RF BYPASS ON THE PROTON SYNCHROTRON VACUUM CHAMBER FLANGES

R. Cappi
CERN, PS Division, 1211 Geneva 23, Switzerland

1. Introduction

Small circuits, generally called "RF-bypass", made with resistors and capacitors, have sometimes been connected accross the isolated vacuum chamber flanges in circular accelerators. The reason why these circuits are installed, the design criteria and some technological aspects adopted in the last fifteen years at the CERN PS machine[1][2] are described in the following chapters.

2. The main problem (i.e. why these circuits have to be mounted)

In circular accelerators with high acceleration rate, the fast variations of the main magnetic field induce currents in the loops created by the vacuum chamber and chamber-to-ground connections generally found in vacuum pumps, RF cavities, septa, pick-up's, etc., see Fig.1.

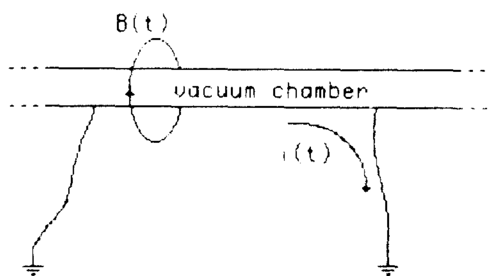

Figure 1

Fig. 1 Ground loop with current induced by the varying main magnetic field B(t).

These current loops produce field disturbances such that, depending on the energy, acceleration rate and loop configuration, the effects on the beam orbit can be very harmful. In the PS machine, for example, at low energy, current loops of several tens of Amps have been measured and their effects can yield losses of 50-100 % of the beam.

Being, most of the time, practically impossible to avoid the ground connections, to overcome the problem one has to "cut" the vacuum chamber in several sectors (one sector for each ground connection) and reconnect them with isolated flanges.

The isolation is generally performed by a ceramic layer on one of the two flanges.

At present, in the PS machine about 150 isolated flanges have been installed.

By curing in this way the current loop problem one introduces a second one. The isolated flange forms a capacitor which inserted in series with the ground loop constitutes a parallel RLC equivalent circuit as shown on Fig.2.

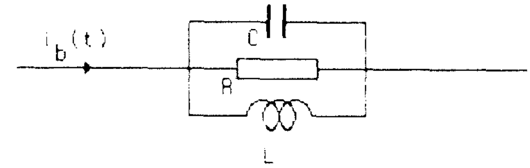

Fig. 2 Equivalent circuit of the isolated flange-vacuum chamber-ground connections. $C \simeq 1000$ pF, $R \simeq 100\ \Omega$, $L \simeq 10\ \mu$H, $i_b(t)$ is the image beam current.

The values of each element have been measured, for the PS machine, and are on average:

$C \simeq 1000$ pF $\quad L \simeq 10\ \mu$H $\quad R \simeq 100\ \Omega$

yielding a resonant frequency of $\simeq$ 1.5 MHz with a $Q \simeq 1$.

Such a resonator is traversed by the beam image current flowing along the vacuum chamber and exibits to the beam a typical coupling impedance leading to longitudinal and/or transverse instabilities (see below) as well as radiating electromagnetic interferences (EMI) at $\simeq$ 1.5 MHz to nearby elecrtonics equipments. This last effect is particularly significant in the PS machine where the spectra of high intensity beams with unequal bucket filling [3] contain all the harmonics of the revolution frequency.

To shift the resonant frequency to a much lower value ($\simeq$ 100KHz) and to reduce the impedance, a large capacitor $C_1 \simeq .4\ \mu$F in series with a small resistor $R_1 \simeq 1\ \Omega$ have to be connected in parallel to the flange, this constitutes the so called RF-bypass. The resultant equivalent circuit is shown on Fig.3, where L_1 is the stray inductance ($\simeq$ 12 nH) of the mechanical support and the individual components.

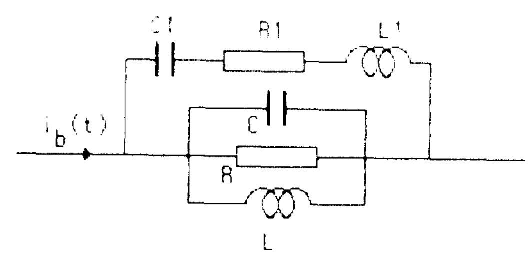

Fig. 3 Resultant equiv. circuit of the vacumm flange with the RF-bypass in parallel. $C_1 \simeq .4\mu$F, $R_1 \simeq 1\ \Omega$ $L_1 \simeq 12$ nH are the components of the RF-bypass.

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The impedances of the flange with and without the RF-bypass are shown on Fig.5 , where the value $|Z|/n$, with $n = f/f_0$ and f_0 = revolution frequency, is plotted versus frequency .

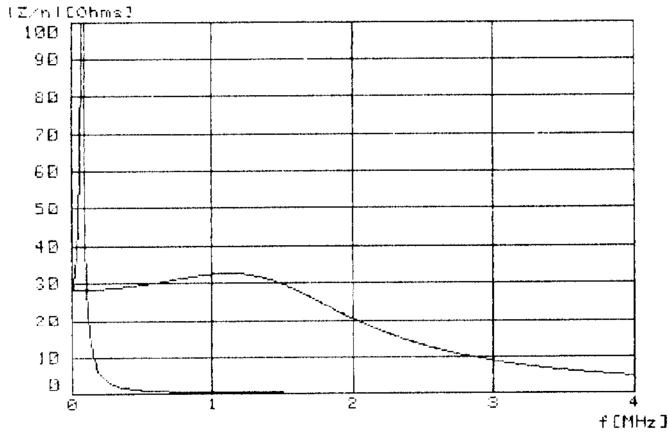

Fig. 4 $|Z|/n$ versus f of the flange alone a), the flange with the RF-bypass installed b) .

3. Practical implementation

The value of the stray inductance has to be kept as low as possible to avoid resonances at high frequency. This prescribes a construction af the RF-bypass by using RF techniques, i.e. small ceramic capacitors and resistors and short connections (a few cm. long).

Furthermore another important point to be considered is the power dissipation P of the resistor R_1, which is :

$$P = \frac{R_1}{T_b} \int_{-T_b/2}^{T_b/2} i_b^2(t)\, dt$$

where T_b is the bunch spacing and $i_b(t)$ is the beam image current, which, at first approximation, can be considered of gaussian shape as

$$i_b(t) = \frac{N_b\, e}{\sigma_t \sqrt{2\pi}} \exp\left(- \frac{t^2}{2\sigma_t^2}\right)$$

where

N_b is the number of particle per bunch
e is the proton charge (=1.6E-19 C)
σ_t is the RMS bunch length in sec ($\sigma_t \ll T_b$)

Generally most of a proton beam spectrum is located between zero and 100 MHz so we assume that all the components of the beam image current are flowing through R_1. Combining the two formulae, one finds

$$P = \frac{R_1\, N_b^2\, e^2}{2\sqrt{\pi}\, T_b\, \sigma_t}$$

For example, in the PS machine, for a high intensity (2×10^{13} ppp) beam with

$N_b = 10^{12}$ p/b, T_b = 105 nsec, σ = 5 nsec

and considering a beam circulating during about half of the machine cycle, we obtain $P \simeq 7$ Watts. The 20x15x.5 mm ceramic resistances employed in the PS are soldered on a thick (5mm) copper support screwed on the flange clamp which actually behaves as a heat radiator. With 10 Watts dissipated in the resistance the clamp temperature rises to about 32°C measured at 5 cm from the RF bypass

Very often these circuits are installed in radioactive and/or difficult access regions, this requires an easy mounting and easy maintainance. For this reason the PS RF-bypass are fastened with a single screw while the capacitors and the contact springs can be quickly replaced, see Fig.5 & 6.

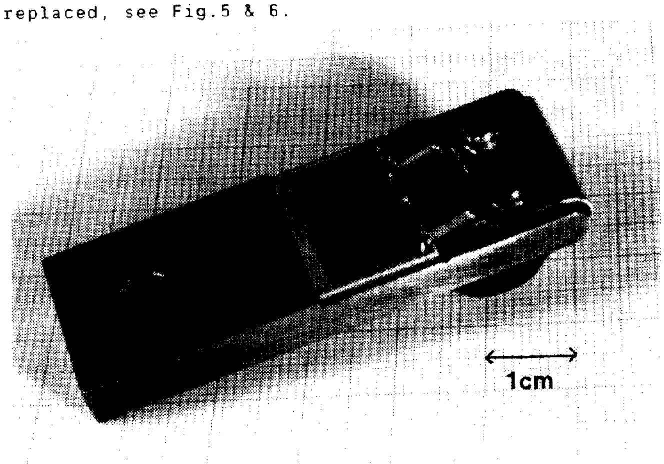

Fig. 5 A PS RF-bypass. Note the flat ceramic resistor and the three ceramic capacitors (2x200μF + 1x10 nF) soldered in parallel. On the bottom the 2 Cu-Be spring contacts.

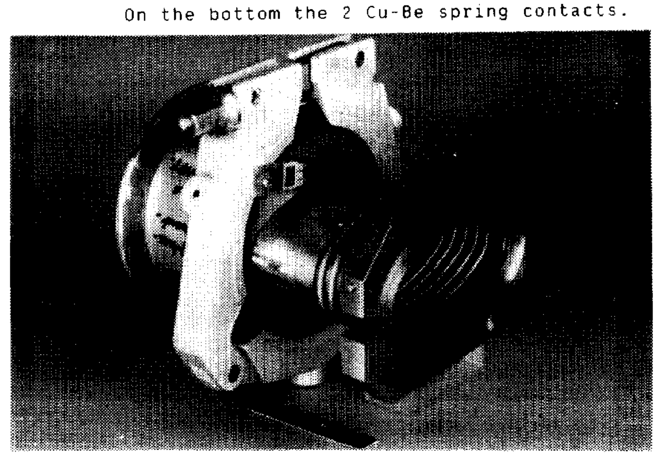

Fig. 6 The PS RF-bypass mounted on the clamp of an isolated flange.

Last but not least is the problem of cleaning the flange surface to obtain a good electrical contact with the Cu-Be spring of the RF-bypass. In the last machine run some 30 RF-bypass were found faulty.

At that time transverse head-tail instabilities on mode $m=1$ (no evidence of longitudinal instabilities) with rise time of $\simeq$ 3 milliseconds were observed. A 1.5 MHz resonator with transverse impedance of $Z_\perp \simeq 7$ MΩ/m could explain these figures. Computing the corresponding longitudinal impedance $|Z_L|/n$ from

$$\frac{|Z_L|}{n} = \frac{b^2}{2R} Z_\perp$$

where

b is the equivalent chamber radius ($\simeq$ 6.6 cm)
R is the machine radius (= 100 m)

one finds $|Z_L|/n \simeq 150$ Ω, which is smaller than 900 Ω that one would expect by 30 times 30Ω. The discrepancy can be explained by the large spread in the resonant frequencies of the individual resonators (for ex. the value of the capacitance C can vary by 30 % with different strength of the clamp tightening).

By repairing the faulty contacts the beam was stable again.

4. Conclusions

Running the PS machine with higher and higher intensity (an increase of a factor 20 in the last 20 years) we had to improve the early version of the RF-bypass. The latest version gave complete satisfaction except for some problems on the quality of the contacts (a better way of cleaning the flange surface has to be found).

Moreover the existence of such circuits is now a necessity for beam stability as well as for reduced EMI.

However, keeping in mind that the ideal situation would be the one with no isolated flange, no ground connection and no RF bypass, one should try to minimize their number avoiding unnecessary (and uncontrolled ?) proliferation.

Acknoledgements

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References

[1] A. Faltens, H.H. Umstatter, "Longitudinal coupling impedances at insulated PS vacuum chamber flanges", MPS/LIN/Note 74-5, 18.3.1974.

[2] A. Faugier, "Les brides de chambre à vide du PS". PS/OP/Note 77-4, 25.1.1977.

[3] R. Cappi, R. Garoby, N. Rasmussen, J.P. Riunaud, K. Schindl, H. Schoenauer, "Upgrading the CERN PS BOOSTER to 1 GeV for improved antiproton production". This conference.