New Grade of Temperature Compensated Samarium Cobalt Permanent Magnets and Design Considerations

Electron Energy Corporation

April 30, 2009

Outline

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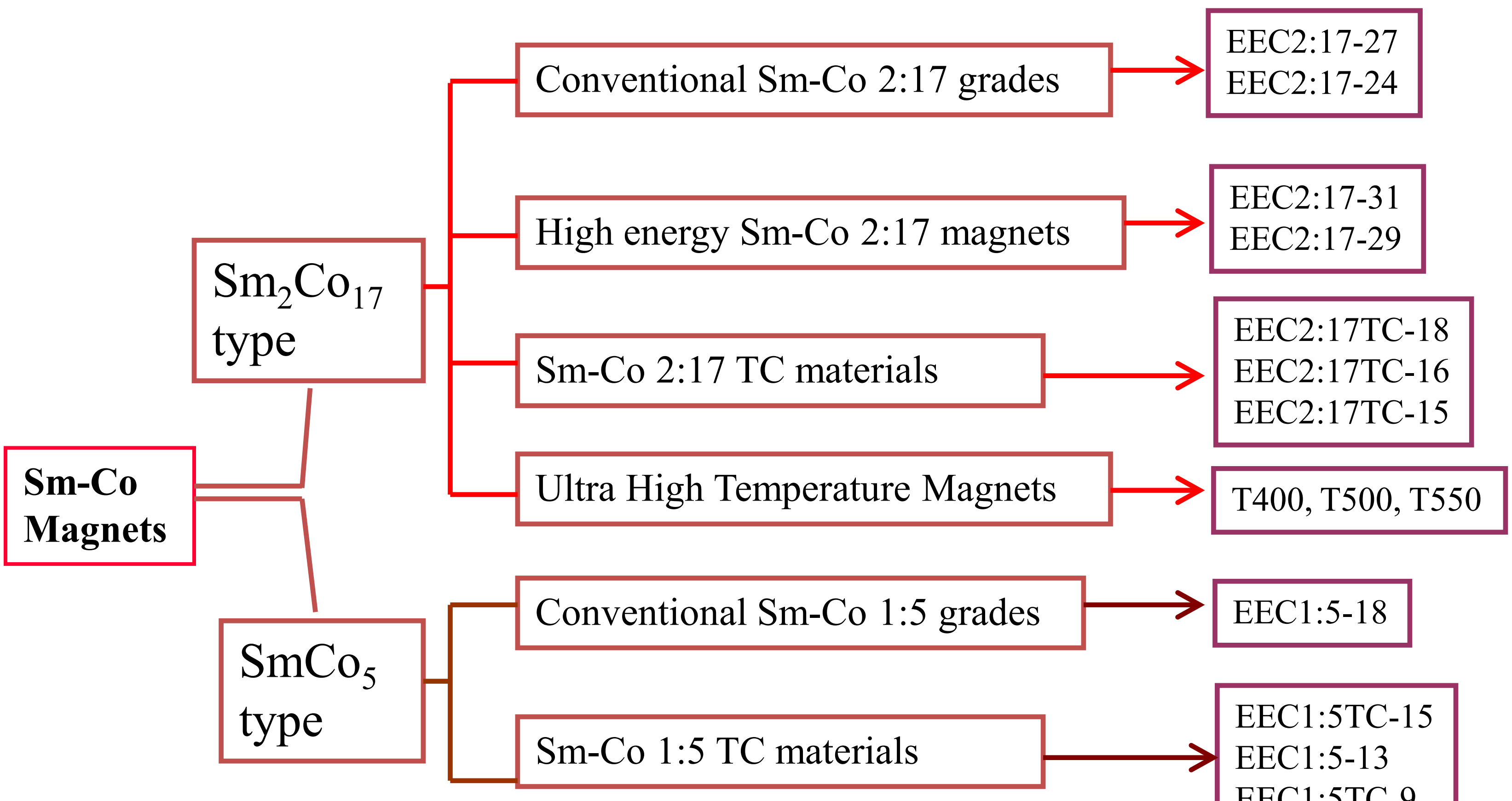
Sm-Co Material Tree



TC: Temperature Compensated

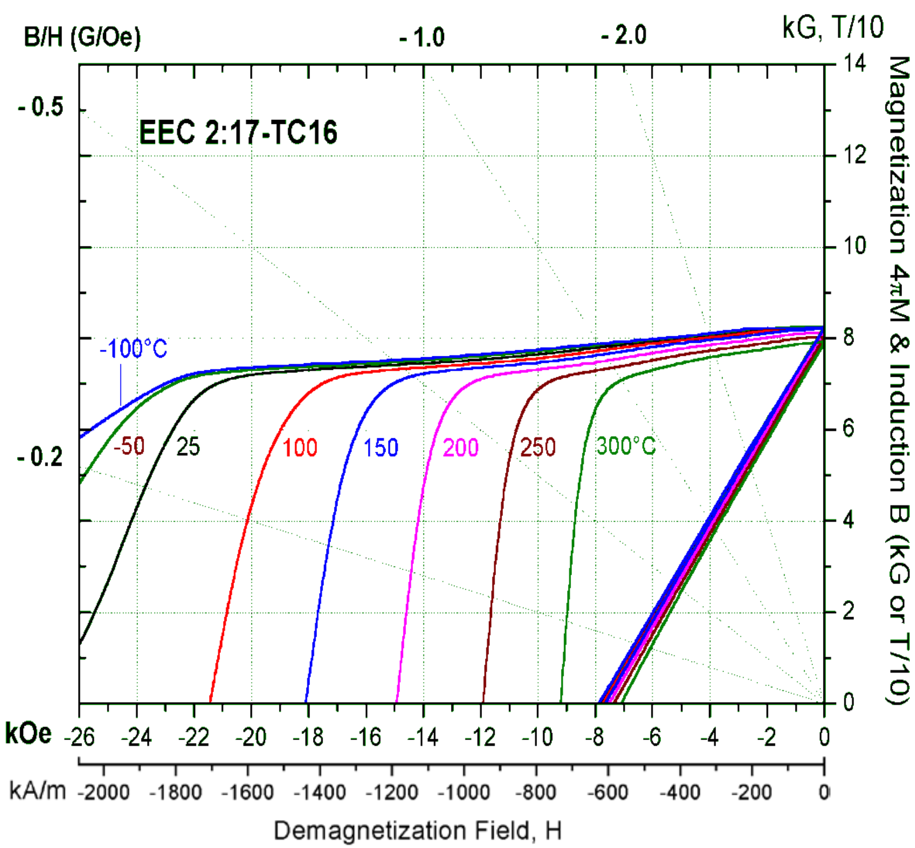
Reversible Temperature Coefficient

- Residual induction (B_r) changes with temperature for permanent magnets
- The ***Reversible Temperature Coefficient*** (RTC) of B_r is defined as:

$$\alpha = \Delta B_r/(B_r * \Delta T) \ \ \text{x } 100\%$$

- Some applications, such as traveling wave tube amplifiers (TWTA) and inertial devices, require small RTC of B_r
- EEC developed temperature compensated magnets with the RTC of B_r close to zero. These grades of material are referred to as ***"0TC magnets" or "zero-RTC magnets"***.

Demagnetization Curves for EEC zero RTC Magnets

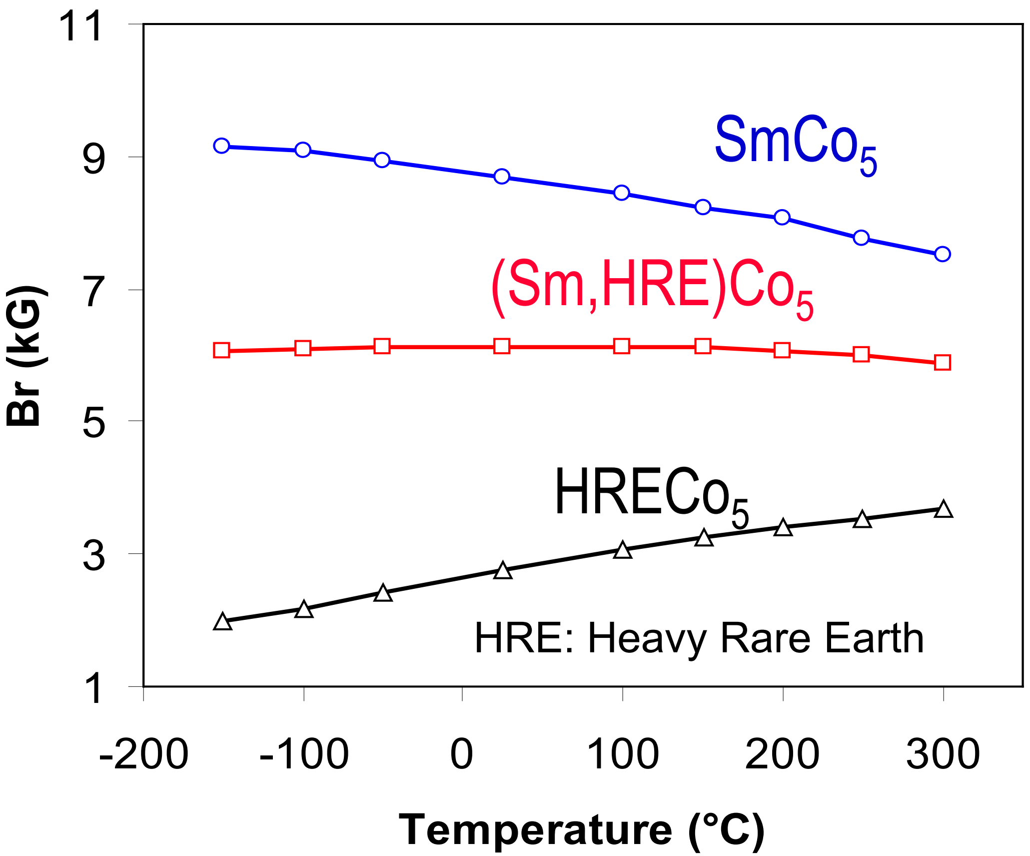


- TC16 is the best commercially available 0TC material
- The reversible temperature coefficient (RTC) of B_r can be controlled by substituting a heavy *RE* from the group of *Gd*, *Tb*, *Dy*, *Ho* and *Er*, for a portion of the *Sm*.

The maximum operating temperature of these magnets is 300°C.

Temperature Compensated Sm-Co Magnets

0TC Magnets



- Parallel coupling of magnetic moment between light RE and TM sublattice - Negative RTC

- Antiparallel coupling of magnetic moment between heavy RE and TM sublattice - Positive RTC

Temperature Compensated SmCo1:5 Magnets

Grades	(BH)max	RTC	Comment
EEC 1:5-18	18 MGOe	-0.04 %/oC	No Compensation
EEC 1:5TC-15	15 MGOe	-0.03 %/oC	Some Compensation
EEC 1:5TC-13	13 MGOe	-0.02 %/oC	Half Compensation
EEC 1:5TC-9	9 MGOe	0.001 %/oC	Full Compensation

RTC of Br is calculated in the temperature range –50 to +150oC

Temperature Compensated SmCo 2:17 Magnets

Grades	(BH)max	RTC	Comment
EEC 2:17-24	24 MGOe	-0.035 %/oC	No Compensation
EEC 2:17TC-18	18 MGOe	-0.02 %/oC	Some Compensation
EEC 2:17TC-16	16 MGOe	-0.001 %/oC	Full Compensation

RTC of B_r is calculated in the temperature range –50 to +150oC

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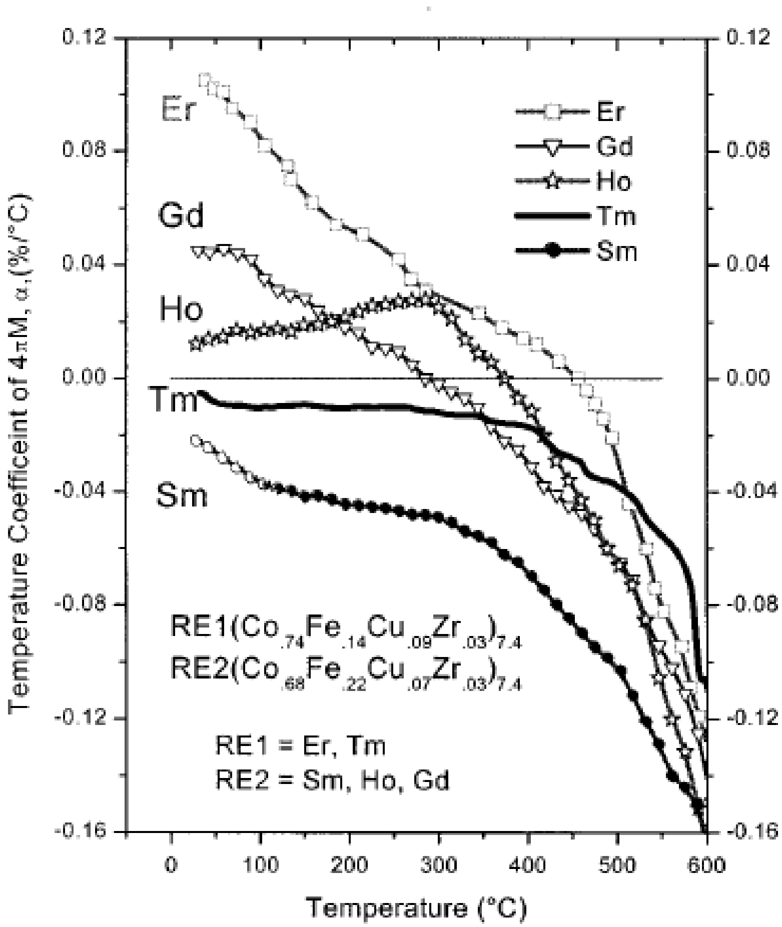
- MAGNET DESIGN
- MAGNET SYSTEMS

New 0TC Magnets

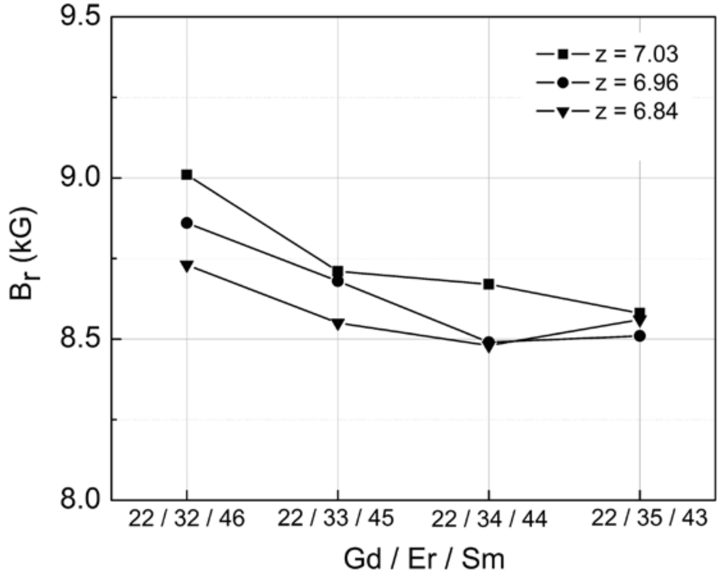


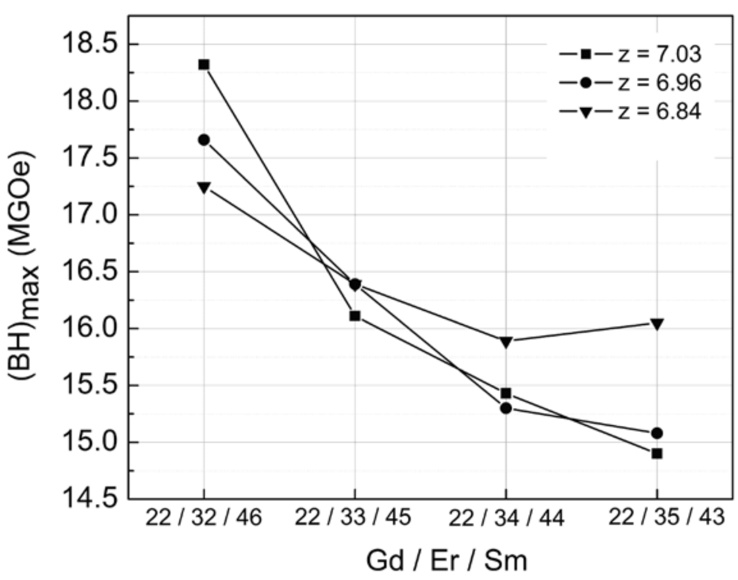
- RTC of Er based 2:17 is more positive than that of Gd based 2:17
- It is difficult to develop high H_k and H_{ci} for Er based 2:17
- Combined substitutions of Er and Gd led to the development of the new 0TC-18 magnets

C. Chen, W. Gong, M. Walmer, S. Liu and G. Kuhl, *J. Appl. Phys*., 91, 10, 2002, 8483

New 0TC Magnets (cont.)

Effect of composition modifications on the magnetic properties





The *Er / (Gd+Sm)* ratio need to be lower than 33% in order to obtain good H_k.

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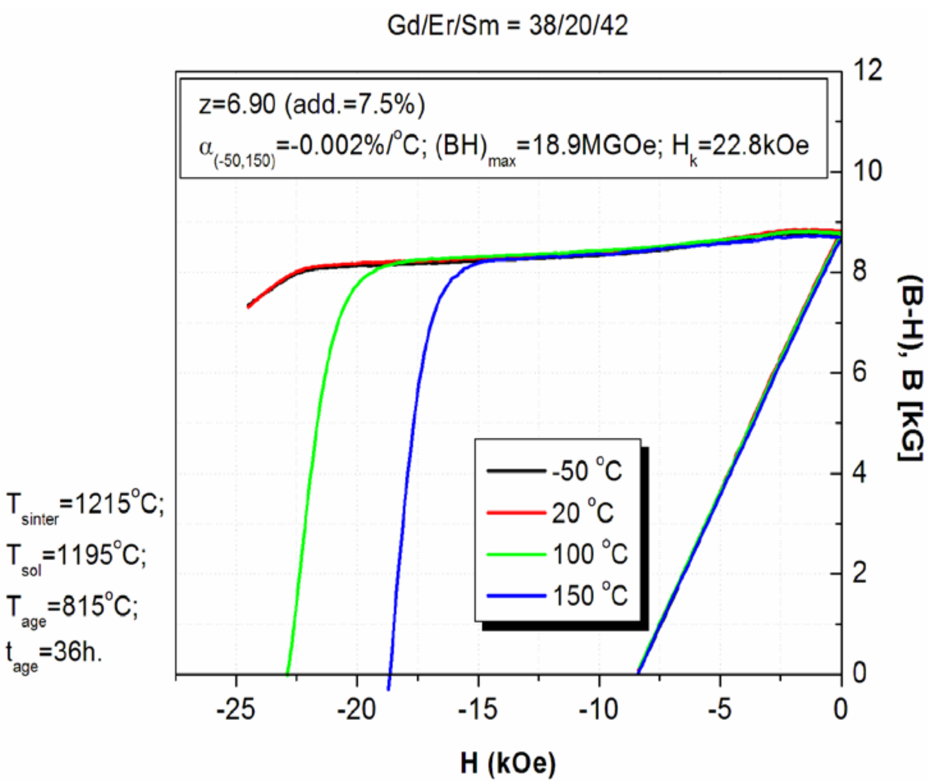
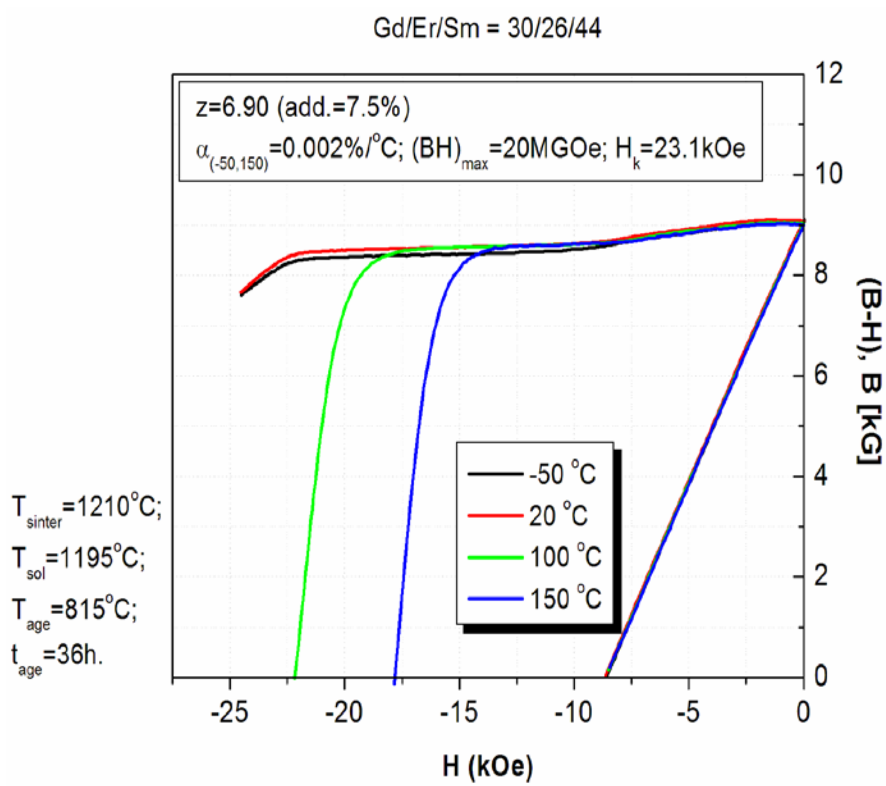
- MAGNET DESIGN
- MAGNET SYSTEMS

New 0TC Magnets (cont.)

Addition of *Er* and *Gd* for a New Grade of zero-RTC Magnets





Specification of the new TC 18 material

Residual Induction: B_r = 9000 G nominal

- *Maximum energy product: $(BH)_{max}$=18 MGOe nominal*
- *H_k greater than 12 kOe*
- *Intrinsic coercivity: $H_{ci} > 25$ kOe*
- *Typical RTC of B_r : -0.001 %/ºC*

The (BH)max of this new 0TC magnet (0TC18) is 12.5% higher than that of the best available 0TC magnet (0TC16)

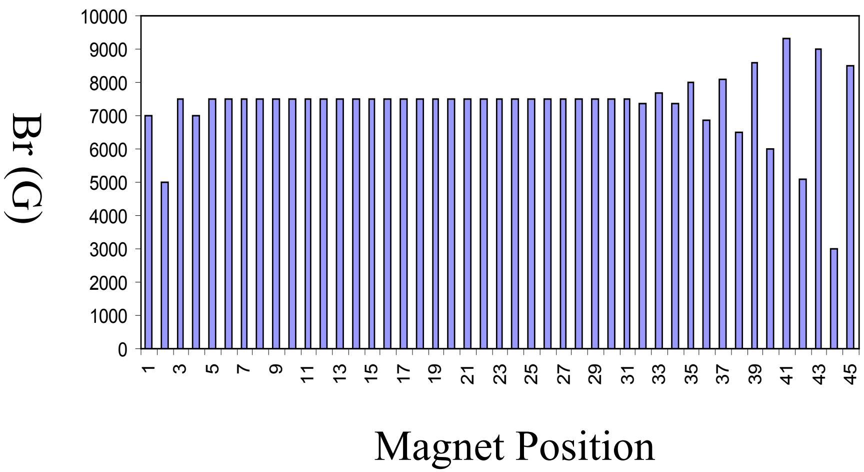
Magnet Stack Design Considerations

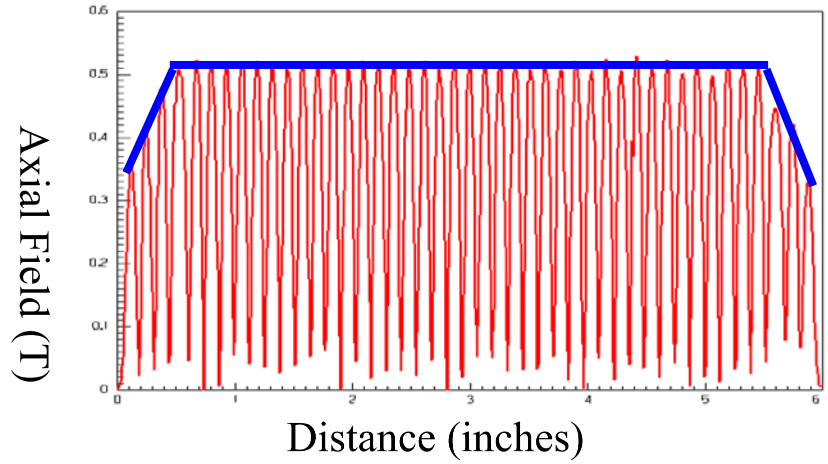
- B_r and H_c are used in the numerical simulations, which determines the axial field of the TWT magnet stack
- H_{ci} is a measure of resistance to demagnetization, which determines the maximum service temperature of the TWT magnet stack
- $(BH)_{max}$ can be estimated as $(B_r{*}H_c)/4$ for SmCo magnets with straight demagnetization curves
- RTC of Br determines the temperature dependence of the magnetic axial filed of the magnetic stack

Magnet Stack Design Considerations

- A TWTA magnet stack normally consists of dozens of magnet rings and pole pieces. Different positions of the stack require different magnetic properties in order to meet the requirements of the axial field

- The RTC of Br will be different for different magnet positions of the stack. It is not possible to make all parts with the same RTC in a stack





Magnet Stack Design Considerations

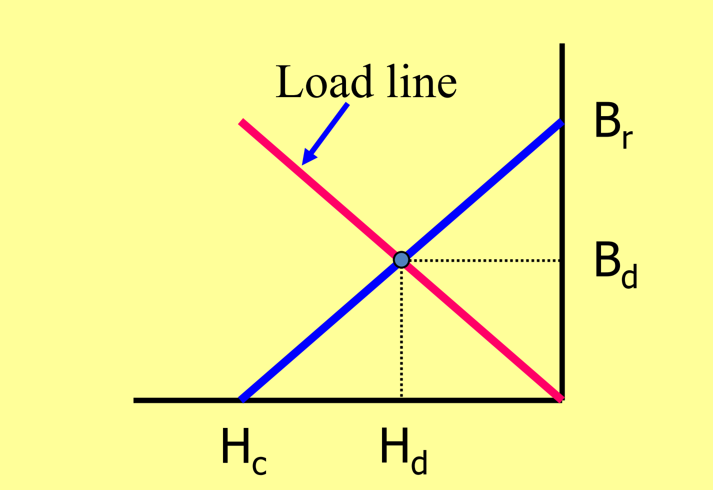
- Recommended recoil permeability to use in TWTA magnet stack simulations:
  - For SmCo5 magnets: $\mu = 1.03$
  - For SmCo 2:17 magnets: $\mu = 1.05$
- All published magnetic properties are tested in saturated conditions. A drop of up to 4% in magnetic strength is expected during thermal stabilization. *This factor should be considered in numerical simulations.*

Magnet dimensions for a TWTA stack

Permeance Coefficient Pc

In the magnetic circuit, a magnet will operate at a specific point on its extrinsic demagnetization curve:

$$P_c = B_d / H_d$$



- **Also known as load line or operating point**

- **It is related to the dimensions of the magnets and the associated magnetic circuit**

- ***The smaller the magnet thickness in a TWTA magnet stack, the lower the load line will be, and the more difficult to manufacture due to its requirement of extremely high H_k and H_{ci}***

Magnet dimensions for a TWTA stack

- Pole piece diameter of about 80% of magnet OD produces maximum axial field for the stack
- If larger OD is required for the pole piece to conduct heat, magnet OD would have to be increased to reach the same axial field
- SmCo magnets are very brittle. Very thin magnets (<0.060” or 1.5 mm) pose challenges mechanically as well as magnetically.

Communications between designers and manufacturing is strongly recommended.

Summary

- A new zero RTC magnet with $(BH)_{max}$ of 18 MGOe has been developed for the TWTA industry, which is **12.5% higher in maximum energy product** than that of the best commercially available 0TC magnets.
- The RTC of Br for different magnet positions is different in a magnet stack. It is not possible to make the entire magnet stack with the same RTC.
- The recoil permeability is slightly different between SmCo 1:5 and 2:17 magnets, which should be treated differently in numerical simulations.