Extending the limits of the Sm2Co17 System

35 MGOe and Beyond

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## Global Supply Chain—from Mine to Motor

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<th>Mining &amp; Processing (Joint Venture)</th>
<th>Magnet Production &amp; Fabrication</th>
<th>Permanent Magnets &amp; Assemblies</th>
<th>Precision Thin Metals</th>
<th>High Performance Motors</th>
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<td>- Ganzhou, China (JV with rare earth producer)</td>
<td>- Samarium Cobalt RECOMA®</td>
<td>- Rotor build</td>
<td>- Specialty alloys from 1.75 µm</td>
<td>- Smaller, faster, hotter motors</td>
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<td>- United States</td>
<td>- Alnico</td>
<td>- Rotor machining</td>
<td>- Sheets, strips, &amp; coils</td>
<td>- Power dense package</td>
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<td>- Multiple sources of supply</td>
<td>- Injection molded</td>
<td>- Rotor sleeving inc. carbon fiber</td>
<td>- Milling, annealing, coating, slitting</td>
<td>- High RPM magnet containment</td>
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<td>- Flexible rubber</td>
<td>- Rotor balancing</td>
<td>- ARNON® motor lamination material</td>
<td>- &gt;200°C operation</td>
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<td>- Rotor/motor design</td>
<td>- Light-weighting</td>
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<td>- System integration</td>
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- Engineering
- Consulting
- Testing
- Stabilization & Calibration
- Distribution
- Fully Integrated Supply Chain
- Mine to Motor
Soft Magnetics – Precision Thin Metals

- **Silicon Steels for High Frequency Applications**
  - Arnon – Non Oriented (0.18 mm & 0.13 mm)
  - Grain Oriented (0.03 mm - 0.15 mm)

- **Popular Materials Available**
  - Titanium & Its Alloys
  - Arnokrome (FeCrCo)
  - Nickel & Its Alloys
  - Nickel Irons & Soft Magnetics

- **Exceptionally thin strip and coil**
Why is thinness important?

- Let’s look at an example of a rotating machine
- We can compare the losses with a pure sine wave to the losses with harmonic content
- Using stator steel materials:
  - M19, 0.35mm (29 AWG)
  - Arnon 7 NGO Si Steel, 0.18mm

IPM Motor:
1800 rpm, 60Hz
112mm Outside Diameter
16Apk Rated Current

Pure Sine Wave Excitation
- 30% Reduction

High Harmonic Excitation
(Switching Power Supply)
- 54% Reduction

Excitation Type

Stator Iron Losses

Pure Sine
M19
Arnon 7

Sine + Harmonics

30% Reduction

54% Reduction
Arnold in Europe

- Founded by Brown-Boveri Cie (today ABB) in 1972, making SmCo. Today:
  - Recoma HT
  - Recoma STAB
  - Recoma 33E
  - Recoma 35E
  - Did I mention Recoma?
When we introduced 33E, we wanted to call it 32E, but that name was already taken by the 31 grade material!

Today we are in the Spinal Tap Zone, where 35E is “two better” than 33E.
When compared to Neo, SmCo does bring some unique capabilities to the table, and these capabilities are greatly enhanced by higher energy density.

Because NdFeB was discovered so soon after SmCo, research in enhancing SmCo soon flatlined, suggesting there may be untapped potential to mine.

The zone where Samarium Cobalt performance overlaps NdFeB correlates to the operating points for automotive and aerospace applications. Additionally, in these ranges, SmCo varies much less with respect temperature, meaning the device needs less temperature compensation.
How to Improve SmCo

- Elemental substitution
- Improve starting alloy condition
- Eliminate contamination
- Improve alignment
- Thermal processing & microstructure development
Improved SmCo – Elemental Substitution

Sm2Co17

- **Samarium, 25%**
  - Provides crystal structure and contributes to remanence and coercivity

- **Cobalt, 51%**
  - Provides the primary magnetic properties

- **Iron, 15%**
  - Substitutes for Cobalt and provides higher Br with lower temperature performance and coercivity

- **Copper, 6%**
  - Helps formation of nanostructure in intergranular regions for coercivity and lowers remanence

- **Zirconium, 3%**
  - Helps formation of nanostructure in intragranular regions for coercivity and lowers remanence
Elemental Substitution — Iron

Easy solution – add iron at the expense of cobalt = more energy!

Problem – the more iron you add, the smaller your composition window gets.

Traditional binary alloy processes make it even worse!

Functional Benefits of Cu and Zr

Cu rich Sm$_2$Co$_5$ nanocell boundaries

Zr rich intergranular region

Cu and Zr aid the development of the nanostructure that delivers the magnetic properties.
As we continue to increase the iron content, other things have to be reduced.

**Copper and Zirconium** are good targets, since they don’t help the remanence of the material.

But Copper and Zirconium **DO help the coercivity**. So how do we keep that effect while getting rid of the drag on remanence?

**The secret is in the oven.** *(More on that later.)*
Eliminate Contamination

New outgassing cycle to eliminate organics

Increased used of protective atmosphere

Specialty carts for transport under gas

New Sinter Boat construction
Co-parallel direction
One block of magnetic material is composed of many discrete grains. An important part of the process is orienting all of the grains in a co-parallel direction.

Trumpeting effect
One significant challenge is the trumpeting effect. This is due to the difference in permeability and saturation of the die material and magnet powder.

Property matching
Property matching our die materials yields improvements in the quality of orientation.
Improve Alignment

Every 1% improvement in alignment quality = 2% more energy in the magnet
**Thermal Processing**

**Sinter**: As we increase iron content, lower temperature and shorter duration cycles are more successful.

**Solutionize**: Magic happens.

**Quench**: A straight run to room temperature is not necessary. We use a variable quench strategy.

**Temper**: Small optimizations in temperature can enable dramatic changes in cycle time.

**Cool**: As with quenching, a variable program has yielded significant improvements.

**Age**: With better control on the previous steps, this step becomes less important.

**Outgas**: Arnold has developed a new, separate outgas cycle we perform in a common lab furnace that eliminates about 3 times more organics.

**Figure 9.** Sinter, solution and tempering thermal treatment as described in Strnat [95] showing development of the hysteresis loop shape.
Thermal Processing

**CHALLENGE: Uniformity**
Minimize/eliminate the variations in temperature in a furnace, under partial pressure

**ANSWER: Design**
Optimize the design to select off the correct microstructure during the process and quench out when desired

**RESULT: Coercivity**
Develop the best coercivity while depleting the material of all of the constituents that help coercivity
Conclusion

- SmCo still has significant potential to be unlocked.
- Small increases in the energy density of samarium have dramatic effects on its usefulness.
- A top-to-bottom look at the process is necessary in order to make these improvements work.
- Process changes have synergistic effects on each other.
- Arnold continues to lead the way in the development of samarium cobalt.
Talk to us about your application at
(800) 593-9127

www.arnoldmagnetics.com