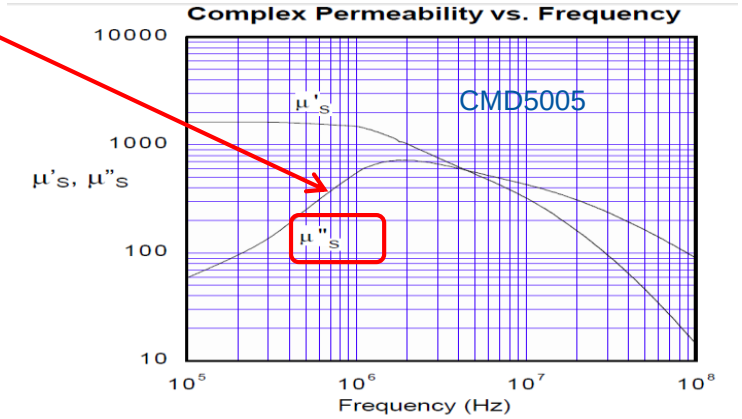
- Recent price enquiries have shown increased difficulties in obtaining the required large cores. Main difficulties are:
  - Machining to our stringent tolerances.
  - Suppliers with limited factory capacity.
  - Long lead times (6 to 12 months).
- In all price enquiries we were “obliged” to enlarge our tolerances, as a condition from the supplier to produce the ferrite cores;
- All ferrites cores were already manufactured in the past, with the same tolerances.



Main usage of Ferrite at CERN

- Magnetic kickers require magnetic material to achieve good field uniformity with fast rise and fall time to reduce the require current (for a given length and aperture dimensions).
- Fast magnetic kickers typically use NiZn ferrite, e.g. 8C11 or CMD5005:
  - ✓ fast field response, negligible eddy-currents, acceptable outgassing;
  - ✓ Limited Curie temperature (~125°C), limited saturation flux density (~0.32T at 25°C);
  - ✓ Beam induced power deposition in the ferrite yoke is mainly influenced by μ_s".





Lack of certified suppliers

- Although there are more than fifty [50] ferrite suppliers around the world, we lack those with production capacity to manufacture large cores.

- CERN certification of a new supplier is a lengthy and stringent process, which requires different steps:

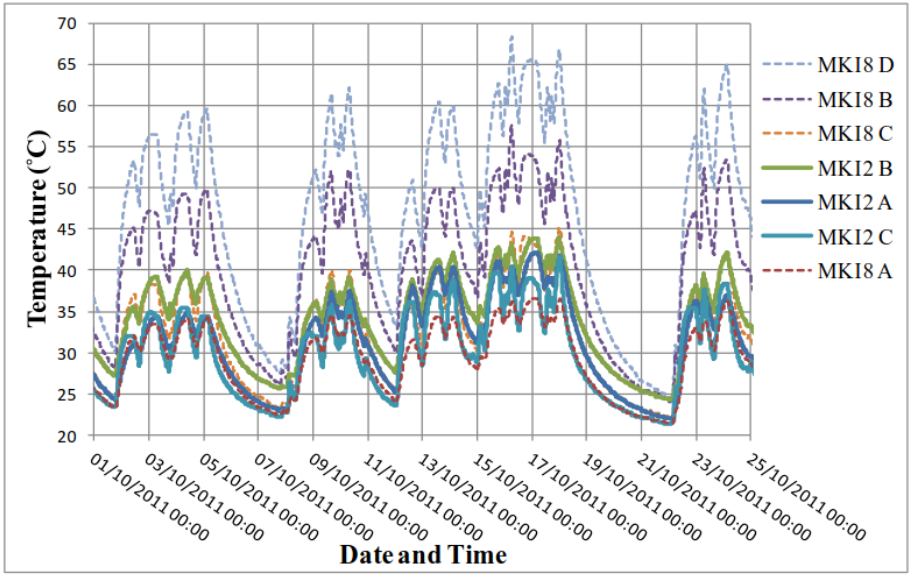
  - Vacuum acceptance (outgassing rate should be < 2×10^{-9} Pa m s^{-1}).

  - DC and HV tests on the laboratory.

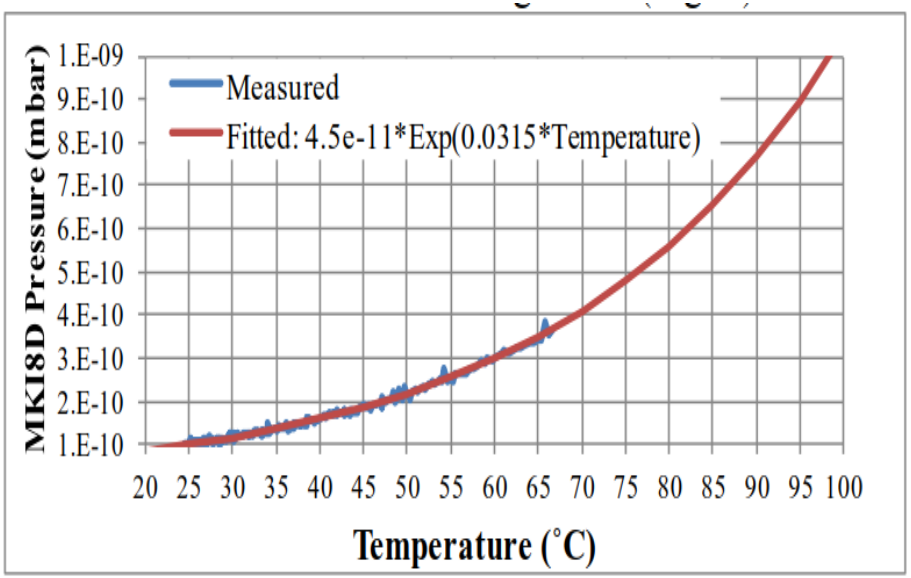
  - Approval of the Kicker performance with beam.

Experience with the LHC Injection kicker

- With high LHC beam currents, integrated over the several hours of a good physics fill, the impedance of the magnet ferrite yoke can lead to significant beam induced heating, reaching values close to the ferrites magnet curie temperature.
- A ferrite with a Curie temperature 50˚ C greater than that presently used for the yoke would permit high-intensity beam operation with better availability.



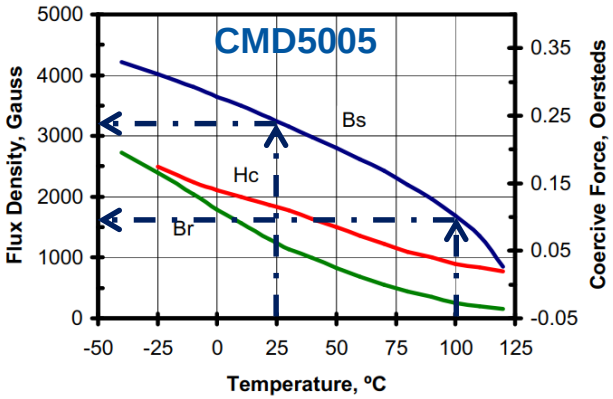
Rise-time of MKI8 TMR waveforms versus measured temperature, averaged for 7 pulses, during a SS

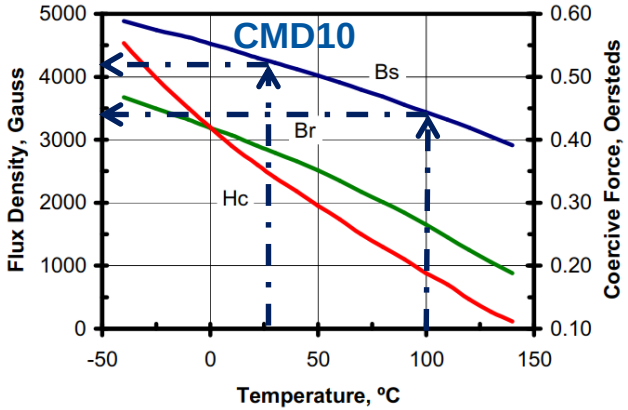


MKI8D pressure versus measured temperature

New Ferrites types testing

- Discussions started, initially with Ceramic Magnets, re possibility of reducing μs", increase Curie temperature (≥ 130˚C for CMD5005) while still obtaining a low out-gassing rate;
- Other types of ferrite, with higher Curie temperature are being considered, and CMD10 may be a promising alternative to CMD5005.

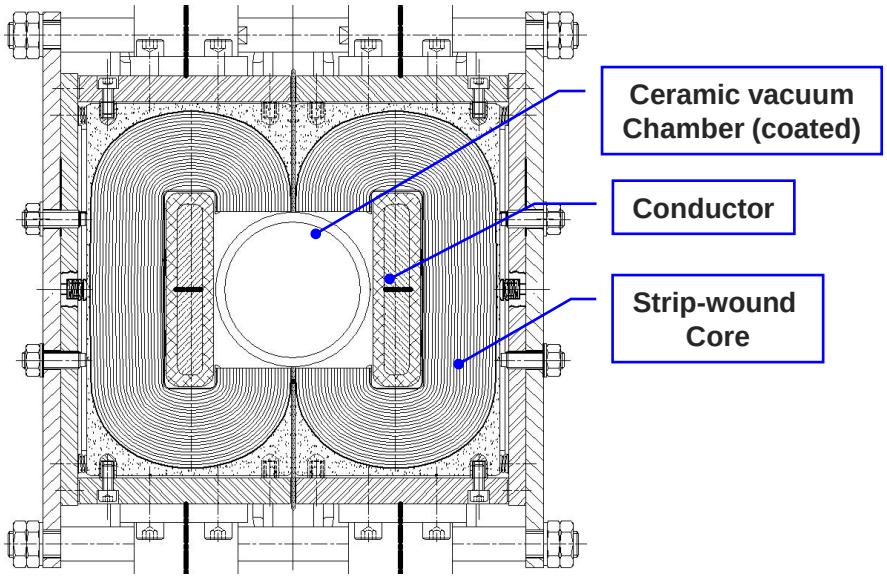


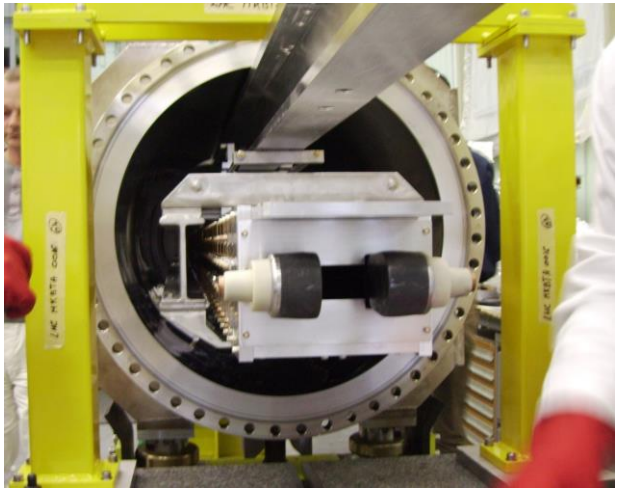


Ferrite	Tc (˚C)	Bs (T)	Br (T)	Hc (A/m)	Denisty (g/cc)	u'
CMD5005	**130**	**0.33**	0.13	9.5	**5.27**	**1150**
CN20	185	0.4	0.26	15.9	5.24	650
CN20B	160	0.41	0.21	15.9	5	1375
CM400	300	0.46	0.24	51.7	5.2	450
N40	600	0.25	0.15	636.6	4.8	15
CMD10	**250**	**0.43**	0.29	28.6	**5.2**	**650**

Potential alternative materials - strip-wound cores

- It's a technology already in use at CERN, in MKD& MKB kicker magnets;
- Mainly use for LHC beam dump;
- Needs to tested in pulsed kickers.





Potential alternative materials - Nanocrystalline

- Nanocrystalline = amorphous alloy of Fe, Si, B, Nb Cu.
- Magnetic flux density – up to 1.5 T
- Coercivity ~ 10 A/m
- Permeability – up to 1e5
- Low temperature coefficient

Material **Material basis**	**Co - based amorphous approx. 77 % Co**	**NiFe Permalloys 60 % Ni**	**MnZn Ferrite MnZn**	**Nano-crystalline approx. 73.5 % Fe**
Permeability $\mu_{r,max}$ (10 kHz)	>90 000	< 20 000	15000	**15000... > 80 000**
Losses $P_{Fe,\,typ}$ (25 kHz, 200 mT, 100°C)	5 W/kg	14 W/kg	17 W/kg	**3 W/kg**
Saturation Induction B_s	0.6 T	0.8 T	0.48 T	**1.2 T**
Curie Temperature T_c	210°C	400 °C	220°C	**> 600°C**
Upper Cont. Operation Temperature T_{max}	90 °C	120°C	<100°C	**>120°C**

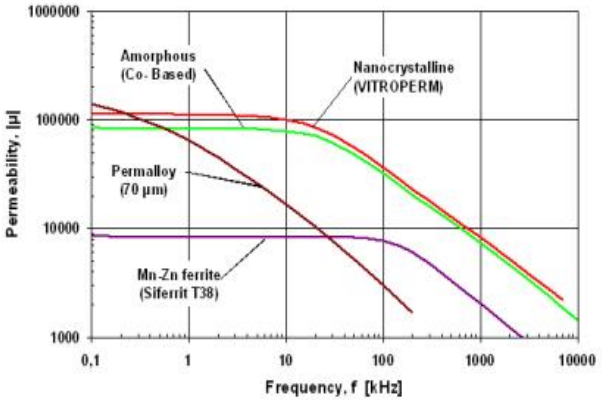


Figure 4: *Comparison of initial permeability vs. frequency curves of soft magnetic materials used for common-mode chokes*

Wrap-up

- Ferrites procurement has became a extremely difficult process, mainly due to small capacity production and difficulties in machine cores with strict tolerances.
- Conversations with procurement started with the objective of launching a market survey outside Europe
- New ferrite power(CMD10) will be tested in a kicker magnet in 2019.
- Ferrites alternative options exists, as strip-wound cores and Nano-crystalline materials .
- Procurement will conduct a market survey outside Europe in 2018/2019

Thank you for your attention !

Questions, comments, etc …