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COUPLER HV BIAS STUDIES ON ESS ELLIPTICAL CAVITIES

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Abstract

The spoke and elliptical superconducting cavities for ESS are equipped with a coupler capable of being DC-biased. This is to give the capability of shifting multipactor bands using a DC voltage bias, which can allow for complete suppression of multipactor with a sufficient voltage.

A very conservative initial estimate of the voltage required for ESS was given as 10 kV. Initial observations suggested approximately 300 V would be sufficient, subsequent studies showed that higher bias values were sometimes required.

1 kV, 3 kV and a 6 kV unit were tested on couplers at ESS Lund Test Stand 2 (TS2). Operations at TS2 include coupler conditioning (standing wave operation - SW) and travelling wave (TW) during cavity conditioning. The nature of the observed activity is very dependent on the mode of operation.

INTRODUCTION

Each cryomodule follows a Site Acceptance Testing process to validate its performance and suitability for installation to the tunnel. For the elliptical cryomodules, these tests are carried out at TS2 [1]. The modules are taken through a well-defined workflow, in order to test performance of the cavities and subsystems [2]. The tests are carried out thanks to the long-standing collaboration with IFJ-PAN, working together as a unified team.

As part of this testing process, tests of the High Voltage bias (HV bias) have been carried out in order to verify the HV power supply specification that would be required for the Superconducting Linac.

OBSERVATIONS OF MULTIPACTOR AT TS2

Diagnostics

The couplers [3] are fitted with a number of diagnostics which we can use to monitor the progress of multipactor at TS2.

Electron Pick-Up probes (EPU)

The electron pick-up probes (EPU) signal comes from a 45V biased probe in the coupler. This gives a very accurate and time-resolved reading of the electron activity in the coupler vacuum, which is digitized and handled in the Fast Interlock Module (FIM) of the Local Protection System (LPS) of the RF stations, which provides technical interlock protection to the RF power sources and the cavities. Due to the nature of the probe, it is also very localised, which gives additional information on the location of the activity (allowing us to distinguish between coupler activity and (rare) cavity activity. The LPS will interlock the RF operation on the cavities if the current captured by the EPU reaches above 4.5 mA along the RF pulse.

Arc detectors

Two Arc detectors (AD)fibres collect light signals for each coupler, one on either side of the RF window to photomultipliers (PMT) in the gallery racks. Due to the window transparency the air-side AD generally shows an attenuated version of the light activity occurring within the vacuum environment during coupler multipacting. The output signal of the PMT is processed in the fast electronic of the AD rack and a digital signal is sent to the FIM for interlock purposes.

The AD signal is very informative and has a slightly inferior time resolution than the EPU. It is highly sensitive to light in the coupler region and to a lesser extent in the cavity, due to the reflectivity of the surfaces.

ADs can also provide spurious signal [4] due to ionizing radiation generating light in the fibre. Effort is being put into analysing the spectral content of genuine arcs and radiation, with the intent to discriminate the later out.

Vacuum

The vacuum signal is of limited use for fine multipactor detection, due to lag and inertia over the EPU and AD signals. The vacuum level indicates the severity of the multipactor barrier, while also enhancing arcing at higher pressures due to the density of ionisable particles. Our vacuum interlock is set at 5 10^{-7} mbar, but we generally operate at ~10^{-8} mbar in warm conditions, and ~10^{-9} mbar when cold.

HV power supply read-back

The HV power supply we use (ISEG DPR series) provides a current and voltage readback which we can monitor through EPICS. When the power supply is off, the value is floating and can provide an indicative measurement of the multipactor current. This can be a good way of identifying single point or multi point multipactor as single point multipactor does not generate a current.

Radiation – scintillator count rates

Multipactor itself does not generate radiation, the impact energies being far too low. The electron cloud it generates can however be captured by the cavity RF and accelerated to levels sufficient to create a signal visible on the scintillators. We can verify whether the radiation is induced by coupler multipactor by changing the bias [4].

Coupler Conditioning – SW Operation

The elliptical cavity cryomodule couplers are conditioned prior to tuning the cavity. This operation is carried out in a well-defined sequence, where pulse length and repetition rate are increased up to the design limits. The operation is carried out at room temperature (warm coupler conditioning) and at 4 or 2 K (cold coupler conditioning).

As the RF cannot couple to the cavity, a standing wave pattern is formed in the waveguide, always ensuring the occurrence of a resonant path somewhere along the coupler

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and leading to wide multipacting bands during the conditioning process (Fig. 1).

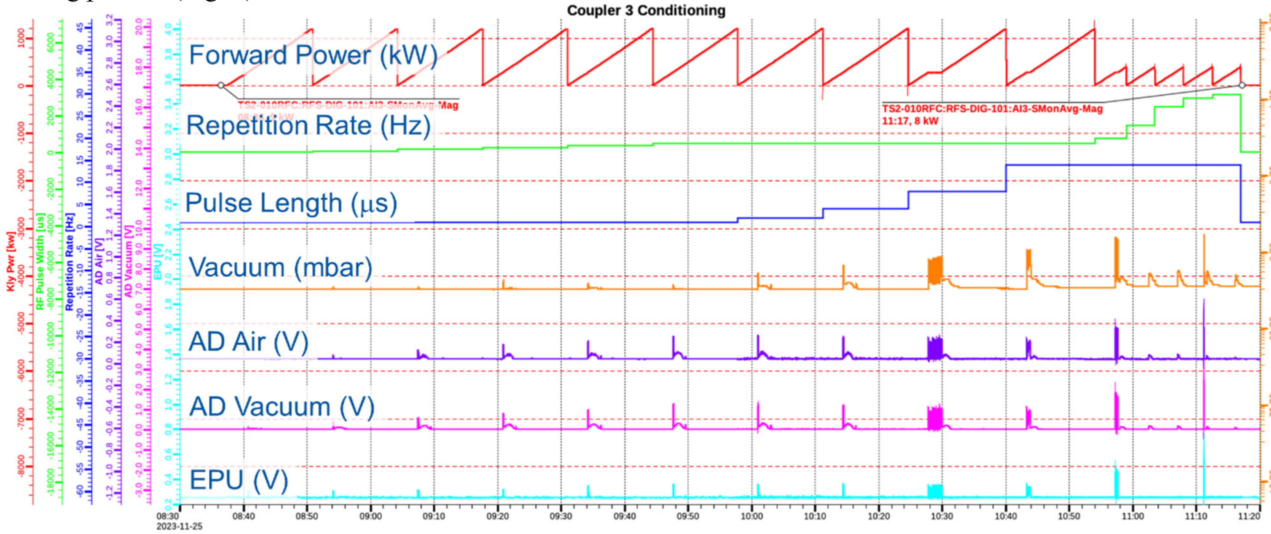

Figure 1: Example of a conditioning plot (Cold coupler conditioning, CM 37 Cavity 3).

The existence of multipacting bands appears clearly showing vacuum, AD, EPU signals against forward power. Figure 2 shows the EPU (normalised for repetition rate and pulse length), for both the warm (top) and cold (bottom) coupler conditioning operations.

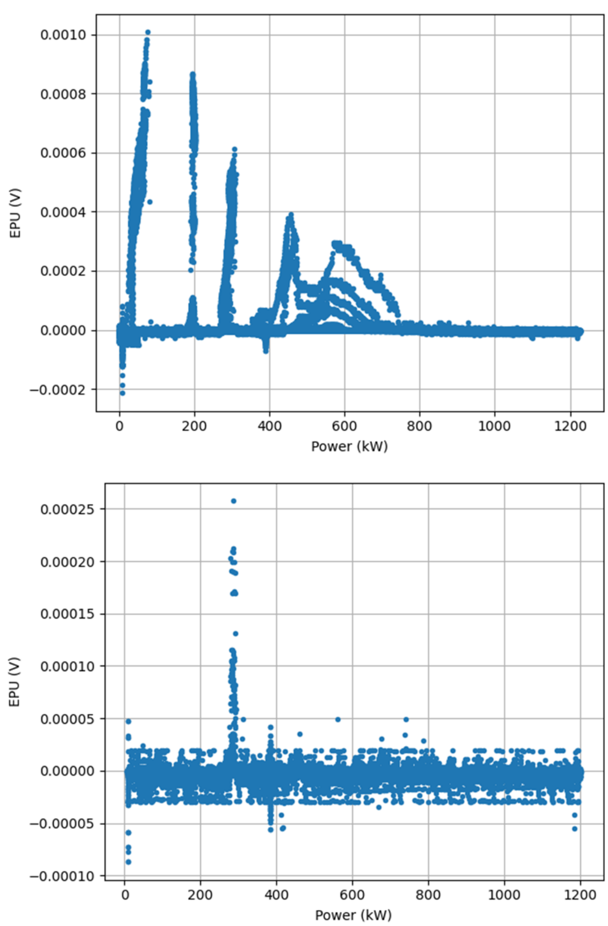

Figure 2: Warm (top) and cold (bottom) conditioning distribution of electron activity over power.

From the figures above we can see that the conditioning process removed activity at 30-73, 187-200, 416-478 and 546-720 kW, while the band at 262-312 kW persisted to the cold conditioning and was not completely removed even at the end of the process (as can be seen on Fig. 1).

Over the various couplers we have processed, few provide such clear band structures, as most couplers are much cleaner. When the band structure is visible, the exact band positions tend to follow the same general structure but at varying power levels. This can be explained by either variations in the power calibration chain or by small geometrical variations in the coupler region. Fig. 3 shows the superposition of all of the recorded conditioning cycles that had a significant EPU trace.

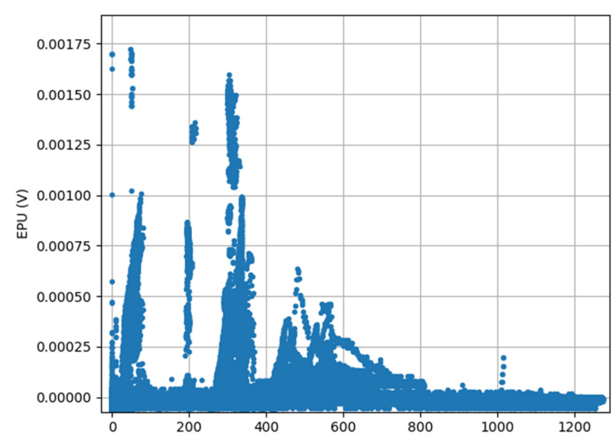

Figure 3: Plots combining all bands from a selection of coupler conditioning cycles (warm and cold) from CM09, CM33, CM37 and CM38.

Cavity Conditioning – TW Operation

Following the conditioning process, the cavities are brought to tune and cavity conditioning begins. The RF in

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the coupler is no longer operating in a standing wave pattern, but in a combination of directional patterns along the pulse length: Forward Travelling (during cavity fill), Standing (after the filling) and Backward Travelling (during the cavity field decay).

Multipactor is generally only observed during the (unmixed) filling and decay parts of the RF pulse, in which a traveling wave field pattern is established in the transmission line. In the case of the cavity decay, the multipactor bands are located at very specific power levels that the coupler sees as the stored energy empties through the coupler.

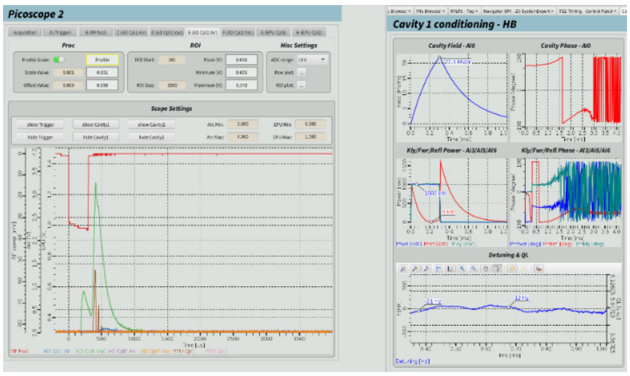

Figure 4: Scope traces (left) of AD (green) and EPU (red) with a square RF pulse (right) at 1 MW.

From Fig. 4, one sees that the arc detector picks up activity at the reflected power minimum at 200 µs, as well as a broad signal after the pulse in the cavity decay. The EPU provides greater resolution, and shows 3 multipactor bands at different power levels.

The bands occur at very specific power levels, and will slide on the time axis as the forward power changes in order to remain at the same reflected power level.

Application of the HV bias can also affect the bands. In the example above, a number of bias settings were applied.

Suppression of the multipactor could be achieved in the conditions above with a bias voltage of +270 V, as can be seen in Fig. 5 below.

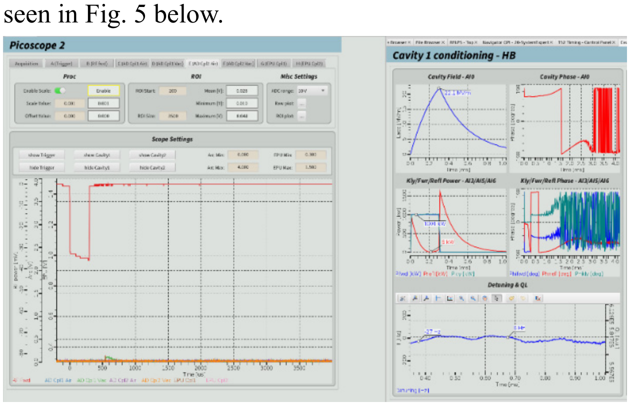

Figure 5: Multipactor suppression with 270 V applied bias voltage.

Varying the HV bias voltage shifts the bands, and can in some cases worsen the situation as can be seen in Fig. 6 around -550 V.

The suppression band in that case was from 270 V to 900 V (limited by the 1 kV power supply).

The range of suppression has been the topic of much research [5, 6], and applying scaling laws available in the literature, derived from similar coupler designs, to the ESS case results in a required voltage of ~1.3 kV for the spoke cavities, and ~2.6 kV for the elliptical cavities (medium and high beta).

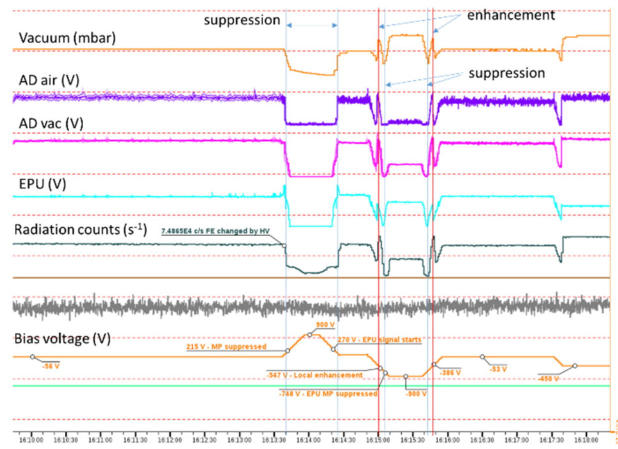

Figure 6: High voltage DC bias sweep showing enhancement and suppression at different settings.

We have seen in some cases that the 1 kV power supplies were not sufficient to completely suppress the multipactor. A 3 kV power supply was tested in later modules and has so far been able to suppress every band.

We have verified that the effectiveness of the bias was independent of the make of the power supply.

CONCLUSION

Multipactor observations have been carried out at TS2 on the elliptical module couplers. While so far, it has so far been possible to condition every multipactor band with sufficient time, we prepare for the possibility that an unconditionable band may present itself in the future during the machine operation. The HV bias has been tested to verify the effectiveness of multipactor suppression before deciding the procurement specifications for the solution to be deployed for the Superconducting Linac.

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