A Golden Anniversary: 50 Years of Superconductivity at MT

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Abstract - The niobium based high field superconductors were discovered and developed in the 1950s, and by the early 1960s small superconducting solenoids had started to appear. Several of these solenoids were reported at the first Magnet Technology Conference, held at Stanford Linear Accelerator Centre in 1965. At MT-1 however superconductivity was a minority interest, accounting for only about 20% of the papers presented, compared with 50% on resistive magnets. This situation would soon change however, with superconducting magnets overtaking resistive magnets at MT-3 and increasing steadily so that by MT-15 they accounted for 80% of presentations, with resistive magnets contributing only 10%.

High energy physics and accelerators HEP have always been the largest application sector for superconducting magnets at MT, accounting for 20% to 30% of superconductivity papers at every conference. Next in line has been fusion, which started rather later than HEP, but then rose to 15% to 20% of papers at subsequent conferences.

HEP and fusion have been the major technology drivers for low temperature superconducting magnets. The big bubble chambers used as particle detectors at high energy laboratories were the largest superconducting systems of their day, using magnets which were made possible by the principle of cryogenic stabilization, which had already been described by Stekly at MT-1. The ambition of accelerator builders to achieve higher energies via higher magnetic fields stimulated a deeper understanding of ac loss and flux jumping, which led to the development of filamentary superconducting wires and Rutherford cable. Much of the early development work on superconducting accelerator magnets was done in Europe, but the first superconducting accelerator was the Tevatron, built at Fermilab in USA. The need for optimum performance and uniform quality in the Tevatron magnets stimulated major improvements in the process technology of NbTi, which have benefitted the whole community. The Tevatron was followed by HERA at DESY, RHIC at Brookhaven and LHC at CERN, while in future FAIR at GSI Darmstadt will push the technology of superconducting accelerator magnets even further.

Many large superconducting fusion experiments have been built, starting with the ill-fated MFTFb mirror fusion test facility at Livermore Laboratory USA, sadly closed down for economic reasons on the very day of its completion. More fortunate was the Tore Supra tokamak at Cadarache France, which pioneered the large scale use of subcooled helium II as a very efficient coolant. The Large Helical Device LHD has successfully operated for many years in Toki Japan and will shortly be followed by another

stellarator, Wendlestein 7, in Greifswald Germany. The superconducting tokamaks EAST in Hefei China and Kstar in Daejon S. Korea have been operating for several years and SST-1 is nearing completion at Gandhinager India. The world's largest Tokamak ITER, now under construction at Cadarache France, will be the first to generate net fusion power. As well as the technology development work for ITER, many earlier technology demonstration projects like NET and LCT have been extensively reported at MT. The most important technology development to have come out of these large fusion projects has been the cable in conduit conductor CICC, which has made it possible to combine the low ac loss of fine filamentary wires with the reliable performance of cryogenic stabilization in a conductor which is big enough and robust enough for very large scale coil manufacture.

Surveys by CONECTUS indicate that for the last 20 years MRI has accounted for ~ 80% of world activity in superconductivity, yet MRI and NMR together account for only about 5% of contributions at MT conferences over the same period. The reasons for this are not clear, but are probably more connected with commercial culture and confidentiality than with technology interest.

High temperature superconductivity HTS was discovered in 1986 and in the following year MT-10 saw one paper about these exciting new materials. At MT-11 there were already 21 papers, 9% of all contributions on superconductivity and this number has risen steadily until recent years, where HTS accounts for about 35% of the total. Not surprisingly, materials science and magnet technology accounted for most of the early HTS contributions, but papers about using HTS in practical applications have risen steadily over the years. Unlike LTS however, these applications are not dominated by HEP and fusion, which have only accounted for about ~ 4% of total HTS. Neither has MRI excited much interest, with about 5% of papers. Instead, the majority interest has been in heavy electrical engineering: rotating machines, transformers, fault current limiters, magnetic separation, bearings and magnetic levitation. Perhaps the simpler and more robust cryogenics associated with HTS will prove to be a more decisive advantage in the rough world of engineering than in the more controlled environment of a big science laboratory or hospital.

Fault current limiters FCL have been exciting a lot of interest at recent MT conferences, accounting for 15% to 20% of all HTS contributions. Perhaps one of the reasons for this high level of activity is that there is no conventional alternative able to perform the same current limiting function. Early FCLs used BSCCO in either tape or bulk form and fell into two broad categories depending for their operation on either the increase in resistance when a tape quenches or the increase in inductance when the short circuited secondary (a ring of bulk BSCCO) of an inductor quenches. In recent years there has been a swing of both types from BSCCO to thin film YBCO, which runs at much higher current density and therefore experiences a greater increase in resistance at quench. Also at recent conferences, there has been an upsurge in papers looking at the broader effects of FCLs on the overall network – perhaps a sign that this technology is now nearing commercial exploitation.

Although the ‘traditional’ application sectors of HEP and fusion have not yet shown much activity in HTS at MT, the potential advantages are substantial. Particle accelerators will be able to reach higher energies and stronger focusing magnets will produce brighter beams. For fusion, the compact spherical tokamak offers the prospect of power generation in modules of only ~100MW size rather than the much larger ~1GW size needed for conventional tokamaks of the ITER type. The economic benefits of such smaller modules are clear but the price is that the toroidal coils must work in fields of 15T to 20T under conditions of high neutron heating - HTS is the only possibility. So there are many exciting challenges ahead for MT!

Keywords (Index Terms) - Superconducting magnet, HEP, fusion, MRI, NMR, CICC, FCL.