REDUCTION OF THE IMPEDANCE CREATED BY THE INSULATED VACUUM FLANGES IN THE PS BOOSTER

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Abstract

The original vacuum flange assembly in the PS Booster (PSB) was designed to present insulation at low frequency and conduction to the beam image current above 2 MHz. However, in order to satisfy the needs for the LHC, the RF harmonic in the PSB had to be changed from $h=5$ to $h=1$, leading to a reduction of the lowest accelerating frequency to 600 kHz. The RF component of the beam was therefore passing through the main resonance of these flanges giving a total (integrated around the ring) longitudinal coupling impedance of 1000 Ω at 750 kHz, taking into account some additional RF bypasses. The voltage generated by the beam current was coupling to various electronic devices which therefore had to be equipped with common-mode rejection circuits. After some non-essential insulated flanges had been replaced by conducting ones during the 1998-99 shutdown, the total impedance was lowered to about 200 ohms (still higher than the maximum value for $h=5$ which was 130 ohms). This was one of the improvements that made it possible to reach a new intensity record in September 1999. New RF decoupling flanges introduced in 2000 to further reduce the impedance are described here, together with the results obtained.

1 DESCRIPTION OF THE PROBLEM

At the construction of the PS Booster, the vacuum chamber was interrupted in many places at the vacuum gasket level to avoid induced currents along the vacuum chamber when pulsing the magnets,. For each of the sixteen lattice periods, six insulated vacuum flange assembly (Fig.1) were introduced. The equivalent circuit of the flange assembly (Fig.2) is represented by two identical ensembles in series, each composed of a capacitor C (about 30nF) in parallel with a resistor (hundreds of ohms). An inductance L in parallel to this ensemble represents the earth connection of the vacuum chamber. The latter introduces resonances that were in some cases in the RF frequency range (from 3 to 8.5 MHz). When the PSB was accelerating high intensities (up to 10^{13} protons per pulse and per ring), the electromagnetic emission (e.m.) from the beam was excessive, and it also perturbed the signals used for feedback in some systems (RF and power supplies, for example). In a first attempt to lower the e.m. emission,

RF bypasses were introduced around the flange assembly at some critical places to damp and displace these unwanted resonances to lower frequencies. These by-pass circuits were composed of a 1 Ω resistor Rd in series with a 400 nF capacitor Cd. This reduces the measured impedance around 5 MHz to 130 Ω/ring.
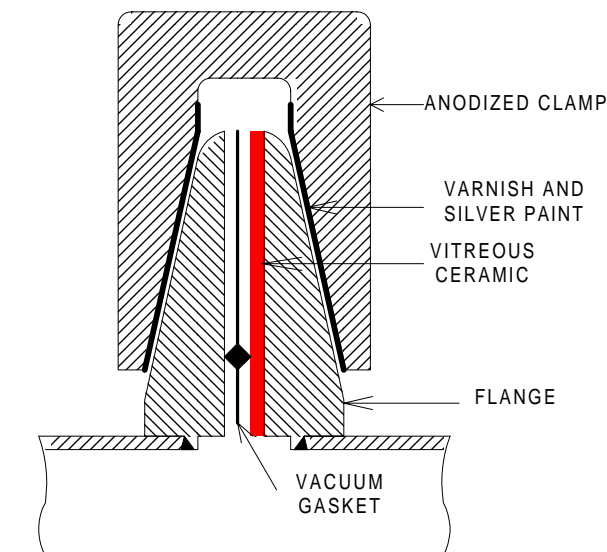

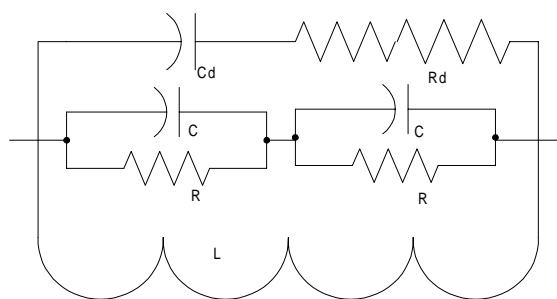Figure 1: Scheme of the insulated clamp mounted around the flanges of the vacuum chamber.

Figure 2: Equivalent circuit for the flange assembly. The ensemble C, R represents one contact between the clamp and the flange. The inductance L is the connection to ground between the two sides of the flange. The ensemble in series Cd Rd is the by-pass circuit. On the new clamps, three of them are installed in parallel.

However, to cope with the needs of the LHC, the fundamental of the RF system had to become $h=1$. Then the main resonance of the flange assembly (around 750 kHz) was within the RF frequency range and gave a total impedance of about 1000 Ω/ring at resonance. This led

again to an electromagnetic emission from the beam that was so high that most of the electronics of the power supplies and RF systems were perturbed .

2 DESCRIPTION OF THE SOLUTIONS

2.1 The new layout

Because pulsed quadrupoles will not induce currents along the vacuum chamber, the insulating clamps around the quads were removed. It was decided to keep only the downstream DC insulation at each bending magnet. In practice, only two insulating clamps were kept per lattice period and all the others were replaced by conducting ones.

2.2 The new clamps

Although the flanges were not changed, the new clamps (Fig.3) were anodised using up-to-date techniques (40μm of Al_2O_3 sealed under demineralised water at 93^0C). A radiation resistant varnish layer was then applied to the
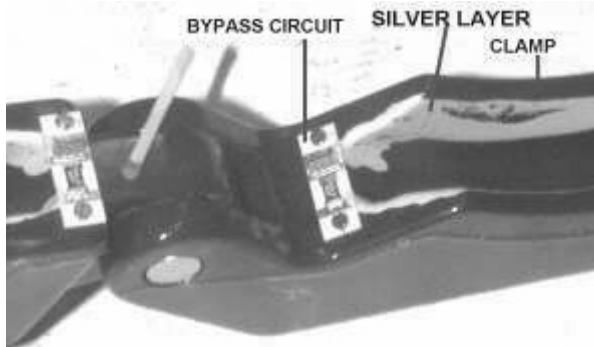

Figure 3: Part of the new clamp where some details are shown

contact surfaces to fill the remaining porosity of the anodised layer. The resistance obtained was larger than 10 MΩ. Silver paint was applied on the 20° flanks, which are the contact surfaces between the clamp and the flange. A capacity is thus created between this conducting layer and the body of the clamp. This layer is prolonged to a flat part of the clamp where the by-pass circuit (0.5 Ω, 1 W in series with 400nF mounted on an alumina support) is mounted. This circuit connects the two contact surfaces. Each one of the 3 jaws of the clamp receives one by-pass circuit. If one assumes perfect contacts, the impedance at 600 kHz and above should be less than 0.2 Ω per flange assembly.

2.3 Flange assembly measurements in the lab

The measurement of the impedance of such a flange assembly was made using a network analyser measuring S11. A wire connecting the two extremities of the test vacuum chamber simulated the external inductance (1 μH is the standard value measured in the ring). The

equivalent circuit of the assembly is described in Figure 1 and it can be shown that the total impedance is lower than 0.5 Ω in the frequency range from 0.6 to 3.5 MHz, with a resonance around 150 kHz. These measurements indicate (Fig. 4) a perfect insulation (>1 MΩ) and a capacity of the clamp around 15 nF.
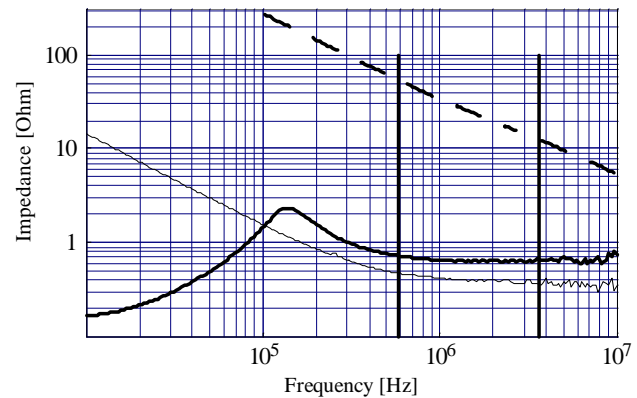

Figure 4: Measurement on the flange assembly, without by-pass circuits and inductance (dashed), with by-pass circuits and without inductance (thin line), with all (thick line)

3 THE RESULTS

3.1 The measurements in the PSB

At the beginning of 1999, two thirds of the insulating clamps were replaced by conducting ones. The existing RF bypasses were relocated where the measured shunt impedance of the remaining insulating clamp was too high. The entire set of insulating flange assembly was measured by the technique described above. In the following, the so-called one-ring impedance is the sum of all flange assembly impedances in the working frequency range. The real ring impedance must be lower, because the impedance of each individual flange assembly has
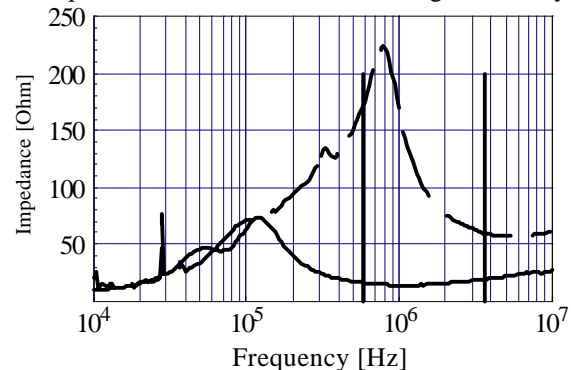

Figure 5 : Modulus of the measured impedance of ring 4 of the PSB (1999: dashed line, 2000: continuous line). The frequency range for h=1 and h=2 is indicated by the two vertical thick lines.

a different phase at any frequency. This action lead to a reduction of the ring impedance (Fig. 5) from 1000 Ω to

200 Ω. At the beginning of 2000, the new clamps replaced the old ones. The one-ring impedance was then further reduced to less than 20 Ω in the present working frequency range. It should be noticed that two resonances often appear around 80 kHz and 150 kHz, instead of one around 150 kHz depending on the flange environment.

3.2 The common mode measurements

Some measurements were made with beam, first in October 98, when the equipment suffered from the beam e.m. emission, and afterwards, when some improvements have been imade in the ring (Jul 99 and May 2000). The method employed (Fig 6) was to measure the common-mode current at the RF frequency, flowing along some coaxial cables belonging to the beam
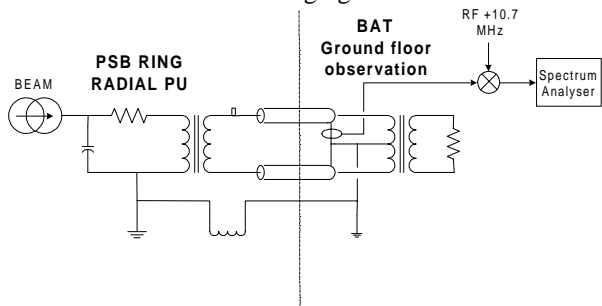
Figure 6: Common-mode current measurement set-up used for each of the 16 straight sections.
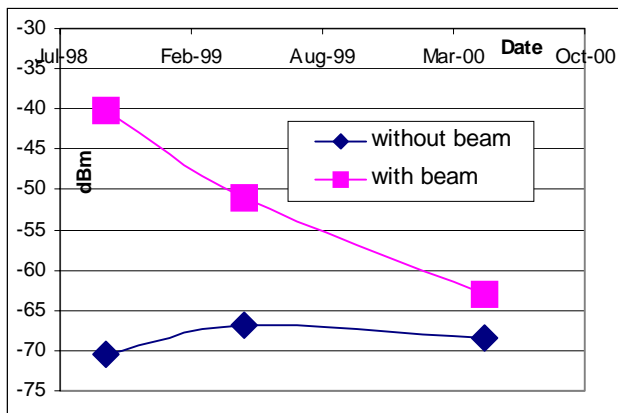
Figure 7:Improvement (in 2000), with respect to Oct 98, in terms of maximum RF common-mode current on cables from the ring to the equipment room. Top line is without beam and bottom line is with beam (10^{13} protons). The bump in section 15 is due to a new vacuum tank which appears to be more leaky than previously.

position measurement (one for each of the 16 straight sections). A heterodyne circuit was used to extract the RF component, and the measurement was made over the cycle, from injection until extraction. The peak value during the cycle was recorded and used to produce Figures 7 and 8. These measurements indicate no drastic variation of the common-mode coming from the RF cavities but a large reduction (about –25 dBm) of the RF coming from the beam itself. In addition, the absolute value of the measured common-mode with beam is just 5 dBm above the measured common-mode without beam.
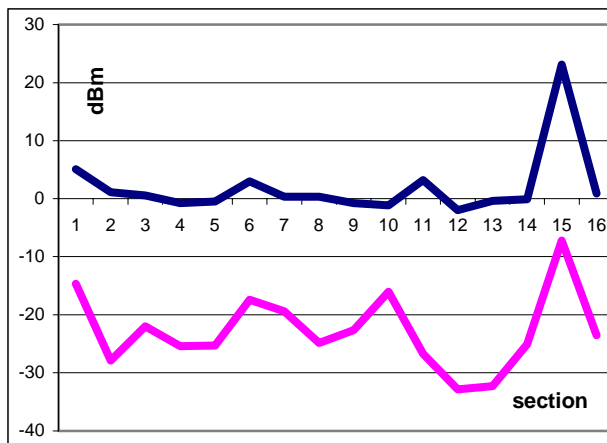
Figure 8: Evolution of the common-mode signal received from the ring during the last two years.

4 CONCLUSIONS

The actions taken to reduce the number of insulating clamps and by replacing the old clamps of the PSB, have greatly reduced the total impedance of the rings in the present frequency range of the RF cavities. This was seen in the reduction of the electromagnetic emission from the beam detected on the cables coming from the ring.

ACKNOWLEDGMENTS

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