New European Accelerator Project EuCARD: Work Package on High Field Magnets

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***Abstract* – The European accelerator community has successfully applied on an FP7 (Seventh Framework program) infrastructures call under the name EuCARD. The program consists of five Joint Research Activities (JRAs), two networks and two work packages to provide transnational access to research facilities. EuCARD starts on 1 April 2009 and will have a duration of 4 years. One of the JRAs is the work package on high field magnets. It foresees to build a 15 T large-aperture high-field dipole model, a high temperature superconductor (HTS) very-high-field dipole insert, a HTS current link and a superconducting helical undulator. Thirteen European institutes will participate. In parallel, more general worldwide high field magnet collaboration is being set up.**

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I. THE EUCARD PROJECT

EuCARD is the new accelerator R&D project of a consortium of 37 European accelerator laboratories, institutes, universities and industrial partners. It has the total approved budget of 31 M€ and is co-funded by the European Commission's Seventh Framework Program (FP7). The EuCARD project will have duration of 48 months, starting on April 1, 2009. This new project's website is: https://eucard.web.cern.ch/EuCARD/.

EuCARD's main goal is to upgrade the large European research accelerators through R&D on innovative concepts and techniques, thereby offering researchers the best facilities. EuCARD is a successor to the FP6-CARE program, that laid the foundations for collaborative accelerator research. The project is inspired by the accelerator priorities for the next 15 years as defined by the European Strategy Group for Particle Physics in July 2006. These priorities include an LHC upgrade, R&D on TeV linear colliders and studies on neutrino facilities. The R&D will be conducted on high field superconducting magnets, superconducting RF cavities for proton linacs, two-beam acceleration, high efficiency collimation and new accelerator concepts. Each of these priority themes represents a work package. EuCARD will include networks to monitor the performance and risks of innovative solutions and to disseminate results. Transnational access will be granted to users of beams and advanced test facilities. Strong joint research activities will support priority R&D themes. This article overviews the high-field magnet (HFM) work package (WP-7).

II. THE HIGH-FIELD MAGNET WORK PACKAGE

A. Requirements, Participants and Funding

Magnets with Nb_3Sn conductors are needed to upgrade existing accelerators in Europe, such as the LHC, on medium term and to prepare for new projects on a longer time scale. High-current density properties in high fields (critical current density of superconductor $J_c > 1500$ A/mm^2 at 15 T) and large temperature margin will be needed to meet the fields and gradients requirements and to withstand the heating due to the radiation in both new and upgraded machines. On the very long term (> 20 years), an LHC upgrade to 2-3 times the energy is an option to be considered. For such an energy level, dipole magnets with a field of around 20 T would be needed. These accelerator magnets are beyond the possibilities offered by Nb-Ti or Nb_3Sn conductors alone. A possibility is to use a layered coil with an outer coil of 14 T in Nb_3Sn conductor and an inner coil of high-temperature superconductor (HTS), delivering a field contribution of 6 T. High-field capabilities are also the limiting parameter for undulators when increasing the central field and reducing the period of the field. The limitations can be overcome using Nb_3Sn conductors also for these devices.

Institutes participating in this work package are: CEA-Irfu (France, F), CERN, CNRS-Grenoble (F), Columbus (Italy, It), DESY (Germany, D), BHTS (D), FZK (D), INFN-Milano (It), Polytechnic of Wroclaw (Poland, Pl), Southampton University (United Kingdom, UK), STFC-DL (UK), Tampere Univ. (Finland, Fi), and Genève University (Switzerland, CH). The total budget for the HFM work package is 6.4 M€ with an EC contribution of 2.0 M€.

B. High Field Model

The goal for accelerator magnets is to reach high fields in large apertures with good temperature margins in the coil, beyond the possibilities of Nb-Ti conductors. As a test bed for high-field accelerator magnets, a 1.5 m long dipole model will be build with an aperture of 100 mm and a design field of 15 T. The technologies to be used for Nb_3Sn magnets, which are residing with individual partners (*e.g.*, high current density conductors, Nb_3Sn wind-and-react coil fabrication, insulation) are to be brought together and tested in this model dipole magnet. Several of these technologies (superconducting cable, insulation, coil design, support structures) were partly developed during the CARE-NED project, within the EC 6th Framework Program (PF6). The proposed dipole model will afterwards be used to upgrade the superconducting cable test facility FRESCA at CERN from 10 T to 15 T. The upgraded test facility will be needed to characterize conductors for future LHC upgrade projects that will employ Nb_3Sn magnets. The institutes participating in this task are: CEA-Irfu (F), CERN and Polytechnic Wroclaw (Pl).

Figure 1 shows cross-section of an early pre-design of one of the two alternative design options for the 15 T dipole model. In 2009, the options will be investigated to select the final design approach. In the central hole are the Nb3Sn coil blocks wound from Rutherford cable, all vertically oriented. This is not anymore a cosθ geometry as was used until present (*e.g.*, in LHC). The 4 blocks around the coil are steel pieces used to pre-stress the coil. Two magnetic half yokes are split vertically. Around it is the Al shrinking cylinder. (the white space) and the stray field shield.

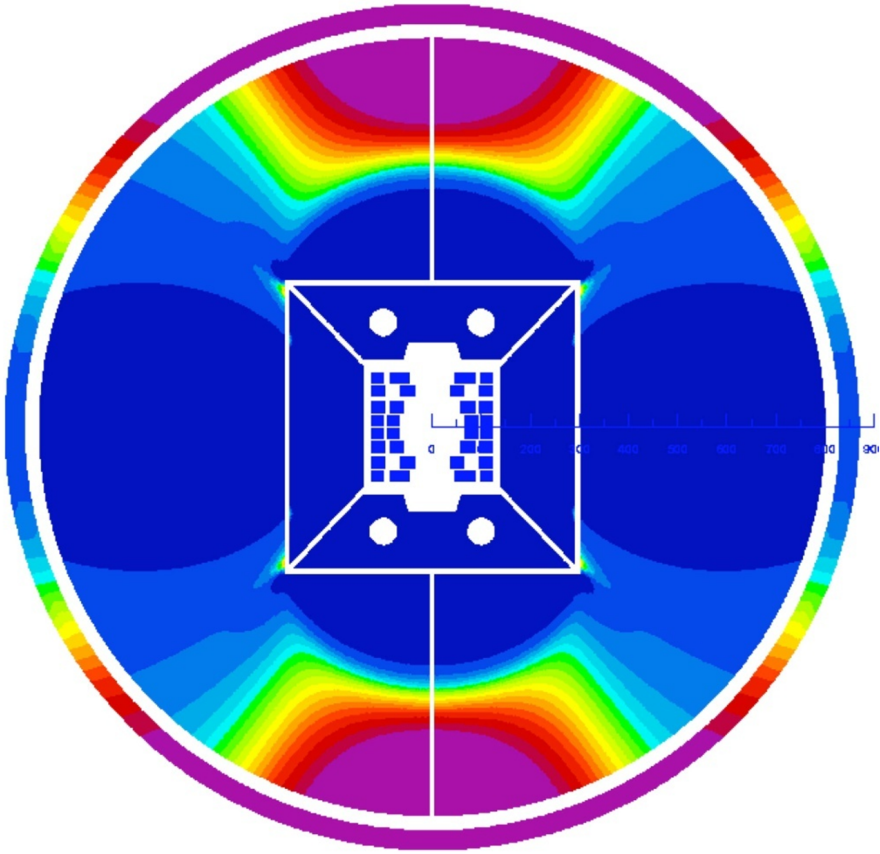

Fig. 1. Cross section of an early pre-design of the proposed 15 T dipole model magnet without the HTS insert. The picture was generated with the Roxie(TM) code. The coil at the centre, wound of Rutheford cable has a block geometry. It is pre-stressed by a LBNL style support structure. Around the steel yoke there is an Al shrinking cylinder (the white ring). To reduce stray fields a soft steel cylinder surrounds the magnet (the outer ring). The field in the steel parts is indicated with colors, where dark blue is high field and purple is low field.

C. Very High Field Dipole Insert

The most important issue for reaching fields in the 20 T range is the conductor to be employed. Recent progress resulted in outstanding intrinsic current transport properties of HTS Bi-2212 round wires, well suitable for magnets (effective or engineering current density J_e = 450 MAm^{-2} and J_c = 1800 MAm^{-2} at 4 K and 25 T). This should open the road to higher magnetic fields. The very-high-field magnet task is the first step to prospect for this possibility. The dipole model constructed in this WP will serve as the outer layer coil. The development will proceed in three steps. First studies will deal with the specification of several HTS conductors. This will be completed by modelling work focused on stability and quench. The quench of HTS coils with their very often occurring degradation is an identified issue. Due to the difficulty of making in one go a dipole insert coil of HTS conductor, several HTS solenoid insert coils will be made and tested in existing high-field solenoid magnets. The experience so gained will be used to construct the dipole insert coil. The institutes participating in this task are: CEA-Irfu (F), CNRS-Grenoble (F), FZK (D), INFN-Milano (It), Polytechnic Wroclaw (Pl), STFC-DL (UK), Tampere Univ. (Fi) and Genève Univ. (CH).

D. High-T_c Superconducting Link

In the LHC accelerator, an identified future limitation will be the temperature margin on the superconducting bus linking superconducting magnets in high radiation areas. The use of HTS material in these is thus becoming of interest. Existing buses use Nb-Ti superconductors, maintained at temperatures below 6 K. The use of HTS enables operation at higher temperatures and offers a significant gain in temperature margin. In the case of LHC, the use of HTS links is of specific benefit to an upgrade: it provides long-distance electrical connections between power converters and superconducting magnets. It also links cold magnets electrically. In cases where space is limited and the radiation environment is harsh, it also provides more flexibility in the location of the cryostats supporting current leads. HTS links of the type required for the accelerator technology do not exist yet, and significant work has to be done to develop a long-length multi-conductor operating in helium gas at about 20 K. Considerable R&D is being done on HTS cables for electrical utilities, and it might be thought that one could simply apply these technologies. However, this work is focused at present on using single or 3-phase AC conductors with high-voltage insulation and liquid nitrogen cooling. Particle accelerators require high quasi-DC current carrying links with many cables (up to about 50) in parallel, all cooled with liquid or gaseous helium. Thus the need specific to accelerator applications is for a new type of link with multiple circuits, electrically isolated at around 1 kV to 2 kV, carrying quasi-DC currents. The design study has to cover the option to use MgB_2 at the temperature of 20 K as well as the electrical connections between HTS and LTS. The institutes participating in this task are: CERN, Columbus (It), DESY (D), BHTS (D) and Southampton Univ. (UK).

E. Short Period Helical Superconducting Undulator

This task is focused on increasing the achievable magnetic field levels in short-period magnets through the use of advanced materials (Nb_3Sn conductors) and innovative designs (helical coils). For example, single-pass free electron lasers (*e.g*., X-FEL at DESY, FERMI at ELETTRA) could cover a wider wavelength range through field enhancement or, alternatively, operate at significantly lower electron energy. Additionally, short-period magnets could be used in the production of positrons for any future lepton collider where increased magnetic field levels will increase the positron yield. The first part of this task will be a design study of the undulator using an Nb_3Sn conductor. A comparison will be made with existing Nb-Ti undulators. Following this design stage, a short prototype (~ 300 mm) will be manufactured and tested magnetically. Basing on the results from this prototype, the design will be iterated in order to provide the strongest possible field level. This second design will then be prototyped (~ 500 mm) and characterized. The results will be analyzed and full description of the study will be given in the final report. The participating institute on this task is: STFC-DL (UK).

F. Support Studies

Magnets in accelerators like the upgraded LHC and neutrino factories are subjected to very high radiation doses. The electrical insulation employed on the coils must be resistant to this radiation. A certification program for the radiation resistance is needed in parallel to the modelling efforts for such magnets. The same radiation is also depositing heat in the coils. Heat removal from the coils needs to be modelled. These models have to be supported by measurements. A thermal design of the dipole model coil can then be made. The institutes participating in this task are: CEA-Irfu (F), CERN and Polytechnic Wroclaw (Pl).

G. Scheduling and Outlook

The EuCARD-HFM program will start on 1st April 2009 and will run for 4 years. The support studies need to give results within the first 2 years so that results can be worked into the design of the dipole. The dipole should be tested in the last 6 month of the project. The very-high-field insert will be tested after the 4 years outside the EuCARD framework.

The upgrade scenarios for the LHC require large aperture (150 mm), high gradient (180 T/m) quadrupole magnets for low-β insertions. Additionally, 12 T dipoles might be needed in several key positions of the machine. These magnets will need Nb_3Sn conductor technology. The EuCARD-HFM project is the first step in the European effort to master this magnet technology. After EuCARD, European institutes will continue with more targeted quadrupole and dipole developments for the LHC in collaboration with efforts existing elsewhere (LARP in the US, KEK in Japan).

III. THE HIGH FIELD MAGNET COLLABORATION

In parallel to the EuCARD-HFM project, an initiative is under way to set up worldwide high field magnet collaboration. The collaboration should function as a network from which actual construction projects can branch off. Presently existing projects like the Short Model Coil (CEA-Irfu, CERN, STFC-RAl and LBNL), EuCARD-HFM, the KEK-CERN collaboration, LARP, *etc*., can be seen as linked to this global collaboration. The collaboration should organise a bi-annual HFM workshop that can be seen as a successor of the CARE-HHH WAMSDO workshop series. This collaboration will not be connected solely to one specific funding source (like CARE or EuCARD) but should guarantee a longer-term continuity for the HFM community and generate new initiatives for HFM projects.

IV. CONCLUSION

The European accelerator community has an FP7 successor to the FP6 CARE accelerator programme. This new EuCARD program is extending the experience gained in CARE to directly work on upgrades of existing machines and on new accelerators. For high-field magnets the trend is to develop significantly higher fields, better temperature margins and improved radiation hardness. The first application will be to upgrade the conductor testing facilities at CERN (FRESCA) for the Nb_3Sn field range and then to use these in the development of magnets for LHC upgrades.