MECHANICAL DESIGN UPGRADE OF THE APS STORAGE RING RF CAVITY TUNER

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Abstract

The Advanced Photon Source (APS) storage ring (SR) rf system employs four banks of four spherical, single-cell resonant cavities. Each cavity is tuned by varying the cavity volume through insertion/retraction of a copper piston located at the circumference of the cavity and oriented perpendicular to the accelerator beam. During the commissioning of the APS SR, the tuners and cavity tuner ports were prone to extensive arcing and overheating. The existing tuners were modified to eliminate the problems, and two new, redesigned tuners were installed. In both cases marked improvements were obtained in the tuner mechanical performance. As measured by tuner piston and flange surface temperatures, tuner heating has been reduced by a factor of five in the new version. Redesign considerations discussed include tuner piston-to-housing alignment, tuner piston and housing materials and cooling configurations, and tuner piston sliding electrical contacts. The tuner redesign is also distinguished by a modular, more maintainable assembly.

1 INTRODUCTION

The APS SR rf cavity tuners have been redesigned to improve mechanical and vacuum performance while maintaining consistent rf performance. The tuner consists of a moveable piston that is inserted/retracted into the 352-MHz spherical cavity, thus changing the volume and the frequency of the resonant cavity. The approximate size of the components are as follows: the rf cavity radius is 13 inches, the tuner piston radius is 2.75 inches, and the overall length of the tuner is 25 inches. The piston, housing, electrical contacts, bellows, and drive have all been redesigned. The piston diameter and motorized drive performance have been maintained to allow consistent rf feedback and controls. Diagnostic thermocouples have been added to the tuner piston within the vacuum housing and to the exterior of the piston housing mounting flange to monitor tuner temperatures for interlock and performance logging purposes. Figure 1 is a section drawing of the tuner assembly highlighting major design features. The tuner piston is shown in the approximate cavity-tuned position.

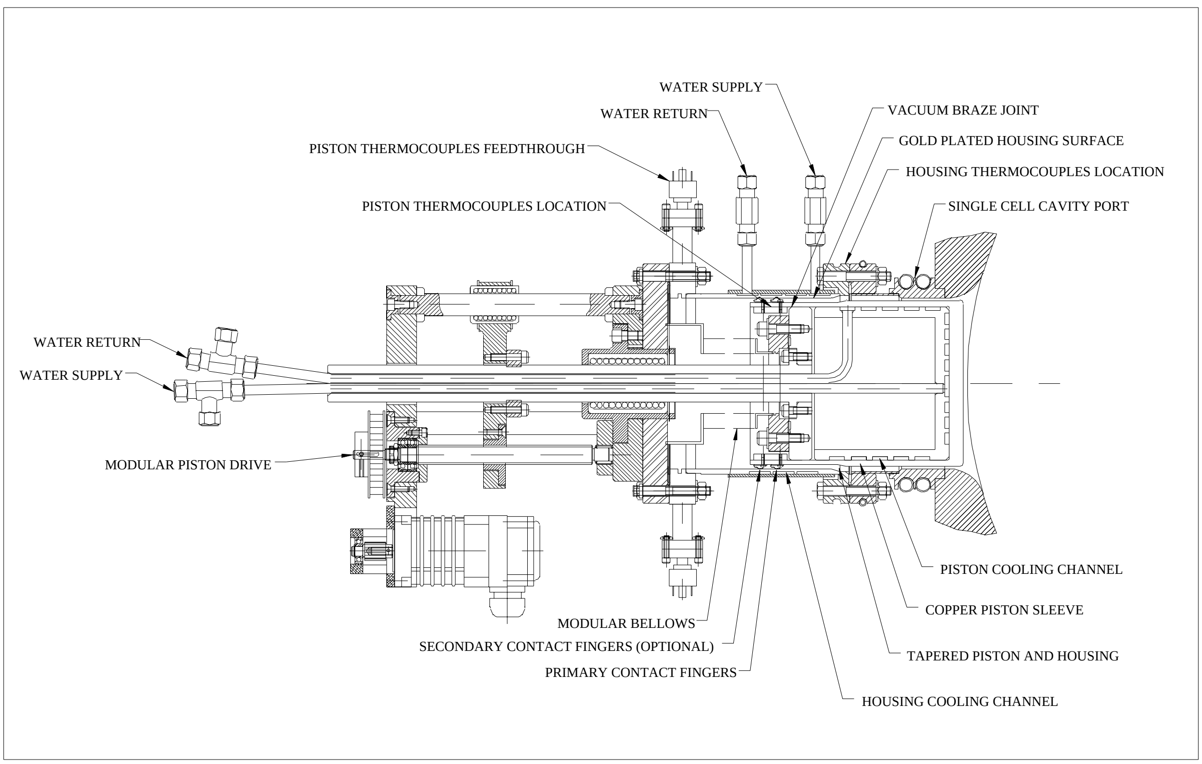

Figure 1: APS storage ring rf cavity tuner.

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2 TUNER DESIGN DISCUSSION

2.1 Tuner Piston

The tuner piston consists of a one-piece, oxygen-free, high-conductivity (OFHC) copper cylinder hollowed out to include water cooling channels. The water channel is a spiral at the base of the piston and a helix on the circumferential surface of the piston. The water flow inlet is at the center of the base of the piston; from there the water flows outward to the circumference of the piston and then upward toward the sliding electrical contacts. The coverage area of the water channels has been increased toward the electrical contacts to more effectively cool the piston and sliding contacts as described in section 2.3. The interior of the piston also includes the vacuum-to-air joint that consists of a standard Conflat-type flange joint (a policy of no vacuum-to-water joints has been maintained throughout the tuner assembly). One flange is brazed to the inner diameter of the piston, while the second flange is welded to a modular welded bellows. The piston itself is modular as the piston can be removed solely by unfastening the Conflat flange joint. In the current design only the copper sheath portion of the piston is exposed to cavity rf energy. All braze joints and stainless steel vacuum hardware is enclosed and protected. The piston is electrically shorted to the stainless steel vacuum housing via sliding electrical contacts. The contacts are attached to the piston with silver-plated stainless steel pan head screws. The screws are fastened to a tapped retaining ring inserted into the piston body. The retaining ring interlocks with the piston vacuum flange and additionally functions as a redundant attachment of the piston to the flange. All braze joints are made using a copper-gold braze material. Finally, the cylindrical copper surface of the piston sheath is coated with titanium by a vacuum vapor deposition process to reduce secondary emission of electrons and potentially eliminate the problem of multipactor.

2.2 Piston Housing

The piston housing functions as the tuner vacuum enclosure, the tuner-to-cavity mount, and the piston drive support. The housing is constructed as a 304 stainless steel tube within a tube welded to Conflat flanges at either end. The interior tube is machined with a helical cooling channel groove that is enclosed by the outer tube. The flange surfaces are carefully maintained perpendicular to the housing bore as critical piston-to-housing alignment and ultimately piston-to-cavity alignment is set by these flange positions. The interior of the housing is exposed to cavity rf fields and currents and is the running surface of the sliding electrical contacts. To optimize the performance of this surface both surface finish and surface composition have been considered. The surface should be as fine as possible and free of all circumferential cracks and protuberances. As such, the surfaces are mechanically polished to an 8-microinch finish and then electropolished to remove any remaining surface burrs and contaminants. The surface is then gold plated 0.0002-0.0005 inch thick to reduce electrical resistance and sliding contact friction.

2.3 Sliding Electrical Contacts

The sliding electrical contacts are attached to the upper portion of the piston outer diameter. The fingers electrically short the piston to the piston housing and protect the bellows from the cavity rf energy. The contacts are fabricated from 98% Cu-2% Be alloy spring finger stock [1]. The material is silver-plated 0.0002-0.0005 inch thick to reduce both surface and contact resistivities. Also, an additional 0.003 inch of silver is plated onto the sliding surface for contact lubrication. A primary goal of the improved cooling of the piston and housing is to reduce the operation temperature of the sliding contact fingers. Cooler finger temperature is expected to prolong the lifetime of the fingers by slowing elevated temperature annealing and thermal set. Reduced spring force will increase electrical contact resistance and finger heating. The linear stroke of the piston has been extended to allow inspection and replacement of the finger components without additional disassembly of the tuner. The design incorporates the location for an optional second set of contact fingers, but operational tests with only the primary set of fingers indicate that this redundancy is not necessary.

2.4 Modular Bellows

The linear motion of the tuner piston is accommodated by a welded bellows assembly. The bellows is modular, terminating to Conflat flanges by interior weld joints. A modular bellows was developed to both facilitate bellows replacement and avoid final assembly welding processes in the tuner assembly. Previous experience has shown that welding of the bellows assembly to the tuner piston shaft results in distortion of the shaft and a corresponding loss of control of the piston orientation and alignment. The bellows is cooled by circulating air over the surface of the bellows.

2.5 Tuner Drive

The tuner drive is a modular linear motion system that is capable of delivering three inches of travel. The drive is compactly nested within and attached to the bellows upper flange. All drive components are accurately machined to eliminate angular misalignment of the piston. The tuner piston is supported by a stainless steel shaft bolted directly to the piston vacuum flange. To ensure piston alignment, the final machining of the piston is performed relative to the attached, pin-located shaft. In the final assembly the piston is aligned to the housing bore such that the piston axis is colinear to the housing bore axis to within 0.010 in. The alignment is verified by employing a coordinate measuring machine. Drive motion is powered by a stepper motor turning a pulley, timing belt, pulley, and lead screw system.

2.6 Tuner Piston Mechanical Analysis

Cooling and stress analyses of the piston, electrical contact, and housing systems have been performed using the ANSYS finite element modeling system. The piston and housing water systems have been designed to accommodate the 150 psi cooling water system. Thermal analyses of the electrical contact fingers have demonstrated that with the one-piece, copper piston sheath construction the fingers operate at a temperature of 77^{o}C; the temperature rise is 50 percent of that of the original tuners.

2.7 Tuner Rf Analysis

Computer analysis of the electromagnetic properties of the rf cavity and tuner piston was performed to estimate electrical power dissipation for cooling system design. Analysis is based on the tuner piston-to-cavity port radial gap being set at 2 mm. The gap size was developed to support the piston-to-cavity port potential while minimizing finger contact heating. In the case of the piston aligned concentric to the cavity port, the power dissipated on the piston and housing surfaces is approximately 2 kW for a cavity input power of 100 kW. In the case of the piston misaligned to the housing and cavity port, the power dissipated in the tuner surfaces can increase to approximately 4 kW for a similar 100 kW of cavity input power; the power dissipated in the spring fingers also increases with the misalignment of the tuner piston. This result neglects the contribution of dissipated power due to arcing between the piston and the housing and/or cavity port. In fact, analysis shows that the maximum electrical field strength surpasses 1 MV/m when the piston is completely offset in the cavity port and arcing is a distinct possibility.

2.8 Tuner Diagnostics

The tuners were instrumented with K-type thermocouples attached to the piston inside the vacuum enclosure and attached to the housing flange circumference. In vacuum thermocouple wire is insulated with binderless fiberglass braid sleeving. The piston thermocouples are screw clamped to the interior of the piston opposite the sliding contact fingers. Exterior thermocouples are clamped to the tuner mounting flange. The redesigned tuner operating temperatures have consistently proven to be significantly lower than any of the original tuners that were modified to include thermocouple instrumentation. Typical temperature rises of 5^{o}C on piston temperatures and 15^{o}C on housing flange temperatures are, respectively, 20% and 50% of the temperature rises for properly functioning, original tuners. Two thermocouples are also installed on the air side of the bellows to indirectly monitor the performance and condition of the sliding electrical contact finger.

3 CONCLUSIONS

As discussed, significant improvements have been made to the SR rf cavity tuners. The one-piece piston sheath design, improved piston cooling, and piston alignment have reduced tuner operating temperatures by a factor of five. Additionally the maintainability was improved with the increased accessibility of the system.

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5 REFERENCE

[1] Instrument Specialties, Co., Inc., Delaware Water Gap, PA 18327-0136.