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# SUPERCONDUCTIVITY: THE PROMISE AND REALITY

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The discovery of superconductivity brought with it the promise of a miracle solution to many technological problems encountered by the electrical power industry. That discovery was at Leiden in 1911. Since then, engineering designs and prototypes have been developed for the use of superconductive materials in electric power transmission, transformers, and machinery. The development of superconducting magnetic energy storage systems also held great promise. Superconductivity was even used to build marine propulsion systems and levitated track vehicles. Despite that, and despite the financial support of governments for prototype developments, the only commercial application of the technology, outside of laboratories, is for MRI magnets. Similar experience is encountered in superconducting applications to electronics, although some success has been achieved in the communication industry. The discovery of high temperature superconductivity, despite its promise, did not significantly change the situation. The developments will be reviewed, and some of the reasons why superconductivity is still mainly confined to the laboratory will be given with the view of what we, as scientists, can do in order to enhance and hasten the commercial adoption of superconducting technology.

Superconductivity was discovered in 1911 by H. Kamerlingh Onnes and his assistant Gilles Holst at the University of Leiden, The Netherlands, three years after Kamerlingh Onnes managed to liquefy helium. The element was Hg, and its transition temperature was very close to the point where helium liquefied. Because of that, it was initially thought that the phenomenon was an accidental short in the circuit upon cooling in liquid helium. Since then, many other materials were found to be superconducting, and the intrinsic feature of superconductivity became its "perfect diamagnetism" — the exclusion of magnetic flux — rather than zero resistance.

From the beginning, the lack of resistance held the promise of electric power transmission with no loss, however, in the materials then considered, type I superconductors, the critical current density as well as the critical magnetic fields were low, in addition to having to cool the substance to very low temperatures. This, however, did not stop physicists from devising logic circuits[1] and other devices which were later duplicated and surpassed by semiconductor devices.

The realization that there are intrinsic type II superconductors in the late 50s and 60s made the large scale application of superconductivity feasible and many initiatives were started and prototypes of power machinery and power transmission lines were built. An example of what was accomplished can be seen in the Reports of the NATO Advanced Study Institute, Entreves, Italy September 1973.[2] At that time, all the applications were designed to work at helium temperatures or slightly above that. The prototypes were internationally supported by government grants and industry. By the beginning of the 80s many of those projects were either dormant or abandoned.

The discovery of High Transition Temperature Superconducting, (HTS), materials revived hopes of large scale applications of superconductivity. However, a look at the reports of the 1973 conference[2] and the web sites of the DOE and the companies which are the major players in the Superconductivity business, show that little progress has beem made in the commercial application of superconductivity in the last 30 years. There have been major successes in the large scale application of superconductivity to accelerators and detectors at research laboratories. There has also been success in the medical field, where high magnetic fields for MRI can be achieved only by superconducting magnets. The latter might be the only example of a "COMMERCIAL" application. It is also noteworthy that that application is an application of low temperature superconductivity, (LTS). Besides that, however, very little progress has been made. The puzzle is WHY.

Let us now review some of the demonstration projects and their present status. Most of the information comes from the web. The information can be accessed on the *www.doe.gov*, Supercpnductivity Partnership Initiative, (SPI), *www.southwire.com*, *www.americansuperconductor.com*, *www.cnn.com*, *www.epri.com*, and other sites. What happened to the projects of 1973 and were they duplicated with the new HTS materials, and at what temperature? The successes are achieved mainly with the low temperature superconductor materials, NbTi and NbSn, the latter having come into use within the last 10 years.

We can take as a starting point the list of topics given by Powell in Ref. 2.

(a) Energy Storage
(b) Energy Modification-AC and DC Generators and Motors
(c) Energy Transmission-DC, AC
(d) Magnetic Levitation-High speed Ground Transportation
(e) Industrial Processing

Energy Storage: In the early 90s, several laboratories and companies developed a Superconducting Magnetic Energy Storage System, (SMES), and a company, Superconductivity, Inc. installed several of those at a production plant and at a utility. The technique was LTS and the promise was that it will alleviate short duration power interruptions which, because of the use of computers, could cause long down times. The premise was that the power density in a high magnetic field can exceed that in many other energy storage systems. The installations were trailer sized. The company has since been bought up by American Superconductor and

SMES no longer appears on the DOE website. Instead, an HTS Flywheel Electricity System, by Boeing, is now under construction and "undergoing extensive testing". The capacity of the system is 2kWh.

AC and DC Generators and Motors: According to the DOE-SPI, an HTS "1000 HP motor has been assembled and is undergoing operational testing. Preliminary conceptual designs for the 5000 HP motor are being finalized." This is succeeded by previous similar successes in the LTS developments, where generators and motors had been constructed. The important thing here is a systems approach where, cryogenics and superconductivity and power companies are involved in this development.

HTS Current Controller: A "15 kV current controller was tested at a Southern California Edison substation in July, 1999. Modifications and further testing". Again, the system is trailer sized. There have also been installations of HTS transformers which are still being modified.

Energy Transmission DC, AC: This is, in my opinion, one of the success stories. A 30m HTS three phase 12.5 kV 1250A power line was installed at the Southwire Company and has been in use for two years. It seems reliable and has exceeded specifications. The fault is that it cost $18M and its maintenance, at the present time, exceeds the cost of a comparable length of line by at least a factor of 100. Plans are being made to install longer lines in existing urban power grids to increase capacity and lower losses. With an eventually integrated cooling system, the maintenance costs could come down to compete with conventional power cables. There is also the question of whether an AC or a DC system is more desirable. An AC system has been constructed and fits most of the existing power grids. A DC system could be truly lossless, as far as the electrical losses are concerned. On the other hand, in order to fit the existing power grid, elaborate AC–DC and DC–AC converters are required. A solution to this problem was suggested by this author.[3]

Magnetic Levitation-High speed Ground Transportation, (MAGLEV): Models and prototypes have been build utilizing mainly LTS technology because of the high magnetic fields required. The 80s saw a levitated train installed in Berlin, without superconductivity, and there was testing of a MAGLEV train in Japan. However, here the nonsuperconducting solution won out with the installation of a MAGLEV line in China, Pudong-Shanghai, using conventional German technology. Here, once again, a superconductivity solution was replaced by more conventional technology.

This review cannot end without the mention of the Boat YAMATO, built by Mitsubishi Heavy Industries Limited in Japan in the late 80s and early 90s. It was powered by a magneto-electric-hydrodynamic motor with no moving parts. It achieved 8 knots with the use of LTS magnets. It made only a few runs, and then put on pylons as an exhibit. Industrial Processing: At the 1973 workshop, industrial processing was confined mainly to the removal of impurities by means magnetic fields. This is currently done by means of conventional magnets and the increase in the efficiency of using superconducting, mainly LTS, technology does not warrant the increased maintenance and cost of superconducting systems. The only commercial success is in the medical field, and there, mainly in the LTS superconducting magnets which are used by MRI systems. In this, Oxford Instruments is the leader.

Why, after 90+ years, is superconducting technology still in the development stage as far as commercial uses are concerned? The answer is in the fact that other techniques can do the job just as well and we have paid more attention to component development rather than system development. Also, most of the proposed uses of the technology are replacement rather than new and unique uses. In our eagerness of getting the technology adapted, we have not addressed many of the problems which are necessary for commercial applications. Those are: (1) the problem of scaling up the manufacturing process from lab to factory floor, (2) reliability and the criterion of the 30 years of operation under adverse conditions have not yet been met, (3) the cost of installation and highly skilled workforce to maintain the systems has to be lowered, (4), neither have we succeeded in creating a *TURN KEY*, ready to plug in and use, system. We have not yet breached the transition between lab and industry. *We have been working on replacemant and gradual improvement technology, rather than thinking of uses unique to the capabilities of supercondutivity.* We have been developing components as opposed to systems.

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