ELECTRON CLOUDS IN THE SPS: PROGRESS IN THE ANALYSIS OF CURES/MITIGATIONS MEASURES AND POTENTIAL SCHEDULE OF IMPLEMENTATION

J.M. Jimenez, CERN, Geneva, Switzerland

Abstract

After a brief review of the studies (simulations and measurements) made so far, a set of priorities for new studies will be presented and justified. These proposals will include all studies related to coating techniques, clearing electrodes, active feedbacks, together with their related instrumentation.

The feasibility, state-of-the-art, hard limits and open questions, required infrastructures, schedule implications, phasing feasibility of the proposed mitigation solutions will be considered in the framework of an upgrade of the SPS (i.e. without removing the beampipes from the magnets) and in the framework of combining the SPS upgrade with its required long-term consolidation (exchange of the magnet beampipes as an alternative). A tentative schedule of milestones in the decision making will be presented and discussed.

INTRODUCTION

Operating the SPS with high bunch intensity, up to 2.5×10^{11} p/bunch and small emittances (LHC requirements) at 25 ns bunch spacing cannot be guaranteed due to the following limitation of the electron cloud effect that have been identified: pressure rise (beam gas scattering, dose rates to tunnel and components) and beam instabilities (transverse emittance blow-up and single bunch vertical instability). This statement is confirmed by many studies and Machine Developments (MD) carried out in the framework of the SPS-U Study Group [1]. Indeed, these studies allow the identification and understanding of the potential limitations. Significant progresses have been made on the effects of beams and beam scrubbing and other mitigation solutions mainly amorphous carbon a-C studied in the SPS.

This talk is a summary of the views of the author and meant for a recommendation to the Project Leader. For detailed results and pictures, please refer to presentations given during the LIU Day [2].

REVIEW OF THE STUDIES MADE SO FAR

Beam Scrubbing

Beam scrubbing is successfully used since 1999 to reduce the electron cloud activity in the SPS but complete suppression was never achieved except in field free regions. Even after a dedicated week of beam scrubbing, residual electron cloud activity remains in the bending sections.

This result illustrates the fact that the beam scrubbing is a mitigation solution and not a suppressing method. Indeed, beam scrubbing has intrinsic limitations. Decreasing the secondary electron yield (SEY, δ) needs larger electron bombardment doses (log behaviour); the closer we operate to the threshold for a given bunch population the lower will be the electron bombardment thus the electron doserate.

Since the electron cloud is a threshold phenomenon with a build-up varying with the bunch train length, the use of higher bunch populations and smaller bunch spacing during the scrubbing runs is the optimum choice. The scrubbing will then allow running at lower bunch population and larger bunch spacing. Indeed, the scrubbing is most efficient when we operate subsequently with a lower bunch intensity taking profit from threshold effect, resulting in the avalanche no longer building up.

Coatings

The coating techniques i.e. diode and magnetron sputtering are mastered techniques at CERN. Amorphous carbon (a-C) (Fig.1) has been selected since it provides a low SEY (<1.1) (Fig.2) and is only slightly affected by venting to atmosphere. In addition, it does not require any activation (bake-out) to provide such a low SEY.

Right from the beginning, two options have been considered:

- Coating the beampipes in-situ, i.e. without removing the beampipes from the magnets. The use of the dipole field of the magnet itself to enhance the glow discharge used for the sputtering has been tested with limited success, the coating being inhomogeneous.
  Using an internal magnetron sputtering looks more promising since tested successfully in a 50 cm beampipe mock-up with identical shape. The tooling is being prepared to coat a 2 m dipole chamber by March'11.
- Coating the beampipe prior to their installation in the magnets. This option is the easiest and preferred solution from the coating point of view. Indeed, it will allow using the magnetron sputtering facilities developed and successfully used for the non-evaporable getter (NEG) coatings of the long straight sections of the LHC, where more than 1250 beampipes were coated.
  This option ensures the homogeneity (Fig.1) of the coating but implies to open the magnets to install the new coated beampipe.

The efficiency of the coatings and their behaviour in terms of deterioration of the SEY upon venting and long time aging in the machine need still more investigations for validation. The present results and limitations are the following:

- The ECM (e-cloud monitors) in the SPS show effective mitigation of the e-cloud even for coatings exposed to the machine operation during 2 years and vented for more than 2 months in between [2]. However, for the coatings in the main machine dipoles (4 prototypes) the diagnostics available in the SPS accelerator allow only indirect measurements through pressure readings. Some of the experiments carried out [2] were not always very conclusive, pointing out the risk of artifacts while using the existing pressure sensors as diagnostics.
- The static outgassing of the coating per surface area is larger than for stainless steel, but this disadvantage can be mitigated by coating only the portion of the pipe which is relevant for e-cloud.
- The quality and especially the adhesion of the coating is strongly dependant from the efficiency of the surface preparation (cleaning). Obviously, this is easier to solve with new beampipes. It becomes an issue if the beampipes have to be cleaned once installed in the magnets. The radiation issues, identified as a potential show stopper, have been studied and preliminary measurements are promising. After cleaning the beampipes of 15 magnets coming from the SPS tunnel, no activation of the liquids used for the cleaning and rinsing have been measured.
- The lower deposition rate imposed by the maximum temperature allowed in the magnet (insulation of the coils, 120°C) during the in-situ coating has to be taken into account but is not a major issue.
- The ageing and peel-off is of concern and has been studied with particle counter measurements and by visual inspection of the samples installed in the electron cloud monitors for 2 years in the SPS. No sign of peel off has been observed (Fig.3). No dust is coming out from the samples, even though exposed to electron bombardment and radiation doses.
- Simulations are needed to identify the maximum length acceptable without coating, as it will be very difficult to coat all exposed surfaces of the beampipes. The feasibility of the coating of the short straight sections is a concern and need to be studied. In addition, removing the quadrupoles from their place in the tunnel will lead to a new machine since these magnets will not come back to the same place. Another issue is the expected radiation dose to the personnel which can prevent the coatings from being acceptable.

The required infrastructures and tooling depend strongly on the option selected: coating of the existing beampipe in magnets or coating of new beampipes. On one hand, doing these operations at the surface in optimized infrastructures has many advantages. So far, no building has been identified and building a new one is not compatible in term of schedule and costs. On the other hand, this solution has the disadvantage of too many transports which will increase the duration of the activities. An alternative is to reuse the SPS ECX5 cavern, an option successfully used for the consolidation of the cooling circuits of the SPS magnets. The final choice will impact significantly the schedule. If the option of coating in-situ is retained, the transport of the magnets will dominate the schedule; the opening and closing of the magnets will dominate for the second option i.e. new beampipes. The second solution is also more difficult to do in the ECX5 cavern due to the limited space available. Both options can be considered in a staged approach, however, the use of the ECX5 cavern will imply the dismounting and re-commissioning of the tooling since the set-up cannot stay in the cavern during the operation with beams. This staged approach can only be considered if the shutdown durations are at least 4 months, and 3 shutdowns will be required to complete the work.

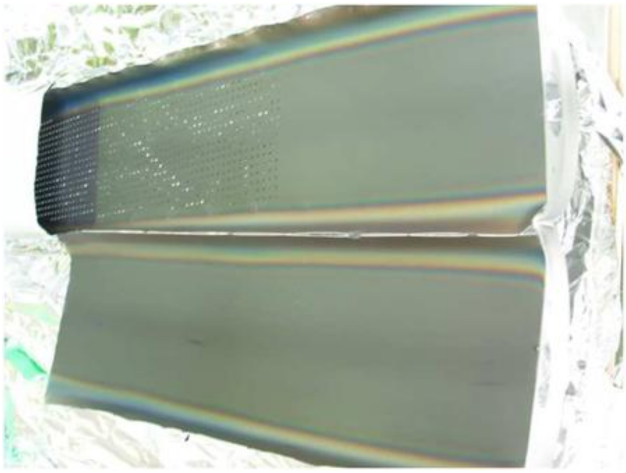

Fig.1: Picture of an SPS dipole chamber coated with amorphous carbon (a-C).

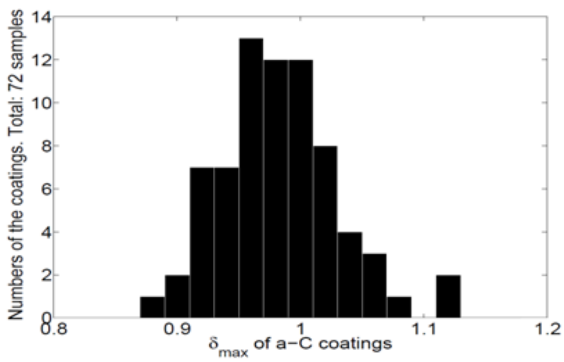

Fig.2: Distribution of SEY measured on various samples coated with amorphous carbon (a-C).

Fig.3:

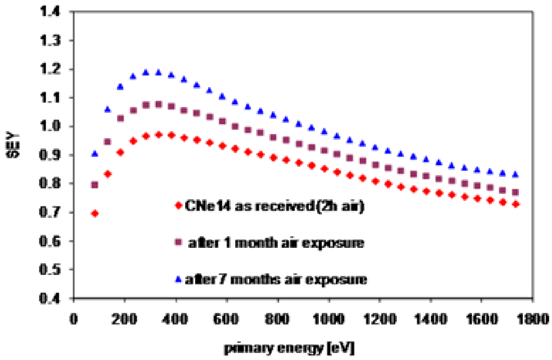

Fig.3: Measured SEY ageing of a stainless steel sample coated with amorphous carbon (a-C) installed in an electron cloud monitor.

Clearing electrodes

Clearing electrodes have been used successfully in the past in particle accelerators. In the SPS, the clearing electrodes shall be placed vertically to take into account the trapping of the electrons spiraling along the dipole field lines. The feasibility study has not been pushed forward since resulting in a aperture restriction (~1 mm in total) and due to impedance issues. The clearing electrodes have been validated at low magnetic field in the PS ring [3,4] but undoubtedly, the studies are much less advanced than with coatings. Some issues are still pending:

- Required clearing voltage which should be compatible with all energies and beam configurations.
- Cost and maintenance of the cabling and required power supplies and their long term reliability (active system with feedthroughs exposed to corrosion risks) still need to be evaluated.
- The difficulty to equip the quadrupoles and short straight sections could also be an issue since they represent about 15% of the total length of the ring.
- Engineering issues are more challenging compared to the coating. Indeed, equipping the new chambers will result in a significant increase in cost since mechanical tolerances for manufacturing (twist and straightness) shall be significantly decreased as compared to existing beampipes.

The infrastructures and tooling required are comparable in size and building surface with the one needed for the coating solution. This is not the case for the skills of the technicians doing the work: mechanics and welders for the clearing electrodes, plasma discharge experts for the coatings. Retrofitting the clearing electrodes in the existing dipole chambers will require development of complex tooling and a long development and optimization time, at least 2 years.

Feedback system

The feasibility study of a high bandwidth feedback system has been started in the framework of LARP. This system will require a new pick-up, a new kicker, high speed digitization and digital treatment as well as power amplifiers.

The new pick-up is a long strip lines pick-up, at least 1.5 m. The complex design resulting from the required accuracy and 50 Ohm impedance is technically challenging but feasible.

The new kicker has also a complex design but is technically feasible. The electromagnetic simulations could be delegated to L. Berkeley Laboratory in the framework of the LARP collaboration.

The high speed digitization and digital treatment required for the high bandwidth are a technical challenge. The prototype system being developed in the framework of LARP, will only be able to treat a small number of bunches.

The high bandwidth feedback system will be a useful diagnostic tool which would certainly help to cure electron cloud induced coherent effects. But, this system will not help when the emittance growth is dominated by incoherent effects which cannot be damped. A concern exists also on the potentially high power required to correct effects on all bunches due to the fast growth rates. At this stage of the studies, the following points are challenging but not thought to be "showstoppers":

- Adjustment of the loop delay will be very delicate for the high frequency high bandwidth system (GHz)
- Mix-up with longitudinal motion is possible if bunches not are stable longitudinally
- Suppression of common mode signal crucial to avoid amplifier saturation and to allow good usage of the dynamic range available
- It could be required to split the system into several bands in order to be able to cover the entire frequency range

The new high bandwidth feedback system will require modifications of the layout, pulling of additional cables and local shielding against radiation in the tunnel to house electronics and amplifiers. The preferred location is in BA3 (dispersion suppressor) since it is close to the low level RF equipment, an advantage as the required RF signals for digitization and synchronization are readily available. Alternatively, BA5 can be used but will require pulling optical fiber cables for transmission of the RF (clock and synchronization) signals.

The proposed schedule foresees the modification of the layout and the installation of new cables during the 2011-12 winter technical stop for the demonstrator. Following its validation which is expected to be completed by end of 2013, the go-head for the final version could be given. Then, the new electronics will become available two years after the complete validation with the demonstrator (2014-15). The final system needs the installation of the new pick-up and a new kicker. These systems could also be ready by end 2013. The layout modification and cabling could be advanced to the winter technical stop in 2012.

PROPOSED MILESTONES

The schedule to be followed in order to be ready for the installation in 2016 is challenging.

By end of September 2011, the following milestones have to be fulfilled:

- Feasibility studies on clearing electrodes,
- Industrialisation of a-C coatings,
- Enhancement of electron cloud for scrubbing purposes,
- Development of additional electron cloud diagnostics,
- SPS MD measurements to validate efficiency of proposed solutions

Then, by end of December 2011, the preparation of a prototype section of 1 or 2 a-C coated half-cells has to be completed in order to allow the installation during the winter technical stop 2011-12. Special efforts shall be made to have all diagnostics available on due time.

By end of September 2012, it will be time to proceed to a complete evaluation. Waiting for Chamonix will not be an option since it would be too late for the preparation of the winter technical stop 2012-13. The aim is to install a pilot sector of about half an arc (~450 m).

The final decision shall be made end of 2016 for a complete implementation in the long shutdown of 2017-2018.

CLOSING REMARKS

Questions still to be answered

Despite the huge work carried out in the framework of the SPS-U Study Group, questions still need to be answered.

The clearing electrodes, an electron suppression method, cannot be pushed forward without looking into details of the impact on aperture, impedance and lifetime. The technical solution, full-scale feasibility, in particular for the quadrupoles and short straight sections, as well as the cabling and powering must be studied.

The coating with amorphous carbon (a-C), an electron mitigation solution, is much more advanced since it is at the industrialisation stage. Still, the lifetime, stability with venting, outgassing rates, in-situ coating and coating of the short straight sections, in particular of the quadrupoles, need to be validated.

The scrubbing run is also a mitigation solution but its efficiency for higher bunch populations i.e. more than 1.7×10^{11} protons per bunch still need to be validated. Machine development (MD) time are required for this validation.

The use of a bandwidth feedback system to cure the effects of the electron cloud on the beams is pending until positive results from the demonstrator with high speed digitization and digital treatment are available.

Finally, as stated earlier, simulations are needed to provide the electron cloud budget, the stability expected, the emittance growth, the impedance from electrodes and the effectiveness of a high bandwidth feedback.

Priorities versus Resources

At this stage of the project and considering the need to start validating the proposed solutions already during the next winter technical stop, the efforts devoted to the different proposed solutions will need to be reconsidered.

The status of the mitigation solutions (scrubbing and coatings) is satisfactory. The scrubbing run is scheduled and MDs have been requested. In addition, the LHC scrubbing run will also provide valuable information. The studies on coatings are progressing well; new approaches have been tested recently showing very promising results from the "industrialization" point of view. However, their validation with beams needs certainly strengthening of the efforts on diagnostics.

The feedback systems can be on track with reasonable efforts. Indeed, the collaborations in the framework of LARP will help for the electronics and simulations as the engineering and manufacturing can be internalized.

The situation of the clearing electrodes is more uncertain since running "out-of-phase" as compared to the other ongoing studies. The resources to be allocated to achieve a status which could allow a decision making are still reasonable in theory, but in practice, where to find them? Then, going for industrialization of the clearing electrodes is another challenge.

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