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THE ESS MEBT RF BUNCHER CAVITIES CONDITIONING PROCESS*

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Abstract

As part of the 5 MW European Spallation Source (ESS), the Medium Energy Beam Transport (MEBT) was designed, assembled, and installed in the tunnel since May 2019 by ESS-Bilbao. This section of the accelerator is located between the Radio Frequency Quadrupole (RFQ) and the Drift Tube Linac (DTL). The main purpose of the MEBT is to match the incoming beam from the RFQ both transversely and longitudinally into the DTL. The longitudinal matching is achieved by three 352.21 MHz RF buncher cavities. In this paper, we focus on the RF conditioning process for each set of power coupler and buncher cavity. For this purpose, different tools were developed on EPICS and Python as well as electronics hardware such as Fast Interlock Module (FIM) and timing system. These tools served to automate both the cavity frequency tuning and the power ramp-up process and will be described in detail in the following sections.

INTRODUCTION

The ESS [1] MEBT buncher cavities have been designed according to electro-magnetic, thermo-mechanic, RF and beam dynamics to provide an effective voltage of V_oT = 160 kV [2–4]. These particular bunchers are manufactured from stainless steel copper plated with a layer of 30 µm-thick. The cavity has a nose-cone single gap type used for longitudinal focusing with a resonant frequency of 352.2 MHz.

When buncher cavity and its coupler are designed, manufactured, assembled reaching high vacuum pressure, they still need to be conditioned coupling high RF power. For conditioning process, good vacuum level is required, tuning capabilities, monitoring system and high power RF signal. But it should be done in a gradual way. This process is called conditioning, and its strongly related to two main phenomena: *multi-pacting* and *break-down*, that limit the amount of power that can injected into the cavity. The process can be described as a gradually increase of the power, while maintaining the vacuum pressure within safety limits. After sufficient time the vacuum pressure and breakdown rate decreases and once certain conditions are met, cavity and coupler can be considered as conditioned. This conditioning time strongly depends on the geometry of the cavity, required performance and it surface history conditions.

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TEST STAND AT ESS-BILBAO

The conditioning process needs to be performed using a 30 kW amplifier from BTESA [5] working at 352.21 MHz frequency using solid-state technology (SSPA), to provide up to 3.5 ms pulse-width and 14 Hz repetition rate (4.9% duty cycle). For monitoring the out-gassing contaminants a Residual Gas Analysis (RGA) sensor is connected to the cavity. Forward and reverse power are monitored with coaxial dual directional couplers before and after the circulator. On top of that, additional thermo-couples are installed next to the cavity water inlet and outlets.

Figure 1 shows the different parts of the test bench implemented. As mentioned before, the tuner motion control is based on a stepper motor and incremental encoder connected to a µTCA with an EPICS interface. Moreover, the forward and reflected power signals at the cavity input are acquired by a cRIO 9024 with a N-9223C module using three differential inputs. With a sampling rate capability of 350 kS/s, the cRIO is programmed with Labview with 200 kS/s at the trigger employed to generate the RF signal introduces to the cavity. Working as an EPICS IOC, it provides the information referred to the input and output power to the control computer used as EPICS client on which the control algorithm is developed using a Jupyter notebook programmed in python.

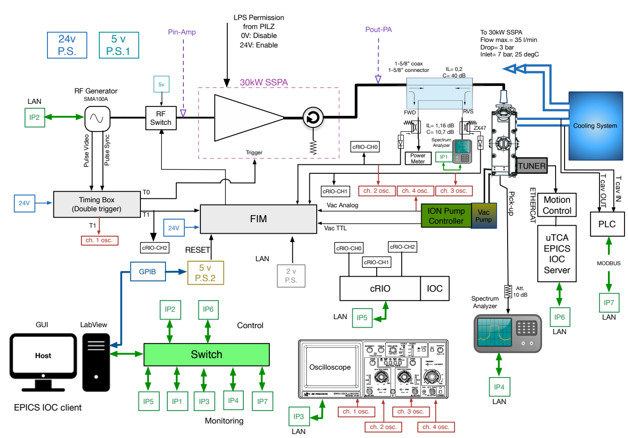

Figure 1: Cavity Test Stand Diagram.

The only manipulable variable at this point in control terms is the tuner position (see Fig. 2) in absolute values, as it is configured in the IOC, and it is limited by software in 50 mm span (25 mm inside, 25 mm outside).

In our particular case, there are three cases, were the interlock shuts the RF down, (i) In case vacuum pressure inside the cavity reaches 1.10^{-5} mbar. (ii) In case radiation level reaches 2.5 µSv/h measured by the radiation area detector

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(iii) Water cooling system reaches an alarm level, either by pressure, temperature, flow values, or a combination of those.

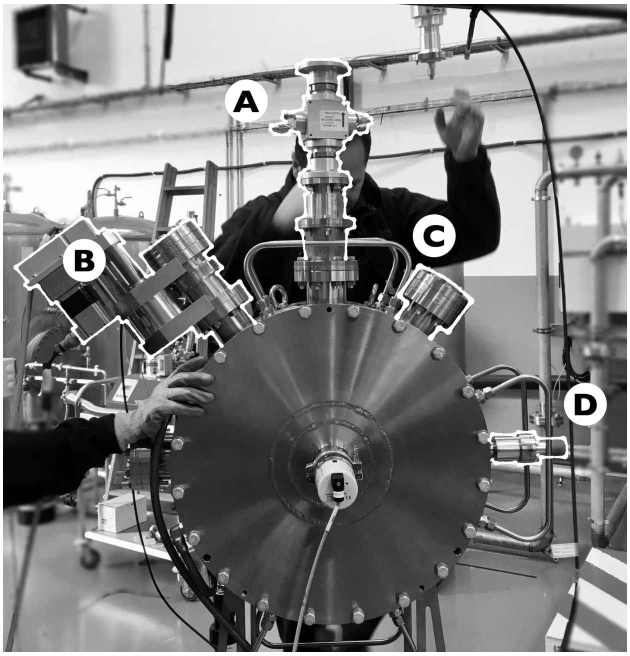

Figure 2: Buncher connection and setup process in Zamudio. Coupler (A) Movable (B) and Fixed tuner (C). vacuum gauge (D).

CONDITIONING PROCEDURE

Based on the previous experience [6], the control system allows the user to set up a sequence of sweeps, thus delivering RF power to the coupler and the cavity with gradually increasing power, pulse width and repetition rate in nested loops, until the nominal operating conditions are achieved, while the vacuum level is acceptable.

For the ESS MEBT coupler and cavity, the sweeps have been the following:

Pulse widths: 0.25, 0.5, 1.0, 2.0, 3.0 and 3.5 msec;

Pulse repetition rates: 1, 2, 4, 8, 12 and 14 Hz;

RF Power ramp: from -16 to -1.5 dBm at RF generator (0.8 to 22.5 kW at cavity input);

Power step: 0.05 dB (slow mode), 0.1 dB (normal mode), 0.5 dB (fast mode).

Vacuum pressure inside the cavity is continuously monitored. The interlock threshold (2×10^{-5} mbar) is defined, such that, above this level, the local protection system turns RF permission off until it is reset. Figure 3 presents the three software vacuum thresholds, on top of the hardware interlock trip level. These determine the power ramps as follows:

- Below the low vacuum threshold (e.g.: 4×10^{-6} mbar), RF power increases at nominal speed (e.g. $+\Delta P_1$ = +0.1 dB per step);
- Above this level, but below the mid threshold (e.g.: 8×10^{-6} mbar), RF power increases at reduced speed (e.g.: $+\Delta P_2$ = +0.025 dB per step);
- Above this level, but below the high threshold (e.g.: 1.4×10^{-5} mbar), RF power is decreased (e.g.: $-\Delta P$ = -0.05 dB per step);
- Above the high vacuum threshold, RF power is turned off. RF power is not turned on again until the vacuum pressure decreases below the mid threshold again. When this happens, RF power level will have been reduced following the mentioned negative slope law.

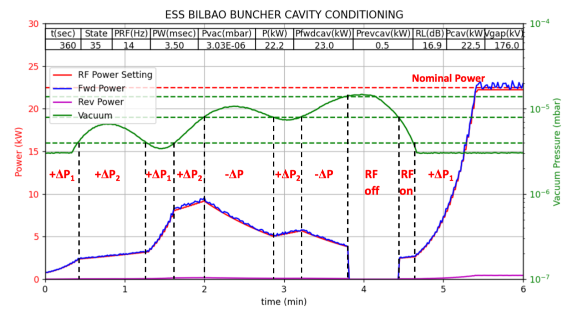

Figure 3: Simulation of a power ramp with varying vacuum pressure level.

EXPERIMENTAL RESULTS

The automatic procedure starts with the lowest power level at the State 0 (shortest pulses and lowest repetition rate). The power is gradually increased up to nominal level. Once this level is reached, it is maintained for a certain defined time duration. Then, the power ramp is restarted for the next state (State 1: next pulse width, lowest repetition rate). As presented in Fig. 4, after completing the power ramps for all the defined pulse widths at the lowest repetition rate, the control system turns to the next repetition rate, and so on. Eventually, the automatic procedure achieves the last state (State 35: 3.5 msec, 14 Hz) and the nominal RF power. Once this final setup is achieved, it is held for at least 12 hours without any interlock trip (see Fig. 5).

Along this process, in parallel, cavity frequency tuning is carried out by measuring reflected RF power and setting the movable tuner to a suitable position. By means of this algorithm the level of acceptable reflected power can be adjusted, for instance to a minimum (e.g.: below 200 W for tuned operation) or to any suitable value (e.g.: 4000 W for a partially detuned operation).

Figure 6 depicts the tuning algorithm in action. The observed oscillations in the reflected power can be explained as follows: (i) heat loads produce deformations in the cavity; (ii) this deformations shift the resonant frequency, resulting in an increase in the reflected power. (iii) As a consequence, less power will be dissipated in the cavity, (iv) Deformations will be reduced and cavity will commence to approximate to the resonant frequency, improving thus the reflected power ratio.

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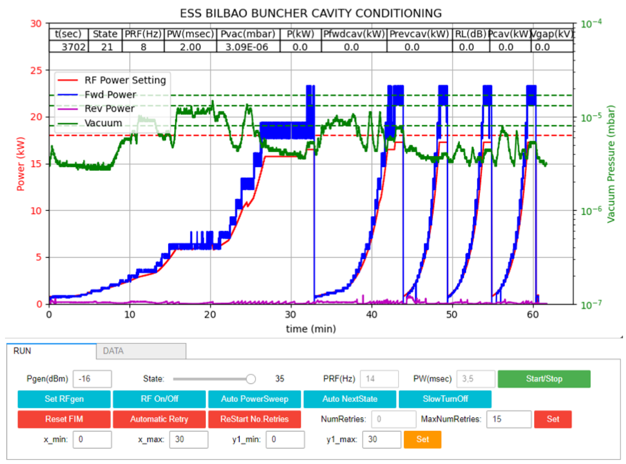

Figure 4: GUI interface during different states power sweeps. In particular, from state 17 to 21.

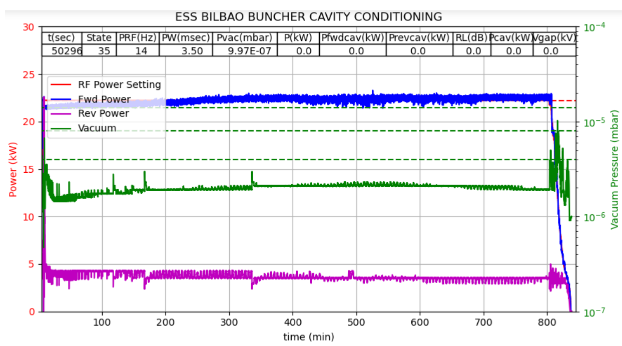

Figure 5: GUI interface during long run process for the case of the last state (State 35: 3.5 msec, 14 Hz).

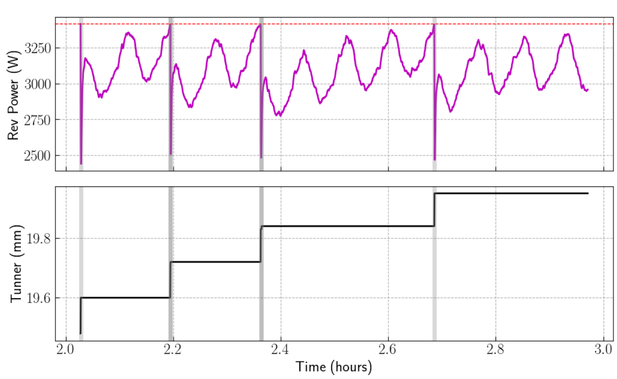

Figure 6: Tuner performance along 1 hour, keeping the forward power steady at 25458 W. The algorithm maintains the reflected power within the acceptable limit marked in blue (upper frame), by adjusting the tuner position (lower frame).

CONCLUSION

The three (3) MEBT buncher cavities with their correspondent couplers were conditioned at high RF power, last quarter of 2020 for the ESS linac, these were shipped back to Lund and they are currently installed back into the accelerator tunnel (see Fig. 7).

Figure 7: MEBT Assembly in the ESS LUND accelerator tunnel close up.

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