ELECTRON CLOUD MEASUREMENTS OF COATED AND UNCOATED VACUUM CHAMBERS IN THE CERN SPS BY MEANS OF THE MICROWAVE TRANSMISSION METHOD

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Abstract

Electron cloud is a limitation to increasing the beam current in the CERN SPS in the frame of an intensity upgrade of the LHC complex. Coating the vacuum chamber with a thin amorphous carbon layer is expected to reduce the electron cloud build-up. Three SPS MBB magnets have been coated to study the performance of this carbon coating. The microwave transmission method is one possible way to monitor electron cloud and hence to test the effect of the coating. In this paper the evolution of the experimental setup for measurements of the electron cloud using LHC type beams will be described. Due to the low revolution frequency of about 43 kHz serious electromagnetic compatibility problems as well as intermodulation have been found. These effects and their mitigation are described. Finally, we present the measurement results illustrating the possible reduction due to the carbon coating.

INTRODUCTION

An electron cloud is generated by photoemission when synchrotron-radiation photons hit the surface of the vacuum chamber, by the ionization of the residual gas, and by an avalanche process involving acceleration of electrons in the field of the beam together with a secondary emission yield larger than unity. This effect reduces beam luminosity and beam quality and hence poses a severe performance limitation in high-current accelerators worldwide. Techniques to reduce and suppress these electrons are therefore of main interest to existing facilities as well as newly constructed accelerators and damping rings [1, 2]. Clearing electrodes have been successfully tested in the PS and work reliably [3]. An alternative is a coating of the accelerator vacuum chamber with a thin film providing a low secondary electron yield. In this paper we focus on amorphous carbon coatings of SPS dipole vacuum chambers.

A possible means to investigate the beneficial effects of electron cloud mitigation techniques is the microwave transmission method. Unlike common local measurement techniques such as shielded button pickups, this method provides information on the integrated electron cloud density over a larger section of the accelerator and was already successfully tested in CERN SPS in 2003 [4]. Currently the beneficial effect of amorphous carbon coating in the CERN SPS is being investigated using this method along with local electron cloud monitor and pressure measurements.

THEORY

A wave passing through a plasma filled waveguide obtains a phase shift due to the different dispersion relations in vacuum and plasma. This phase shift can be related to the electron cloud density via [5]:

$$\Delta\varphi = \frac{L\,\omega_{\mathrm{p}}^2}{2\mathrm{c}\,(\omega^2-\omega_{\mathrm{c}}^2)^{\frac{1}{2}}} \tag{1}$$

where L is the transmission length, ω is the injected frequency, ω_{c} the cutoff frequency of the waveguide, c the speed of light and $\omega_{\mathrm{p}} = 56.4\sqrt{n_{\mathrm{e}}}$ the plasma frequency in Hz.

The presented measurement technique is aiming to measure the phase shift of a microwave induced by the electron cloud. Relation (1), though only valid for neutral plasma, is applicable, since the perturbation due to the charges is very small in the present setup.

At SPS injection energy of $26\,\mathrm{GeV/c}$ the cyclotron resonance is $3.3\,\mathrm{GHz}$ [6, 7] and is not excited in the presented experiment since all frequencies used are well below $3\,\mathrm{GHz}$.

EXPERIMENT

The experiment was setup in sector 5 of the CERN SPS, comprising two MBB (main bender type b) magnets, one with a bare stainless steel vacuum chamber, the other one with a coated vacuum chamber. The MBB vacuum chamber dimension is $52 \times 132 \times 6500\,\mathrm{mm}^3$. The coating is a $200-300\,\mathrm{nm}$ thick amorphous carbon layer, applied with a sputtering process using the magnetic field of the dipoles.

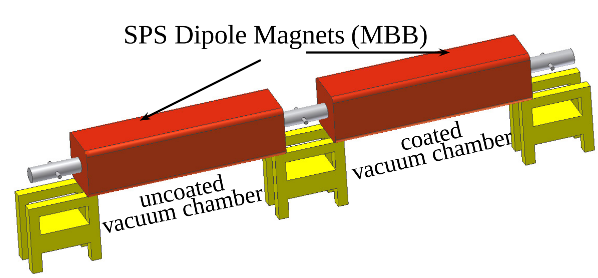

Figure 1: Schematic overview of the transmission sections. The left dipole has the uncoated, the right dipole the coated vacuum chamber.

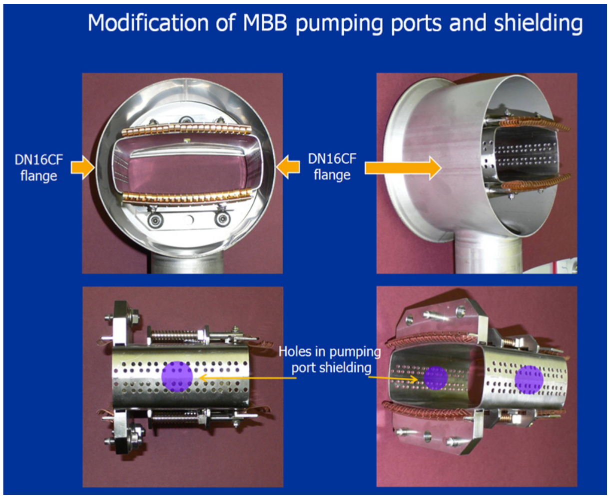

Figure 2: Principle of the SPS MBB pumping port and shielding modifications necessary for the integration of the microwave transmission coupling loops.

The microwave, generated by a signal generator, was injected after amplification and filtering in the pumping port between the two magnets and picked up at either end (Figure 1). Due to space constraints in the pumping ports, RF couplers as small as possible were needed as well as a modification of the standard SPS pumping port shields.

The modification of the MBB pumping ports and shields is schematically shown in Figure 2. A picture of the specially designed and built SPS coupling loops, mounted on a DN 16 CF flange, is shown in Figure 3. The receiver paths were designed such, that only a small amount of electronics, namely a hybrid, a filter and a circulator would be in close distance of the SPS accelerator since damage due to radiation and stray fields is very likely. The received signal was measured using a Vector Spectrum Analyzer (VSA) with analog demodulation function.

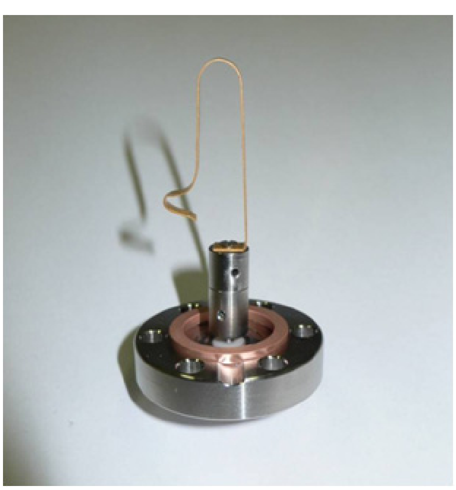

Figure 3: Picture of a coupling loop used for the injection and pickup of the microwave signal.

RESULTS

After first operation of the setup, a clear effect of intermodulation distortion (IMD) near the SPS revolution frequency of 43.35 kHz could be seen. Three main sources for this were identified [2]:

- via the power supply lines (15 V) entering via power supply input of the amplifiers
- via the cables at the amplifiers input and output
- via the beam harmonics at the input and output of the amplifiers

The main objective became the mitigation of this IMD. First, the power supply of the amplifiers was provided over an additional coaxial cable instead of using one of the conductors of the coaxial RF feeds with DC bypasses at the amplifiers. Furthermore, a high-pass filter at the end of each coaxial cable was installed and a capacitor parallel to each DC input of the amplifiers was used. This reduced the amount of IMD by 40 dB and hence reduced the first two IMD sources to an acceptable level.

The intermodulation caused by the beam harmonics is the most important cause and unfortunately proved to be very difficult to reduce. A combination of special amplifiers with a high intercept point of 3rd order (IP3) and a

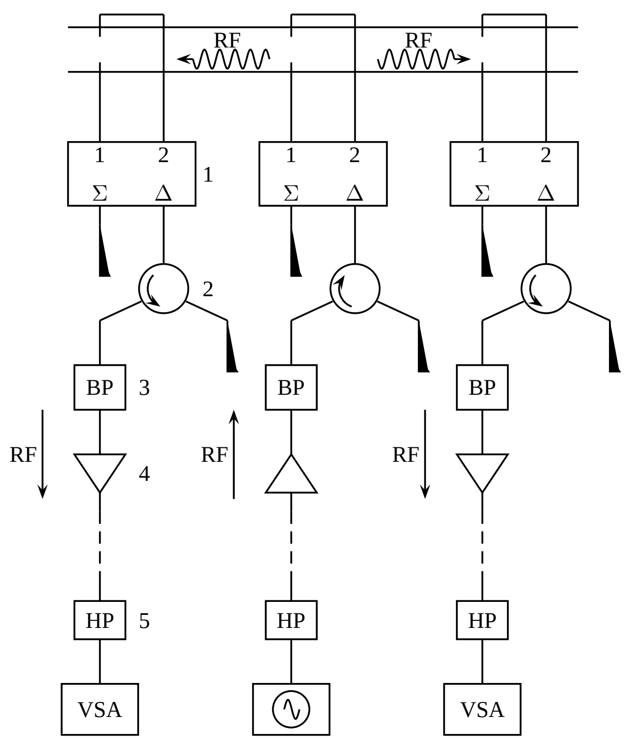

Figure 4: Schematic overview of the experimental setup containing hybrids (1), circulators (2), band passes (3), amplifiers (4) and high passes (5).

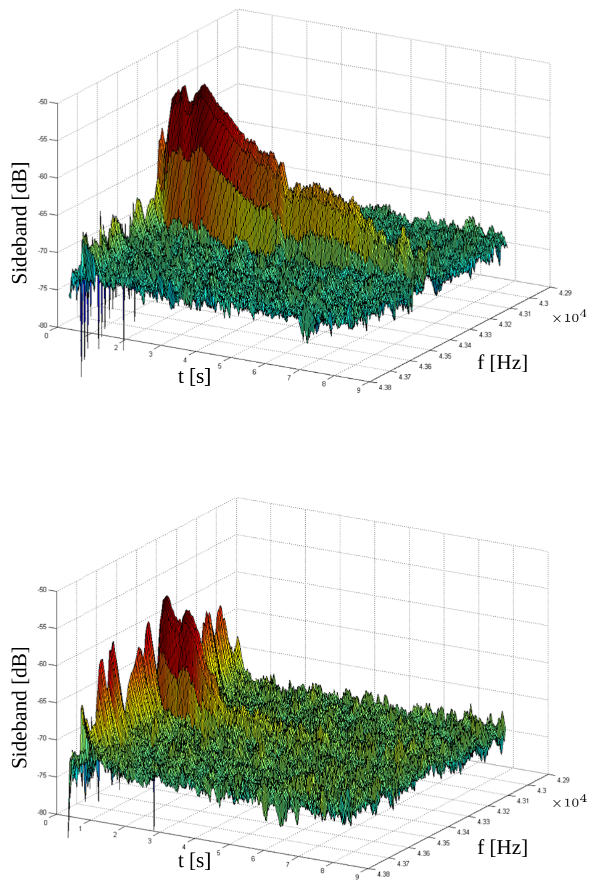

Figure 5: Phase modulation sideband versus time and frequency in case of the uncoated (upper graph) and coated (lower graph) vacuum chamber. The signal in the coated section vanishes shortly after injection, whereas in the uncoated section the signal remains well above the noise floor. The large signal in the beginning corresponds to the injection of the beam where the used electronics are driven into saturation. The valid range for evaluation starts about $3\,\mathrm{s}$ after injection.

narrowband filter was chosen to minimize the intermodulation distortion induced by the beam harmonics. The amplifier was chosen to work at $0.01\,\mathrm{dB}$ compression point and is hence operating well below the usually used $1\,\mathrm{dB}$ compression point. These changes in the setup also reduced the conversion from amplitude to phase modulation occurring in the amplifiers used before. This lead to the final setup depicted schematically in Figure 4.

Using this setup, a significant difference between the uncoated and the coated SPS vacuum chamber was seen during the last two machine development (MD) runs in 2009. After injection, the phase modulation signal in the uncoated section is clearly visible whereas in the coated section it becomes indistinguishable from the noise floor (Figure 5). A clear beneficial effect of electron cloud reduction of the amorphous carbon coating could be deduced [8].

OUTLOOK

Since the electronics close to the accelerator are considerably damaged by ionizing radiation, the feasibility of amplifiers in proximity to the SPS machine is currently discussed. Recent measurements show, that the coupling efficiency of the used coupling loops can be improved by using modified coupling that provides no or little aperture restriction. Damping inside the vacuum chamber is negligible in the SPS, since it is in the order of $0.1\,\mathrm{dB}$ per meter for the waveguide mode under consideration.

SUMMARY AND CONCLUSIONS

The development of the experimental setup for microwave transmission measurements in the CERN SPS has been presented. The biggest challenge proved to be the intermodulation distortion distortion caused by the power supply, the amplifiers used and most importantly by the beam harmonics. The steps performed to reduce these effects have been described and their implementation discussed.

We conclude that after one year of commissioning the new SPS microwave transmission experiment, the setup is by now well understood and yields clear evidence that amorphous carbon coating of the SPS main dipole vacuum chambers is beneficial for electron cloud mitigation. More systematic and quantitative experiments will follow.

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