RECENT DEVELOPMENTS IN SUPERCONDUCTIVITY IN JAPAN

The Committee of Superconducting Magnets
of the Institute of Electrical Engineers of Japan

Presented by

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Recent developments in Japan of the study on 1) superconducting wires, 2) magnets, 3) other devices, 4) cool down techniques for the magnets, and 5) some aspects of future projects, are described in this paper.

I. SUPERCONDUCTING WIRES

In Japan the study on superconducting wires was started in 1962, and since 1966 several kinds of superconducting wires have been developed in many research laboratories.

Alloys

The superconducting wires developed in Japan have the interesting feature that most of them are ternary alloys with niobium base material. Some typical ternary alloys are NbZrTi, NbTiHf, and TiNbTa. Each of these have better H_c, I_c characteristics than the usual binary alloys such as NbTi or NbZr.

Binary alloys have also been investigated. Several of these are NbTa, NbZr, NbTi, NbMo, TaRe, V-Cr, V-Ti, InPb, SnIn, ZnMn and ZnCd. These alloys are not all necessarily being developed to achieve good characteristics for wire for superconducting magnets. Some are for the study of basic phenomena and some are to develop materials which have higher critical temperatures.

Compounds

Many basic studies on the superconducting compound wires have been carried out but no practical wires have yet been developed. To get basic data, Nb_3Sn, NbB_2, $NbMoB_2$, NbS_2, NbN, Nb_3V, V_3Ga, etc. are being studied. The last compound, especially, V_3Ga, is being examined with keen interest as a possible practical material that can be produced on an industrial scale. The V_3Ga is made into a tape with the continuous diffusion method and has a critical field of about 200 kG at the current density of 10^5 A/cm^2. This is a value higher than that obtained with other materials such as Nb_3Sn.

Composite Conductors

Large current conductors for the MHD saddle-type magnets and high energy physics magnets have been studied. Techniques of embedding a number of superconductors into normal metals such as copper or aluminum are being studied.

The ratio of the cross section of superconductors to that of normal metal and the contact resistance between these two are studied as part of the development of the optimum stabilized superconductors.

Some results of these studies are being made use of in the National R&D Program for the MHD generator and at the present time the construction of a saddle-type magnet is in progress.

II. MAGNETS

In Japan the development of superconducting magnets is being carried out for MHD generators, for high energy physics, and for other applications. The first type of magnets have saddle shape configurations, so that they can be used as the field windings of electrical machines such as dc motors or alternating machines.

Saddle-Type Magnets

The saddle-type superconducting magnets are being developed as part of the National R&D Program for MHD generators planned by the Agency of Industrial Sciences and Technology. The parameters of one of these magnets which has already been constructed and tested are given in Table I. This magnet is only a prototype for the MHD generators, but another magnet which is to be combined with an experimental generator is now under construction. This second magnet is to be set in a Dewar which has a room temperature bore at the center. The magnet has an inner diameter of 38 cm and is to produce the field strength of 45 kG at the center of the bore. This magnet system is to be completed by early 1969. The details of this magnet are listed in Table II.

TABLE I

Details of a Model of Saddle-Type Magnet

	Tested	Under Test
Inner diameter	33 cm	33 cm
Outer diameter	43.5 cm	57 cm
Coil length	91.3 cm	91.3 cm
Weight	600 kg	1200 kg
Stored energy	110 kJ	-
Field strength at the center of bore	13.8 kG	16 kG
Current	695 A	-

TABLE II

Details of Saddle-Type Magnet for MHD Generator

Inner diameter	38 cm
Room temperature bore	25 cm
Coil length	190 cm
Field strength at the center of bore	45 kG
Stored energy	6 MJ
Current	585 + 540 A
Weight	6 ton

High Energy Physics Magnets

For preliminary studies for high energy physics magnets such as bubble chamber or beam focusing magnets, many small magnets wound using the stabilized strip conductors are being tested in many research laboratories. For instance, one magnet consists of a Helmholtz pair which have an inner diameter of 5 cm, an outer diameter of 20 cm, and a length per coil of about 20 cm. The gap between two coils can be changed to adjust the field distribution. The field strength at the center of the bore of one coil is about 40 kG. Another example is a pancake coil that has an inner diameter of 8 cm, a length of about 63 cm, and a field strength of 56 kG at the center.

A cusp magnet, which can confine the high temperature plasma produced by laser rays, is also being tested. This magnet has an inner diameter of 1.5 cm, an outer diameter of 9 cm, a length of 5 cm, and can produce a field strength of 40 kG at the center of one coil.

Various Magnets for Experiments

A number of magnets have been constructed and used for the study of solid state physics. In general, superconducting alloy wires are used up to about 60 kG or so and higher magnetic fields are generated by Nb_3Sn tape-wound magnets. The highest magnetic field produced by superconductors in Japan so far is about 100 kG.

III. OTHER DEVICES

To reduce the heat input through large current power leads from room temperature to low temperature devices, flux pumps are also being studied. At present no practical flux pumps have been constructed, but to get useful data for the construction of more effective flux pumps, a number of basic data have been taken as part of the National R&D Program for the previously mentioned MHD generator.

Two types of flux pumps have been studied. One is a moving magnet type and the other is a rectifier type like that developed by Dr. Buchhold. One of the first type was used to supply a current of about 200 A to a small magnet, but the output voltage of this type of flux pump is very small. Therefore, efforts are now focused on how to increase the output voltage as well as to increase the current capacity. The second type of rectifier has not generated a current, but the dynamic performance needed for a complete pump has been tested successfully with a half wave rectifier circuit. This flux pump will have an output voltage of about 10 mV and the current of about 500 A.

IV. MAGNET COOL DOWN TECHNIQUES

Liquid helium is so expensive in Japan that the techniques used to cool the large superconducting magnets from room temperature to $4.2^{o}K$ are very important from an economic point of view.

For small superconducting magnets, precooling by liquid nitrogen before using liquid helium is widely practiced. But this method is not appropriate for the cool down of larger magnets because it causes contamination of helium gas. Therefore, cool down from room temperature to slightly above liquid helium temperature is generally accomplished with a refrigerator.

The previously-mentioned saddle-type magnet tested at the Electrotechnical Laboratory of the Agency of Industrial Sciences and Technology was cooled to $47^{o}K$ by a refrigerator and then liquid helium was transferred.

The cool down process combined with the refrigeration system in one research laboratory has been analyzed. The process is as follows: First, the magnet is cooled down to about 90°K by helium gas which is cooled by liquid nitrogen. The magnet is then cooled down by a helium refrigerator from 90°K to about 20°K, after which liquid helium is transferred from a liquid helium storage Dewar. In the analysis, the cool down time is calculated using several parameters which include the weight of the magnet, the heat input to the magnet, the efficiency of heat transfer between the magnet and the cooling fluid, and the power of the refrigeration system. The results of this calculation are represented in graphical charts to estimate the cool down time immediately.

V. FUTURE PLANS

It is difficult to discuss what fields have opened for the applications of superconductivity.

Considering, however, the extremely rapid advances in superconducting technologies since the discovery of practical superconducting wires in 1957, many devices may be improved by making use of new knowledge of various superconducting phenomena to be obtained in the near future. As seen in the development of V_3Ga wire, for example, efforts are still being continued to develop new materials which are able to produce still higher magnetic fields. If it is to be easy to generate high magnetic fields over 200 kG by a superconducting magnet, a number of developments must come in the field of engineering as well as in basic science.

Applications for the ac devices are considered to be just at the starting point as compared with dc devices, although the basic research has long been done.

If superconducting materials applicable for ac devices are developed, electrical machines will occupy an important position in future superconducting applications.

Thus, the superconducting technology which has advanced from small superconducting magnets to the present large size magnets is now gradually changing into the technology that is useful in applications for industrial equipment such as generators, motors, transmission lines, and so on.