A THIRD-HARMONIC RF CAVITY FOR THE ADVANCED LIGHT SOURCE*

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Abstract

It is proposed to upgrade the Advanced Light Source by the addition of an RF system at the third-harmonic (1.5 GHz), of the existing system. With the new system it will be possible to control the bunch length and charge density profile independently of the RF bucket height, improving the Touschek-dominated beam lifetime. A third-harmonic cavity design is described which has good efficiency and is relatively simple to manufacture. The cavity shape is presented and issues of shunt impedance, power dissipation, higher-order modes, fabrication and installation are discussed. Design options for the cavity tuner and RF window are also considered.

1 INTRODUCTION

To a user of synchrotron radiation, the beam lifetime is one of the most important aspects of a synchrotron light source. In low to medium energy storage ring light sources, the lifetime is usually dominated by large-angle intrabeam (Touschek) scattering. This process is particularly important for storage rings such as the Advanced Light Source (ALS) because of the high density of electrons resulting from the small transverse beam size. One proven method for increasing the lifetime from Touschek effect without compromising the transverse beam brightness is to reduce the peak longitudinal charge density of an electron bunch using a higher harmonic RF system to modify shape of the RF bucket [1].

A higher harmonic cavity has several other benefits to machine operation. When the phase of the harmonic voltage is adjusted such that the bunch lengthens, there is an increase in the spread of synchrotron frequencies within the bunch. This spread can help in damping coherent instabilities such as the longitudinal coupled bunch instabilities through an effect known as Landau damping. For this reason, harmonic cavities are sometimes called "Landau" cavities. The decrease in peak current and synchrotron tune spread is also useful in raising the threshold for single bunch instabilities. This may allow higher single bunch currents than the current limit of about 20--25 mA/bunch. Another benefit is that the phase of the harmonic voltage can adjusted such that the bunch is shortened. This mode of operation may be of interest to a select group of users for whom lifetime is not the primary concern.

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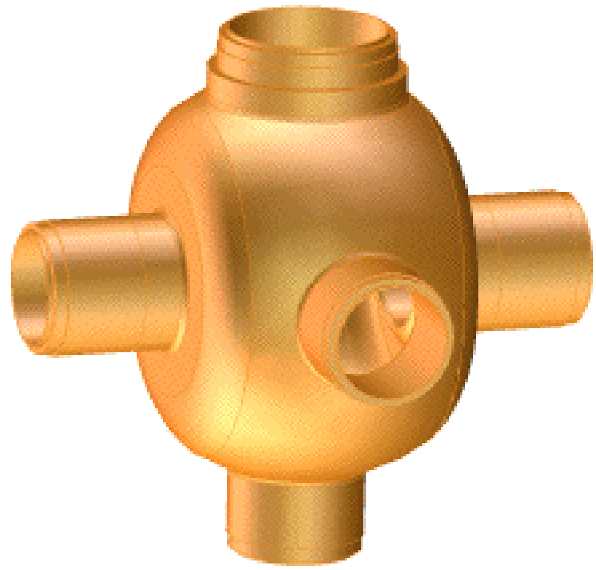

Figure 1. CAD model of 1.5 GHz cavity

2 RF DESIGN

The cavity shape is based on a conventional re-entrant profile but because of the high frequency and the large beam stay clear required, the beam-pipe diameter is a significant fraction of the cavity diameter, leading to some loss in shunt impedance. The use of nose cones and careful optimization of the cavity shape to maximize the shunt impedance result in a useful improvement over pill-box or bell-shaped designs with the same bore. This also minimizes the number of cavities required and the power dissipated per cavity. The parameters of the cavity are listed in table 1 (with the power requirements for a 4 cell active system). The center of the cavity body is made to be a section of a sphere, see figure 1, rather than the more common toroid, which greatly simplifies the machining of the port penetrations, which can be lathe turned rather than milled [2].

Table 1: Harmonic cavity system parameters

Frequency	1.5 GHz
total voltage	500 kV
bore diameter	5 cm
cavity R/Q*	80.4
calc. Q	27677
calc. Rs	2.23 MΩ
Rs x 70%	1.56 MΩ
number of cells	4
power per cell	5.01 kW

$^*R=V^2/2P$

The nosecone radius is chosen to keep the electric field enhancement to a reasonable level (5.3 x effective) and the peak field (8.3 MV/m) is well below the Kilpatric level (~34 MV/m at 1.5 GHz). The wall power density is within reasonable limits for 5 kW total dissipation (125 kV). There is about a factor of two increase where the wall current is concentrated around the port openings, see figure 2.

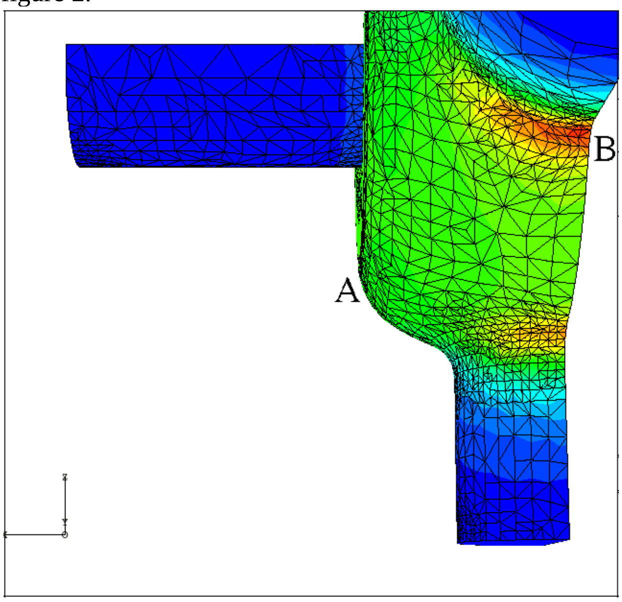

Figure 2. Wall power distribution calculated by Omega. Average body dissipation (A), Peak (B) ~ factor 2 higher.

3 MECHANICAL DESIGN

The design of the harmonic cavities employs many technologies developed for the 476 MHz PEP-II RF cavities [3], allowing rapid development of a robust design using tried and tested construction methods. The new spherical geometry allows the use of simple round ports and many common parts. This and other simplifications allowed the elimination of many parts and manufacturing steps to minimize the overall cost and fabrication time. There are six openings on the cavity: two beam ports in the end caps and four ports in the spherical body section (a tuner port, pick-up port, coupling port and a spare port which may be used for a fixed tuner). All of these except the coupling port are the same diameter and use the same flange. The coupling port is slightly larger and uses a larger flange but the manufacturing processes are similar. All of the ports and their interfaces with the body are simple figures of revolution and can be lathe turned. The inside and outside contours of the cavity can also be turned, with internal access through one of the end openings. The cooling passages will be N.C. milled, like the PEP-II cavities, but with much simpler programming. The cavity body will be made from OFE high conductivity copper except for the plating over the water passages which will use the so-called "brightened" copper, which has additives to improve the plating process, see figure 3.

4 FABRICATION

The center section of the body including the four round ports on the equator will be machined from a solid billet of copper. This will eliminate a number of joints and machining operations compared to an assembly fabricated from separate parts. The end caps will be machined from plate stock and are identical parts through most of the fabrication processes. Approximately 2 mm of stock will be left on all interior surfaces for the finish operations. The water passages are milled on the outside of all three parts. One end cap is then joined by e-beam welding to the body, which also has some excess material. After the weld the inner contour of the cavity is turned through the remaining opening to a finish of 24 µinch (0.6 µm) Ra or better. The other end cap is then put in place, the frequency is measured, and a final tuning cut can be made on the nose if necessary. Once the frequency is correct the second end cap is e-beam welded in place. Any frequency change from the final weld will be taken out by the tuner.

The beam-port extensions are e-beam welded to the end caps and the body is leak-checked. The body assembly is then sealed for the plating process. Plating wax is cast into the cooling channels and the surface is made conducting with silver powder and activated. A thick jacket of plated copper is grown over all of the channels in one operation. By using a brightened copper plating it is possible to eliminate the intermediate turning stage necessary for the pure copper jacket used on the PEP-II cavities. The separate brazed water channel covers used on the port assemblies of the PEP-II cavities can also be eliminated, reducing the number of parts and processes. Once plating is completed the wax is melted and flushed out of the channels. The e-beam joints are uncovered by machining through the plated layer to eliminate the

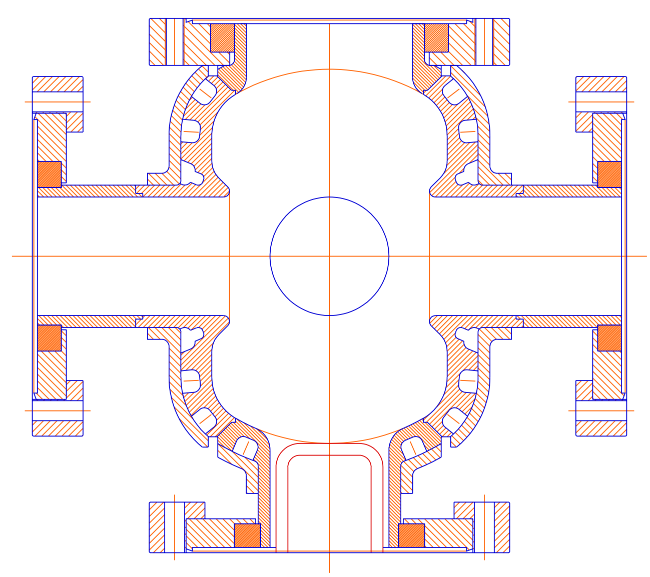

Figure 3. Cross section through the center of the cavity showing the cooling passages in the end caps and the spherical body section.

possibility of water leaks to vacuum. The passages are hydrostatically tested to 150 psi (1 MPa). The flanges are then attached by e-beam welding. These are standard stainless steel circular knife-edge flanges with copper inserts. The final process is to clean the inside of the cavity using a mild chromic acid bright dip. This removes any residue from the e-beam welding that may have condensed on the inside surface and improves the surface finish to 16 µinch (0.4 µm) Ra or better. The cavity is then blanked off and backfilled with dry nitrogen at atmospheric pressure for shipping.

5 TUNER

The tuner is a simple piston type operating from the bottom of the cavity with a commercial stepper-motor driven actuator. The dimensions are chosen so that the tuning range is adequate for all operating scenarios (300 kHz), and safe parking off resonance (750 kHz), while the smallest step size gives a tuning sensitivity of less than 2 kHz to maintain optimum lifetime within 1%. The piston will be water cooled and the length of the tuner and tuner port will be chosen to avoid harmful resonances that may cause heating of the bellows.

6 WINDOW AND COUPLER

The cavity can be operated in passive mode without an RF window, with the flange blanked off, but it is intended to use a window and coupler with an adjustable matching stub and external load which will allow adjustment of the cavity Q. This adjustment and the control of the cavity frequency with the tuner should allow the ideal cavity amplitude and phase to be maintained for a wide range of beam currents. The window and coupler will be designed to be compatible with an active (powered) system if such an upgrade is desirable in the future.

7 HOMS

Because of the large beam-pipe diameter there are relatively few HOMs trapped in the cavity below cut-off. The trapped modes are listed in table 2. The increase in Landau damping of longitudinal modes from the third harmonic system is expected to more than compensate for the additional impedance and is likely to significantly reduce the growth rate of coupled-bunch instabilities driven by HOMs in the main RF cavities. In the event that the harmonic system is not in use and/or it is suspected that a HOM in the harmonic cavity is driving an instability it can be detuned in several ways: using the movable tuner, changing the water temperature or with an additional fixed tuner, or its Q could be reduced by the addition of a damping antenna.

Table 2: Harmonic cavity HOMs

monopole	freq. (MHz)	Rs* (kΩ)
0-M-1	2248	874
0-E-2	3248	105
0-E-3	3683	173
0-M-2	4104	0.462
dipole		$R_\perp^\dagger$ MΩ/m
1-M-1	1941	0.754
1-E-1	2363	15.2
1-M-2	2882	35.3
1-E-2	3253	1.14

$^*Rs=V^2/2P$, $^\dagger R_\perp=R(r)/kr^2$

TM_{01} cut-off=4590 MHz, TE_{11} cut-off=3514 MHz

8 INSTALLATION

The harmonic cavities will be installed in part of one of the straight sections of the ALS, close to the existing RF system. This will simplify cabling, interlocks, water and controls which may be shared between the two systems. The harmonic cavities will be pre-assembled and aligned on a support raft along with tuners, couplers, pumps, masks etc., and will be baked out before installation. This should allow the assembly to be installed during a short shutdown, and to be commissioned expeditiously.

9 CONCLUSIONS

The harmonic cavity project should yield a substantial improvement in beam lifetime for the ALS user community. The adaptation of technology from the PEP-II RF cavity construction project has allowed the development of a robust, efficient and low-risk cavity design in a relatively short period of time and should allow fabrication to proceed equally quickly and at a reasonable cost.

10 ACKNOWLEDGMENTS

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REFERENCES

[1] "Beam dynamics in a double RF system", A. Hofmann and S. Myers, Proc. of the 11th Int. Conf. on High Energy Acc., ISR-TH-RF/80-26, 1980.

[2] "Notes from the RF cavity production close-out meeting, LLNL, 11/13/97", R. Rimmer et. al., PEP-II EE note 97.07.

[3] "Fabrication Processes for the PEP-II RF Cavities", R.M Franks et. al., PAC 97, Vancouver, B.C., Canada.