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DEVELOPMENT OF A MOVABLE PLUNGER TUNER FOR THE HIGH-POWER RF CAVITY FOR THE PEP-II B FACTORY*

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Abstract

A 10 cm diameter by 5 cm travel plunger tuner was developed for the PEP-II RF copper cavity system. The single cell cavity including the tuner is designed to operate up to 150 kW of dissipated RF power. Spring finger contacts to protect the bellows from RF power are specially placed 8.5 cm away from the inside wall of the cavity to avoid fundamental and higher order mode resonances. The spring fingers are made of dispersion-strengthened copper to accommodate relatively high heating. The design, alignment, testing and performance of the tuner is described.

INTRODUCTION

The PEP-II B-Factory uses 26 copper cavities which are designed to dissipate 150 kW of RF power at 476 MHz to produce a gap voltage of 1 MV each [1]. Beam currents of up to 3 A are anticipated causing excitation of higher order mode resonances.

A movable frequency tuner was developed for these cavities (Fig. 2) in form of a 9.2 cm diameter copper plunger which is used to compensate for temperature related frequency changes and beam caused reactive detuning. The total tuning range is mostly determined by the detuning of ± 340 kHz required to park pairs of cavities, when they are not energized. To cover these requirements a total tuner range of 1 MHz was specified which can be realized by a tuner movement from 2 cm outside the cavity wall to 3 cm penetration into the cavity (see Fig. 6).

The tuner uses bellows as a vacuum barrier to translate the tuner movement into the vacuum envelop and spring fingers are used to prevent fundamental and higher order mode RF currents from reaching the bellows.

Tests of the tuner assembly were performed in cavities operating at power levels below the design level of 150 kW because presently planned cavity operating levels for the PEP-II rings are lower.

TUNER DESIGN

The plunger design was optimized using a surface mesh model of the cavity and tuner created in the mechanical stress analysis code ANSYS [2]. This model was the basis for calculating the RF power dissipation using a Boundary-Integral Method Code developed at Chalk River Labs in Canada [3]. Once the power dissipation was established the ANSYS code could then predict temperature rise and stress and allow optimization of the plunger shape and cooling.

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The corner of the tuner plunger penetrating into the cavity is radiused to 1/2 inch to minimize current concentration (Fig. 2). The power dissipated in the tuner plunger for operation at 150 kW dissipation in the cavity was calculated to be 5.1 kW at full insertion into the cavity and 2.5 kW at the nominal insertion point. Average surface power dissipation on the flat part of the plunger at full insertion is 28 W/cm^2 with a peak of 36 W/cm^2 at the radius.

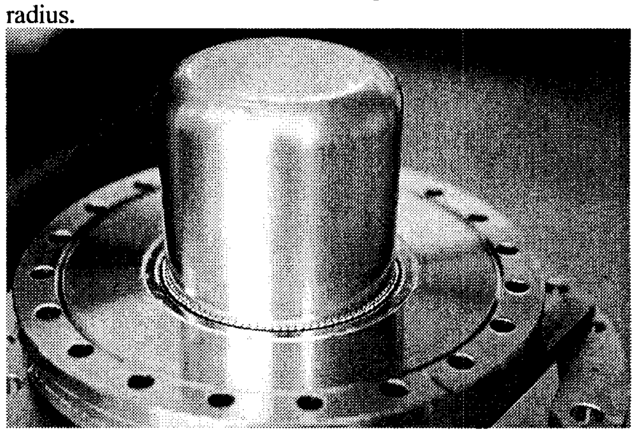

Figure 1: Tuner Assembly showing Plunger and Mounting Flange with Spring Fingers.

The gap between the tuner plunger and the tuner port was originally planned to be 1 mm to stay below multipactor threshold but was increased to 4 mm when it was found that alignment and arcing in the gap were a problem. Surface currents in the gap did not change significantly for the different gap widths as calculated by MAFIA [4] simulations.

The placement of the fingers is determined by two conflicting requirements:

1) The fingers should be placed far away from the high field area of the cavity to reduce fundamental mode currents and power dissipation. With only rapidly decaying evanescent waveguide modes launched into the gap between the tuner plunger and the tuner port of the cavity, placement of the spring fingers in the gap about 10 cm away from the cavity wall would make the dissipated power manageable.

2) The fingers should be placed in the tuner gap close to the cavity wall to avoid 1/4 or 3/4 wavelength resonances in the gap at the fundamental cavity resonance and higher order modes which can be excited by the multibunch beam. The lowest two longitudinal cavity modes at 750 MHz and at 1300 MHz are of particular concern since they are likely to be excited by the multi-bunch beam even though they are damped to a Q of 70 or 500 respectively by the higher-order-mode loading of the cavity. An optimum position for the fingers was determined to be 8.5 cm back from the cavity wall, placing

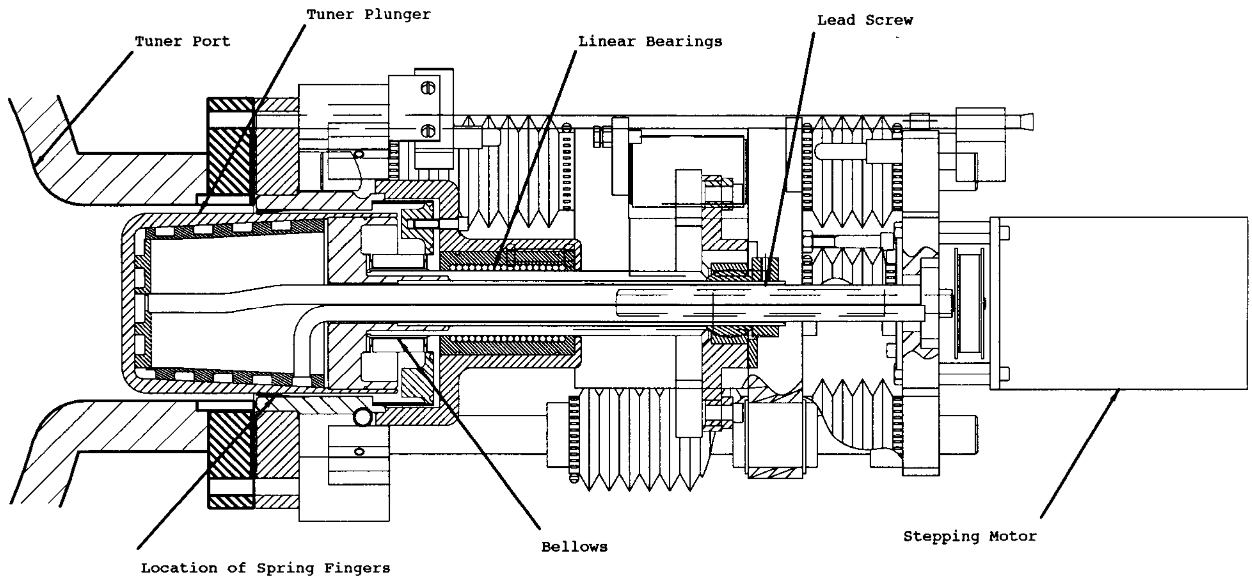

Figure 2. Tuner Cross-Section with Stepping Motor Drive.

the 1/4 wavelength resonance of the gap between these two higher order modes. The 1/4 wavelength resonance in the tuner gap was simulated with MAFIA to move with tuner position between 780 MHz and 1100 MHz.

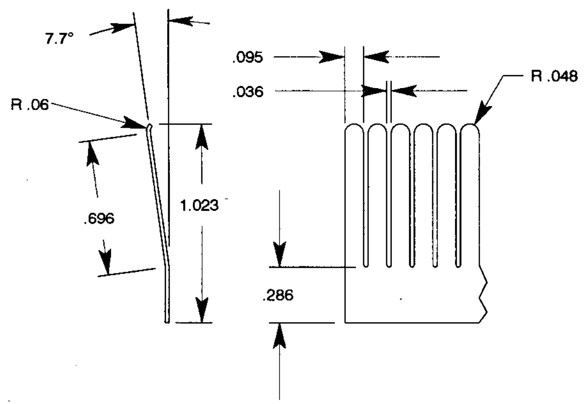

Figure 3. Spring finger Dimensions in Inches.

The 8.5 cm finger location was adopted with the fingers fixed to the tuner port flange (Fig. 4.). The fundamental mode wall currents in this finger position were calculated to 26.5 A/cm peak and the related power dissipation is 2 W/cm^2 for the tuner at a nominal position of 10 mm insertion and 150 kW power loss in the cavity. This relatively high power dissipation led to the design of spring fingers made of dispersion-strengthened copper or GlidCop® [5] after tests with beryllium copper alloy fingers had failed. The advantage of the GlidCop is its high thermal conductivity similar to that of copper compared to beryllium-copper alloys with 25% the conductivity of copper. The stress relaxation temperature for GlidCop is 350 °C compared to 150 °C for commercial beryllium copper alloy spring fingers.

SPRING FINGER DESIGN

GlidCop spring fingers were designed using the grade AL-25 (0.46% Al_2O_3). Since no fingers of this material were available commercially the fingers were fabricated by a photo-etching process and then bent to the right shape (Fig. 3). The GlidCop fingers are electron beam welded (Fig. 4) into the tuner flange which is used to mount the tuner onto the tuner port of the cavity.

Dissipation of the calculated RF power of 2 W/cm^2 would cause the tip of the fingers to experience a temperature rise of 40°C. Additional heating comes from the electrical resistance at the contact point which is not well known. To facilitate a good contact under ultra-high vacuum condition it was decided to silver plate the finger tips (0.0004 inch Ag) and plate the polished sliding surface on the tuner plunger with rhodium (0.0002 inch Rh). In order to assure good alignment and uniform contact pressure of 113 grams per finger it was necessary to use a linear bearing at the shaft of the tuner.

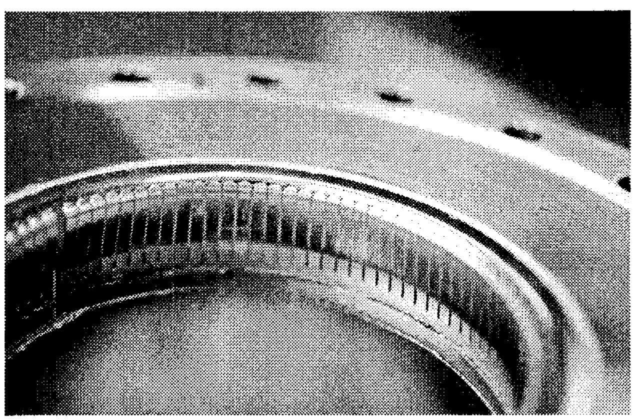

Figure 4. Spring Fingers as welded into Mounting Flange.

TUNER TEST RESULTS

The spring fingers were tested for mechanical life in a test fixture which in a vacuum of 4x10^{-7} Torr moves a flat sample of the fingers with the nominal contact pressure over a rhodium-plated plate. The test ran for 90,000 cycles with a stroke of 4 mm simulating the tuner movement associated with a beam fill one an hour over the period of

10 years. At the end of the test most of the silver plating on the finger contact area was transferred to the rhodium-plated surface, a result of normal contact wear (Fig. 5). Some small pieces of silver were actually broken off at later tests seen as glowing spots in the cavity. Overall the test shows that the fingers sliding on the hard rhodium surface can withstand the rigors of 24 cycles a day for a 10 year total life of the tuners.

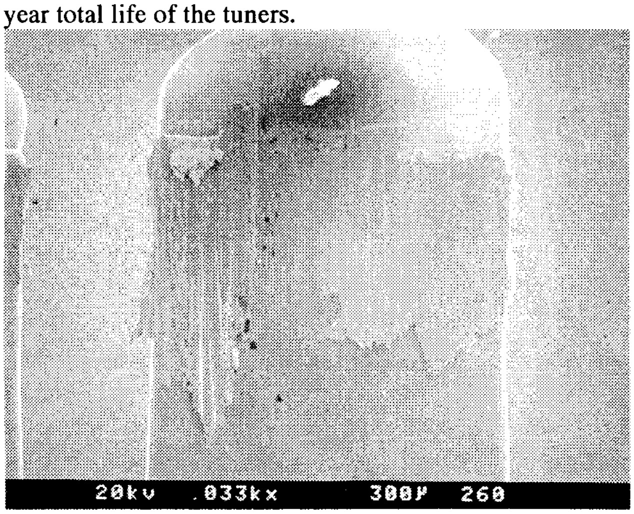

Figure 5. Electron microscope picture of spring finger contact area showing wear after 90,000 cycles on silver plating and silver chips.

The spring fingers were also tested as part of a prototype tuner in the RF environment of the prototype cavity and were operated at 120 kW cavity wall power, 20% above the highest power needed for the low energy ring. The source frequency was swept and a tuner feedback loop kept the cavity in tune forcing the tuner to follow the swept frequency. This test assembly operated successfully for 17,000 cycles over a stroke of 9 mm. Again the test showed that some small amount of silver had transferred from the fingers to the rhodium plated surface of the tuning plunger and some silver chips had separated. Although the test had to be terminated for reasons not related to the tuner it appears there was considerable life left on the spring finger contacts.

Tuners have since been installed and operated in 12 production cavities. Each cavity is processed in a test stand [6] up to the operating level of the high energy ring (85 kW wall dissipation) and several cavities have been processed higher to the low energy ring level (103 kW wall dissipation). The cavities are first processed in a pulse mode by sweeping the frequency of the source with a fixed tuner position and then reprocessed CW keeping the vacuum in the 10^{-8} Torr range. A video camera is trained on the tuner through a window on the opposite wall of the cavity. No arcing was observed but at 1 kW power level occasionally some glow from multipactor is seen. Another observable phenomenon is the bright glow of some silver chip removed from the spring fingers being heated up by the RF power. No deleterious effect of this glow was ever noticed. The measured power dissipation in the tuner plunger is 1.85 kW at nominal position and a cavity power of 85 kW. This indicates a 30% higher loss compared to the calculated plunger loss of 2,5 kW at nominal position and 150 kW wall dissipation. This increase in loss is partially attributed to the higher resistivity of the rhodium plating on the skirt of the copper plunger. The tuning curve for the tuner showing its range of 1.2 MHz is shown in figure 6.

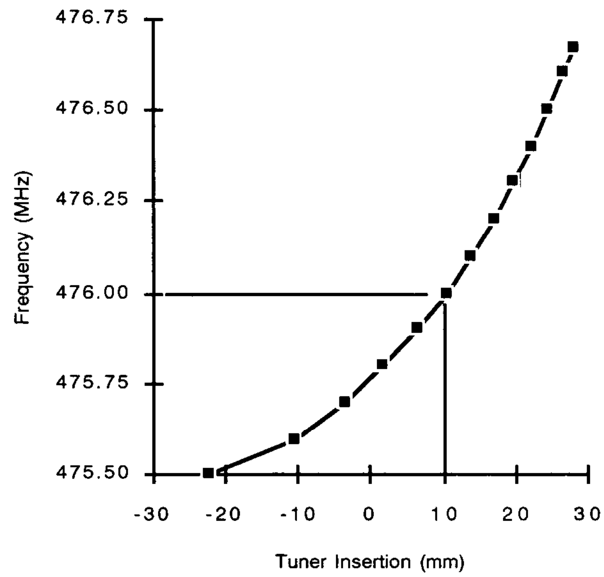

Figure 6. Cavity frequency versus tuner insertion.

CONCLUSION

A tuner plunger was developed which incorporates a rugged finger contact design capable of operating in the ultra high vacuum and high power environment of the PEP-II RF cavities. Many years of operation with tuner movements several times a day are predicted by the tests.

ACKNOWLEDGMENTS

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[3] "Cavity RF Mode Analysis Using a Boundary-Integral Method", M.S. de Jong, PAC93 proceedings, pp 835.

[4] MAFIA design code, available in US from AET Associates, Inc., 20370 Town Center Lane, Suite 260, Cupertino, CA 95014, tel: (408) 996-1760, fax: (408) 996-1962.

[5] GlidCop is a dispersion-strengthened copper alloy made by SCM Metal Products, Inc., Research Triangle Park, North Carolina, USA.

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