MAGNETICS 2017

The International Forum on Magnetic Applications, Technologies & Materials

JANUARY 18-19 • ORLANDO, FL

What's New in Materials, Applications and Patents

Dr. John Ormerod

Senior Technology Advisor

Magnet Applications, Inc.

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A Disclaimer

METALLURGIST

A pseudo scientist, who uses undetermined suppositions, indefinite theories, and inexpressible hypotheses; which are based on unreliable information, uncertain quantities, and incomplete data; derived from non-reproducible experiments and incomplete investigations; using equipment and instruments of questionable accuracy, insufficient resolution, and inadequate sensitivity, to arrive at timid, tentative cloudy, abstruse, and non-committed conclusions prefaced by the phrase,“ IT DEPENDS”.

Obviously written by a Physicist who is baffled by phase diagrams!

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What’s New in Permanent Magnets?

- AM/3D printing
- GBD Dy-diffused magnets
- Rare earth magnet recycling
- Nanocomposite magnets
- High Br Sm2Co17
- MnBi magnets
- Daido Steel low Dy magnet
- Fe16N2 magnets
- Hyperloop
- Marine electrical drives
- Hitachi Metals Patent Litigation
- Anisotropic bonded magnets
- Aerospace electrical drives
- Magnetic Refrigeration

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Presentation Outline

- Introduction to Magnet Applications, Inc..
- Patents - Hitachi Metals NdFeB patent litigation update
- Materials - Additive Manufacturing/3D printing of permanent magnets
- Applications - Magnetic Refrigeration Systems

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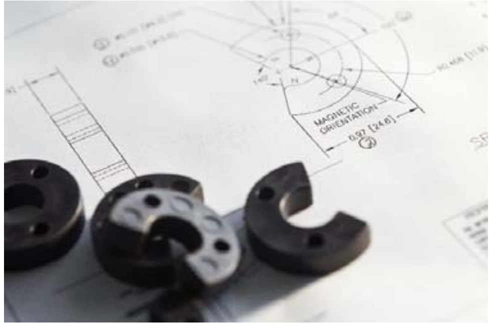
Introduction: Magnet Applications, Inc..

- Visit the new website at: http://magnetapplications.com.
- A Bunting Magnetics Company: https://buntingmagnetics.com/.
- Largest North American manufacturer of compression bonded NdFeB and injection molded ferrite, NdFeB and hybrid magnets.
- Supply full range of engineered magnets and magnetic assemblies.
- Located in DuBois, PA – Originally established in UK over 50 years ago – sister company located in Berkhamsted, UK.
- Primary applications are BLDC motors and sensors in the automotive, medical and industrial markets.



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Introduction: Magnet Applications, Inc..

- Pre-production magnetic design services including 3D magnetic modeling.
- Industry leading technical services to optimize the material for the application.
- Investing in R & D for next generation of magnetic materials.
- The backing of strong family ownership – in business for over 55 years.
- ITAR / DFARS registered for Defense Industry.
- ISO-9001 Certified Quality System with a strong continuous improvement culture.
- Very strong international supply chain for the complete range of permanent magnet materials.

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Hitachi Metals NdFeB Patent Litigation Update
History Part 1 – USITC Phase

- At the start of the decade the industry was eagerly anticipating the expiration of the compositional/tetragonal structure HML NdFe(Co)B US patent 5,645,651 in July 2014.
- August 2012 HML filed a complaint with the USITC against 29 manufacturers and importers of RE magnets and products containing RE magnets.
- 4 US patents cited; 6,461,565, 6,491,765, 6,527,874 and 6,537,385.

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Hitachi Metals NdFeB Patent Litigation Update
History Part 1 - Key Claims of Cited Patents

- 6,461,565 – Method of pressing a RE alloy magnetic powder in a controlled environment from 5°C to 30°C and RH from 40% to 65%.
- 6,527,874 – RE magnetic alloy containing 0.1 to 1.0 At % Nb.
- 6,491,765 and 6,537,385 – Removal of RE-rich particles less than 1 micron from RE alloy magnetic powder.

Magnet Applications
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Hitachi Metals NdFeB Patent Litigation Update
History Part 1 – USITC Phase

- USITC instituted a section 337 investigation in September 2012; multiple law firms and dozens of attorneys were involved.
- During the ensuing months the 5 original licensed Chinese manufacturers (plus 3 others) agreed to new terms under the cited patents.
- A matter of days before the July 2013 trial HML announced that settlement agreements had been reached with all parties and withdraw the petition to the USITC i.e. no day in court to determine validity of the cited patents.

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Hitachi Metals NdFeB Patent Litigation Update

History Part 2- Alliance of Rare-Earth Permanent Magnet Industry

- August 2013- It was announced that "a dozen Chinese rare earth magnet companies have formed an industrial alliance to sue Japan's Hitachi Metals for holding invalid patents and infringing patent rights of Chinese companies".
- Petition for Inter Partes Review (IPR) of certain claims of 6,491,765 and 6,537,385 filed with USPTO August 11, 2014.
- IPR's granted by Patent Trial and Appeal Board on February 2015

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Hitachi Metals NdFeB Patent Litigation Update

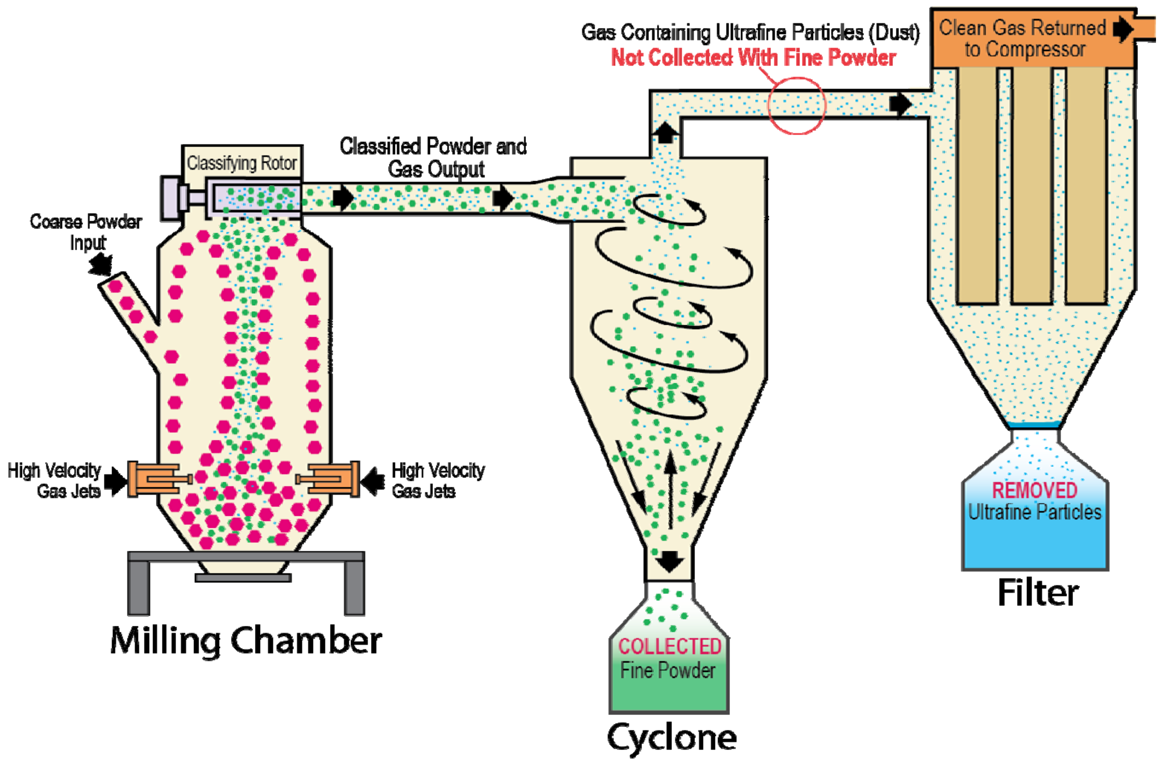
History Part 2 - Independent Claim Construction

USPN 6,537,385 (IPR2014-01265)
1. A method for manufacturing alloy powder for R--Fe--B rare earth magnets, comprising
a first pulverization step of coarsely pulverizing an R--Fe--B alloy for rare earth magnets **produced by a rapid cooling method** and
a second pulverization step of finely pulverizing the material alloy,
wherein said second pulverization step comprises a step of **removing at least part of the powder in which the concentration of rare earth element is greater than the average concentration of rare earth element contained in the entire powder**.

USPN 6,491,765 (IPR2014-01266)
1. A method for manufacturing alloy powder for R--Fe--B rare earth magnets, comprising
a first pulverization step of coarsely pulverizing a material alloy for rare earth magnets and
a second pulverization step of finely pulverizing the material alloy,
wherein said first pulverization step comprises a step of pulverizing the material alloy by a hydrogen pulverization method, and
said second pulverization step comprises a step of **removing at least part of fine powder having a particle size of 1.0 μm or less to adjust the particle quantity of the fine powder having a particle size of 1.0 μm or less to 10% or less of the particle quantity of the entire powder**.

Hitachi Metals NdFeB Patent Litigation Update

History Part 2 – Jet Milling



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Hitachi Metals NdFeB Patent Litigation Update

History Part 2- Alliance of Rare-Earth Permanent Magnet Industry

On February 8, 2016 the PTAB issued their Final Written Decision for Patents 6,537,385 and 6,491,765 as follows:

"ORDERED that claims 1, 5, and 6 of the '385 patent have been shown by a preponderance of the evidence to be unpatentable."

"ORDERED that claims 1–4, 11, 12, and 14–16 of the '765 patent have been shown by a preponderance of the evidence to be unpatentable."

Hitachi Metals NdFeB Patent Litigation Update

History Part 2- Alliance of Rare-Earth Permanent Magnet Industry

- Case closed – not quite!
- April 8, 2016 HML files notice of appeal.
- September 16, HML files appeal brief of PTAB's decision to Federal Court of Appeals.
- October 26, 2016 Alliance files their Appellee Brief.
- December 21, 2016 HML files their reply brief.
- If you are suffering from insomnia the briefs are available at http://www.jocllc.com/news.html.
- Probably another 6 to 9 months before the Appeals Court rules.

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Additive Manufacturing/3D Printing of Bonded Magnets

MAI and ORNL Joint R and D Project

MAI and ORNL were awarded a Cooperative Research and Development award to study the application of additive manufacturing to bonded magnets and systems.

BUNTING Magnetics Co.

www.buntingmagnetics.com
800-835-2526

PRESS RELEASE
Date: September 30, 2015
Contact: John Ormerod
E-mail: jormerod8@gmail.com

FOR IMMEDIATE RELEASE

Magnet systems provider Magnet Applications, Inc. Signs CRADA with ORNL to enable the rapid design and manufacturing of isotropic bonded magnets by additive manufacturing technologies.

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Additive Manufacturing of Bonded Magnets
Acknowledgements and Credits

Oak Ridge National Laboratory

Ames Laboratory
Creating Materials & Energy Solutions
U.S. Department of Energy

CMI | Critical Materials Institute
An Energy Innovation Hub

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Additive Manufacturing/3D Printing of Bonded Magnets

- Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. The term "3D printing" is increasingly used as a synonym for Additive Manufacturing.
- AM can form complex shapes requiring little or no tooling and post-processing thus reducing the amount of waste generated.

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AM is an Industrial Manufacturing Technology

TRUMPF

Press Release

TRUMPF presents process chain for industrial 3D printing

Powerful medium format machines with tool change cylinder concept for industrial-scale LMF production – industry-ready periphery for external part and powder management – TruConnect solution range and monitoring for connected manufacturing includes additive manufacturing as well

Ditzingen, November 15, 2016 – TRUMPF, the laser systems manufacturer and Industry 4.0 pioneer, is at the Formnext trade fair in Frankfurt to present its new 3D printers – TruPrint 3000 and TruPrint 5000. These medium format machines are based on laser metal fusion (LMF) technology, using lasers to generate complete parts layer by layer in a powder bed. These parts can measure up to

Types of Additive Manufacturing/3D Printing

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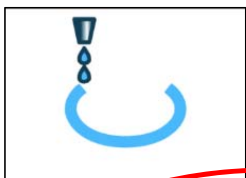
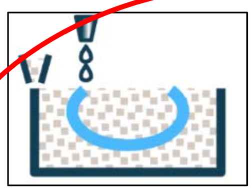
Types of Additive Manufacturing

ASTM International: Technical Committee F42 on Additive Manufacturing

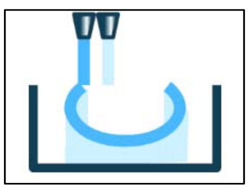
Vat Photo-polymerization



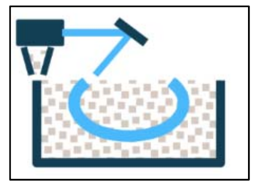
Material Jetting



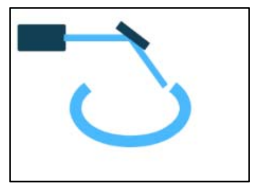
Binder Jetting



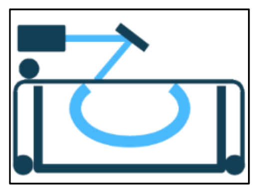
Material Extrusion



Powder Bed Fusion



Directed Energy Deposition



Sheet Lamination

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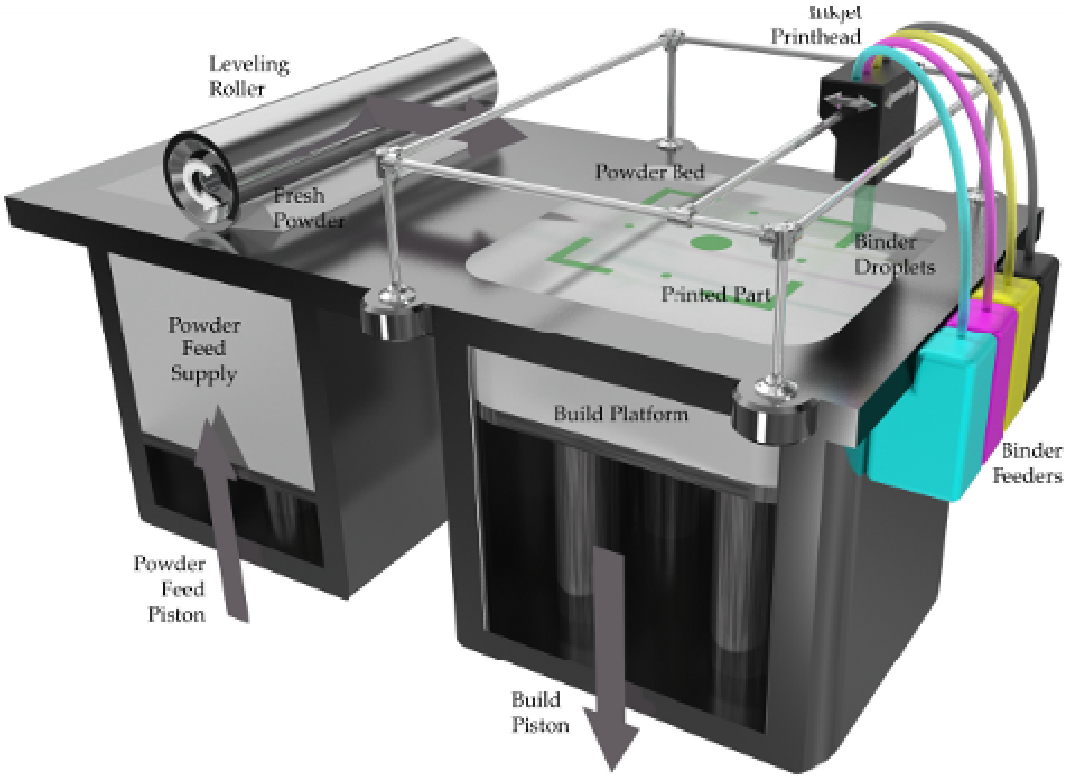
Indirect 3D Printing - ExOne Binder Jet Process



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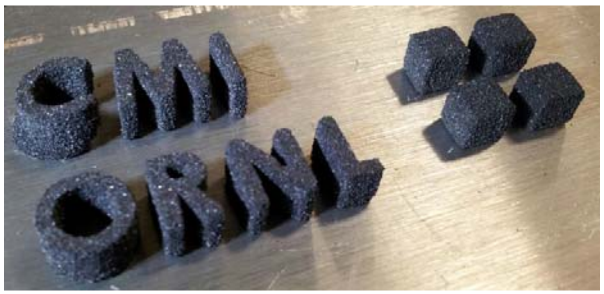
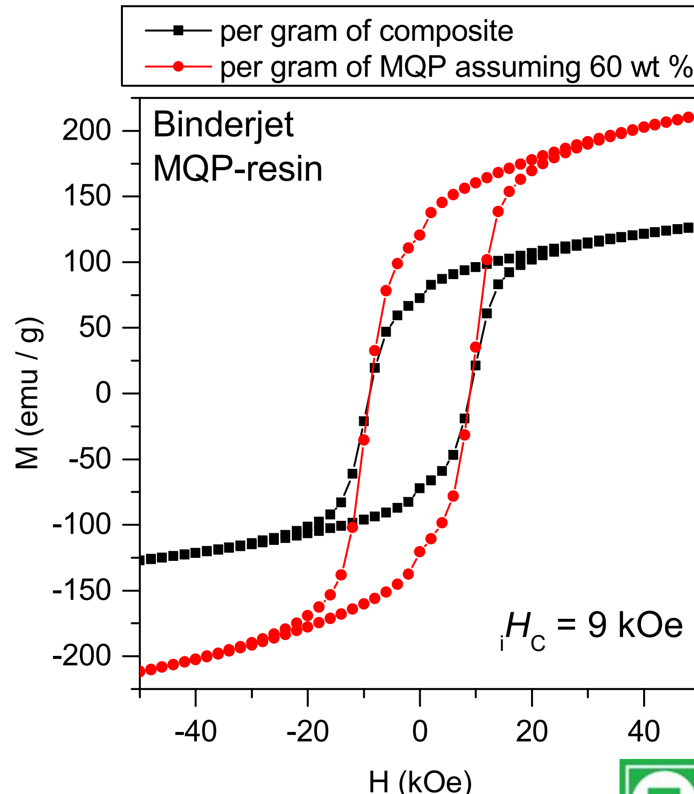
Bonded NdFeB Magnets Produced by Binder Jetting





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Binder Jetting of NdFeB Bonded Magnets

JOM, The Metals & Minerals & Materials Society, April, 2016

JOM
DOI: 10.1007/s11837-016-1883-4

CrossMark

Binder Jetting: A Novel NdFeB Bonded Magnet Fabrication Process

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1.—Chemical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA. 2.—The University of Tennessee, Knoxville, TN 37996, USA. 3.—Energy and Transportation Science Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA. 4.—Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA. 5.—Tru-Design, LLC, Knoxville, TN 37936, USA. 6.—Magnet Applications, Inc., DuBois, PA 15801, USA. 7.—e-mail: paranthamanm@ornl.gov

The goal of this research is to fabricate near-net-shape isotropic $(Nd)_2Fe_{14}B$-based (NdFeB) bonded magnets using a three dimensional printing process to compete with conventional injection molding techniques used for bonded magnets. Additive manufacturing minimizes the waste of critical materials and allows for the creation of complex shapes and sizes. The binder jetting process works similarly to an inkjet printer. A print-head passes over a bed of NdFeB powder and deposits a polymer binding agent to bind the layer of particles together. The bound powder is then coated with another layer of powder, building the desired shape in successive layers of bonded powder. Upon completion, the green part and surrounding powders are placed in an oven at temperatures between 100°C and 150°C for 4–6 h to cure the binder. After curing, the excess powder can be brushed away to reveal the completed "green" part. Green magnet parts were then infiltrated with a clear urethane resin to achieve the measured density of the magnet of 3.47 g/cm³ close to 46% relative to the NdFeB single crystal density of 7.6 g/cm³. Magnetic measurements indicate that there is no degradation in the magnetic properties. This study provides a new pathway for preparing near-net-shape bonded magnets for various magnetic applications.

INTRODUCTION

Permanent magnets are used for many different applications including electromechanical machines such as motors, generators and electronic devices such as speakers, and hard disk drives.[1] Neodymium and dysprosium, used in $(Nd)_2Fe_{14}B$-based (NdFeB) magnets, were both reported as critical elements in the 2011 U.S. Department of Energy's Critical Materials Strategy Document with respect to importance to clean energy and supply risk.[2–6] Typical sintered manufacturing techniques waste magnetic material from the cutting, grinding, and machining steps of the shaping process or at the very minimum are limited in the geometric complexity that can be achieved. The complex geometries can be achieved using the current bonded magnet manufacturing techniques. However, tooling is necessary for printing new designs. Additive manufacturing (AM) is a unique method of fabrication that creates a complex shape from a computer-aided design (CAD) which requires little or no tooling and post-processing, thus reducing the amount of waste generated.[7] The main goal of this research is to develop an AM process to fabricate bonded magnets in complex geometries.

The bonded magnet fabrication process generally involves mixing magnet powders with a polymer (typically a thermoset, thermoplastic or elastomers) and produces various shapes and sizes of magnets through injection molding, calendaring, roll molding, compaction molding and extrusion molding. Materials and associated processes for bonded magnet fabrication have been reported in detail in the

Published online: 05 April 2016

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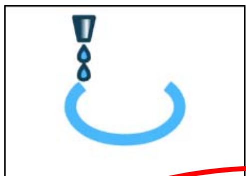
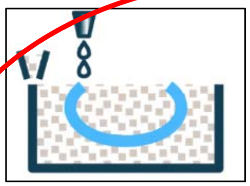
Types of Additive Manufacturing

ASTM International: Technical Committee F42 on Additive Manufacturing

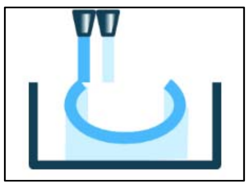
Vat Photo-polymerization



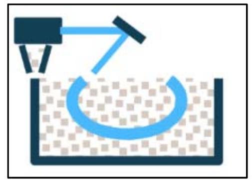
Material Jetting



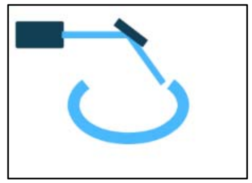
Binder Jetting



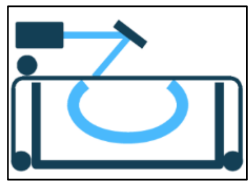
Material Extrusion



Powder Bed Fusion



Directed Energy Deposition



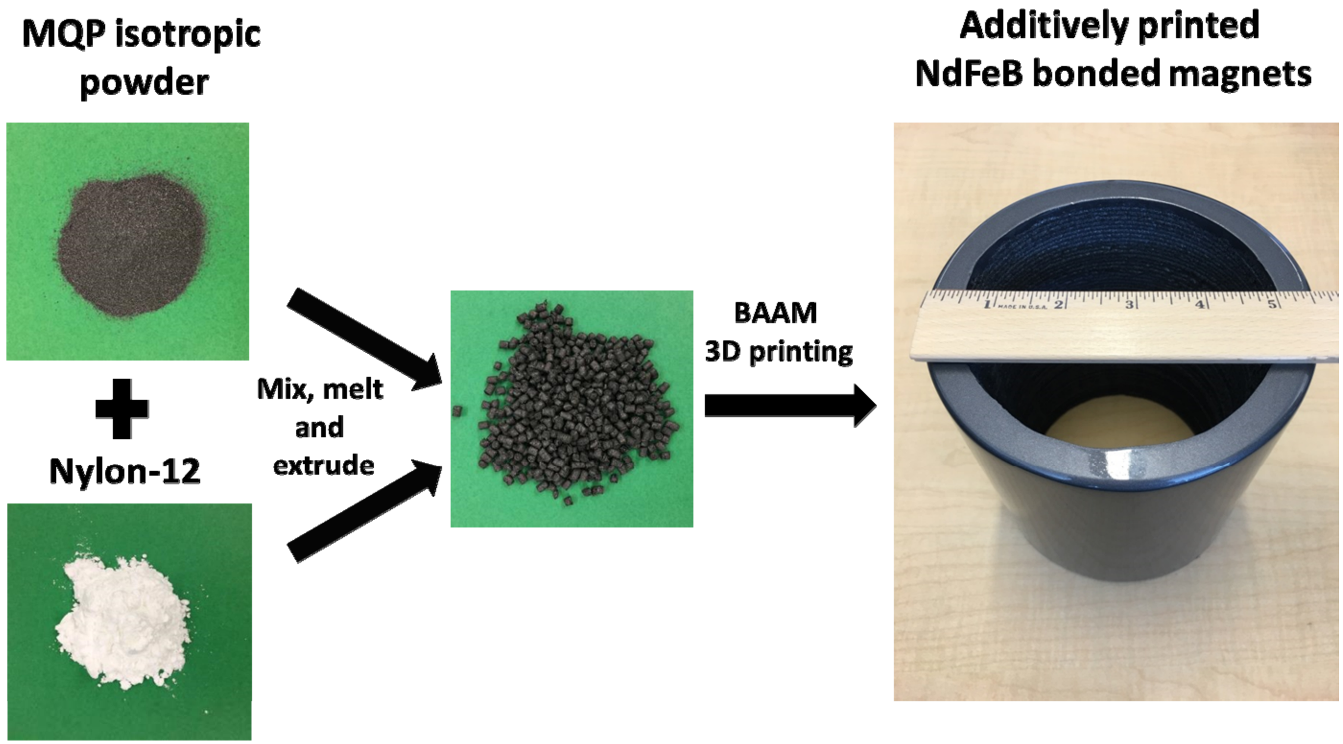
Sheet Lamination

Big Area Additive Manufacturing (BAAM) of NdFeB Bonded Magnets

OAK RIDGE
National Laboratory

BAAM is an industry scale material extrusion additive manufacturing system that enables rapid and cost effective production of large scale components

Big Area Additive Manufacturing of NdFeB Bonded Magnets



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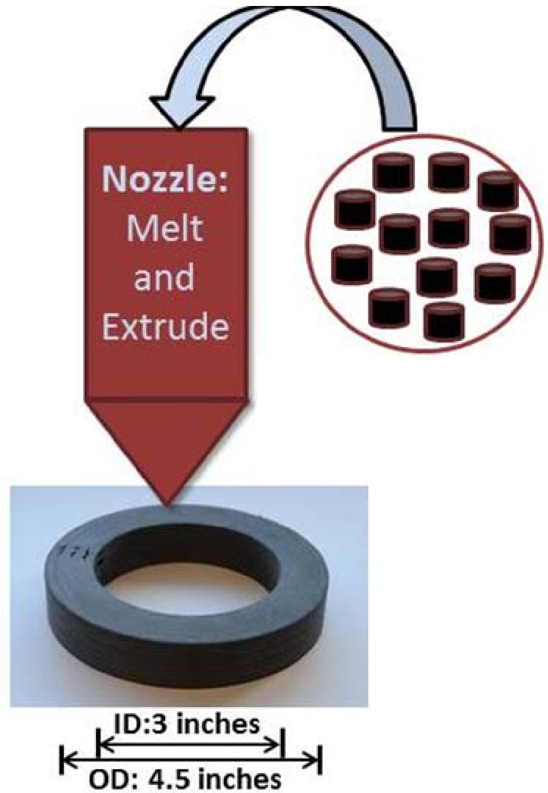
Big Area Additive Manufacturing of NdFeB Bonded Magnets



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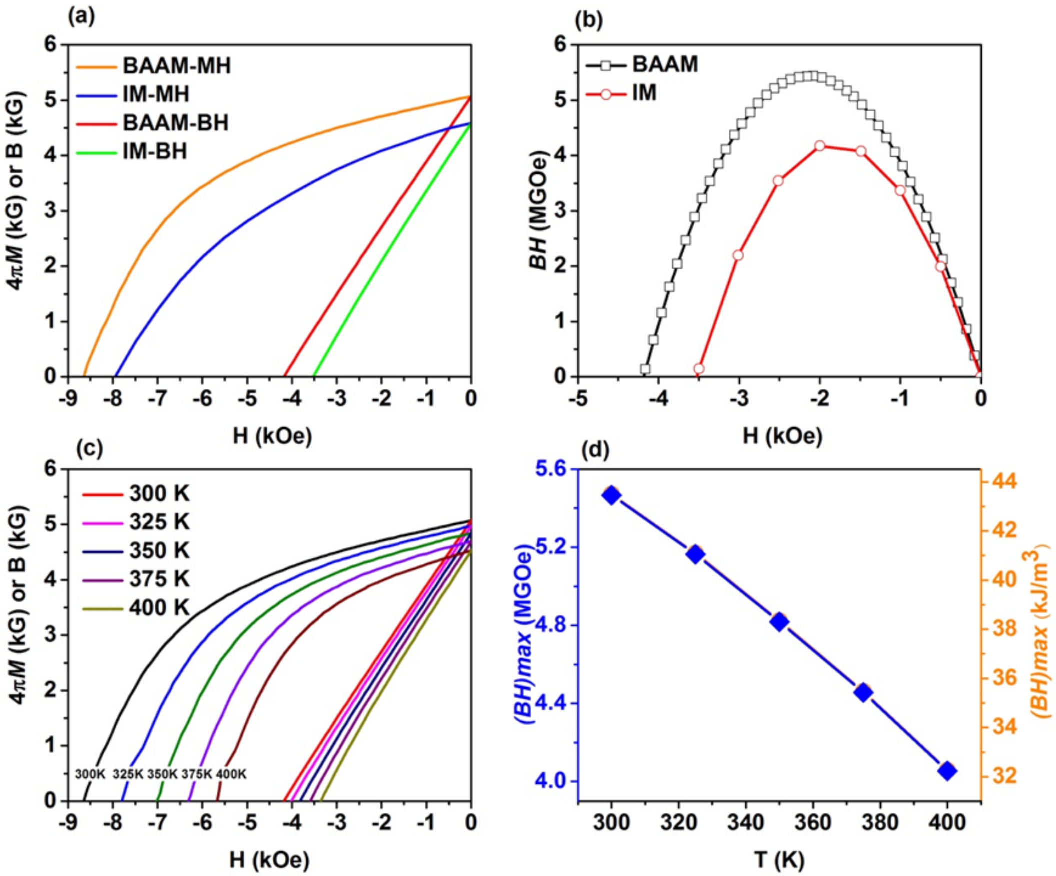
BAAM versus IM Magnetic Properties



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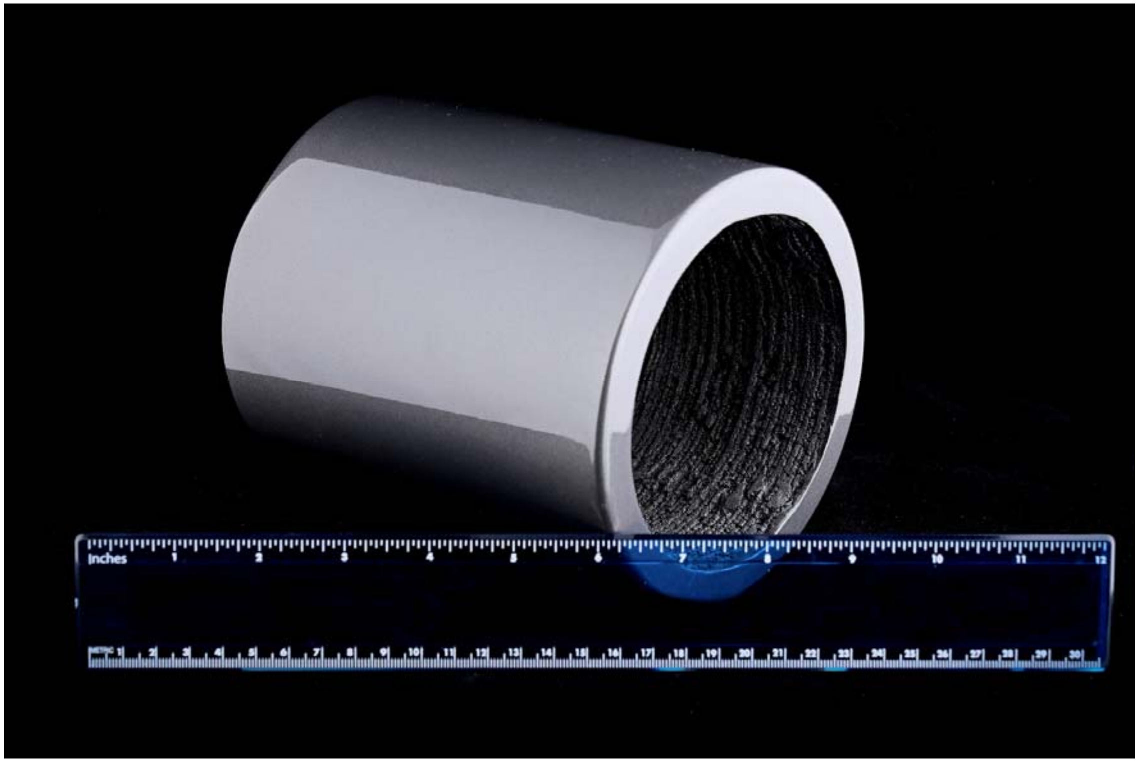
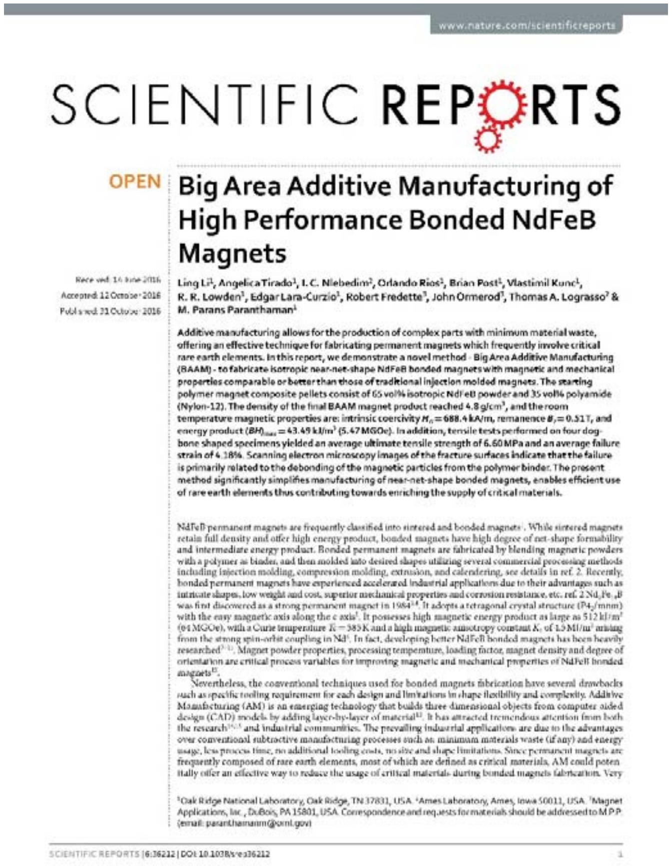
Big Area Additive Manufacturing (BAAM) of NdFeB Bonded Magnets
Surprise – you can make big magnets!



Big Area Additive Manufacturing (BAAM) of NdFeB Bonded Magnets

Scientific Reports, October 2016 (www.nature.com/scientificreports)



www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Big Area Additive Manufacturing of High Performance Bonded NdFeB Magnets

Received: 14 June 2016
Accepted: 12 October 2016
Published: 31 October 2016

Ling Li[1], Angelica Tirado[1], I. C. Nlebedim[2], Orlando Rios[1], Brian Post[1], Vlastimil Kunc[1], R. R. Lowden[1], Edgar Lara-Curzio[1], Robert Fredette[3], John Ormerod[3], Thomas A. Lograsso[2] & M. Parans Paranthaman[1]

Additive manufacturing allows for the production of complex parts with minimum material waste, offering an effective technique for fabricating permanent magnets which frequently involve critical rare earth elements. In this report, we demonstrate a novel method - Big Area Additive Manufacturing (BAAM) - to fabricate isotropic near-net-shape NdFeB bonded magnets with magnetic and mechanical properties comparable or better than those of traditional injection molded magnets. The starting polymer magnet composite pellets consist of 65 vol% isotropic NdFeB powder and 35 vol% polyamide (Nylon-12). The density of the final BAAM magnet product reached 4.8 g/cm^3, and the room temperature magnetic properties are: intrinsic coercivity H_{ci} = 688.4 kA/m, remanence B_r = 0.51 T, and energy product $(BH)_{max}$ = 43.49 kJ/m^3 (5.47 MGOe). In addition, tensile tests performed on four dog-bone shaped specimens yielded an average ultimate tensile strength of 6.60 MPa and an average failure strain of 4.18%. Scanning electron microscopy images of the fracture surfaces indicate that the failure is primarily related to the debonding of the magnetic particles from the polymer binder. The present method significantly simplifies manufacturing of near-net-shape bonded magnets, enables efficient use of rare earth elements thus contributing towards enriching the supply of critical materials.

NdFeB permanent magnets are frequently classified into sintered and bonded magnets[1]. While sintered magnets retain full density and offer high energy product, bonded magnets have high degree of net-shape formability and intermediate energy product. Bonded permanent magnets are fabricated by blending magnetic powders with a polymer as binder, and then molded into desired shapes utilizing several commercial processing methods including injection molding, compression molding, extrusion, and calendering, see details in ref. 2. Recently, bonded permanent magnets have experienced accelerated industrial applications due to their advantages such as intricate shapes, low weight and cost, superior mechanical properties and corrosion resistance, etc. ref. 2 $Nd_2Fe_{14}B$ was first discovered as a strong permanent magnet in 1984[3,4]. It adopts a tetragonal crystal structure ($P4_2/mnm$) with the easy magnetic axis along the c axis[5]. It possesses high magnetic energy product as large as 512 kJ/m^3 (64 MGOe), with a Curie temperature T_C = 585 K and a high magnetic anisotropy constant K_1 of 4.5 MJ/m^3 arising from the strong spin-orbit coupling in Nd[6]. In fact, developing better NdFeB bonded magnets has been heavily researched[7–11]. Magnet powder properties, processing temperature, loading factor, magnet density and degree of orientation are critical process variables for improving magnetic and mechanical properties of NdFeB bonded magnets[12].

Nevertheless, the conventional techniques used for bonded magnets fabrication have several drawbacks such as specific tooling requirement for each design and limitations in shape flexibility and complexity. Additive Manufacturing (AM) is an emerging technology that builds three dimensional objects from computer aided design (CAD) models by adding layer-by-layer of material[13]. It has attracted tremendous attention from both the research[14,15] and industrial communities. The prevailing industrial applications are due to the advantages over conventional subtractive manufacturing processes such as minimum materials waste (if any) and energy usage, less process time, no additional tooling costs, no size and shape limitations. Since permanent magnets are frequently composed of rare earth elements, most of which are defined as critical materials, AM could potentially offer an effective way to reduce the usage of critical materials during bonded magnets fabrication. Very

[1]Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA. [2]Ames Laboratory, Ames, Iowa 50011, USA. [3]Magnet Applications, Inc., DuBois, PA 15801, USA. Correspondence and requests for materials should be addressed to M.P.P. (email: paranthamanm@ornl.gov)

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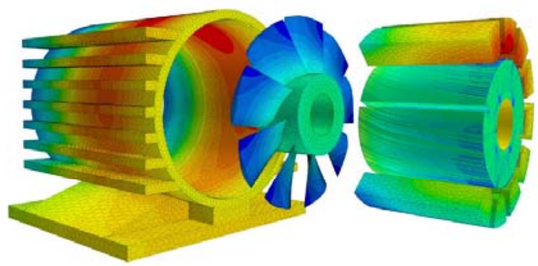
Can we "3D print" an Electric Motor?

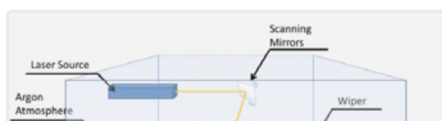
University of Nottingham, UK – Blog/INNOVATE April 2015

August 10, 2015, by Michele Garibaldi

Can we "3D-Print" an Electric Motor?



The well-established success of the Rapid Prototyping technologies derives from the possibility of creating parts with almost any shape at no added costs. However, in order for a part to be functional (i.e., with good mechanical properties), high density and tailored material properties are desired. In the past few years, Additive Manufacturing (AM) technologies such as **Selective Laser Melting** (SLM, shown in Fig. 1) have been proving more valuable than Rapid Prototyping in that they can achieve densities comparable to those obtained through classical subtractive and formative processes. Thus, AM is showing great potential for moving from Rapid Prototyping to Rapid Manufacturing. For this reason, SLM is emerging across a broad range of sectors, including automotive, medical and aerospace, for the creation of functional parts. It is of public domain that one of the most prominent aerospace names regularly associated with AM is GE Aviation, which already in 2013 was leading the way with its plans to produce a fuel nozzle using SLM. A little more than two years have gone by, and GE best-selling engine of all times (the LEAP engine) is set to enter into production by end 2015. Indeed, it will feature the 3D-Printed fuel nozzles that have been making the headlines in 2013.



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About this blog

This blog is produced by the members of the multi-disciplinary INNOVATE research team at the Institute for Aerospace Technology (IAT). INNOVATE is an EC-funded Marie Curie Innovative Doctoral Programme, enabling 13 researchers to develop a range of novel aerospace technologies for integration into a vision of a future air transport system. Here the team discuss their research, ranging from propulsion systems to navigation, and their experiences of life in Nottingham.

Useful links

Institute of Aerospace Technology

Recent posts

Will Planes Be Pilotless? The Future of Commercial Aviation

Can we "3D print" an Electric Motor?

University of Nottingham, UK – Blog/INNOVATE April 2015

"*Until now the design of standard magnetic devices has not gone much beyond the two-dimensions, especially due to constraints imposed by the (mainly subtractive and formative) manufacturing processes employed*."

"*The possibility offered by AM* to extend the design of components to three-dimensional space *without the constraints of traditional manufacturing introduces new opportunities towards the production of highly power-dense electrical machines, where the core magnetic material is added only where it is actually needed*. The impact of such innovative devices would be highly beneficial especially for transport applications, where weight is the primary determinant of vehicle efficiency"

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Presentation Outline

- Introduction to Magnet Applications, Inc..
- Patents – Hitachi Metals NdFeB patent litigation update
- Materials - Additive Manufacturing/3D printing of permanent magnets
- Applications - Magnetic Refrigeration Systems

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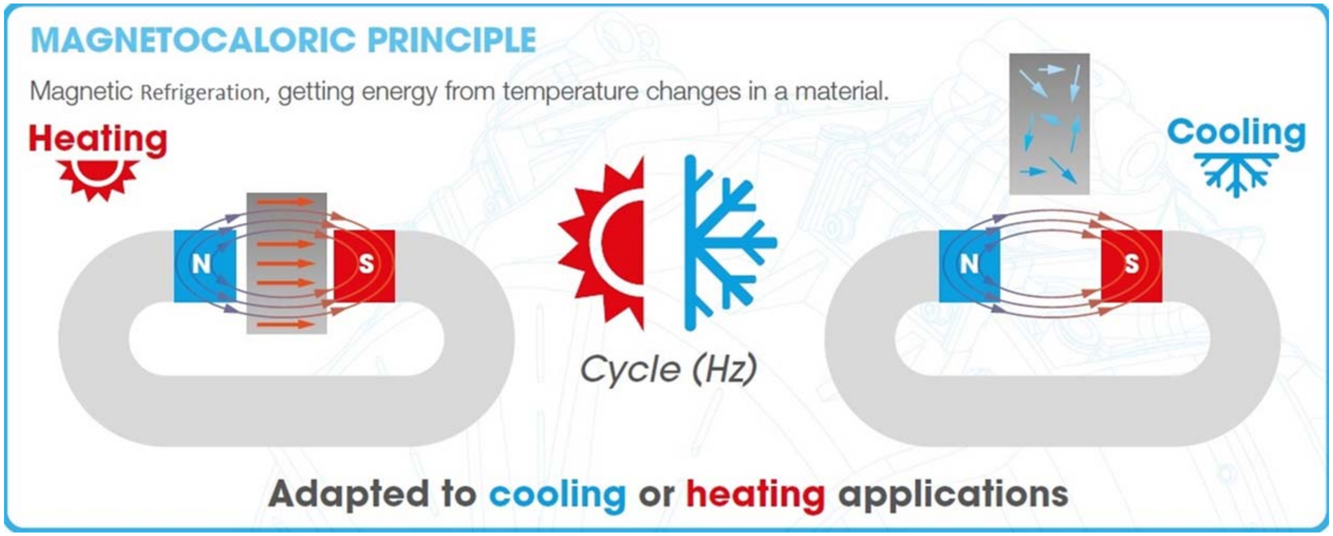
Magnetic Refrigeration Systems
Acknowledgements and Credits

- Timothy Lorkin – MoveOnn Inside
- Cooltech Applications - http://www.cooltech-applications.com/

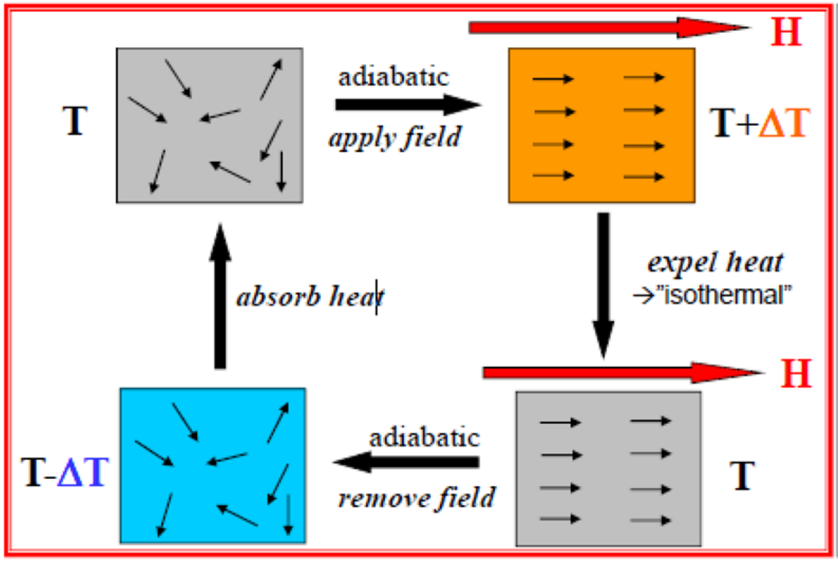
Magnetic Refrigeration Systems
The Next Big Application for Magnets?

- Some classes of materials, called Magnetocaloric Materials (MCM), heat up when immersed in a magnetic field and cool down when removed from it, almost instantaneously. The phenomenon, known as Magnetocaloric Effect (MCE), was discovered by E. Warburg in 1881 and is derived from the ordering and disordering of magnetic domains by an applied field.



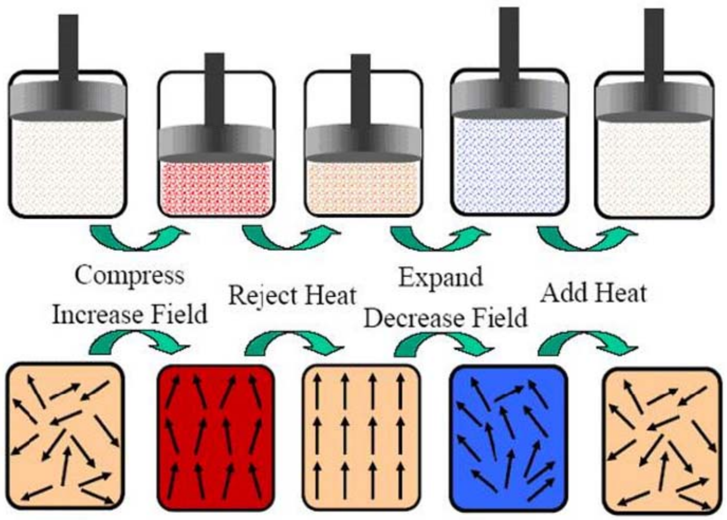
Magnetic Refrigeration Systems

- In 1997, the Ames Laboratory implemented a proof of principle using Gadolinium. Reacting at ambient temperature (~20°C), the use of Gadolinium was a milestone for all developments of magnetic refrigeration systems for commercial applications.
- All else being equal, the degree of temperature change depends on the strength of the magnetic field



Magnetic Refrigeration Systems

- The cycle is performed as a refrigeration cycle that is analogous to the Carnot refrigeration cycle, but with increases and decreases in magnetic field strength instead of increases and decreases in pressure.
- Magnetic refrigeration is the only alternative technology which would simultaneously eliminate the need for harmful refrigerant gases and reduce the energy requirements, and hence carbon dioxide emissions



Magnetic Refrigeration Systems
Giant Magnetocaloric Materials

alloy	T_c (K)	structure	ΔV	problems
$Gd_5(Si_{1-x}Ge_x)_4$	130-270	orthorhombic⇔ monoclinic	0.5 %	high purity Gd
$La(Fe,Si)_{13}H_x$ also Si or Co	**200-330**	**cubic → cubic ($NaZn_{13}$)**	**1.5 %**	**α Fe**
MnFe(P,As) MnFe(P,Ge)	150-340 250-580	hex → hex (Fe_2P)	0.1 %	toxic
MnAs Mn(As,Sb)	317 reduced hysteresis	hex → ortho (NiAs→MnP)	2.2% 0.7 %	toxic
$Ni_{55.2}Mn_{18.6}Ga_{26.2}$ NiMnInCo	315 various	$L2_1$ ⇔ 5M martensitic trans.	0	large strain, hysteresis

- Strong temperature dependence of magnetization, large entropy jump at Tc.
- Large ΔT/ ΔH driven by moderate magnetic field level.
- Small thermal and magnetic hysteresis
- Low material cost (e.g. Gd)
- Non-Hazardous (e.g. As)
- High thermal and low electrical conductivity
- Mechanical and chemical stability, high ductility

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Magnetic Refrigeration Systems Key Players (OEM and MCM suppliers)

- Cooltech Applications (France)
- Camfridge Ltd. (UK)
- Astronautics Corporation of America (US)
- Whirpool Corporation (US)
- NexTpac (France)
- Vacuumscmelze (Germany)
- IFW/IFAM Fraunhofer institutes (Germany)
- General Electric Co /Qingdao Haier Co. Ltd. (US/China)
- BASF SE (Germany)
- Eramet SA (France)
- Samsung Electronics Co Ltd. (Korea)
- Toshiba Corporation (Japan)

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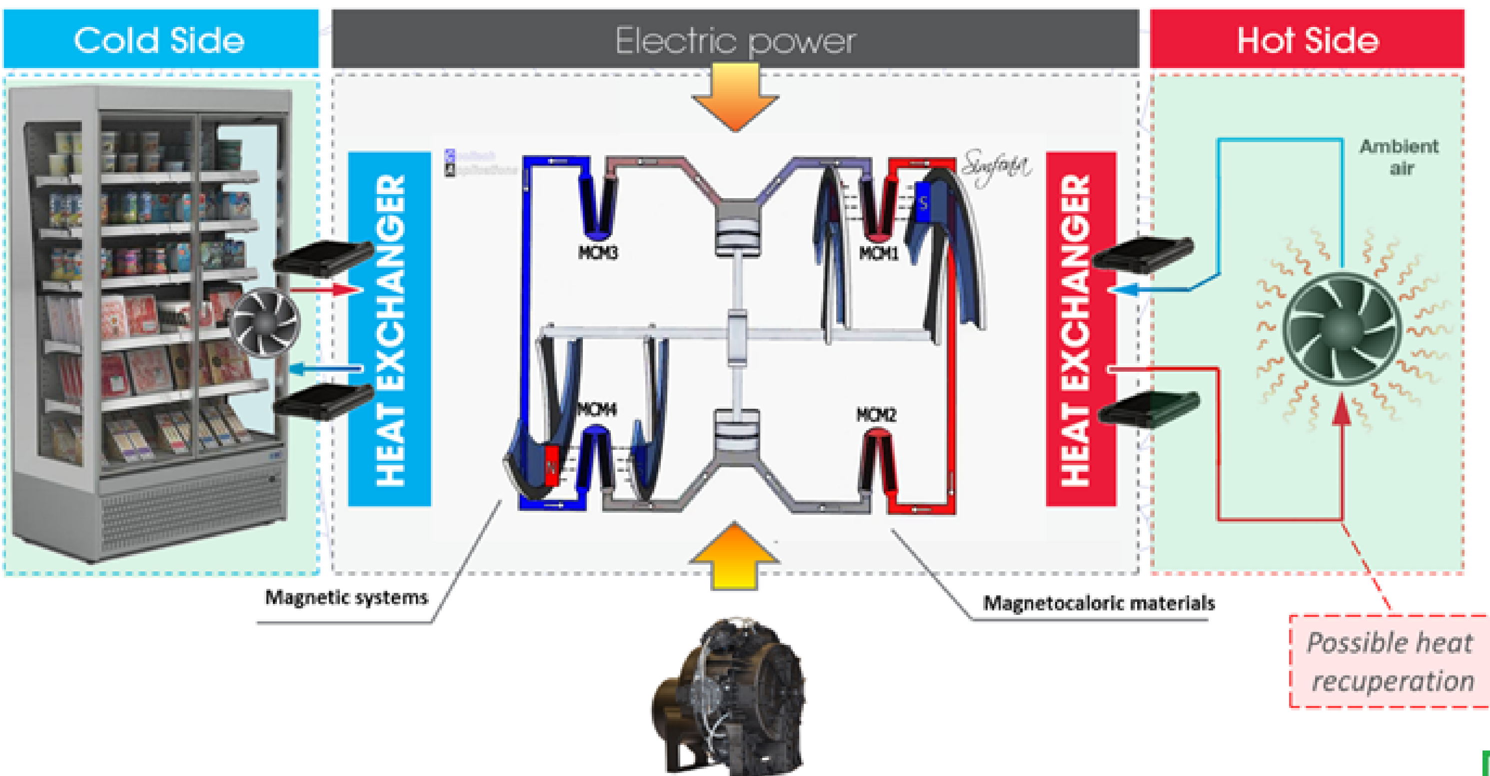
General functioning of the Cooltech's Magnetic Refrigeration System



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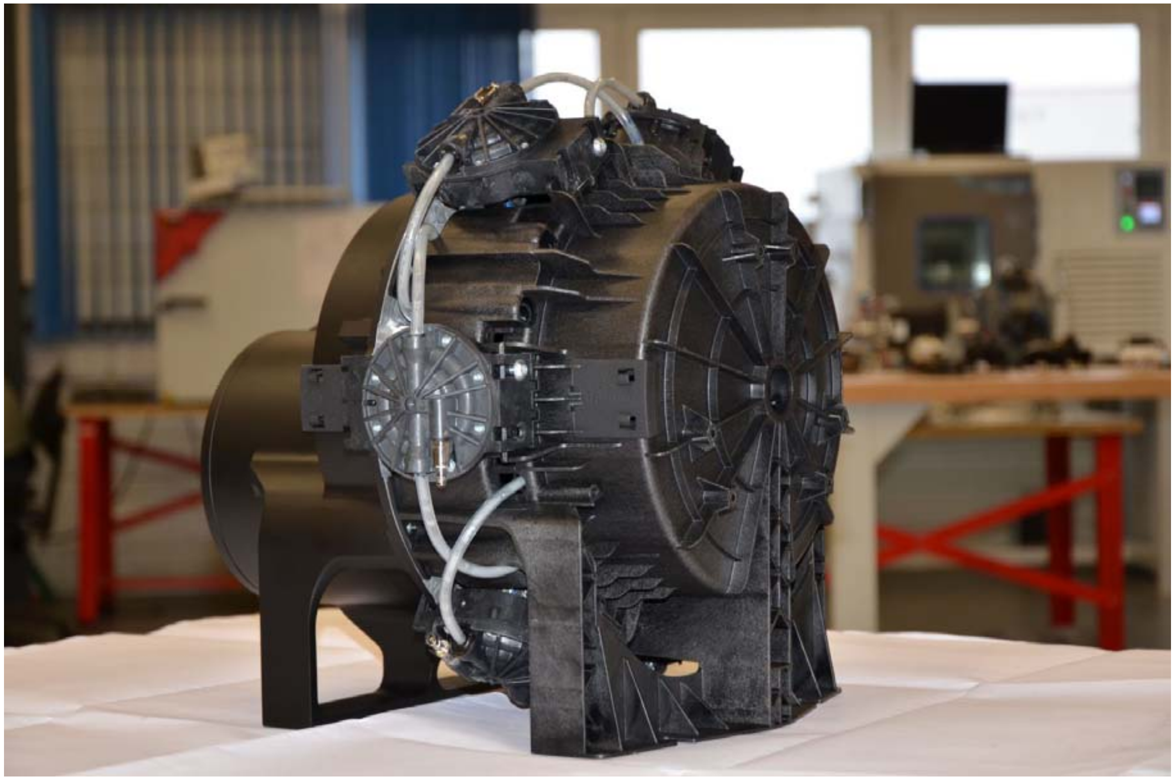
CoolTech's Magnetic Refrigeration System



Magnetic Refrigeration Systems
Challenges – It's been known since 1881

Even though some products have come to market, there are still challenges that need to be addressed before there is large scale deployment of the technology.

- The main issue is the supply of magnetocaloric materials, which are scarce. Reducing the material content, or identifying new materials, would increase viability.
- Low cost, high (BH)max magnets are needed e.g. $Fe_{16}N_2$.
- According to magnetic refrigeration engineers Cooltech Applications, the fabrication process is not yet optimized and production costs are still high.
- Interface optimizations (for example, heat exchangers) between the devices and the equipment to be refrigerated also need to be modified for maximum efficiency.
- Cooltech, Camfridge and Astronautics all have demonstration systems in the field

Summary - IT DEPENDS

- **NdFeB patent dispute** – what will happen? - IT DEPENDS on the Federal Court of Appeals ruling plus there maybe more challenges in 2017.
- **3D printing of magnets**- will this be a viable option for manufacturing permanent magnets? – IT DEPENDS on feasibility of combining multiple processes to produce a complete magnetic circuit.
- **Magnetic Refrigeration** – will it become a major market for permanent magnets? -IT DEPENDS on Governmental energy efficiency and environmental policies and resulting regulations.

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Apologies - I'm guilty as anyone inflicting PowerPoint poisoning

Thank you for your kind attention

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