DEPARTEMENT PHYSIQUE INSTRUMENTATION ENVIRONNEMENT ESPACE (DPHY)

CONDITIONING OF SURFACES IN PARTICLE ACCELERATORS

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RESUME

During the operation of particle accelerators with high intensity and positively charged beams, an electron cloud may build up in the beam vacuum pipe resulting from the generation of primary electrons (by photoelectric effect induced by the synchrotron radiation and/or from gas ionization), their acceleration by the beam potential and their multiplication at their impact with the chamber wall. Such a cloud is responsible for beam instabilities as well as vacuum degradation through electron stimulated desorption. Moreover, as a source of heat load, the electron cloud is currently one of the main limitation to the beam intensity in the LHC and its future upgrade, the High Luminosity LHC, since more than 80% of the circumference of these machines is or will operate at cryogenic temperature.
During LHC operation, conditioning of the copper beam pipe surface occurs, decreasing the cloud intensity. Conditioning is known to rely on the reduction of the secondary electron yield (SEY) of the inner surface of the beam pipe, i.e. of the quantity governing the multiplication of the primary electrons, under the effect of the cloud itself. However, the subjacent mechanisms are not fully understood yet. In particular, a large scattering of the beam-induced heat load is observed along the LHC ring, pointing towards strong differences in electron cloud activity between sections of the machine although supposed to be identical by design, even after years of accumulated conditioning dose.
Since no in-situ surface analysis setup exists in the LHC, the mechanisms of copper conditioning were studied in the laboratory where the evolution of the SEY and surface chemistry (monitored by X-ray photoelectron spectroscopy) of copper samples was followed during their irradiation by an electron beam.

A clear decrease of the SEY was observed from a maximum SEY value of 2 down to about 1.1 after full conditioning of the surface. The role of the different chemical components of an air exposed copper surface (bulk copper, cuprous oxide Cu2O, copper hydroxide and carbon contamination) in the conditioning process was disentangled. It was found that Cu2O helps reducing the maximum SEY of copper thanks to the lower intrinsic maximum yield of Cu2O with respect to pure Cu. However, it was proved that the presence of this oxide is not sufficient and it is actually the modification of the adventitious carbon layer present on the air exposed copper surface into a more graphitic form which allows the decrease of the maximum SEY of such a surface down to about 1.1.

Currently, the analysis of components exposed to the cloud in the LHC is only possible after their extraction from the machine. Such events are rare and require the venting of the corresponding parts of the ring. Thus, the mechanisms of the deconditioning occurring at the venting of an irradiated surface were studied to optimize the venting and storage conditions of such components and define the limits of accessible information about their in-situ conditioning state when analyzing their surface. In particular, this work showed that any SEY contrasts eventually present on an irradiated surface disappear with storage time. The comparison of the surface of components exposed to the cloud in the LHC with some conditioned in the lab revealed common features proving that conditioning did occur in the machine under the effect of the electron cloud. In addition, a different type of copper oxide was found on LHC components, showing that the lab and LHC conditionings are still different.

In parallel, the hypothesis of a modification of the inner surface of the beam pipe, which could prevent its conditioning, thus explaining a stronger electron cloud activity in different parts of the LHC, was proposed. Therefore, the effect of different modifications of the beam pipe surface on its conditioning was assessed in the lab. Among all the possibilities tested, only residues of detergent used for the cleaning of the UHV parts could inhibit the conditioning of the surface. However, it was not possible to conclude with certainty that such a contamination is responsible for the observed heat load.

The opportunity of analyzing the surface of beam pipes hosted in a high and a low heat load LHC cryo-dipole occurred during the LHC Long Shutdown 2. These ongoing analyses, namely looking for differences in surface chemistry and conditionability between the two types of surfaces, are expected to clarify the origin of the observed heat load dispersion.

According to these topics, the PhD thesis will include a first part introducing the problematics of electron cloud in accelerators, in general and in the particular case of the LHC, and defining the objectives of this work. The second chapter will give the details of the experiments performed in this study. The third chapter will gather the three axes of the laboratory study: investigation of the copper conditioning and deconditioning mechanisms and of the impact of modifications of a copper surface on its conditionability. The results related to the surface analyses performed on components exposed to the electron cloud in the LHC will be presented in the fourth chapter. Finally, a discussion and a conclusion about the presented work will close the manuscript.