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FIRST MEASUREMENTS ON MULTIPACTOR STUDY

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Abstract

Multipactor (MP) is an undesired phenomenon of resonant electron build up encountered on particle accelerators. It can induce anomalous thermal losses, higher than the Joule losses, inducing a decrease of the superconducting cavities quality factor, it can even lead to a cavity quench. On couplers, it can produce irreversible damages or generate a breakdown of their vacuum window. Multipactor may lead to Electron Cloud build up as well. The accelerator group at LPSC has developed a test bench dedicated to the multipactor studies. This paper presents the experimental set-up and its first measurements.

INTRODUCTION

Multipacting occurs under vacuum when an electron is accelerated by the electromagnetic field and hits the device's wall. Depending on the secondary electron yield of the surface, more than one electron can be emitted and if it is accelerated by the electromagnetic field, a self-sustained electron avalanche can be created.

We define:

- The MP order: as the number of RF cycles that an electron takes to return to its original emission site.
- The Y-point classification: as the number of impacts sites (Y) per MP cycle.

TEST BENCH

The test bench is composed of a MT400 (Prana) RF amplifier (80 MHz to 1 GHz, up to 54 dB) delivering a 400 W guaranteed power driven by an SM300 (Rohde & Schwartz) signal generator (9 kHz to 3 GHz).

A bidirectional coupler E4417A (Agilent power meter) inserted at the amplifier output allows measuring the output and reflected power. A ZX47-50-S+ power detector is connected to the acquisition system to obtain a synchronous image of the power signal shape.

The main test bench device is a measurement vessel. It consists in a vacuum chamber traversed by a 1''5/8 EIA 181 mm long coaxial line made of copper tubes. A turbopump is mounted on the chamber to generate the vacuum and several elongated holes were machined on the outer conductor to ensure a good pumping of the coaxial volume. Two alumina vacuum windows are brazed at the coaxial extremities to ensure the vacuum sealing.

When the phenomenon of multipactor occurs, an electron current is emitted, leading to outgassing and an increase of temperature. Thus, different diagnostics are set in the measurement vessel, an electron pickup (antenna polarized at +48 V), vacuum gauges (Pirani and Penning) and thermocouples.

All voltage signals are acquired by a cDAQ-9174 (National Instruments) chassis with an NI 9201 analog inputs module to digitize fast signals (up to 500 kS/s), and an NI 9211 module for type J thermocouples.

The test bench can be assembled in the two travelling wave and standing wave configurations.

Travelling wave configuration

In travelling wave configuration, the measurement vessel is terminated by a 50 Ω load. The coaxial line of the measurement vessel is used as a simple coaxial section between the amplifier and the load. A flexible 7/8''EIA cable is used to connect the amplifier to the vessel input and another one to connect the output to the load. In this case, a travelling wave propagates in the measurement coaxial.

Scaling laws of Somersalo *et al.* [1] show that the electrical field range where multipactor should be observable is proportional to the frequency. Hence this configuration has been used for low frequencies (up to 180 MHz).

Standing Wave Configuration

In standing wave configuration, the measurement vessel coaxial is part of a 3λ/2 coaxial resonator [2], where λ is the wavelength corresponding to the input signal frequency. The resonator input port is created using a coaxial T junction set approximatively at λ/2 from one resonator extremity. The vessel ports are connected to two rigid coaxial lines terminated by shortcuts so a standing wave is formed with a voltage magnification K factor. This coefficient K factor is approximately equal to $K \approx \sqrt{2Q_0/3\pi}$ where Q_0 is the unloaded quality factor. K factor is also the ration between the maximum voltage inside the cavity and the input voltage (see Fig 1).

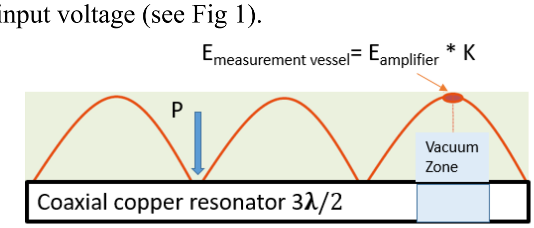

Figure 1: Schematic view of the experiment.

As in standing wave configuration multipactor appears at the maxima of the electrical field is maximum, the coaxial line lengths are chosen to set the coaxial vessel section where the maximum electric field is generated, at λ/4 or 3λ/4 from the shortcuts. To optimise the power transmission to the cavity the two shortcuts can slightly be moved.

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To proceed the measurement, first, a network analyser is connected to the input port to measures the resonant frequency and the unloaded quality facto, leading to K factor estimation. The amplifier is then connected to the input port to proceed with multipacting experiments at the resonant frequency.

See Fig. 2 for resonant coaxial cavity at 900 MHz.

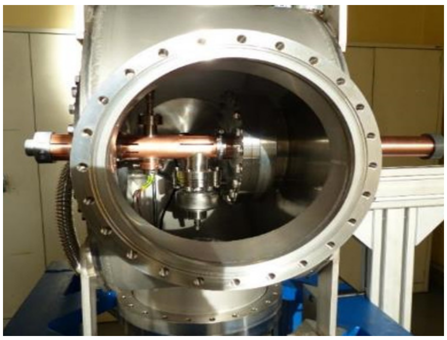

Figure 2: 900 MHz resonant coaxial cavity.

This configuration is mainly used to study the multipactor at higher frequencies requiring higher electric field.

LABVIEW SOFTWARE

Setup control and Data acquisition is handled by software developed with LabVIEW, on a standard PC.

Software comprises an online application that drives instruments and acquires measurements, and an offline data browser.

The online application provides setup controls, monitoring measurements (temperature, power, pressure and multipactor current) where maximum values are recorded once per second, and faster snapshots of waveforms that are continuously sampled and processed at a typical rate of 20 kS/s (multipacting current, pressure, transmitted power, reflected power and the envelope of the injected power signal). Hence about 4000 samples are taken during a 200 ms long power pulse.

Real-time software processing allowed to test various triggering and recording strategies. Eventually, snapshots are triggered every second upon a rising front of the power envelope channel, recording waveforms over a 300 ms time window including the 200 ms long power pulse.

Rather than trying to catch only the most visible multipactor events, it was chosen to record significant waveforms in a lossless file, along with their main characteristics and setup configuration parameters, for every power pulse snapshot, and to develop an offline data browser enabling both general and in-depth analysis of the data. Files recording and caching algorithms provide fast browsing of lossless data.

FIRST MEASUREMENTS

Measurements in Travelling Wave Configuration

Measurements have been done in travelling mode for frequencies ranging from 100 MHz up to 180 MHz by steps of 20 MHz. At each frequency, the power is steadily increased from 0 W to the maximal power delivered by the amplifier and then decreased down to 0 W. Pulsed RF mode is used with a 1 second period and a 200 ms long power pulse in order to avoid a fast multipactor conditioning.

At 120 MHz, one multipacting barrier (1-point order 1) is found from 75 W to 416 W when the power is increasing. The maximum electronic current (multipactor) measured is 41 µA at 238 W. This multipacting barrier is found also when the power is decreasing but the power range is slightly moved to higher powers from 100 W to 446 W. The maximum electronic current measured is 32 µA at 253 W (Fig. 3).

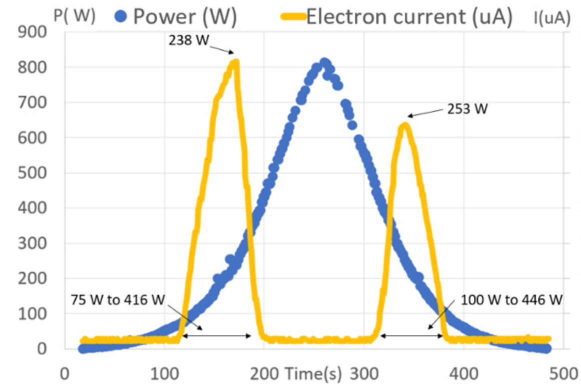

Figure 3: Multipacting measurement at 120 MHz.

The comparison (Fig. 4) of waveforms at maximum multipactor current when the power increases (for example at 238 W @ 120 MHz) for all measurements show that the measured multipactor current is higher at higher frequencies with exception the 180 MHz current, that the value remains almost similar to that of 160 MHz.

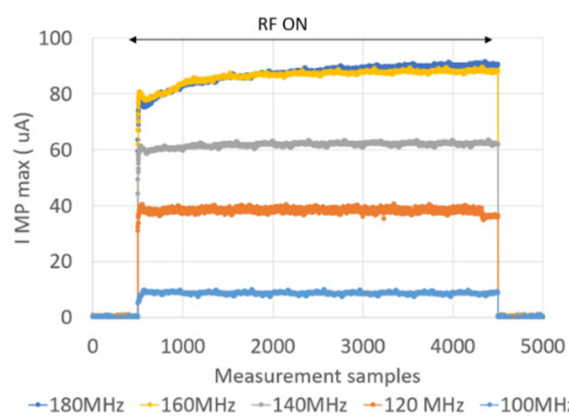

Figure 4: Waveforms at maximum multipactor current when the power is increasing.

The same trend can be observed when the power is decreasing, with lower intensities. For example at 120 MHz, the maximum electron current is 41 µA @ 253 W when power is increasing whereas it is 32 µA @ 253 W when power is decreasing. This could be explained as some conditioning is performed as the power is ramped up and then down thus lowering the multipactor current at the ramp down.

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It is also detected with the vacuum measurement that higher frequency give rise to higher vacuum rise (Fig. 5), even at 180 MHz. We explain this with elevated multipactor current, and thus more outgassing of the surface.

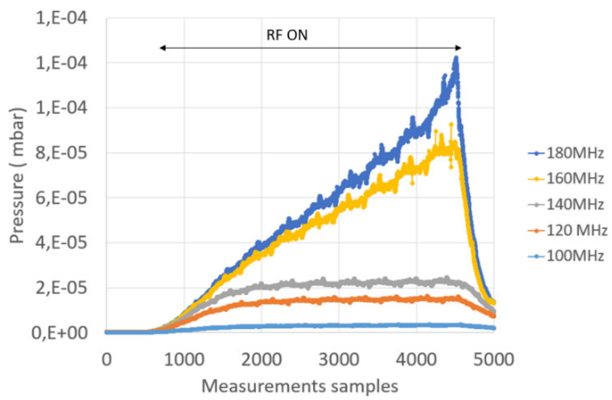

Figure 5: Waveforms of pressure@maximum multipactor current when power is increasing.

Figure 6 shows the electric field multipactor ranges found for the different frequencies, in both the increase and decrease cases. For all frequencies, the range slightly moves toward high electric field in the case where the RF power is decreased.

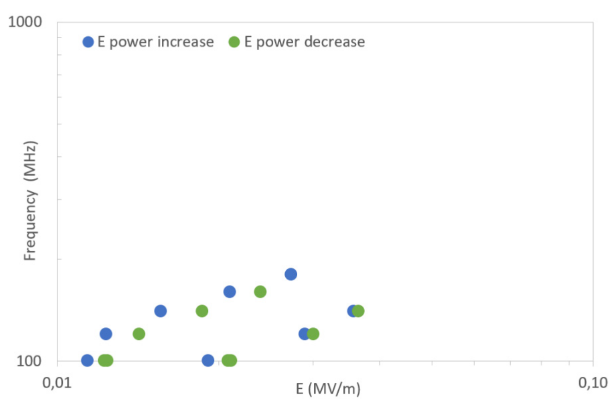

Figure 6: Range of the electrical field where multipacting has been measured.

Measurements in Standing Wave Configuration

Preliminary measurement of multipactor also carried out at 900 MHz were in the standing wave configuration. Simulations performed without dielectrics gave a K factor of 30. Experimentally, a K factor of 18 was measured using the network analyser, given the importance of dielectrics losses. The range of electrical field where multipacting might appear for 1 point order 1 is not reached with our test bench. Instead, two multipacting for upper order are found around 0.16 to 0.44 MV/m and 0.53 to 0.6 MV/m. These multipacting barriers are observed with the electronic current and the pressure measurement but also with changes in the reflected power.

Comparison Measurement with Simulation

MUSICC3D (@IJC Lab/ France) simulations [3] were performed of our coaxial resonant at 100 MHz, 625 MHz and 900 MHz. These simulations determine the electrical field range where the multipactor phenomenon should be observable. As display on Fig. 7 a very good agreement between simulations and measurement is found.

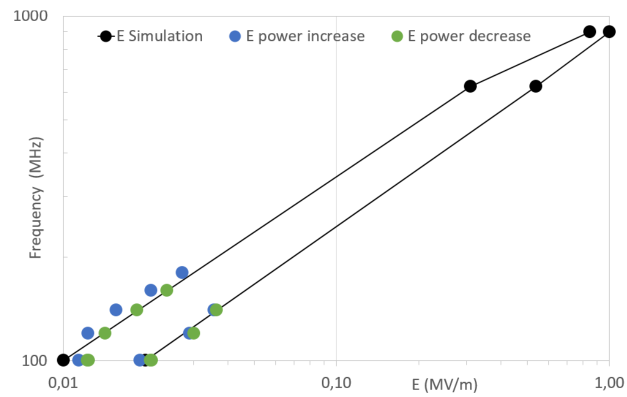

Figure 7: Range of the electrical field where multipacting has been measured versus simulation results.

CONCLUSION

The test bench dedicated to multipactor measurement is operational and validated in both travelling and standing wave configurations as simulations show a good agreement with measurements.

We detected that multipacting barriers are slightly shifted depending on the ramp up or down of the power. We also observe that multipactor seems to be stronger (more electronic current and pressure rise) when the power frequency increases.

Only multipactor (1 point order 1) is observed up to 200 MHz, but at 900 MHz multipactor of upper orders are measured. Experimental campaigns will follow to investigate upper order multipactor at low frequencies, and multipactor above 200 MHz.

The final goal is to reach a comprehensive understanding of the phenomenon and to find protocols minimizing the multipactor by an adapted RF conditioning or better surface preparation.

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