

RF TEST BENCH FOR ELECTRON CLOUD STUDIES

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Abstract

In the framework of the CERN program on the electron cloud effects in existing and future accelerators, a coaxial multipacting test stand was built. It consists of a 100 mm diameter vacuum chamber forming the outer conductor and 6 wires cage-aerial-type as the inner conductor. In order to simulate the bunched beam, this test stand is submitted to short RF pulses. The available field strength in a travelling wave mode allows to trigger electron multipacting in as received or baked stainless steel surfaces, but not in chambers treated to reduce the secondary emission yield. Thus a number of upgrades in the bench set-up have been pursued, mainly in two directions. The first one is a general improvement on mismatches and losses. Second, instead of dumping the pulsed power into a load, it is re-circulated in a multiple frequency ring resonator. For this purpose, we designed a directional coupler with several kV DC isolation, very low transmission losses and a four octave bandwidth. In this paper, we give an overview of the present status of the set-up highlighting the latest improvements.

1 INTRODUCTION: THE NEED OF A RING RESONATOR

Multipacting is an electron multiplication resonance, which develops in RF devices when a periodic field strength is maintained between two opposite surfaces and if energy and resonant conditions for electron kinetics are met. Such conditions will show up in the Large Hadron Collider (LHC). In order to study those phenomena in a laboratory, a bench test set-up [1] was built where six wires are inserted in a circular vacuum chamber and submitted to RF pulses simulating the Transverse Electro-Magnetic (TEM) field produced by a bunched beam. That Travelling Wave (TW) coaxial structure is powered by a wideband power amplifier* driven from a pulse generator. The output of the chamber was connected to a RF load, which absorbs the transmitted power and prevents undesirable reflections. Two probes have been installed to collect the electrons, one placed on top of the chamber, the second one in the middle of it.

The electric field strength achievable in the chamber is mainly limited by the output power of the amplifier which can deliver a maximum voltage of 100 V (baseline-peak) to a 50 Ω load, corresponding to a multipacting electron energy of 75 eV (according to

* Amplifier research, Model 100W1000, 1-1000 MHz, 100 W.

both simulations and measurements [1]). Such an energy is sufficient to trigger multipacting in “as received” chambers, but not in treated chambers [2] or after that the material has been exposed to a relevant electron dose. For common materials in accelerator technology, the minimum multipacting energy can be moved up to the 200 eV range. Therefore it is desirable to reach higher multipacting energies in the bench test stand.

A possible way to increase the field strength (without changing the amplifier), is to re-inject a fraction of the output power into the system, similarly to what is proposed in [3]. Such a re-circulating scheme is called Ring Resonator (RR) and its conceptual scheme is shown in Fig. 1: the RF pulses coming from the signal generator are amplified in the power amplifier, and then introduced in the wideband directional coupler. Part of the pulse power is dumped to the RF load, while another part enters into the chamber. When leaving the chamber, the pulse again goes through the coupler, where it is added to the next pulse delivered by the amplifier. The wideband (20-600) MHz 90° phase shifter compensates the 90° offset introduced by the coupler.

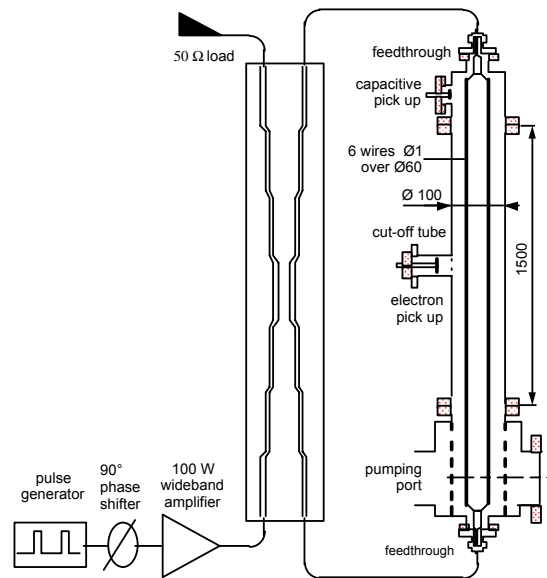


Figure 1. Ring Resonator outline. The pulse coming from the chamber and the pulse coming from the amplifier are superimposed by means of a directional coupler and it re-circulates again in the chamber.

In the RR shown on Fig. 1, the maximum power gain (G) depends on α (the one-way attenuation in the ring) and C , the voltage coupling factor of the coupler. To

get a useful gain ($G \sim 8-9$ dB, i.e nearly 10 times the amplifier output power), a possible choice is $\alpha < 0.5$ dB and $C \sim 10$ dB [4] in the whole frequency range. The lowest working frequency (f_L) is fixed by the spacing between the RF pulses. Since the aim is to simulate LHC bunches, where the bunch spacing can go up to $\Delta T = 50$ ns, the lowest relevant frequency should be $f_L = 1/\Delta T = 20$ MHz. For practical reasons, we chose a design minimum frequency of 30 MHz. The maximum frequency f_{MAX} is fixed by the relative bandwidth of the coupler (i.e. $BW = 20$ from previous experience) and by f_L , i.e. $f_{MAX} = BW * f_{MIN} = 600$ MHz.

The RR has stringent requirements: low reflection from the TW transmission line and a RF coupler designed “ad hoc”. In the following we report about the necessary steps to build the RR: improvements on the TW chamber (sec. 2) and design and test of the coupler (sec. 3). Final achieved performances are given as well (sec. 4).

2 IMPROVEMENTS ON THE ORIGINAL CHAMBER

Reducing the one way attenuation (α) requires acting both on the transmission losses of the six wires in the (circular) vacuum chamber and on the impedance matching among cables, feedthroughs and the coaxial structure. The frequency response of the initial set-up has been measured with a Vector Network Analyser† (VNA), and it is shown in Fig. 2. This plot compares the transmission coefficient versus frequency for the initial situation (dotted line) to the improved one (solid line). The redesign of the parts producing the mismatches has been carried out in order to provide a smooth RF transition following indications in [5]. All these improvements produced the effect seen in Fig. 2, solid line. The transmission coefficient is now within the correct limits (0.5 dB at 600 MHz), since the impedance is reasonably close to 50 Ω all along the line. The impedance along the line has been measured with the time domain option (step mode) of the VNA.

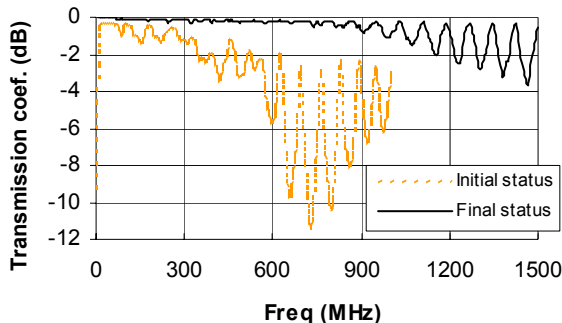


Figure 2. Transmission coefficient of the TW chamber before (dotted orange line) and after (solid black line) the improvements.

† VNA model HP8753D

3 COUPLER DESIGN

As stated above, the coupler should have a voltage coupling factor $C = 10$ dB in the whole frequency range. On top of that, the coupler must stand DC isolation up to 1 kV between the strip-lines and ground (according to multipacting simulations).

The $\lambda/4$ symmetric 9 sections coupler described in [6] accomplishes our requirements. Since the central frequency is 300 MHz, each section is $\lambda/4 = 25$ cm, which implies a coupler length ~ 2.25 m. Due to the non standard specifications, the coupler has been built “ad hoc” using copper strips 0.3 mm thick (to reduce ohmic losses). The voltage coupling factor depends on the characteristic impedance for the odd and even TEM propagating modes (Z_{odd} and Z_{even}) for each section. The free design parameters are the geometrical dimensions: they are carefully determined to meet the required value of Z_{odd} and Z_{even} for each section [7]. For a given geometry Z_{odd} and Z_{even} are first computed with *SuperFish*, a 2-D electrostatic computer code widely used in RF accelerating cavities [8], and then measured on a special test stand. This procedure has been then repeated for each section.

Figure 3 shows the final coupling factor, C , comparison between the ideal case (corresponding exactly to the theoretical impedance values given in [7]), the calculated behaviour of C from Z_{odd} and Z_{even} measured for each section separately and the measurement on the whole coupler. Actually, the coupler working range is 20-530 MHz (instead of 30 - 600 MHz): the effects of this difference are negligible in the final RR performances.

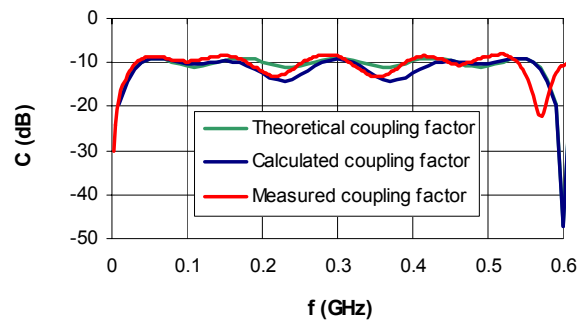


Figure 3. The C of the final coupler (violet line) is reasonably close to both theoretical (green line) and calculated (blue line) behaviour in the relevant frequency range.

4 FINAL RING RESONATOR

In order to see the power enhancement effect of the RR, we measure the transmission between the button probe located on top of the chamber and the bottom connection of the chamber (Fig. 1). Figure 4 compares the signals using the RR (black line) compared to the signal in the original TW chamber (orange line). The power enhancement occurs only at particular frequencies which are integer multiples of $f_R=1/T_R$, being T_R the round trip time in the RR. The round trip time depends also on the length of the connecting cables and was chosen to be 25 ns, according to the nominal LHC bunch spacing. Figure 4 shows a value of f_R close to 40 MHz. The difference between the orange line (measured directly to the chamber) and the black curve (measured using the RR) shows an average gain at $(n*f_R)$ of 6 dB, where n is a natural number.

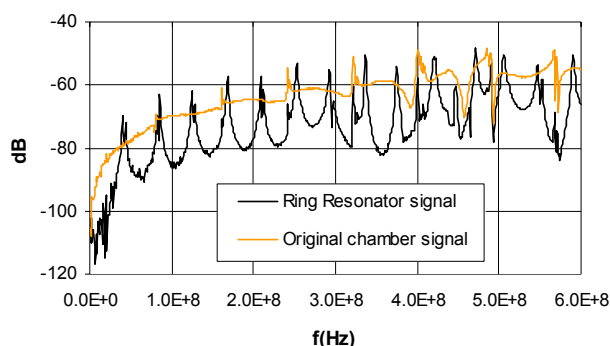


Figure 4. Amplitude of the signal seen as a function of the frequency with the effect of the RR (black line) compared with the original chamber (orange line).

To compensate the 90° phase offset intrinsically given by the coupler, the pulse has been “pre-distorted” with a phase shifter placed just after the source (Fig. 1), allowing a better use of the power amplifier. A unitary (gaussian) pulse entering an ideal 90° phase shifter results (at the output) in a “bipolar-like” signal varying from -0.65 to $+0.65$. Assuming that the amplifier output voltage swing is ± 1 (after normalisation), the “bipolar-like” signal is amplified by $2/1.3=1.53$, i.e. 3.7 dB. Thus the total power enhancement is $6+3.7=9.7$ dB, which means an available amplitude of the TW pulses at least 3 times bigger in voltage.

5 CONCLUSIONS AND OUTLOOK

First results using the RR are in good agreement with the design expectations and multipacting signatures

have been detected in a chamber where the effect was not found before using the original TW set-up. Thus the travelling pulses inside the chamber must have an amplitude significantly bigger. Anyway for the precise measure of the voltage circulating inside the chamber, a suitable sample signal will be introduced as a part of the RR. Priority will then be given to the measurement of the electron energy spectrum, the electron cloud build up time, as well as the characterization of scrubbing effect in different surface treatments. It is worth mentioning that this set up is suitable for studying the effect of propagating microwave modes on the e-cloud. Such asynchronous fields could inhibit the coherent build up of the cloud, as suggested in a recent workshop [9].

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