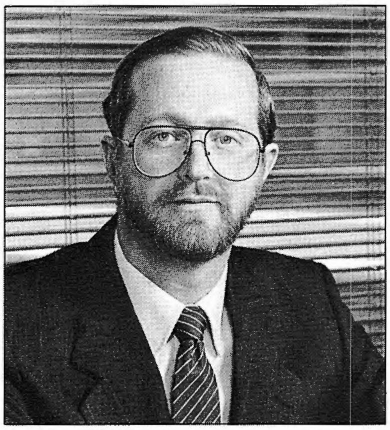
IEEE MAGNETICS SOCIETY NEWSLETTER

VOLUME 30, NO. 1 ISSN 1059-8340 January 1993

JODIE CHRISTNER, EDITOR

PRESIDENT'S COLUMN



David A. Thompson

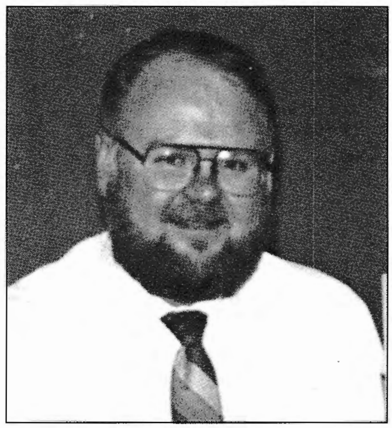
As I enter the President's job, I'm delighted to see that the Society is stable, prosperous, and important to the technical community. In spite of the recession, the conferences that we sponsor continue to attract excellent papers and numerous attendees. The Transactions on Magnetics continues to show unusually high citation rates by other journals, and the student membership is close to its all time high.

On the engineering side, the importance of magnetism to the power, electronics, and data storage industries has never been greater. To scientists, recent discoveries such as giant magnetoresistance offer exciting opportunities to extend our understanding of basic science. In the universities, magnetism continues to offer an amazing diversity of topics worthy of study.

My thanks to outgoing President, Stan Charap. Since the Society isn't broken, I don't plan to fix it. However, I do welcome your suggestions for improvement. This is a volunteer organization. Feel free to volunteer your ideas and yourself.

TECHNICAL COMMITTEE UPDATE: PERMANENT MAGNETS

By Reinhold M.W. Strnat, Chair and KSJ Associate, Inc.



Reinhold Strnat

TC15 - Permanent Magnets

The general mission of this committee is to facilitate the exchange of technical information within the global permanent (PM) community, promote PM-related activities within the IEEE and its Magnetics Society, and to further the education of specialists for the benefit of the PM manufacturing and using industries. There are currently 29 active members representing a broad spectrum of interests from within academia, government and industry. The group comprises 12 Voting members, 12 Associate members, and 5 "Interested Participants."

This article presents a brief overview of some of the exciting work that is being done in the field of permanent magnet materials development. It also identifies some topics which have been raised by Committee members during meetings, which are of practical concern to various sectors of the magnet industry.

Nd-Fe-B ("Neo") Magnets

"Nd-Fe-B" magnets have developed a reputation as "the strongest permanent magnets in the world." Although this

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is true at room temperature, there are applications where the rather high negative temperature coefficients of both induction and coercivity (resulting in the low upper use temperature of about +100 C) make Nd-Fe-B unsuitable. These tempcos are due primarily to the low Curie Temperature of 320-350 C. At cryogenic temperatures a different phenomenon called spin-reorientation takes place. K.H.J. Buschow reported in 1986 that below 135 K the angle between the easy-axis of magnetization and the crystallographic c-axis (normally coaxial) begins to increase with decreasing temperature, approaching a maximum of about 30° at 0 K. This results in a substantial lowering of the effective bulk magnetization. Chemical stability is also a problem in any but the most benign environments. (Appropriate coatings can prevent undue corrosion.)

In spite of the negative factors cited above, Neo has found widespread application in many products, and is frequently the most cost-effective solution available to a particular magnetic design problem. Examples where sintered Nd-Fe-B magnets are used extensively include fractional horsepower rotating electrical machines, voice coil motors (VCM's) in hard disk drives, and in consumer electronics products.

The stoichiometric $Nd_2Fe_{14}B$ composition has long since given way to extensive alloying modifications, much as has happened with Sm_2Co_{17}. Work continues with attempts to substitute Pr, (PrNd) and Mischmetal in place of Nd. In addition to studying the effects of adding Dy, Co, Nb, Ga, Zr and other elements, researchers are exploring new and more practical ways of processing the material into usable forms. Much of the work now being done on Neo is aimed at bringing down processing costs to make it even more price competitive. The broad application of the hydrogen decrepitation (HD) process in producing Nd-Fe-B type sintered magnets is a recent example of the fruits of such work. Other methods under study include improvements on the melt-spinning technology and sintering of powder compacts, use of the Hydrogenation, Disproportionation, Desorption, Recombination (HDDR) process, reduction/diffusion, and hot-rolling, die-upsetting, hot working and other mechanical deformation processes.

Nitrogenated Iron-Rare Earth Compounds

J.M.D. Coey and Hong Sun first reported the magnetic properties of $Sm_2Fe_{17}N_x$ in 1990, generating an enormous amount of interest and speculation that this might be the next major breakthrough in permanent magnet materials. Saturation magnetization is 1.57 T (15.7 kG), anisotropy field 20700 kA/m (260 kOe), and Curie temperature about 470 C. Unfortunately these compounds are unstable above -550 C, making production of anisotropic sintered magnets by conventional sintering impossible.

RE-Fe-nitrides with <5 micron particle size have been used in the laboratory, however, to make respectable aligned powder compacts, and bonded magnets with typical properties Br=0.9 T (9 kG), Hc=446 kA/m (5.6 kOe), and (BH)max=135 kJ/m^3 (17 MGOe). The loop shape of the demagnetization curve continues to be poor compared to commercially available bonded magnets, but this will likely improve with experience. Based on the large volume of recent literature, iron-rare earth nitrides are a hot topic receiving a lot of attention. Much work remains to be done, both in developing compounds and processes to make good bonded magnets, and then in characterizing the short- and long-term chemical, mechanical and magnetic behavior of both the compounds and the magnets as a function of temperature and atmosphere.

Safety Issues

There are safety concerns at many levels in the magnet producing and using industries. The magnet processing side of the business involves handling of, and exposure to, large quantities of fine metal powders which must of course not be ingested or inhaled. Many of the materials used to make rare-earth transition metal magnets are highly pyrophoric in powder form and pose fire and explosion hazards. (There have been a few serious accidents in manufacturing facilities over the years, at least one involving loss of life.) Milling of Nd-Fe-B powders under chlorinated fluorocarbons like Freon can cause severe explosions. Raw materials suppliers are beginning to add warnings of these known dangers to their MSDS, and a generally heightened level of awareness would be desirable.

Another growing concern about personal safety arises during the construction and servicing of larger electrical machines containing high-energy rare-earth permanent magnets (REPM). These devices, which are becoming more common, sometimes contain many kilograms of PM material. This elevates the discomfort of a pinched finger while handling small devices to potential loss of a limb or worse in an accident with a large machine. Particle accelerators and NMR/MRI units also involve personnel working in and near large magnetic fields, raising the possibility that steel tools, carts, or even keys from one's pocket can become lethal flying objects. Proper training, along with explicit written instructions and warnings, must become a standard part of the distribution of such devices.

One of our TC-15 members informally tracks and reports on all types of magnet-related accidents, and we encourage anyone with magnet industry safety-related information to report their concerns and/or experiences to the Committee.

Standards Activities

Although it is not the mandate of TC-15 to write standards, knowledge of various pertinent standardization activities is of ongoing interest. The Committee will of course keep up with IEEE standards. ASTM and the IEC both are working on permanent magnet standards, and there are efforts under way to coordinate IEC and ASTM standards so that testing need not be repeated to meet two different sets of criteria. The U.S. representative to IEC is a member of TC-15 and reports about progress on that front, as do several members who sit on ASTM standards committees. It was recently reported that Japan is now using the IEC

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standard for permanent magnet testing, and will soon begin using SI units. The Magnetic Materials Producers Association, an industry trade group, also publishes practical standards.

Conferences and Forums

Intermag '92 took place in St. Louis, MO in April of this year, and was reported on in the July 1992 issue of this Newsletter. The Proceedings will be published by the IEEE in the Transaction on Magnetics. Don't forget Intermag 93 in Stockholm, Sweden April 13-16, 1993.

The Twelfth International Workshop on Rare-Earth Magnets and their Applications was held in Canberra, Australia July 1992, accompanied by the companion Seventh International Symposium on Magnetic Anisotropy and Coercivity in Rare-Earth Transition Metal Alloys. Some 120 papers were presented and a beautifully printed and bound pair of proceedings volumes was published. For information on availability contact Prof. R. Street, Chairman REMXII, Dept. of Physics, The University of Western Australia, Nedlands 6009, Australia (FAX: +61 9 380 1014). The next Workshop in this series will take place in Birmingham, U.K. in September of 1994.

The 37th Annual MMM Conference was held in Houston, TX in December 1992, and the proceedings will appear in May 1993 as a special issue of the Journal of Applied Physics. The 38th MMM Conference will be held in Minneapolis, MN 15-18 November, 1993, and the 6th Joint MMM-Intermag is scheduled for June 1994 in Albuquerque, NM. Watch the Newsletter's Conference Calendar for updates.

CALL FOR NOMINATIONS:

REYNOLD B. JOHNSON INFORMATION STORAGE AWARD

- An IEEE Field award for significant contributions to information storage.
- Nominees will be judged on the historical significance and the impact of their contribution on the evolution of computer storage systems.
- The recipient will receive $5,000 and a medal.
- Nomination forms are available from:

Maureen Quinn, Manager
IEEE Awards and Recognition
345 East 47th Street
New York, NY 10017
Phone: 212-705-7882
FAX: 212-223-2911

CALL FOR SPEAKER NOMINATIONS

AN INTERNATIONAL CONFERENCE ON MAGNETIC RECORDING HEADS

The fourth Magnetic Recording Conference (TMRC'93) will be held September 13-15, 1993 at the University of Minnesota in Minneapolis, Minnesota, USA.

TMRC'93 will focus on topics relevant to state-of-the-art advanced magnetic recording heads which extend the limits of areal storage density, increase data rate, reduce noise, increase durability, reduce cost, and increase reliability.

About 30 invited papers of the highest scientific and/or engineering quality of about 25 minutes in length each will be presented and subsequently published as refereed paspers in the *IEEE Transactions on Magnetics.* There will also be late-afternoon sessions. There will be no parallel sessions. The topics to be presented include

- Thin Film Inductive Heads for Disk Drives
- Magnetoresistive Heads for Disk Drives
- Heads for Digital Tape Drives
- Magnetic and Tribological Materials for Heads
- Modeling and Characterization of Heads
- Head Mechanics and Tribology

The Program Chairman invites nominations of speakers for this conference and suggestions of specific topics for presentation. **The strict deadline for nominations is April 1, 1993.** All nominations should be sent to the Program Chairman.

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Palo Alto, CA 94304
(415) 857-5651
FAX: (415) 852-8579

Any inquiries with respect to housing or administrative issues should be directed to Mardi Geredes, IIST, (408) 554-6853, FAX: (408) 554-5474.

IEEE Magnetics Society Newsletter is published quarterly by the Magnetics Society of The Institute of Electrical and Electronics Engineers, Inc. Headquarters of the IEEE is 345 East 47th Street, New York, NY 10017-2394. $1.00 per member per year (included in Society fee) for each member of the Magnetic Society. Printed in USA. Second-class postage paid at New York, NY and at additional mailing offices. **Postmaster:** Send address changes to IEEE Magnetics Society Newsletter, IEEE, 445 Hoes Lane, Piscataway, NJ 08854-4150.

The objective of the **IEEE Magnetics Society Newsletter** is to publicize activities, conferences, workshops and other information of interest to the Society membership and technical people in the general area of applied magnetics. Copy is solicited from the Magnetics Society membership, organizers of conferences, officers of the Society and local chapters and other individuals with relevant material. Send copy to Dr. Jodie A. Christner, Dept. 2H2, IBM Corporation, 3605 Hwy 52 North, Rochester, MN 55901-7829, Telephone: (507) 253-5513 FAX: (507) 253-4146.

TECHNICAL COMMITTEE UPDATE: LARGE MAGNET TECHNOLOGY

by P.G. Marston, Committee Chair and MIT/Plasma Fusion Center

Large Scale Superconducting Magnets and Technology Applications

Introduction

The recent discovery of high temperature superconductivity has spawned a seemingly endless array of applications review articles, international technical and investor conferences, and technology centers. This article will focus on the design issues represented by the various applications and briefly highlight their status. Comment on the impact of high Tc (critical temperature) materials is included in the summary.

Primer on Superconducting Magnet Design

Superconductors can be considered for virtually any electromagnetic device but are most beneficial to those which require large amounts of electrical power and/or can benefit from high magnetic flux density. For some applications, reduced size and weight are the driving consideration. The following discussion and definitions will help to understand the comparative design and technology issues.

Superconductors

Superconductors are materials which exhibit a total loss of resistance when operated below certain limits of magnetic flux density (B), temperature (T) and current (I).[1] Performance is thus bounded by a three dimensional surface of B, T and J (current density). Although there are hundreds of superconductive compounds and alloys, only two (at present) are of practical use for large scale applications. These are alloys of niobium titanium (NbTi) and niobium tin (Nb_3Sn). The performance of each will depend on the detailed metallurgy and method of manufacture and can be optimized for each application. Table I compares the general characteristics of these remarkable materials.

NbTi represents the dominant usage. It is an excellent engineering material; strong, flexible and easily processed. It is well understood with a broad data base and is reliably available in a large variety of configurations from a number of suppliers worldwide. At conveniently available operating temperatures (~4.5 K), it is serviceable to ~8 T and if operated at ~1.8 K (superfluid helium) can be considered up to 10 T.

For flux densities above the 8 to 10 T range, the Nb_3Sn alloys dominate. Fifteen T operation for large scale devices and up to 20 T for small scale devices are within the range of existing technology, but represent substantial materials, design and manufacturing challenges. The material is brittle, strain sensitive and difficult to fabricate. Certain applications (most notably magnetically confined fusion) are impractical without very large volumes of very high flux density and there is an aggressive, coordinated international development effort to solve the engineering problems of Nb_3Sn superconductors.

Conductor Configurations

In all practical conductors the superconducting material (NbTi or Nb_3Sn) is in the form of very fine filaments within a coprocessed matrix of normal conductor (usually high quality copper). Filament diameter is typically in the range of 5 to 50 microns for NbTi and 1 to 5 microns for Nb_3Sn. The number of filaments in a wire strand may vary from a few to as many as 7000. The volume fraction of superconductor in the multifilamentary composite wire strand is typically in the range of 20 to 50% (Cu:SC ratio of 5:1 to 1:1). The wire strand is twisted to transpose the filaments and reduce AC losses. It is common practice to twist anywhere from a few to a few hundred of these strands together to form a cable.[2] These cables are often compacted and soldered (or otherwise bonded) to additional normal conductor (high grade copper or aluminum) thus making a "monolithic conductor" having good mechanical integrity and ease of handling.

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Table I

Comparative performance of Niobium Titanium and Niobium Tin

Nb_3Sn data is for different alloys doped with either Ti or Ta and represent upper limits of laboratory tests. NbTi data represents commercially available materials.

B (Tesla) T (Kelvin) J (Am^{-2})

Parameter	Operating Conditions	NbTi	Nb_3Sn
B	T = 4.2 J = 0	12.0	26.9
T	B = 0 J = 0	9.8	18
J	T = 4.2 B = 3	4.2×10^9	1.1×10^{11}
J	T = 4.2 B = 5	2.8×10^9	6.4×10^{10}
J	T = 4.2 B = 10	0.2×10^9	4.3×10^9
J	T = 2 B = 10	1.5×10^9	—
J	T = 4.2 B = 15	—	3.0×10^9
J	T = 4.2 B = 20	—	4.0×10^8
J	T = 1.8 B = 20	—	6.0×10^8

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The major focus of present conductor development for large scale applications is for a configuration descriptively called "cable in conduit conductor" (CICC) in which a multistrand, fully transposed cable is compacted to approximately 70% density inside a high strength, helium leak tight conduit.

Stability, Recovery, Quench

In any practical device the superconductor is operated at some fraction of its limiting field, temperature and current. There are a number of sources for transient perturbations which can momentarily drive some portion of the superconductor beyond its limits, thus forcing a transition from the superconducting to normal state. The electro- and thermodynamic mechanisms (and their design) by which the superconductor can recover (to the superconducting state) from such perturbations are the subject of "superconductor stability" or "stabilization." The coprocessed normal conductor (Cu or Al) which is in intimate electrical and thermal contact with the superconducting filaments is termed the "stabilizer."

The normal state resistivity of the superconductor is two to three orders of magnitude greater than that of the stabilizer. Thus during the transient perturbation, current transfers from the superconductor to the stabilizing conductor resulting in local resistive heating. This "normal" region will either grow or shrink depending on the local cooling. If cooling is adequate to absorb the I^2R heating *without exceeding the critical temperature of the superconductor* (at the local B and J), the normal region will shrink and the superconductor will "recover" from the perturbation. If local cooling is inadequate, the normal region will propagate throughout the entire superconducting coil winding and the magnet is said to have "quenched." The dynamic electrical, thermal and hydraulic behaviors of these mechanisms can be extremely complex and are the subject of intensive analytical and experimental investigation. Stability can be achieved in differing degree and is often defined in terms of "energy margin" which is simply the maximum amount of perturbation energy from which the winding can recover. Stability can range from "full cryogenic stability" wherein cooling is adequate to permit operation of the conductor in the normal state for long periods of time (without exceeding the critical temperature) to energy margins of only a few microjoules. To appreciate the delicacy of the thermodynamic balance, one should recognize that the specific heat of all solid materials in the operating temperature range ($T<10$ K) is essentially zero. Ninety-five percent of the local thermal mass (enthalpy) is in the helium coolant. The available specific enthalpy of helium is only a few joules per cubic centimeter and transient heat transfer mechanisms limit the rate at which the helium can absorb energy. Seemingly insignificant thermal perturbations can thus easily drive the superconductor above its "transition temperature."

Sources of Transient Perturbations

Stability analysis assumes a thermal transient during which some amount of energy is deposited into some defined region of a magnet coil winding.[3] Both the spatial and the temporal distribution of the transient is important. The magnitude of the perturbation is determined by analysis of both normal and "credible fault" conditions. Of principal concern are electromagnetic transients (dB/dt) and frictional heating from motion of the conductors in the winding (coil windings are complex composites having less than perfect structural integrity). The latter are most difficult to predict. Other thermal sources exist but are generally predictable and easily accommodated by design.

Protection

Superconducting magnets often operate at very high average current density (up to 5×10^8 Am^{-2}) and/or with very large stored energy (gigajoules). Loss of superconductivity can result in severe overheating and failure of the coil windings. Protection against such failure is generally accomplished by quench detection circuitry which senses the early onset of a propagating normal zone and triggers protection circuitry which simultaneously opens the magnet power (current) circuit and connects the winding (terminals) to an external "dump" resistor. Current decays with the L_{magnet}/R_{dump} time constant and most of the stored energy is "dumped" into the external resistor rather than the "normal" region of the winding. In some instances there is adequate thermal mass in the total winding to absorb the stored energy without overheating and protection is accomplished by forcing a rapid, global quench of the entire winding. Energy and heat are thus uniformly distributed throughout the winding and there is no excessive heating or thermal stress.

Design Issues - Options

The basic coil design problem is simply to keep the magnet winding cold and hold it together (more easily said than done).

Cooling is provided by helium refrigerator/liquefier systems. These represent highly sophisticated technology but with qualified and caring operation have good availability and reliability. The best cooling (and stability) is achieved by immersing the winding in a bath of liquid helium (referred to as "pool cooled"). In this instance the conductor electrical insulation is lattice-like allowing direct contact of the coolant to the conductor surface. This, however, compromises the electrical and structural integrity of the winding but stability is adequate to accommodate resulting conductor motion, etc. Large pool cooled magnets require large, heavy-walled helium vessels which must withstand the internal pressure generated by heating during a magnet quench.

In CIC windings supercritical (~ 3 atm) helium is contained inside the conduit where it is in direct contact with the very large conductor surface provided by the multistrand cable. The outside of the conduit is fully electrically insulated providing windings of excellent electrical and structural integrity. Stability against fast transients is excellent. The absolute energy margin is limited by the enthalpy of the available helium inside the conduit but is generally adequate to provide a large margin of safety. There is another conductor (referred to as "force cooled") which is similar

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to CICC except that the helium is contained in a separate tube which is bonded to a monolithic conductor. The cooling surface is comparatively small and stability is degraded, particularly against transients of less than 10 milliseconds, but some aspects of fabrication are easier. Both CICC and forced cooled windings have excellent integrity and eliminate the need for a large helium vessel. The last generic cooling method is indirect cooling. As the name implies, there is no direct contact between the helium coolant and the conductor. Windings are fully insulated and cooled via helium cooling tubes attached to cooling plates or in many instances to the winding force containment structure. Heat transfer (and thus stability) is poor but the technique permits windings of excellent structural integrity (usually fully epoxy impregnated) which in turn minimizes frictional thermal perturbations.

Structural containment of the electromagnetic forces is often the major design challenge, particularly for large magnets. Design is complicated by the large thermal motions (from 300 to 4.2 K) and by the fact that structural materials become brittle (though stronger) at very low temperatures. Great care must be taken with fatigue and fracture mechanics.

Research Applications

Despite their 30 year availability, the primary use of superconducting magnets is still for basic research. The technology has enabled the development of particle accelerators and detectors of unprecedented size and performance.[4] The most ambitious of these is the superconducting supercollider presently under construction in Texas. This machine will require two rings of magnets each more than 80 kilometers in circumference and containing a total of more than 10,000 5 cm bore, 6.5 T magnets. They are wound with a flat NbTi cable operating at a temperature of 4.5 K. One of the detector magnets (GEM) has an inside working volume of 18 m diameter by 32 m long. This 0.8 T, single layer solenoid is wound from NbTi CICC operating at 50,000 amperes. Ring magnets for the proposed Large Hadron Collider at CERN will provide 10 T in each of two 5 cm diameter apertures housed in a single structure. The NbTi cable conductors operate at 2 K.

Solid state physics has similarly benefitted from the affordable availability of very high, continuous magnetic fields. A number of superconducting/conventional hybrid magnets providing flux densities in excess of 30 T are in operation, and a system under construction for the high field laboratory in Tallahassee will provide 45 T in a 33 cm diameter bore. This magnet will consist of an outer NbTi region providing 8 T in a 1.1 m diameter bore. Inside this are Nb_3Sn windings which, in combination with the NbTi outermost winding, will provide 14.2 T in a 71 cm diameter bore. Inside these is a conventional (resistive) magnet which provides the additional 30.8 T at a DC power level of 24 megawatts.

The Astromag experiment proposed for the U.S. space station would have two opposing, 2 m diameter, epoxy impregnated, indirectly cooled NbTi coils operating at 7 T (B peak). With multiple, individually cooled thermal radiation shields, the 3440 liter helium cryostat will maintain the 1.8 K operating temperature for several years without refill.

A magnetic field is one of the principal tools for all research disciplines. The thousands of superconducting magnets in the world's laboratories continue to make immeasurable contributions to science and technology.

Energy

Magnetohydrodynamic Power Generation (MHD), Controlled Thermonuclear Fusion (FUSION) and Superconducting Magnetic Energy Storage for commercial power distribution (SMES) would be totally impractical without superconducting magnets. Commercial scale MHD requires 4 to 6 T dipole magnets having apertures in the range of 1 to 4 m in diameter and 10 to 20 m long. This performance is well within existing NbTi technology and enjoys a solid data, design and demonstration base.[5] Advanced conductor and structural concepts recently developed at MIT promise a factor of 3 cost reduction (compared to the established art). MHD R&D is active and a 35 MW MHD "topping" system for commercial power plant retrofit is proposed under the U.S. Department of Energy Clean Coal Program.

The toroidal and poloidal coil systems for Tokamak fusion reactors push the limits of existing superconductors, structural materials and manufacturing capabilities. The focus of the present International Thermonuclear Experimental Reactor (ITER) Program is a machine requiring 8 T windings with dimensions up to 30 m, average flux densities of 13 T (in a 4 m bore, 12 m long solenoid) and total stored energies of 200 GJ. Conductor development at a number of locations in the U.S., the former Soviet Union, Europe and Japan emphasize Nb_3Sn CICC. Designs must minimize AC losses from pulsed fields and plasma disruptions and electrical insulations must endure intense radiation. Structural materials must operate at very high stress (800 MPa) under severe fatigue conditions. These formidable engineering challenges are the subject of an ongoing two hundred million dollar, international design and development effort.

Superconducting magnetic energy storage (SMES) for load leveling in power grids must be able to store (during off peak hours) and later deliver on the order of 5000 MWh to be cost effective. The coils for such systems would be more than a kilometer in diameter and several tens of meters in height. Proposed systems use CICC operating at 100,000 to 200,000 amperes. Force containment would be provided by the substrate (such as bedrock) into which the systems are built. The technology for these systems is adequately well developed and available to realistically assess cost and performance. A small, 30 megajoule system was tested in 1983 by the Bonneville Power Administration and SDIO is presently funding the development of a nominal 300 MWh Engineering Test Model for powering ground based lasers.

Other energy related applications include motors, generators, transformers, current limiters, and power transmission. These have all been thoroughly studied and demonstrated on a significant scale but have yet to be commercially accepted.

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The most promising application has been lightweight - gas turbine - electrical propulsion systems for high speed naval vessels and although successfully verified at modest scale, full scale demonstration has yet to materialize.

Transportation

Perhaps the most exciting commercial application of superconductivity will be high speed ground transportation. These trainlike vehicles will be propelled by linear motors located in an aluminum guideway. Powerful magnets in the undercarriage of the moving vehicle induce eddy currents in the aluminum thereby generating repulsive lift forces which magnetically "float" the vehicle in the guideway. Maglev study and model scale demonstration was completed in the U.S. in the mid to late '70s. A 44-passenger, 400 km/hr vehicle has been demonstrated in Japan where a 45 km commercial scale demonstration is presently under construction. Although performance will benefit from Nb_3Sn, the existing NbTi based technology is adequate for commercial demonstration. The major design challenge is the development of configurations which enable more cost effective guideway - propulsion systems. A number of designs are presently being evaluated in the U.S. and accelerated development is anticipated in the near future. High speed wheeled train technology (such as the French 300 km/h TGV), however, continues to improve and represents serious competition.

The feasibility of seawater, magnetohydrodynamic thrusters for marine propulsion was demonstrated in the U.S. thirty years ago and has received renewed attention in recent years. The focus of the U.S. effort has been for quiet tactical submarines and Japan's Ship and Ocean Foundation has recently completed ocean trials of a 200 ton surface vessel. In these systems, DC current is forced through the seawater in the presence of a magnetic field. The vessel is propelled by the resultant $J \times B$ body force on the water. The primary obstacles to acceptance are electrode and magnet technology. The requirements for the latter are in many ways similar to those for FUSION - the need for high flux densities and efficient ship propulsion are within reach, their development will be expensive and in the present world economy, funding will be difficult at best.

Existing Commercial Applications

Several modest scale, superconducting high gradient magnetic separators (HGMS) have been installed recently in Georgia for the beneficiation of kaolin clays. Other minerals processing and environmental cleanup applications have been demonstrated. Most applications, however, can be reasonably satisfied with conventional magnets (for which there is a sizable world market) and acceptance of superconductivity by the inherently conservative mining industry has been slow. By far the largest commercially accepted markets for superconducting magnets are medical applications of nuclear magnetic resonance imaging (MRI)[6] and spectroscopy. The conductor performance requirements for these systems are, by today's standards, "low tech" ($B < 2$ T) but the field, and therefore the winding current distribution, must be ultra precise in order to get clear images. Improvements in both system design and medical application technology continue to expand market growth and competition is keen. It is interesting and enlightening to note that this sole application to be truly accepted by market economics is also the sole application that was not foreseen by the pioneers of superconductivity.

Summary: High Tc and the Next Century

The above discussion includes the major applications for large scale superconducting magnets.

For nearly all of these, the required helium refrigeration represents a small part of the total system cost. For many, the force containment structure is the dominant challenge and the high strength of materials at cryogenic temperatures is a significant advantage. Superconductors which are sensitive to tensile strain will also seriously complicate the design of structurally efficient support. One must therefore be cautious about the degree to which the availability of high temperature superconductors will accelerate the commercialization of applications which are reasonably satisfied by existing technology. They will replace low temperature superconductors when reliably available as reasonable engineering materials (which is adequate justification for investment in their development) but broad commercial acceptance of their applications may be more strongly influenced by the growing awareness of the need for energy efficiency, environmentally sound policies for sustainable development and, in the U.S. at least, promised new economic policies to foster long term, technological development.

References

The past 30 years has produced an enormous body of literature. The Proceedings of the 12th International Conference on Magnet Technology (IEEE Transactions on Magnetics, Vol. 28, No. 1, Jan. 1992) provides an excellent update on materials and design. Recommended references on magnet design include:

"Superconducting Magnets," Martin Wilson, Clarendon Press.

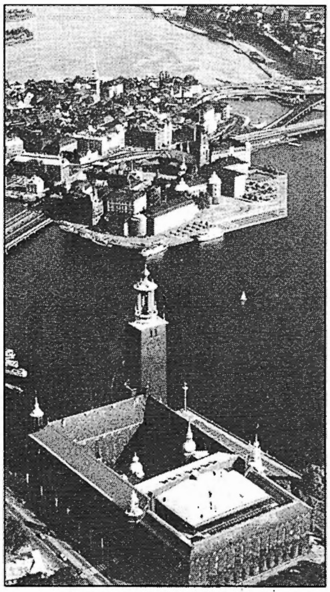
"MHD and Fusion Magnets," Thome & Tarrh, Wiley Interscience.

The author has more than thirty years experience with the development of superconducting magnet systems and is presently head of the Magnetohydrodynamics and High Energy Physics magnet technology groups at MIT's Plasma Fusion Center.

REFERENCES

1. Careful testing shows resistivity less than $4 - 10^{-25}$ ohm-m. This is a factor of 10^{17} less resistive than copper and from an engineering analysis point of view, represents "a total loss of resistance."
2. For a superconductor any rate of change of current and magnetic field is analogous to high frequency. Conductors thus have the general form of "litz wire."
3. Usually defined as joules per unit volume of winding or as joules per unit length of conductor.
4. The 4 m diameter $-$ 3 m long, 2 T superconducting magnet for the ANL 12-foot Hydrogen Bubble Chamber was commissioned in 1968 and is still in operation. The nearly 1000 superconducting magnets of the FNAL Tevatron have reliably operated for more than a decade.
5. The first truly large scale superconducting magnet was developed for MHD and demonstrated in 1966 at The Avco Everett Research Laboratory (now Textron Defense Systems). Several large systems followed in Europe and Japan and in the late 1970s two large MHD magnets were constructed at ANL. One was delivered to the High Temperature Institute near Moscow and the other is still in use at Argonne for studies of MHD ship propulsion.
6. The "nuclear" image is unpopular with users and so expurgated.

1993 INTERNATIONAL MAGNETICS CONFERENCE, APRIL 13-16, 1993 STOCKHOLM, SWEDEN



The International Magnetics Conference (INTERMAG), sponsored by the Magnetics Society of the Institute of Electrical and Electronic Engineers (IEEE) will be held from Tuesday, April 13 through Friday, April 16, 1993 at the Folkets Hus, Stockholm, Sweden. The purpose of INTERMAG '93 is to provide a forum for presentation of new developments in applied magnetics, related magnetic phenomena, and information storage techniques. In addition to the contributed papers, there will be invited papers, sessions wherein competing technologies can be assessed, tutorial sessions, and workshops for less formal discussion of timely and/or controversial topics. Special emphasis will be placed on applications oriented topics. The presentations at INTERMAG '93 will cover all areas of applied magnetics, magneto-optics, related magnetic phenomena and information storage technologies. Topics in recent years have included all aspects of magnetic recording, various magnetic and other memory technologies, microwave magnetics, permanent magnet materials and technologies, magnetic multilayers, control and power conversion and conditioning, magnetometry and transducers, magnetic separation, magnetic levitation and drives, applied superconductivity, field calculations, and magnetic materials — properties and processing. The digest deadline was November 1, 1992.

Information on registration and accommodations for the conference can be obtained from the Conference Coordinators:

Congrex (USA), Inc.
7315 Wisconsin Avenue, Suite 606W
Bethesda, MD 20814 USA
(301) 469-3355 FAX (301) 469-3360

Congrex (Sweden)
P.O. Box 5619
11486 Stockholm, Sweden
46(8)-612-6900 FAX 46(8)-612-6292

Conference information may also be obtained from the Publicity Chairman:

Prof. John Nyenhuis
1285 Electrical Engineering Building
School of Electrical Engineering
Purdue University
West Lafayette, IN 47907-1285 USA
(317) 494-3524 FAX (317) 494-6440
Internet: nyenhuis@ecn.purdue.edu

IEEE-USA SEEKS AWARD NOMINATIONS FOR TECHNOLOGY JOURNALISM EFFORTS

IEEE Offices, Washington, Nov. 13 — Nominations are being solicited to recognize outstanding journalistic efforts that contribute to the enhancement and expansion of public understanding of the engineering profession.

Entries may be either a single printed article or broadcast or a series of presentations that appeared during 1992. All efforts will be judged on their individual quality in portraying subjects, themes or incidents leading to a better public understanding of how engineering professionals are adding to the nation's social, economic and cultural life.

Winning journalists will be honored by the United States Activities' unit of The Institute of Electrical and Electronics Engineers, Inc. (IEEE-USA).

The IEEE is the world's largest technical professional society, with a worldwide membership of more than 320,000 electrical and electronics engineers and computer scientists. IEEE-USA is responsible for promoting the professional careers and technology policy interests of the 250,000 IEEE members who live and work in the United States.

One or more awards will be given by the United States Activities Board of the IEEE for distinguished literary contributions furthering public understanding of the profession. Nominations can be submitted by any U.S. member of the IEEE or by the publisher, author, radio or television station responsible for the effort.

The nomination must include: complete identification of the print or broadcast piece, with place and date of publication or location and time presented; and a 300-500 word summary of the entry and why it meets the objectives in an outstanding way. In addition, a copy of the printed articles or tapes or transcripts must be included for use by the judging panel.

Nominations and supporting materials should be sent to: Awards and Recognition Committee, IEEE-USA, 1828 L Street, N.W., Washington, DC 20036. Entry deadline is March 30, 1993.

Further information concerning the award for literary contributions can be obtained from William R. Anderson in the IEEE-USA Office: telephone, 202-785-0017; fax, 202-785-0835.

MAGNETICS SOCIETY CHAPTERS, 92-93

Chairman: Dr. H.S. Gill
IBM Corporation
N17/142
5600 Cottle Road
San Jose, CA 95193
Bus: 408/256-2308
Home: 415/851-5168
FAX: 408/256-2700
e-mail: HSGILL@SJEVM13.VNET.IBM.COM

1. **Santa Clara Valley**
   Tom Campbell
   833 Hierra Court
   Los Altos, CA 94024
   Home: 415/948-5277
   Meeting day and time: 3rd Tuesday, 8:00 P.M.

2. **San Diego**
   Prof. Frank Talke
   CMRR
   R-001, UCSD
   La Jolla, CA 90093
   Bus: 619/534-3646
   Meeting day and time: 3rd Thursday, 7:00 P.M.

3. **Pittsburgh**
   Prof. Mike McHenry
   Carnegie Mellon University
   Schenly Park
   Pittsburgh, PA 15213
   Bus: 412/268-2703
   Meeting day and time: 2nd Thursday, 7:00 P.M.

4. **Twin Cities**
   Pat Ryan
   1249 Scheffer Ave.
   Saint Paul, MN 55116
   Bus: 612/844-7530
   Meeting day and time: No fixed day, 7:30 P.M.

5. **U.K.**
   Prof. David Melville
   Middlesex University
   Bramley Road Oakwood
   London N14 4XS, England
   Bus: 44-813-681299
   Fax: 44-814-490798

6. **Boston**
   John Judge
   John Judge and Associate, Inc.
   11 Magrath Road
   Durham, NH 03824
   Bus: 603/868-1644
   Meeting day and time: No fixed day, 6:00 P.M.

7. **Los Angeles**
   Werner Treitel
   22040 Celes Street
   Woodland Hills, CA 91364
   Bus: 818/715-2635
   Home: 818/887-1835
   Meeting day and time: 3rd Wednesday, 8:00 P.M.

8. **Philadelphia**
   Prof. Bryen E. Lorenz
   School of Engineering
   Dept. of EE
   Widener Univ., Chester, PA 19013
   Bus: 215/499-4040

9. **Washington, D.C.**
   Prof. M.P. Horvath
   EECS Dept.
   George Washington Univ.
   Washington, DC 20052
   Bus: 202/994-5516

10. **West Lafayette, IN**
    Herbert Pietsch
    7740 N. 100 W.
    West Lafayette, IN 47906
    Bus: 317/497-0077

11. **Tokyo**
    Yo Sakai
    4-22-4 Tsuganodai
    Chiba-shi 260 Japan
    Bus: 81-472-521111

12. **Houston**
    Jeffery T. Williams
    Univ. of Houston
    Dept. of Electrical Eng.
    4800 Calhoun Road
    Houston, TX 77004
    Bus: 713-749-2782

13. **Denver**
    Dr. Subrata Dey
    Storage Technology Corp.
    2270 South 88th St.
    Ms 8110
    Louisville, CO 80028
    Bus: 303/673-6494
    Fax: 303/673-5019

14. **Milwaukee**
    Abd A. Arkadan
    Marquette University
    Electrical and Computer Engineering
    Milwaukee, WI 53233

CONFERENCE CALENDAR

MARCH 22-26, 1993

9th Annual Applied Computational Electromagnetics Society (ACES) Symposium and Short Courses.
Naval Postgraduate School, Monterey, California.

Perry Wheless, Dept. of Electrical Engineering, University of Alabama, Box 870286, Tuscaloosa, Alabama 35487-0286. TEL: 205-348-1757, FAX: 205-348-6959, E-MAIL: wwhelessua@vm.ua.edu.

APRIL 13-16, 1993

International Magnetics Conference (INTERMAG).
Stockholm, Sweden.

INTERMAG '93, % Congrex (USA), Inc., 7315 Wisconsin Avenue, Suite 606W, Bethesda, MD 20814 USA. TEL: 301-469-3355, FAX: 301-469-3360.

JULY 5-9, 1993

Joint International Symposium on Optical Memory and Optical Data Storage.
Maui, Hawaii.

Cathy Goldsmith, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331. TEL: 908-562-3894, FAX: 908-562-1571, E-MAIL: c.goldsmith@ieee.org.

AUGUST 23-28, 1993

EMMA-European Magnetic Materials and Applications.
Kosice, Czecho-Slovakia.

P. Sovak, Dept. of Exp. Physics, Faculty of Sciences, nam.Febr.vitazstva 9, 041 54 Kosice, Czecho-Slovakia. TEL: xx42-95-21128.

SEPTEMBER 13-15, 1993

The 4th Magnetic Recording Conference (TMRC'93).
University of Minnesota, Minneapolis, MN.

E.S. Murdock, Seagate Technology, 7801 Computer Avenue South, Minneapolis, MN 55435. TEL: 612-844-4400, FAX: 612-844-8074.

NOVEMBER 15-18, 1993

38th Conference on Magnetism and Magnetic Materials (MMM).
Minneapolis, MN.

Ms. Diane Suiters, Courtesy Associates, 655 15th St. NW, Suite 300, Washington, DC 20005, TEL: 202-639-5088, FAX: 202-347-6109.

38TH ANNUAL CONFERENCE ON MAGNETISM AND MAGNETIC MATERIALS:

Minneapolis, Minnesota USA
November 15-18, 1993

The Thirty-Eighth Annual Conference on Magnetism and Magnetic Materials will be held at the Hyatt Regency Hotel, Minneapolis, Minnesota USA. The Conference annually brings together scientists and engineers interested in recent developments in all branches of fundamental and applied magnetism. Emphasis is traditionally placed on experimental and theoretical research in magnetism, the properties and synthesis of new magnetic materials and advances in magnetic technology. The program will consist of invited and contributed papers. Selection of contributed papers is based on abstracts. An Abstract Booklet will be available in advance of the Conference from the American Institute of Physics. Registrants will receive the booklet at the Conference. Proceedings will be published in the Journal of Applied Physics.

Individuals who are not on the Conference mailing list may obtain Conference information and details concerning the preparation of abstracts by contacting Janis Bennett, American Institute of Physics, 500 Sunnyside Blvd, Woodbury, NY 11797; telephone (516) 576-2403, FAX (516) 349-0247; or Diane Suiters, Courtesy Associates, 655 15th Street N.W., Suite 300, Washington, DC 20005; telephone (202) 639-5088, FAX (202) 347-6109.

This topical conference is sponsored jointly by the American Institute of Physics and the Magnetics Society of the IEEE in cooperation with the American Physical Society, the Office of Naval Research, the Minerals, Metals and Materials Society, the American Society for Testing and Materials and the American Ceramic Society.

The meeting will be open to all persons subject to a registration fee of approximately $250 (marked reduction for students).

This publicity is released by the Conference Steering Committee % John Nyenhuis, Purdue University, School of Electrical Engineering, 1285 Electrical Engineering Building, West Lafayette, IN 47907-1285, telephone (317) 494-3524, FAX (317) 494-6440.