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OPERATIONAL EXPERIENCE AND REDESIGN OF THE TUNER WITH-OUT SPRING FINGERS FOR THE LEReC WARM CAVITY

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DISCLAIMER

OPERATIONAL EXPERIENCE AND REDESIGN OF THE TUNER WITHOUT SPRING FINGERS FOR THE LEReC WARM CAVITY*

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Abstract

A folded coaxial tuner without spring fingers was designed for the Low Energy Relativistic Heavy Ion Collider (RHIC) electron Cooler (LEReC) 2.1 GHz warm cavity. During RHIC run 2019, this tuner was found to cause cavity trips via different failure modes. After analyzing these failure modes, a new straight coaxial tuner without spring fingers was proposed and was installed. We show the operational experience of the new tuner in this paper.

INTRODUCTION

Cooling of beams of gold ions using radiofrequency (RF) acceleration of electron bunches, named LEReC, was recently experimentally demonstrated in the Relativistic Heavy Ion Collider at Brookhaven National Laboratory [1]. In the linear accelerator (Linac) of the LEReC, a 2.1 GHz warm cavity is used as the third harmonic resonator to de-chirp the electron bunches. This cavity is located right on the downstream of a superconducting RF (SRF) 704 MHz booster cavity. This SRF booster cavity has a special higher order mode (HOM) coaxial damper design on the downstream of the beampipe, with a Cu pipe inserted into the beampipe and its tip close to the fundamental power coupler (FPC) of the SRF booster cavity [2]. This Cu pipe is at room temperature (or higher) during operation, thermal anchor cannot be applied to it. This structure cannot prevent particulates generated downstream from entering the SRF cavity, especially to the FPC section, at where multipacting can happen. All components of the 2.1 GHz warm cavity were cleaned and assembled in class 10,000 cleanroom and the beampipe connections of this cavity were performed in a portable cleanroom. During operation, in case one of the vacuum gauges for 2.1 GHz warm cavity appears to be higher than 5×10^{-8} torr, a vacuum valve located between SRF booster cavity and 2.1 GHz warm cavity will be shut off to isolate these two systems. In such a configuration, a conventional tuner that uses spring fingers is not preferred since particulates may be generated. A special folded coaxial tuner without spring fingers was designed [3]. During RHIC run 2019, this tuner was found to cause cavity trips via different failure modes. Without opening the cavity to check the tuner, we analyzed these failure modes and applied temporary patches to ensure operation of 2.1 GHz cavity within RHIC run 2019 and started to design and fabricate a new tuner without spring fingers. After RHIC run 2019 was finished, the old tuner was removed from 2.1 GHz cavity and the new one was installed. During RHIC run 2020, the new tuner ensured smooth operation of the 2.1 GHz cavity.

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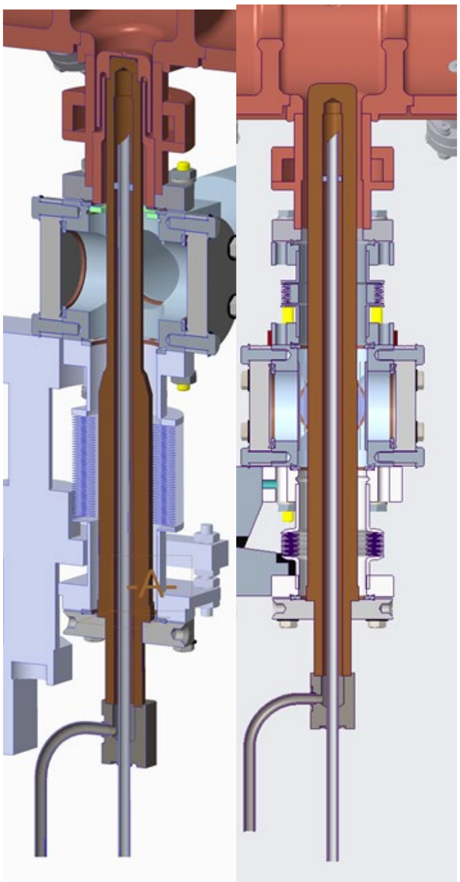

Figure 1: Left: folded coaxial tuner design; right: straight coaxial tuner design.

DESIGN AND OPERATION OF FOLDED COAXIAL TUNER

As shown in the left of Fig. 1, a folded coaxial main frequency tuner was designed. The gap in this folded coaxial tuner is 1mm. The cavity fundamental mode couples to a TE_{11}-like mode in the coaxial line. This mode has a much higher cutoff frequency than that of the fundamental TM_{010} π mode, and it does not easily transform into the TEM mode. This design eliminates the RF contacts between moving parts in a traditional plunger-type tuner to improve reliability. During the PEP-II & NLC designs, R. Rimmer considered to use a coaxial tuner, the same idea in this paper, so that spring fingers can be avoided [4]. The demountable tuner cap is threaded onto the tuner rod, TiN coating is applied for multipacting suppression. The length of this tuner is tailored to reject 2.1 GHz fundamental mode. An

UHV design LSM CAR1596-S-22053 actuator was used, with the load within its specification. Based on multiphysics simulations, a 0.2 mm tilt of the tuner cap can be tolerated.

At the beginning of RHIC run 2019, the 2.1 GHz cavity was found not being able to provide 160 kV cavity voltage, the operating voltage needed for this run, and it was observed that the tuner cannot move smoothly.

At low voltage (0.5 kV or so), we scanned the tuner locations, monitored the voltage response, and it is noticed that at certain tuner locations, cavity voltage was lower than normal (other locations). See Fig. 2**Error! Reference source not found.**. This is not related to multipacting or field emission, since it happened with extremely low cavity voltage, it is the RF response of tuner misalignment. Geometric survey also suggested that the tuner cap might touch the tuner port at certain locations. A Cu block was added on the bottom of the tuner, with its weight and torque carefully adjusted, so that the voltage decreasing can be eliminated.

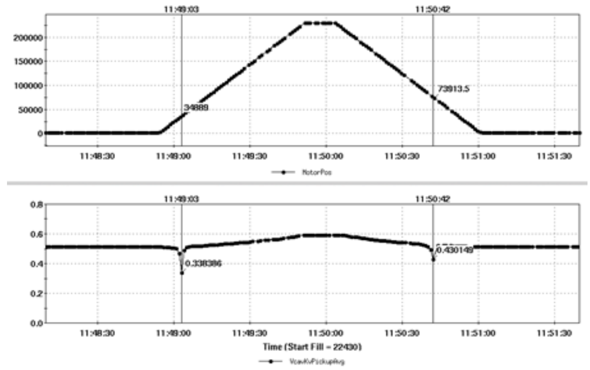

Figure 2: Voltage response of the problematic tuner, from top to bottom: Tuner location (steps) versus time; Voltage versus time.

At high voltage (above 100 kV), while tuner is not moving, vacuum spikes might also happen. The vacuum increasing happens first on the vacuum gauge at the bottom of the tuner, with its number increases for a few tens of seconds before a spike appears, which then can be seen from other vacuum gauges on the FPC or cavity downstream. It trips the RF amplifier and causes the valve between 704 MHz SRF booster cavity and 2.1 GHz cavity to close. Usually a few spikes appear within the first hour of the cavity operation before the tuner finds a "good" location it can stay. The readings from thermal sensors attached to the tuner housing revealed that the temperature of the tuner bellow increased ~9 °C with 160 kV cavity voltage, while the other places increased < 2 °C. It is not a multipacting effect, it is a thermal effect associated with RF heating, and it is from 2.1 GHz mode, not the HOM since the cavity behaves the same with and without beam. The cavity was conditioned with all valves closed and with vacuum trip point at 2×10^{-6} torr, which is much higher than the trip point for operation; A fan was added to cool the tuner bellow; A "deadband" was added to limit the movement of the tuner, with the cost of higher power from amplifier needed during operation; A special script was used so that the tuner do not move if not necessary, even with cavity voltage off and back to the operating voltage at 160 kV.

With all above efforts, the cavity was able to provide 160 kV till the end of RHIC run 2019. After that, tuner was disassembled from the cavity to exam the possible damages, see Fig. 3. It was found that the Cu cap that was threaded onto the tuner rod came out loose, and marks of arcing between cap and cavity port were also found. The cap was also deformed, it is believed that RF induced heat softened the Cu cap, and the loose cap touched the center rod and caused deformation.

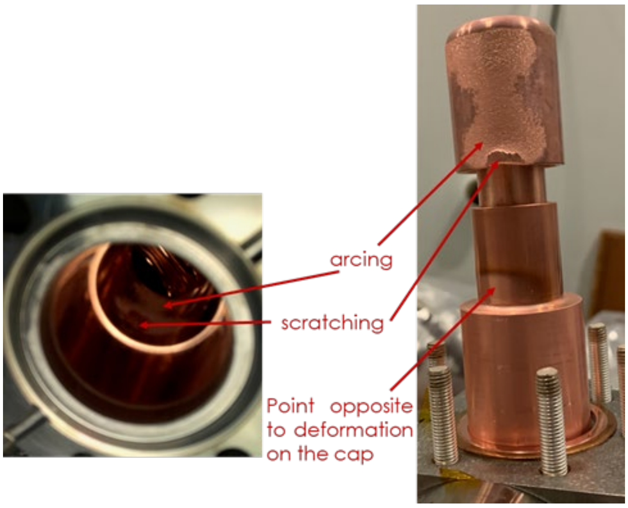

Figure 3: Damages on the cavity tuner port (left) and the tuner (right).

DESIGN AND OPERATION OF STRAIGHT COAXIAL TUNER

The folded coaxial tuner showed a complex problem including mechanical, RF, thermal and vacuum issues. The cause is the misalignment that comes from: 1, inadequate actuator design that cannot handle the vacuum force associated with the tuner weight, and the force was uneven due to the design of guiding rod; 2, the tuner cap that was threaded onto the tuner rod became loose during operation; 3, The port aligner was not in correct location; 4, Grease was not applied after baking.

A simple model is used for explanation, see Fig. 4. With tuner perfectly aligned in the tuner port, the resonances within the tuner can be treated as a quarter wave resonator (QWR), while the tuner is tilted to touch the tuner port, it becomes a half wave resonator (HWR). With the tuner length to be L, the resonant wavelengths λ_Q in QWR can be determined using $L=(2n+1)\lambda_Q/4$, and the resonant wavelengths λ_H in HWR can be determined using $L=(n+1)\lambda_H/2$. The bottom plot of Fig. 4 showed the measurement results, with orange curve aligned and yellow curve misaligned to touch. Ideally, one would like to choose a tuner length that 2.1 GHz mode is right in the middle of two adjacent resonating frequencies (ideal case).

Based on the above analysis, it is suggested that alignment is important in this tuner design. A conventional tuner design with spring fingers is not considered since: 1, conventional design also requires good alignment; 2, conventional design produces particulates, which affects the performance of adjacent SRF cavity; 3, conventional design is known to be fragile and will fatigue over time.

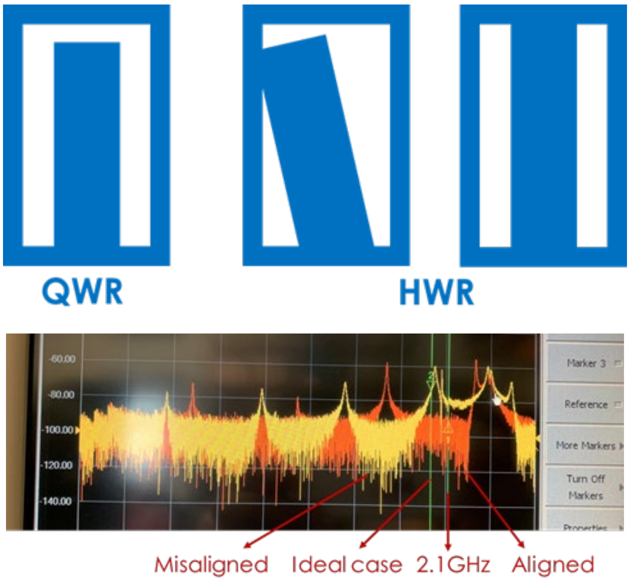

Figure 4: With tuner aligned, it is a QWR (top left); with tuner touches the port (top middle), it is equivalent to a HWR (top right); Bottom: measured resonances in the tuner, with x-axis frequency and y axis S_{21} in dB, with the tuner aligned (orange) and tilted to touch the center (yellow).

The new tuner design is shown in the right of Fig. 1. With this tuner, the cavity design, especially the tuner port, can be remain unchanged. Mechanical polishing was done to smooth the damaged surface of cavity tuner port, and the cavity was re-cleaned in cleanroom. The gap between the tuner and tuner port was enlarged from 1mm to 2.5 mm. A straight structure was used to eliminate the folded structure with screw-in treads. A more robust tuner drive that machined from solid aluminium block with dual precision machined guided rails and stainless-steel brackets is used. This tuner drive also has location indicators on both sides, and encoder and potentiometer are added. Port aligner was added right below the tuner port and was used to fine tune the tuner.

An aluminium tuner with different spacers that change the tuner length, together with an aluminium 2.1 GHz cavity, is used to test new tuner design. Two RF antennae were added on the six-way cube below the port aligner. We use the FPC and an antenna in the tuner to monitor the RF leakage into the tuner and use two antennae in the tuner to monitor the resonances in the tuner. By adjusting three screws on the port aligner, tuner tilting angles can be controlled. Results are shown in Fig. 5.

From the simulation, as well as the measurement, it is found that RF is not sensitive to transverse tilt, as long as the tuner does not touch the port. In the original design, the weight of the actuator makes it possible to tilt the tuner along the beampipe. In the new design, the actuator was rotated 90 degree, thus only possible to tilt transversely due to the tuner weight.

For the Cu cavity in the RHIC tunnel, to avoid scratching, the tuner was first installed and tuned using port aligner under the guidance geometric survey group so that the tuner is close to its geometric center. Then S_{21} from FPC to tuner antenna was used to fine tune the tuner to its RF center, and the output RF signals from tuner antennae are further used to monitor the RF leakage during operation. Please note the geometric center and RF center might not be close to each other due to possible assembling errors of the tuner housing, this was found in the LEReC 1.4 GHz cavity design, but even with this, the RF center based on minimizing the RF leakage from cavity to tuner is still a good indicator.

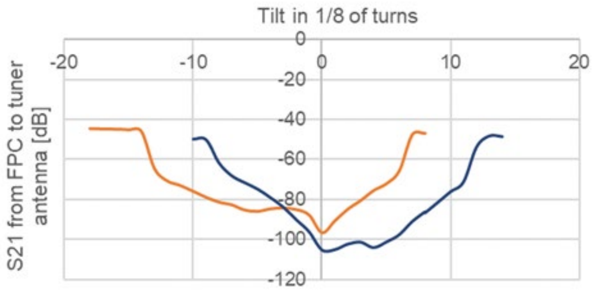

Figure 5: Tilting along the beampipe (in 1/8 of turns of the screws) versus S_{21} from FPC to tuner antenna in dB. Two curves are with different tuner lengths, and the S_{21} the lower the better.

The HOM induced voltage fluctuation was also simulated, the new design gives 0.65 kV fluctuation in the worst case. For comparison, the folded coaxial tuner design gives 0.67 kV fluctuation, see reference [3].

The 2.1 GHz cavity with straight tuner ran without the above-mentioned issues during RHIC run 2020.

CONCLUSION

A folded coaxial tuner without spring fingers was designed for LEReC 2.1 GHz warm cavity. This design caused misalignment between tuner and tuner port and caused operational difficulties in RHIC run 2019. A new straight coaxial tuner without spring fingers was designed and was proved to solve the issues in previous design in RHIC run 2020.

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