



Sm-Co Magnets and Applications

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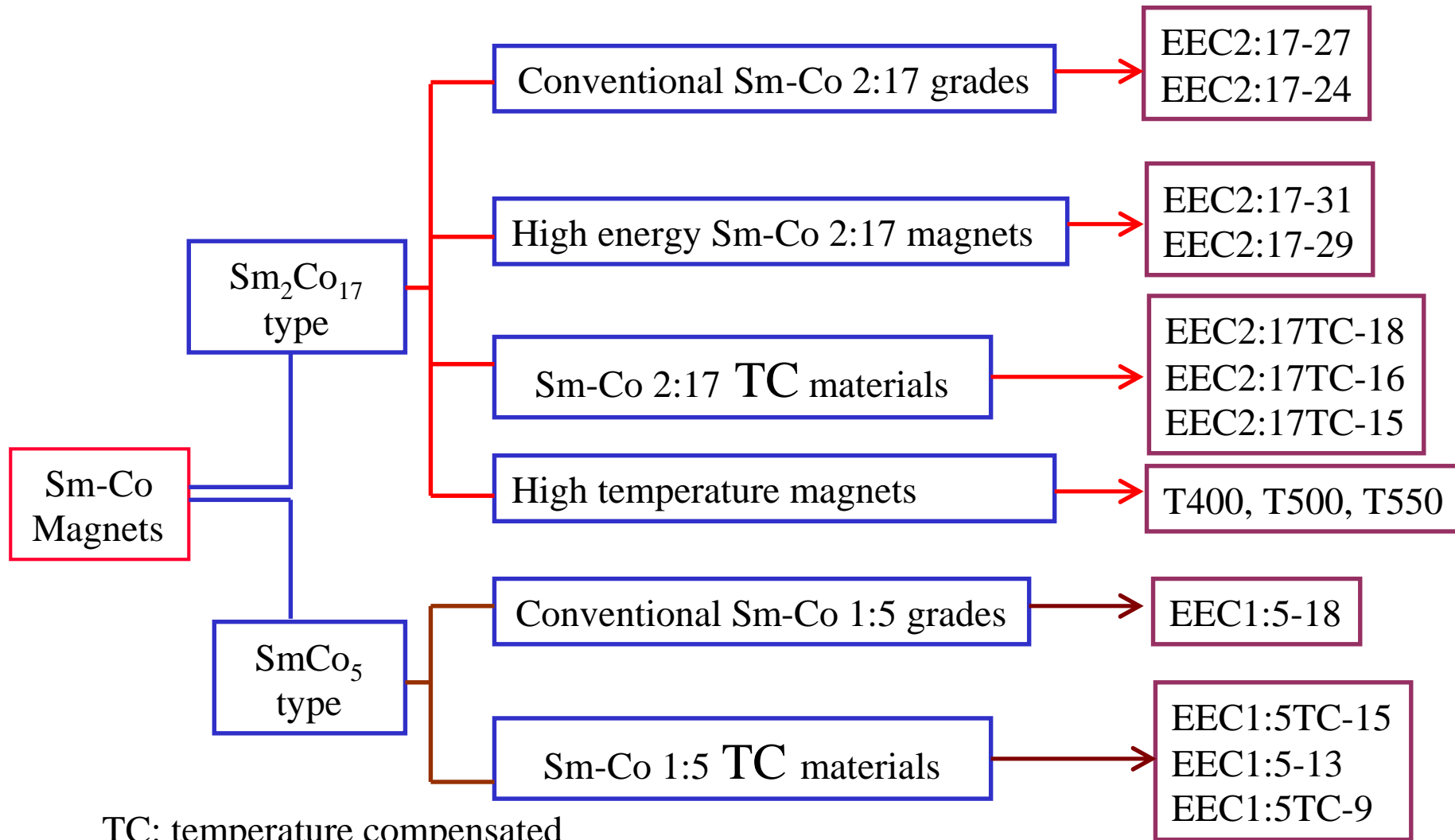
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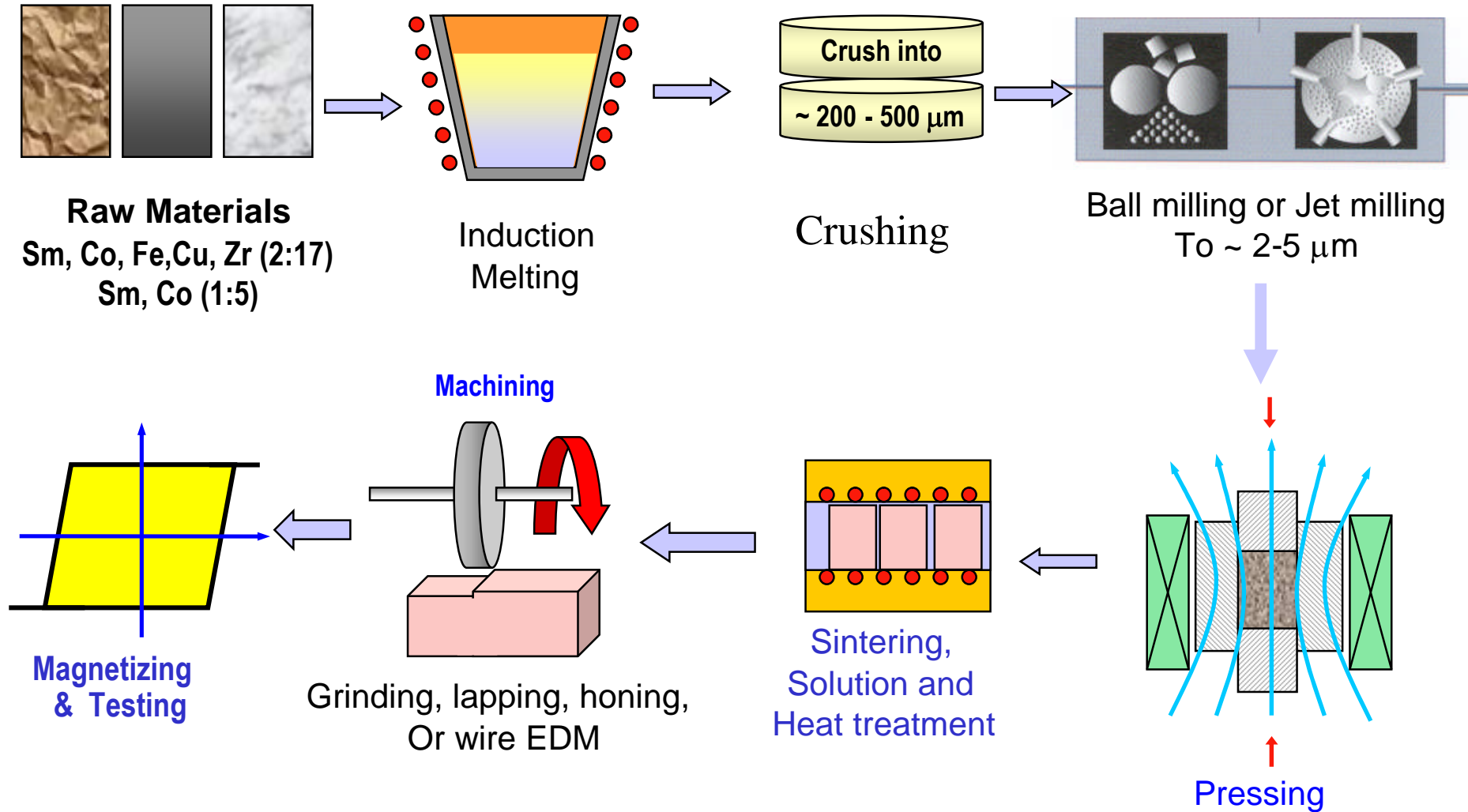
International Magnetics Association

- Sm-Co magnets overview
- Properties of SmCo_5 and $\text{Sm}_2\text{TM}_{17}$ magnets
- Temperature compensated magnets
- High temperature magnets
- Microstructure and thermal stability
- Applications

Sintered Sm-Co Magnets (Overview)



Typical Manufacturing Process for Sintered Sm-Co Magnets



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Properties of SmCo₅ Magnet



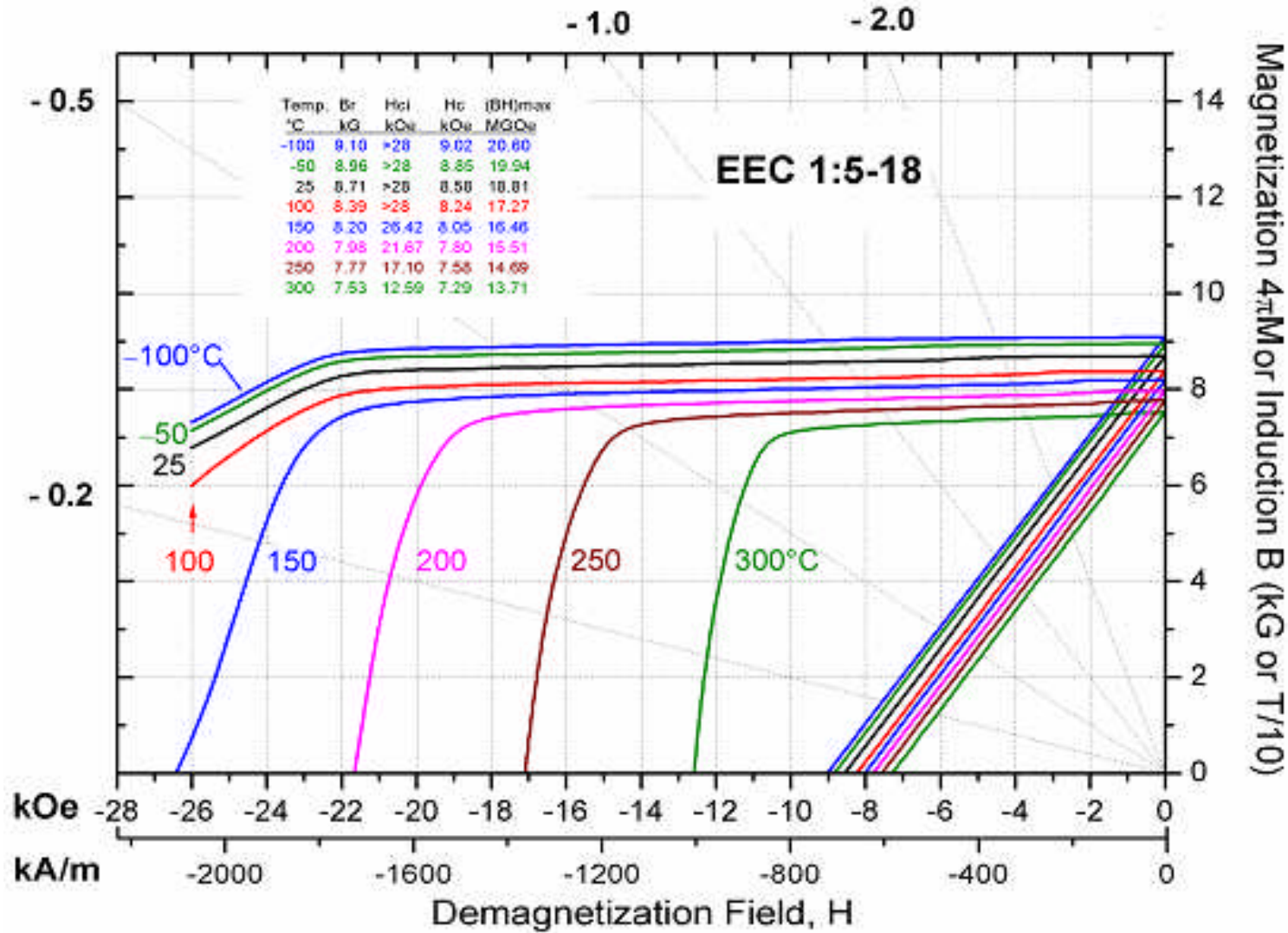
Typical properties:

- $B_r = 8750$ 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 SmCo₅ Magnet



Composition SmCo 2:17 Magnets



Why we call it SmCo 2:17?

- It is an evolution from the $\text{Sm}_2\text{Co}_{17}$ phase
- $\text{Sm}_2\text{Co}_{17}$ can also be written as $\text{SmCo}_{8.5}$
- Other transition metals (Fe, Cu, Zr) are added for the development of optimum magnetic properties
- Then we have $\text{Sm}(\text{Co}_{(1-u-v-w)}\text{Fe}_u\text{Cu}_v\text{Zr}_w)_{8.5}$
- Extra Sm added to compensate oxygen pick-up in the process, so we change the formula to the following:

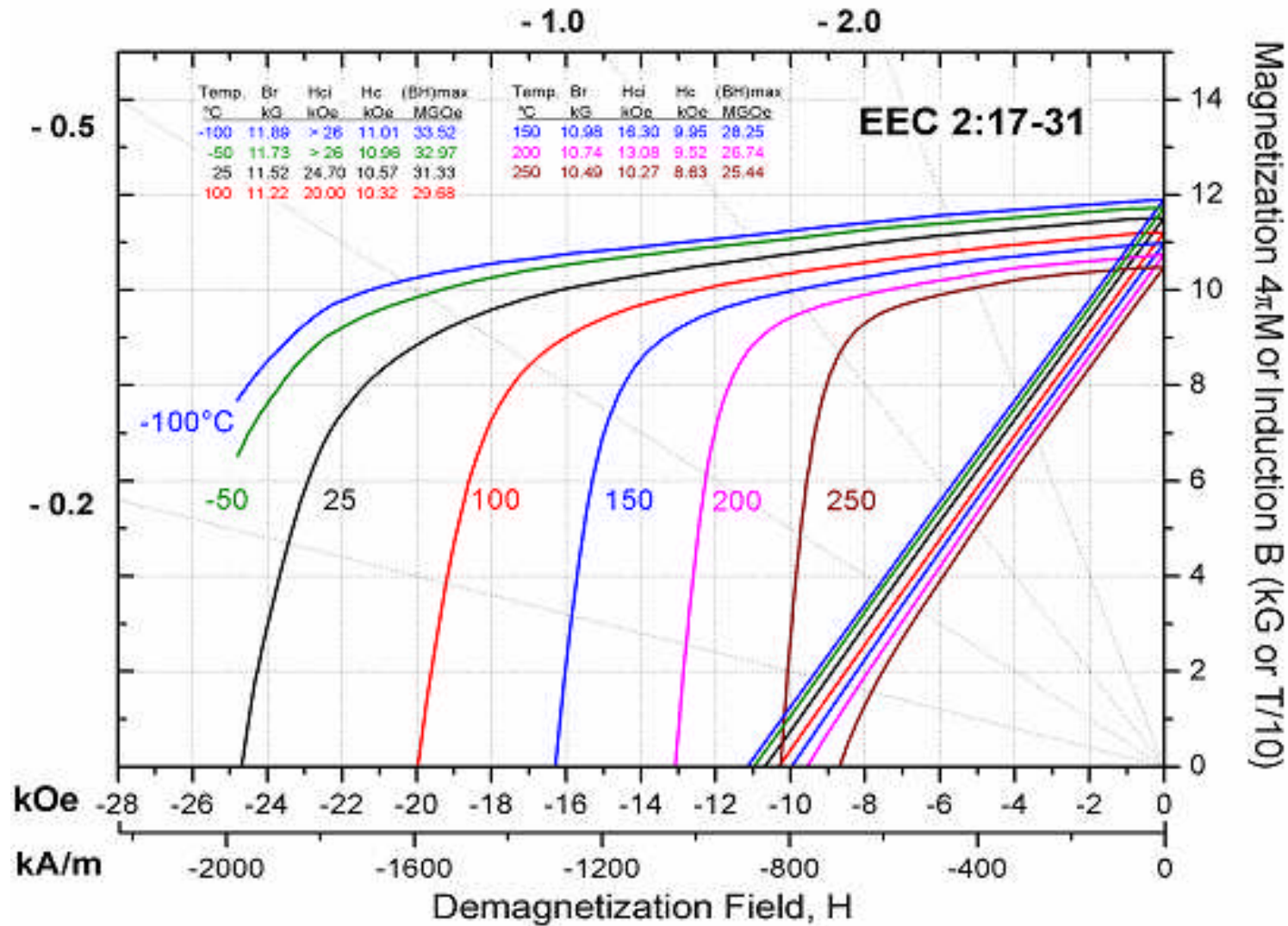


Properties of SmCo 2:17 magnets



- 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

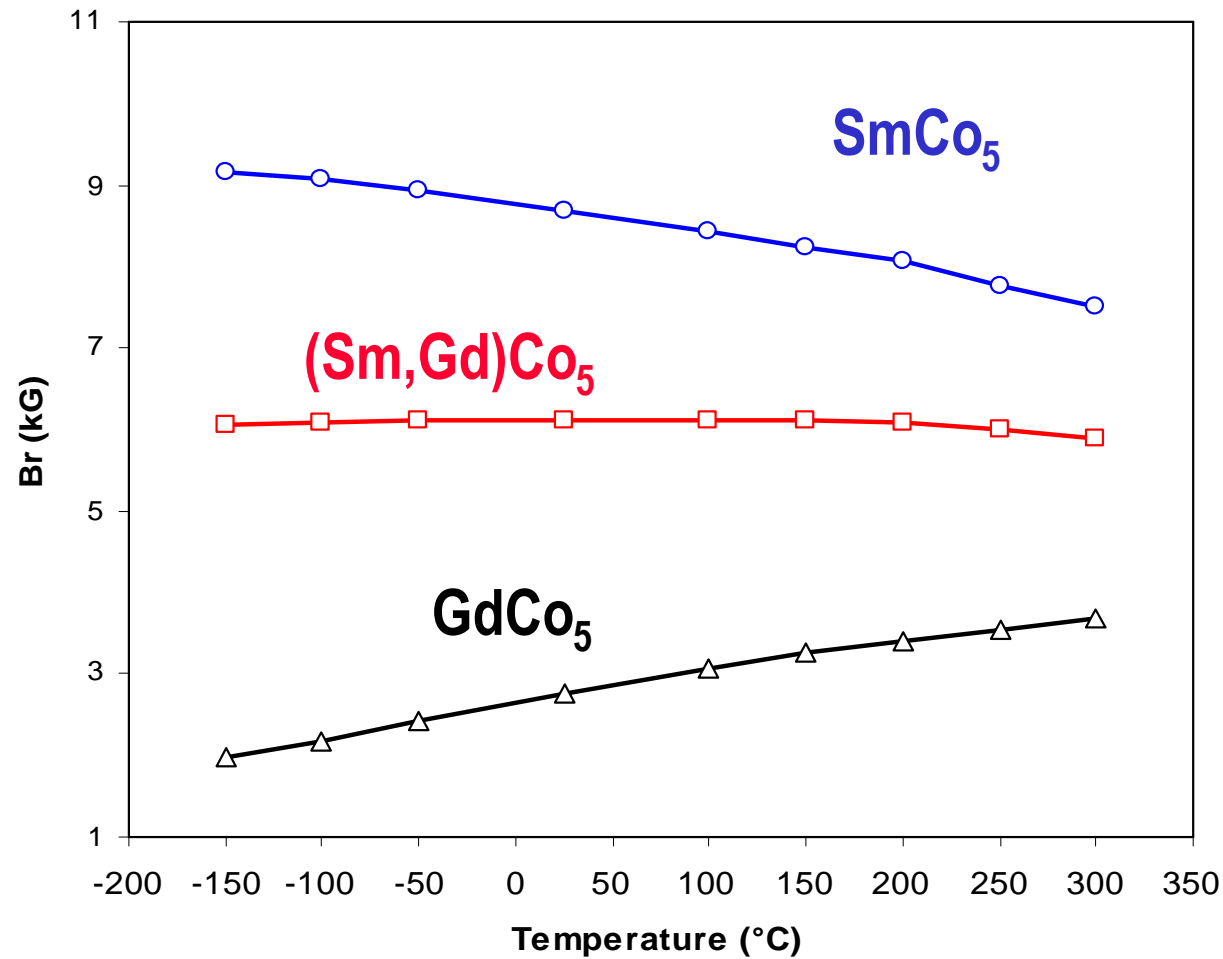


- B_r changes with temperature
- Some applications, such as gyro and TWTs, require stable B_r over a wide temperature range
- The reversible temperature coefficient of B_r is defined as:

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

- 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

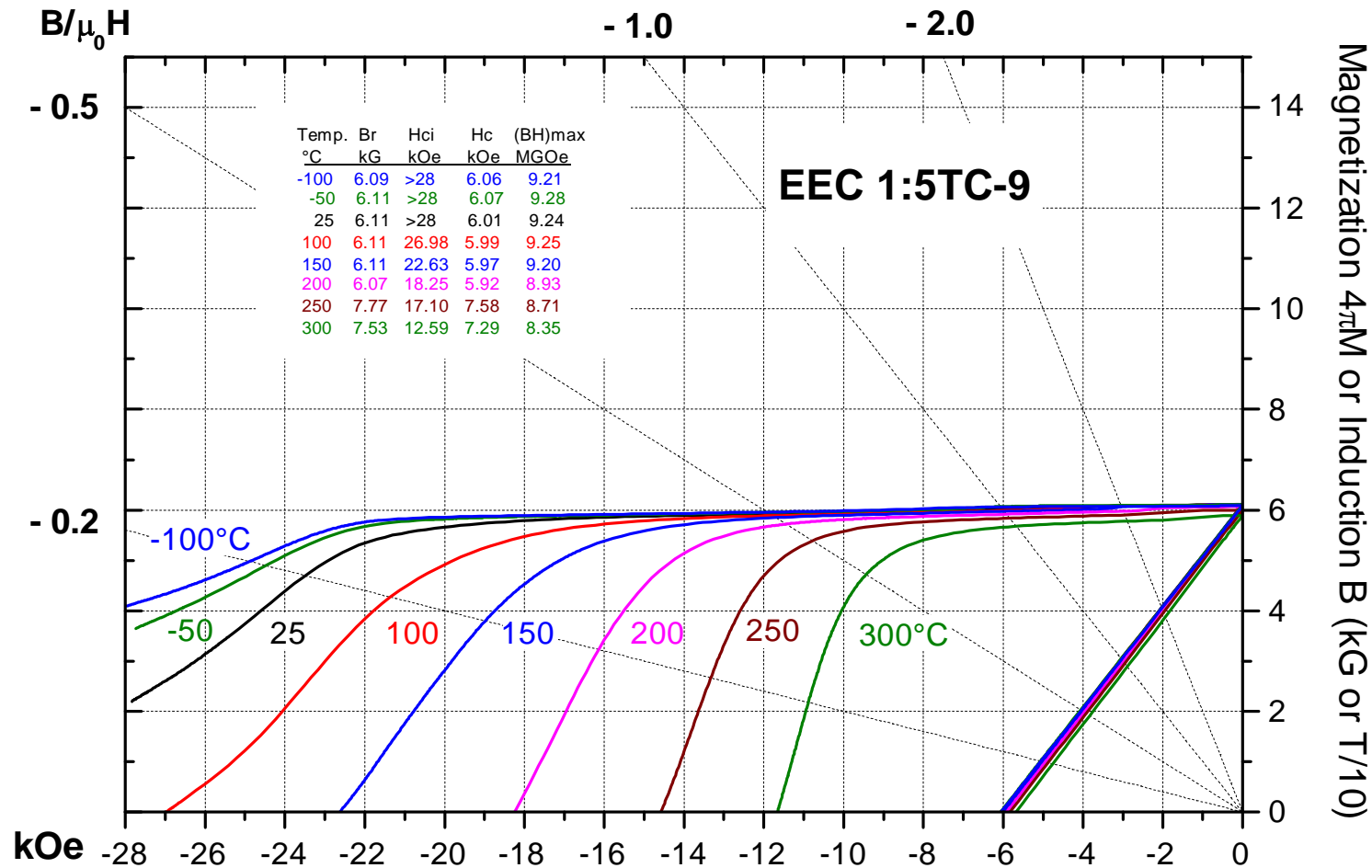


Grades	$(BH)_{\max}$	RTC* of B_r	Comment
EEC 1:5-18	18 MGOe	-0.04 %/°C	no compensation
EEC 1:5TC-15	15 MGOe	-0.03 %/°C	some compensation
EEC 1:5TC-13	13 MGOe	-0.02 %/°C	some compensation
EEC 1:5TC-9	9 MGOe	-0.001 %/°C	full compensation

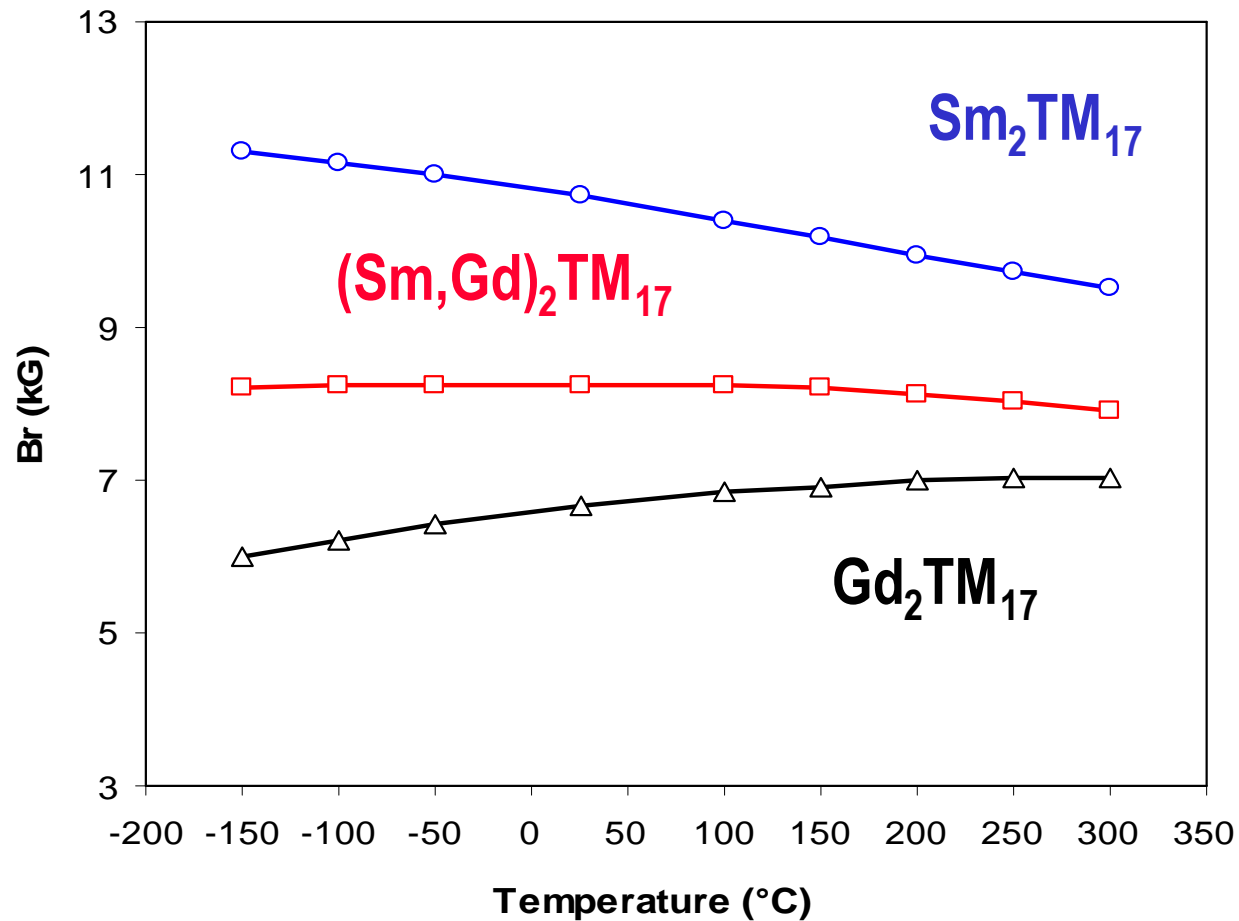
*RTC: Reversible temperature coefficient

- Reversible temperature coefficient of B_r of fully compensated SmGdCo 1:5 magnets is 40 times smaller than the non-compensated SmCo₅ magnets
- The $(BH)_{\max}$ decreases for the temperature compensated magnets due to the low saturation magnetization of GdCo₅

RETM₅ type 0TC material



Temperature compensation for $\text{Sm}_2\text{TM}_{17}$ magnets



Temperature compensated Sm-Co 2:17 magnets

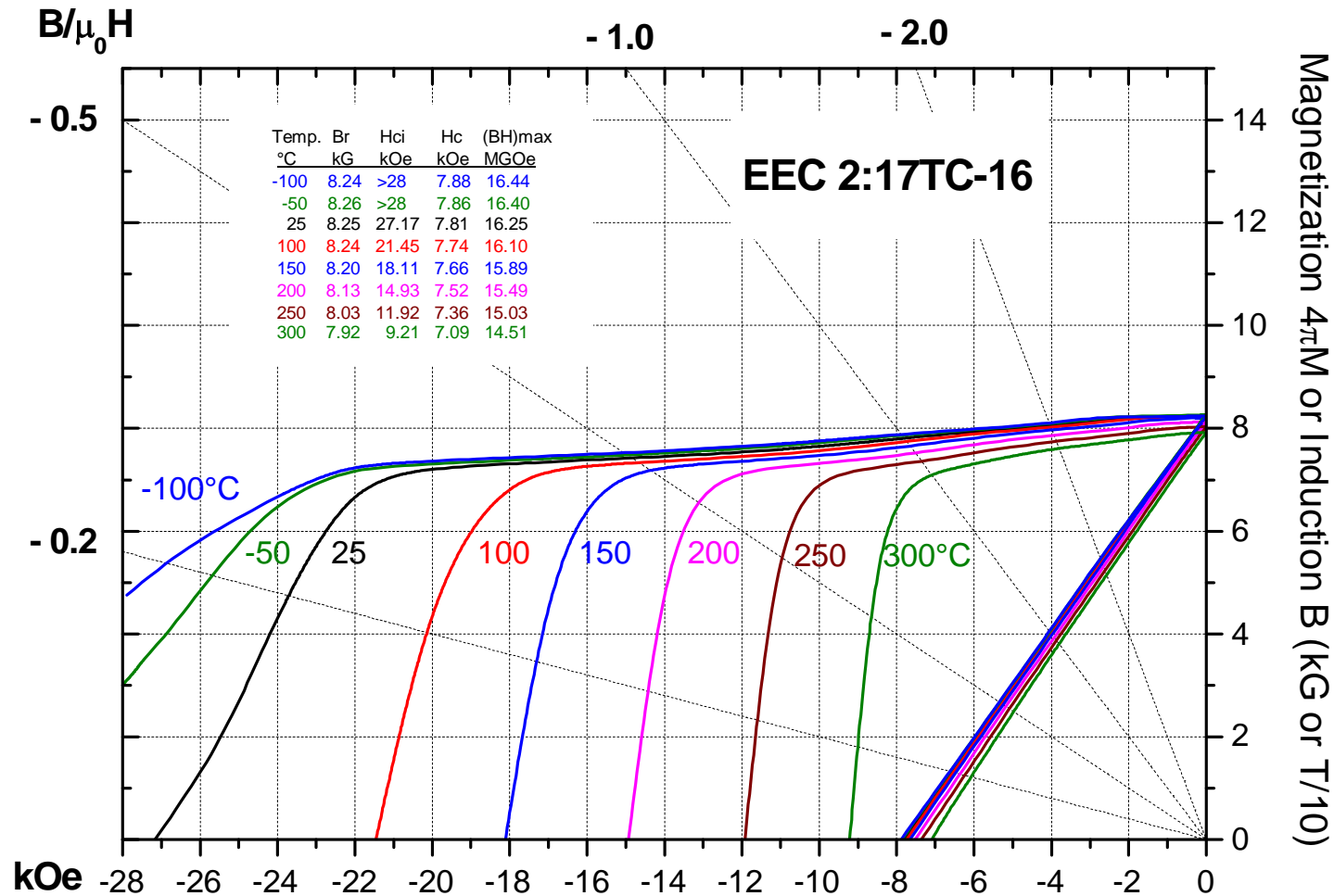


Grades	$(BH)_{\max}$	RTC* of B_r	Comment
EEC 2:17-24	24 MGOe	-0.035 %/°C	No compensation
EEC2:17TC-18	18 MGOe	-0.02 %/°C	Some compensation
EEC2:17TC-16	16 MGOe	-0.001 %/°C	Full compensation

*RTC: Reversible temperature coefficient

RTC of B_r is calculated within the temperature range -50 to $+150^\circ\text{C}$

RE₂TM₁₇ 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 (°C)
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

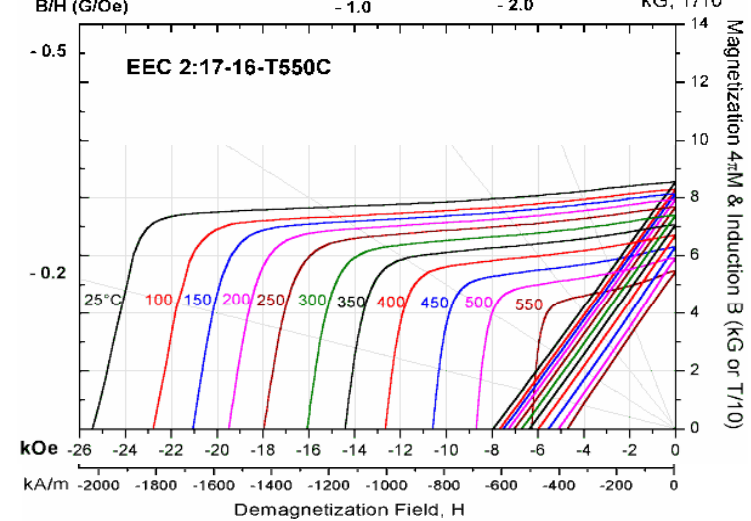
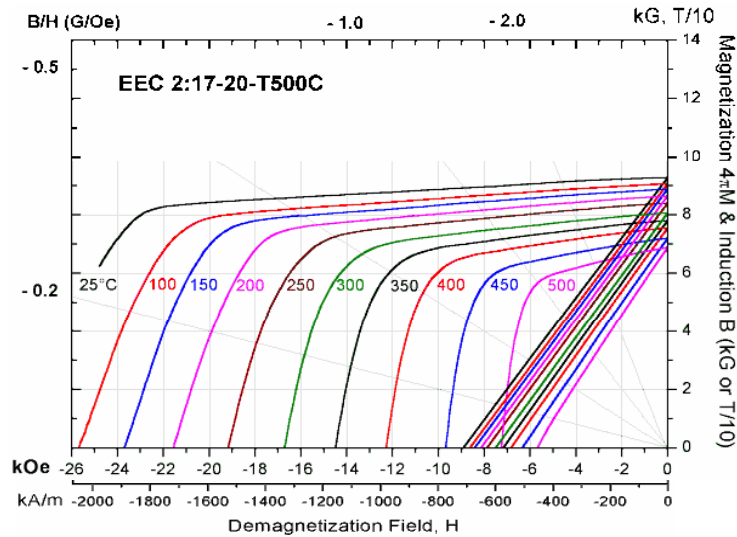
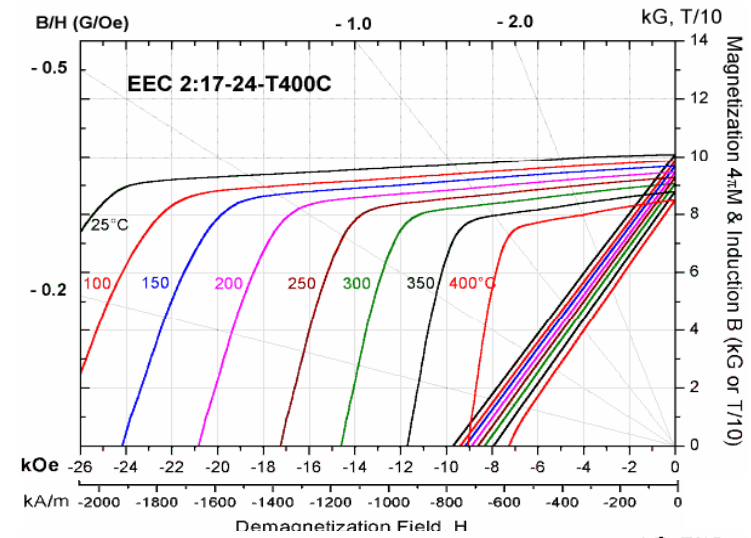
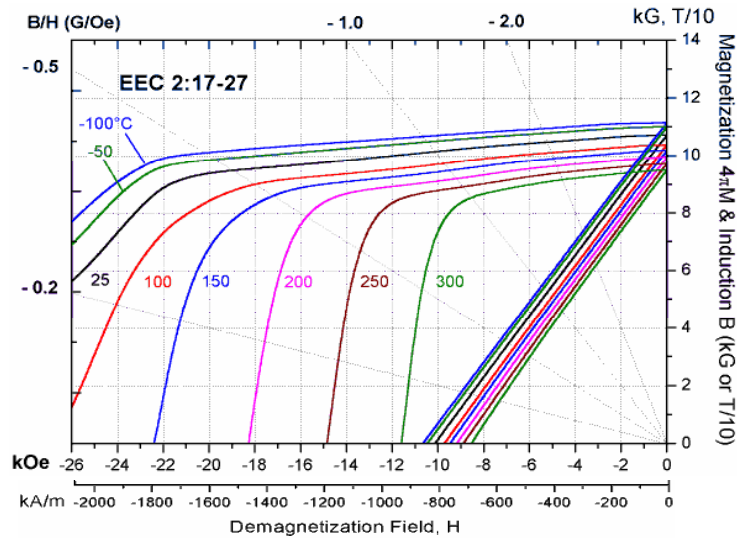
More high temperature magnets with $T_M = 400^\circ\text{C}$



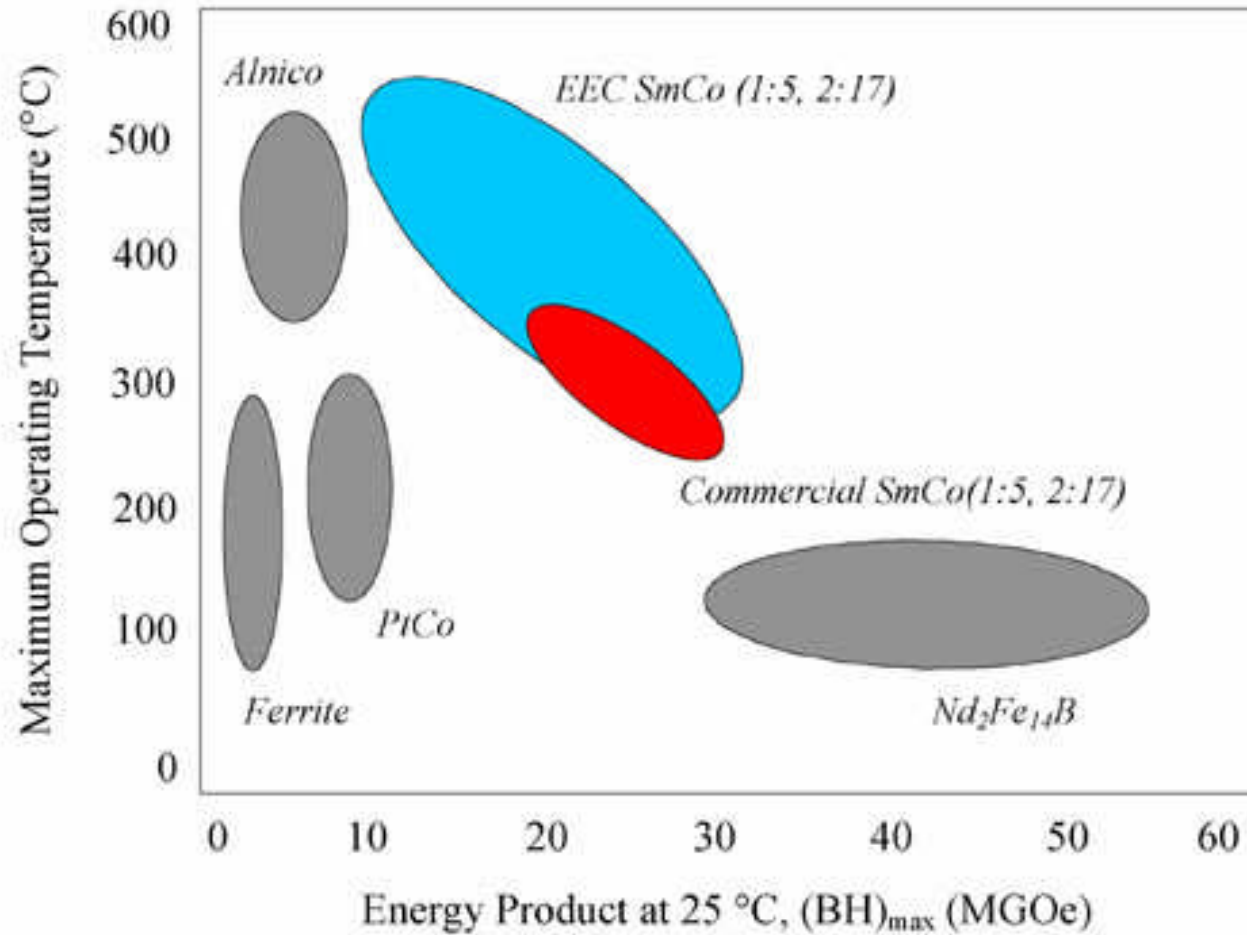
BOM	B_r	H_c	(BH)_{max}	H_{ci}	RTC of B_r
	(kG)	(kOe)	(MGOe)	(kOe)	%
9500H	9500	9.03	21.3	>25	-0.035
9250H	9250	8.79	20.2	>25	-0.030
9000H	9000	8.55	19.2	>25	-0.025
8750H	8750	8.27	18.0	>25	-0.020
8500H	8500	8.03	17.0	>25	-0.018
8250H	8250	7.80	16.0	>25	-0.015
8000H	8000	7.56	15.1	>25	-0.010
7750H	7750	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

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Demagnetization Curves for High Temp. Magnets



Comparison of maximum operating temperature



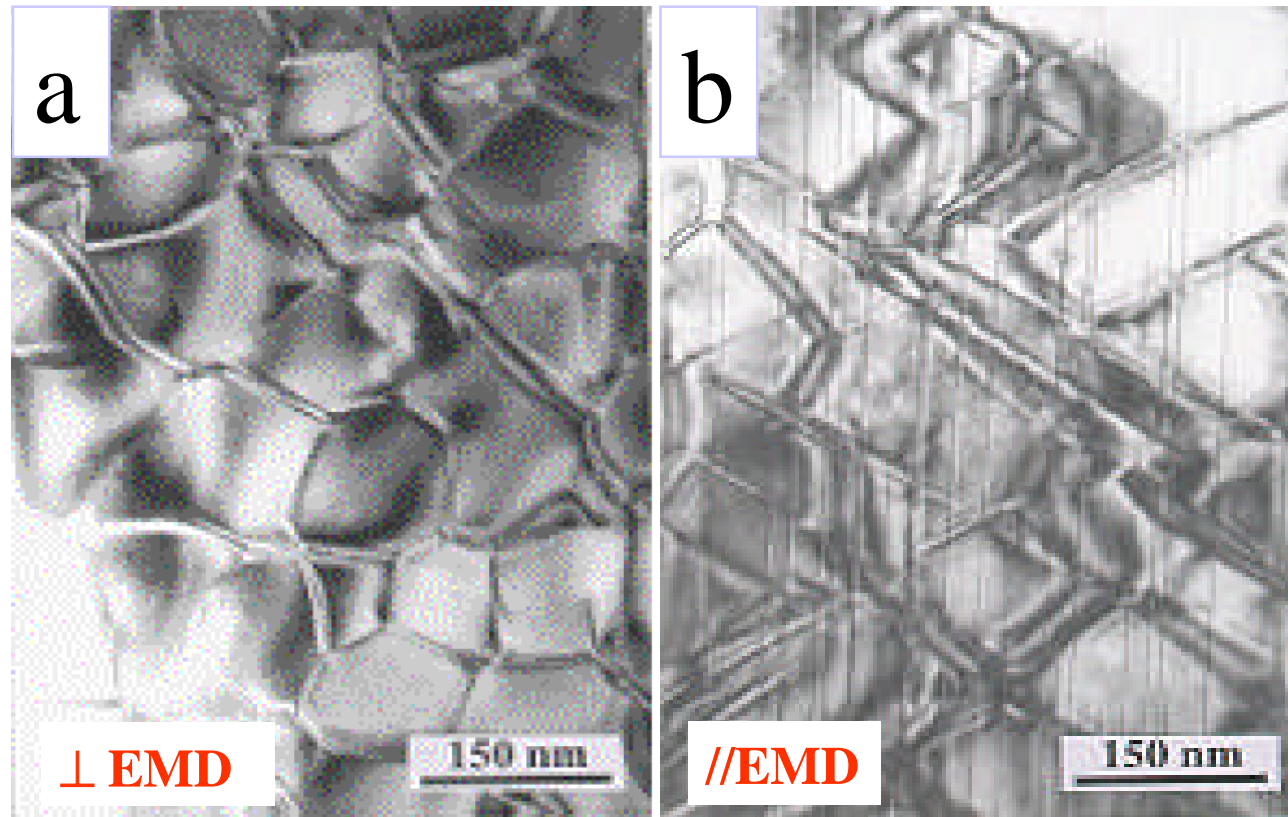
Important Features of High Temperature Magnets



- ✓ 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.

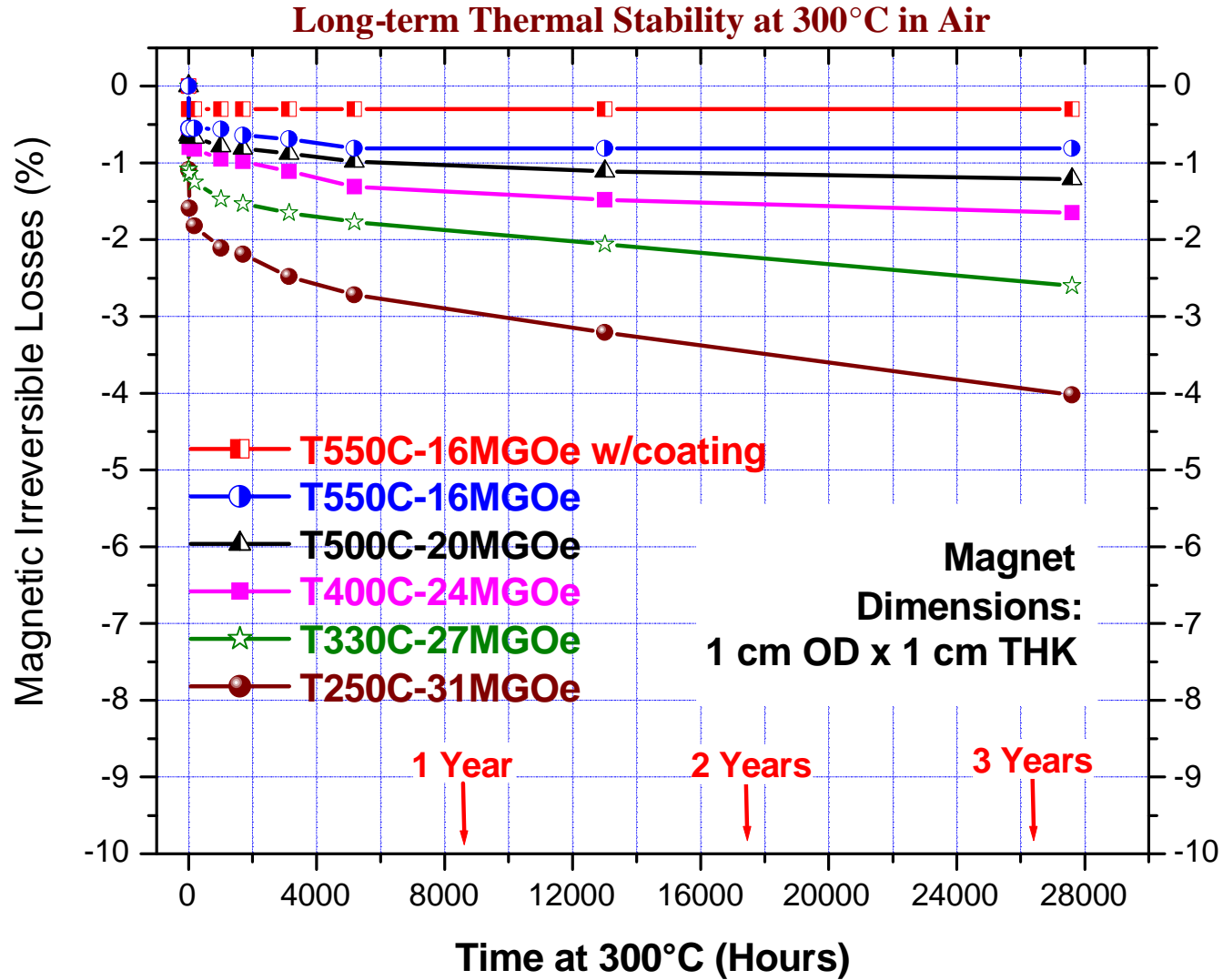
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Cellular microstructure of Sintered SmCo 2:17 Magnets



EMD: Easy magnetization direction

Thermal Stability



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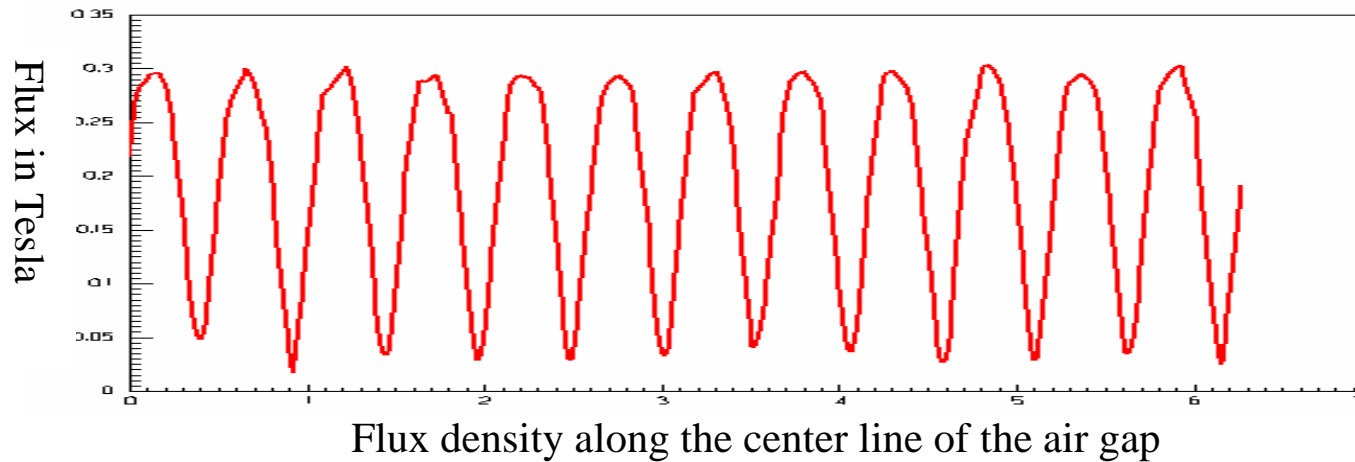
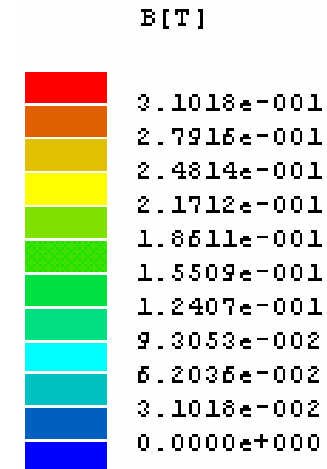
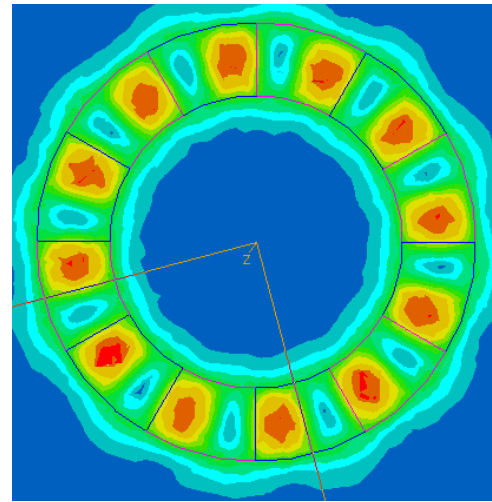
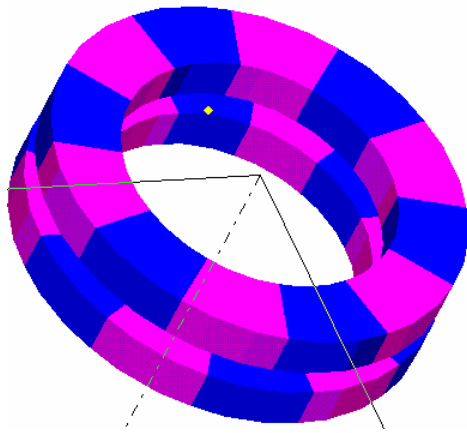
Applications of Sm-Co magnets



- ✓ 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

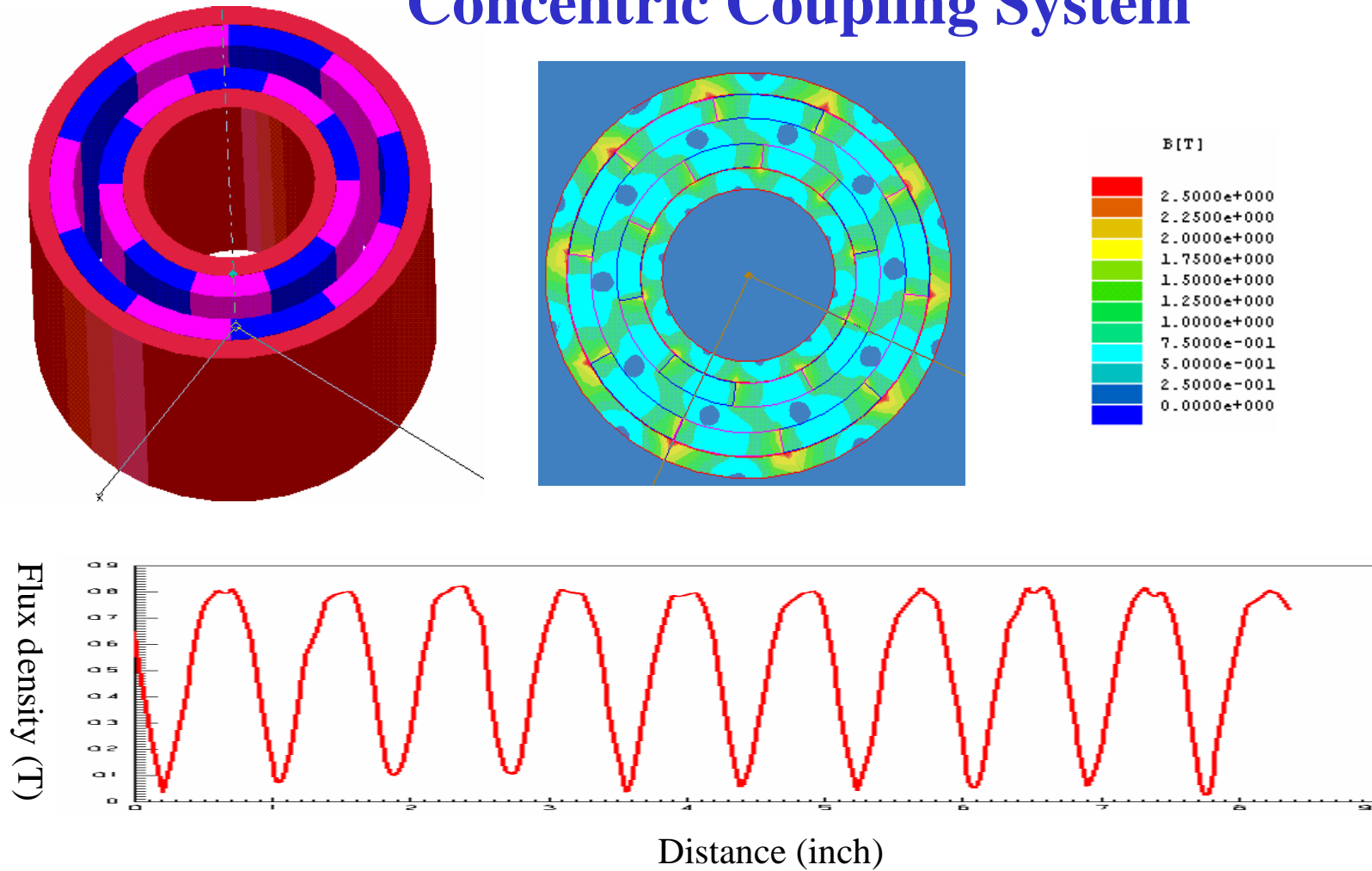
Surface Coupler with 12 Alternating Poles



FEA is a useful tool



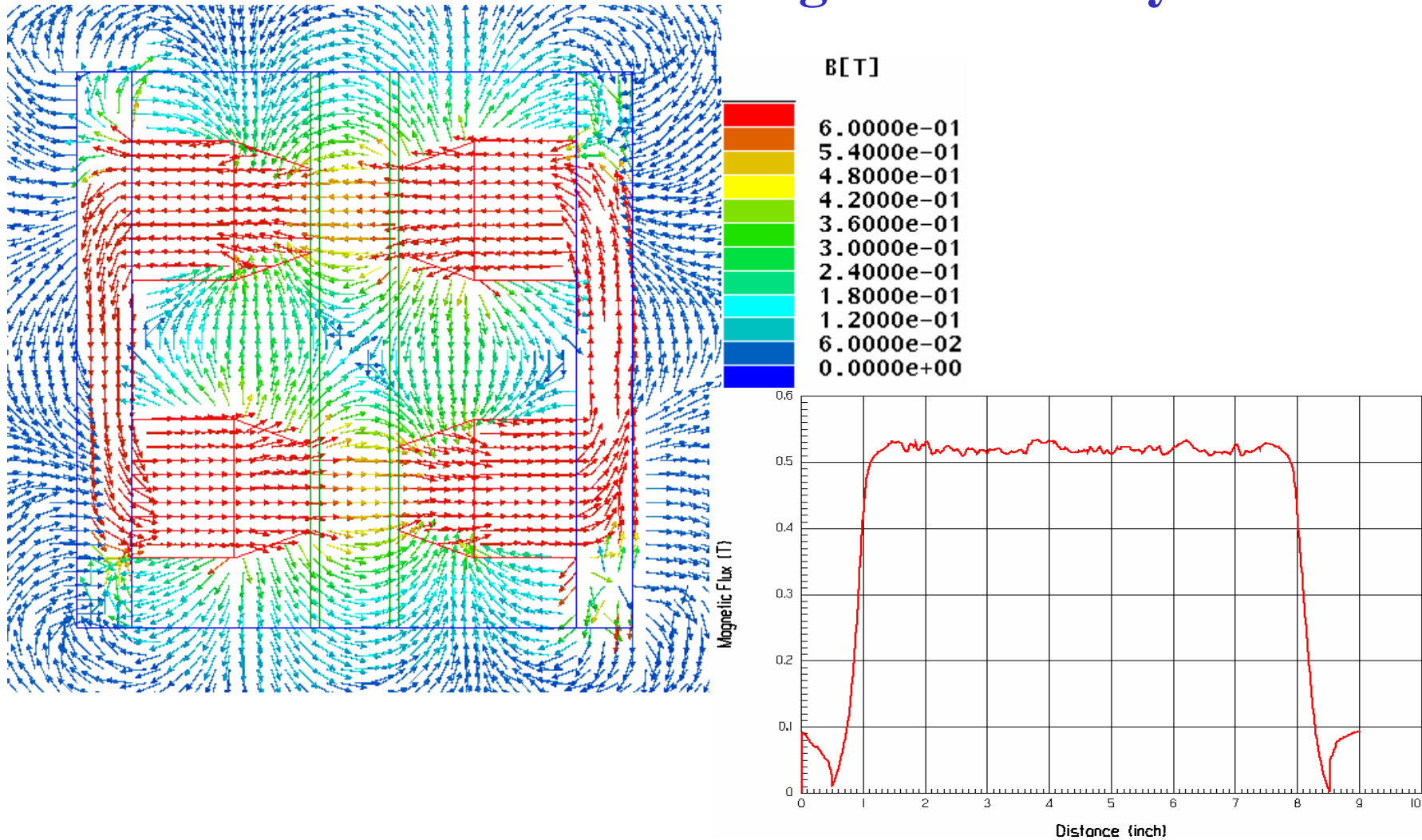
Concentric Coupling System



FEA is a useful tool



Magnetic Security Devices

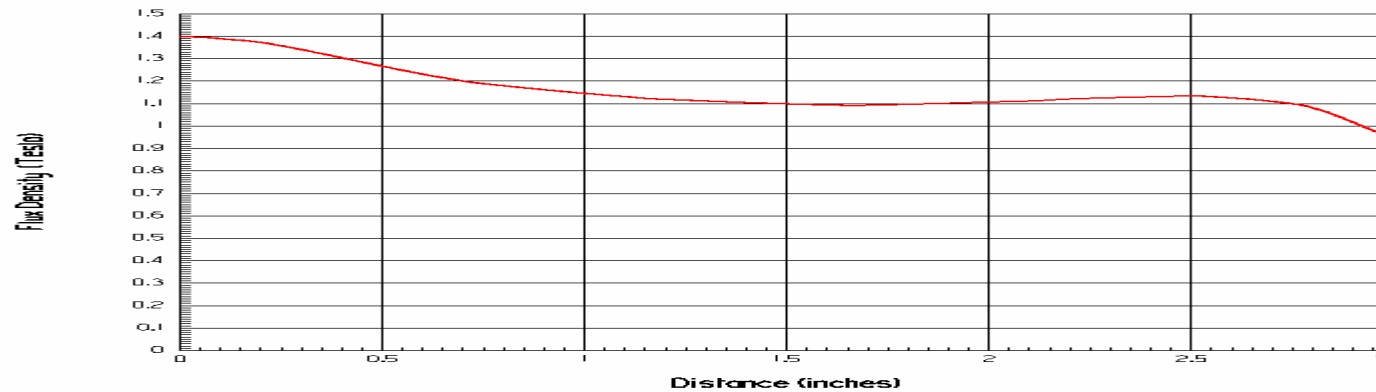
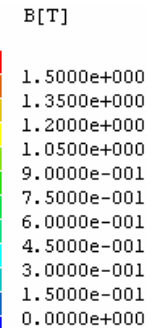
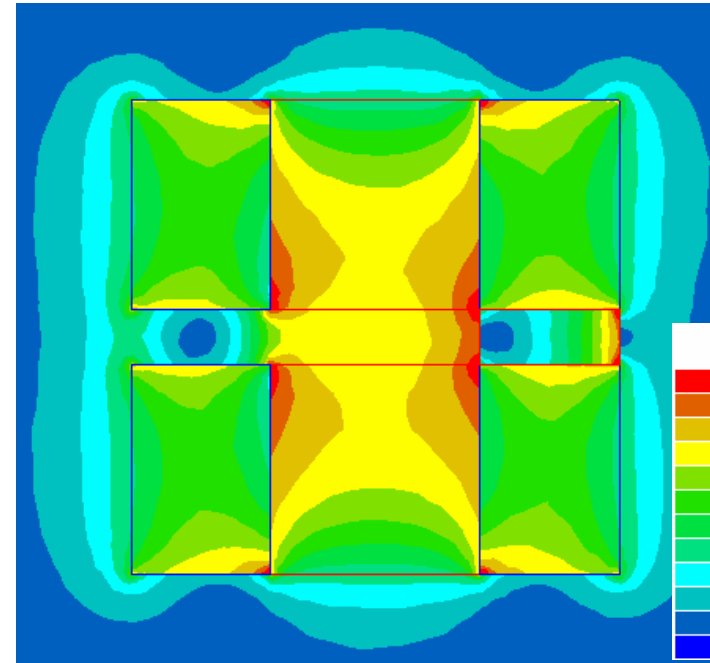
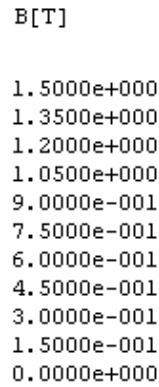
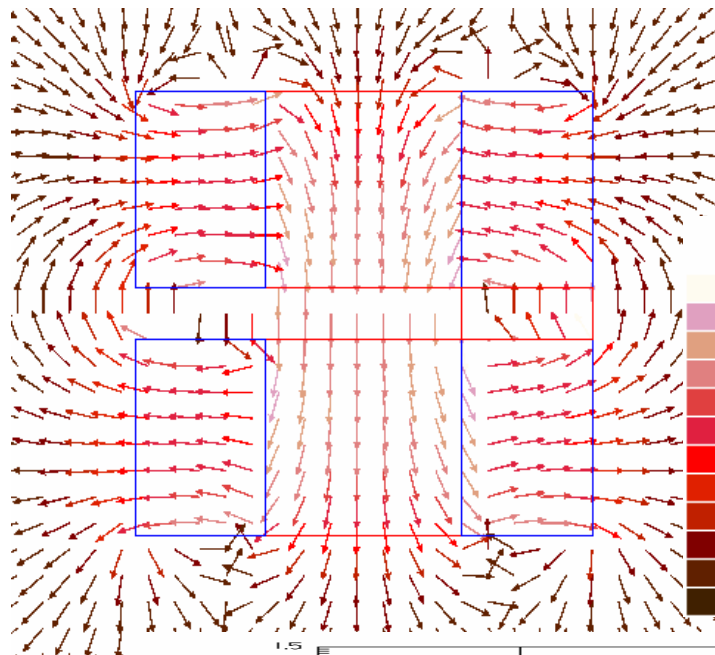


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FEA is a useful tool



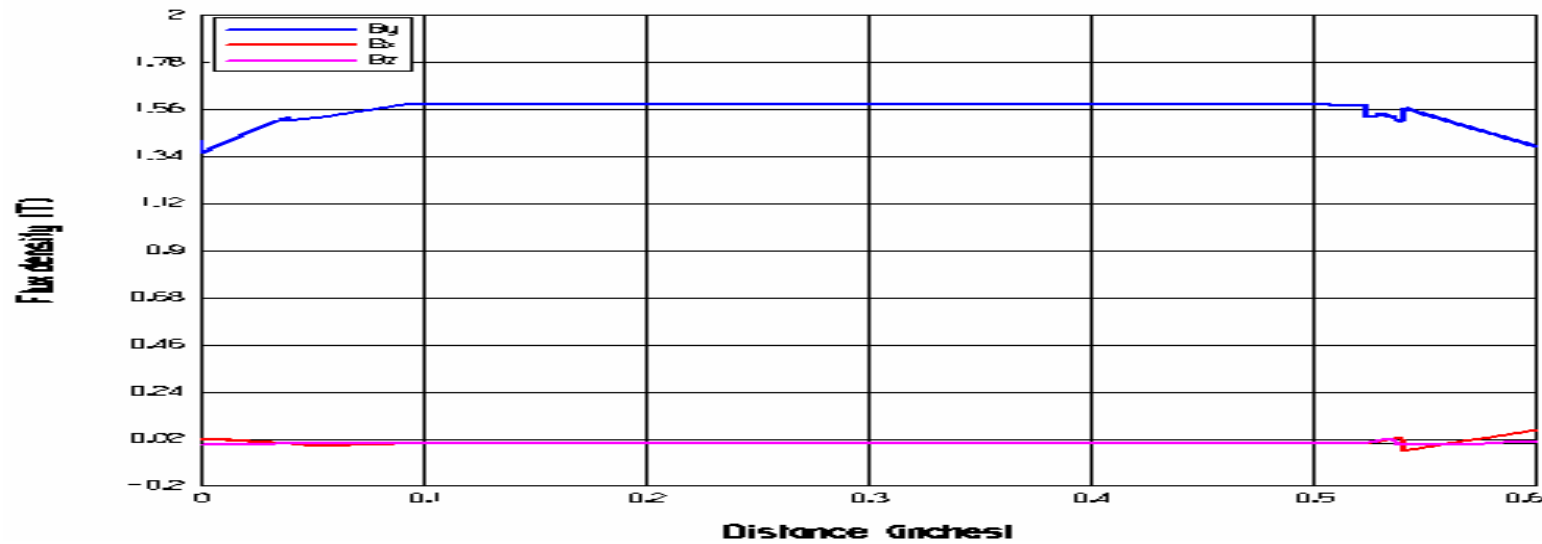
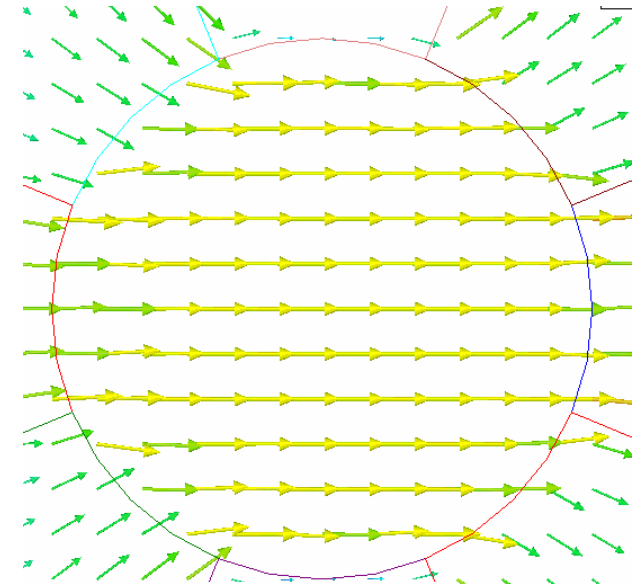
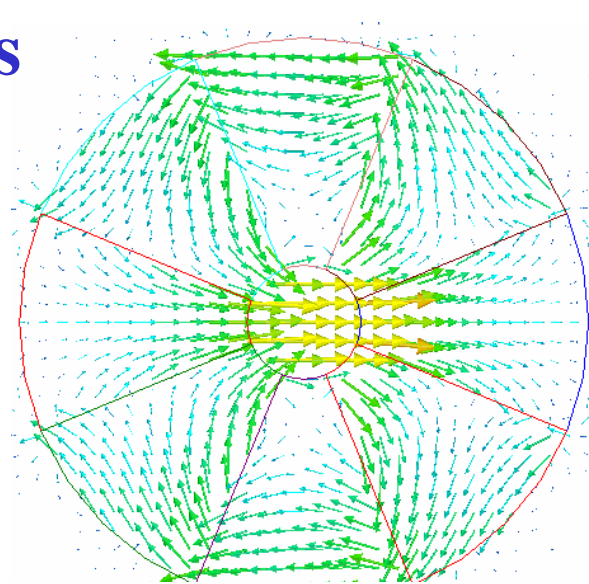
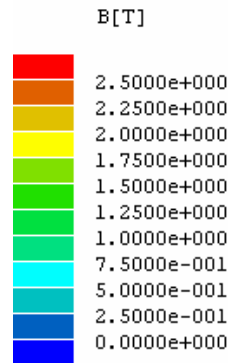
Magnetizing System



FEA is a useful tool



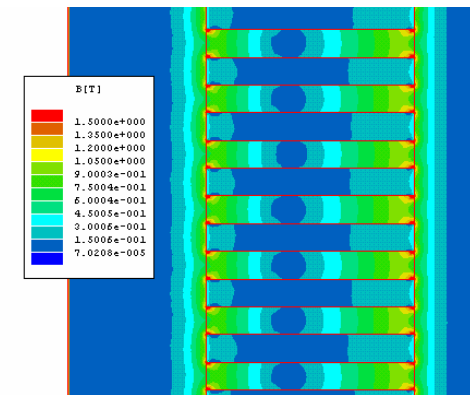
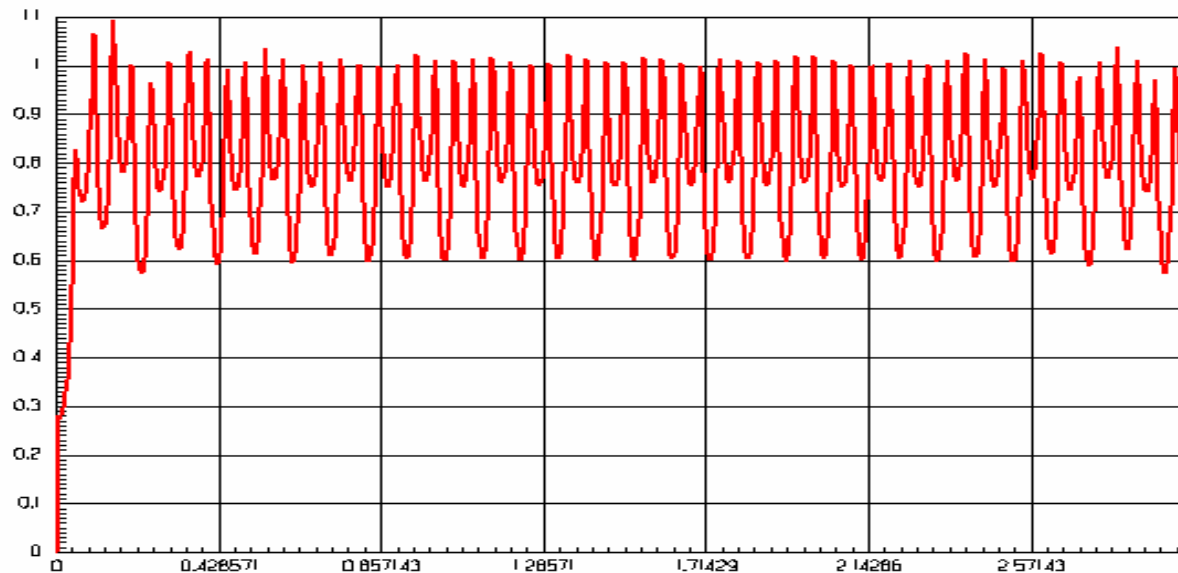
Halbach Cylinders



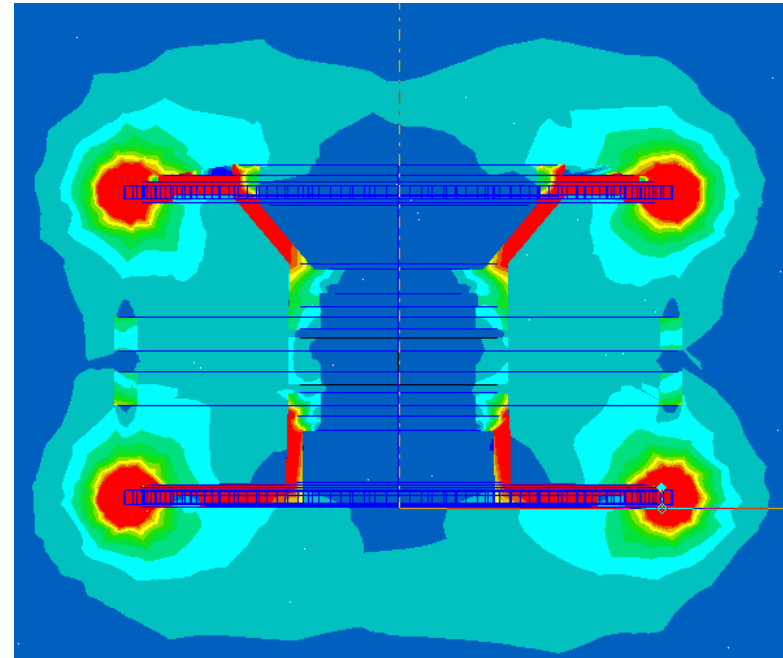
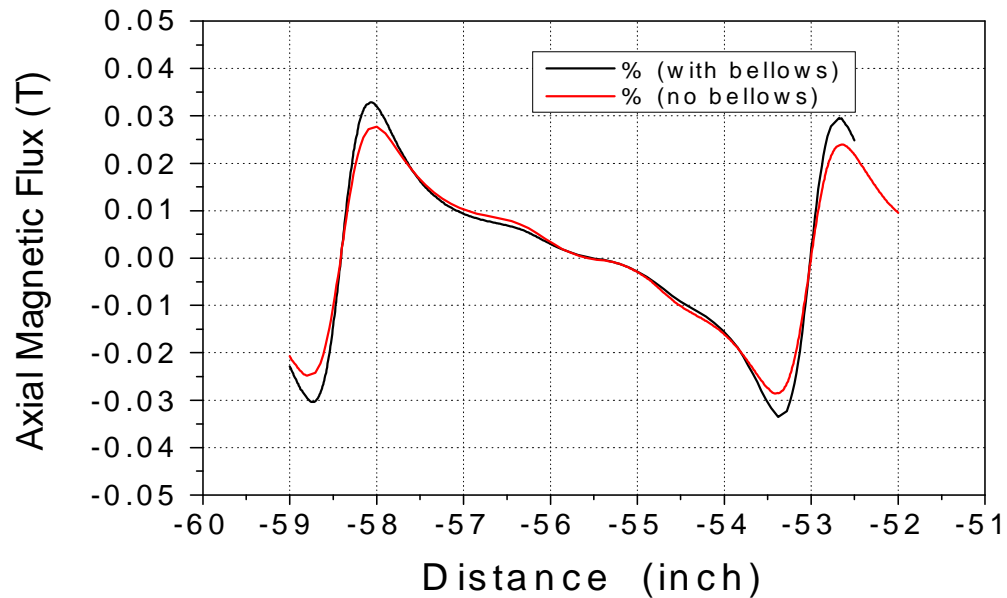
FEA is a useful tool



Multipole Magnetic Magnetizing System



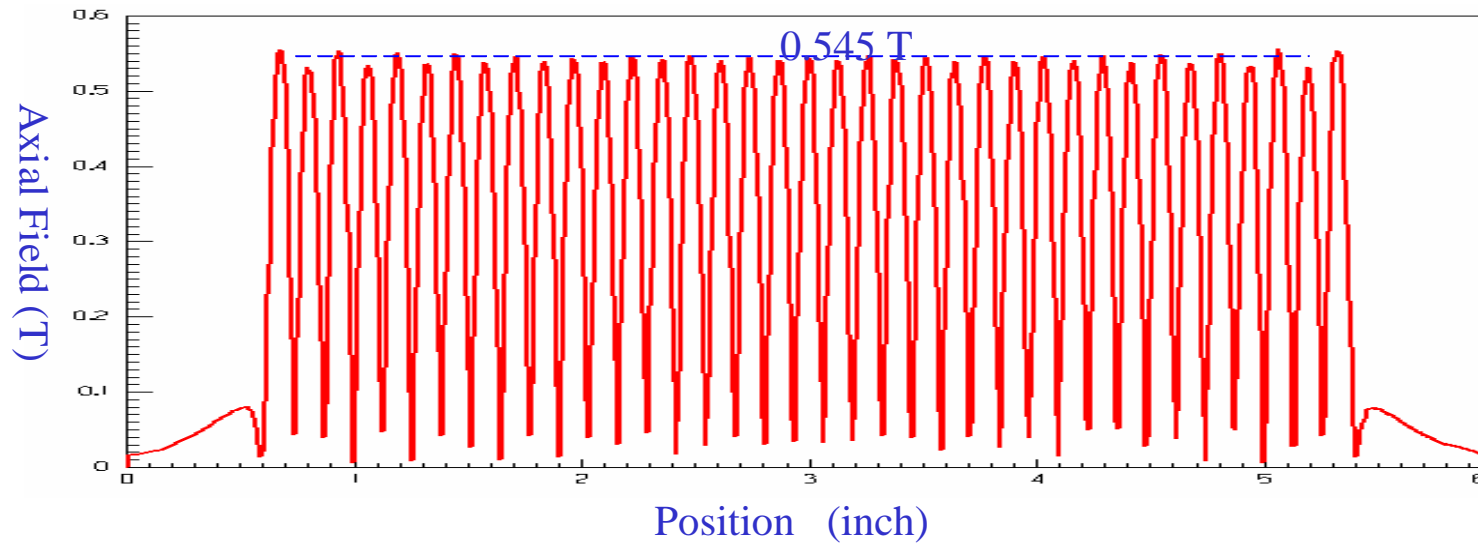
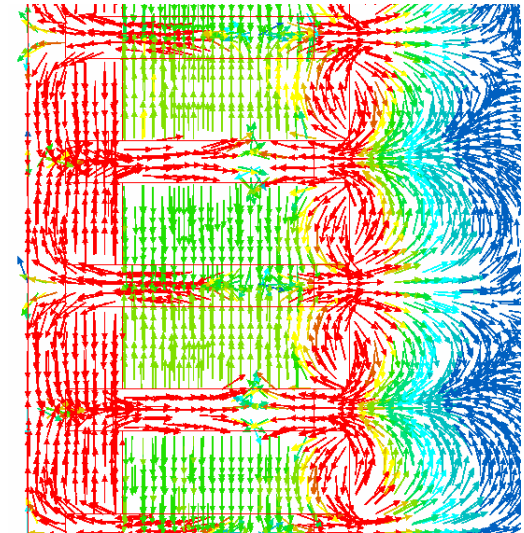
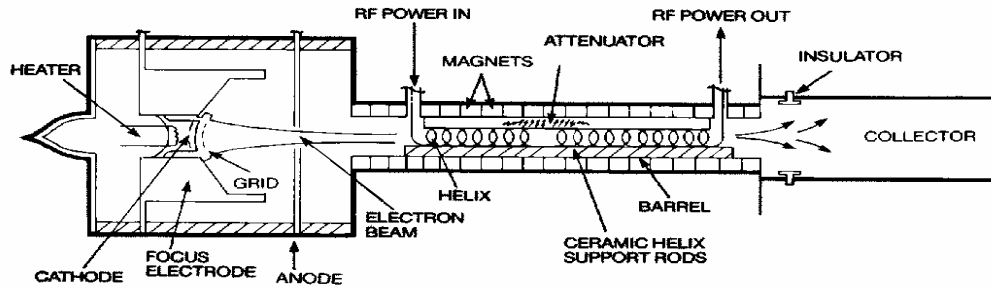
Magnetic Sensing System



FEA is a useful tool



Traveling Wave Tube (TWT)



About EEC

- Founded 1970
- SmCo technology leader (1:5, 2:17, “Zero RTC”, 550 C)
- Only US Based, US owned RE PM Producer
- Customized Solutions-Extremes in Performance
- Rare Earth, sintered and bonded Magnets & Assy’s
- Vertically Integrated
- 40,000 sq ft modern facility - Lancaster, PA
- US Gov’t & Primes key customers
- ISO-9001:2000 Certified

International Magnetics Association



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