Sm-Co Magnets and Applications

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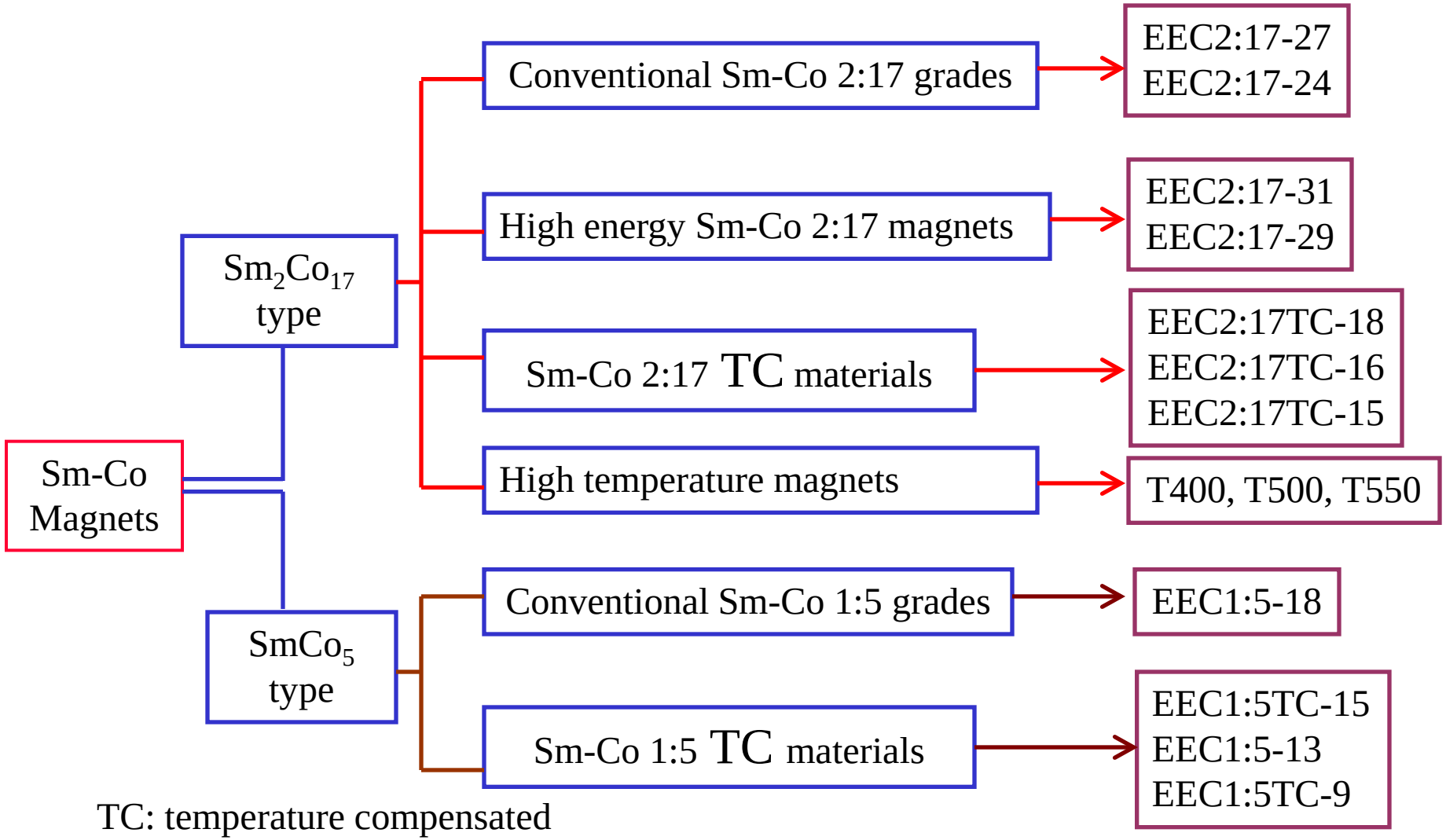
Outline

- Sm-Co magnets overview
- Properties of $SmCo_5$ and Sm_2TM_{17} magnets
- Temperature compensated magnets
- High temperature magnets
- Microstructure and thermal stability
- Applications

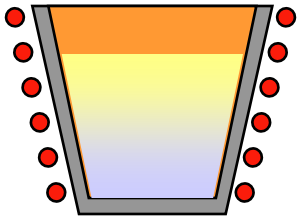
Sintered Sm-Co Magnets (Overview)



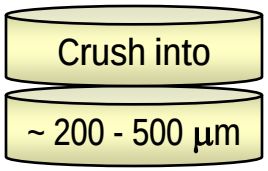
TC: temperature compensated

Typical Manufacturing Process for Sintered Sm-Co Magnets

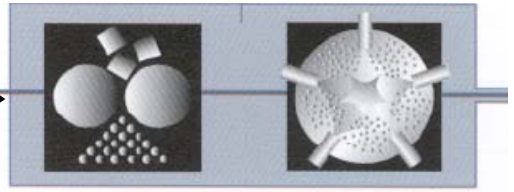
Raw Materials
Sm, Co, Fe,Cu, Zr (2:17)
Sm, Co (1:5)



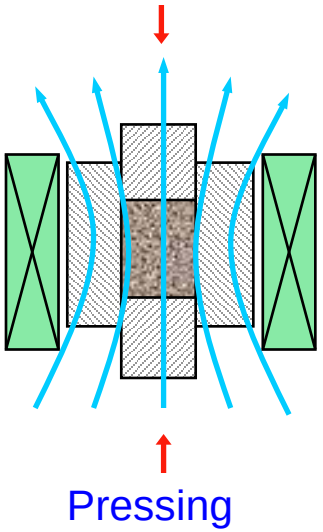
Induction Melting



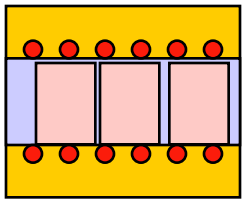
Crushing



Ball milling or Jet milling
To ~ 2-5 μm

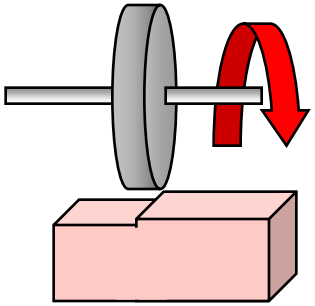


Pressing

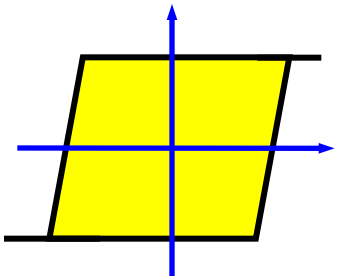


Sintering, Solution and Heat treatment

Machining



Grinding, lapping, honing, Or wire EDM



Magnetizing & Testing

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Properties of $SmCo_5$ Magnet

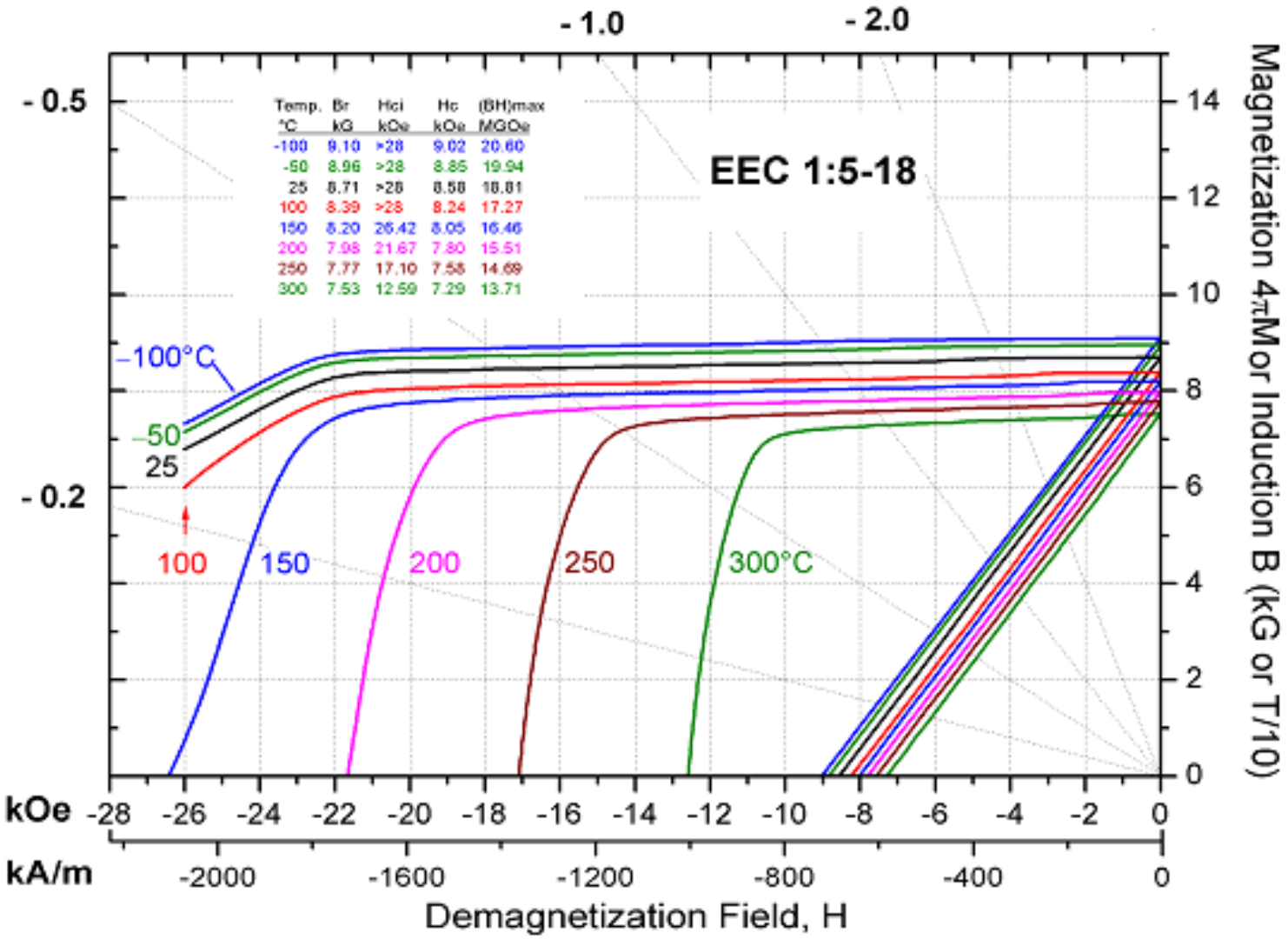
Typical properties:

- B_r = 8750 to 9000 G
- H_c = 8.5 to 8.8 kOe
- H_{ci} > 30 kOe (It could be as high as 50 kOe)
- $(BH)_{max}$ = 18 to 20 MGOe

Advantages:

- Maximum operating temperature up to 300°C
- High resistance to demagnetization
- Superior corrosion resistance

Demagnetization Curves of $SmCo_5$ Magnet



Composition SmCo 2:17 Magnets

Why we call it SmCo 2:17?

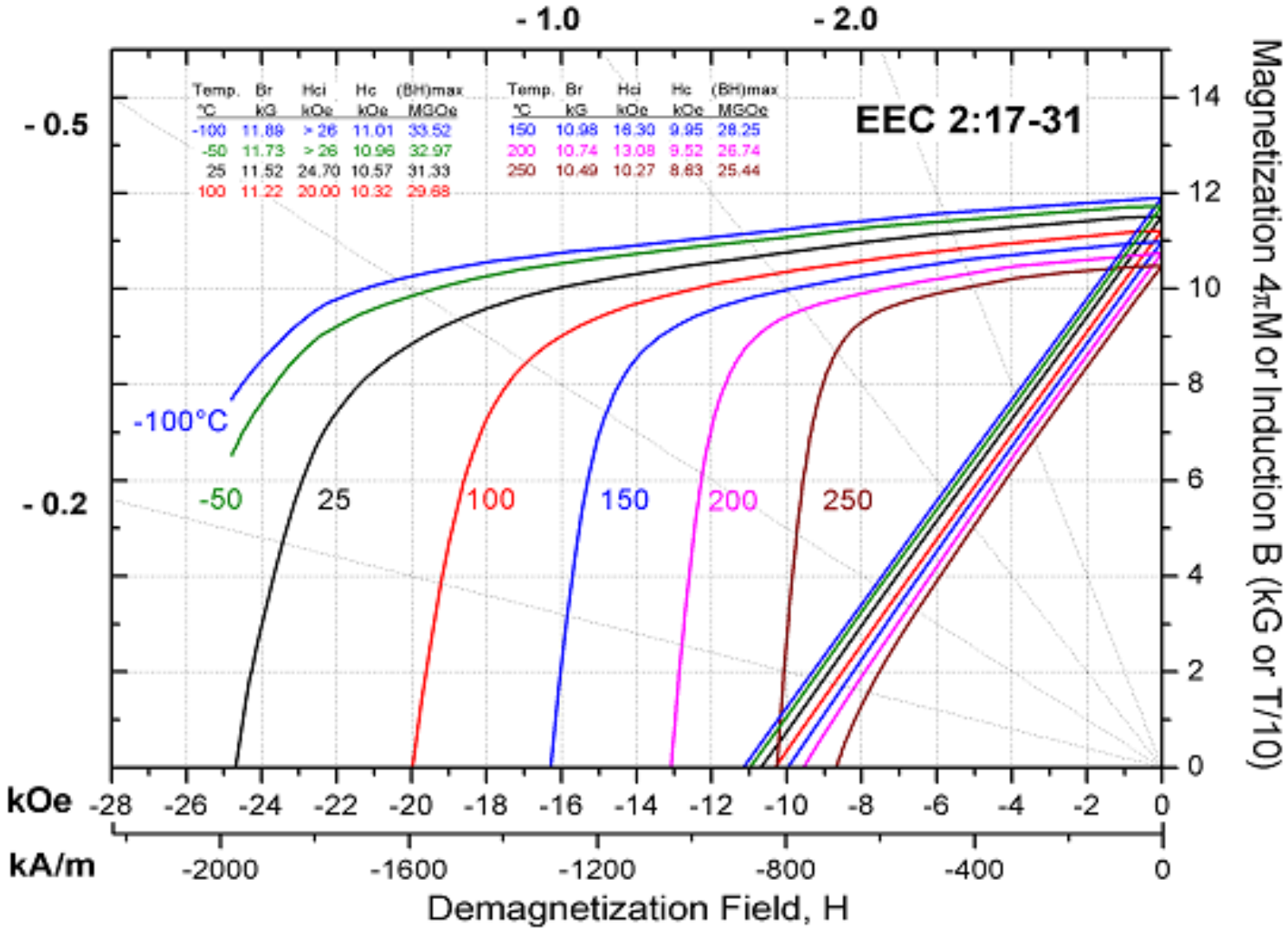
- It is a evolution from the Sm_2Co_{17} phase
- Sm_2Co_{17} can also be written as $SmCo_{8.5}$
- Other transition metals (Fe,Cu,Zr) are added for the development of optimum magnetic properties
- Then we have $Sm(Co_{(1-u-v-w)}Fe_uCu_vZr_w)_{8.5}$
- Extra Sm added to compensate oxygen pick-up in the process, so we change the formula to the following:

$$Sm(Co_{(1-u-v-w)}Fe_uCu_vZr_w)_z$$

Properties of SmCo 2:17 magnets

- Maximum energy product, $(BH)_{max,}$ to 32 MGOe
- Residual induction, B_r, to 11,600 Gauss
- Coercive force, H_c, to 10.6 kOe
- Intrinsic coercive force, H_{ci}, > 25 kOe
- Maximum operating temperature, T_M , from 250°C to 550°C

High Energy SmCo 2:17 magnets



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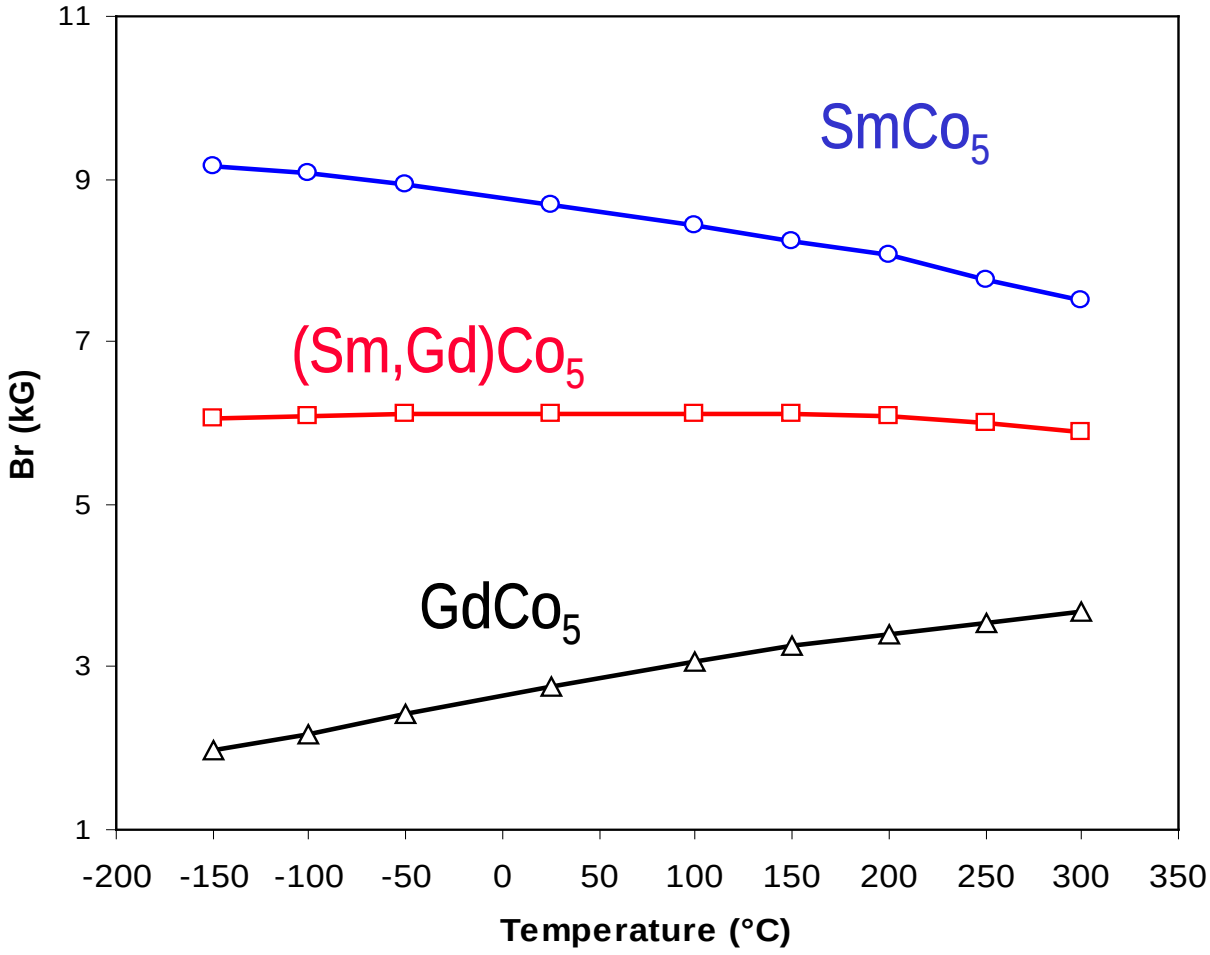
Reversible temperature coefficient

- B_r changes with temperature
- Some applications , such as gyro and TWTs, require stable B_r over a wide temperature range
- The reversible temperature coefficient of Br is defined as:

$$\alpha = \frac{\Delta Br}{Br} \frac{1}{\Delta T} \times 100\%$$

- To address above requirements, EEC developed temperature compensated magnets with the reversible temperature coefficient of B_r close to zero

Temperature compensation for RE-Co 1:5 magnets



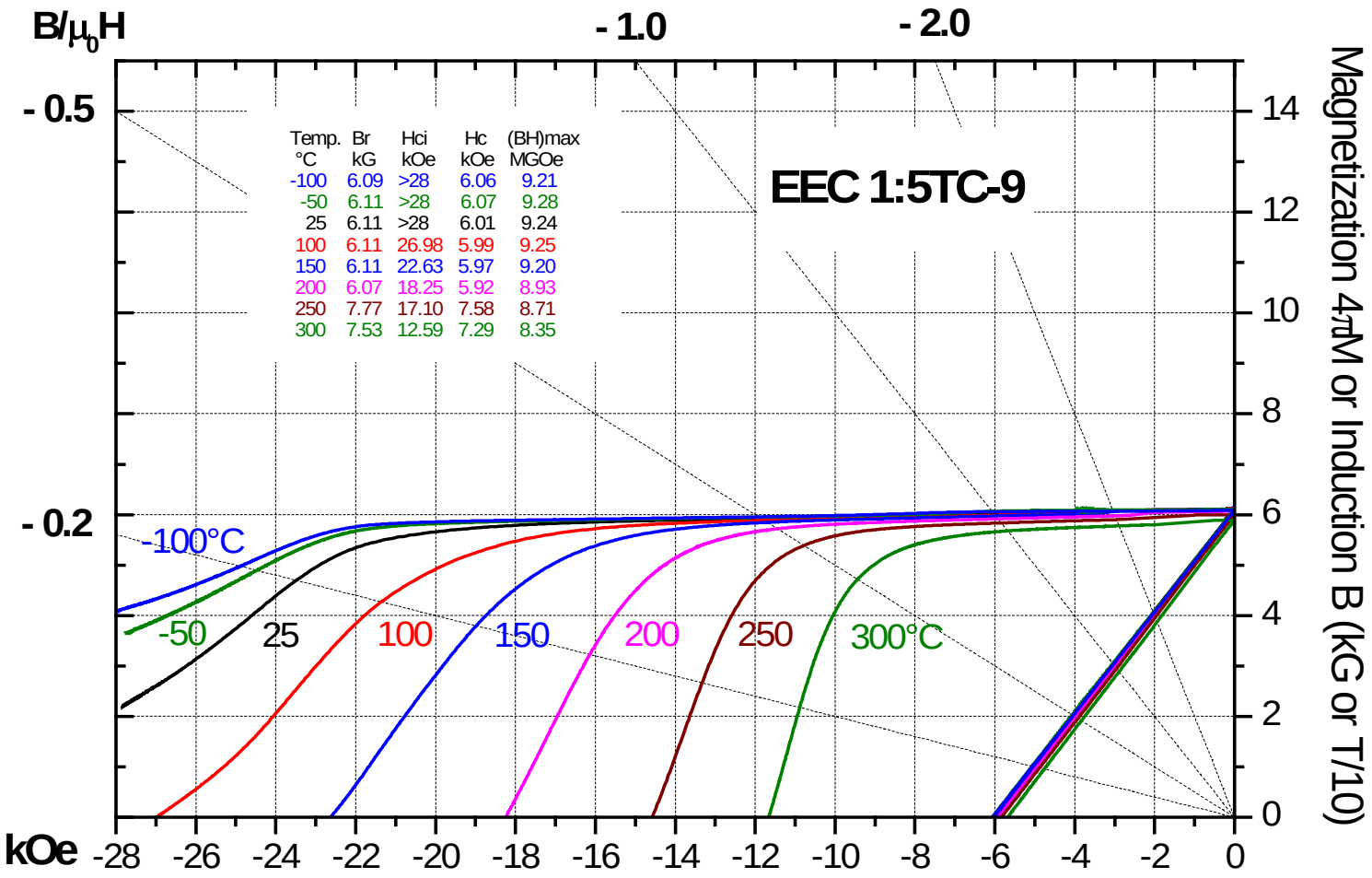
Temperature compensated RE-Co 1:5 magnets

Grades	$(BH)_{max}$	RTC* of B_r	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	some compensation
EEC 1:5TC-9	9 MGOe	-0.001 %/^oC	full compensation

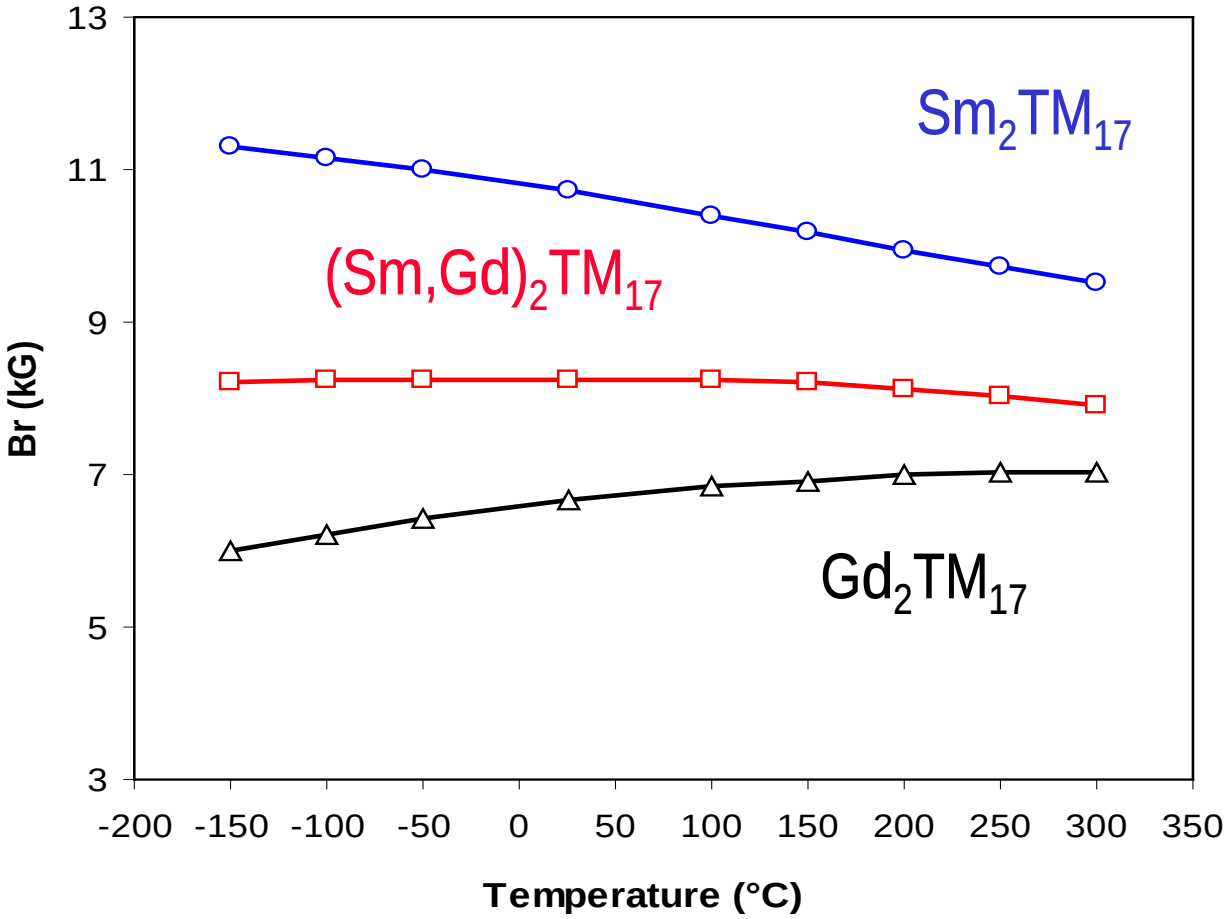
*RTC: Reversible temperature coefficient

- Reversible temperature coefficient of B_r of fully compensated SmGdCo 1:5 magnets is 40 times smaller than the non-compensated $SmCo_5$ magnets
- The $(BH)_{max}$ decreases for the temperature compensated magnets due to the low saturation magnetization of $GdCo_5$

$RETM_5$ type 0TC material



Temperature compensation for Sm_2TM_{17} magnets



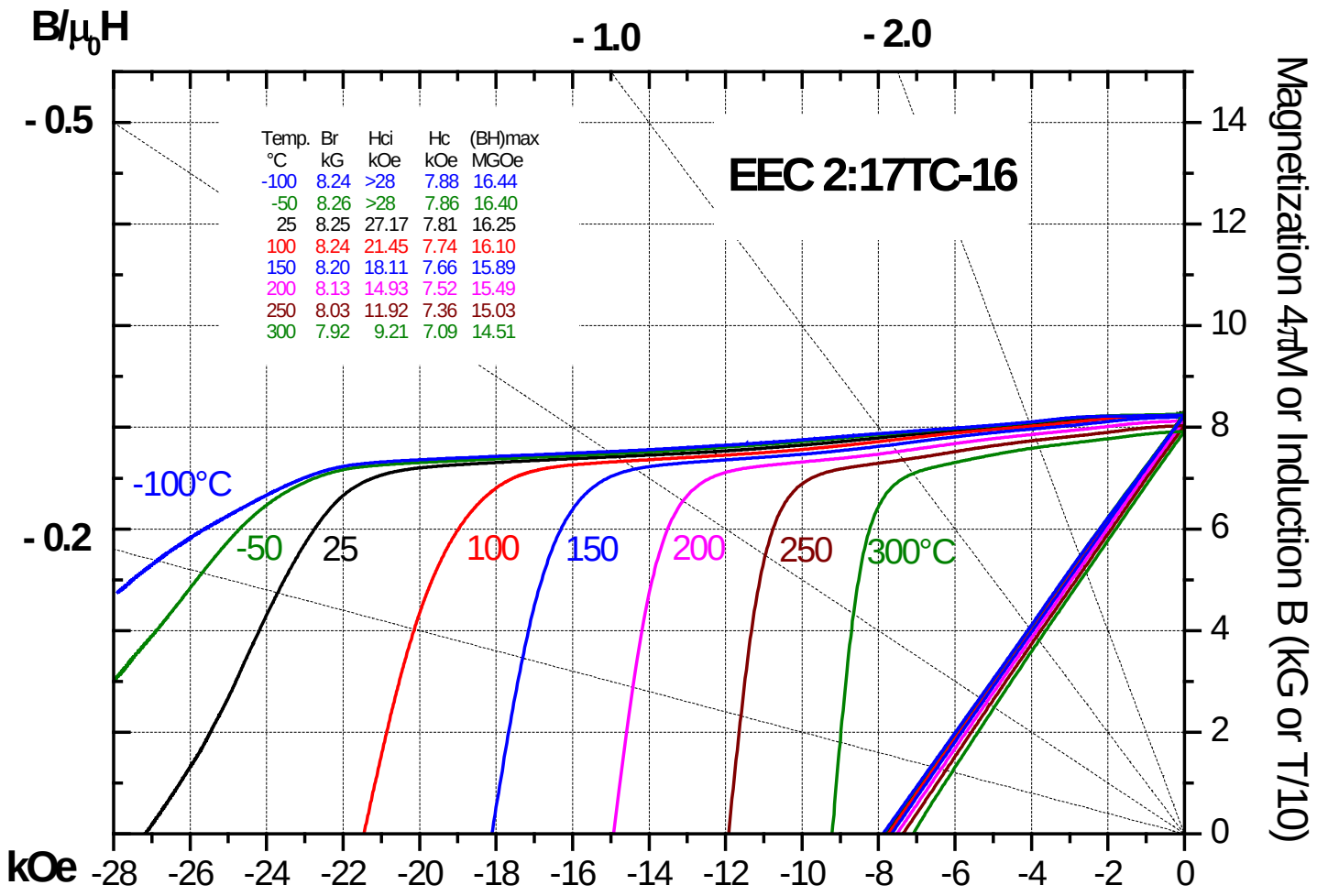
Temperature compensated Sm-Co 2:17 magnets

Grades	$(BH)_{max}$	RTC* of B_r	Comment
EEC 2:17-24	24 MGOe	-0.035 %/^oC	No compensation
EEC2:17TC-18	18 MGOe	-0.02 %/^oC	Some compensation
EEC2:17TC-16	16 MGOe	-0.001 %/^oC	Full compensation

*RTC: Reversible temperature coefficient

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

RE_2TM_{17} type 0TC material



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High temperature magnets

- A few years ago, the maximum operating temperature of SmCo magnets was only up to 300°C
- DoD initiated the More Electric Aircraft program, which requires magnets with maximum operating temperature more than 400°C
- Funded by Department of Defense, we developed a series of sintered SmCo 2:17 magnets with maximum operating temperature as high as 550°C

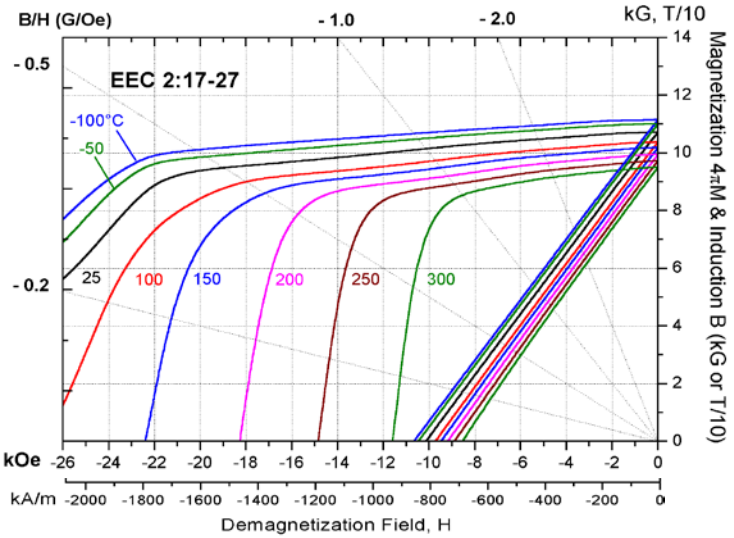
High temperature magnets

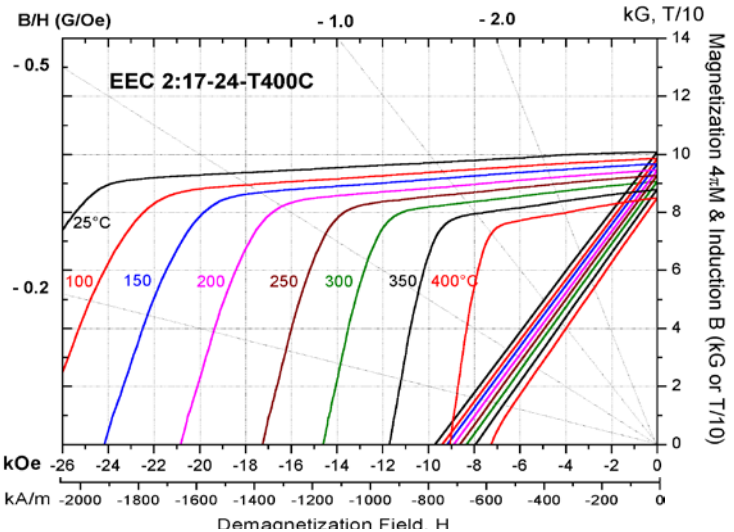
Grades	B_r (kG)	$(BH)_{max}$ (MGOe)	T_M (^oC)
EEC 24-T400	10.2	24	400
EEC 21-T400	9.5	21	400
EEC 20-T500	9.2	20	500
EEC 18-T500	8.7	18	500
EEC 16-T550	8.5	16	550
EEC 15-T550	8.0	15	550

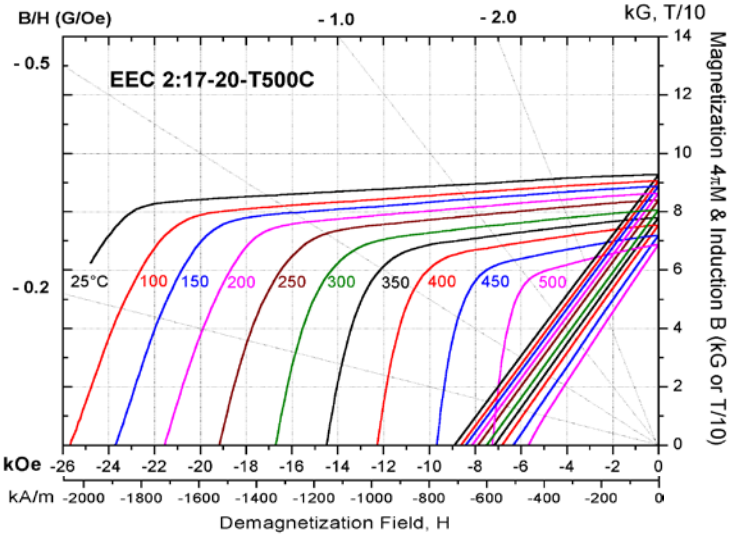
More high temperature magnets with $T_M = 400^oC$

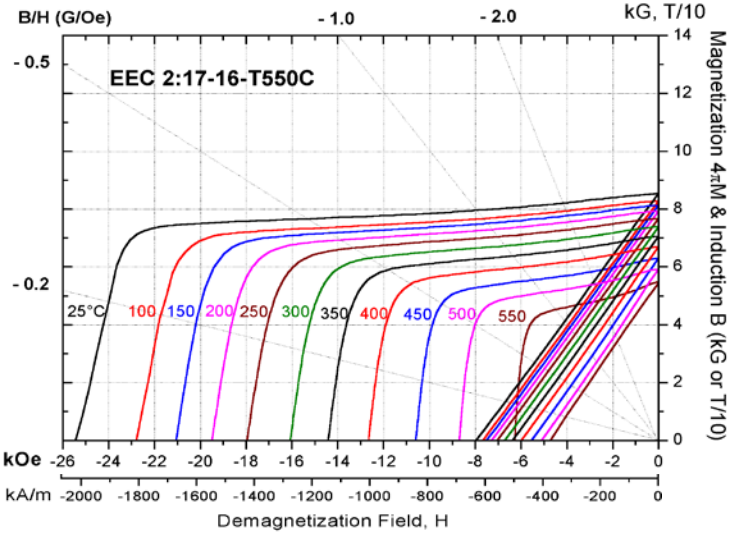
BOM	B_r	H_c	$(BH)_{max}$	H_{ci}	RTC of B_r
	(kG)	(kOe)	(MGOe)	(kOe)	%
9500H	9500	9.03	21.3	>25	-0.035
9250H	9250	8.79	20.2	>25	-0.030
9000H	9000	8.55	19.2	>25	-0.025
8750H	8750	8.27	18.0	>25	-0.020
8500H	8500	8.03	17.0	>25	-0.018
8250H	8250	7.80	16.0	>25	-0.015
8000H	8000	7.56	15.1	>25	-0.010
7750H	7750	7.32	14.1	>25	-0.007
7500H	7500	7.05	13.2	>25	-0.003
7250H	7250	6.82	12.3	>25	0.001
7000H	7000	6.58	11.5	>20	0.004
6750H	6750	6.35	10.7	>20	0.008

Demagnetization Curves for High Temp. Magnets

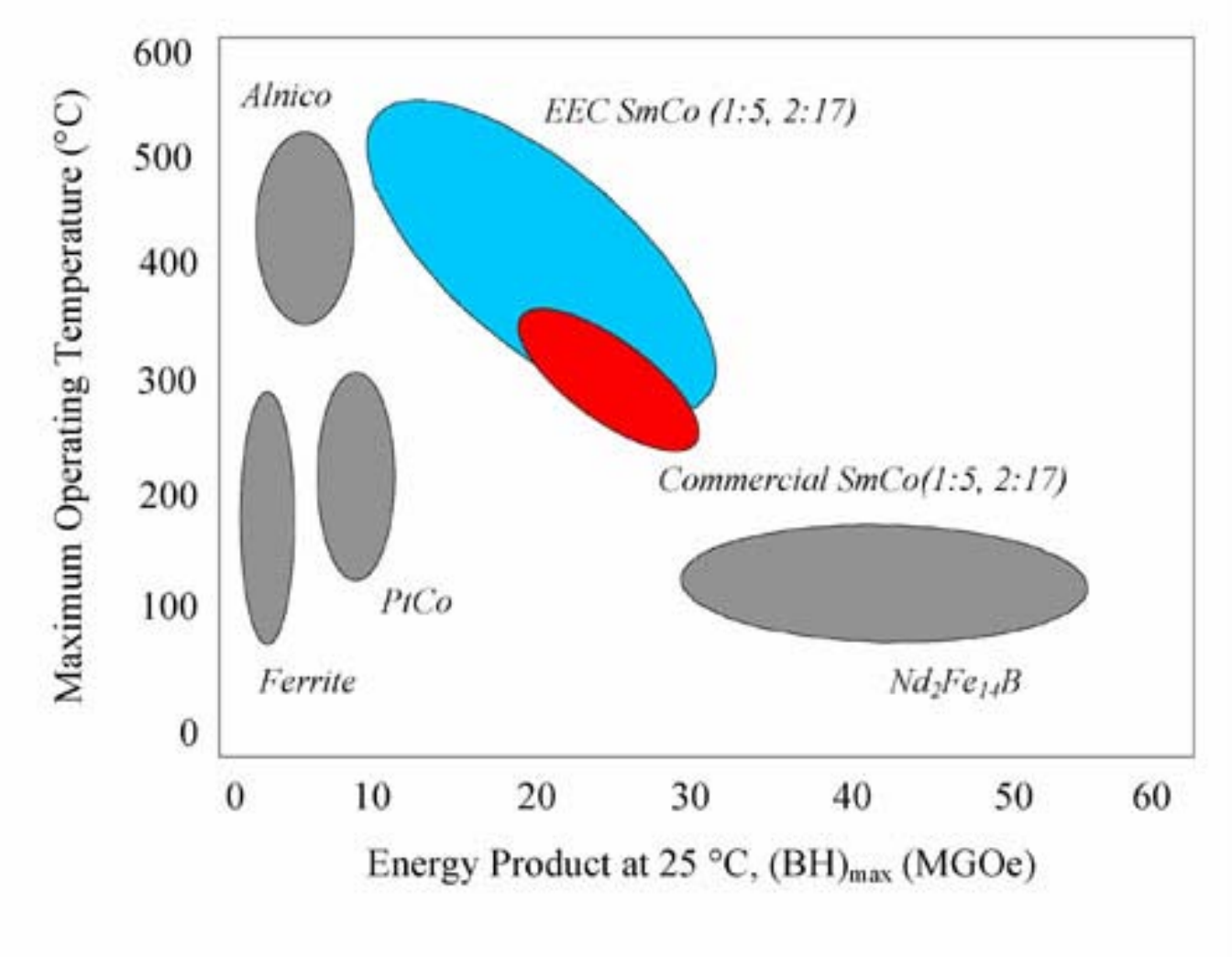








Comparison of maximum operating temperature



Important Features of High Temperature Magnets

- ✓High intrinsic coercivity H_{ci} at elevated temperatures to resist demagnetization
- ✓Low temperature coefficient of H_{ci}
- ✓Straight-line demagnetization curves *at* maximum operating temperatures
- ✓The maximum use temperature is defined as T_M , at which a straight line demagnetization curve can exist.
- ✓Magnets can be made for any specified T_M up to 550°C with highest possible $(BH)_{max}$
- ✓High temperature magnets require surface coating (such as Ni-plating) if used above 400°C continuously.
- ✓High temperature magnets still belong to Sm_2TM_{17} type magnet family.

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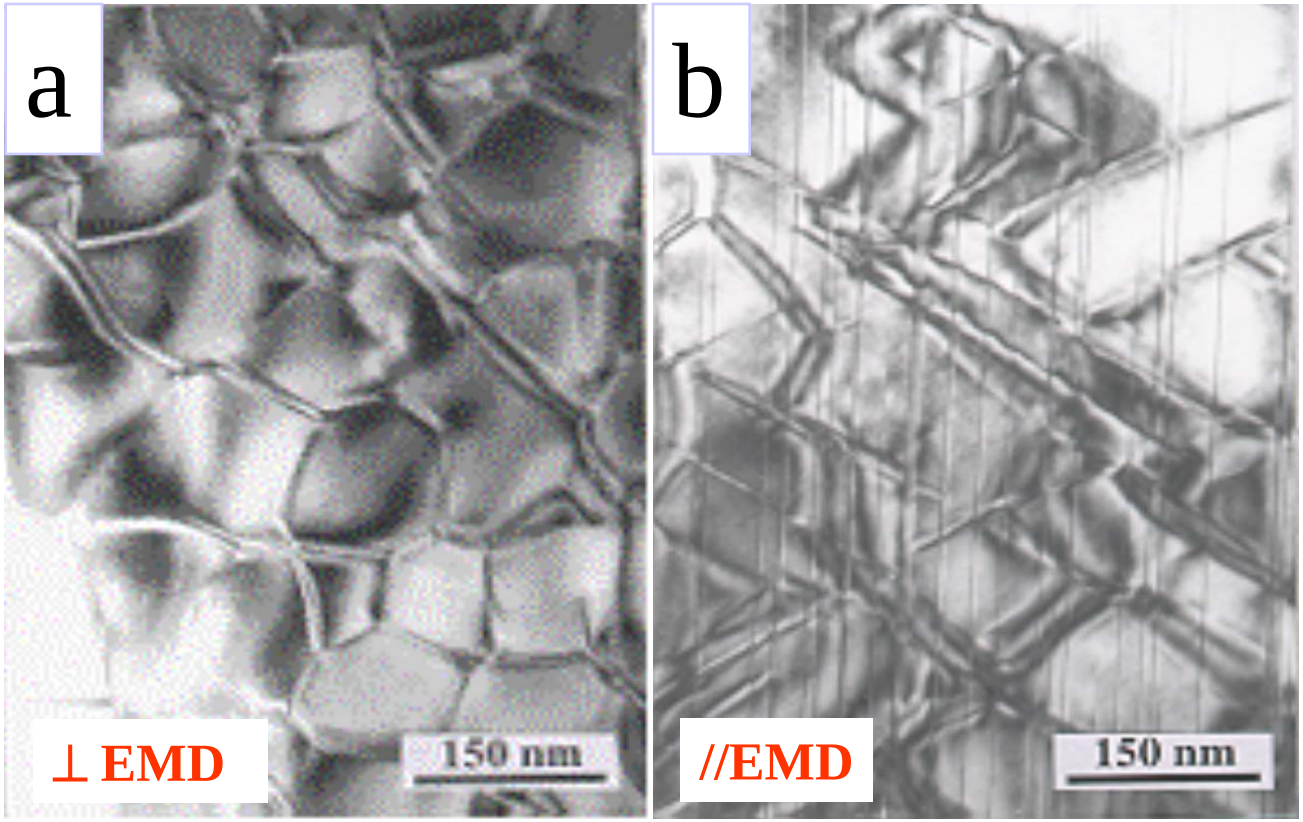
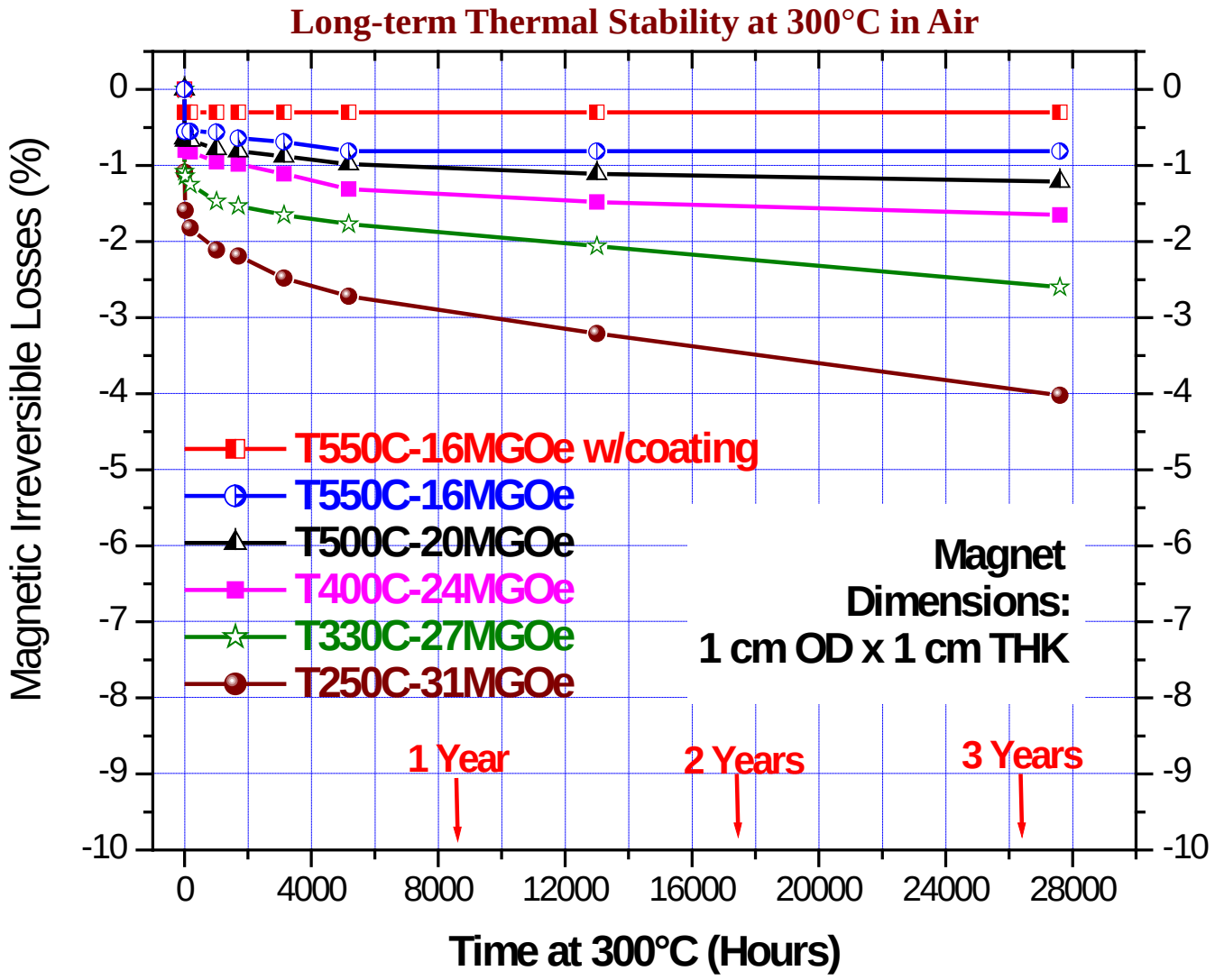
Cellular microstructure of Sintered SmCo 2:17 Magnets



EMD: Easy magnetization direction

Thermal Stability



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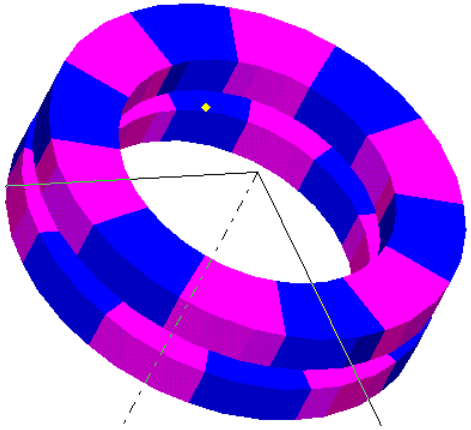
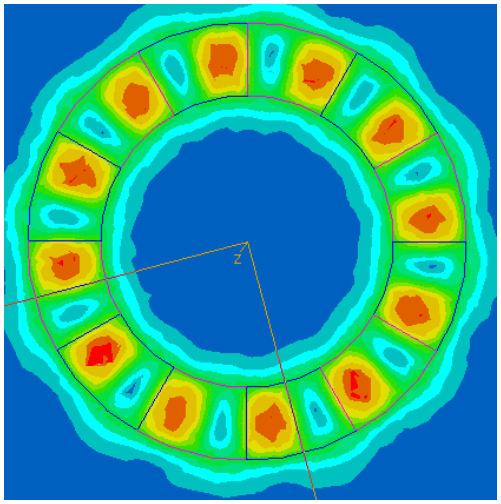
Applications of Sm-Co magnets

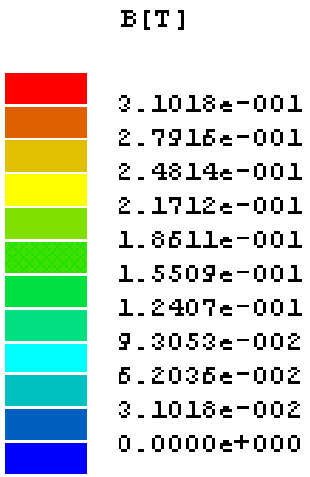
- ✓ Accelerometers and gyroscopes
- ✓ High performance motors and generators
- ✓ High temperature magnetic bearings
- ✓ Magnetic couplers and actuators
- ✓ Hall effect devices
- ✓ High performance pumps and mixers
- ✓ Traveling wave tubes

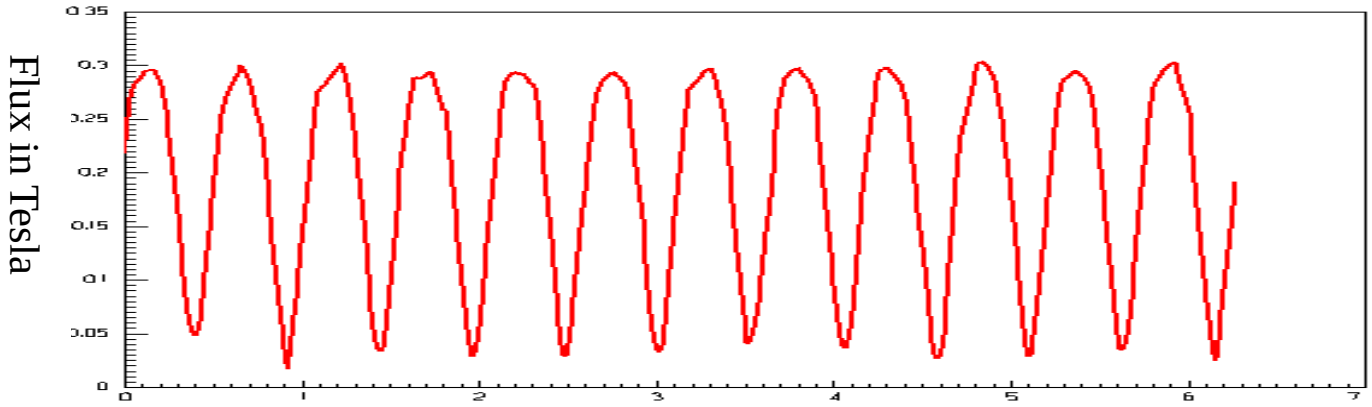
FEA is a useful tool

Surface Coupler with 12 Alternating Poles



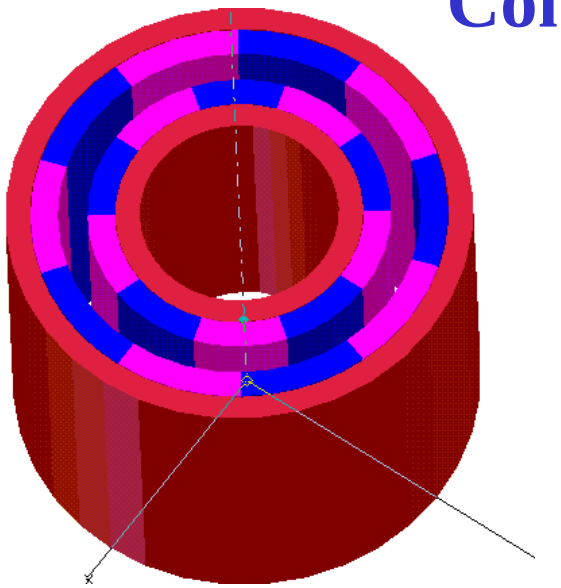


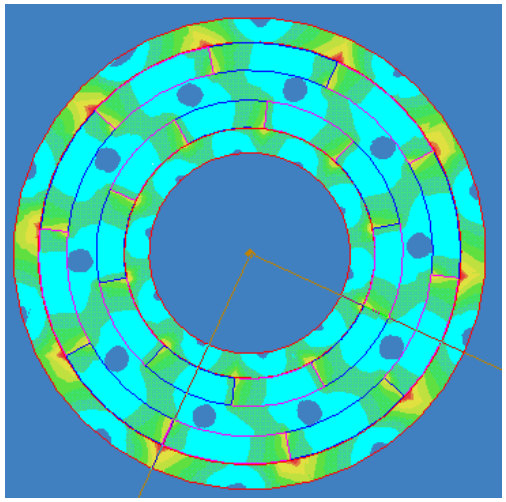


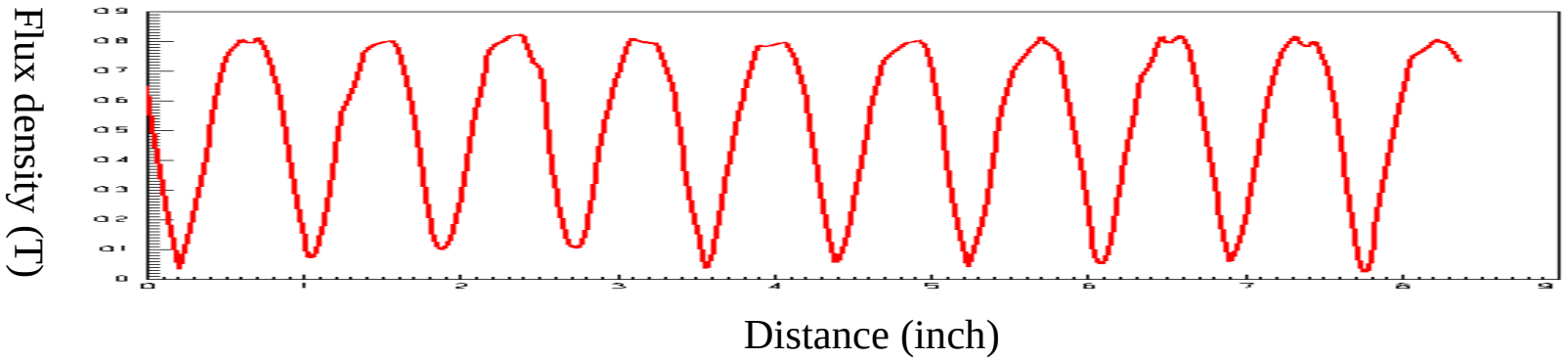


Flux density along the center line of the air gap

Concentric Coupling System

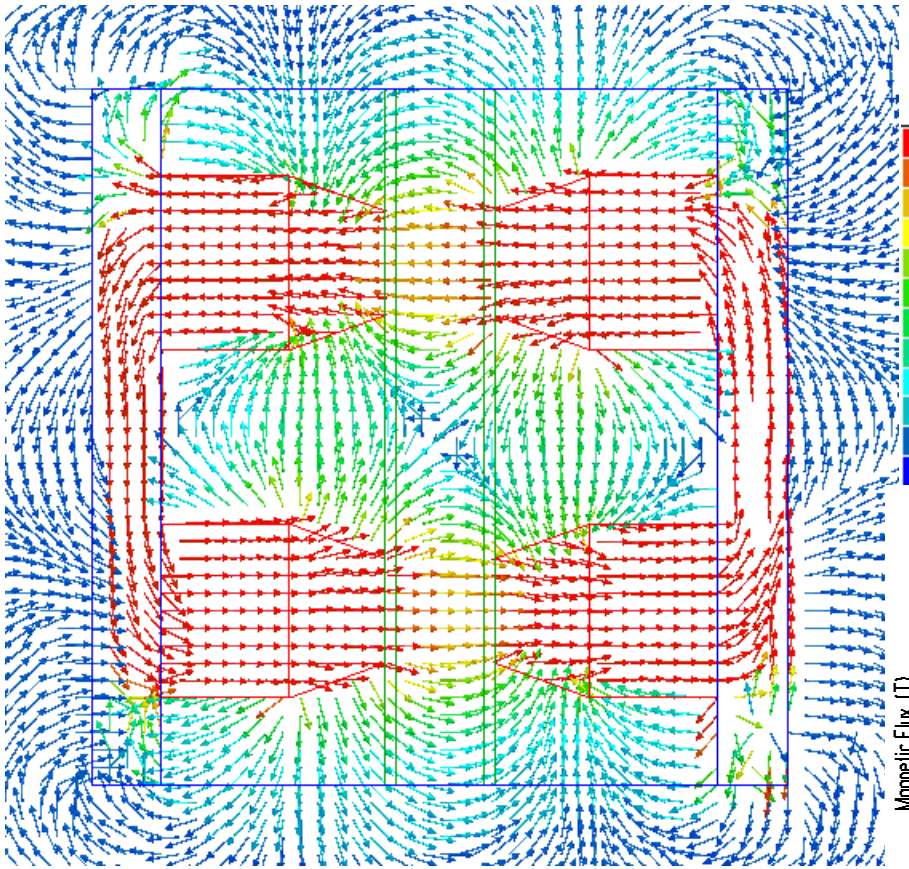


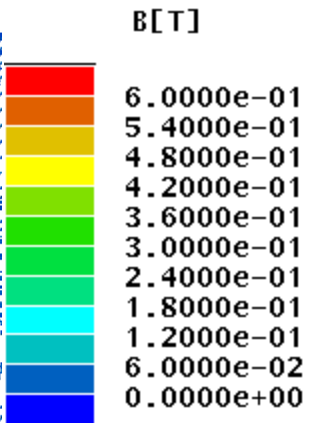


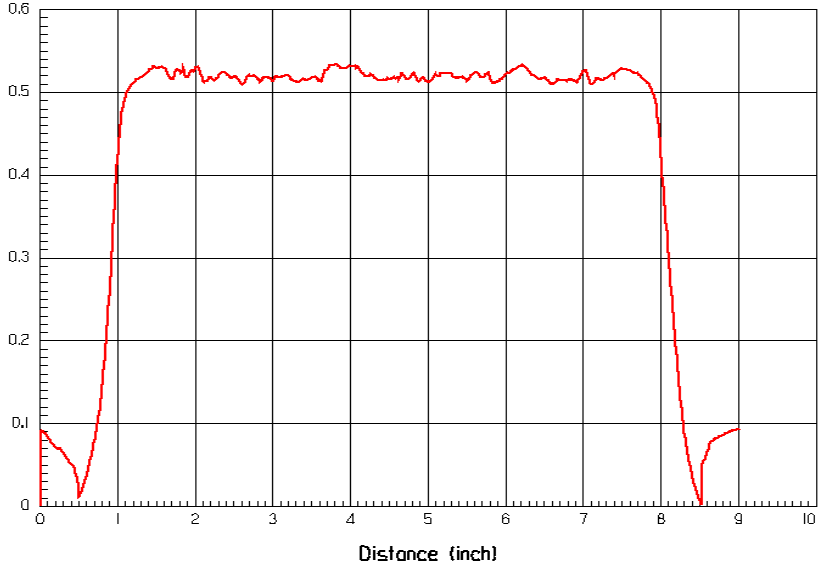


FEA is a useful tool

Magnetic Security Devices

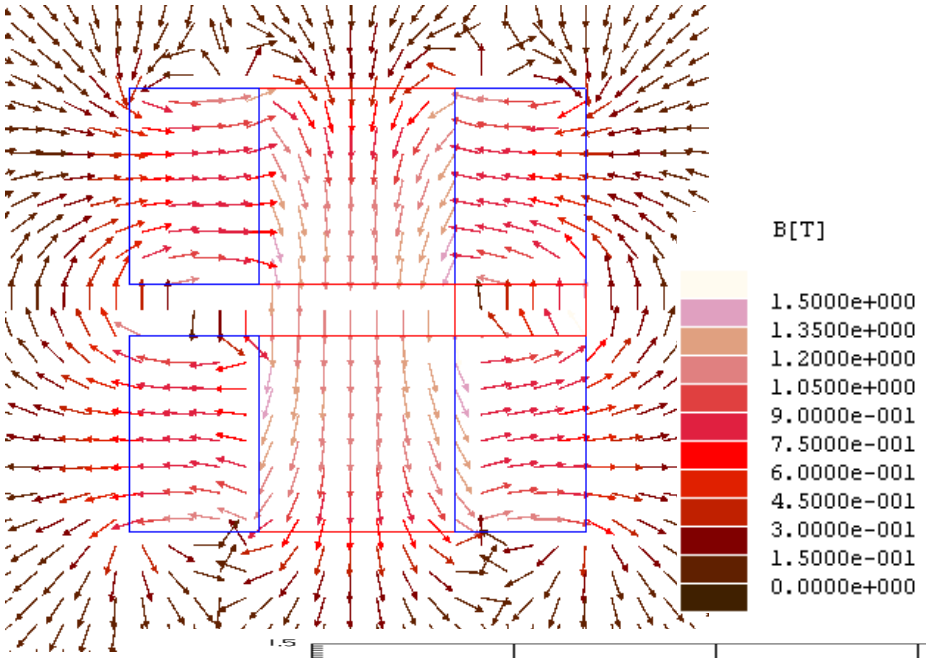


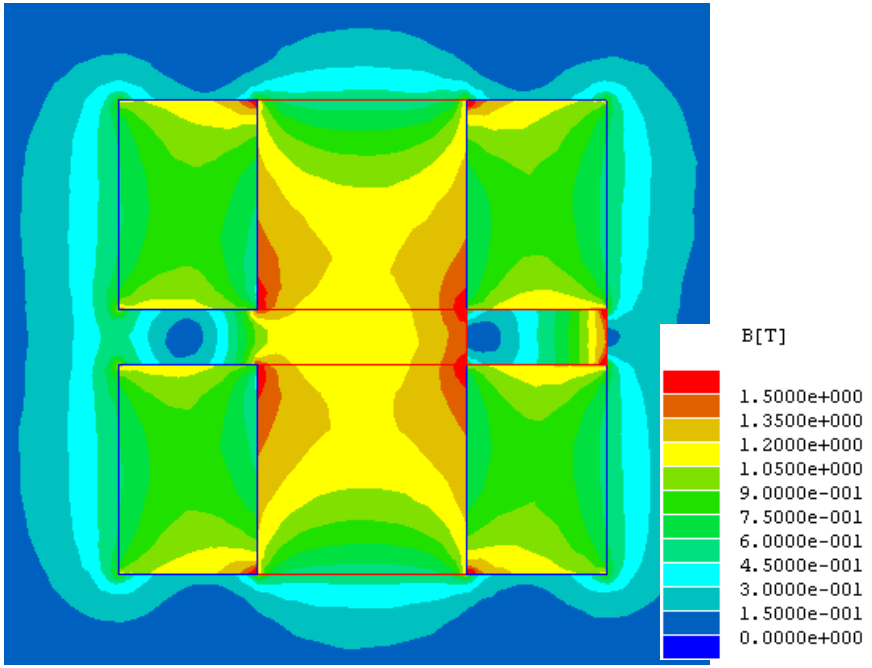


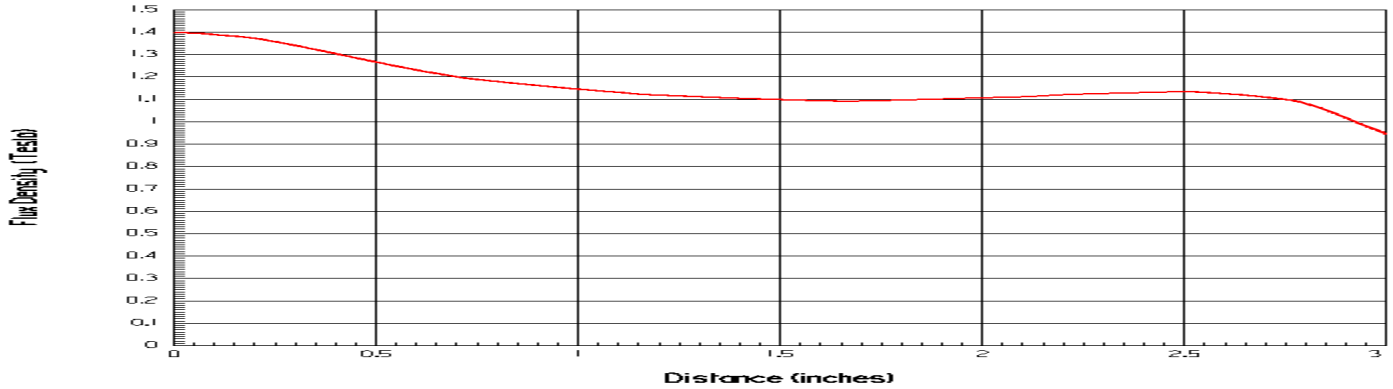


FEA is a useful tool

Magnetizing System

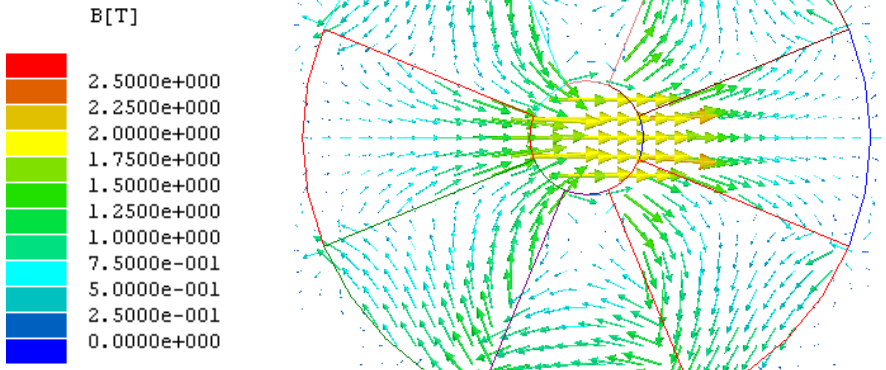


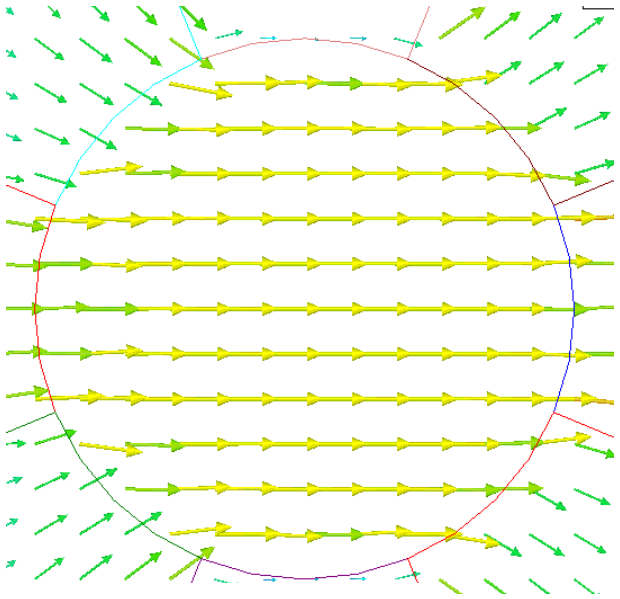


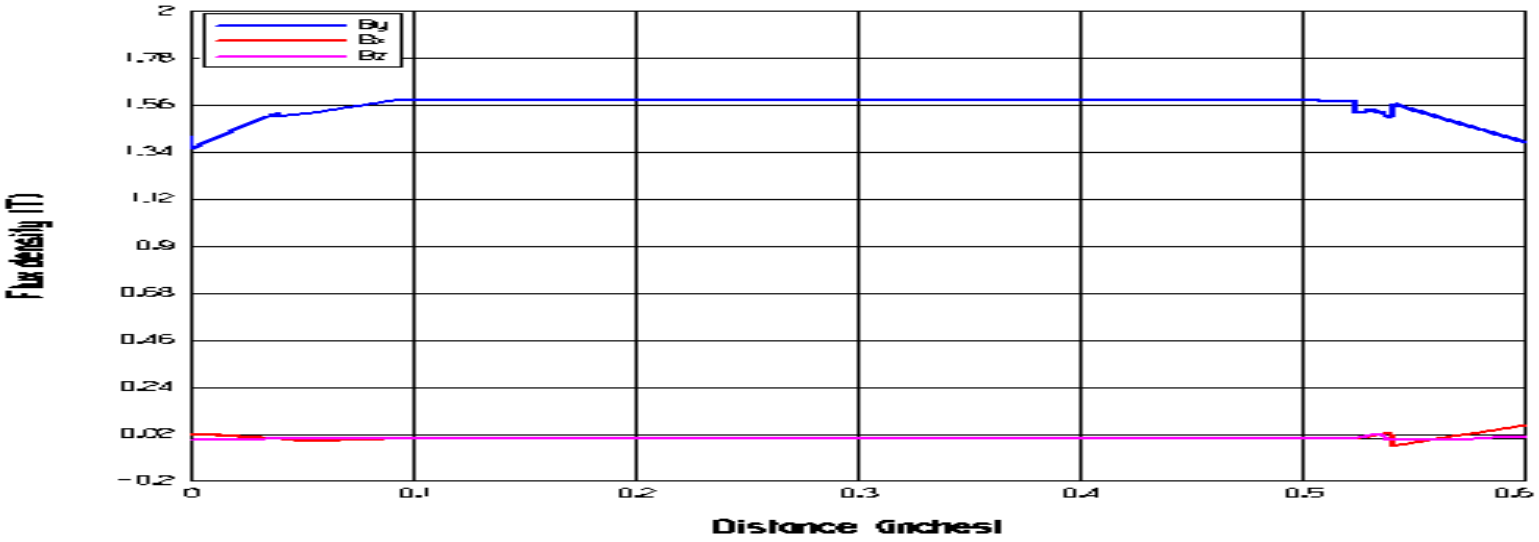


FEA is a useful tool

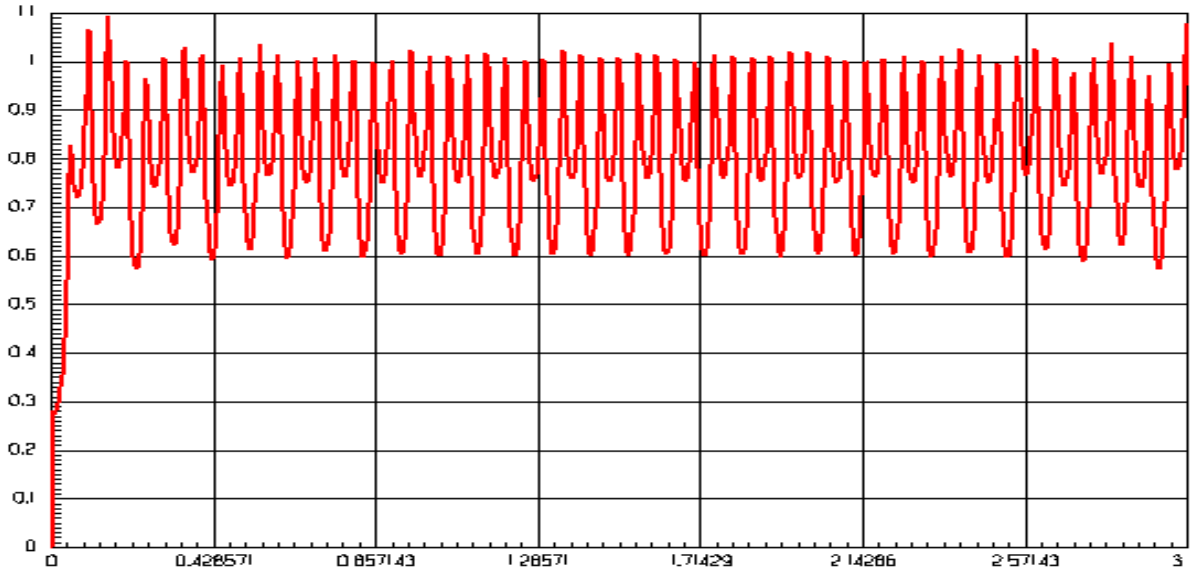
Halbach Cylinders

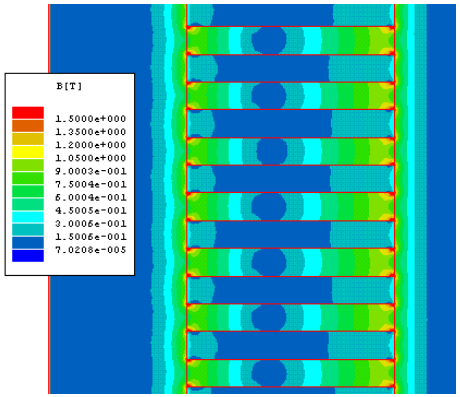




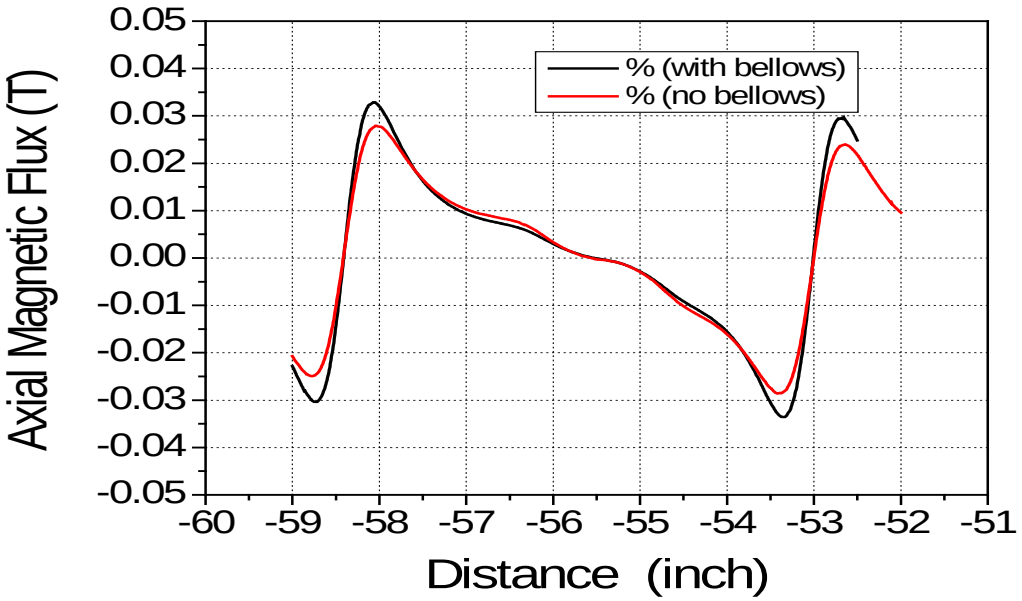


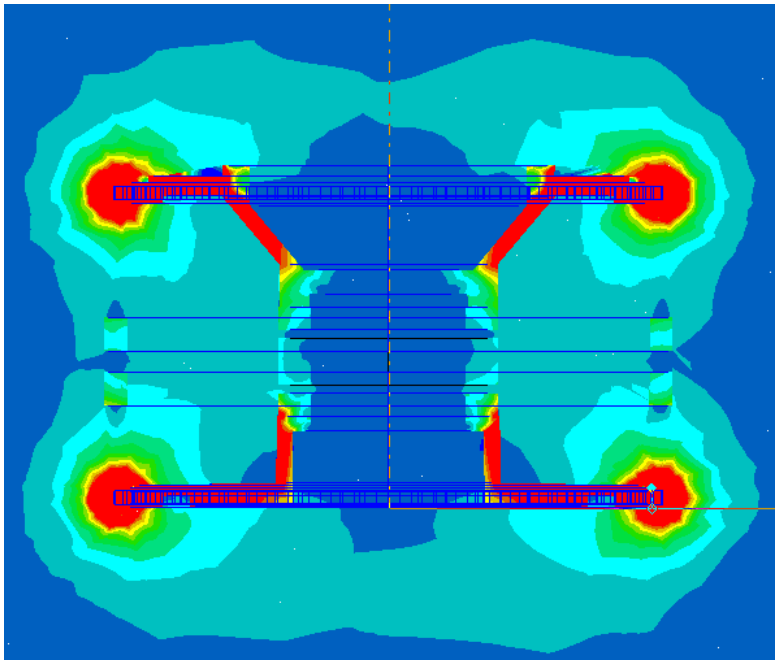
Multipole Magnetic Magnetizing System



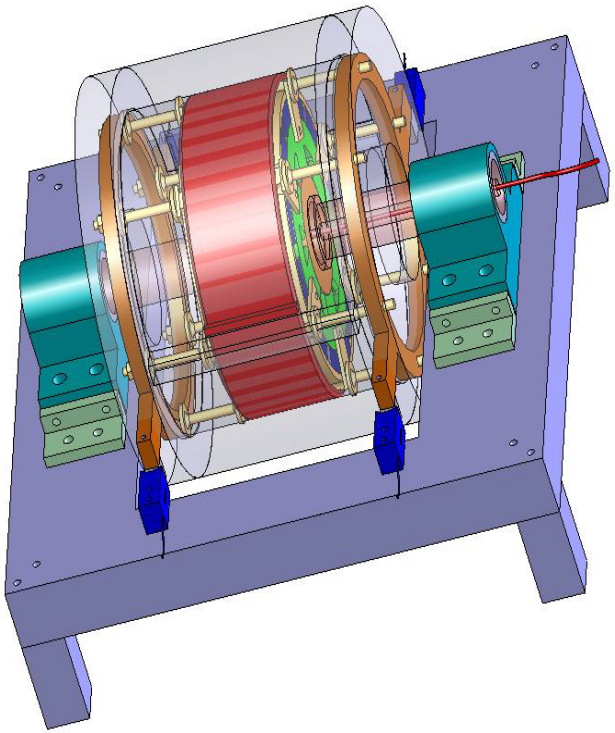


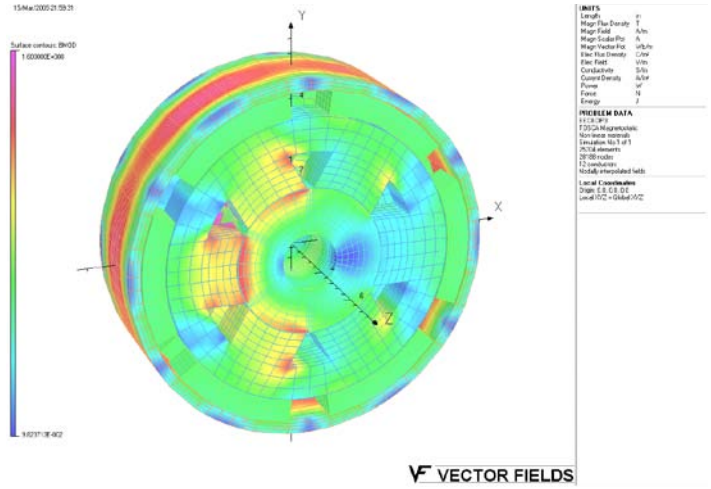
Magnetic Sensing System





High Temperature Magnetic Bearings





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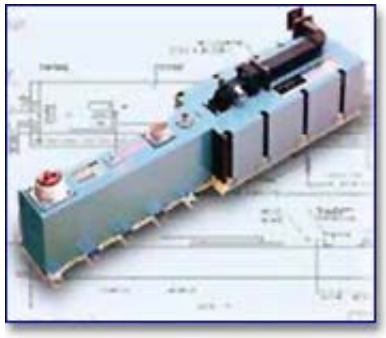
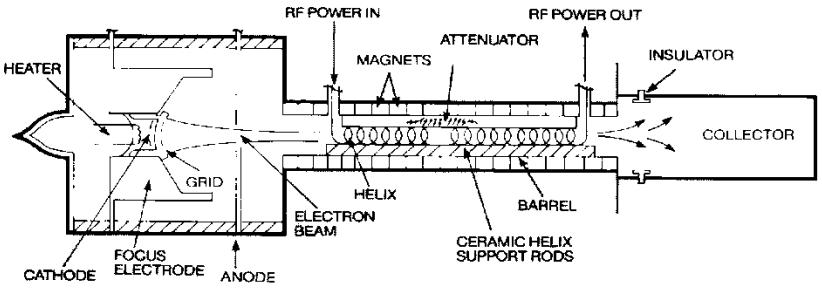
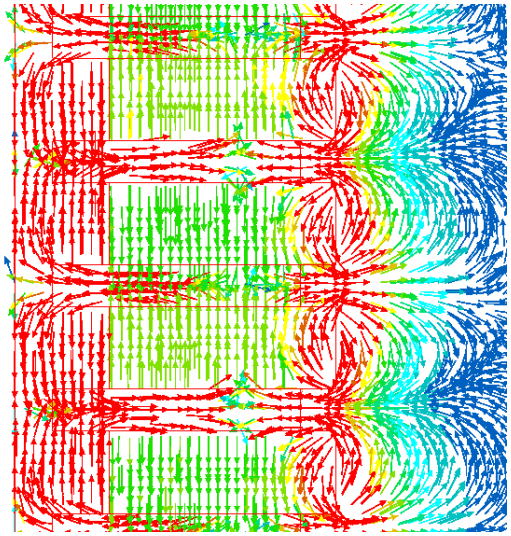
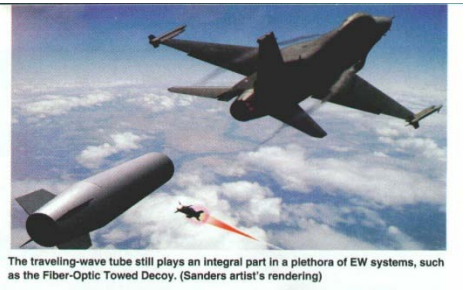


Traveling Wave Tube (TWT)

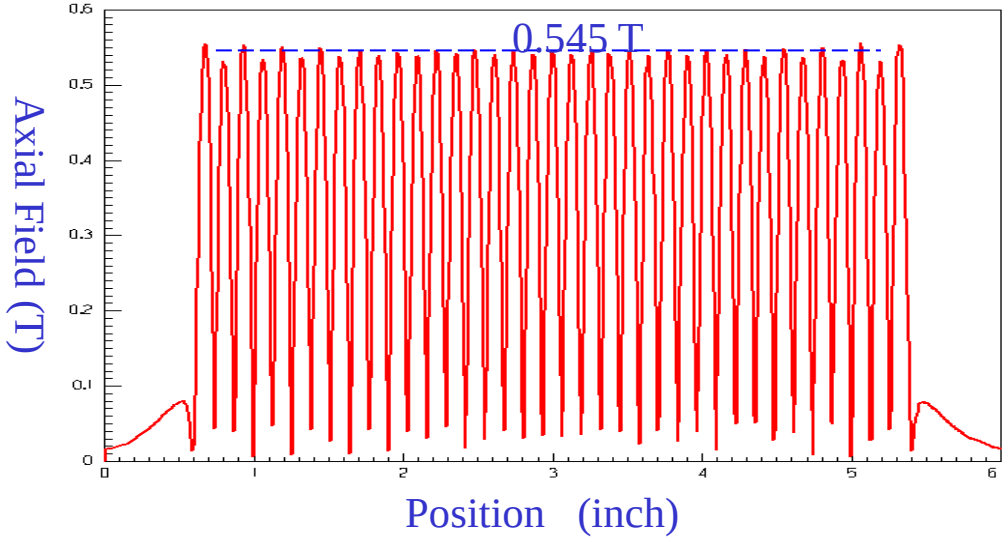






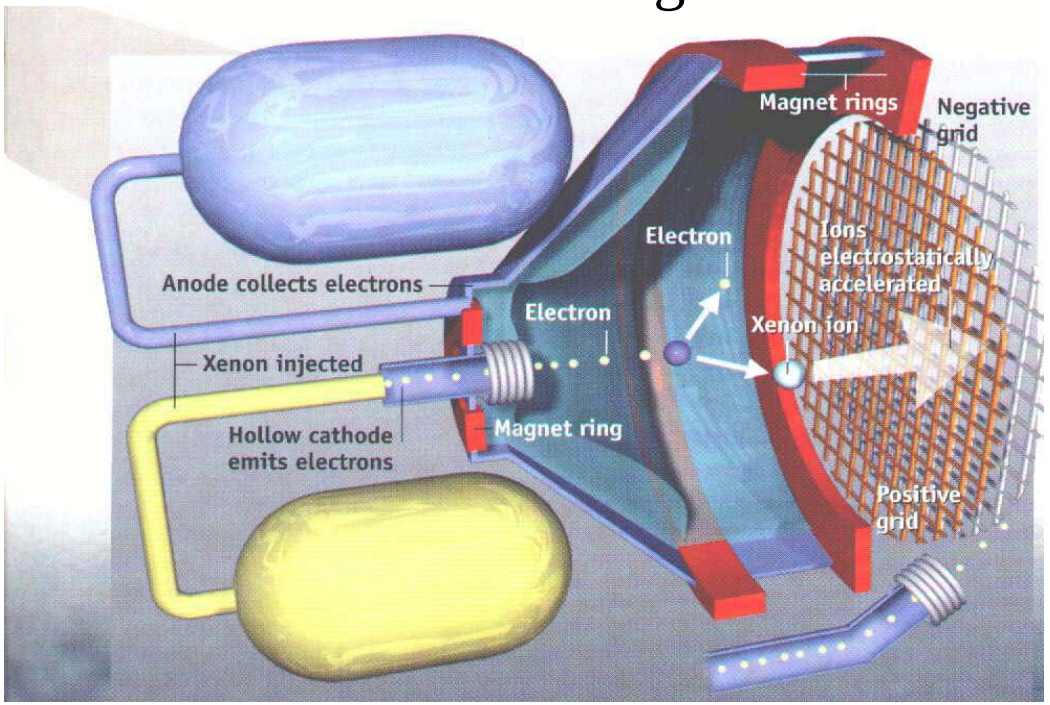
The traveling-wave tube still plays an integral part in a plethora of EW systems, such as the Fiber-Optic Towed Decoy. (Sanders artist's rendering)

Towed Decoys could improve survivability of current military Aircraft

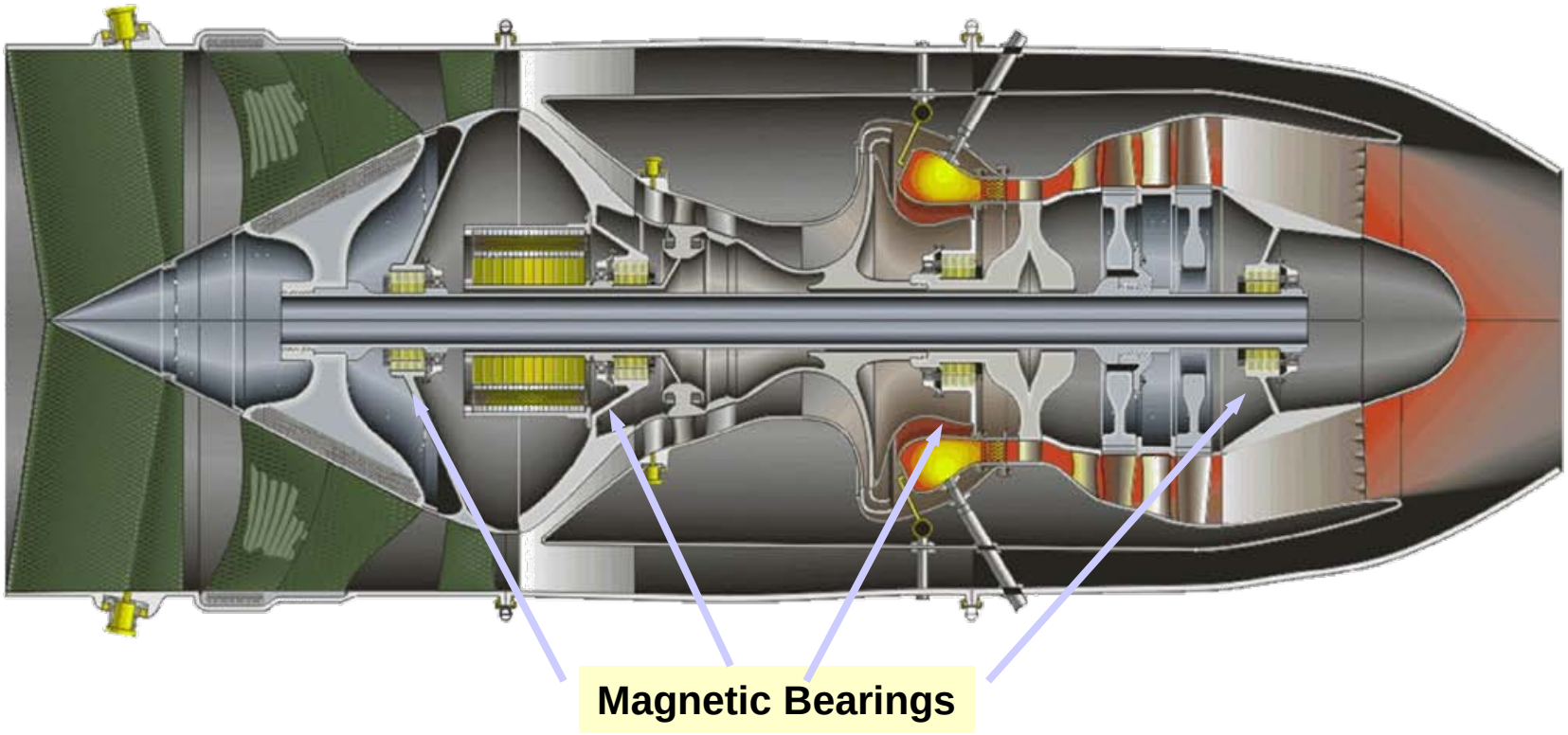


Ion Thrusters with Sm-Co Magnets in NASA's Deep Space I

Ion engine



MEA-IPU preliminary design with high temperature Sm-Co magnets (~ 425°C)



More Electric Aircraft – Integrated Power Unit

MEA Initiative by the US Air Force

EEC Magnets for Medical Devices

Micro-sized surgical drills and saws enabled by Sm-Co magnets

Powered Instruments with Sm-Co magnets are designed to be efficient and dependable during surgery

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