Impedance Measurements of Components for the ALS*

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Abstract

The high current and short bunch length of the ALS beam make the machine susceptible to beam instabilities over a frequency range extending to 13 GHz and beyond. All components of the storage ring have been carefully designed to minimize the impedance presented to the beam, and assemblies have been laid out to avoid resonant enclosures between components. Novel bellows shields allowing considerable mechanical movement while maintaining a low impedance are described. Results are presented of impedance measurements of ALS components and assemblies of components, using a precision coaxial wire technique in frequency domain, extending to frequencies beyond cut-off. All measurements were performed at the Lambertson Beam Electrodynamics Laboratory of the Center for Beam Physics at LBL.

I. INTRODUCTION

The ALS storage ring consists of twelve straight sections containing transitions from curved section to straight section aperture, bellows, vacuum valves, injection equipment, RF cavities, feedback equipment and transitions into the insertion device apertures. The design current is 400 mA in 250 bunches (there is a gap of 78 RF buckets for ion clearing) in multibunch mode, and 7 mA per bunch in single bunch or few-bunch mode With a natural bunch length of 12 ps (sigma) the significant frequency content of the bunches extends to approximately 13 GHz, and such high currents over a broad frequency spectrum lead to concerns about multi-bunch and single bunch instabilities, and heating of vacuum vessel components by the beam.

In order to minimize the impedance of vacuum vessel components in the ALS, the designs of all transition sections and devices in the vacuum vessel have been carefully developed to minimize the beam impedance. Impedance measurements of components have been made during the engineering design process, using the coaxial wire method.

II. IMPEDANCE MEASUREMENT METHOD

Using the coaxial wire method a thin wire is placed along the beam path through the device under test, supported by styrofoam guides [1]. Fields at the surrounding wall induced by the currents carried by the wire are assumed to be equivalent to those of a relativistic beam. Tapers from 50 Ω cables transform into the higher impedance of the test setup to minimize reflections of the TEM waves over the frequency range of interest.

Unlike the TEM waves, travelling waveguide modes can reflect off the tapers, and in order to minimize these reflections absorptive material (Emerson & Cuming Eccosorb AN73) is placed on the walls of the transition tapers. Although attenuating the TEM signal as well as the unwanted TM waveguide modes, this can be accommodated by the dynamic range of modern network analyzers.

A normalizing measurement through a smooth reference pipe allows the calculation of beam impedance Z_b from the characteristic impedance of the device Z_l and the measured S_{21}:

$$Z_b = 2\, Z_l \left(\frac{S_{21,\text{reference}}}{S_{21,\text{ object}}} - 1 \right)$$

III. FLEXIBLE RF BELLOWS SHIELDS

A. Description

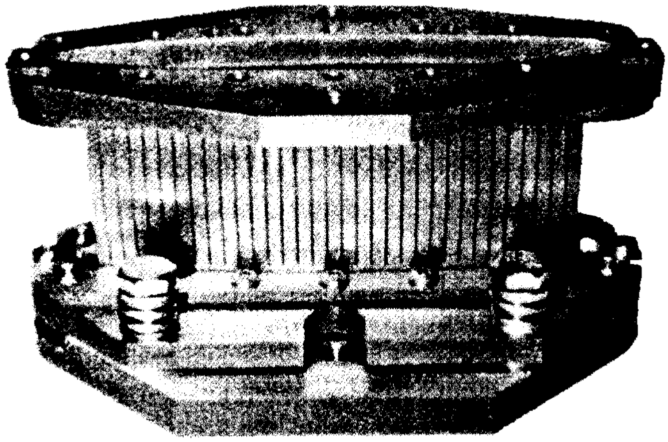
Bellows sections are located at either end of the straight sections, to allow for movement due to thermal expansion during normal operations and during bakeout of the vacuum vessels. To minimize the beam impedance the cross section of the adjacent beam tube is extended across the bellows by an RF shield as shown in figure 1. This consists of flexible strips, that can be seen, and spring fingers between the flanges at one end. The strips are of beryllium copper foil 0.003 inch thick with longitudinal slits to allow bowing without damage. This bowing accommodates the 5 - 10 mm compression of the bellows during bakeout. During normal operations the bowed shape must be avoided because it would support resonant modes excited by the beam. This is achieved by a spring arrangement which maintains the strips in tension up to a temperature of 29°C. The normal operating temperature of the chamber is 24°C ± 1°C, with an expected movement of approximately 0.1 mm. This small movement is absorbed by the spring fingers.

The beryllium copper foil section does not have strips at the horizontal extremes to avoid interference with the bellows during contraction. This does not deteriorate the impedance properties since there is little image current in this region.

*This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

0-7803-1203-1/93$03.00 © 1993 IEEE

Figure 1. Elliptical section bellows shield.

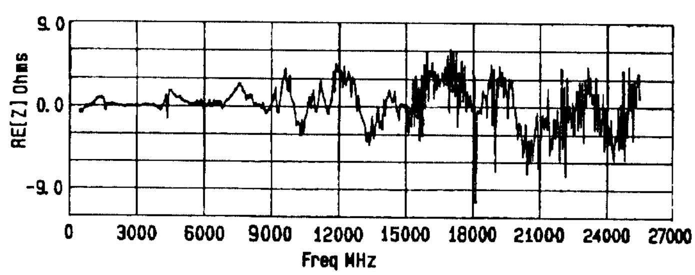


If the chamber cools to 17°C the spring fingers will lose contact and the impedance will increase due to the gap created, however this is significantly below the nominal operating temperature and is not likely to occur.

B. Measurements

Impedance measurements of the RF shield have been made in frequency domain up to 26 GHz, using the coaxial wire method. A number of small resonances have been observed, and a typical impedance measurement result is shown in figure 2, all are below 5 Ω shunt impedance and of low Q values. The corresponding Z/n values are less than 1 mΩ. Cut-off occurs at 9 GHz for the TM modes. Above approximately 15 GHz the uncertainty in the measurement becomes appreciably worse, with reproducibility of the order of ± 10 Ω.

Figure 2. Impedance measurement of bellows shield.



Summing the loss parameters for the measured resonances below 13 GHz we have

$$k = \sum_i \frac{\omega_i}{2}\left(\frac{R}{Q}\right)_i e^{-(\omega_i\sigma)^2} = 0.03 \text{ V pC}^{-1}$$

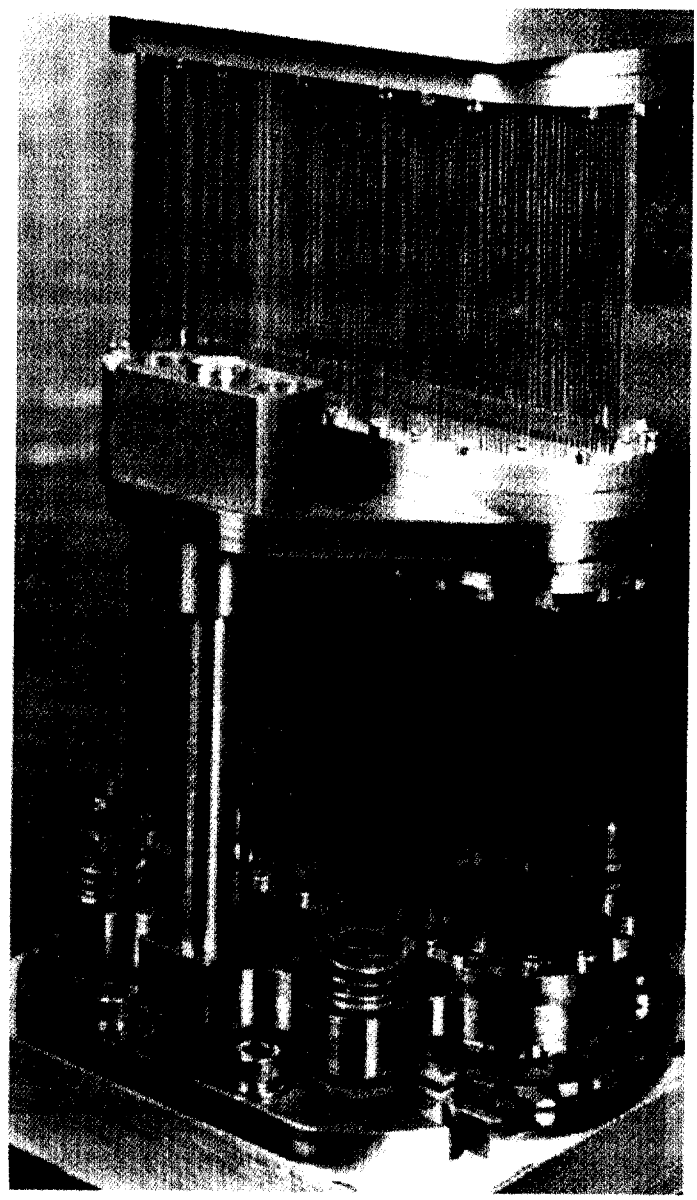
The strength of these resonant modes increased rapidly with compression of the shield, leading to a criterion of 1 mm maximum deviation from flat (i.e. bowing) during operation with beam.

IV. FLEXIBLE SECTIONS FOR TRANSVERSE DISPLACEMENT

A. Description

The injection straight is moveable in the transverse direction to allow optimization of the injection process by moving the the injection septum relative to the closed orbit. This movement is permitted by bellows sections at the ends of the straight. In this case the bellows shield must also be free to move transversely, with one flange allowed to be displaced with respect to the other.

Figure 3. Flexible cage and bellows shield assembly.



To accommodate this motion a cage of wires was built which maintains the racetrack cross-section of the injection straight and has sufficient flexibility to accommodate a transverse displacement of ± 10 mm of one flange with respect to the other. Figure 3 shows the cage, in an assembly including the foil and spring finger sections which allow for longitudinal motion and are similar to those described above. As the cage is displaced, the longitudinal movement is accommodated in a double set of spring fingers designed to accommodate the additional longitudinal motion required in this section.

B. Measurements

Measurements of the cage section with displaced ends were complicated by length changes in the apparatus, but showed the generation of resonant modes as one end was displaced. As the cage is displaced a pair of modes are observed around 2.4 GHz, with impedance < 20 Ω at 4.75 mm offset, corresponding to Z/n < 12.5 mΩ. The total loss parameter for these modes is 0.003 V pC^{-1}.

V. TRANSITIONS, VACUUM VALVES AND SUB-ASSEMBLY OF COMPONENTS

Transitions between vacuum vessels of different cross-section occur predominantly at the ends of the straight sections, since the curved vessels and the major part of the straight sections are made from single pieces of aluminum and have uniform beam apertures. Measurements of the curved sector tank impedance are described in [2]. From the curved vessel to the straight section the beam aperture transforms from a diamond shape to an ellipse, over a distance of approximately 50 mm. With the future installation of insertion devices some further transitions will be introduced to accommodate a more reduced vertical aperture.

Vacuum valves with RF shields have been used at both ends of all straight sections. These valves have metal foil inserts which bridge the gap between the valve flanges to provide a smooth, continuous path for beam induced wall currents when the valve is open. Visual inspections indicated considerable variations in quality from valve to valve, with the RF shield being bowed, and/or a step of up to a millimeter between the shield and the body of the valve in some cases. Measurements were performed on a typical valve, indicating few resonances, however all valves were visually inspected and the worst cases were corrected by adjusting the foil to reduce bowing and displacements of the RF shield.

An assembly consisting of a transition from a diamond shape to an ellipse, an elliptical bellows shield, a dummy vacuum valve, and a second elliptical bellows shield was measured. In addition to the effects of the bellows shields a broad resonance centered at 13 GHz was observed, shunt impedance 15 Ω and Q value approximately 8. For this mode the loss parameter k is 0.03 V pC^{-1}.

VI. INJECTION BUMP MAGNETS

Ceramic vacuum vessels are used in the injection bump magnets to allow penetration of the pulsed magnetic field. The inside surface of the tubes is coated with a thin layer of titanium to allow passage of the beam image current. The metallization is arranged in strips to minimize perturbations of the pulsed magnetic field while reducing the beam impedance. The impedance of this device is expected to peak at low frequencies, due to resonant effects in the arrangement of metallized strips. A low frequency impedance measurement was made using a coaxial wire resistively matched to 50 Ω at the ends.

Measurements show broad resonances at 50 MHz and 190 MHz as predicted [3], with impedance < 20 Ω.

VII. RF CAVITIES

Measurements of the RF cavity modes have been made using a spare cavity, with higher order mode damping filters in the feeder waveguide, as described elsewhere [4]. The strongest higher order longitudinal mode has a measured shunt impedance of 1.05 MΩ, with other modes less than 33 kΩ. The sum of loss parameters for the longitudinal modes below cutoff frequency of the beam pipe (3.3 GHz) is 0.40 V pC^{-1}. By equating this loss parameter to that of a single Q=1 resonator centered at the beam pipe cut-off frequency gives a shunt impedance of 40 Ω, and a corresponding estimate of Z/n = 18 mΩ per cavity.

VIII. ACKNOWLEDGEMENTS

Thanks are due to J. Menenghetti for conceiving and developing the flexible bellows shields, to T. Henderson and K. Kennedy, and to G. Lambertson for helpful advice on all impedance issues.

IX. REFERENCES

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