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Advances in Materials Technology: MONITOR

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METALLIC SUPERCONDUCTORS

Distributed free to a targeted audience in developing countries

Dear Reader,

This is number 32 of UNIDO's state-of-the-art series in the field of materials entitled *Advances in Materials Technology: Monitor*. The title of this *Monitor* is **METALLIC SUPERCONDUCTORS**.

The main article for this *Monitor* was written for us by H. Köfler from the Anstalt fuer Tieftemperaturforschung, Joanneum Research, Graz, Austria and University of Technology Graz, Austria.

At the occurrence of high-temperature superconductivity in 1988, little attention has been paid so far to "low temperature" superconductors, although they offer a wide variety of interesting industrial solutions in processes connected to magnetic fields. These superconductors, mostly metallic in their components, are already used in industry and the interest in them continues to grow. The research is rapidly moving from the basic to the applied stage, with many prototypes being demonstrated. However, commercialization for some applications is still a long way off and companies must be patient before they can benefit from expanding the markets.

We invite our readers to share with us their experience related to any aspect of production and utilization of materials and especially comments on the subject of this *Monitor*. It will be appreciated if you answer the few questions on the "Reader Survey" which you find at the end of this *Monitor* and return to us. Thank you for taking your valuable time.

Industrial Technology and Promotion Division

CONTENTS

1. METALLIC SUPERCONDUCTORS AND THEIR INDUSTRIAL APPLICATION

H. Köfler

Preface:

At the occurrence of superconductivity in connection with "high temperature" in 1988 reduced attention has been paid to "low temperature" superconductivity by the public interested in science. However, these superconductors, most metallic in their components, offer a wide variety of interesting industrial solutions in processes connected to magnetic fields. They are already in industrial use and progress in their application is steady. Starting with a short introduction to the essential features of superconductors a review of applications either in prototype stage or in actual industrial use of metallic superconductors will be given.

Introduction:

Today's metallic superconductors have only small similarity with early superconductors of this type. Progress in knowledge on their physical behaviour and progress in manufacturing led to conductors of high quality, high current carrying capacity which are easy to process. What is the base of these metallic superconductors? Starting point of technical conductors are different superconducting alloys some of it listed in table 1 (see page 6).

Superconductor wires have a cross section made up mainly from copper. This copper clad houses fine superconducting filaments and stabilizes the operation of the conductor in case of disturbances. By the example of the widely used superconductor material NbTi offered for sale, first in the 1970s and the same conductor offered today, improvement of conductors shall be demonstrated. For clarity basic physical quantities connected to superconductivity shall precede this comparison. Superconductivity is a special phase state of material which shows loss of resistivity when a distinct low temperature is trespassed. The driving voltage for constant current drops below any measurable value and this effect gives rise to so called loss-less current transport. Thus DC equipment by use of superconductors will gain substantial benefits. But "no losses" is combined with some special features of the superconductors. As we know current is connected to magnetic field. This magnetic field in superconductors sets limits to the current carrying capacity of the conductor. Therefore a conductor always is described by the dependence of current carrying capacity versus magnetic field. For a distinct operating temperature this dependence shows the current which in a specific device would be possible due to magnetic field coming from the current flow in the conductor itself and from magnetic fields originating from external sources. Current carrying capacity can also be expressed by current density in the superconductor material cross section alone. This gives the user the chance to define its own specific mix of stabilizing copper and superconductor filaments for the intended use. However there are many common designs of wires from stock available at the wire manufacturers. Cross-section of one of those conductors is shown on page 6 (figures 1 and 2). The copper matrix (white) encloses thousands of NbTi filaments.

What was expressed in the text above briefly in terms of formulas can be expressed as follows below.

$$j_C = j_{Co} \cdot \left[1 - \frac{B}{B^*}\right]$$

In both conductors, the old and the new, we find a linear dependence of critical current from the actual field. This holds for flux densities in the range from three to nine Tesla. No common formula for conductors of different production is possible because values of j_{C0} and also B^* of the materials of different years and manufacturers differ.

$$j_{C0} = 3100\ \mathrm{A/mm^2} \quad B^* = 10.57\ \mathrm{T}$$
$$j_{C0} = 6425\ \mathrm{A/mm^2} \quad B^* = 10.23\ \mathrm{T}$$

Turning to the graphical representation it shows curves with critical current density of NbTi superconductors of same nominal cross-section and same amount of superconductor in this cross-section. One can easily recognize the large improvement in current carrying capacity of the wires. This improvement traces back to higher purity of the starting materials, better mechanical processing of the drawing billet in the drawing benches and to better heat treatment of the conductor at different stages of the production process. The improvement of mechanical treatment leads to remarkable reduction of the filament diameter of the superconductor in the stabilizing copper matrix. Submicron filaments can be produced and statistical scatter in performance data of wires has been reduced to a very low level. Beside NbTi another material is in use for special applications at high magnetic field. This A15 alloy is Nb_3Sn. Processing of this material is more complicated because of the brittle nature of the superconducting phase of this material. There are two different routes to prepare this material for use in technical equipment. One is called "React and Wind" the other "Wind and React". In case one, the wire is processed to the end and a superconducting electrically insulated wire is wound onto the bobbin of the application. In case two, a wire containing all necessary elements for building the superconducting phase of Nb_3Sn is electrically insulated with a heat resistant insulation (preferably glass fibres) and then wound onto the bobbin of the application. The complete winding assembly after the winding procedure is transferred to an oven and annealed for several days allowing diffusion processes which form the superconducting phase Nb_3Sn. Most of the equipment built up to now follows the second route because the mentioned brittleness makes less problems when the manufacturing process runs this way. Difficulties with electrical insulation are the burdens of the method. In Nb_3Sn we see also a steep increase in performance of the conductors in the past. Current densities have been improved by changing the production routes and the thermal diffusion treatment. Manufacturing and insulation of the magnets built from this material have been improved too. So in case of high field magnets this material is preferably applied. Trying an analytical expression for the current density of this material we find a changed expression. First, we must take into account the increased critical flux density of Nb_3Sn and second we have to move the window of validity to higher magnetic flux density values. This corresponds to the usual field of application of Nb_3Sn. Doing so, we can write again (for the range between 10 and 15 Tesla).

$$j_c = j_{co} \cdot \left[1 - \frac{B}{B^*}\right]$$

$j_{C0} = 1500\ \mathrm{A/mm^2}$ $B^* = 16.9$T early 1980
$j_{C0} = 2445\ \mathrm{A/mm^2}$ $B^* = 17.3$T late 1980
$j_{C0} = 4300\ \mathrm{A/mm^2}$ $B^* = 17.9$T early 1990

There are some other metallic superconductors which are produced in laboratory scale for special applications. But NbTi and Nb_3Sn are the only materials which are used in industrial scale.

Applications of metallic superconductors

The title of this paper indicates that there will be treated products which are already in industrial use or which are in a prototype position in development programmes of industry. What is clear from the preceding paragraph is the fact that most of the applications are based on use of magnetic field. Short attention will also be paid to some few superconducting SQUID (superconducting quantum interference device) applications.

Magnets for physics research physics machines.

Particle physics and use of accelerated atomic particles is tied to the use of particle accelerators, magnetic lenses and magnetic detectors. In accelerators we find a large number of high field magnets which keep the particles on track. These magnets are dipole magnets operating at 4.2 Kelvin and magnetic field of 5 to 8 Tesla. Higher magnetic fields in NbTi magnets can be attained by reducing the operating temperature to 1.8 Kelvin. These superfluid Helium cooled magnets can reach up to 10 Tesla. In development are magnets with Nb_3Sn which will operate at 10 or 11 tesla at 4.2 Kelvin. The magnets located between tracking dipoles and at the end of the accelerating device are mainly quadrupoles for focusing the particle beam onto the research or production target. Behind these magnets research instruments mostly detector magnets with specially designed field and tailored features for the aim the magnet is intended for are used. In industrial scale of mass production dipoles are built or have been built for particle storage machines or accelerator ring machines. Number of quadruple production is smaller and detector magnets are singular items which nevertheless demand industrial manufacturing due to size and performance goals. An important use of particle accelerators can be found in special lithographic methods developed for future miniaturized electronic elements. Another use of particle beams may be denominated as tools in health care. As an example of such magnets figures 3 and 4 on page 7 show the cross-section of Superconducting Super Collider Dipoles. This SSC is a huge accelerator which at time is on the way of construction and prototype manufacturing. The track of this accelerator which shall stimulate physics in the beginning of the next century needs thousands of magnets. By this demand the magnets are to be manufactured in an industrial scale like mass products because "hand craft" manufacturing cannot meet the demand in due time. The qualification scheme for industrial suppliers taking part in the supply of magnets for this huge physics machine is currently on its way.

Magnets for chemistry and medicine

Important in terms of industrial use is application of superconducting magnets in nuclear magnetic resonance (NMR). The method is a widely used diagnostic tool in chemistry and industry with chemical background and in medicine. The principle shall be described briefly. Electrons running around their nuclei and the nuclei themselves having electric charge too, and spinning about their own axis show in static magnetic field magnetic phenomena which may be considered as properties of extremely small bar magnets or dipoles. When a sample containing for instance hydrogen atoms is immersed in a very strong static magnetic field the individual dipoles or better "spins" precess about the field axis. We may for simplicity think that the individual dipoles align with the magnetic field. If this alignment is disturbed by a suitable method which is a radio frequency magnetic field the dipoles will be diverted from their position of equilibrium and fall back to equilibrium after the disturbance has been switched off. From the signal occurring at this occasion information on this nuclei is received. Elaborate treating of all the signals coming from the sample allow to form an image of this sample with respect to content of hydrogen. At different static magnetic field levels (for instance up to 18 Tesla) and radio frequency magnetic field for disturbance information on concentration of different nuclei can be gained. So in medium-sized high field superconducting magnets, the method is used for instance for purity control of organic compounds, for moisture content control of different substances, for studies on chemical reaction kinetics and so forth. The list of applications cannot be extended to completeness as new applications evolve from research and production needs at every moment. Spectacular for the public, is the use of this method for medical diagnostics on human beings. At that time only hydrogen nuclei are used for diagnostics but use of phosphorus in diagnostics as an important component in living tissue is under experimental investigation. In medical diagnostics, the instrument basically is composed from a big superconducting solenoid producing the necessary magnetic field in the range of 1 to 1.5 Tesla. In addition, there is the radio frequency coil which is used to disturb the alignment of spins and to detect their signal on the occurrence of the swing-back of the disturbed spin precession. We will concentrate our attention upon the superconducting coil producing the static magnetic field. These coils are rather huge in dimensions. Two objectives cause a big magnet. First we need a free bore to place the human being into the magnetic field and second, we shield the magnet by passive methods for reasons of management of the magnetic stray field of the surrounding area. The magnet is composed from several solenoids each of them wound on very accurate machined bobbins with superconductor wires of narrow tolerances with respect to their geometrical dimensions. The call for a rigorously homogeneous magnetic field makes necessary mechanical precision in manufacturing of the magnet as well as in the manufacturing of wires and other important components like the mentioned bobbin. All coils are placed in a common helium vessel insulated thermally to a very high efficiency. Thermal in-leak to the helium vessel is further reduced by using current leads which can be withdrawn after the magnet has been charged with current to the nominal field. The current circuit is closed in advance to the withdrawal by a superconducting switch in parallel to the magnet terminals inside the kryostat. An artist's view of such an equipment is shown in figure 5 on page 8.

Magnets for energy conversion

With respect to energy conversion we refer in this paragraph to the task producing electric energy from mechanical energy and to the future task producing energy by nuclear fusion. In both cases rather big magnets are used. These magnets naturally can be loss-saving if built superconducting. Pursuit of improvement of electric machinery is a challenging task. The principles of operational performance since the invention of the machines are constant. Only parts in the complete machine can be developed when new materials are available. AC rotating machinery of conventional design and material has attained high performance level and high output rates in the past. [illegible]ly in the field of generators for power stations, limitation in output due to cooling problems have arisen. They are a force which stimulated search for new design and use of new material. So after 1960, when hard superconductors became a feasible product for large magnets, naturally application in magnets operating in electric machines was investigated. Studies revealed that application of superconductors operating at high current density in modestly high fields will result in space and weight improvement of such generators. Early development gave confidence that properly designed vacuum insulated rotating vessels can build up enclosures for superconducting magnets. Performance of such rotating kryostats with inclusion of rotating helium transfer equipment was such that reduction of losses of the total synchronous machine, taking cooling into account by 0.5 per cent to 1 per cent, could be envisaged. By this efficiency, rotating electric machinery could for the first time surmount the threshold of 99 per cent efficiency. Resulting economic revenue stimulated research world-wide.

In principle many or even most of the technical problems in connection with superconducting synchronous generators are solved. There is still need of refinement and optimization in all fields of electric machinery. This holds especially for equipment at the starting phase of its use. At the time, the point of main effort in research has been shifted to other topics in research and development on superconducting synchronous generators has slowed down. A short view on the principles which apply to electric machines shall lead to the different topics which are the main concern in superconducting machinery. The simplified cross-section of a synchronous power generator shows the essential members which are necessary to get torque and electric power from such a machine (see figure 6 on page 8).

The torque equation itself simply makes use of the well-known expression for force exerted on a current carrying conductor in a magnetic field. To some electric machines specific expressions like sine distributed current-sheet A (with its effective value of the fundamental $A_{1.\mathrm{eff}}$) appear in this formula. The coefficients used are a result of rough simplification. From the very simple model we find:

$$P = 7.0\cdot\xi\cdot\cos\varphi\cdot A_{1.\mathrm{eff}}\cdot{}^{1}B_{1.\mathrm{max}}\cdot D^{2}\cdot L_{1.2}\cdot f_{m}$$

(See figure 7 on page 9)

Beside the superconducting magnet in rotating or linear machinery, there is an application for superconducting magnets in the field of magnetohydrodynamic energy conversion. These MHD magnets provide magnetic field for direct energy conversion from plasma streams. The principle itself can be used also for drives as shown in an experimental ship named "Yamamoto" with magnet hydrodynamic thrust device. Also in the field of application of forces to fluid metals, we can find some experimental use of superconducting magnets. But these ideas have not yet led to superconducting magnets ready for use in industrial scale. More serious effort can be found in the field of superconducting magnets for fusion devices. In the Tokamak machine superconducting magnetic coils are necessary for magnetic confinement of the plasma and for driving the heating current in the plasma. The elegant combination of both tasks lead to rather complicated magnets shown in figure 8 on page 9.

Finally here shall be included the electric energy storage. As a natural companion magnetic field is associated with stored energy. We know that storage of electric energy in most cases is done by some intermediate material. So if mountains are available pumped hydro storage is widely used. Lack of mountains can be overcome by huge magnets which can act as long-term storage devices for electric energy. Recently in the modest scale of less than 1 MVA the idea of Superconducting Magnetic Energy Storage (SMES) has been introduced to industry for stabilizing supply of sensitive electric equipment against disturbance by sags, impulse, power failures and surges which occur in the mains. The equipment is very compact and includes beside the magnet the refrigerator and the power electronics necessary for connecting the device to the electric grid. Two different applications can be suggested. The individual layouts of these applications are shown in figures 9 and 10 on page 10. The system of a SMES operates in principle very simply. When the magnet is charged with its current to the nominal field several thousands of Joule are stored in this magnetic field. If part of this energy is withdrawn in a transfer with properly designed discharge electronics, we can achieve supply of energy at a different rate as it was supplied to the SMES. Disturbance events are short and singular events. Therefore small SMES are rarely an advantageous measure to diminish disturbance effects. SMES of modest size can be used for stabilizing of energy transport systems. This application is likely to be the next step of superconducting devices to the market. Very big SMES seem to have a longer development time schedule despite the fact that they were discussed first as possible application of a superconducting magnet.

Magnets for transportation and separation

High speed ground transportation is an essential feature most communities need very urgently. The use of dynamic magnetic levitation opens one route to comply with this request. Dynamic magnetic levitation is tied to superconducting magnets. If a superconducting magnet is moved along a conducting plane it will show drag and levitation forces. The system is considered to be a very promising use of superconducting magnets. Also with MAGLEV projects most of the technical problems of superconducting magnets are already solved. Slow but steady progress moves the programmes for new ground transportation systems to the point of realization. At the start of such a dynamic magnetic levitated train system industry will be faced with a sharply increased demand of superconducting magnets. Figure 11 on page 11 shows schematically the configuration of such a magnetically levitated train. The performance data of such vehicles are summarized in the table attached to the figure.

Magnetic field with steep gradients of magnetic flux density either produced by magnetic bodies like wire mesh inside a volume under high magnetic flux density or by properly shaped coils can act as separating devices even for materials of paramagnetic character. Ordinary magnetic separation is tied to ferromagnetic behaviour of the material to be separated but using superconducting magnets shifts the performance of separation in a range of susceptibility which is near to the susceptibility of the vacuum. There are different approaches to master the task. One is named High Gradient Magnetic Separator and the other Open Gradient Magnetic Separator. Theory behind the effect is simple and can be expressed by a few formulas.

$$F_{magn} = \chi \,.\, V_p \,.\, \left(\frac{B_0 \,.\, \Delta B_0}{\mu_0} \right)$$

The force F_{magn} on a particle is given by the equation above where χ is the volumetric magnetic susceptibility of the particle with volume V_p.B_0 is the applied flux density and ∇B_0 the flux density gradient and μ_0 the permeability of vacuum with 4π.10-7 Vs Am.

Difficulties are found in the problems of flow of slurry and attraction from particles out of this flowing slurry. Due to the rather complex environment experimental test of separation procedures is necessary. The result of such experiments are machines which now are in test use at different locations throughout the world and will hopefully find increasing use in the future.

SQUIDS for medicine and for prospection

The last example of metallic superconductor use introduces an electronic device called in short SQUID. This is a superconducting quantum interference device and allows measuring of very small quantities of magnetic flux by use of the Josephson effect. The device therefore can be used for detection of magnetic anomalies in the earth shell or for detection of very small currents as can be found in the signal transfer inside the human body especially brain and heart. The device rarely is dealing with an energy level so low that it is completely different to the energies which are involved in building and operating superconducting magnets. The device is useful for detecting magnetic flux quantities near to the smallest unit of flux which is Φ_0 2.067 10^{-15}Vs (see figure 12 on page 11).

This application is attacked by ceramic superconductors which have already working SQUIDS at temperatures of liquid nitrogen. We should remember detecting signals with very low power is the outstanding features of SQUIDS. Future development will increase this pressure on metallic superconductors in the field of cryo electronics. So we will find metallic superconductors especially in applications where power is converted and large magnetic energies are moved and stored. These fields of application will stand in future for a longer period with the metallic superconductors.

References

Information on the subjects reported in this overview paper can additionally be found in publications emerging from important conferences in this field of application and research. These conferences are:

Magnet Technology Conference MT, held every two years. Proceedings earlier published separately and now published as part of IEEE Transactions on Magnetics.

Cryogenic Engineering Conference, CEC. Proceedings published as the well known series of books entitled *Advances in cryogenic engineering*.

International Cryogenic Engineering Conference, ICEC. Proceedings earlier published separately by Butterworth and now published as part of Cryogenics.

Applied Superconductivity Conference, ASC. Proceedings published in IEEE Transactions on Magnetics.

In addition a few papers on the subjects of the overview article are mentioned and some comprehensive articles presented in the above-mentioned conferences are attached.

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Table 1

Metallic Superconductor Alloys

Superconductor of 3rd kind	Critical temperature T_c[K]	Critical field B_{c2}[T] (T-0)
NbTi (approx. 50%)	10.5	>>14
NbZr (approx. 25-33)	11	>>8
V_3Ga	16.8	>>21
V_3Si	17	>>23.5
Nb_3Al	17.5	>>29.5
Nb_3Sn	18	>>25
Nb_3Ge	23	>>38

Figure 1

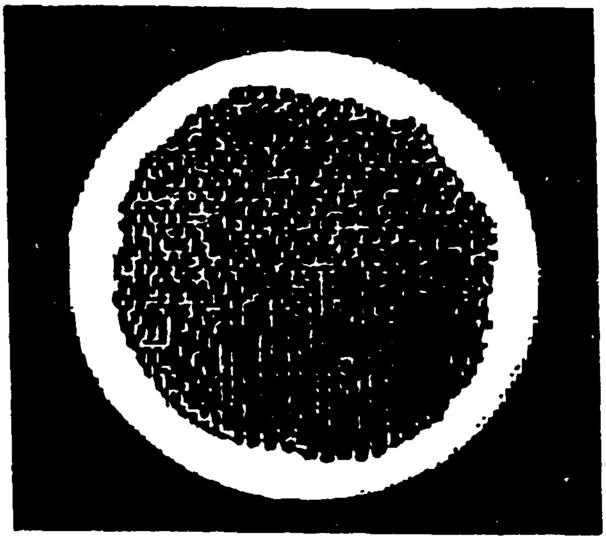


Figure 2

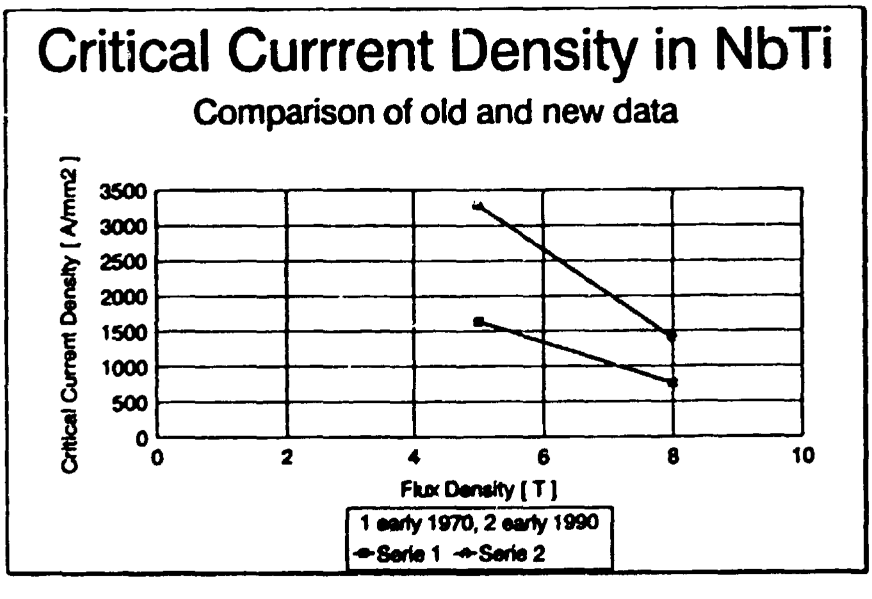


Figure 3

Cross-section of an SSC Dipole

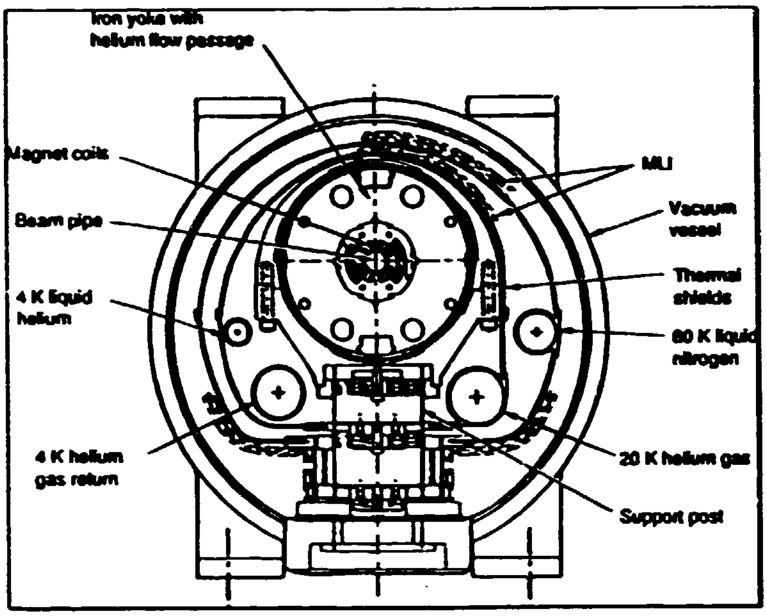


Figure 4

SSC Track and Refrigeration Stations

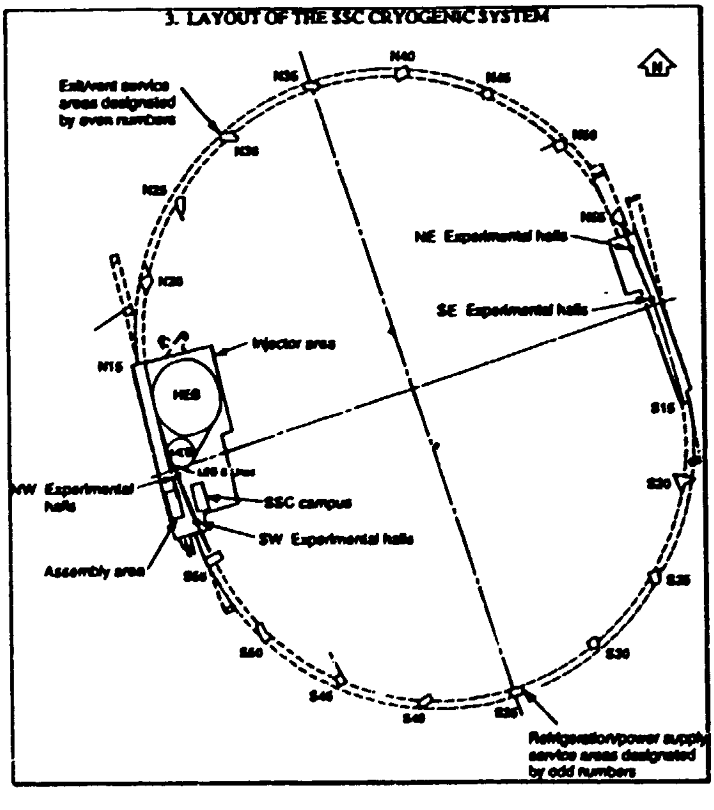


Figure 5

Artist view of an NMR diagnostic system

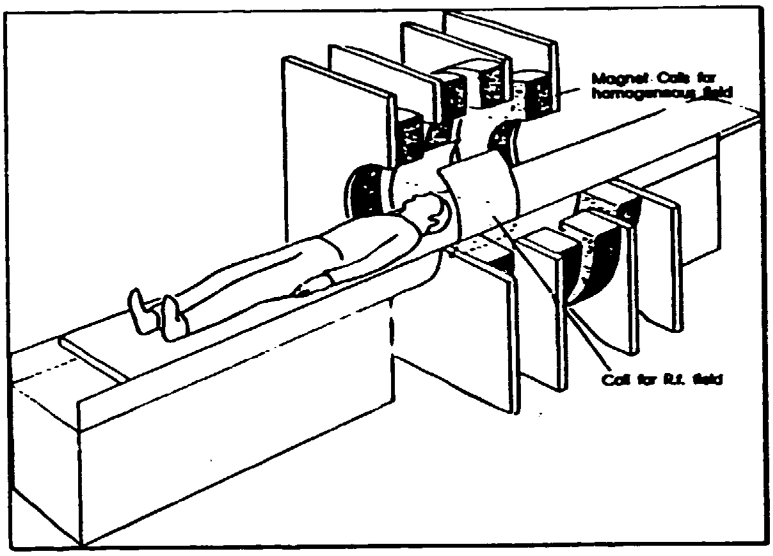
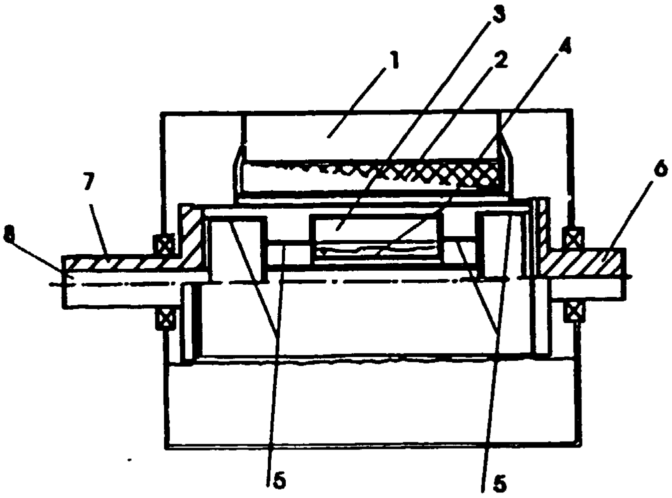


Figure 6



1. Stator core (guides flux, shields environment against excessive magnetic field.
2. Stator winding (location of power conversion from mechanical to electrical and vice versa).
3. Exciter winding (DC current winding made from superconductor and cooled with liquid Helium).
4. Central rotor (Helium tight containment for liquid Helium in which the liquid is held onto the outer surface due to centrifugal forces).
5. Torque tubes (transfer members for the reaction torque built between stator and rotorwinding, cooled by return flow from central rotor).
6. Driven shaft.
7. Supply shaft.
8. Central bore (containing current leads and Helium supply and exhaust line).

Figure 7

Isometric sketch of a superconducting rotor

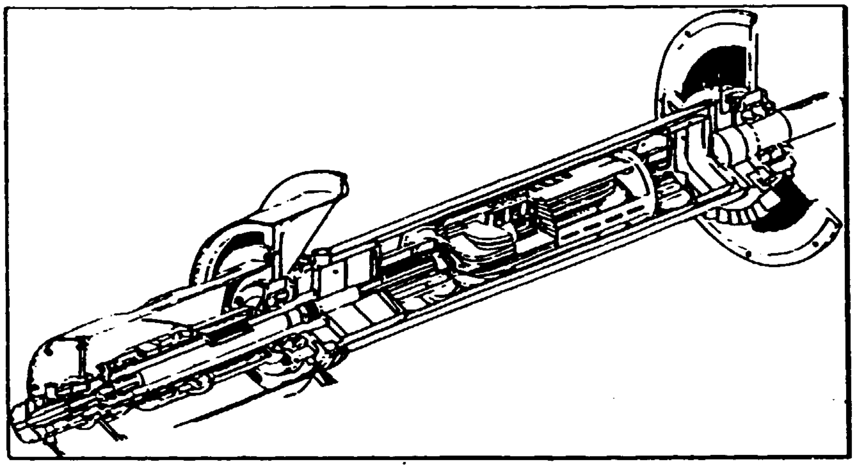


Figure 8

Sketch of a Stellarator Magnet Assembly

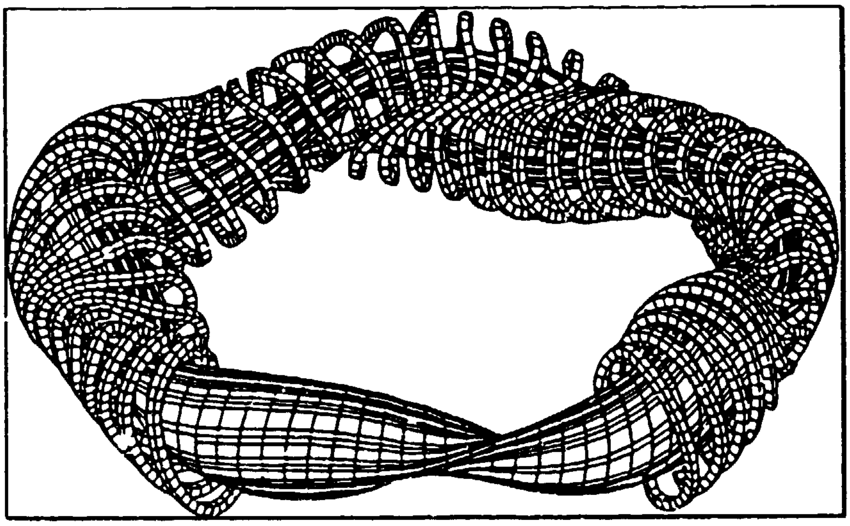


Figure 9

Motor drive
Superconducting Storage Device (SSD)

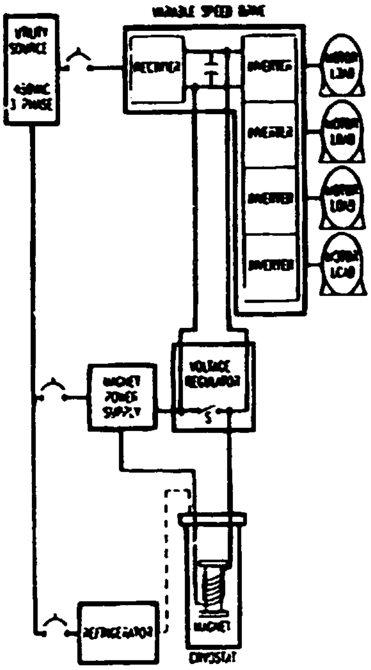


Figure 10

Shunt-connected
Superconducting Storage Device (SSD)

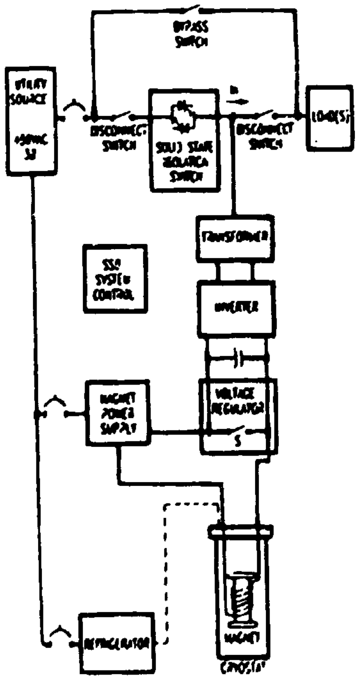
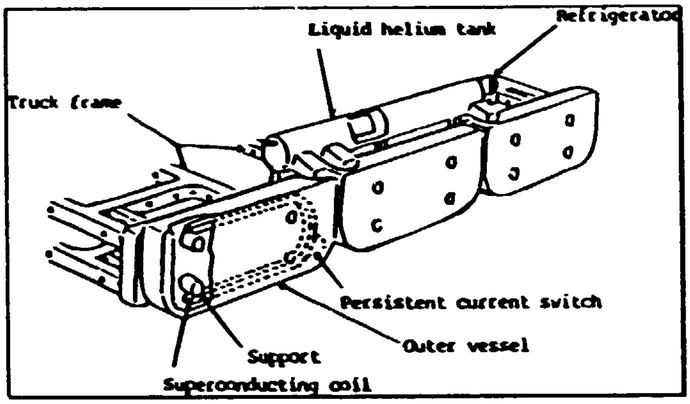
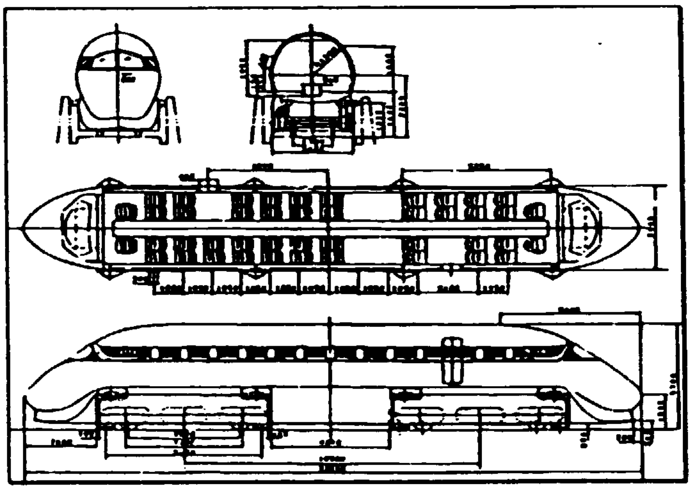


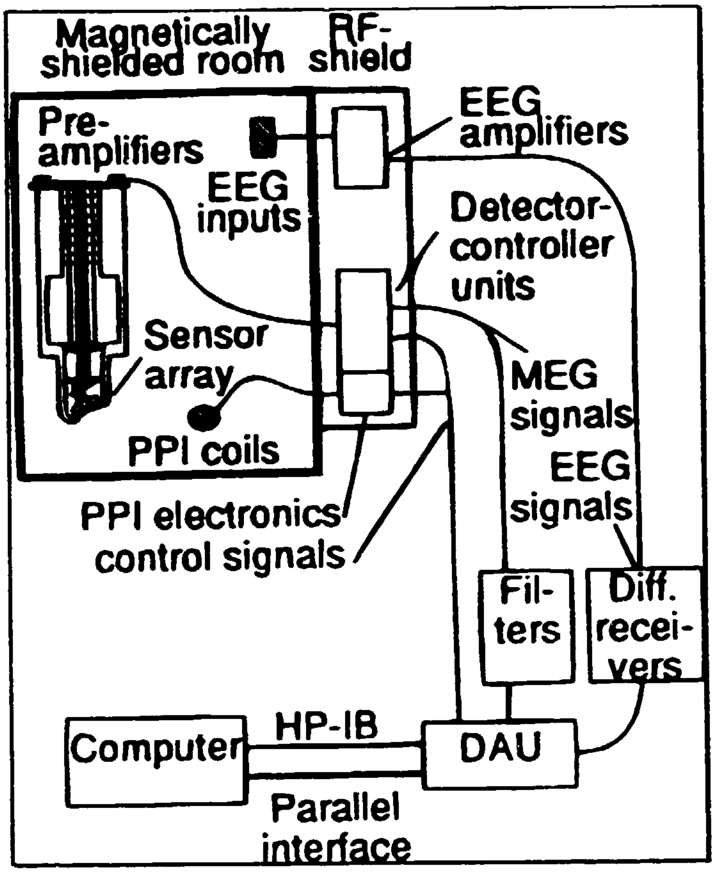
Figure 11





Speed of prototype vehicles: 1988 380 km/h with 44 passengers

Figure 12


Magnetically shielded room
RF-shield
Pre-amplifiers
EEG inputs
EEG amplifiers
Detector-controller units
Sensor array
PPI coils
MEG signals
EEG signals
PPI electronics control signals
Fil-ters
Diff. recei-vers
Computer
HP-IB
DAU
Parallel interface

2. ADVANCES IN RESEARCH AND DEVELOPMENTS

One hundred degrees of separation: Can the superconductivity temperature threshold be raised to room temperature?

Ever since superconductivity was discovered, physicists have been attempting to raise the temperature threshold. US researchers recently succeeded in reaching superconductivity at a temperature of -140° C, a remarkable achievement considering that in previous attempts, the phenomenon could not be obtained above -243° C.

There is now reason to believe that a leap of 100° C may have been achieved. Researchers at the Institute of Physics of Metals of the Ukrainian Academy of Sciences have developed a new material which becomes diamagnetic at a temperature of -40° C. The main ingredient of superconducting materials has always been copper used in combination with thallium and calcium, and "baked" in oxygen, thus producing the best of metaloxide superconductors. The head of the Superconductivity Laboratory at the Institute, Dr. Sergey Tolpygo, confirms that they, too, first used copper. Then, quite recently, they decided to switch to cobalt. The results have been amazing.

In a demonstration arranged for our benefit, a small amount of the new material attached to a fine was immersed in a vessel containing liquid helium. The other end of the wire was hooked to a computer. As the temperature continued to drop, the instruments recorded a sudden surge.

"The material has turned diamagnetic", explained Tolpygo. This was recorded by a sensitive scale. The magnetic field inside sample made it "heavier". Then the weight dropped - a sure sign of a superconductivity. This was performed at a temperature of only -40° C.

Now the goal of scientists is to attain superconductivity at room temperature. So far, the resistivity of the new composite material cannot be brought down to zero.

Samples of the new material have been tested for the phenomenon of diamagnetism at the Institute of Physics of the Ukrainian Academy of Sciences. It was discovered though that, so far, superconductivity does not cover the whole mass of a sample, but develops only in some isolated areas of the material. Scientists have not been able to explain this peculiarity.

The work of the Ukrainian researchers may herald what amounts to a technical revolution, ushering in fantastic power transmission lines without any losses of electricity, fundamentally new electronic devices and mighty atom smashers. (Source: *Science in the USSR*, No. 1, January/February 1992)

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The following three articles were given to us courtesy of the author of the main article, Mr. H. Köfler.

Some remarks on transient currents and their time constants in the superconducting field winding of synchronous generators

H. Köfler

Synchronous machines with superconducting field winding are investigated in many places of the world. The published reports scarcely cover the transient performance of the machines especially with respect to the field winding. The currents in this winding can be calculated with d - q axis theory if the current path of the winding is closed by a source with known source resistance. Superconducting field windings are supplied with current by constant current sources and shunted by diodes in series with dump resistors. These elements change the experimental performance of the winding and the trace of transient currents in the superconducting field winding. The paper describes some of the changes and will show influence of different current paths on time constants connected with superconducting field windings. It will be shown that the plain description of performance used for time constants and current traces of solenoids do not apply in the case of a superconducting field winding of a generator. Tests reveal that time constants calculated with simple models are far too long. Possible sources of additional resistances are proposed. Highly conductive shells serving as thermal screen, stainless steel structures in the rotor body and problems of current distribution in the superconductor influence the performance.

Introduction

Time constants in transient performance of electrical machines play an important role. In few of them the field winding is predominant. At first view a high number of ampereturns in superconducting field windings should cause time constants considerably longer than those observed in conventional generators. The time constants linked with the inductance of the field winding are well known from theory of electrical machines. We follow the description of transient behaviour [1, 2] and find two time constants strongly influenced by the field winding and two time constants weakly influenced by it. The usual expressions for these time constants are transient open circuit time constant of direct axis, transient short circuit time constant of direct axis, subtransient open circuit time constant of direct axis and subtransient short circuit time constant of direct axis. The magnitude of these time constants are not only governed from the inductances and linkages between windings but also from the resistance of the circuit where the current flows. This resistance in superconducting field windings needs special attention.

Basics of theory

In brief we want to remember that description of synchronous machines is based on coupled differential equations linking together the winding systems of the stator, the rotor and the mechanical behaviour. In case of superconducting generators the equations are linear and can be computed with aid of Laplace transformation. The windings are reduced to equivalent network parts represented by lumped parameters. This method is sufficient as shown elsewhere [3]. The result of the extensive mathematics yielding the time constants is given in formula 1.

$$T = \frac{T_{fdo} - T_{Ddo}}{2} \cdot \left\{ 1 \pm \sqrt{1 - 4 \cdot \sigma_{Dfd} \cdot \frac{T_{fdo} \cdot T_{Ddo}}{(T_{fdo} + T_{Ddo})^2}} \right\} \quad (1)$$

The expression in the root can be further reduced if the assumption of very long field time constant to short damper time constant is true. We find four typical time constants as shown below.

transient open circuit time constant T_{ao}'

$$T'_{do} = T_{fdo} + T_{Ddo}$$

subtransient open circuit time constant T_a''

$$T_{do}'' \approx \sigma_{Dfd} \cdot \frac{T_{fdo} \cdot T_{Ddo}}{T_{fdo} + T_{Ddo}} \approx \sigma_{Dfd} \cdot T_{Ddo}$$

In similar manner we can find the short circuit time constants. Only the final approximate expressions are given below.

transient short circuit time constant T_a'

$$T_d' \approx \sigma_{afd} \cdot T_{fdo} + \sigma_{aDd} \cdot T_{Ddo} \approx \sigma_{afd} \cdot T_{fdo}$$

subtransient short circuit time constant T_a''

$$T_d'' \approx \frac{\sigma_{Dfd} \frac{x_d''}{x_d} \cdot T_{fdo} \cdot T_{Ddo}}{\sigma_{afd} \cdot T_{fdo} + \sigma_{aDd} \cdot T_{Ddo}} \approx \frac{x_d''}{x_d} \cdot \frac{T_{do}''}{\sigma_{afd}}$$

In these expressions we find in principal time constants of the individual windings, some coefficients which express the coupling between the windings and inductance values from synchronous machines as seen from the terminals of this machine at different operation states. Firstly we will concentrate on the time constants of the individual windings. All other terms are thought to be invariable at the moment. Without further excursion into theory of electric machines we report that the above shown time constants govern the time behaviour of the field winding current during irregular operation of the synchronous generator.

Resistances in the windings

Because the current in the field winding is influenced by the self-time constant of the field winding, the damper winding and the stator winding one has to examine three winding systems. In this paper we will concentrate work on field winding and damper winding.

Resistances in the field winding circuit

We consider a rather simple supply system for the exciter current. The wiring diagram in figure 1 on page 16 sketches the situation. In case of abnormal operation of the synchronous machine excitation current is changed either by some control equipment or by shift of current from one winding to another. The normal transient operation like increase or decrease of the field winding current is slow. The field current source is working in normal forward condition and therefore beside the inductance of the field winding resistances of contacts, current leads, wiring, slip ring and brushes and of the source itself have to be taken into account. By transformation some of the resistance of the conducting thermal screen and the metallic structure is added to the total resistance. In our model this influence is taken into account by two windings, damper winding in direct and quadrature axis. The magnitude of the resistance depends on machine construction and machine rating. The experimental results shown refer to a machine with nominal rating of 2 MVA. More detailed information on this machine can be found in literature [4]. Table 1 on page 16 summarizes the inductances and resistances of the individual components of the machine itself and the field winding circuit. We consider an experiment in which the field winding current switch is tripped arbitrarily. The stator winding is in open circuit state. The damper therefore will try to maintain the flux level from the time before the switch was tripped. In figure 2 on page 17 the experimental trace of the experiment is shown. The evaluation of the time constants of the two distinct time regimes and the split of these constants into self-time constants of field winding and damper winding is shown in table 2 on page 16. The calculated results are based on circuit analysis of the experiment. We easily find the resistances in the circuit in this case. They are composed from resistance of current feed, slipring and brushes, safety diode and dump resistor. In this case, result of calculation and experiment come together. Another experiment is cancelling the three phase short circuit of the stator winding. The winding currents start from stationary equilibrium at the short circuit. In the time before the cancelling, the excitation due to the stator currents and the field winding current balance each other. After the cancelling, therefore transient currents appear in the field winding circuit, which try to maintain the starting condition. The damper winding which comes into play in the initial time steps of the experiment is stressed as in the first experiment. Therefore the time constant for this winding should be the same as we found already. The field winding current now has another path. The current runs in the forward circuit of the excitation power supply system. So no dump resistor and no diode is in the current path. The internal resistance of the current source is difficult to estimate. It depends, in case of controlled equipment, strongly on the action of the control circuit. The traces of the experiments shown are taken from tests in which control was eliminated to the best degree. Returning to the cancelling of the short circuit we find the experimental long-time constant in poor agreement with calculated values. The explanation we adopt for this disagreement is based on the assumption that step decrease of the field winding current or step increase for the instant short circuit (figures 3, 4 on page 17) cannot be mastered in the superconductor part of the winding. The field winding for the explanation is substituted by an equivalent network consisting of paralleled components, one representing the ohmic resistance of the stabilizing copper and one the inductance of the twisted bundle of superconductor filaments. A step current forced through this arrangement will first flow in the resistive part of the circuit. The current in the superconductor filaments will rise with the integral of the resistive voltage drop in the parallel resistive part. It turns out that the time constants calculated with the residual resistance of the copper part of the field winding fits to the experiment. The field winding in all experiments remains superconductive. This is a strong indication that the transient currents run outside the superconductor material. Diffusion of current from copper to superconductor of course occurs. The long-time constant of such diffusion process is mentioned in [5] for contacts.

Conclusions

In the figures we additionally show results of currents in which the control of the current source was in ordinary adjustment. First it is mentioned that simple straightforward calculation of time constants in field windings of superconducting generators will lead to errors. Secondly the origin of deviation of time constants observed experimentally has to be checked carefully. Our explanation has been developed for a conductor with twisted filaments inside a massive highly conductive matrix. If the conductor has a resistive matrix like AC superconductors then transient current is shifted more easily to the superconductor. In this case the fast changes of current may cause excessive losses in the superconductor. We end therefore at a new question of balance of losses. If the current is driven in the copper, the losses there heat the conductor as the losses in the superconductor do. The performance of field windings in transient operation of synchronous generators improves if the balance of losses in copper and superconductor is optimized.

Acknowledgements

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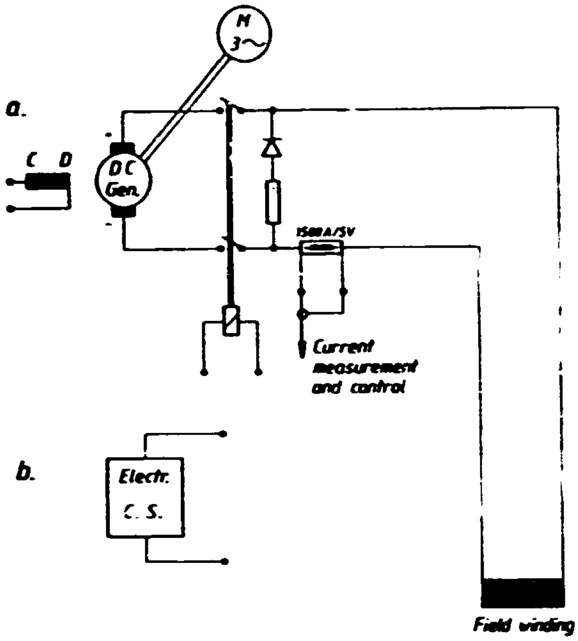

Figure 1 Sketch of exciting system

		L [H]	R [Ω]
field winding		1.93	0.005...0.383
damper winding			$\sigma = 12.10^{6}$ 1/Ωm
source circuit	a	-	0.72
	b	-	0.75

Table 1 Resistances and Inductances

Time constants [s]		calculated straight	corr.	measured
field winding		386	1.82/2.68/5.05	-/2.76/-
damper winding		0.417	0.417	0.43
transient	T_{do}'	386	2.15/3.1/5.47	2.0/3.09/-
	T_d'	247	1.89/1.84/3.23	-/ -/3.13
subtrans.	T_{do}''	0.125	0.1/0.11/0.12	0.04/0.037/-
	T_d''	0.11	0.08/ - /0.9	0.025

Table 2 Time constants with influence of various circuit resistances

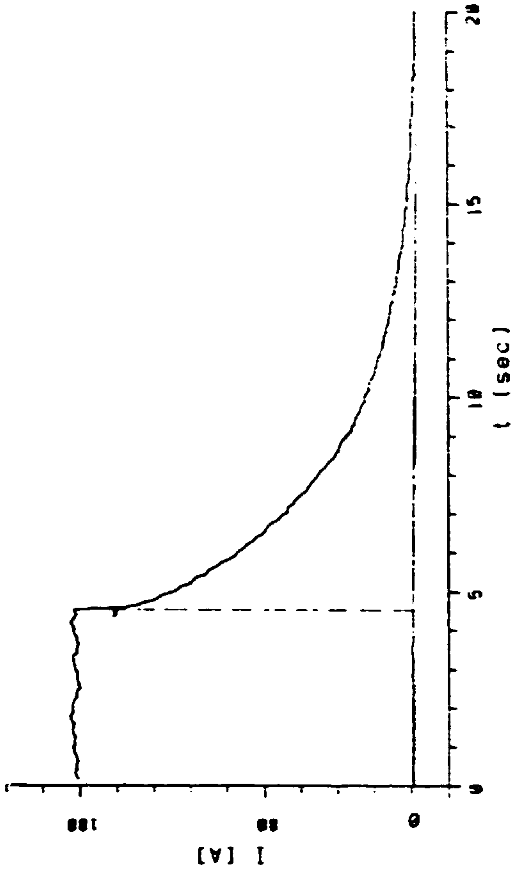

Figure 2 Field current dump

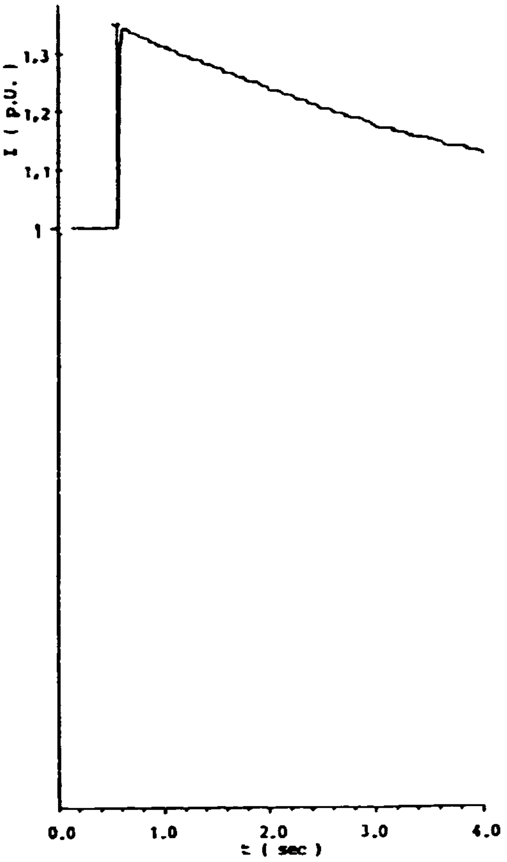

Figure 3 Field current at 3 ≈ short circuit

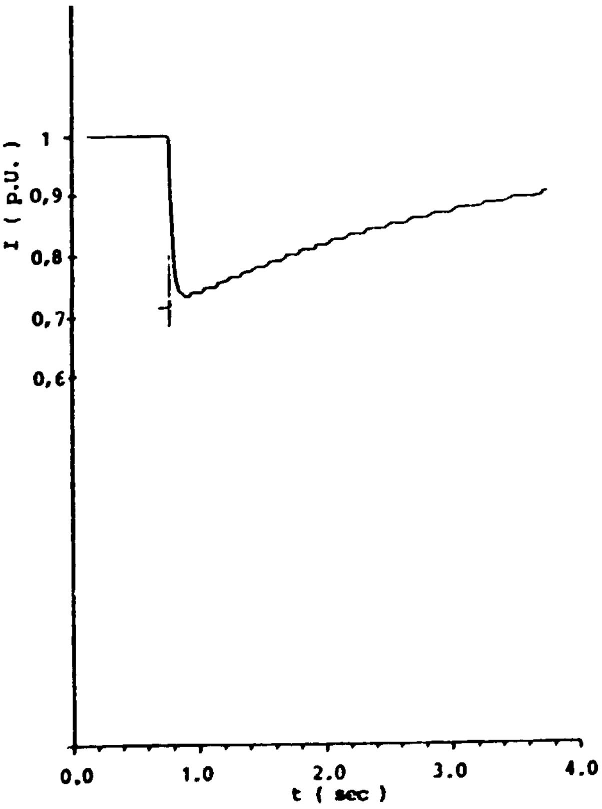

Figure 4 Field current at cancellation 3 ≈ short circuit

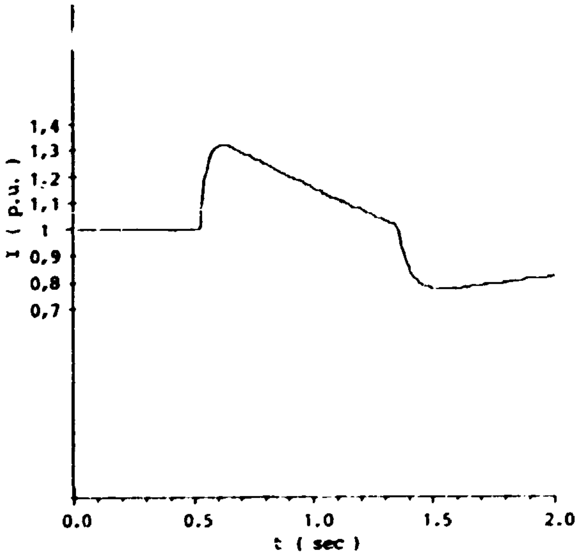

Figure 5 Field current at short circuit with influence of control

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Magnetic resonance imaging of the process of freezing and thawing in bulk tissues

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1. Introduction

Freezing is an important preservation technology. Modelling of the freezing process is important to help increase understanding of the mechanisms involved. In order to model the process, data are needed relating to the extent of freezing. This requires the use of thermocouples to follow temperature change, and calorimeters to measure heat content. It would be useful to have a rapid, non-invasive method to supplement these traditional methods. Magnetic resonance imaging, long used in medicine, provides a potential method to achieve this. We are performing experiments to evaluate the capabilities of MRI applied to freezing studies.

2. Material and methods

A variety of samples have been frozen in the imaging cavity of a GE machine. In the initial experiments, 1/ the freezing process has been achieved simply by adding dry ice to the top of the sample in container insulated on all other sides. Thawing has been achieved by exposing the frozen sample, still in the insulated container, to room temperature air. Images of the system have been generated at different times during the process. False colour images, in which colour indicates proton mobility, with red being most mobile, and blue least mobile, have been prepared. Due to the success of these initial experiments, more controlled freezing has been obtained by delivering cold air, at a preselected temperature and velocity, to a chamber in the magnet cavity. A Frigoscandia Research Freezer was used to provide this cold air. Insulated ducting was utilized to route the air through the magnet cavity, and back to the freezer. An access hatch allowed the sample to be located in the imaging position, with the air circulation diverted. Experimentation showed that a sample with embedded thermocouples can be imaged, without too much loss of image quality. Freezing and thawing are followed. Once again, a variety of images have been generated at preselected times during the entire process.

The freezer configuration allows for the rapid removal of a test sample at any time during the freezing process. Thus, calorimetric determination of the product enthalpy at times which correspond to particular images, and positions of the freezing front, is possible. Calorimetric data have been obtained already to correspond with some of the images. Full details of the procedures will be reported once the study has progressed further.

3. Results and discussion

In the MRI images, presented as slides and/or videotape the freezing interface can clearly be seen. Thawing can be seen not to be the reverse of freezing. A video programme which shows the progress of freezing under various conditions, and which also shows the progress of thawing, will be shown. The MRI images indicate the progress of the freezing front. The location of the freezing front can be readily compared with the measured temperature history provided by the embedded thermocouples in selected samples. The freezing front is indeed accurately located by the MRI image. Predictions of the behaviour of the freezing front are in the process of being generated using various computer models of the freezing process. The value of the different models will be compared. There is strong evidence for the existence of an undercooled region preceding the freezing front. 1/ This is not taken account of in models, and might be expected to lead to some discrepancies. The predictions of the computer models can be further checked by comparing the predicted enthalpies to the measured enthalpies from the calorimetric procedure. The work is in an early stage, but it should allow us to better characterize the processes of freezing and thawing.

4. Conclusion

MRI is a valuable new technique for the monitoring of the freezing process. Already, MRI experiments lead us to question the validity of existing models of the freezing process. There appears to be undercooling in the medium just prior to the passing of the freezing front, in rapid freezing conditions. The video sequences which can be put together with MRI images lead to a better appreciation of the complexities of freezing and thawing. By combining MRI, calorimetry and computer modelling we will improve our understanding of the freezing and thawing processes. This should lead to improvements in future technology, and control systems.

5. Acknowledgement

We thank Frigoscandia Inc. for the loan of a laboratory freezer.

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Multi-squid magnetometers for neuromagnetic research

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Some of the basic concepts of magnetoencephalography and neuromagnetic instrumentation are reviewed. State-of-the-art multichannel SQUID magnetometers, with more than 20 SQUIDs, are presented. An example of magnetoencephalographic experiments with such an instrument is given.

Introduction

The human brain can be studied in vivo through several windows provided by modern imaging techniques. Computer-assisted X-ray tomography (CT) and magnetic resonance imaging (MRI) offer high quality but static views into the anatomical structure. Functional information about the brain on a time scale of minutes or seconds can be obtained with regional cerebral blood flow (RCBF) and positron emission tomography (PET) measurements, based on changes in cell metabolism and indicated by radioactive tracers. All these methods allow studies of the brain without opening the skull, but they are not totally non-evasive because the subject is exposed to X-rays, magnetic fields, or radioactive substances.

Magnetoencephalography (MEG), the study of the weak magnetic fields generated by the human brain, typically of 50 - 500 fT amplitude, is a completely non-evasive and powerful tool for locating sources of cortical activity. The method offers good spatial and temporal resolution, on a millimetre and millisecond scale, making it possible to find the position of sources not revealed by electroencephalography (EEG), (1) which is another fully non-evasive method, known for a long-time.

In a typical magnetoencephalographic experiment, the subject receives some sensory stimuli, e.g., short tones. Following the stimulation, several tens of milliseconds later, specific areas of the cerebral cortex are activated, and a rapidly changing magnetic field can be recorded. On the basis of the spatial field distribution it is possible to locate the cortical area which was elicited by the stimulus.

So far, neuromagnetic measurements have been largely carried out by means of instruments utilizing only a few SQUIDs. At present, new developments in SQUID technology have allowed the introduction of systems using tends of SQUIDs. Such devices, allowing for more complex and sophisticated experiments, are soon commercially available. This paper reviews briefly the basic concepts of MEG and presents some state-of-the-art instruments.

Basic principles of neuromagnetism

Information from one neuron to another, via a synapse, is mediated by the release of transmitter molecules, which increase the ionic permeability of the postsynaptic cell membrane. As a result of the interaction between chemical and electrical gradients there is a net current flow through the membrane and a change in the voltage, the so-called postsynaptic potential (PSP). If the sum of PSPs received by a neuron exceeds a certain threshold, an action potential is created and it propagates along the axon to make synaptic contact with the next neuron. For a detailed description of neural electrical events see, for example, Reference (2).

To a first approximation, PSP is like an intracellular current dipole, oriented along the dendrite, and the action potential may be described by means of a current quadrupole. Magnetic fields detectable outside of the head are produced only when a large number of neurons act in concert: typically, the strength of a PSP current dipole is 10^{-14} Am (1). The observed magnetic fields are believed to be largely due to PSPs in pyramidal cells, which are perpendicular to the cortex. Fields due to other neurons, being randomly oriented, tend to be averaged out. The field due to an action potential, being quadrupolar, diminishes more rapidly as a function of distance. In addition, the action potentials last only a few milliseconds whereas the duration of the dipolar PSPs is an order of magnitude longer.

Currents flowing in neural tissue are customarily divided into intracellular primary currents Jp and volume currents $Jv = \sigma(r)E(r)$, where $\sigma(r)$ is the conductivity of the tissue and $E(r)$ is the electric field. Both $\sigma(r)$ and $E(r)$ must be regarded on a macroscopic length scale, on the order of 1 mm. The primary currents are usually approximated by one or by a few current dipoles in a conducting body, e.g. in a sphere with a conductivity profile $\sigma(r)$. A spherically symmetric geometry has several important consequences: (1) Radial dipoles and their volume currents cancel each other and thus do not generate any magnetic field outside the conducting body; (2) The radial component of the magnetic field is produced by the primary current density only, and (3) Both radial and tangential field components are independent of $\sigma(r)$ [1, 3].

The fact that radial dipoles cannot be seen in MEG is not a serious drawback since most of the cortical surface is in the fissures. Because the pyramidal cells are oriented perpendicular to the cortex, the flow of the primary current in fissures is tangential to the surface of the head.

Although the tangential field components have non-zero contributions from the volume currents as well, their usefulness or that of other than axial derivatives $\partial B_z/\partial$ is not reduced. [1] The effect of volume currents is such that the tangential field component outside the conductor can be obtained without explicit reference to volume currents, as long as spherical symmetry is maintained.

The widely used spherical conductor model is, of course, a crude approximation of the human head. In a series of simulations [4] the magnetic fields were compared using three different volume conductor models: (i) a realistically shaped three-layer model, consisting of the brain tissue, the skull, and the scalp, (ii, a homogeneous body having the shape of the inner surface of the skull, and (iii) the sphere model. Neglecting the skull and the scalp in the second model seems justifiable, since the conductivity of the skull is almost two orders of magnitude smaller than that of the brain tissue and the scalp. It was found that in regions with no abrupt changes of local curvature, e.g., in the occipital or parietal areas, the sphere model gives the correct field values to a few per cent, with the radius of curvature fitted to the local curvature. In the frontotemporal area, where the deviation from sphericity is large, the spherical model fails to reproduce the correct field pattern. However, the homogeneous head model is an excellent approximation even there. Since the potentials need not be found on the skull or the scalp the homogeneous model is computationally less demanding than the full three-layer model.

The previous calculations also illustrate the relation of MEG and EEG. The measured magnetic field is caused by currents that flow along approximately undistorted paths in the brain tissue where the current dipole is located, while the scalp potentials measured in EEG suffer from distortion caused by local irregularities in the extracerebral conductivities. This fact largely explains the better locating accuracy of the MEG method.

During measurements of evoked responses, i.e., the fields elicited following peripheral stimulation, it is common to assume that the measured signals consist of the correct value plus Gaussian noise. The signal-to-noise ratio is augmented by averaging multiple, typically 100, evoked responses. The MEG data are normally viewed by plotting the isocontour maps of the field distribution, sampled at 20-50 points, as a function of time. A simple field pattern can often be accounted for by a current dipole, the parameters of which are found by a least-squares fit. Thus, one may trace the equivalent source location with a millisecond resolution.

In the mathematical analysis the estimates of the equivalent dipole parameters are random variables with the mean coinciding with the true dipole. By evaluating the confidence intervals for the dipole parameters, one may obtain a quantitative measure of the reliability of the estimates. A signal current dipole in a spherical conductor has five parameters, three position coordinates and two strength components in the tangential plane. The confidence limits are generally largest in the radial direction, i.e. the depth, and the smallest in the direction perpendicular to the dipole in the tangential plane.

Instrumentation

The SQUID magnetometer (5) is the only device of sufficient sensitivity for neuromagnetic studies. The external field to be measured is normally coupled to the SQUID, which is sensitive to the magnetic flux threading it, via a superconducting flux transformer, consisting of a pickup coil and a signal coupling coil in series.

Since the environmental noise in a normal laboratory is several orders of magnitude greater than the signals of interest, precautions are needed. The flux transformer is normally made gradiometric, by connecting an oppositely wound compensation coil in series with the pick-up coil, and the measurements are carried out inside a magnetically shielded room, constructed either from several layers of high-permeability mu-metal and of high-conductivity material or having only the latter which works as an eddy-current shield. In an unshielded environment a second-order gradiometer must normally be used. Even in shielded rooms, magnetometers are rarely practicable because of vibrations in the remanent field and because of local noise sources, including the heart of the subject; first-order gradiometers, however, are sufficient.

In a first-order gradiometer, with the base length long compared with the average distance from the source, the effect of a compensation coil placed in the axial direction is only to cancel the far-away external disturbances which cause almost uniform fields; thus, the output is essentially proportional to the magnetic field due to the neuromagnetic source itself. In a second-order gradiometer, the signal is attenuated. Instead of the axial derivative $\partial B_z/\partial_z$, the tangential derivatives $\partial B_z/\partial x$ and $\partial B_z/\partial y$ can be utilized as well. The advantages of the latter type of gradiometers is their flatness and the possibility to fabricate them in thin-film techniques.

A major step forward in the development of magnetometers was the introduction of reliable, very low-noise DC SQUIDs with tightly coupled input coils and with flux sensitivities well below $10^{-5}\ \Phi_0/\sqrt{\mathrm{Hz}}$. The SQUID itself is no longer the dominating source of noise; it has been possible, for example, to push the magnetometer noise below the thermal noise of the dewar radiation shields. Thus a modern neuromagnetometer system detects fields smaller than 10 fT/$\sqrt{\mathrm{Hz}}$ or gradients less than 10 fT/(cm$\cdot\sqrt{\mathrm{Hz}}$), $1/f$ noise onset is below 1 Hz, or even below 0.1 Hz. Values of the slew rate, bandwidth, and gradiometer balance, high enough to meet all practical requirements, are easily achieved, at least in properly shielded environments.

The ability to record the field at many positions simultaneously, without the need of moving the dewar, is important not only to speed up MEG measurements but also to get more reliable data. In a long experimental session, during which the magnetic field is mapped by scanning over the head, the evoked responses may not remain constant because of fatigue in the subject. Moreover, the study of spontaneous processes in the human brain cannot be based on an assumption of signal reproducibility; these measurements must be made in real time.

In designing a multichannel system, factors of concern are the sensor type, the sensor size, their noise level, and their distribution, as well as the coverage of the head. Because of the large variety of the possible source current distributions in the human brain, general criteria of optimality do not exist; assumptions about the signal sources and their characteristic field distributions must be made. In general, one has to calculate the signal-to-noise ratio of channels, taking into account the distance of the sensors from the head and their separation. Channels very close together measure mostly the same field aspects and thus do not add, in proportion to their number, to the information conveyed by the system. Some figures-of-merit used in these calculations are the accuracy of locating a current dipole [6, 7] and information-theoretical channel capacity of magnetometers [8].

State-of-the-art multichannel systems

Until now, MEG measurements have been carried out using instruments having only 4-7 channels. These first and second generation instruments have been reviewed in detail in Ref. [9]. Quite recently, third generation magnetometers with 20 and more channels on an area more than 10 centimetres in diameter have been introduced. In Helsinki University of Technology, a 24-channel planar gradiometer system is now in routine use [10]; 37-channel axial gradiometers have been announced by two commercial manufacturers [11, 12]. In addition, a commercial two-dewar 2·14-channel system has been developed [13], and 19-channel systems are being built [14, 15].

The 24-channel gradiometer in the Helsinki University of Technology

The 24-channel system was completed in Helsinki in 1989. It has twelve 2-gradiometer units, each measuring the off-diagonal derivatives $\partial B_z/\partial x$ and $\partial B_z/\partial y$, see figures 1 and 2 (page 28). The units, spaced 30 millimetres from each other, are located on a spherical cap with a diameter of 125 millimetres and a 125-millimetre radius of curvature. The SQUIDs, fabricated by the IBM [16], are mounted on a conical former above the wire-wound coils. The sensor array is housed in a dewar with a curved and tilted bottom with a capacity of 10 litres of liquid helium; this gives a three-day period between refills. The distance from the sensors to the outside of the dewar is only 15 millimetre.

The device uses conventional flux-locked loop electronics with a modulation of 90 kHz applied in phase to all channels. The resonant impedance matching transformers are located in the pot-belly of the dewar and the preamplifiers, in groups of eight, are on top of the cryostat in detachable aluminium boxes. The detector-controller units, each on a Euro-1-sized printed-circuit board, are outside of the shielded room in an RF shielded cabinet. The equivalent gradient noise of the system is 3-5 fT/(cm·$\sqrt{\text{Hz}}$).

Figure 3 (see page 28) gives an overview of the whole measurement system. The magnetic signals from the SQUID electronics are anti-alias filtered, digitized with a HP3852 data-acquisition unit (DAU) and stored in a HP1000 A900 computer, which controls the measurement and calculates averages on-line. For later analysis, the data are transferred to a HP835 computer via a local-area network In addition, the system includes a commercial 32-channel EEG amplifier.

The data-acquisition unit controls also stimulation and a system to determine automatically the location and orientation of the gradiometer with respect to the head. The probe position indicator (PPI) is based on three small coils, placed at known positions on the head; these coils are energized sequentially and the signals are measured with SQUIDs; the location information can then be obtained with a least-squares fit.

An example of measurements carried out with this instrument is showing in figure 4 (page 29). In the experiment, all fingers were sequentially stimulated electrically. The equivalent dipoles of various fingers, spaced only a few millimetres apart from each other, demonstrate the resolution of the method. More examples about magnetoencephalographic studies can be found, e.g., in recent review articles [17, 18].

The Siemens 37-channel "Krenikon" system

Figure 5 (page 29) shows the schematic layout of the pick-up coils of the 37-channel axial gradiometer manufactured by Siemens Ag [11]. The hexagonal array of hexagonal coils was fabricated by using printed circuit techniques. The coils are all in plane inside a 20-cm-diameter circle. The system includes 3 additional magnetometers to measure the x-, y-, and z-components of the field for noise cancellation. The SQUIDs are in four separate superconducting shields on chips, each having ten dc SQUIDs. The noise of the system is less than 10 fT/$\sqrt{\text{Hz}}$ at frequencies over 10 Hz. The flat-bottom dewar, especially suitable for cardiologic measurements, has a rather large distance of over 25 millimetres to the brain. The probe position is read mechanically; the subject bites a plate fixed to the measurement system.

The BTi 37-channel gradiometre

The 37-channel system manufactured by BTi Corp. [12] has a hexagonal coil arrangement as well, but now the round coils, with diameters of 20 millimetres and spaced 22 millimetres apart, are located on a curved spherical cap with 120-millimetre radius of curvature. In addition of the wire-wound 37 first-order gradiometres, there are 8 additional SQUIDs for noise cancellation. For the PPI system, BTi uses separate receiver and transmitter coil sets consisting of three orthogonal coils. They constitute an inductive magnetometer operating roughly at 10 kHz. The noise of the system is 10-20 $\mathrm{fT}/\sqrt{\mathrm{Hz}}$.

The Dornier two-dewar system

The 2·14 channel rf SQUID system delivered by Dornier GmbH [13] to University of Ulm utilizes a different approach. It has two dewars with roughly D-shaped curved bottoms to be positioned as close to each other as possible with the straight sides adjacent (see figure 6, page 29). Each dewar has a magnetometre array with the coils wound on 16 cubic coil formers, spaced 20.5 millimetres, having coils in all orthogonal directions. They are connected to SQUIDs via a switching matrix which, when the device is warmed up, allows one to choose any 14 coils to be measured. A gradiometric response of the device is formed by calculating differences electronically. The equivalent noise of the magnetometres is 15 $\mathrm{fT}/\sqrt{\mathrm{Hz}}$ and that of the gradiometers 21 $\mathrm{fT}/\sqrt{\mathrm{Hz}}$. The radius of curvature of the dewar bottom is 118 millimetres.

Conclusion

It is expected that within the next few years, fourth-generation neuromagnetometres that cover the whole head, with more than 100 channels, will be introduced. Several such projects have been announced, for example in Japan and in Finland. The magnetoencephalographic method itself is well-established, providing good spatio-temporal resolution and complete non-evasiveness. However, the clinical applications of MEG have not yet emerged in a larger extent. The introduction of the next-generation devices will certainly speed up this development considerably.

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* * * * *

The mercurial rise of a superconductor

A new superconductor, which contains mercury and is easy to make, has been demonstrated by an international team of scientists. The team believes that similar materials will become superconductors - that is, lose all electrical resistance - at a temperature as high as 125 kelvins (-148° C), the highest known transition temperature for a superconductor.

The superconductor, which loses its resistance when cooled below 94 K (-179° C), is made of layers of copper oxide, interspersed with layers of mercury oxide and barium oxide. It has a similar structure to the material with the highest known superconducting transition temperature, except that it has fewer layers of copper oxide and contains mercury instead of thallium.

Massimo Marezio of CNRS, Grenoble and AT&T Bell Laboratories, Murray Hill, New Jersey, and a team from Russia, France and the US, mixed barium copper oxide with mercury oxide and baked them at 800° C for five hours. A variant of the mercury compound with more copper oxide layers could reach the record superconducting transition temperature.

The basic building block, or unit cell, of the compound is $HgBa_2CuO_4$. It contains a layer of copper oxide, followed by layers of barium oxide, mercury oxide and barium oxide. The structure of the compound is also denoted as Hg-1201, where the figures represent the numbers of mercury, barium, calcium or yttrium, and copper atoms.

In contrast, the thallium version of the 1201 compound, $T1Ba_2CuO_6$, becomes superconducting only below 10 K (-263° C). Several groups of researchers believe that replacing the thallium in other superconductors with mercury could produce compounds with much higher superconducting temperatures.

Thallium-1212 or $TiBa_2CaCu_2O_7$ becomes a superconductor at 85 K (-188° C), so Hg-1212 is an obvious compound to make and test. But Marezio says his team has not yet found the right recipe for making it. The presence of calcium is a problem. From the chemical point of view, it is very difficult to make a calcium and mercury compound. Mercury is a funny element - it is volatile and [disappears]. We need to hit the right thermodynamic conditions.

Marezio and his colleagues have already made a variant on Hg-1212 with yttrium instead of calcium, but it did not become a superconductor. However, the researchers believe the calcium material is more likely to become a superconductor because of the way its electronic charges are distributed in the molecule.

Scientists at the Interdisciplinary Research Centre in Superconductivity at the University of Cambridge, together with BICC Cables and GEC, have also spent the past year working on a variety of mercury compounds. Yao Liang, the centre's director, says they are gradually replacing the thallium atoms with mercury.

The researchers at Cambridge, led by Tim Beales of BICC, have made a 1212 compound, but with strontium instead of barium, calcium and yttrium instead of calcium, and a mixture of mercury and lead taking the place of the thallium. Liang says the material begins to superconduct at 92 K (-181° C), but its exact chemical structure is still being worked out. (Source: *New Scientist*, 27 March 1993)

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New cuprate superconductor

A research team of Professor J. Akimitsu of Aoyama Gakuin University and Professor T. Hirai of the Institute for Materials Research, Tohoku University, has synthesized a new cuprate superconductor. The transition temperature was about 63 K, about 40 K higher than the conventional Nb_3Ge superconductor.

Recently, to classify all existing cuprate superconductors, the concept of block layers representing the intervening components between the CuO_2 planes was proposed. These block layers are important in structure stabilization and in adjusting the carrier density in the CuO_2 sheets. It is crucial to find the new block layers because combination of new and "old" block layers may form a new superconductor structure by appropriate carrier doping.

A cuprate superconductor $(Ba_xSr_{1-x})_2$-$Cu_{1+y}O_{2+2y+d}(CO_{3)1-y}$ with T_c(onset) up to 40 K and zero resistance at up to 26 K was synthesized, demonstrating the existence of a new type of block layer containing CO_3, suggesting the possibility of other higher-T_c superconductors.

The newly developed cuprate superconductor has a crystal structure of $(C_{0.4}\text{-}Cu_{0.6})Sr_2(Y_{0.86}Sr_{0.14})Cu_2O_7$ and achieved a T_c(onset) up to 66 K and zero resistance at up to 37 K.

It was synthesized from $SrCO_3$, $CaCO_3$, Y_2O_3 and CuO powders. The powder mixtures were pressed into pellets and fired at 1,050° C for 15 h under a flow of O_2(80%)-CO_2(20%) and quenched to room temperature. After calcination, an autoclave furnace for hot isostatic pressing was used to anneal the samples at 700° C for 30 h in 99.9%O_2 plus 0.1%CO_2 at a total pressure of 10 MPa.

The resistivity measurements were carried out by the standard four probe d.c. method. Resistivity decreases slowly with decreasing temperature, showing the metallic nature of this system, with a slight upturn just before the critical temperature. The onset temperature T_c(onset) is ~ 66K and T_c(zero) is 37K. The highest T_c was obtained for a composition around $(Y_{0.5}Ca_{0.5})_{0.95}Sr_{2.05}Cu_{2.4}(CO_3)_{0.6}O_y$.

Magnetic measurements with a SQUID magnetometer showed the temperature dependence of magnetic susceptibility under 10 Oe field cooling and zero field cooling process. T_c determined from the magnetic susceptibility measurements (T_c ~ 63K) was a little lower than that determined by measuring the resistivity of the sample.

A double periodicity superstructure along the a- and c-axis was clearly demonstrated by high resolution transmission electron microscopy (HRTEM). The origin of the superstructure is mainly due to the structural modifications at the basal CuO layers. Regions of strong and weak dark contrast were clearly observed alternately along the basal Cu-O planes. The research team considers that these characteristic image contrasts are due to periodic replacements of Cu sites with the CO_3 group at the basal planes. So, the regions of light contrast are considered to be the CO_3 sites.

(Aoyama Gakuin University, College of Science & Engineering, 6-16-1, Chitosedai, Setagaya-ku, Tokyo 157. Tel: +81-3-5384-1111, Fax: +81-3-5384-6100) (Source: *JETRO*, October 1992)

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Niobium-aluminium superconductor for large currents and intense magnetic fields

The Japan Atomic Energy Research Institute, with the cooperation of Sumitomo Electric Industries Ltd., has commercialized a niobium-aluminium (Nb_3Al) superconductor operating with a current as large as 40,000 A for producing the high magnetic field superconducting magnets essential for the building of nuclear fusion reactors.

The superconducting magnet is used for containing the ultra-high temperature nuclear fusion plasma at about 200 million degrees centigrade, and accounts for about one third of the cost of constructing a nuclear fusion system. This superconducting magnet is massive (height: 17 m) and works with an intensive magnetic field of about 12 T, so the electromagnetic force applied on a single magnet may be as much as 40,000 t. This intense force will deform even the most rigid magnets, so the generation of about 0.4 per cent strain is regarded as unavoidable.

Previously, only niobium-tin alloy was used to produce superconductors for superhigh-intensity magnetic fields of over 10 T, but the superconductivity is deteriorated substantially by the stress distortion. Niobium-aluminium is well known as a superconducting material with excellent stress distortion resistance, but the conventional niobium-aluminium superconductor requires heat treatment at temperatures as high as about 1,500° C, with the result that adequate superconductivity cannot be obtained, making commercialization of the alloy difficult.

The new conductor is produced by first layering niobium foils and aluminium foils, rolling the lamination on a copper bar, then inserting the bar into a copper pipe and drawing into wire. Five hundred and eighty-eight of these wires are bundled together, inserted into a copper pipe, then drawn into an element wire of 1 mm diameter. Four hundred and five element wires are bundled and inserted into a cupro-nickel pipe, then heated to obtain the superconducting material.

To solve the stress-distortion problem in this manufacturing process, the thickness of the niobium and aluminium foils are less than 0.1 μm and joined snugly, while a new technique was devised to bond the two materials together by two-stage heat treatment, so the heat treatment temperature was lowered to 800° C.

Tests conducted on the superconductor at the Japan Atomic Energy Research Institute corroborated that superconductivity is retained even when the conductor passes a current as large as 40,000 A in an intense magnetic field of 12 T. Also, measurements of the critical current property showed that deterioration in the maximum passable current value in the superconducting state is only 5 per cent with a stress distortion of 0.4 per cent. This deterioration ratio is only one sixth that of a niobium-tin conductor (30 per cent) under identical conditions.

The commercialization of this niobium-aluminium conductor, highly resistance to stress distortion and capable of working in an intense magnetic field, will be important not only in the sector of nuclear fusion but also for the realization of electric power storage systems requiring large-capacity magnets, performance and reliability improvement of particle detection magnets used in high-energy physics research, and for the development of medical diagnosis systems using highly intense magnetic fields.

(Japan Atomic Energy Research Institute, 801-1, Mukoyama, Naka-machi, Naka-gun, Ibaraki Pref. 311-01. Tel: +81-292-70-7214, Fax: +81-292-95-1549). (Source: *JETRO*, October 1992)

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Yttrium-based superconducting pellet with excellent magnetic repulsion

Shikoku Research Institute Inc., under consignment from Shikoku Electric Power Co. Inc., has succeeded in developing a yttrium-based superconducting pellet. The pellet with 55 mm diameter and 17 mm thickness features a magnetic levitation force of 20 kgf at liquid nitrogen temperature when closed up with a permanent magnet having 36 mm diameter and 5,500 G surface flux density. This is 1.5 times the maximum force recorded previously. Using the superconducting pellet, a 100 Wh-class power storge system is now under development.

When a magnetic field is applied on a superconductor, quantized magnetic flux infiltrates inside and the line of magnetic flux is captured in the non-superconductor crystal particles. The larger the crystal particles inside ths uperconductor and finer the non-superconducting substances dispersed, the stronger this pinning effect becomes.

Up until now, the levitation force generated by using permanent magnets and superconducting pelets was limited to 13 kgf. The present melt-pulverization-melt-growth (MPMG) process was improved, the blend of raw materials such as yttrium, barium and copper changed, and the cooling method improved to make the crystal particles larger after melting. As a result, the diameters of the crystal particles inside the superconducting pellets, which were 10-20 mm by the conventional process, have been enlarged to a diameter of 4 cm and thickness of about 1 cm by the new process.

The future plan is scaling up the 100 Wh-class power storage system to the 1 kWh-1,000 kWh class. (Shikoku Research Institute Incorporated, 2109-8, Yashimanishi-machi, Takamatsu City, Kagawa Pref. 761-01. Tel: +81-878-43-8111; Fax: +81-878-41-6972) (Source: *JETRO*, February 1993)

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Superconducting wire with high critical current density

Toshiba Corporation and Showa Electric Wire and Cable Co. Ltd. have jointly developed a bismuth-based oxide superconducting wire with a maximum critical current density of 66,000 A/cm^2 at the temperature of liquid nitrogen (-196° C).

Previously, the wire surface was vapour-deposited with a thin film of superconducting material, achieving a critical current density of over 100,000 A, but since the material is on the wire outside, the wire was brittle, preventing commercialization. The new superconducting wire substance is coated with silver, making the wire highly promising for commercialization.

The new superconducting wire is produced by the powder-in-tube method of processing the wire by filling a silver tube with an oxide powder. The silver tube has a width of 2 mm, thickness of 0.07 mm, and an oxide powder is filled inside, after which the tube is drawn and rolled, then heat treated and pressed into a wire.

The extra-high critical current density was attained by: (1) filling the oxide powder uniformly and in high concentration, (2) improving the wire drawing and rolling processes to improve the smoothness and crystal particle orientation at the boundary where the silver tube and oxide material come into contact, while the electrical bonding between particles has been strengthened to improve the current flow efficiency, and (3) adjusting the composition of the filled oxide material, improving the superconductor ratio and minimizing the non-superconductor ratio which reduces the current flow.

The research team is currently engaged in further research to commercialize the wire for use in the manufacture of superconducting coils. (Toshiba Corporation, Public Communications Office, 1-1-1, Shibaura, Minato-ku, Tokyo 105. Tel:+81-3-3457-2100, Fax:+81-3-3456-4776) (Source: *JETRO*, February 1993)

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Superconducting flywheel system for energy storage

The Superconductivity Research Laboratory, in collaboration with Nippon Seiko KK, has developed a prototype superconducting flywheel system which can store about 700 J of energy and can be used for running miniature trains.

A flywheel is a simple device to store energy in the form of kinetic energy by rotation but has not been widely used as an energy storage system because stored energy is dissipated in a relatively short time due to friction at the rotation axis.

Recently, it has been found that a ring magnet can rotate without friction, when levitated by superconductors. The researchers have already succeeded in fabricating YBaCuO-based superconductors with large pinning forces. Such superconductors contain fine Y211 inclusions, which are considered to act as pinning centres. Strongly pinned superconductors can repulse a very strong magnetic field, allowing a large flywheel to be made.

The flywheel consists of an aluminium disk (270 mm in diameter and 7.5 kg in weight) where small Fe-Nd-B magnets are embedded concentrically and 19 MPMG (melt-powder-melt-growth) processed YBaCuO superconductors (40x40x16 mm) are cooled by liquid nitrogen. The disk can rotate at 1,200 rpm using an induction motor and the stored energy is discharged by a simple generator.

The researchers will build a larger similar flywheel system which can store more energy and use a vacuum chamber to prevent energy loss by air friction. (Superconducting Research Laboratory, International Superconductivity Technology Center, 1-10-13, Shinonome, Koto-ku, Tokyo 135. Tel:+81-3-3536-5703, Fax:+81-3-3536-5717) (Source: *JETRO*, February 1993)

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Active control type superconducting magnetic bearing system

Koyo Seiko Co. Ltd. has developed a superconducting magnetic bearing system using active control, which succeeded in supporting a rotating 70-mm diameter, 2.5 kg rotor shaft at 42,000 rpm with no mechanical contact with an yttrium superconductor, and the rotational energy extracted as electric power.

Ever since the superconductor was discovered, attention has focused on non-contact rotation, and its application to vacuum pumps and energy storage systems with flywheels has been proposed. Using permanent magnets and superconductors for non-contact rotation requires attenuating the rotational runnout, caused by non-uniformity of flux density, and the rotation loss, prevention of frost formation when cooling with liquid nitrogen, and economical methods for using liquid nitrogen.

In these respects, the new superconducting magnetic bearing system adopts the hybrid structure using superconducting bearings and active control radial magnetic bearings, which enables non-contact, high-speed control when any rotational runnout is generated in the rotor. The system also incorporates an initial-gap positioning device. It can maintain the rotor at the prescribed position until the superconductor is cooled with liquid nitrogen and non-contact levitation becomes stable by the pinning force. In addition, a cryostat is mounted that supplies the liquid nitrogen used for superconductor cooling and the rotational part is accommodated in low vacuum chamber to prevent frost formation at the levitation gap.

The new superconducting magnetic bearing system is capable of suppressing to the practical level of 4 μm the rotational runnout that was a problem up until now (several tens to several hundred micrometres).

The maximum rotational speed of the system exceeds 42,000 rpm. This is the limiting value due to the tensile strength of the rotor magnet under centrifugal stress, and is not a problem associated with the superconducting magnetic bearing. At this speed, it was possible to extract an instantaneous power of roughly 50 W from the motor. The rotor shaft is not fitted with a flywheel, so the energy storage magnitude is rather small (1.8 Wh at 40,000 rpm), but it will be possible to increase the magnitude to 60 Wh by fitting a 5-kg flywheel, and to 200 Wh with a 16-kg flywheel.

(Koyo Seiko Co. Ltd., 3-5-8, Minami-Senba, Chuo-ku, Osaka 542. Tel: +81-6-271-8451, Fax: +81-6-245-7892) (Source: *JETRO*, February 1993)

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Low-loss superconducting wire for applications

Hitachi Cable Ltd. has developed a niobium-titanium (NbTi) superconducting wire for use with low losses.

The frequency is 50 Hz, the magnetic field amplitude 0.5 T, the loss 3.3 kW/m^3, and the transport current density 1,200 A/mm^2, twelve times the maximum allowable transport current density of a copper wire, and about double that of an ordinary superconducting wire.

The superconducting wire has an electrical resistance that becomes nil at D.C., but a loss is generated by being exposed to a fluctuating magnetic field. This problem must be solved for superconducting wire commercialization, but decreasing the loss is accompanied by the problem of the current capacity decreasing.

The new superconducting wire has a diameter of about 0.2 mm, the centre is copper and the periphery cupronickel, with the part between these two consisting of 54 blocks of a hexagonal superconducting material aligned in doughnut configuration, each block consisting of 85 sub-blocks.

In addition, each of these sub-blocks consists of 85 niobium-titanium alloy wires with a diameter of

0.1 μm, which are arranged equidistant inside a cupronickel alloy containing manganese. This suppresses the hysteresis and bonding losses which cause the loss.

This research project was advanced under consignment by the New Energy and Industrial Technology Development Organization (NEDO) as a link of the Moonlight Project of the Ministry of International Trade and Industry. (Hitachi Cable Ltd., Legal and Document Section, 2-1-2, Marunouchi, Chiyoda-ku, Tokyo 100. Tel: +81-3-5252-3261; Fax: +81-3-3214-5779) (Source: *JETRO*, February 1993)

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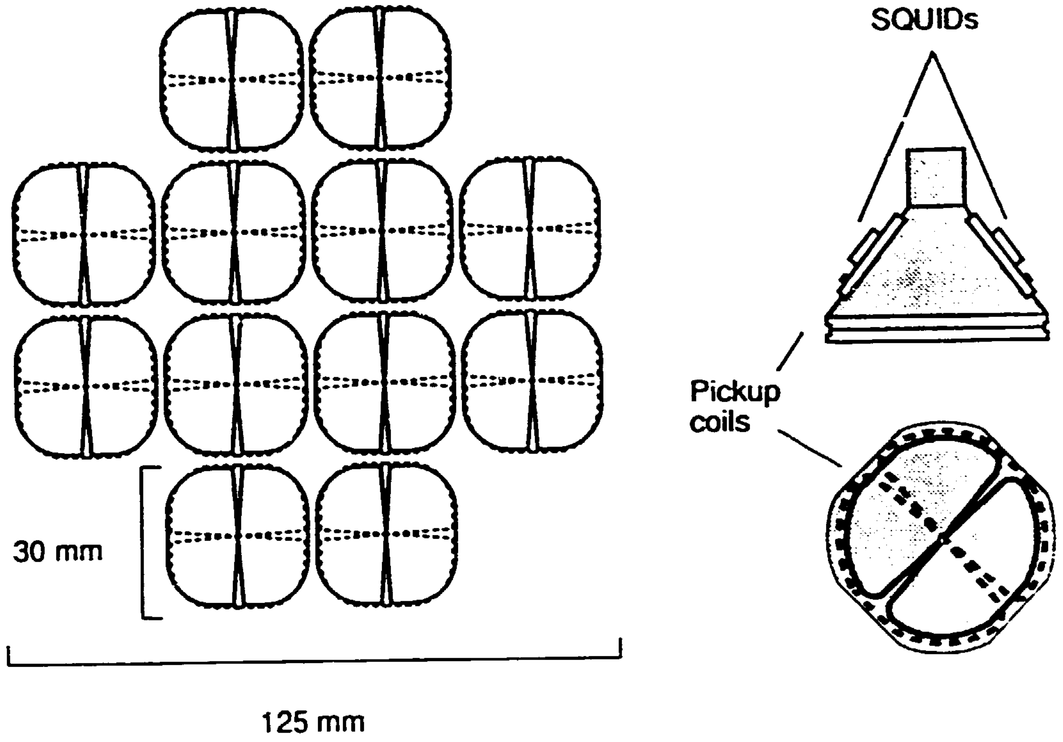


Figure 1. The coil arrangement of the 24-channel system in Helsinki. The two orthogonal pickup coils have been indicated with solid and dashed lines. The SQUIDs were provided by the IBM Thomas J. Watson Research Laboratory at Yorktown Heights, on the basis of a joint research program.

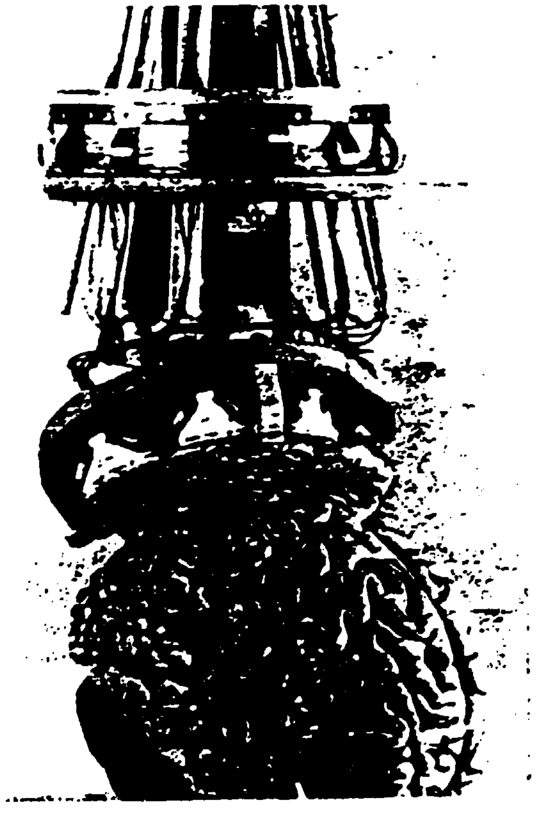


Figure 2. The 24-channel gradiometer above a plastic brain model

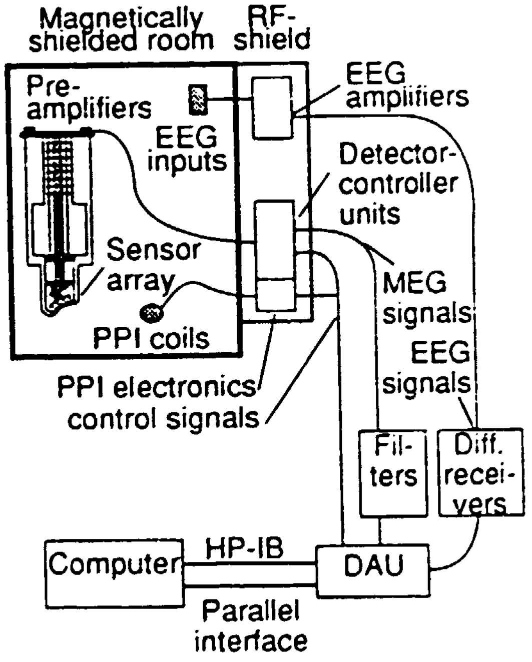


Fig. 3. Block diagram of the measurement system in use at Heisinki.

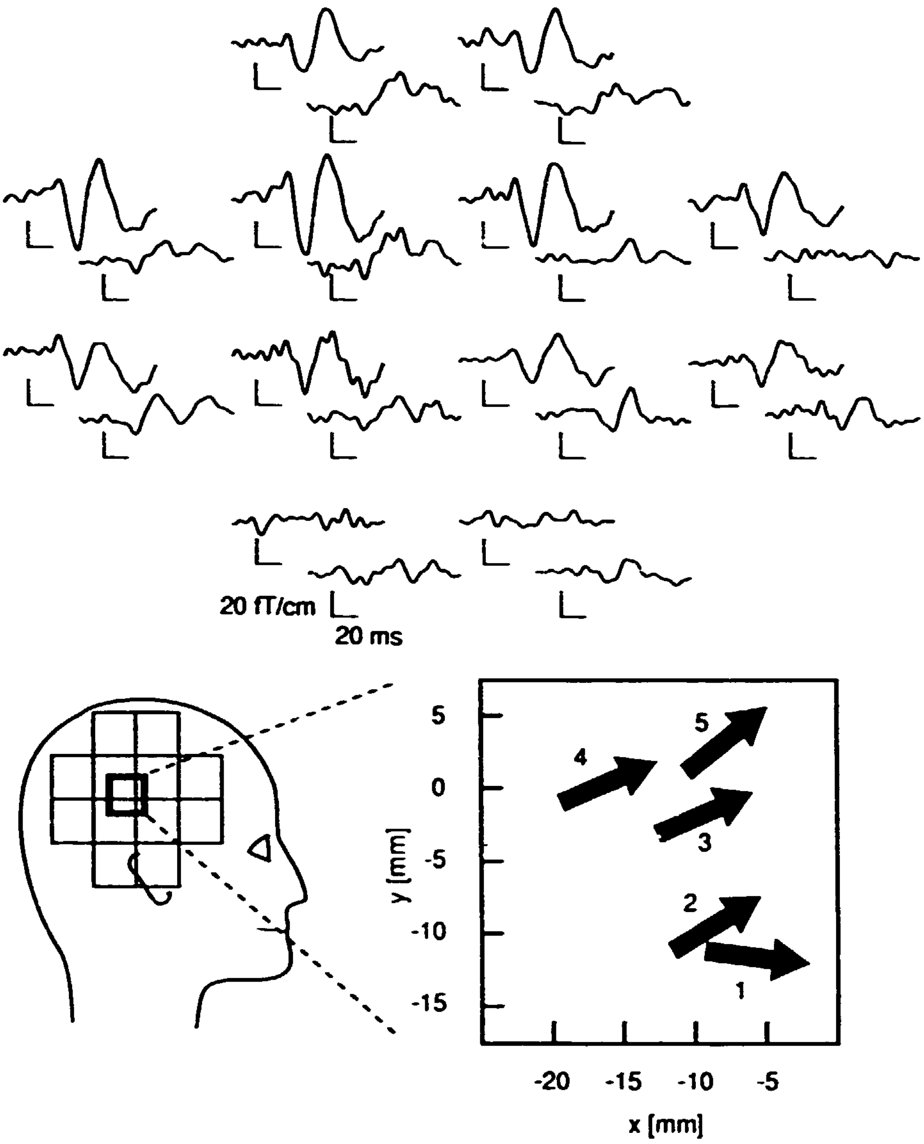
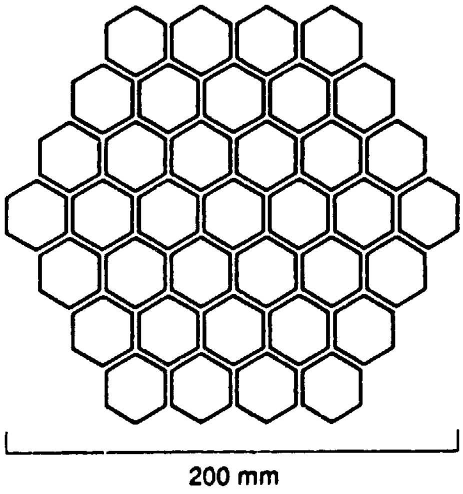


Figure 4. Responses to electric stimulation of the middle finger recorded with the 24-channel system in Helsinki. On the lower half of the figure, the equivalent dipoles elicited by stimulation of different fingers are shown 26 ms after the stimulus. The thumb is denoted by (1) and the little finger by (5).



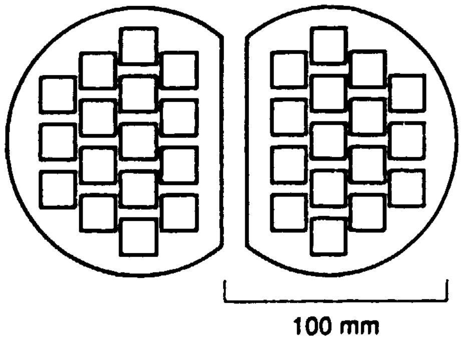


Fig. 5. Schematic view of the coil arrangement of the "Krenikon" system [11]. For details, see text.

Fig. 6. Coil arrangement of the Dornier system [13]. See text for details.

3. TESTING

Critical current and A.C. loss measurements of superconductors developed for the super-GM project under cyclic mechanically loaded condition

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Abstract

This paper describes the design philosophy of the test facility constructed at CRIEPI and the test results of critical currents and A.C. losses of superconductors for 200 MW-class generator rotor winding developed in the Super-GM project under a cyclic mechanically loaded condition. The facility can provide a sample current up to 15 kA, D.C. magnetic field up to 7T, 3 Hz of A.C. magnetic field up to ±0.9T, and compressive mechanical force up to 100 kN to simulate the centrifugal force of generator rotor winding. We evaluated the good performance of three types of NbTi superconductor under 10,000 applications of cyclic load.

I. Introduction

Development of a 200 MW-class superconducting generator is under way in Japan as the Super-GM project through funding supported by NEDO.[1] This work was started in 1988. The Central Research Institute of Electric Power Industry (CRIEPI) received a grant to test superconductors developed in Super-GM under circumstances which simulate actual rotor conditions, including mechanical roads. On the superconducting generator rotor, cyclic compressive force is applied to superconductors because a 200 MW-class generator will be operated under the daily-start-stop (DSS) condition.

CRIEPI has constructed a test facility to measure critical currents and A.C. loss of the superconductor, including several power supplies and a helium liquefier, at the Akagi Testing Centre.

Three types of superconductor developed in Super-GM for rotor winding [2] have already been tested, and showed good performances in the application to a 70 MW-class model superconducting generator.

II. Test facility

A. Test conditions

Testing conditions of critical current and A.C. loss measurement for the superconductors are determined by the design of the 70 MW-class model superconducting generator.[3] Major parameters of the conditions are shown in table 1. The maximum value of the sample current is determined to be 15 kA from the field winding operation current of 3 to 5 kA for the model machine. Amplitude and frequency of the A.C. magnetic field are determined to be ±0.9T and 3 Hz to simulate the field change in the generator rotor during power system line failures for low-response and high-response types of generator design. The maximum value of mechanical compressive force is determined by the calculated value of compressive force, 30 to 50 MPa, in the field winding of the model machine, including centrifugal force and electromagnetic force.

Determination of the critical current and A.C. loss of the conductors is followed by a test code locally determined in Super-GM.

Table 1

Testing conditions of the test facility

Magnetic field	DC 0-7T AC 0~0.9T (3 Hz)
Sample current	DC 0~15 kA
Mechanical compressive force	0~100 kN (2 Sec/cycle)

B. Samples

Different shapes of samples are used to measure the critical current and the A.C. loss of the same superconductor under mechanical force.

As for critical current measurement, a one-turn ring-type sample is used with separated upper and lower sample holders made of fibre-reinforced plastics (GFRP), as shown in figure 1 (page 35).

A.C. loss of the superconductor is measured with 20 to 40 turns of single-layer solenoid sample coil with current leads, having the same diameter as the sample for critical current measurement. The configuration of the sample holder for A.C. loss measurement is very similar to that for critical current measurement.

Compressive mechanical force can be applied to the sample in the direction of the axis of the single-layer solenoid, which corresponds to the transverse direction of the superconductor. The volume of the superconductor for A.C. loss measurement is determined by the sensitivity of the colorimetric method, 0.5 W to 1 W, and the rated A.C. loss of the conductor, 10 kW/m^3 to 30 kW/m^3. The sample is contained in an inner GFRP vessel to measure the helium vaporization rate due to A.C. loss independent of vaporization due to superconducting magnets and gas-cooled current leads.

C. Apparatus of the test facility

Superconducting magnets

D.C. and A.C. magnetic fields are both generated by superconducting magnets. The D.C. superconducting magnet, which generates 7T, has a rated current of 1135A and a clear bore 450 mm in diameter.

The A.C. superconducting magnet, which generates ±0.9T at 3Hz, has two windings. One is the main magnet wound in a clockwise direction. The other is a cancel magnet wound counterclockwise to minimize mutual inductance between the D.C. magnet and the A.C. magnet. Both magnets are operated in serial connection up to 92A. The terminal voltage of the A.C. magnet under rated operation is 4.5 kV. The induced voltage to the terminal of the D.C. magnet is below ±15 V during A.C. magnet operation. This induced voltage is compensated by a current supply to the D.C. magnet. Consequently, the amplitude of the D.C. magnetic field is kept constant when the A.C. magnetic field is superposed on the D.C. field.

Cyclic fatigue test machine

Compressive mechanical force onto the superconductor is transmitted from the cyclic fatigue test machine located on the top of the cryostat at room temperature. The test machine is driven by oil pressure and has a rated force of 100 kN. A pull rod located inside a compression pipe is made of stainless steel in the upper part and GFRP in the lower part to reduce eddy current loss during A.C. loss measurement.

The assembled apparatus, including the test machine, the superconducting magnets, and the sample in the cryostat, is shown in figure 2 (page 35).

Power supplies

Both sample current and D.C. magnet power supplies are controlled by parallel connected power transistors to minimize current ripples down to 10^{-4} $_{p\text{-}p}$ or less. The rated output current of the sample current power supply is 15 kA, and the rated output voltage is ±10 V to compensate the induced voltage from the A.C. superconducting magnet. The rated output current of the D.C. magnet power supply is 1300A and the rated output voltage is ±15 V.

The power supply for the A.C. magnet utilizes the resonating circuit method with inductance of the A.C. magnet itself and capacitors in the power supply. Current oscillating at 3 Hz in the circuit is kept constant by a serially connected transistorized inventor current feeder. The maximum output voltage of the inventor is ± 100 V.

Helium liquefier

The helium consumption rate of the test facility is between 50 *l*/hr to 100 *l*/hr. To supply liquid helium continuously, a fully automated helium liquefier is installed in the facility. Helium liquified at a rate of 100 *l*/hr is stored in a 1000 *l* liquid helium tank, and then automatically transferred to the outer vessel of the cryostat to keep the liquid helium level of the outer vessel constant.

III. Measurement methods

A. Measuring system

In the test facility, all of the apparatus and instruments of measurement are controlled by a HP9000/385 workstation through a GP-IB bus. Consequently, magnetic field, sample current, and mechanical compressive force are automatically controlled to the set values; then measurement is started. Measured data converted into digital signals are transferred into the same computer and analyzed. This automated system ensures reproducibility and repeatability of the measurement because each measurement of values is done at the same accuracy and timing in the measuring sequence.

B. Critical current measurement

In the critical current measurement, voltage taps are attached to the conductor at the end point of the one-turn ring-shaped sample in the midplane to detect as large a normal voltage as possible. At the voltage tap, a thin wire is wound around the conductor to detect the average voltage over all of the strands.

Voltage leads are non-inductively wired from the sample to the isolating amplifier with a twisted and electromagnetically shielded cable. This method reduces voltage noise extensively.

Output voltage of the amplifier is filtered with a 48dB/oct low-pass filter. An example V-I curve is shown in figure 3 (page 35) where the oblique line corresponds to $1/8\times10^{-13}\Omega$m of resistivity. The cross point of the line and the V-I curve gives the critical current.

It is confirmed that quenching of the sample in the critical current measurements always occurs at points between the voltage taps.

C. *A.C. loss measurement*

In the facility, A.C. loss is measured by two methods. One is calorimetric and the other is electrical using pick-up coils. In the calorimetric method, A.C. loss is measured from the decreasing rate of the liquid helium level in the inner vessel. Calibration of measurement is done using an electric heater. The result is shown in figure 4 (page 35). Standard deviations among calibrating measurements are between 0.1 to 0.2 W. These values correspond to nearly 5 per cent of sample A.C. loss in actual measurements.

In the calorimetric measurement, the measured value includes eddy current loss at bus bars. To obtain exact A.C. loss, eddy current loss should be subtracted.

In the electrical method, hysteresis of the magnetization curve of the sample conductor is measured by integrating the voltage detected from the pick-up coils. The magnetization curve gives qualitative information on A.C. loss.

IV. Results and discussion

A. Critical current

Critical currents of the Nb-Ti/Cu-Ni/Cu composite conductor developed in Super-GM are shown in figure 5 (page 36). There is no change in critical current when 30 MPa of compressive mechanical force is applied up to 10,000 times over the range of magnetic field from 4T to 6.5T.

This is true for the three types of conductor developed in Super-GM for high-response and low-response superconducting generators.

All of the conductors developed in Super-GM are single-or double-cabled types, which introduce stress enhancement at the crossing points of strands. The value of peak stress may exceed the yield strength of the composite strand. But the result shows that the conductor developed in Super-GM survives compressive stress in the generator rotor for a lifetime of 30 years from the viewpoint of critical current.

B. A.C. Loss

A.C. losses of the conductors with strand insulation or single-cabled with a bare copper surface strand show no change before or after applying mechanical force.

In the case of the double-cabled pure aluminium stabilized conductor, in which soldering is employed to assemble superconducting strands and the centre stabilizer for the first cabling, A.C. loss increase by 20 per cent when 26 MPa of compressive force is applied, as shown in figure 6 (page 36) for two kinds of sample, A and B. Cyclic application of the stress also increases A.C. loss gradually by nearly 5 per cent.

The reason for this A.C. loss increment is improvement in electrical conductivity between solder-covered first cables due to mechanical compression. Since the pure aluminium stabilized conductor is designed with fully stabilizing criteria, increment of A.C. loss is irrelevant in the operation of the superconducting generator. As for the A.C. loss of the conductor developed in Super-GM for the superconducting generator, there is no serious problem under cyclic mechanical force application similar to the actual rotor conditions.

V. Conclusions

The test facility to measure critical current and A.C. loss of the conductor developed in Super-GM for the superconducting generator under cyclic mechanical compressive force has been developed at the Akagi Testing Centre of CRIEPI.

The conductors survived 10,000 applications of 30 MPa mechanical compression, and showed no serious degradation in critical current or A.C. loss. The three types of developed conductors can be effectively applied to the 70 MW-class model generator rotor which will be developed in the future in Super-GM.

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(*Article through courtesy by the author of the main article, Mr. Köfler*)

* * * * *

Stability test facility for superconducting rotor magnets

The Electrotechnical Laboratory has developed a rotating stability test facility for superconducting generators. The system tests the stability of rotating superconducting field coils (rotor magnets), a major component of superconducting generators. Valuable information has already been acquired for the development of the 70,000 kW model generator presently in progress in Japan as well as for designing the next stage of pilot machines.

The superconducting generator revolves a superconducting coil at high speed to generate electricity by the interaction with the fixed coil (armature coil) in position on the outside. Weight and power generation losses can be halved compared with conventional generators.

In Japan, an eight-year research project to develop a 70,000 kW superconducting model generator was started in fiscal year 1988 as part of the Moonlight Project of the Agency of Industrial Science and Technology. Design standards will also be established for the pilot generator (200,000 kW class). One of the vital themes is the problem of stability of the rotating magnets. Research advanced at the laboratory will establish a design criterion for stabilizing them.

The new testing system uses a multicylindrical rotating cryostat of vacuum adiabatic construction fitted with rotor magnets, a helium transfer coupling (HTC) for feeding liquid helium, a magnetic shield, a set of slip rings for transmitting sensor signals, and a driving motor. The system is about 6 m long, and the rotor is about 1.8 m long, with an outside diameter about 50 cm and coil length about 80 cm. The rated speed is 3,600 rpm, the centrifugal acceleration about 2,000 times gravity, and the maximum coil current 2,000 A.

The rotating cryostat has vacuum sealing that can be disassembled and reassembled to permit sequential replacement of the rotor magnets. Highly reliable data and efficient research for the development of stability design criteria for magnets of different characteristics can be achieved.

The stabilities of rotor magnets were tested with the new system at 3,600 rpm, which provided new data on (1) better liquid helium cooling effect at higher speed, and (2) better stability of superconducting wires without insulation than with insulation.

The laboratory plans to build rotor magnets with various characteristics, replace them sequentially and test stabilities during disturbances possible with superconducting generators, to establish the stability design criteria.

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* * * * *

Quantitative control of oxygen concentration in superconducting film

Teijin Ltd. and Professor M. Ishigame of the Research Institute for Scientific Measurements, Tohoku University, have jointly developed a technique for quantitatively controlling the oxygen concentration in oxide superconducting films using an electrochemical method with a solid state electrolyte.

Yttrium-based and bismuth-based oxide superconductors are sintered at as high as 800-900° C after mixing with several ceramic materials. However, the chemical composition and crystal structures are changed subtly each time due to the oxygen in the air. Therefore, even when using the same ceramic materials, it is quite difficult to produce identical oxide superconductors.

The new technique uses a solid state electrolyte, for example an yttria-stabilized zirconia (YSZ) that injects oxygen ions proportional to the current when an electric current is applied. An oxide superconducting film is deposited on one side of the YSZ by the sputtering process, then a platinum electrode is over layered and then a magnesium oxide film forming a barrier to oxygen ion is formed on the oxide superconducting film. On the opposite side of the solid state electrolyte a porous platinum electrode is deposited, and a current is passed between the two electrodes at 400-500° C.

A fixed quantity of oxygen ions can be supplied through the YSZ electrolyte into the superconductor. In an experiment using 2212 BSCCO thin film, the Tc was changed from 61 K to 83 K reversibly by controlling the oxygen concentration.

The new technique is still in the basic research stage, but it may allow the accelerated development of oxide superconductors. Also, while this technique can be applied to the manufacture of oxide superconducting films, it is useful for the manufacture of Josephson devices.

Teijin Ltd., Public Relations Section, 2-1-1, Uchisaiwai-cho, Chiyoda-ku, Tokyo 100, Tel.: +81-3-3506-4055, Fax: +81-3-3508-2767 (Source: *JETRO*, September 1991)

* * * * *

Analysis of Cu and O in oxide superconductors

Japan Fine Ceramics Centre has developed a method using an electron probe microanalyser (EPMA) for investigating the chemical states of copper (Cu) and oxygen (O) in oxide superconductors in the superconducting state. This method uses the characteristic X-rays generated by irradiating an electron beam on a specimen.

The characteristic X-rays have specific energy levels depending on the element, but the energy profile will differ depending on the chemical environment of the atoms. The valence of Cu inside a superconductor was measured using the relationship between chemical state and energy profile.

The critical characteristics of an oxide superconductor rely largely on the chemical states of oxygen, copper and electrons. With the exception of single-crystal specimens, a second phase such as an impurity phase exists in oxide superconductors. Therefore, to analyse the states of oxygen and copper in an oxide superconducting phase accurately, it is important to conduct specific state analysis for local regions.

In general, state analysis of oxide superconductors uses X-ray photoelectron spectroscopy (XPS) because a sharp spectrum reflecting the energy level can be obtained. However, this method uses X-rays as the excitation source, so it is impossible to analyse local regions smaller than a few micrometers even when using, for example, the micro-XPS method.

The new method enables focusing with an electromagnetic lens since it uses an electron beam as the X-ray excitation source, allowing measurements of superfine regions with diameters of about 1 µm, and by using a cooled specimen stage, it will be possible to measure the chemical state of the superconducting material.

The centre used this method to determine the Cu valence in local regions and in the superconducting states of several yttrium-based superconductors with different oxygen mole ratios and bismuth-based superconductors present in multiphase mixtures.

The Cu valence measurement method measures the peak intensity ratio between the Cu characteristic Lα and Lβ rays. The relationship between the valence and Lβ/Lα ratio is obtained from the known valences of CU Cu (valence 0), Cu_2O (valence 1) and CuO (valence 2), and this is used as the analytical curve for measuring the valence of Cu in the specimen.

The valences of local regions were determined from the results of these valence measurements. It was also confirmed that the specimen temperature has a large influence on the measurement of valence by the EPMA method. This is presumably due to specimen damage by electron beam irradiation when measuring at near room temperature, bringing about a change in the chemical state.

The centre is further studying the EPMA method for investigating the chemical state of oxygen, especially vital in yttrium-based superconductors.

Japan Fine Ceramics Centre, Research and Development Laboratory, 2-4-1, Mutsuno, Atsuta-ku, Nagoya City, Aichi Pref. 456, Tel.: +81-52-871-3500, Fax: +81-52-871-3505. (Source: *JETRO*, November 1991)

* * * * *

Quick test for superconducting thin films

The transition temperature of superconducting material can be determined quickly by a simple technique. A small transmit coil fed with an AC supply of approximately 50 kHz induces a voltage in an adjacent receive coil (see diagram). The film to be examined is placed between the two coils and cooled with liquid helium in the vapour chamber of a container. After the transition to the superconducting state, the Meissner effect causes shielding of the receive coil.

A thermoelectric couple in the receive coil, whose reference point is held at the temperature of liquid nitrogen to spread the measuring range, is used to measure the temperature. A complete transition curve can be recorded by an x-y plotter. The sensitivity of the measurement set-up can be increased further by adding a capacitor to the receive side to form a resonant circuit. The idea for this technique came from three co-workers of the Corporate Research and Development Department of Siemens AG. (Source: Siemens Review Special, R&D, F&E - Fall 1989)

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Figure 1

Configuration of a sample for critical current measurement under mechanical compressive force

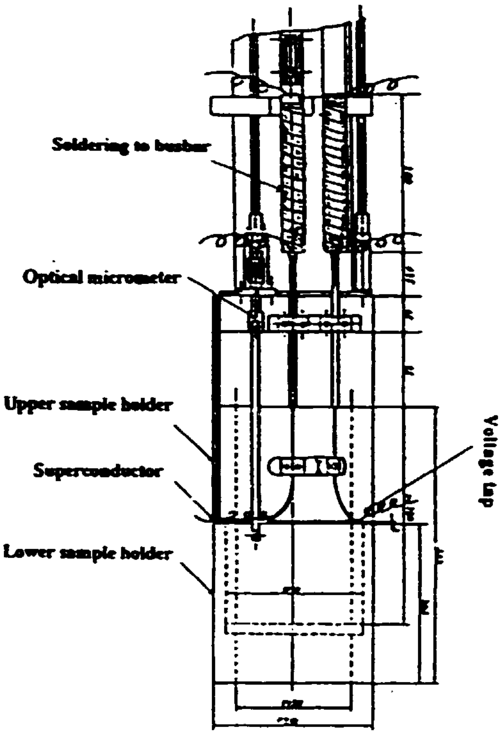


Figure 2

Configuration of the assembled testing apparatus

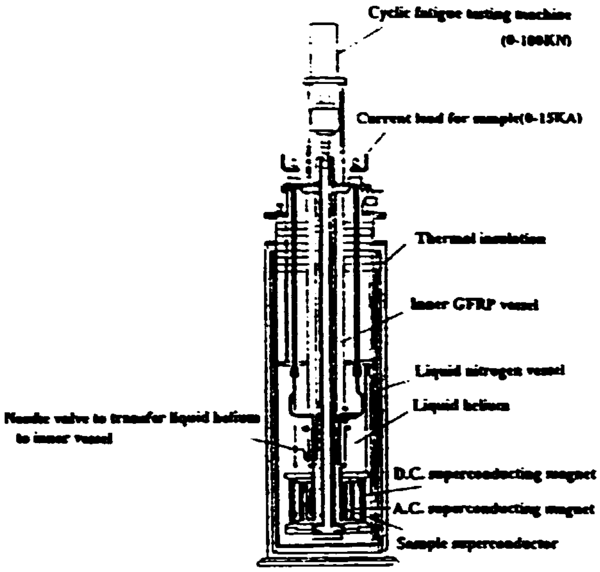


Figure 3

An example of V-I curve of critical current measurement

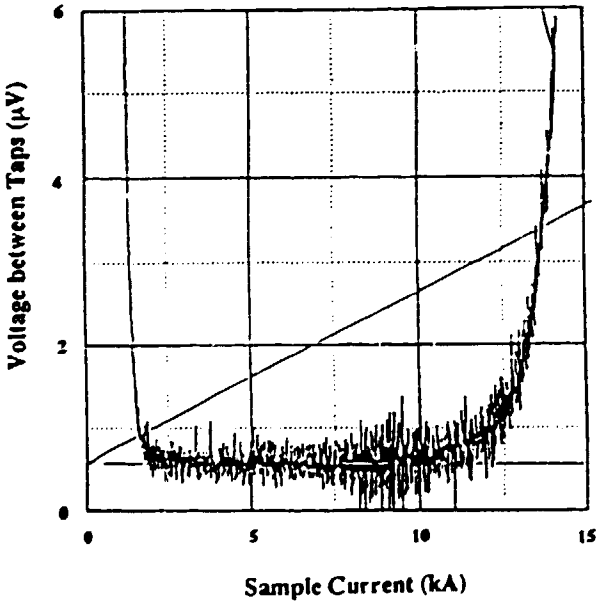


Figure 4

Results of heater calibration for calorimetric A.C. loss measurement

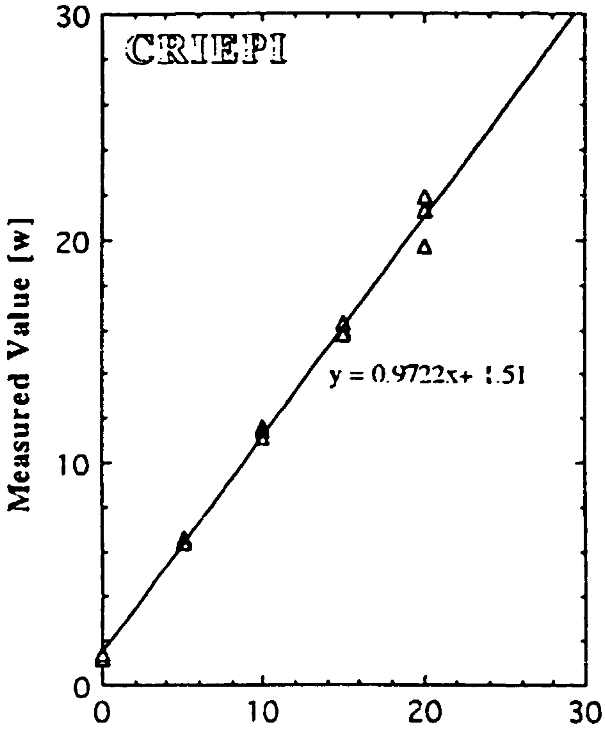


Figure 5

Critical current of the conductor developed in Super-GM under cyclic mechanical compression with 30 MPa stress

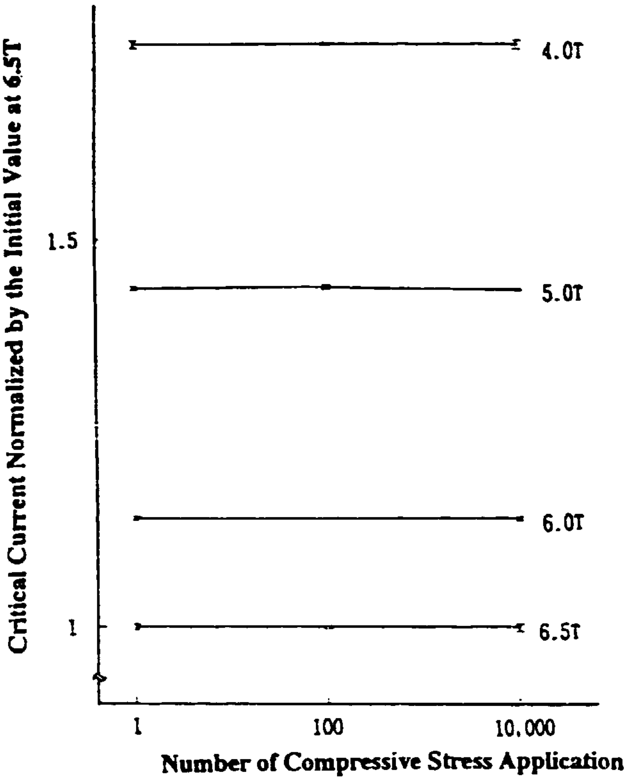
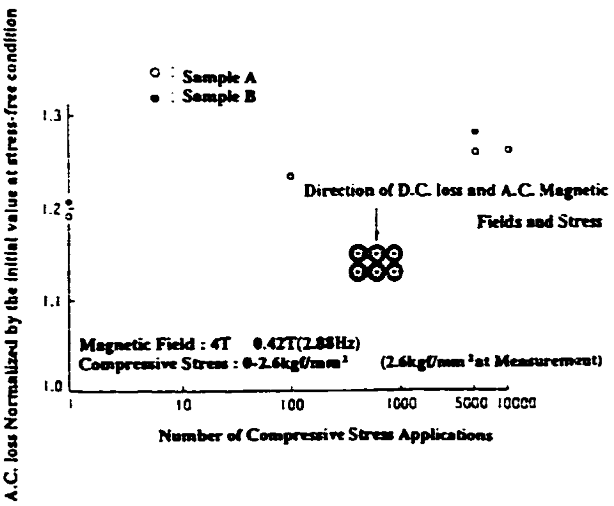


Figure 6

A.C. loss of the pure aluminum stabilized conductor assembled with soldering for the first stage of double cabling



4. APPLICATIONS

The following two articles were given to us by courtesy of the author of our main article, Mr. Köfler.

Feasibility study on Kaolin clay purification and coal desulphurization by superconducting HGMS

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Research work on Kaolin clay purification and coal desulphurization has been carried out at the Institute of Electrical Engineering, when a superconducting high gradient magnetic separation (HGMS) device was put into operation. This device consists of a superconducting magnet with its cryostat and a separation system. A lot of sample tests were conducted. The results show the good feasibility of superconducting HGMS for Kaolin clay purification and coal desulphurization. The brightness increment of some Kaolin clay samples has reached about 10 per cent, the reduction of pyrite and total sulphur has already achieved about 70 per cent and 60 per cent respectively.

Introduction

Along with the development of magnet technology, magnetic separation has entered upon the superconducting magnetic separation stage. As a result of 20-year research and development, superconducting magnetic separation begins moving towards the industrial application phase.

Since superconducting magnetic separation can produce strong separation force, it is a powerful method to separate weakly magnetic and microsize materials. This widely extends the application range of magnetic separation. Superconducting magnetic separation now can be applied to not only the process to treat ferrous, non-ferrous and rare metals or other industrial raw materials, but also the measures to eliminate the environment pollution. In a few words, it has a bright application prospect in the field of resources utilization and environment protection. Especially in China, the application of superconducting magnetic separation will be paid more and more attention because most minerals are increasingly dependent on using lower grade ore bodies, and the pollution is getting more and more serious with the growth of industry.

Because superconducting magnetic separation is not a unique separation method, it will have the vitality only after finding some separation targets with great social and economic benefits, then the feasibility study has great practical significance.

In order to know the effectiveness of HGMS for Kaolin clay purification and coal desulphurization, a laboratory superconducting HGMS device has been constructed and put into operation at the Institute of Electrical Engineering. A lot of sample tests have been conducted during the last two years.

Sample test device

The superconducting HGMS sample test device consists of a superconducting magnet with its cryostat and a separation system. To get large separation volume and enough effective length, the magnet is composed of a long superconducting solenoid and two compensating coils. The main coil is wound with 0.75 mm and 0.5 mm diameter NbTi superconductors while the compensating coils use only 0.5 mm diameter NbTi conductors. The homogeneity of the magnet over 80 mm diameter and 400 mm effective length is 95 per cent. The test results prove that the magnet can operate at 5T.

Figure 1 (page 39) shows the schematic view of the magnet and its cryostat. The outer diameter of the cryostat and its height are 473 and 1230 mm respectively. The room temperature bore is 80 mm. In order to reduce liquid helium loss of the cryostat, some special attentions have been paid in design and construction. The cryostat has two 1100 mm stainless steel chimney-like columns. A liquid nitrogen vessel is wreathed round the magnet with 18 mm copper pipe. A shield with the temperature 77-100K is attached to the pipe. There are also another two shields with the temperature 20-30K and 6-10K. Between the shields some kind of superinsulation is adapted (Gs-80). A special liquid helium transfer tube can play as a part of the current lead. To reduce the storage volume of liquid helium around the magnet, the gap between the wall of the cryostat and the magnet surface is 2.5 mm only. The main stored liquid helium above the magnet is 9.5L, the total volume is about 11L. It was designed that the liquid helium vessel can withstand the pressure about 7 kg/cm^2. It is already seen from the test that when the magnet quenched, the pressure in the cryostat rose to about 5 kg/cm^2. The test also shows that the cryostat has a good thermal insulation performance, the liquid helium vaporization rate is about 0.2 L/h.

In the wet beneficiation mode, there are two separation systems available, one is the upward pumping feeding system and the other is with the downward gravity feeding. The canisters are made of stainless steel tube and divided into 6 parts filled with stainless steel wool. Three canisters with 72 mm and 40 mm in diameter can be used. For Kaolin clay and coal, No. 1 and No. 5 wool with thickness and width (30-60) x 20μ and (150-200) x 60μ have been used in the separation process.

Test results for Kaolin clay purification

Art paper requirement has increased very fast in China in recent years. High quality Kaolin clay is the important coating material of paper. A lot of mines especially along the south-east coast of China, including Jiangsu, Fujian, Hunan, Jiangxi and Guangdong province, have been discovered, some of them are quite good for paper industry in the sense of the grain size, flat structure and viscosity produced, but the natural brightness is not high enough for paper due to the high contents of Fe203 and Ti02.

Since there is a big project to develop superconducting industrial prototype separator for Kaolin clay purification carrying on in the Institute, the task of the sample test is to define the feasibility of magnetic separation for various samples collected from different places as to offer the possible application mines for the industrial separator, and to provide the reasonable technological process and optimal operational parameters as well.

In the sample tests, the effect of field intensity and slurry flow velocity, the saturation and repeated processing performance have been tested. Four Kaolin clay samples have been studied in detail. Two of them, No. 1 and No. 2 are collected from Henan province, No. 3 comes from Guangdong province and No. 4 is supplied by Hunan province. All tests were conducted at about 20wt% solid concentration. The dispersant applied is sodium hexametaphosphate. Figure 2 (page 39) shows the dependence of brightness increment and Fe203 reduction on the field intensity. It can be seen that for sample No. 4 the quite good results have been obtained, the brightness increment has reached above 10 per cent and Fe203 reduced from 1.67 per cent to 0.7 per cent.

Test results for coal desulphurization

The annual production of coal in China now is more than 1,000 million tons, among them about 20 per cent is the high sulphur coal (more than 2 per cent). On average, about 50 per cent sulphur is inorganic, which could be removed by magnetic separation. There are also some coals, their inorganic sulphur reaches 80-90 per cent of total sulphur. The high sulphur coals are widely distributed in China, especially in central and south-west China. It is reported that in China there are about 50 high sulphur coal-fired electrical power stations consuming more than 20 million tons of coal every year. Burning of these high sulphur coals created a big problem with air pollution. The total S02 emission is about 1.5 million tons which is half of S0 emission of the total power stations. It is planned to build 10 high sulphur coal-fired power stations in the seventh five-year plan period. At that time the total S02 emission will reach more than 4 million tons. Therefore coal desulphurization possesses great social and environment benefits in China.

To know the feasibility of HGMS for removal of sulphur and ash-forming minerals from Chinese high sulphur coals, eight coal samples were collected from Sichuan, Guizhou and Shanxi province, three of them have been experimentally studied with the above device. Table 1 (page 39) summarizes the analytical results for three original run-of-mine coal samples. The susceptibility measurements show a big differentiation between original samples and cleaned coals, this provides a clear evidence of magnetic separation. Figure 3 (page 39) demonstrated the effect of field intensity on three selected samples. For two Sichuan samples No. 3 and No. 5, the reduction of pyrite and total sulphur has achieved 58.25 per cent, 66.37 per cent and 47.4 per cent, 57.4 per cent while the recovery can keep 79.2 per cent and 76.68 per cent. For a Guizhou sample No. 8, the reduction of pyrite is about 50 per cent. There still exists the possibility to get better results if the experimental method is further improved.

Conclusions

The sample test results for Kaolin clay purification and coal desulphurization show good feasibility of superconducting HGMS. The increment of Kaolin clay brightness and the reduction of Fe203 have reached about 10 per cent and 60 per cent, the reduction of pyrite and total sulphur have already achieved about 70 per cent and 60 per cent.

To provide the reasonable technological process and optimal operational parameters for the superconducting industrial prototype separator, it is necessary to continue the sample tests in more detail.

When all collected high sulphur coal samples or even more are experimentally studied, it is possible to know the whole outline of the separation feasibility for the main Chinese high sulphur coals, and then the next development step could be adopted.

Acknowledgements

The authors are very much indebted to Miluo Kaolin Clay Company, Beijing Institute of Papermaking and Packing, and Xian Institute of Thermoengineering for their sample collecting and analysing. Thanks are also due to the members of the cryogenic station of the Institute.

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Figure 1

Schematic view of the magnet and its cryostat

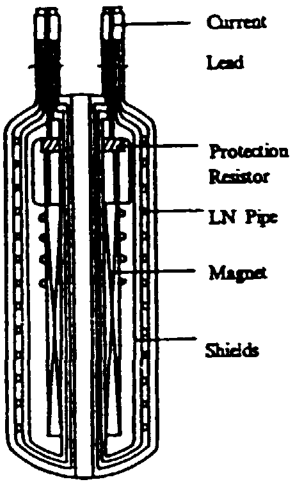


Figure 2

Effect of field intensity

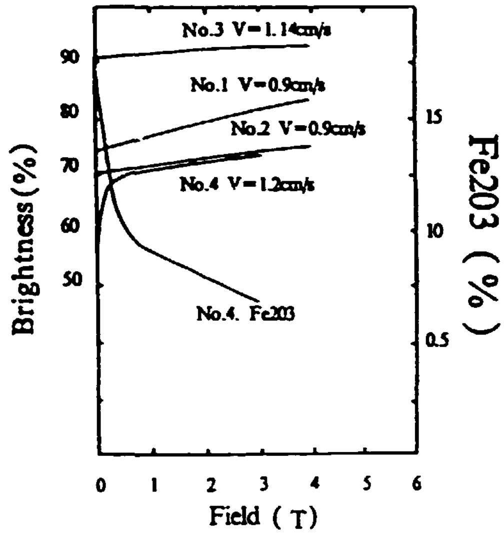


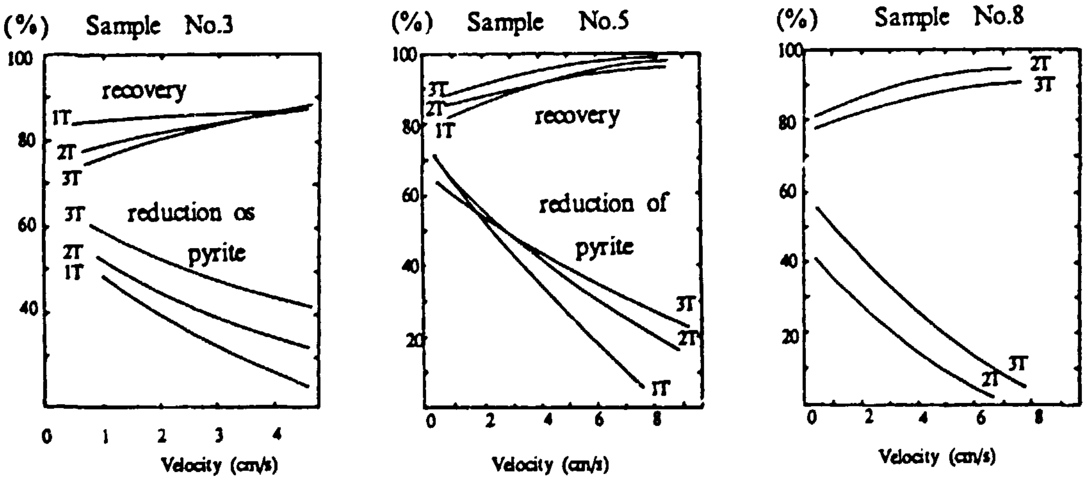
Table 1

Analysis result of coal samples

No. of Sample	Power Station	Ash	Total Sulfur	Pyrite	Sulfate	Fe203
No.3	Baoji	42.81	4.26	3.77	0.09	4.69
No.5	Chongging	27.55	3.58	2.29	0.07	2.85
No.8	Qingzheng	33.61	4.22	3.09	0.11	3.85

Figure 3

The relation between the reduction of the pyrite, the recovery and the field



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SSD Operating experience

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Abstract. Superconductivity Inc. has developed a self-contained system called the SSD^{TM} that uses the energy stored in a superconducting magnet to provide voltage support for large electrical loads. This paper reports on operating experience gained during the development and first two years of SSD field operation. The SSD delivers energy from its superconducting magnet to a customer's load using a current-to-voltage converter which feeds an inverter. Two different systems have been developed based on different inverter topologies. One configuration supports an adjustable speed motor load. The other supports diverse ac loads and incorporates a static isolation switch. After commissioning on SI's test floor these systems have been installed at customer sites. Each system has successfully carried industrial loads through numerous voltage sags. Field operating data on both system configurations is reported. A companion paper by Buckles *et al.* (1) contains a detailed discussion of the design of the SSD.

I. Introduction

Large-scale superconducting magnetic energy storage systems, such as those anticipated by the Engineering Test Model, (2) (3) have focused on the benefits of load levelling to electrical utilities. To be economically competitive, these systems must store and deliver large amounts of energy. Beginning in 1988, Superconductivity Inc. (SI) began examining a different application for superconducting magnetic energy storage in the power quality market. This application has relatively small energy storage and comparatively high power delivery requirements. Initial units store about 1 MJ and are able to discharge at rates of 1 MW.

The economic justification for SI's system, called the SSD, is not based on the cost of the energy stored in the unit. It is based on the value of avoiding an interruption of the power supply. The cost of shutdowns that are caused by sags and outages has been estimated to be in the billions of dollars per year in the United States alone. (4) While long-term outages have been effectively reduced by electric utilities, momentary voltage disturbances have actually increased on many power systems across the country. At the same time many industries have dramatically expanded their use of electronically controlled equipment. This sophisticated new electronic equipment is particularly sensitive to momentary voltage disturbances. These two factors have resulted in an increased need for quality power in many segments of the economy. SI has developed the SSD to meet this need. While superconducting magnets have been connected to utility grids on an experimental basis, (5) we believe the SSD represents the first commercial use of superconductivity for industrial process power applications.

II. System configuration

SI has developed two different SSD system configurations. The motor drive system protects large motor loads from voltage sags and brief outages. The shunt-connected SSD is designed to carry multiple and varied loads through short-term disturbances. The shunt-connected system is shown in figure 1 (page 45) and is discussed briefly below. For more detailed descriptions of these systems please see references (1) and (6).

The shunt-connected SSD's high-speed controller monitors the incoming line voltage. When a sag or outage is detected, the dc current in the superconducting magnet is redirected to the inverter capacitor bank by a gate turnoff thyristor (GTO) located in the voltage regulator cabinet. The GTO directs current to the inverter capacitor bank in the form of current pulses. The current pulse height is governed by the dc current level in the magnet. The pulse width and frequency are a function of the power requirements of the inverters and the current pulse amplitude. As each pulse charges the capacitor bank the magnet current decreases. Since the magnet delivers less energy per unit of time as its current decreases, the width of the current pulse to the capacitor bank increases.

The twelve-pulse inverter converts the energy delivered to the capacitor bank into ac power for the load. This process of supplying power to the load during a sag or outage is called a "carryover". At the start of the carryover the isolation switch opens to isolate the load and the SSD from the utility grid. This ensures that the SSD will not feed a fault on the source side of the isolation switch and also guarantees that all of the SSD's energy will be delivered to the critical load. When the grid voltage returns to normal the inverter output is resynchronized to the grid and the isolation switch then closes to reconnect the load to the grid. Asea Brown Boveri (ABB) builds the inverter, isolation switch and high speed controller for this system.

III. Field test and demonstration sites

The initial SSD field installation was a 460 kVA prototype motor drive system that was installed at a generating plant operated by Iowa Public Service Corporation in the summer of 1990. This unit was located on the turbine floor of a coal-fired power plant. It proved to be a challenging environment - temperatures reached 120° F and coal dust coated all exposed surfaces. Field modifications were necessary to keep the power electronics from overheating.

After the initial field installation the decision was made to package the entire system in a semi-trailer and provide closed system cooling for the power electronics.

The unit was then tested and used for demonstrations by Wisconsin Public Service Corporation (WPS), Pacific Gas & Electric (PG&E) and Puget Sound Power & Light Company (Puget). PG&E tested the unit for approximately three months at their Modular Generation Test Facility in San Ramon, California. As part of this testing the magnet was discharged and recharged at five-minute intervals for a period of several days. All system components functioned smoothly during this cycling test.

Experience gained during these field tests prompted a number of modifications and improvements in the system. The most significant of these was the Data Acquisition System (DAS), designed to provide continuous information about the status of the SSD. Such information allows SI to respond quickly to any changes in the condition of the SSD. The DAS receives information about components of the SSD from digital and analog interfaces. When a carryover occurs, data is collected in pre-trigger mode by a high-frequency analog-to-digital converter. With this information, SI determines the severity of the voltage disturbance and is able to document the response of the SSD to it. The SSD's support systems are monitored continuously. All information is automatically sent to SI's field service computer via telephone modem. In addition to the ability to send data to SI, the DAS computer is capable of being operated remotely to allow monitoring of system status at any time.

IV. Customer installations

The first commercial application of an SSD was in Washington state. In cooperation with Puget Sound Power & Light Company, SI installed a 750 kVA motor drive SSD at a Georgia-Pacific papermill in Bellingham, Washington in July 1991. This unit protected a clear-water pump from 8 July 1991 to 3 September 1991. In early September the unit was moved to an induced draft fan at the boiler plant. Over ten significant carryovers were recorded during the July 1991 to February 1992 period. During the same period the SSD also provided voltage support well over 500 times during the small sags caused by in-plant heavy motor starts. The value of continuous monitoring became clear during the course of the Washington installation. Examination of day-to-day data regarding cryogenic and helium liquefier operation allowed anticipation of problems and corrective action before system operation was jeopardized. Up time for this unit was about 95 per cent.

Figure 2 (page 45) shows a carryover that occurred on 29 August 1991. The top trace shows the voltage on the incoming line, initially at 480 VAC. The bottom trace shows ac power flows into and out of the SSD's inverter. As the line voltage drops to 435 VAC, the power input drops to near zero while the power output, supported by the energy stored in the SSD's magnet, remains constant. The initial voltage sag ends after about 600 ms and the inverter is back on line power 300 ms later. Note that the line voltage after the first sag has risen to 490 VAC due to the loss of other, non-SSD-protected loads on the grid. A few seconds later another, smaller, dip in the line voltage occurred. This dip was probably due to the restart of heavy motors elsewhere in the plant and also resulted in a transfer of stored energy from the SSD to the load.

The first commercial shunt-connected system was delivered to Central Hudson Gas and Electric Company in New York in May 1992. It protects sensitive loads at an important industrial customer. To date this system has protected its load from 26 significant voltage disturbances and an additional 38 minor disturbances. Figure 3 (page 45) shows a carryover that occurred on 29 July 1992. Equipment protected by the SSD rode through this sag and a second sag that occurred 16 minutes later. Equipment in the same plant not protected by the SSD dropped off line. To date, up time for this unit is approximately 97 per cent - a 2 per cent improvement from the first commercial unit.

V. Conclusions

The first two years of field operation of the SSD have demonstrated the ability of Superconductivity Inc. to build and operate utility-connected superconducting magnetic energy storage systems. Efficient and reliable operation of these systems represents a significant challenge which can be met by careful design, diligent monitoring and timely maintenance. The SSD exploits the unique capacity of superconducting magnetic energy storage to deliver large amounts of power on demand through many deep discharge cycles. Operating experience shows that the systems can respond rapidly to repeated voltage sags and keep critical equipment on line.

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(4) Business Week, 8 April 1991.

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* * * * *

Superconducting magnet system using no liquid helium

Associate Professor K. Watanabe of the High Field Laboratory for Superconducting Materials, Institute for Materials Research, Tohoku University, and Sumitomo Heavy Industries Ltd. have jointly used a current lead made of a high-temperature oxide superconductor to operate a superconducting magnet in a vacuum without liquid helium (4.2 K), creating a magnetic field of 4.6 T (46,000 G) at an absolute temperature of 11 K. Since liquid helium, which is costly and difficult to handle, is not used, the system is simplified and enables substantial cost reduction. Sumitomo Heavy Industries plans to market the system for use in medical equipment and linear motors.

The superconducting magnet enables an electric current to be passed through a superconducting coil free of electrical resistance, so an intense magnetic field is created without large power consumption. The magnetic field obtained is several or several dozen times that created by an iron core magnet (ordinary copper coil), and can be applied to various systems such as linear motorcars, magnetic resonance imaging and accelerators, and for measuring the characteristics of magnetized materials.

Previously the method for transforming the coils of magnetic systems into the superconducting state was to cool the coil by immersion into liquid helium, but since liquid helium is quite costly, vaporized with ease and handling difficult, the magnet structure was complicated and massive. Recently, the improved performance of compact cryocoolers has allowed the development of cryocooler cooling type superconducting magnets, but present cryocoolers have a poor efficiency at temperatures below 10 K (-263° C).

Therefore, to commercialize superconducting magnets operating at temperatures higher than 10 K, niobium-3 tin was selected as the coil material. This superconducting material is capable of retaining superconductivity up to about 18 K (-255° C). The current lead carrying electricity from the power source through the coils was high-temperature oxide superconductor using bismuth, strontium, calcium and copper in the ratios of 2:2:2:3, developed by Sumitomo Heavy Industries. This superconductor retains superconductivity below about 110 K, so by placing it in an environment of a lower temperature, the current lead will not generate heat, the conduction of heat into the superconducting coil will be decreased substantially and, in a non-magnetic field of liquid nitrogen temperature (77 K), it has a critical current property of over 1,000 A.

Also, since this superconductor is a ceramic, it prevents thermal conductance and its thermal conductivity is only one-several hundredth that of copper generally used as the current lead material. This new current lead can pass a large current in an environment controlled to a temperature around 10 K level, which helped develop a superconducting magnet system requiring no liquid helium.

This new current lead and the magnet cooled in a vacuum achieved a magnetic force of 4.6 T, comparable to that of a linear motor, at a temperature of 11 K and current of 465 A. This system can pass a current of up to 500 A, and temperature control is possible in the range of 10-30 K. It is compact with an outer diameter of 32 cm and height of 92 cm. The system will be sold at a price of Y20-30 million in Japan. (See diagrammes on page 46)

Sumitomo Heavy Industries Ltd., Public Relations Dept., 2-2-1, Otemachi, Chiyoda-ku, Tokyo 100. Tel.: +81-3-3245-4079. Fax: +81-3-3245-4337. (Source: *JETRO*, December 1992)

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Improved superconducting magnetic rotary bearings

Improved magnetic rotary bearings can be designed by exploiting the properties of type-II superconducting materials. Depending on the particular design and application, a bearing of the new type can provide fixed or adjustable compensation for the lateral (that is, perpendicular to the axis of rotation) vector component of the weight or other lateral load on the rotor.

A type-I superconductor exhibits perfect diamagnetism at an applied magnetic field up to some critical value, above which superconductivity is lost and the magnetic field penetrates. A type-II superconductor allows an applied magnetic field to penetrate it partially in clusters of field lines, with the concomitant establishment of undamped circulating electric currents within the material. Type-II superconductors have critical magnetic fields and critical (superconducting-transition) temperatures greater than those of type-I superconductors; the type-II superconductors include the well-known ceramic compound $YBa_2Cu_3O_x$ and other, lesser-known ceramics based on thallium and bismuth.

A rotor supported magnetically according to the general concept (see figure, page 46) includes two axially polarized permanent-magnets, one at each end of the rotor shaft. A superconducting bearing structure confines each end of the shaft, leaving a little room for lateral movement. Each end of the shaft is thus levitated diamagnetically by interaction with the superconducting bearing structure; in effect, suspended by a magnetic cushion within the bearing structure.

Lateral displacements of, and loads upon, a shaft can be counteracted in any of several ways, all of which involve the introduction of compensatory assymetries into the levitating magnetic fields. In the examples shown in the figure, the vertical positions of the ends of a horizontal shaft are sensed electronically to detect any deviation of the shaft from the designated centerline; the position signals are processed through feedback control circuits that adjust the magnetic fields to force the shaft back towards the centerline. In the first example, the adjustment is made via electromagnet coils atop the bearing structures. In the second example, the adjustment is made by applying varying amounts of heating power to the top sides of the superconducting bearing structures to decrease the degree of type-II superconductivity asymmetrically by an amount that compensates for the weight of the rotor.

In another method (not shown in the figure) for adjusting the lateral positions of the ends of the shaft, each superconducting bearing structure could be divided into quadrants, which could be adjusted mechanically. Fixed compensation for lateral loads could be provided by bearing structures in which type-II superconductivity is distributed asymmetrically via asymmetrical shape, the use of two different type-II superconductors, or both.

Goddard Space Flight Center, Greenbelt, Maryland, USA. (Source: *NASA Tech Briefs*, October 1992)

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Superconducting transformer made of niobium 3-tin

The Kansai Electric Power Co. Inc. and Mitsubishi Electric Corp. have jointly succeeded in fabricating the world's first superconducting transformer made of niobium 3-tin superconducting wire with a capacity of 667 kVA, equivalent to one phase of a three-phase 2,000-kVA transformer.

Metallic superconducting materials are used in magnetic resonance imaging (MRI) systems and generators operating on DC current and made of niobium and titanium. Niobium 3-tin has the excellent characteristic of displaying the superconducting phenomenon at a higher temperature than niobium and titanium.

The development of the transformer using niobium 3-tin superconducting wire enables superconducting technology to be applied to alternating current, and is the first step towards the commercialization of alternating current superconducting technology. The two companies are presently engaged in research to apply this superconducting wire to fields other than the transformer, such as power storage systems (SMES = superconducting magnetic energy storage) and generators.

The superconducting transformer enables the current loss to be decreased to virtually nil, and the capacity can be increased by laminating the coils, so it will be possible to pass large currents several dozen times larger than when using copper wires of the same size. Introduction into power systems will provide the next-generation transformer featuring compactness, light weight and low loss.

The superconducting wire developed is produced by first preparing a wire by using 1,720 superfine wires, each with a thickness of 0.4 μm, next bundling seven of these wires into a strand with a diameter of 0.6 mm, then further combining seven of these strands into a coil with a diameter of 1.8 mm.

The new transformer uses less than one-half the volume of coil compared with conventional types of transformers. In the basic characteristic tests which were conducted, a current of 1,618 A (712 kVA) was passed successfully, though only for a period of 30 s.

Niobium 3-tin generates the superconducting phenomenon at a relatively high temperature of -225° C, so the companies fixed the coils in position with epoxy resin and improved the transformer reliability by suppressing the deflection when AC current flows through the coil. In addition, the new transformer is of the shell type that is most common for power transformers, so can be fabricated into a large-capacity type with ease.

Mitsubishi Electric is to test the new transformer up till the end of March 1994.

The Kansai Electric Power Co. Inc., Public Relations Dept., 3-3-22, Nakanoshima, Kita-ku, Osaka 530. Tel.: +81-6-441-8821, Fax: +81-6-443-0233) (Source: *JETRO*, January 1993)

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Biomedical applications

Devices are being developed to both shield a person or object from magnetic fields, as well as to detect magnetic fields from the brain or heart. Several Japanese companies have developed magnetic shields, including Nippon Kokan KK (Tokyo). The shield is a cylinder 30.5 cm long and 15.2 cm in diameter made of copper and coated in a 100-μm layer of YBCO. At 77 K the material had a critical current density J_c of 3,000 A/cm^2 and is capable of shielding out magnetic fields as low as 0.6 G. Mitsui Mining and Smelting Company Ltd. is also developing a similar device.

In addition, Nihon Cement and the Technological University of Nagaoka have jointly developed a magnetic shield by depositing a thin layer of bismuth material on a thin plastic sheet, which is formed into a cylinder, 2.4 cm in diameter and 3.6 cm in length, with a thickness of 8 mm. A considerably larger shield has been made at Dow Mining Company, which is 15 cm in diameter and 40 cm in length and which is based on a hollow cylinder made of magnesia coated with bismuth material.

Another joint effort between Furukawa Electric Company and NGK Insulators has produced a magnet shield apparatus that prevents external fields up to 30 G from affecting inside objects. The apparatus is expected to be used for biomagnetism measurements such as measuring the brain magnetic flux. The new apparatus includes a cylindrical or platy Bi-based material that is produced by NGK. Furukawa is also planning to develop a magnetoencephalogram with CTF Systems (Vancouver, Canada), which has developed a SQUID sensor which measures a very weak magnetic field by using the Josephson effect.

Several American companies have also developed similar detectors. Conductus Inc., in conjunction with Lawrence Berkeley Laboratory, has developed an integrated circuit magnetometer using a SQUID and a flux transformer integrated on the same chip. The device contains three layers of the 123 phase separated by two insulating layers, a seed layer for grain boundary creation, and a silver layer for making electrical contact with the device.

The transformer consists of a single continuous SC loop, which picks up magnetic signals over a comparatively large area and concentrates them in a much smaller, multiturn coil. The instrument can detect fields about 10 nG, which is 100 million times weaker than the Earth's magnetic field. Potential applications include biomagnetic research, magnetic anomaly detection, and nondestructive testing.

Biomagnetic Technologies Inc. (BTI) (San Diego, CA), has claimed to have developed the lowest noise Josephson junction, the basic building block for SQUIDs (superconducting quantum interference devices). BTI is evaluating the potential of these Josephson junctions for use in the SQUIDs in their biomagnetometer, which detects electrical activity in the brain and heart. Initial noise measurements were inconclusive about use in detecting magnetic fields from the brain, but the researchers are optimistic about the possibility for cardiac applications in the future. BTI has already developed a reproducible method of making Josephson junction to produce 50 double-junction SQUIDS. (Source: *American Ceramic Society Bulletin*, Vol. 71, No. 8, August 1992)

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Figure 1

Shunt-connected SSD

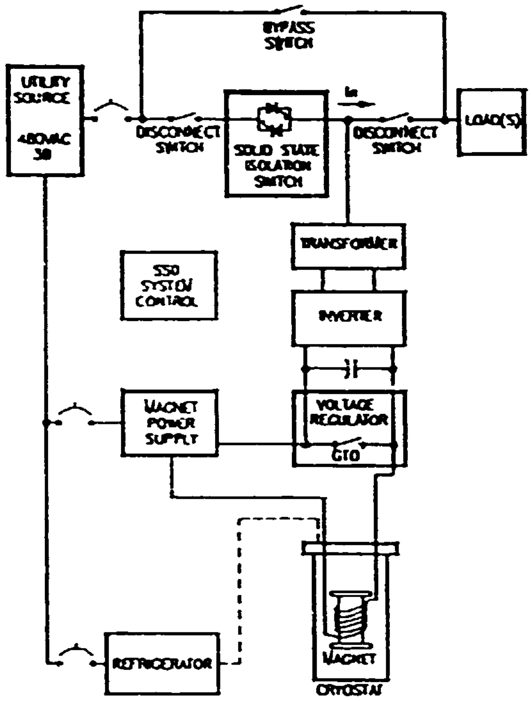


Figure 2

Motor drive SSD operation

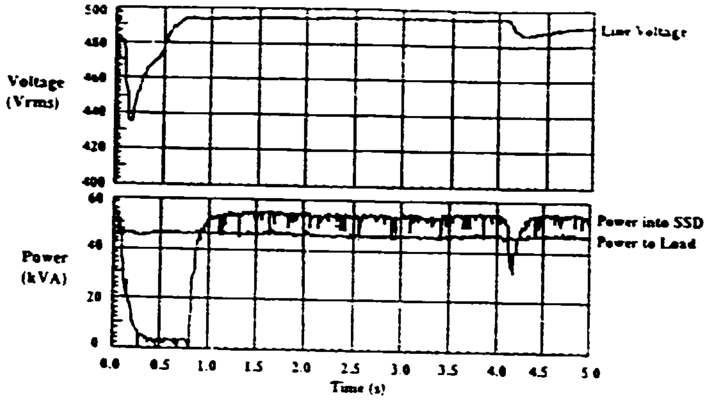
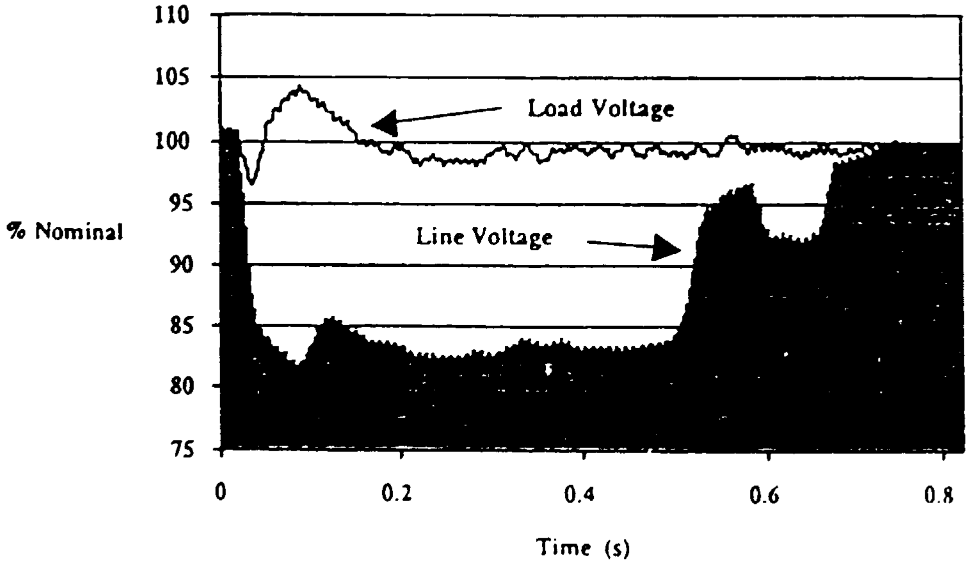


Figure 3. Shunt-connected SSD operation



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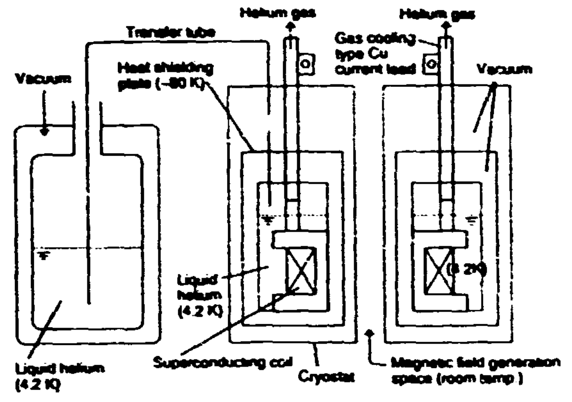
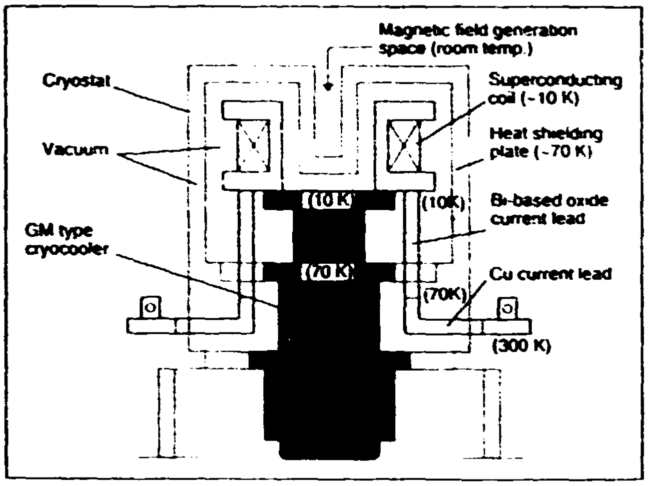
Conventional superconducting magnet cooling system



Helium-free superconducting magnet system



(Source: *JETRO*, December 1992)

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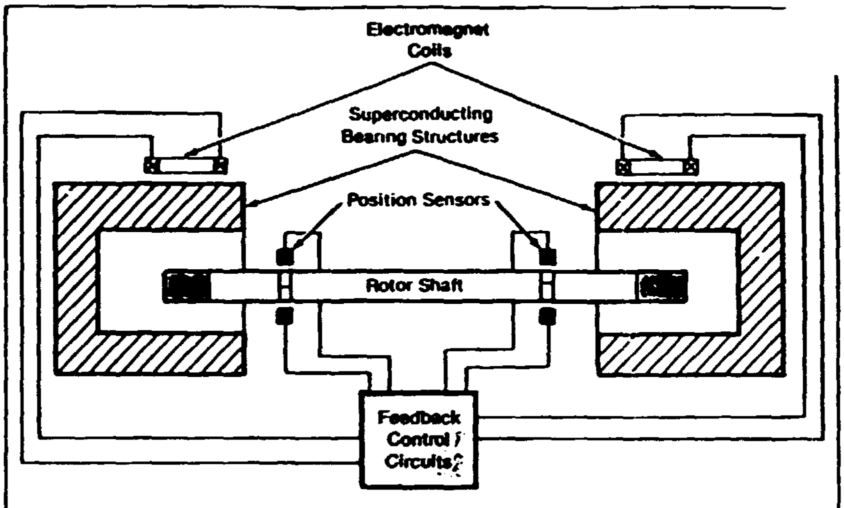
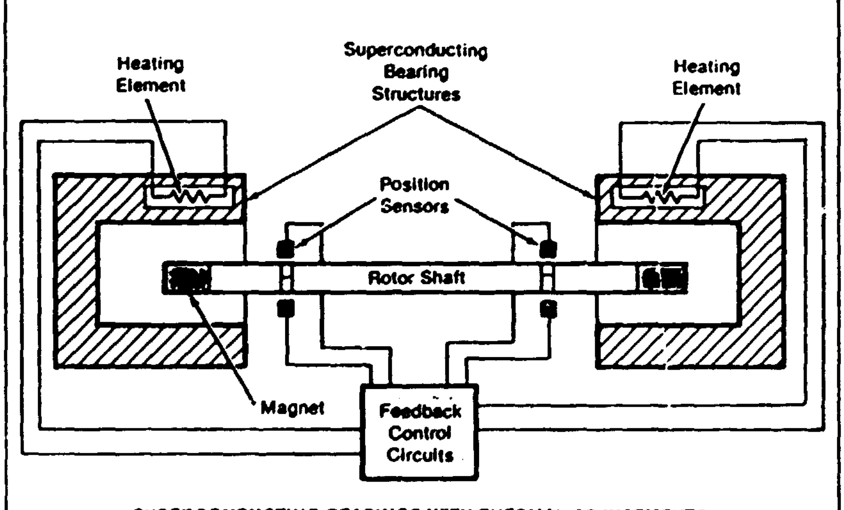
Magnetic rotary bearings that include structures made of type-II superconductors can be adjusted magnetically or thermally



SUPERCONDUCTING BEARINGS WITH MAGNETIC ADJUSTMENTS



SUPERCONDUCTING BEARINGS WITH THERMAL ADJUSTMENTS

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5. TRENDS IN MARKETING

Superconductor applications reach marketplace

Though the US market for superconductors is expected to have an average annual growth rate of 27.5 per cent according to Business Communications Company (BCC), another survey of US superconductor patents issued from 1980-1990 by BCC shows that there is a significant threat from Japan in this area. A total of 935 relevant superconductor patents were issued in this period, which included 200 assignees.

In the first 10 months of 1990 alone, 219 patents related to superconductors (SC) were issued and the top ten most active corporations accounted for 39 per cent of the total issues in 1990. Since 1980, foreign companies have held an equal or greater share of issued patents than have US companies. However, in 1990 more than two thirds of the US patents of foreign origin were from Japan. This trend appears to be continuing.

A closer look at approximately 100 superconductor US patents issued during 1990-1991 may give some indication of who the major players are. There were 17 different organizations representing Japan, including two universities. The clear leader was Sumitomo Electric Industries with a total of nine patents. The Mitsubishi group followed with four patents. On the other hand, of the over 30 US companies holding patents, there was no dominant company. General Atomics led with five, followed by Westinghouse and AT&T Bell Laboratories, each with three. Other major US companies holding patents included General Electric, Dow Chemical Company, Allied Signal, W.R. Grace, Du Pont, Dow Corning, IBM, and Hewlett-Packard.

No matter which country or company is considered the leader, it is obvious the race is on to develop applications based on the conventional YBCO materials, as well as some of the newer compositions. While the search for the perfect material continues, progress has also been made in improving material properties and hence better performance for certain applications. Devices based on thin films will probably be some of the first to be commercialized and there are already simple devices that have reached the marketplace.

Improvements in materials and processes

Researchers from around the world are investigating other compositions in addition to the yttrium, bismuth and thallium materials in an effort to raise the transition temperature. The latter materials are also being improved with adjustments in composition or processing. For instance, joint research between the Superconductor Research Laboratory and the University of Tokyo has developed a YBCO with J_c=20000 A/cm^2 under 35 T and 1-31 K. A precursor-based process is used which includes calcining at 890° C for 5 hours then heating at 750° C in a quartz tube. Reducing particle size can improve the T_c of thallium-based superconductors, according to Dowa Mining Company (Tokyo, Japan). A material made with copper particles in the range 10-20 nm achieved 120 K, compared with a material made using a 1-μm powder which has a T_c about 15 K lower.

Other compositions are under development that contain gallium, gadolinium or vanadium. For instance, Argonne National Laboratory (Argonne, IL) and Northwestern University (Evanston, IL) have made superconductors based on gallium, strontium, yttrium and oxygen at 28 MPa in O_2 atm at 900° C that have T_c of 73 K. They are the first to conduct electricity only along the planes formed by copper and oxygen atoms when they are separated by non-conducting chains. Nippon Steel Corporation (Tokyo) has developed a gadolinium barium copper oxide SC claimed to have a J_c of 40000 A/cm^2 at 4 T. A vanadium-containing material has been jointly developed by Hitachi Ltd. and Nippon Telegraph and Telephone Corporation that is claimed to have a T_c of 130 K.

Improvements in substrate compositions are also being made. The National Institute for Research in Inorganic Materials in Niiharu, Japan, has developed a single-crystal substrate of neodymium aluminate which has similar structure to superconductors. Sizes 60 mm in length by 23 mm in diameter have been grown. Superconix (St. Paul, MN) has also recently introduced to the market a new class of crystal substrates for high-temperature superconductor (HTSC) thin films for microwave and far-infrared applications. Of composition $SrLaAlO_4$ and CaNdAlO4, they have yielded high-quality films of YBaCuO- and BiSrCaCuO-based superconductors. The substrates have no twins or structural phase transitions as with conventional substrates. Lattice mismatches range from 1.6 per cent to 4.4 per cent, depending on substrate and thin-film composition.

Researchers continue to modify powder synthesis methods in an effort to produce materials with better uniformity, purity and homogeneity, as well as to look at other ways to improve sintered properties. CPS Superconductors has patented an improved process for preparing powder by calcining in a controlled atmosphere containing a mixture of oxygen and an inert atmosphere. Rhone-Poulenc (New Brunswick, NJ) now also produces YBCO powders of fine particle size (0.5-5μm) and high purity in batch quantities ranging from 20-100 kg using a proprietary chemical method based on flash drying. A plasma spray grade of material is also available in development quantities.

A variety of chemical methods, including sol-gel and polymer pyrolysis, have also been developed for producing powders. Traditional methods usually have poor homogeneity, sinterability, and reproduceability, and wet chemical methods can overcome these disadvantages. Chemical methods can also have the advantage of reducing sintering times considerably. Korea's Advanced Institute of Science and Technology has developed an emulsion drying method to produce highly pure and small-sized powders (10 μm) of $Bi(Pb)_2Sr_2Ca_2Cu_3Oy$, that sinter at 850° C in 30 hours compared to over 200 hours for conventional processing. Other novel methods are being considered for making powders as well, including combustion synthesis and microwave processing.

HIPing has been used to process superconductors at relatively low temperatures (as low as 750° C) and pressures as low as 100 MPa. Another advantage is the significant reduction in processing times; conventional methods for preparing superconductors can take 30 hours or more. By using HIPing, Kobe Steel, Ltd., has reduced processing to 3 hours for making a 124 phase SC. The techniques uses 1000° C under 250 atm of O_2 producing a material stable to 800° C and a T_c of 90 K for a material partially substituted with calcium.

The US Army Materials Technology Laboratory has used a somewhat similar process for processing bulk superconductors of the 123 phase using BaO_2 as an oxygen donor. The density, hardness, and Young's modulus of HIPed samples (820°C, up to 207 MPa) were higher than those of sintered samples. T_c >92K were achieved without requiring postannealing, which is generally required with conventional HIPing methods.

Electronic devices with better performance

The success in using thin films to fabricate superconducting devices has led to commercialization for certain applications. Much of the research is concentrating in this area, with a variety of methods being used including plasma-based techniques, laser deposition, sputtering, and others. Of the total patents in the processing area approximately 40 per cent were related to thin films. Properties also can be more easily controlled; for instance, Sumitomo Electric Industries and Kansai Electric Power Company (Osaka, Japan) have produced a thin film of a bismuth material that is resistant to magnetic fields. After applying a field of 1 T, the J_c only dropped from 240,000 to 220,000 A/cm^2.

Applications of thin films generally fall into two categories: passive and active devices. Passive devices tend to modify a single electrical signal or input and usually require a single-layer structure consisting of patterned YBCO film for such applications as microwave resonators, filters and delay lines. Active devices tend to have another signal controlling the modification of the input in a nonlinear fashion, such as the Josephson junction, and generally require several layers. The most complex device structure to date is an integrated superconducting quantum interference device (SQUID) magnetometer with 15 individual oxide layers, all epitaxially grown by PLD.

Electronics based on HTSC active or passive devices hold promise for higher speeds, reduced noise, low electrical loss, and high efficiency for a variety of applications in electronic communications and signal processing. Integrated circuits made with these materials could also have the advantage of not requiring external circuitry of any kind, especially for signal processing applications.

Many of these applications will rely on Josephson junctions as part of the integrated circuit. Fabricating these junctions has not been easy though recently there has been some progress. Toshiba Corporation has developed a Josephson device consisting of a praseodymium-barium-copper oxide, sandwiched between two YBCO films, with a total thickness of 50 nm. During fabrication, the substrate temperature is held at 680°C, helping to form flat films with well-aligned axes. A total of 240 devices with reproducible characteristics have been made that have a J_c of 100 A/cm^2 at 30 K.

Josephson junctions play an important role in successful development of SQUIDs and their applications. Conductus, Inc. (Sunnyvale, CA), began marketing SQUID systems designed for use in university experiments and lecture demonstrations earlier this year. The SQUID integrated circuit contains 10 thin-film layers of superconducting material and incorporates biepitaxial Josephson junctions. Conductus has an intensive research and product development programme to develop other SQUID products of more complexity and higher performance.

One such product could be digital logic gates. TRW's Applied Technology Division has developed these logic gates, using direct current 123 SQUIDs for each gate. The logic gates are operational at 65 K, which is supportable in a cryocooler using only 10.5 W. The logic gate can switch some 250 billion times/s and would dissipate only 1 W of power.

Superconductor Technologies Inc. (STI) has received a DARPA contract to develop a high-performance millimetre wave down converter, which will have a lower noise figure than is possible with conventional technologies. This device will integrate both HTS devices (filters, oscillators, Schottky mixer, amplifiers), based on double-sided thallium films deposited on large substrates (2 in.), and cooled semiconductor devices into a single package.

STI has also manufactured eight resonators for the Naval Research Laboratories to be used in the High-Temperature Superconductivity Space Experiment

(HTSSE). The purpose of the programme is to demonstrate the feasibility of the SC in space satellite systems and to test the effects of space radiation on the materials. The resonators will be part of a cryocooled, experimental package in which the rf performance of SC devices during their life in orbit will be measured. The SC resonators have measured Qs in the range of 5,000-11,000 compared to gold resonators of 200-300. STI is also providing thallium-based films to Lockheed Missile and Space Division and Space Systems Division, Loral Inc. for use in their hardware that will also fly on the HTSSE satellite.

Sandia National Laboratories and the University of Wisconsin are working with thallium-based films as well. They have developed a transistor fabricated from such a film called the superconducting flux flow transistor (SFFT). Microwave amplifiers have already been built with the transistor. The SFFT could have potential to link conventional low-temperature SC electronic devices to standard semiconductor electronics. Amplifiers, oscillators and phase shifters have been made with the transistors for communications and signal processing technology. The same devices have been made in collaboration with AT&T Bell Laboratories with the yttrium-based material.

Sandia has built microwave amplifiers with the SFFT that show a gain of 10 dB at 4 GHz, as well as mixers that mix two frequencies together to produce a different output frequency that operate up to 35 GHz. The SFFT can also serve as an interface between conventional, low-temperature superconducting electronics and semiconductor electronics. Low-temperature superconducting electronics rely on Josephson junctions which operate at ultrahigh speeds but are difficult to link directly to semiconductor electronics. The SFFT can overcome this problem because it has resistances that are low at its input and reasonably high at its output.

Microwave filters based on YBCO have been developed by the International Superconductor Technology Center (Tokyo, Japan). The filters have low insertion losses of only 0.2 dB at 77 K and 13.3 GHz, almost 25 per cent lower than conventional filters. The filter consists of strips of thin films deposited via pulsed laser deposition (0.35 μm thick) onto magnesia substrates measuring 10 mm^2. They will be used in satellite broadcasting at 13.3 GHz frequency.

A prototype of a transistor has been made by Hitachi Ltd. The planar device is made from a strontium substrate on which a thin film of a lanthanum-based conductor is deposited. Two thin-film YBCO electrodes are then printed on the conductor. Oki Electric Industry (Tokyo, Japan) has also produced bipolar transistors made by depositing a layer of copper on a silicon substrate before coating this with a thin film of the superconductor. Three terminal elements, which have a response time of only 3 ps, are predicted.

Resonators, devices that exhibit resonance at a particular frequency, are also under development for communications. ICI Advanced Materials (Runcorn, UK) and AT&T Bell Laboratories have jointly developed a family of radio frequency and microwave resonators that generated about 100 times less noise, have better frequency stability, and have at least five times lower insertion loss than conventional all-copper devices. The resonators have been successfully used in several electronic circuit applications, including oscillator stabilizers and supergenerative receivers. They are constructed from copper tubes with inserts of superconducting rods and helical wires. Potential applications include low-frequency communications equipment.

Researchers from Neocera Inc., Los Alamos National Laboratory, and the David Sarnoff Research Center have also jointly developed a 123 resonator 25 μm wide and 8 cm long with a Q value 30 times better than cooled copper. The resonator has a surface resistance of 0.3 mΩ at 77 K and 10 GHz, which matches the lowest resistance previously reported for unpatterned films. The 123 film was grown by laser deposition on a lanthanum aluminate substrate.

A variety of sensors are also under development or have already reached the market. Some of the simplest used to detect liquid nitrogen levels are already being sold. Illinois Superconductor Corporation began selling its Model 90 Series Liquid Nitrogen Level Sensor, using 123 wire as the sensing element, late in 1991. The product is claimed to be the first industrial superconductor product available in the United States. The system provides level monitoring and level control functions for liquid helium and liquid nitrogen simultaneously.

Bolometers, instruments that detect very faint infrared light, are being developed at the Lawrence Berkeley Laboratory in collaboration with Conductus Inc. These devices convert electromagnetic radiation into heat and detect the results as a temperature change. Two types have been fabricated. One approach involves YBCO thin film deposited exitaxially on a 20-mm thick sapphire substrate with a layer of colloidal gold black as a radiation absorber.

The other design uses a lithographed antenna to couple the radiation to a YBCO film that is much smaller than the wavelength to be measured. The film is deposited on yttria-stabilized zirconia and acts a both a resistor and thermometer. This design can potentially be 100 times more sensitive than the pyroelectric infrared detectors, as well as being stronger, easier to make, and much faster. In recent tests, these bolometers have performed up to 1,000 times better than other SC bolometers.

Researchers at the University of Texas-Austin also have demonstrated a light-sensing device based on a molecular dye and a HTSC that can respond selectively to different colours of light. Claimed to be the first of its kind, the device offers the possibility of a new generation of optical detectors and sensors. With this device, porphyrin-based dye molecules are used to absorb light and transfer that energy to the chilled superconductor. Sensors have been fabricated that respond selectively to blue, green or red light, with current work attempting to make a sensor to respond to near-infrared light.

Another type of sensor, based on SQUIDs is being developed for nondestructive testing applications. Quantum Magnetics, Inc. (San Diego, CA), has delivered a high-resolution scanning magnetomer prototype to MIT (Cambridge, MA). These sensors, which convert magnetic flux into voltage, have sensitivity of 6 pT and spatial resolution of 0.5 mm. Signal processing capabilities are being improved to increase the spatial resolution to 100 μm SQUIDs can detect hidden cracks, flaws, local thinning, corrosion, corrosion sensitization, residual stress, thermal ageing, and strain fatigue in metals and composites.

Potential energy applications

Results presented at a recent EPRI-sponsored workshop indicate that high-temperature superconductor (HTSC) wires and tapes are finally approaching materials requirements for practical utility applications. These criteria include sufficient durability to withstand manufacturing processes and the ability to carry large currents in strong magnetic fields at 77 K. Only two years ago, materials were still brittle with low critical current densities.

Intensive research efforts have recently demonstrated that HTSC materials can meet all these requirements, though reproducing the required properties from sample to sample is still a problem. Durable, flexible wires over 100 m long have achieved J_c values of 6500 A/cm^2 at 77 K in 0 T. Critical current densities of 10 per cent A/cm^2 have been demonstrated in 3-cm-long monofilaments under the same conditions. In a 10-T magnetic field, a bulk HTSC has produced a J_c of 2.4 X 10^4 A/cm^2 at 77 K.

Energy applications that could benefit from superconductor wires and tapes cover a wide range and include motors, power electronics, transporation (including superconducting motors and magnetic energy storage devices), electromagnetic pumping, materials fabrication/production, and magnetic separation. A recent study by the US Department of Energy and the Electric Power Research Institute determined that for most of these applications, a critical current density of 10^5 A/cm^2 or higher at liquid nitrogen temperatures (77 K) would be required. For materials production applications, such as metal deformation, superconducting magnets would have to produce high fields up to 40 T, while other applications in this area would require fields in the range of 5-20 T.

Progress is being made in some of these areas, especially motors and energy storage devices, as prototypes are already being demonstrated. Results of a design study conducted by Reliance Electric Company (Cleveland, OH) indicate that operating cost savings from using a 10,000-hp HTSC motor, instead of a conventional constant-speed induction motor, would equal one to two times the HTSC motor's capital cost over a 30-year lifetime.

For instance, Reliance Electric Company has built a prototype dc electric motor under a project funded by the Electric Power Research Institute. The motor was big enough to drive an electric fan, operates at around 1300 rpm, and uses a field winding consisting of a 75-turn YBCO solenoids supplied by Argonne National Laboratories. American Superconductor Corporation (Cambridge, MA) also supplied a wire made of silver and bismuth SC to make a coil 3 inches long. this motor produced about 25 W of power and ran at 1,500-2,500 rpm, which is about the same ouput as a cooling fan on a PC.

A prototype axial-gap superconducting motor with an adjustable speed drive has also been developed at Oak Ridge National Laboratory (Oak Ridge, TN). The motor is equipped with low-temperature niobium-titanium superconducting wires and its armature is 4.1 cm from the face of the magnets. In proof-of-concept tests the axial-gap motor delivered 102 N·m with a magnet current of 2100 A, its torque increased linearly with current, and the ASD had no measurable effect on the magnets. Future tests will assess the performance of HTSC conductors in this design.

Use of HTSC-based switches in inverters for motors could dramatically reduce power consumption as well, as semiconductor switches consume an average of 50 W/kW inverter rating. Researchers at the University of Maryland are developing switches based on their discovery of a large field effect in HTSCs. Preliminary experiments indicate that 50-A HTSC films in rudimentary devices have an off resistance-on resistance/on resistance ratio of 28 to 30. For practical field-effect current switches, this ratio must be increased to about 1,000, which has been predicted to be accomplished by 1993.

HTSCs could also be used to develop frictionless magnetic bearings with high load-lifting capacity, effective vibration damping, and low rotational dissipation. Scientists at the University of Houston have fabricated hybrid bearings composed of melt-textured YBCO and a permanent magnet. These bearings have a lifting capacity of 60 psi. Melt-textured YBCO magnetic bearings that operate at 135,000 rpm have also been developed.

Other magnetic bearings have been made with some success, which could lead to performance improvements in flywheel devices (used for energy storage) and cryocooler rotors. Such bearings can achieve much higher speeds than conventional bearings, ranging from 6 to 100 times higher. A joint effort between the Superconductivity Research Laboratory (Tokyo, Japan) and Nippon Seiko K.K. has resulted in an yttrium-based bearing that can achieve over 30,000 rpm. Argonne National Laboratory, in conjunction with United Technologies Research Center, has made a magnetic YBCO bearing that has demonstrated one of the lowest frictional losses and an even higher speed. The bearing achieved rotor speeds of 200,000 revolutions/m and a 0.000004 drag-to-lift ratio.

This bearing could lead to flywheel devices about half the size of a desk but capable of storing 50 to 500 MJ, enough energy to provide a typical house with electricity for 1-10 days. Allied Signal Aerospace's AiResearch Division has also recently demonstrated one of the highest speeds recorded for YBCO magnetic bearings by rotating a 0.36 inch diameter rotor up to 520,000 rpm. The bearings would have potential to improve cryocooler rotor efficiency and reduce power losses by 70 per cent.

Other energy storage devices have been demonstrated that use magnets. A superconducting flywheel has been developed at the Superconductivity Research Laboratory which has been able to store 100 W·h. The device is a disk-shaped permanent magnet of neodymium boron which is levitated by 33 pieces of YBCO. The International Superconductivity Technology Research Center (Tokyo, Japan) has also developed a levitating flywheel, which stores energy at high speed. Because it is not in contact with any other object, the only energy it will lose through friction will be by contact with air. An aluminum disk weighing 7.5 kg containing a series of permanent magnets has been levitated above a YBCO SC cooled to -196°C. The disk is set spinning by electromagnetic induction to a speed of about 3,600 rpm. Once the disk is spinning, energy can be drawn off in the same way.

The feasibility of retrofitting existing underground power transmission systems with HTSCs has also been studied by Underground Systems, Inc. Primary retrofit advantages of first-generation HTSC wires would be two- to fivefold increases in power rating and lower current losses for the same cross-sectional area as conventional conductors, even considering the energy and space requirements of associated cryogenic channels and cryostats.

Specifications for HTSC conductors in three-phase ac power cables include: the ability to transport at least 1,500 A-rms at 75 K with total electrical losses not to exceed 0.5 W/phase/m; at least 2,000 A-rms at 77 K with losses not to exceed 1 W/phase/m; and a round hollow-core conductor assembly with a maximum outside diameter of 5.5 cm and an inside diameter of 2 to 5 cm.

In addition, the conductors must have sufficient durability to withstand manufacturing, installation and temperature-cycling stresses without failing to meet performance specifications. Researchers have identified 750 underground circuits of at least a mile in length as candidates for retrofits with HTSC conductors having these characteristics.

Superconductors for space

The combination of space's cold environment and superconductors' reduced cryogenic requirements makes these materials suitable for a wide range of space-bound applications. Projects at various NASA laboratories are incorporating superconductors into communications devices, remote sensors, cryogenic systems and propulsion and power systems. For instance, NASA-Lewis Research Center (Cleveland, OH) is focusing on integrating thin-film microwave devices (phase shifters, switches and filters) into space communications systems. NASA-Lewis has already fabricated a prototype antenna array that significantly reduces heat loss. This will be integrated with a receiver built at Johnson Space Center to make a system with high sensitivity, low noise and broad bandwidth. The system will be tested on a shuttle flight.

Space-qualified microwave devices developed jointly at NASA-Lewis and the Jet Propulsion Laboratory (JPL) will also be flown on the shuttle as part of the Naval Research Laboratory's High-Temperature Superconductivity Space Experiment. JPL has provided an HTS filter for phase 1 and is developing a receiver for the second phase, as well as local oscillators, mixers and broad bandwidth detectors. Two of NASA's Centers for the Commercial Development of Space are also flying experiments to investigate processing of HTSC materials in a microgravity environment.

Improving sensitivity and reducing noise in space-based sensors is the goal of Goddard Space Flight Center for developing infrared bolometers designed for thermal emission spectroscopy on outer planet missions. Prototypes have already been found to have improved signal-to-noise ratios and the ability to identify atmospheric molecules. Goddard is also investigating magnetic bearings for flywheels, canned pumps for cryogenics, beam choppers and textile spindles. Marshall Space Flight Center is working on a different bearing application - high-thrust bearings to replace rolling element bearings in rocket engine turbopumps to eliminate maintenance downtime.

Johnson Center is developing HTS magnetic-phased-array antennas for attraction/repulsion systems. Such systems could be used for space vehicle docking, pushing a satellite out of a shuttle bay, or as a tetherless astronaut rescue system. Langley Research Center, on the other hand, is looking at cryogenic applications for reducing the heat load in systems intended to cool space-based sensors (by using HTSC electrical leads), thereby reducing liquid helium evaporation and extending mission life (>5 per cent). This application may eventually find its way for use in ground-based cryocoolers.

Other applications are being developed elsewhere that will have applications both on the ground and in space. For instance, Toshiba Corporation has developed a conveyor belt using HTSC, which will be virtually frictionless, dust-free and independent of gravity, thereby making it applicable for transporting goods in electronic factories and space stations. The system can transport items of several kilograms up walls and across ceilings. A test track 2.2 m long has been built, which can carry containers weighting 1.5 kg with loads of 3 kg, at speeds up to 1.5 km/h.

Joint ventures in research continue

A number of joint programmes between government and industry have been established over the last year, especially in the United States, to improve processing methods and develop applications. With the opening of the federal laboratories to industry for technology transfer, many US companies are taking advantage of this opportunity. Whether it will be soon enough to keep pace with the Japanese remains to be seen.

A joint research agreement between Intersonics Inc. and Argonne National Laboratory, a nine-month, $150,000 programme, will determine which combination of raw materials and processing methods makes the superconductor with the most useful properties. Intersonics will use two "containerless" processes. The first will suspend the spheres in jets of air or other gases and melt them with a laser. The second will suspend and heat samples with electromagnetic fields of different energies.

Intermagnetics General Corporation (IGC) has also joined forces with Argonne to produce SC wires of 100 yards in length using an extrusion process. IGC has already developed wire of similar performance to that in Japan (J_c=64,000 A/cm^2 at 4.2 K, 20 T; 164,000 A/cm^2 at 4.2 K, 0 T; and 30,000 A/cm^2 at 77 K.

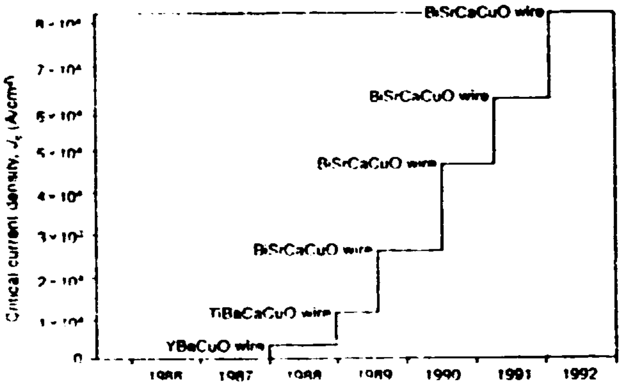
Some of the bigger companies are taking advantage of the laboratories as well. A three-year, $11 million agreement is under way between DuPont, Hewlett-Packard, and Los Alamos National Laboratory to develop thin films for electronic components. Reliance Electric Company is getting together with Argonne and the Electric Power Research Institute to develop electric motors from wires and coils.

Oak Ridge National Laboratory and Corning Inc. also have a joint venture to make thin films on flexible ceramic substrates. Oak Ridge is studying deposition methods such as magnetron sputtering, coevaporation and laser ablation. Corning is providing the flexible substrates. The goal is to produce films in excess of 1,000 A/cm^2.

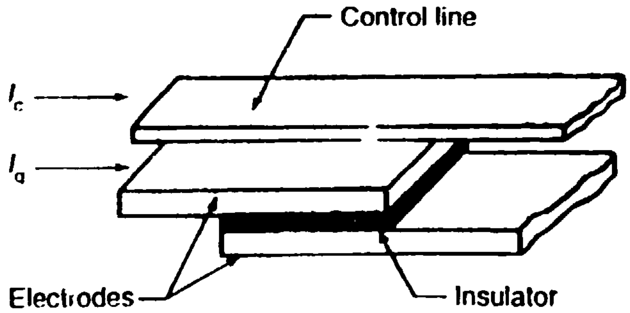
In addition, a number of joint efforts are under way overseas as well. The European Community is funding a project to develop microstrip microwave devices that include several companies from Denmark and Greece. The Australian Government has been awarded funding of about A$ 500 million to develop electrical power cables. A passively cooled superconducting power transmission line has already been demonstrated by Creare Inc. of the United States, who has recently been granted a Phase II Small Business Innovation Research grant by NASA.

The UK Government has also awarded a £1.65 million contract to a consortium of UK companies to test and evaluate microwave devices, sensors and actuators. DTI will provide 50 per cent funding. ICI Advanced Materials will produce complex shapes, Plessey Research will evaluate the microwave devices, Lucas Automotive the sensors and actuators and Birmingham University will do design and basic research.

It is obvious that interest in superconductors continues and research is rapidly moving from the basic to the applied stage, with many prototypes being demonstrated. However, commercialization for some applications is still a long way off and companies must be patient before they can benefit from expanding markets. Hopefully those in the United States will have the patience to remain in the superconductive race.



Some progress in performance of superconducting wires has been made in recent years



Schematic of a Josephson junction, which is important for many thin film applications.

Some Recent Joint Ventures in Research*

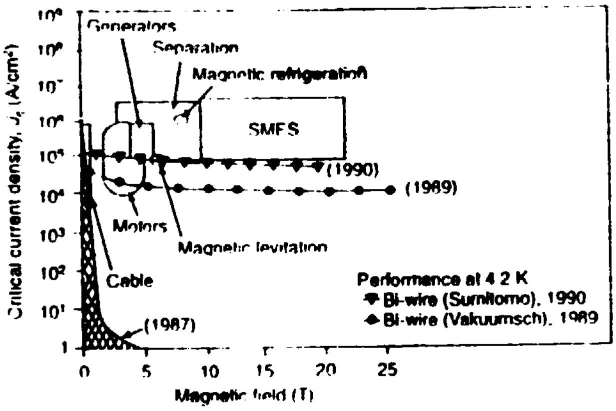
Partners	Objective
Superconix Inc./Argonne Superconductivity Pilot Center	Improve performance of Superconix's textured material
European Community	Develop microstrip microwave devices
Argonne National Laboratory/Reliance Electric Co./Electric Power Research Institute	Two-year, $1.9 million project to develop electric motors from wires and coils
Du Pont/Hewlett Packard/Los Alamos National Laboratory	Three-year, $11 million program to develop thin films for electronic components
U.K. Department of Trade and Industry and various British companies	Test, evaluate microwave devices, sensors, and actuators
Oak Ridge National Laboratory/Corning Inc.	Produce thin films on flexible substrates with 1000 A/cm²
Australian government/industry	Develop electrical cables

*This is not a complete list

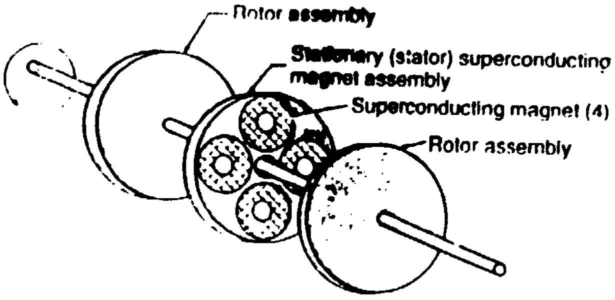
Performance Requirements for Various Applications (77 K)

Applications	J_c (A/cm^2)	Field (T)
Motors	10^5	5
Power electronic switch	$>10^6$	0
Transportation		
SMES	10^5	10–20
Maglev	$>10^5$	5
Electromagnetic pumps for nonmetallic fluids	$>10^5$	10–20
Electromagnetic thrusters	$>10^5$	10–20
Electromagnetic heat pump	$>10^5$	7.5
Gyrotron	$>10^5$	10–30
Magnets for rod/bar drawing	$>10^5$	40
Magnet separation	$>10^5$	2–10

Source: Electric Power Research Institute



Many energy applications will require operation under magnetic field of various magnitudes. Superconducting wires can now meet some of these demands. Source: Electric Power Research Institute.



Schematic of an axial gap superconducting motor.

(Source: *American Ceramic Society Bulletin*, Vol. 71, No. 8, August 1992)

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6. STUDIES AND PUBLICATIONS

Superconductivity studies from Italy

In the Centre for Data, Studies, and Experimentation (CISE) superconductivity studies are carried out in the Physics Technology Department. Activities began in 1974 in collaboration with ENEL (National Electric Power Company) when a laboratory was set up to evaluate the possible applications of superconductors in the transport of electrical energy and in the development of an innovative alternator. Subsequently, the behaviour of superconducting composites in magnetic transistors was studied in collaboration with ENEA (Italian Committee for the Research and Development of Nuclear and Alternative Energies). These superconducting composites will be used to construct the toroidal magnet of the soon to be developed NET (Next European Torus) machine designed for the study of thermonuclear fusion.

Immediately after the discovery of high critical temperature ceramic superconductors (HTSC), ENEL showed a great deal of interest in this pioneer technology and commissioned CISE to carry out research and development in the field. CISE's current goal is to produce HTSCs with a high level of critical current and magnetization, with the prospect of applications in the energy sector. For this reason, superconductor products such as bars, ribbons, etc. are being prepared and studied by using innovative techniques such as fusion and directional solidification and lasers for ceramic coatings on silver ribbons as well as conventional solid state reaction techniques.

The study of materials aims at developing production techniques that are capable of orienting the grains of the structure and increasing their electrical coupling capability, which improves their electrical and magnetic properties as well as structural characteristics. The equipment CISE currently has at its disposal for the characterization of superconducting materials is the only one of its kind in Italy and one of the few in Europe.

The skills that CISE has developed and its existing equipment allow for the complete electrical and magnetic characterization of superconductors. In particular, CISE can carry out measurements of:

- Critical current in the presence of a magnetic field up to 1212 T;
- Critical temperature using a four- wire resistivity method;
- Magnetization and magnetic susceptibility;
- Power dispersed in superconductor wires exposed to a variable magnetic field, or in the presence of AC transport current.

In addition to investigating the mechanisms of energy loss, magnetic measurements permit the density of critical current and the quality of the superconducting ceramic material to be evaluated.

Demonstration models of the inductive limit of currents and of magnetic levitation bearings have also been developed by exploiting the properties of HTSCs.

CISE Instruments for the characterization and preparation of superconducting materials

SQUID Magnetometer (Superconducting Quantum Interference Device) with a high resolution (10^{-8} emu); measurement margin: +/-300 emu; temperature range: 1.8-800 K; magnetic field range +/-5.5 T.

Computerized system to measure the magnetization of superconductor samples exposed to variable magnetic fields ($B^*_{max} = 0.3$ T/sec), based on a highly sensitive integrating magnetometer operating between 1 mHz and 100 Hz developed by CISE. [* - magnetic vectorial field].

Gaseous helium flow calorimeter to measure power dispersed in superconductor wires when an alternating current between 1 Hz and 5kHz passes through, based on a compensation microwattmeter developed by CISE.

Closed circuit refrigerator to measure four wire resistivity at a temperature between 10 and 300 K.

Eight T Cryostat with solenoidal magnet (L = 2.4 henry, D_{int} = 50 mm) and relative power source (12 V, 120 A) for measurements in variable magnetic fields.

Twelve T cryostat with magnet to measure critical current J_c (up to 500 A).

Power supplies: 50 Hz, I_{max} = 2,000 C; 20 Hz-600 Hz, I_{max} = 500 A; 0-5 kHz, 100 V, 20 A.

Equipment to prepare new superconducting ceramic materials on a laboratory scale: kilns, mills, presses, lasers for ceramic coating, etc. (Source: *CISE Newsletter*, July 1990)

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Feasibility study on the application of superconductivity technology

The International Superconductivity Technology Centre (ISTEC) conducted a feasibility study in 1989 on the application of superconducting technology with a grant from the Japan Keirin Association. For this study, the field of superconductivity was divided into five areas. These were separately supervised by the Superconducting Material and Key Technology Working Group, the Transportation Specialists Committee, the Electric Power Specialists Committee, the Electronics Specialists Committee and the Medical and Accelerator Specialists Committee.

1. Trends in the superconducting materials and key technology field

Studies were conducted on the basic physical properties of superconducting oxide materials. The selection of the themes was based on the expectations held for the materials for application. In table 1 on page 63, superconducting materials are divided into seven categories (BPB, La, Y, Bi, Tl, Pb, Nd) and evaluated on their superconducting characteristics, materials characteristics, process compatibility and current stage of development.

The manufacturing methods (solid-phase method, liquid-phase method, gas-phase method) of superconducting wire materials were evaluated for their potential for development. Also, the introduction of long and coil wire materials was studied. Some of the results are shown in table 2 on page 64.

For applications, emphasis was placed on clarifying the superconducting characteristics (B-J-ω) under alternating current, in addition to focusing on the future potential of magnetic shielding technology. Also investigated were promising manufacturing technologies, materials and the expected time of practical application.

2. Application to the transportation field

Studies continued on the magnetic levitation railway, the electromagnetic propulsion ship, and the electric propulsion ship. The latter showed the highest degree of development of all the fields related to transportation examined in fiscal 1988. At the same time, the applicability of the technology was studied for the following three systems: an electromagnetic launching system (for launching spacecraft, etc.), perpendicular use facilities (gravity-free test facilities, etc.) and electromagnetic flow control system for molten metal (electromagnetic pumps, electromagnetic brakes, etc.). These are also showing promise as applications.

For the evaluation of applicability of high-temperature superconducting materials in the transportation field, the empirical maximum magnetic flux density, conductor mean current density, conductor current and frequency were collated as shown in figure 1 on page 66 and their characteristics were reviewed.

On the scale of the future market and the impact on society and the economy, 100 ISTEC supporting member firms were surveyed on the following six items:

1. Magnetic levitation railway;
2. Electromagnetic propulsion ship;
3. Electric propulsion ship;
4. Electromagnetic launching system;
5. Perpendicular use facility;
6. Electromagnetic flow control system for molten metal.

For items 1, 2 and 3, the emphasis was placed on the timing of practical applications, the reason for the introduction of the system and construction costs. For items 4, 5 and 6, the proposed construction of the system was emphasized. Some of the results (Graph 120) are shown in figure 2 on page 67.

In addition to the above, the committee members visited ten organizations pursuing superconducting application development in Europe in order to study the latest trends in the application of superconducting technology with an emphasis on the transportation field.

3. Application to the Electric Power Field

Futuristic electric power systems based on superconducting technology and a likely scenario for their introduction are envisioned.

The conditions set forth for visualizing this scenario were that in 2030 the concentration of the population in major metropolitan areas would accelerate resulting in a threefold expansion in the demand for power in these areas. In order to optimally meet this situation, we expect superconducting technology to reduce losses and lead to a reduction in the size of power equipment. In addition, for the lack of construction space of urban areas, the introduction of superconducting technology would be accelerated.

4. Applications to electronics field

The following three areas were studied:

(1) Feasibility study of applications which are considered important for the application of high-temperature superconducting electronics.

The themes included: (1) Interconnects for packaging (aiming at low loss and non-dispersive transmission), (2) Three-terminal device (development of super high-speed, low-consumption power devices, (3) SQUID (high-temperature superconducting devices which can be expected to be realized in the near future), and (4) High frequency devices (application to antennas and mixers).

(2) Study of materials parameters needed for device design.

The latest data on superconducting characteristics, transmission properties, anisotropy, high-frequency characteristics and crystalline characteristics were collected and collated.

(3) Trends in basic technology on devices.

The current state of prototype devices which use superconducting oxides was examined. It was found that technology for controlling interface between superconductor and barrier materials has become the subject of future R&D activities.

Trends in R&D for high-temperature superconducting devices were also examined by means of a questionnaire.

5. Application to the medical field, accelerators, etc.

This study focused on all superconducting equipment and systems that were not covered in the other studies. Table 3 on page 65 shows the equipment and systems the committee studied.

As shown in the table, the technology for the high magnetic field MRI has made remarkable progress recently. This has resulted in an expanding demand for use in clinical medical equipment. This demand is reflected in the 606 units (for 2 T or smaller models) introduced mainly into large hospitals in 1989. NMR, large-scale nuclear fusion devices, and large-scale accelerators, etc. are three application fields which are entirely dependent on superconducting technology. (Extracted from *ISTEC Journal*, Vol. 3, No. 2, 1990)

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Concise encyclopedia of magnetic and superconducting materials

Edited by Jan Evetts, Pergamon Press, Oxford 1992, 704 pp., hardcover, £140, ISBN 0-09-034722-3.

In the series "Advances in Materials Science and Engineering", Pergamon Press has now published the "Concise Encyclopedia of Magnetic & Superconducting Materials", edited by J. Evetts. This series is a follow-up of the publication of the "Encyclopedia of Materials Science and Engineering", in 1986, and intended to bring specialized subject material from the main encyclopedia together, as well as to revise and update that material. Remembering that the Fe-Nd-B magnets were only discovered in 1983, and that high-T_c superconductivity stems from 1987, this is clearly a much needed update. It is also timely, since, at least for the high-T_c superconductors, the initial confusion due to sample preparation problems has disappeared, leaving an increasingly clear picture of the basic physics and the problems still to be addressed.

The Concise Encyclopedia is a single self-contained volume, in which 117 articles are alphabetically organized. The entries are more or less equally divided between magnetism and superconductivity, and also between the three categories "properties and phenomena" (which includes basic concepts), "classes of materials" and "devices and applications". The symbiosis of magnetism and superconductivity is a very happy one. As pointed out by the editor, there are striking parallels in the phenomenology for both classes of materials, both where intrinsic properties (such as flux structures) or extrinsic properties (e.g. critical current or coercive field) are concerned, and this is made all the more clear by putting them together in one book.

The book is remarkably easy to use and information is found very quickly; due to the mixture of phenomena, materials and applications, and together with extensive cross-referencing between the articles, it is unnecessary to be very ingenious to find the relevant entries. The articles contain useful bibliographies, are very clearly written by acknowledged experts, and are up-to-date, especially where the properties of highly anisotropic superconductors are concerned. Only the recent developments in the area of permanent magnets with N or C interstitials of the type $R_2T_{17}N_{3-x}$, are not covered; even finding a remark on them is difficult, which looks like a small omission. Of course, the book has an extensive three-level index. Unfortunately, the second level often contains so many entries that it is difficult, in leafing through, to discern which is the first-level entry, or even which is the letter treated. This could have been easily remedied by using more spacings and different typesetting. However, those are only minor complaints about a book which for the rest should be highly praised. There are few enough single volume reference works which treat fundamentals and applications, either for superconductivity or magnetism, on an equal footing. This book fills the gap admirably and will probably be found valuable by a large range of scientists.

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Crystal chemistry of high-T_c superconducting copper oxides

By B. Raveau, C. Michel, M. Herview, and D. Groult, Springer, Berlin 1991, X, 331 pp., hardcover, DM 149, ISBN 3-540-51543.

Since the discovery of superconductivity in copper oxides nearly six years ago, an enormous body of literature on this subject has accumulated. The few books that have emerged in the past two or three years were not so much textbooks in character but more a summary or overview of the current literature. As a result of progress advancing at a rapid pace, some of these books were outdated by the time they appeared on the shelves. Is there really a need for yet another book on a subject that is still evolving? This is the obvious question that comes to mind on opening the book on the "Crystal Chemistry of High-T_c Superconducting Copper Oxides" by B. Raveau, C. Michel, M. Herview, and D. Groult. The authors have extensive experience studying these materials for the past twelve years at the Laboratoire de Cristalographie et Sciences des Matériaux in Caen, France, and, in a sense, laid the foundation for the later discovery of superconductivity in copper oxide compounds at the IBM Zurich Research Laboratory. A great deal of the book is based on the authors' firsthand knowledge of the field but it nevertheless summarizes the work done by other researchers around the world.

The authors begin with a brief overview of superconducting oxides before 1986, which are summarized as tungsten bronzes (Rb_xWO_3, Cs_xWO_3), perovskites ($BaPb_{1-x}Bi_xO_3$) and spinels ($Li_{1+x}Ti_{2-x}O_4$). Already here the significance of mixed-valence elements for metallic behaviour and ultimately superconductivity becomes apparent; mixed-valence compounds are the central concept in the search for new superconducting materials. Consequently, the mixed-valence aspect in the superconductivity of copper oxide compounds is the central theme and is emphasized throughout this book. Being solid-state chemists, the authors use "mixed valence" in terms of non-integral mean oxidation state resulting from a requirement to satisfy charge neutrality. For instance the existence of Cu^{III} does not imply that Cu^{3+} ions are actually present in the structure, but rather that there are additional holes with respect to the normal divalent Cu^{II}. In the past this has been a common point of misunderstanding between physicists and chemists; hence its meaning is reiterated several times throughout the book to avoid misunderstanding.

A chapter discussing the structural aspects of the known phases of the La_2CuO_4 and $YBa_2Cu_3O_7$ families follows. The important role of alkaline-earth ions in the stabilization of Cu^{III} is pointed out. In the subsequent chapter the electronic transport properties above and below the critical temperature T_c are considered. Electronic properties leading to metallic conduction and ultimately to superconductivity are intimately connected with the oxygen nonstoichiometry and thus also to the mixed valence of copper.

Because of the central role Cu plays in these materials, an entire chapter is devoted to substitutions of various transition metal elements on the copper sites, as well as substitutions of alkali-earth and rare-earth metal elements on the other sites. The following chapter focuses on the structure of the superconducting phases of the Bi-based and Tl-based copper-oxide superconductors, in particular on their electronic transport properties. "Leaded" copper oxide compounds are also surveyed. The chapter closes with a discussion of structural relationships and common features among the various copper oxide high-T_c superconductors.

The highlight of the book is a detailed chapter on high-resolution electron microscopy (HREM) of extended defects in copper oxides, followed by a discussion of irradiation effects. Structural defects, ion ordering, and intergrowth are prominent features in high-T_c superconductors and greatly affect materials' properties. HREM is a powerful tool for the direct imaging of complex features, yet great care must be exercised in the interpretation of HREM micrographs, as the authors caution the reader. The chapter illustrates a comprehensive study of the relationship between structure and properties in high-T_c superconductors by means of HREM. Ordering in the perovskite framework is covered as well as inter-growth mechanisms, layer interconnections and domains and boundaries. Radiation damage by electrons, neutrons and heavy ions, and phase transformations (e.g. amorphization) induced by heavy ions are among the topics discussed in the chapter on irradiation effects.

The book closes by summarizing the salient features common to all copper-oxide-based high-T_c superconductors, such as low dimensionality of the structure, mixed valence of copper, delocalization of the charge carriers and the role of alkaline-earth elements.

The book is well organized and is a formidable survey of the crystal chemistry of several families of copper-oxide-based superconductors, focusing on structure, chemical bonding and nonstoichiometry. The authors do not claim to be comprehensive and see their work as a reference book aimed to reach a broad audience of "students and teachers, physicists and solid-state chemists, whether directly or indirectly involved in the field of superconductivity". The book is clearly not a textbook but a reference book, and as such not directly suitable for teaching. While the student new to the field, however, might be somewhat overwhelmed, the scientists working in the field will get the most use of the book's 320 figures and more than 670 references. It should be noted, however, that on some of the xy-plots, notably on the ones in chapter 5, the axis scale labelling is so small that it is difficult to decipher, a minor nuisance that could be corrected in a future revision. An inherent disadvantage of books such as this one is that they reflect the state of the field one to two years ago. Most of the references are from the years 1987 to 1989, with a few from 1990. In this case, this shortcoming is outweighed by the advantage of having a survey of the crystal chemistry in one handy volume.

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SQUIDs, the Josephson effect and superconducting electronics

By J. C. Gallop. Adam Hilger, Bristol 1991, x, 232 pp., hardcover, £45.00. ISBN 0-7503-0051-5.

This book contains rather more than the title would suggest. The first two chapters present an introduction to basic superconductivity, and the second and third chapters, to the principles of rf and dc SQUIDs. Chapters 5, 6 and 8 contain an extensive survey of SQUID and junction applications and it is here that the book really scores. The topics covered include analogue field, current and voltage measurements and their applications to geo-and biomagnetism, NMR, magnetic susceptibility and noise thermometry, digital and high-frequency applications of junctions and an interesting survey of the application to fundamental physics and to voltage standards.

Chapter 7 contains a collection of useful hints on how to set up and use a SQUID, the importance of vibration and interference suppression and a short section on refrigeration. The one topic it would have been nice to see included here is the performance and use of commercial SQUID systems, which are becoming increasingly available.

Chapter 8 is an introduction to high temperature superconductors and a comparison of achieved and anticipated performance of HTS junction and SQUID devices. It is a tribute to the very rapid progress in this field that some of this chapter is already out of date.

This is a useful book for people wanting to know what SQUIDs and Josephson junctions are and what they can do and also provides a valuable reference text for those of us who get called upon from time to time to give talks on the applications of superconductors.

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Corrosion of glass, ceramics and ceramic superconductors. Principles, testing, characterization and applications

Edited by David E. Clark and Bruce K. Zoitos, this volume provides a compilation of state-of-the-art understanding of ceramic corrosion. It reveals areas of deficiency and suggests future directions. 1991, 671 pp., $98.

Order ISBN 0-8155-1283-X from Noyes Publications, Mill Rd., Park Ridge, NJ 07656 USA.

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Organic Superconductors - synthesis, structure, properties and theory

By J.M. Williams, J.R. Ferraro, R.J. Thorn, K.D. Carlson, U. Geiser, H. Wang, A.M. Kini and M.H. Whangbo. Further details are available from: Simon and Schuster International Group, Campus 400, Maylands Avenue, Hemel Hempstead, Hertfordshire HP2 7EZ, UK. Tel. +44(0)442-881 900; Fax +44(0)442-257 115.

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Applied superconductivity

By A.M. Wolsky *et al.*, New Jersey, USA: Noyes Data Corporation, 1989. ISBN 0 8155 1191 4, US$ 59.

As its title suggests this is intended as a book for engineers and applied physicists. When the topic is superconductivity this is by no means an easy task, but, when, as in the present instance, an attempt is made to assess the applicability of the new, "warm" superconductors to a wide range of industrial and military applications many conclusions must, in all realism, be regarded as provisional.

It is no exaggeration to say that, despite the quite astonishing amount of work that has been undertaken, and the impressive advances that have been made, formidable problems remain to be solved, many in the complicated field of materials engineering. A brief, but illuminating overview is followed by eight sections covering such topics as generators, transformers, a.c. transmission, magnetic energy storage, motors, separation, levitation and renewable sources for electricity generation.

The material in each topic is well laid out, and clearly written summaries allow rather direct access to such specific information as may be required. Further, given that the overview has been read, each section is self-contained, so that the engineer wishing to gain insight into possible benefits accruing from applications of superconductivity in his particular field will be led quite quickly to the central factors.

The general approach is pre-eminently realistic, with enthusiasm tempered by an acute appreciation of the engineering complexities which can arise in apparently straightforward applications. In this respect the book could also serve as a valuable reference in management.

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Superconductivity sourcebook

V.D. Hunt; 1989. New York/Chichester, John Wiley & Sons. ISBN 0 471 61706 7.

The recent discovery of superconductivity at temperatures above 95 K is one of the most important scientific events of the past decade - a discovery that presents the possibility of superconductivity at temperatures at or above room temperature. This book provides a comprehensive, up to date, and highly authoritative overview of this re-emerging technology.

This sourcebook includes sections on superconductivity applications, the market potential of superconductivity, and commercializing superconductivity. It contains over 600 definitions, acronyms, and abbreviations.

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Superconductivity: a guide for industrial applications

The furore over high-temperature superconductors (first La-, then 1-2-3 Y-, and more recently Bi- and Tl-based oxides) has spawned a resurgence of interest in traditional low temperature superconductors (Nb-based and others). Except for specific electronic end-uses such as superconducting transistors, hybrid superconducting/semiconductingdevices,andcommunication sensors, most proposed HTSC applications had already been investigated, developed, or exploited for the low temperature materials. Applications for superconducting materials are wide ranging and appeal to a spectrum of industrial sectors including aerospace, military/defence, microelectronics, computer, electrical equipment, medical, communications, transportation, power generation, transmission, and distribution, chemical, robotics and high energy physics research. The report provides a realistic picture of both high and low temperature superconducting materials and products, reviewing the state of the art of the technology and updating developments, including processing advances and electrical property improvements. A detailed discussion of industrial applications in two major categories, electronics and high power, highlights the report. Key research activities in Europe, the USA and Japan are provided, and a listing of the major players in the international superconducting arena are included in the report. 200 pp., February 1990, $600 (£310).

(World Business Publications, Ltd. 4th Floor, Britannia House, 960 High Road, London N12 9RY, Fax: 081-446-3659)

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Copper oxide superconductors

C.P.Poole, Jr. *et al.* 1988, New York, John Wiley, ISBN 0 47162 342 3.

The unprecedented world-wide effort in superconductivity research that has taken place over the past two years has produced an enormous amount of experimental data on the properties of the copper oxide type materials that exhibit superconductivity above the temperature of liquid nitrogen. This volume reviews the experimental aspects of the field of oxide superconductivity with transition temperatures from 30 K to above 120 K, from the time of its discovery by Bednorz and Müller in April 1986 until a few months after the award of the Nobel Prize to them in October 1987. During this period a consistent experimental description of many of the properties of the principal superconducting compounds such as BiSrCaCuO, LaSrCuO, TlBaCaCuO, and YBaCuO has emerged. At the same time there has been a continual debate on the extent to which the BCS theory and the electron-phonon interaction mechanism apply to the new materials, and new theoretical models are periodically proposed. These matters are discussed and, when appropriate, comparisons are made with transition metal and other previously known superconductors. Many of the experimental results are summarized in figures and tables.

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Superconducting applications of niobium

O.N. Carlson (ed.): Reprinted from the Journal of the Less-Common Metals, Vol. 139, No. 1; 1988, London/New York, Elsevier Applied Science, ISBN 1-85166-970-1.

This book contains papers presented at the TMS Symposium of Niobium and Niobium Alloys in Superconducting Applications held on 24-27 February 1987.

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Superconductivity fundamentals and applications

W. Buckel: 1991. XVII, 322 pages with 183 figures and 11 tables. Softcover. DM 92.00. ISBN 3-527-27893-1.

Comprehensive and easy to understand. This introductory text presents the fundamental considerations, describes the phenomena connected with the superconducting state, provides experimental facts and discusses numerous examples for modern applications.

VCH, P.O. Box 10 11 61, D-6940 Weinheim. Fax: (06201) 606-184.

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High-temperature superconductivity an introduction

This concise tutorial overview by Gerald Burns focuses on topics, experimental results, and theoretical issues in the field of high-temperature conductivity. Paperback, 1991, 224 pp., $19.95. Order ISBN 0-12-146090-8 from Harcourt Brace Jovanovich, Inc., Academic Press/HBJ Trade, 465 S. Lincoln Dr., Troy, MO 63379-2899 USA.

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Phase diagrams for high-T_c superconductors

This volume, which contains 231 ceramic phase diagrams, was compiled by a team of experts under Robert S. Roth and John D. Whitler. Chemical systems are divided into two parts: alkaline earth, rare earth, copper, and oxygen diagrams; and alkaline earth, bismuth/lead and copper oxygen diagrams. Data evaluations were conducted in the Phase Diagrams for Ceramists Data Center in NIST's Materials Science and Engineering Lab. Hardbound, 1991, $72 nonmembers, $60 ACerS members. Order ISBN 0-944904-41-6 from American Ceramic Society, 735 Ceramic Place, Westerville, OH 43081 USA.

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Science and technology of thin film superconductors

Edited by Robert D. McConnell and Stuart A. Wolf. NY: Plenum Pub, 1989. 557p $95. 621.3 TK7872 89-32432 ISBN 0-306-43215-3.

Comprises 36 referenced papers presented at a forum for specialists in thin film superconductivity. High temperature thin film superconductors are emphasized. Articles cover laser deposition, sputtering, evaporation, metal organic chemical vapour deposition, thick film, substrate studies, characterization, patterning and applications, and general properties. For research level collections.

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Physics of high-T_c superconductors

J.C. Phillips, Boston: Acad Pr, 1989. 393 pp. $49.95. 537.6'23 QC611.98 88-34278 ISBN 0-12-533990-8.

Contents: Old materials. Old theory. New materials. New theory. Isotope effect. Lattice vibrations. Optical spectra. Tunnelling. Relaxation studies. Materials morphology. Bismates and thallates. Indices.

Note: A guide to high-temperature superconductivity based mainly on cuprates. Emphasizes materials and focuses on major experiments in the field, discussing theory when necessary. Solving the gap equation, selective phonon condensation, physical implications of isotope shifts, and intergranular weak links are among specific topics addressed. References included. For academic and research level collections treating high-temperature superconductivity.

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High-temperature superconductors

Edited by S.V. Subramanyam and E.S.R. Gopal. NY: Wiley, 1989. 244 pp. $34.95. 537.6'23 QC611.98 88-38314 ISBN 0-470-21396-5.

Contents, abridged: Crystal growth of high-temperature superconductors. High-temperature oxide superconductors. Critical current sand vortex pinning in (high-temperature) superconductors. Superconducting wires. Superconductivity: introductory phenomenology.

Superconducting tunnelling. Josephson junctions and its applications. Instrumentation for thin film deposition and analysis. Index.

Note: Based on lectures from a national workshop on high T_c superconductors held at the Indian Institute of Science, Bangalore, 27-31 March 1988. Addressed to practising researchers, text covers the principles and applications of high T_c superconductors as well as related topics from conventional superconductivity. References included. For research level collections in the field.

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Superconductivity in the CIS

A new journal on research in superconductivity in the former Soviet Union is now available in English from the American Institute of Physics. *Superconductivity - Physics, Chemistry, Technology*, published jointly by the AIP in New York and the I.V. Kurchatov Institute in Moscow, contains the most noteworthy superconductivity research among scientists in the Commonwealth of Independent States. Now that their articles are appearing in English, contributors to *Superconductivity* can count on an increase in readership and citations in this fast-growing international field.

For more information write to Superconductivity Marketing Dept., American Institute of Physics, 335 East 45th Street, New York, NY 10164-0367, USA.

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Applied superconductivity

Pergamon Press will this year be introducing a new journal, *Applied Superconductivity*, a section of the international journal *Solid-State Electronics*, in response to the increasing importance of superconductivity to the electronics and allied industries. The journal, edited by Robert B. Poeppel of the Argonne National Laboratory, will focus on any process, device, equipment, component, system, machine or structure which incorporates a superconducting element. The annual subscription rate is £345, with reductions for a joint subscription to both journals.

Further information from: Pergamon Press plc, Headington Hill Hall, Oxford OX3 OBW, UK. Tel.: +44-(0)-865-743 479; Fax: +44-(0)-865-743 952.

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The materials revolution

Superconductors, New Materials and the Japanese Challenge. Edited by Tan Forester (Basil Blackwell Ltd., 108 Cowley Road, Oxford 0X4 1JF, UK). ISBN 0-631-16699-8

Contents:

I. The Superconductor Story

  (1) Superconductors! The Startling Breakthrough that could Change our World.

  (2) Are Superconductors really that super?

II. Materials and Society and so on.

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Materials science dictionary

Due for publication in March 1993, *Chambers Materials Science Dictionary* will include areas such as general engineering, plastics, paints, paper, ceramics, electronic materials etc. The hardback is priced at £20, the paperback at £9.99.

For further details contact: W & R Chambers Ltd. Publishers, 43-45 Arndale Street, Edinburgh EH7 4AZ.

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Materials science publications

The 1993 publications catalogue from Materials Research Society, 9800 McKnight Rd. - Suite 327, Pittsburgh, PA 10017, USA, contains information on more than 300 books, videotapes and journals relating to all aspects of materials science and engineering. The 80-page publication is organized by topics including biomedical materials, ceramics and composites, materials characterization, metals and alloys, novel processing, and polymers.

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Materials selection in mechanical design

By Professor M.F. Ashby
Pergamon Press Oxford, £19.50.

Professor Ashby has listed 18 mechanical and thermal properties that are useful for characterizing a material and in engineering design. Each property is considered for each of the nine classes of materials that he covers. The charts show a range of values for each property of each material - this is helpful as, again, it contributes to the designer's feel for the subject. The range of properties for a single material is enclosed by a bubble and, in turn, the bubbles that comprise a class are enclosed in a heavier line to show the more general envelope of properties to be expected.

A chapter on engineering materials and their properties contains an impressive summary of the materials that are available to the designer.

Chapter four sees the first introduction of the materials selection charts compiled by Prof. Ashby as a result of teaching undergraduates the science of materials selection.

Two chapters cover materials processing and its influence on design alongside case studies on process selection. Sources of materials data are discussed as well as ways of exploiting these information resources, again well illustrated using case studies.

The last chapters briefly cover areas of industrial design and aesthetic considerations. The final chapter discusses the forces that are likely to change or influence the results of materials selection in the future.

Overall, this book answers the need for a systematic technique for use in materials selection. The ideas are clearly explained, and there is a wealth of general information about the way materials behave. No design office or college course should be without a copy.

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Table 1

Evaluation of the current status of high-temperature superconducting oxides

Evaluation / Group	Superconducting characteristics			Materials characteristics	Process compatibility			Development level		Others
	Critical value T_c, H_c, J_c	Physical properties ξ, n, Δ	Anisotropy	Strength, stability, etc.	Solid phase method	Liquid phase method	Gas phase method	Physical properties	Process	Safety, resource availability, etc.
BPB	B	A	A	B	C	B	A	A	A	
La	B	A	B	B	C	A	A	A	B	
Y	A	A	B	B	B	A	A	A	A	designated as a toxin
Bi	A	B	B	B	A	B	A	A	A	relatively small reserves
Tl	A	B	C	B	A	C	A	A	A	designated as a noxious chemical substance
Pb	B	C	C	C	C	C	C	C	C	designated as a toxin
Nd	B	C	C	C	C	C	C	C	C	

A: Optimum B: Good C: Not known D: Poor

Table 2

Evaluation of Wire Materials Methods

Process		Development potential											
		Basic properties			Long wires, coils					Processing characteristics			
General Classification	Sub-classification	Uniformity Fine density	Orientation control	Introduction of pinning center	Stabilization	Large capacity	AC loss	Mechanical properties	Coil processing method	Material compatibility	Productivity	Economy	Degree of development of related technologies
Solid phase	Diffusion reaction	C	C	C	B	B	C	C	C	B	C	C	B
	Sheathing	B	A	C	A	A	C	C	B	A	A	C	B
	Explosion compression	B	C	C	A	B	C	C	C	A	B	C	B
	Doctor blade	C	B	C	C	B	C	C	C	A	B	C	B
	Extrusion	C	C	C	C	B	C	C	B	A	B	C	B
	Printing & coating	C	B	C	C	B	C	C	C	A	B	C	B
	Suspension spin yarn	C	C	C	C	B	C	C	C	B	B	C	B
Liquid phase	Sol/gel (organic polymer)	C	C	C	C	B	C	C	C	C	C	C	B
	Molten oxide solution method	A	A	B	C	B	C	C	C	C	C	C	B
	Molten metal solution method	A	C	C	A	B	C	B	B	C	B	C	B
	Spraying method	C	B	C	B	B	C	C	C	A	B	C	A
Gas phase	Sputtering	B	A	B	C	C	B	B	C	A	C	C	A
	Evaporation	B	B	B	C	C	B	B	C	A	C	C	A
	CVD	B	B	B	C	C	B	B	C	B	C	C	B
Notes					Composit with metal	Cross section I_C multi-core	Fine multi-core twist	Flexibility fine density rigidity	Winding			No. of steps Energy Yield Raw materials	

A: Proved by tests B: Possibility seen in basic tests C: Possibility not yet confirmed

Table 3

List of equipment and systems for medical field and accelerators specialists committee

Application Principle	Medical care	Physical tests	Energy	Process application	Others
Zero resistance					
①Magnetic moment	•MRI	[★Magnetic resonance]		[•Magnetic separator]	•Magnetic refrigerator
•resonance	★NMR			[•Monocrystal lifting]	★Non-destructive test of materials
②Charged particle	•Cyclotron	[•Electron microscope]	[★MHD]	•Small SR	
	•Synchrotron	[•Oscilloscope]	•Nuclear fusion device(*1)	•Wiggler	
			★Large-scale particle accelerator	[•Electron beam transfer]	
③Others		[•Hybrid magnet]	★Long solenoid	(•Electromagnetic pump) •Electromagnetic pulse molding and processing	[★He refrigerator]
Josephson effects	(★SQUID)	[•For particle detection]			[•Mining sensor]
(quantum effects/ tunnel effects)	[★Magnetic cadiography] [★Magnetic cephalography] ★Bio-magnetism				
Meissner effects	•Magnetic shield			•Magnetic shield	[•Magnetic bearing]
Low AC loss			[★Nuclear fusion device (*2)]		[•Space launcher]
(1) AC, super-strong magnetic field	[•SCRF]		★Magnets for synchrotrons		
(2) High frequency cavity			★Linear accelerator		[•Rail gun]
SN transition			[★Switch]		
Others					•Waste water treatment, environmental pollution control

( ): To be studied by another committee [ ]: Not included in the scope of this year's study (incl. those studied in the preceding year)

(*1) Troidal magnetic field coil (*2) Poloidal magnetic field coil

★Normal conducting field is advantageous.

★Cannot be realized without superconductivity.

Others: Can be realized in both regions depending on the requirements and the application.

Figure 1

Electric properties required of superconducting materials used for superconducting technology applied to equipment in the transportation field. (a) Conductor mean current density and experimental maximum magnetic flux density of the conductor; (b) Conductor current; (c) Frequency

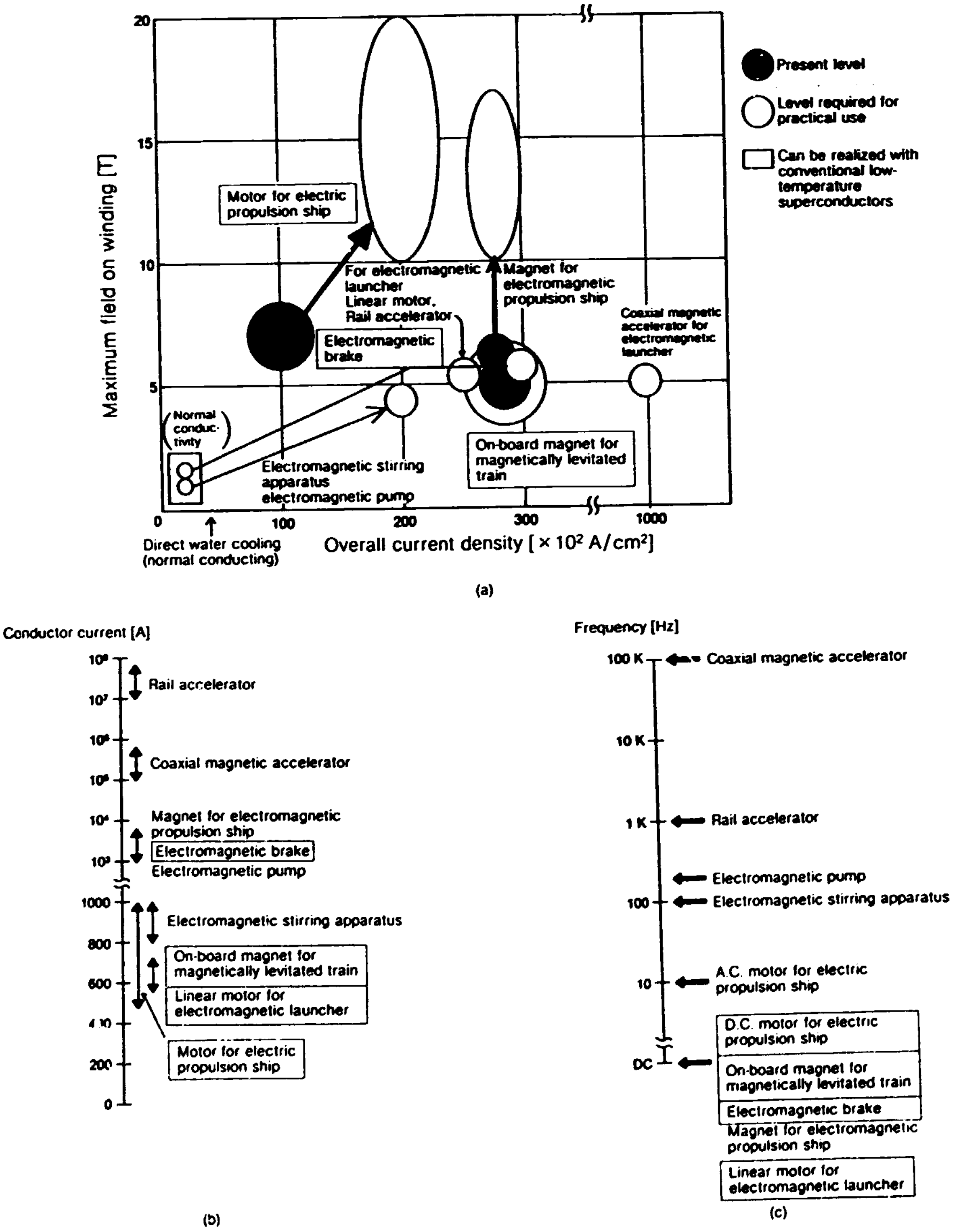
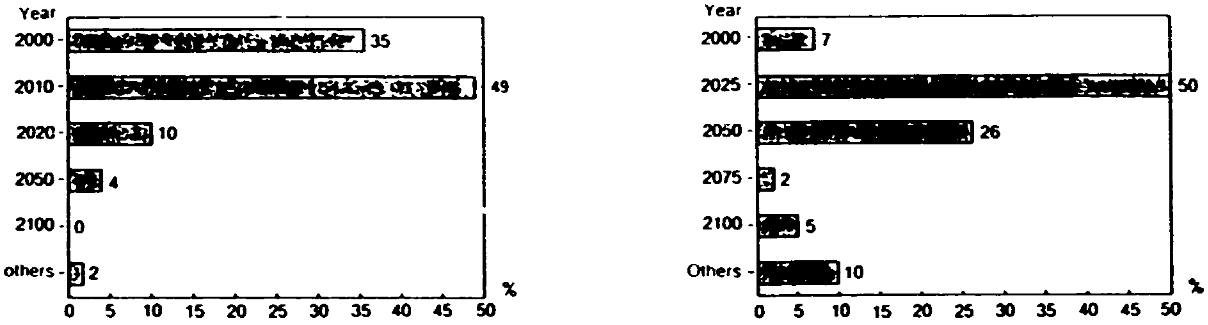


Figure 2

An example of the responses to the questionnaire (a) Expected technical realization of commercial operation of superconducting magnetic levitation railway travelling at 400 km/h or more; (b) Expected realization of superconducting electromagnetic propulsion ship



(a) Respondents 49 firms

(b) Respondents 33 firms

7. PAST EVENTS AND FUTURE MEETINGS

1993

9-14 May Il Ciocco, Italy	Organic Superconductors (Gordon Research Center, University of Rhode Island, Kingston, RI 02281-0801, USA)
24-30 July Seattle, WA	Mathematics of Superconductivity (American Mathematical Soc., P.O. Box 6887, Providence, RI 02940, USA)
27-31 July Eugene, OR	Molecular and Oxide Superconductors (University of Oregon, Dept. of Physics, Eugene, OR 97403, USA)

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19-22 July Aberdeen, Scotland	Materials Chemistry (The Royal Soc. of Chemistry, Piccadilly, Burlington House, London W1V OBN, UK)
23-25 July Santa Barbara, CA	Electronic Materials (Minerals, Metals and Mat. Society, 420 Commonwealth Dr., Warrendale, PA 15086, USA) Fax: (+1 412 776-3770)
28 Aug. - 2 Sept. Quebec City, Canada	32nd Annual Conf. of Metallurgists Symposium on "Developments and Applications of New Ceramics and Metal Alloys" (Dept. of Metallurgical Eng., Ecole Polytechnique, Montreal, Quebec, Canada, H3C 3A7)
30 Aug. - 3 Sept. Tübingen, Germany	Corrosion of Advanced Ceramics: Measurement and Modeling (Univ. Tübingen, Inst. F. Mineralogie, Petr. & Geochemie, Wilhelmstrasse 56, W-7400 Tübingen, Germany)
6-9 September Tokyo	International Conf. on Computer-Assisted Materials Design and Process Simulation - COMMP '93 (Iron and Steel Inst. of Japan, Keidanren Kaikan, 3rd Floor, 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100 Fax: (81) 3-3245-1355)
6-10 September Dresden, Germany	Advanced Polymer Materials (Inst. F. Polymer Research, P.O. Box 411, 0-8012 Dresden, Germany Fax: (+37) 51-4658-214)
13-15 September Washington, D.C.	Forum on Materials and the Global Environment (ASM International, Materials Park, OH 44073-0002 Fax: (216) 338-4634)
13-15 September Cambridge, UK	Interfacial Phenomena in Composite Materials (Meetings Management, Mr. J. Herriot, Straight Mile House, Tilford Rd., Rushmoor, Farnham, Surrey GU10 2EP)

19-24 September Houston, Texas	12th Int. Corrosion Congress (NACE Membership Services Dept., P.O. Box 218340, Houston, Texas 77218 Fax: (713) 492-8254)
20-24 September Clausthal, Germany	Textures of Materials - ICOTOM 10 (Inst. f. Metallkunde und Metallphysik der TU, 10 Grosser Bruch 23, W-3392 Clausthal-Zelierfeld, Germany)
20-24 September Bordeaux, France	Composite Materials (EACM, 2, place de la Bourse, F-33076 Bordeaux Cedex, France Fax: (33) 56-01-50-05)
27-29 September Ottawa, Canada	CANCOM '93 Second Canadian Int. Conf. on Composite Structures and Materials (Institute for Aerospace Res., Nat. Res. Council of Canada, Ottawa, Canada K1A OR6) Fax: (613) 993-7136)
27-29 September Pittsburg, PA	3rd Int. Conf. on Near-Net-Shape Manufacturing (ASM International, Materials Park, OH 44073-0002 Fax: (216) 338-4634)
27-30 September Detroit, MI	9th Annual ASM/ESD Advanced Composites Conf./Exposition (ASM International, Materials Park, OH 44073-0002 Fax: (216) 338-4634)
5-7 October Le Chantecler, Ste-Adele, Quebec	2nd Research Forum on Recycling (Canadian Pulp and Paper Ass.; Mr D. Paterson, Technical Sector, 1155 Metcalfe St., Suite 1900, Montreal, Quebec, Canada H3B 4T6 Fax: (514) 866-3035)
17-21 October Pittsburg, PA	Physical Metallurgy (Minerals, Metals and Materials Society, 420 Commonwelath Dr., Warrendale, PA 15086 USA)
25-28 October Philadelphia, PA	Advanced Materials (SAMPE Int. Business Office, P.O. Box 2459, Covina, CA 91722, USA)
1-4 November Baltimore, MD	12th Biennial Managing Corrosion with Plastics Symposium (Sponsored by the Nat. Ass. of Corrosion Engineers and co-sponsored by the American Soc. for Testing Materials) (Canadian Pulp and Paper Association, 1155 rue Metcalfe, Montreal, Quebec, Canada H3B 4T6)
2-4 November Honolulu, Hawaii	3rd Pacific Rim Forum on Composite Materials (Dept. of Aeronautics and Astronautics, Stanford University, Stanford, CA 94305 Fax: (415) 725-3377)

15-17 November Nagoya, Japan	6th Int. Symposium on Agglomeration (The Society of Powder Technology, Japan, The Iron and Steel Inst. of Japan, The Society of Chemical Engineers, Japan and co-sponsored by The Institute of Materials) (Dept. of Pharmaceutical Engineering, Gifu Pharmaceutical University, Mitahora Higashi, Gifu 502, Japan Fax: (+81) 582-37-5979)
15-19 November Minneapolis, MN	Magnetism and Magnetic Materials (Inst. of Electrical and Electronic Engineers, 345 E 47th St., New York, NY 10017, USA)
16-18 November Perth, Australia	INTO ASIA Convention - Opportunities for New Materials and Advanced Ceramic Industries (Ms. L. Townsend, 22 Towcester Rd., Old Stratford, Milton Keynes MK19 6AQ, UK)
18-20 November Singapore	Int. Advanced Materials & Manufacturing - Technology Conference and Exhibition - Theme: Advanced Materials: The Drive for Industrial Development & Growth (American Powder Metallurgy Inst., Engineering Industries Ass., UK; Metal Powder Industries Federation, USA; The Institute of Materials, UK; Manufacturing Div. IEE, Singapore; Plastics & Rubber Inst., Singapore)
2 December Bangalore, India	56th Annual Session of the Bangalore Chapter of the Indian Ceramic Society (R.G. Shah, M/s. Graphite India Ltd., Whitefield Rd., Bangalore 560 048, India)

Advances in Materials Technology: Monitor

Reader Survey

The *Advances in Materials Technology: Monitor* has now been published since 1983. Although its mailing list is continuously updated as new requests for inclusion are received and changes of address are made as soon as notifications of such changes are received, I would be grateful if readers could reconfirm their interest in receiving this *Monitor*. Kindly, therefore, answer the questions below and mail this form to: Ms. A. Mannoia, Technology Development and Promotion Division, UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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11. Please make any other comments or suggestions for improving the quality and usefulness of this *Monitor*.

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