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Development of Large-Scale Superconducting Solenoid Technologies for Future Accelerator Experiments

In 1980's, three superconducting solenoids with large apertures, TOPAZ[1], VENUS[2] and AMY[3] have been developed to be installed into particle detectors in TRISTAN collider. TOPAZ and VENUS have been successfully developed with pure aluminum stabilized NbTi/Cu conductors in reflection to the demand of high transparency in terms of radiation and absorption lengths. After these successes, Belle in KEKB[4] and ATLAS central solenoid (CS) in LHC[5] have followed same thin solenoid style. Especially a conductor, which has both high strength and high RRR by by adding 0.1wt%Ni to Al clad and cold-work hardening, has been successfully developed for ATLAS CS. High strength Al superconductors have been originally applied to an ultra-thin superconducting solenoid for BESS-Polar cosmic ray spectrometer[6], and the recently developed solenoid in J-PARC, that is COMET capture Solenoid[7] under construction. Solenoids wound with usual Cu stabilized NbTi cable are also being developed; like muon storage magnet for J-PARC g-2/EDM experiment[8], which requires precisely controlled magnetic field distribution.

For the development of superconducting solenoid for future experiments, it is necessary to improve 1) superconducting cable technology and 2) magnet design technology. In the 1), production technology of Al stabilized SC cable is a key point in order to mee the demand of large-scale solenoid for future experiments. Future colliders, ILC, CLIC etc., requires larger-scale detector solenoids, it means to require an advanced cable with the cable with higher mechanical strength and reliability on quench protection than ever before, because an upsizing of solenoids causes the increase of magnetic force and stored energy. The design study for one detector solenoid in ILC, ILD, is being carried out by ILD collaboration where KEK joins. This refers the both conductor concepts for ATLAS CS and CMS, which is combination of high purity Al section and welded high-strength Al alloy block[9]. Several cables having different structure are suggested and studied from the view point of superconducting, economic and manufacturing performance. Basic study of Al stabilized HTS cable is also considered for future application in collaboration with R&D groups for high field A15 and HTS magnets[10]. The key issues for the realization are quench protection and radiation hardness of HTS cable as well as recovery from irradiation damage of Al stabilizer.

The technology 2) is required to be improved in the following 3 points; a) 3D high precision magnetic field design/control, b) 3D mechanical structure design and c) sophisticated cryogenic system. About 2-a), J-PARC muon g-2/EDM experiment requires 3 T superconducting solenoid as muon storage magnet with high homogeneous magnetic field, less than +/- 0.1 ppm. In order to satisfy the requirement, new analytical code using truncated singular value decomposition method to optimize coil position and size is being newly developed[11], and design work is in progress using both the new code and existing commercial FEM code that can calculate with non-linear effect. Other than the high precision design technology, precise magnetic field control technology is also important, so advanced passive shimming technology using commercial MRI magnet is studied. These 3-D magnetic field design and control technologies are being developed in collaboration with Ibaraki University. Accompanying the precise magnetic field control, precise magnetic field monitoring system development is necessary. US-JP collaboration about NMR magnetometer with ultra-high precision[12] is being progressed effectively. As for 2-b), additional dipole field with solenoid field is often required in the recent solenoids. It is required to align the solenoid field along the beam direction in the ILD, and to separate particles and select the beam energy in the COMET. The field strength is not so high, 0.1 - 0.3 T, however, it makes magnetic field distribution complicated. In the COMET phase-II, curved dipole has to be installed on curved solenoid with large aperture, so the complexity of the magnetic force distribution is increased. Cost effective and feasible design technology of mechanical structure is strongly demanded. In 2-c), sophisticated cryogenic systems are also required to meet the need for advanced solenoid system. For the ILD, single refrigerator is required to supply different helium as cryogens, such as, two-phase helium, saturated and pressurized superfluid helium. In addition, transmission of vibration from cryogenic system including cryo- and vacuum pump is demanded to isolate or suppressed to realize a collision of nano-size beams. The basic design work is in progress by the cryogenic group in IPNS, KEK.

Many design and R&D works are proceeded with international collaborations, especially, US-Japan collaborative frame work plays an important role at every key point, for example, basic design study on ILD including dipole on solenoid and insertion quadrupole magnets, and the R&D of winding technology with Al stabilized NbTi cable using high-radiation resistant resin. The collaboration about study of NMR magnetometer with high precision is on going effectively. The collaborative work is expected to be essential in future work of R&D on sophisticated large-scale solenoid.

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