Review of WAMSDO 2011 workshop: Superconductors in HL-LHC

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The present meeting was an attempt to characterize the HL-LHC radiation environment for the cables (superconductor and insulator) of the most exposed magnets: the quadrupoles of the final focus triplet. These quadrupoles are most exposed to the collision debris, for a target integrated luminosity of 3000 fb-1 at 14 TeV center-of-mass energy. The workshop comprised three parts, describing

1. Irradiation of superconductors,
2. Modern models/codes including Coulomb elastic scattering and
3. Irradiation of insulators.

The attention is concentrated here on highlights about experimentally determined irradiation effects on superconductors, including the recent calculations using the MARS and FLUKA results, which give a new insight in the total damage on the superconductor. The irradiation effects on insulators as well as the status about the experiments to be performed will be presented by M. Eisterer (Vienna) during the present RESMM'12 workshop.

The properties of the superconductors in HL-LHC are dominantly influenced by the radiation spectrum determined by F. Cerutti (CERN), who specified indeed several high energy sources: photons (89%), electrons and positrons (6%), neutrons (4.8 %), pions (0.45%) and protons (0.14%), their energies reaching values |well above 1 GeV. For the superconductor, the dominant effect is due to neutrons, protons and pions, photons and electrons being known to have a minor effect, in contrast to the behavior in insulators. An extended set of data is known on the effects of neutron irradiation, in contrast to protons, where only little is known. No data at all were ever published on pions, the necessary high fluences of the order of 1022 p/m2 requiring years of irradiation with the known facilities. At the present day, the damage on the superconductor (which finally determines its transport properties) submitted simultaneously by all these energy sources can only be predicted on the basis of complex calculations, which were presented by N. Mokhov (Fermilab), and F. Cerutti (CERN).

A very detailed report on neutron irradiation was given by H. Weber from Atominstitut in Vienna, comprising the radiation damage on Nb3Sn and HTC superconductors, based on the extensive research already undertaken in view of ITER. In Nb3Sn, the initial increase of Jc is caused by an increase of Hc2 (a mean-free-path effect), and is followed by a drop due to the Tc degradation. A strong difference between binary and ternary alloyed Nb3Sn was shown: for wires alloyed with 1.5 at.%Ti, the maximum of the Jc vs. fluence curve is shifted to considerably lower fluences (from 2x1022 to 5x1021 n/m2). This is explained by the lower degree of atomic ordering with the Ti substitution, resulting in a higher electrical resistivity before irradiation. The change on the mean free path is reflected by the variation of Hc2, as was demonstrated by Flükiger in the same workshop. It is noteworthy that the behavior of Nb3Al under neutron irradiation is very similar to that of Nb3Sn.

The effect of neutron irradiation on the stabilizer was also presented, confirming the enhancement of the electrical resistivity of Cu (approximately a factor of 1.3 at 1022 n/m2). One must keep in mind this degradation in view of the stability of the magnets. More recovery tests up to 300K are needed.

The effect of neutron irradiation on HTC coated conductors (Y stabilized 123) was briefly mentioned, since no way is known at present to build a quadrupole with these materials. The characteristics at 64 K are a decrease of Jc at low fields, followed by an increase of Jc at higher fields (after 1x1022 n/m2, an enhancement by a factor 1.6 at 4T was reported): the observed crossover indicates a change in flux pinning.

The system MgB2 is presently envisaged for the current leads from the surface to the LHC magnets 100 meter below. The effect of neutron irradiation on Tc and Jc is comparable to that of Nb3Sn. A shift in the pinning force Fp indicates that a new

pinning mechanism is working in irradiated MgB2 wires.

The WAMSDO workshop has shown a progress in the calculations performed using as well MARS as FLUKA. Independent FLUKA and MARS results on energy deposition (mostly from EMS) for inner triplet coils are in agreement within a few %, therefore one can predict doses in insulators with same accuracy. The deterioration of critical properties of crystalline materials under irradiation was analyzed as a function of displacements per atom (DPA). The latter is a strong function of projectile type, energy and charge as well as material properties including its temperature. Some of these dependencies were analyzed for superconducting coils of LHC inner triplet quadrupoles. MARS15 results are obtained on composition of particle flux and DPA in the hottest spots of the final focus quadrupole superconducting coils. The major contributors to DPA are sub-threshold particles (40%), neutrons > 100 keV (26%) and pions (15%). Uncertainties on DPA predictions in superconductors can be as high as a factor of 2 to 3.

Preliminary FLUKA calculations (without cold shielding!) indicate that over the HL-LHC target integrated luminosity (3000 fb-1) triplet quadrupole cables and insulators will undergo radiation peak values of the order of 100 MGy (dose), 10-4 (DPA), the corresponding fluences being 1017 neutrons/cm2 and 1016 pions/cm2. Particle fluence spectra on the coils have been calculated. More accurate evaluations have to refer to the final layout/design. The calculations presented at this workshop show that the DPA of pions is comparable to that of neutrons, resulting in a similar damage. In spite of the considerably lower number with respect to neutrons (protons plus pions 0.59%, compared to neutrons, 4.8%), the total damage is expected to be comparable or even larger than that of neutrons alone. This is confirmed by reported data of neutron and proton irradiation on Nb3Sn at 1 MeV. This result is important, since it influences the lifetime of the quadrupoles.

Due to the limited knowledge in view of the action of multiple energy sources, an attempt was done to describe the main points to be elucidated. In particular, more proton irradiations on Nb3Sn and MgB2 at various energies and fluences are needed. The effect of the observed lattice expansion on the transport properties of the wires submitted to compressive forces has to be calculated. Irradiation experiments at 4.2K and transport measurements up to 15T should be performed: this will be realized in the new facility in Japan, as reported by T. Nakamoto (KEK). Finally, DPA calculations including simultaneous irradiations by different sources should be performed.