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THE DESIGN OF A SINGLE-CAVITY HARMONIC BUNCHER FOR ARGONNE'S LOW-BETA HEAVY-ION LINAC*

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Summary

In order to increase the beam capture efficiency of Argonne's heavy-ion linac to over 70%, a single cavity harmonic buncher has been designed as a replacement for the existing fundamental frequency buncher. Because the beam line space between the 1.5-MeV Xe^{+1} preaccelerator and first accelerating cavity is at a premium, especially in the tunnel area near the preaccelerator, a single-cavity design was undertaken. In addition, to further conserve access space, the cavity was designed to fit directly beneath the beam line. The cavity is designed to resonate at the fundamental linac frequency of 12.5 MHz and its first harmonic, 25 MHz. This was accomplished by nesting the 25-MHz resonant section inside the larger 12.5-MHz resonant section. Both sections are heavily capacitively loaded, folded coaxial lines with two 0.008-m accelerating gaps per section. The cavity was designed using a transmission line model taking account of the capacitances of each discontinuity and by use of the RF cavity computer program "Superfish."[1] The transit time factor for the cavity gaps was calculated using the computer program "Poisson"[2] and are 0.44 for the 25-MHz section and 0.70 for the 12.5-MHz section. The transit time factors are "poor" because of the large linac aperture of 0.049 m.

Introduction

Argonne National Laboratory (ANL) is currently developing the injector of a heavy ion beam driver for the inertial confinement fusion program. The first phase of the program is to accelerate about 25 mA of Xe^{+1} from a 1.5 MeV preaccelerator to 8.84 MeV in a low beta RF linac. There are plans to eventually reach 220 MeV. The first section of the linac utilizes independently-phased short linac resonators with a FODO focusing lattice. These are to be followed by a double-stub Wideroe linac to reach 8.84 MeV. Three (of a required five) independently-phased cavities, as well as a single cavity buncher at 12.5 MHz, have been installed and tested with beam.[3]

There are two problems associated with the use of a single cavity buncher. First, a single cavity buncher has a bunching efficiency of at best only 66% without considering space charge effects.[4] Space charge effects with large currents will further reduce the efficiency to about 50%.[5] Second, a single cavity buncher does not fill the longitudinal emittance of the linac uniformly. On the other hand, a harmonic buncher will have a bunching efficiency of 70% even when space charge effects are considered and fills the longitudinal emittance more uniformly.[6] However, the harmonic buncher will take up more space in an already crowded beam line.

Harmonic Buncher Resonator Design

Because of the lack of ceiling height in the tunnel and a desire to preserve access space to the sides, the harmonic buncher cavity has been designed to fit vertically below the beam line. This requirement restricts the maximum cavity height to about 1.6 m to beam line center. Since the resonant sections are designed as quarter-wave coaxial resonators, they will require heavy capacitive loading to fit in this space.

A drawing of the cavity is shown in Fig. 1. The center section containing the two inside gaps is designed to resonate at 25 MHz. The gaps are designed to be 3 π apart in phase at 25 MHz. The top section containing the gaps is designed using a 0.149 m ID copper tube which forms a 106 Ω coaxial line with the center 0.025 m OD copper tube. The lower portion of the cavity is designed using a 0.114 m ID copper tube and forms a 77 Ω coaxial line with its center conductor The capacitance is provided by the open copper cylinder attached to the stem of the drift tube. At the bottom is an adjustable short to tune the section to resonance. Contact pressure for the shorting fingers is provided on the inside by a hose clamp and to the outside by a specially designed "outside" type hose clamp. Also at the bottom are provisions for a RF power coupling loop, fine tuning ball, and RF pickup loop. The center conductor of the section is provided with water cooling. The maximum length of the section from beam center line to short is 1.55 m which allows about 0.05 m for bottom vacuum flange and water connectors.

The section of the cavity containing the two outside gaps is designed to resonate at 12.5 MHz. The gaps are designed to be 3 π apart in phase at 12.5 MHz. The top section containing the gaps is designed using a 0.211 m ID copper tube which forms an 18.35 Ω line with its 0.156 m OD copper center conductor. The center conductor is open at the top. However, it is long enough so that it is cutoff for both 12.5 and 25 MHz. The capacitance as well as a large fraction of the inductance of the resonant section is provided by the open cylinder which forms a 2.98 Ω line with the 0.387 m ID outside copper cylinder. The 0.127 m.OD center conducter forms a 66.9 Ω line with the outside cylinder and a 62.3 Ω line with the inside open cylinder. It also provides a part of the inductance of the resonant section. At the bottom is an adjustable short for tuning the section. Contact pressure for the shorting fingers is provided by inside and "outside" type hose clamps. Also, at the bottom are provisions for a RF power coupling loop, fine tuning ball, pickup loop and vacuum monitor. The maximum length of the section is 1.28 m from beam center line to short. It is foreshortened because of the access space requirements of the 25 MHz section.

A model of an earlier version of the cavity was constructed using stocked large sized aluminum and copper pipe to confirm transit time factor and study field penetration into adjacent resonant sections. This model had a π drift space between gaps and a calculated transit time factor of 0.35 at 25 MHz. A bead pulling measurement confirmed the lack of field penetration and calculated transit time factor. Subsequently, bunching efficiency studies have led to the present 3 π drift space cavity design.

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Design Method

Two methods were used to design the cavity and calculate its properties. The first used a transmission line model accounting for the fringing capacitance of each discontinuity in the line.[7] The second used the RF cavity computer program "Superfish."

In using the transmission line method each part of the resonant section with different inner to outer diameter ratios was modeled as a coaxial line with characteristic impedance, $Z_0 = 60 \ln (D_{od}/D_{id})$. The gaps were represented as the sum of their gap capacitance and fringing capacitance. The impedance of the gap (open end) was transformed to shorted end by the ideal transmission line equation.[7]

$$Z_{input}/Z_0 = \frac{Z_{load} + j\,Z_0 \operatorname{Tan} \beta d}{Z_0 + j\,Z_{load} \operatorname{Tan} \beta d}$$

where d is the length of each uniform impedance section and β is 2π/wavelength. At each geometric line change the fringing capacitance was calculated and added in parallel to the above to form the Z_{load} of the next section. This process was continued until the short was reached (the resonant condition).

The second method using "Superfish" required that an irregular triangular mesh be generated. The difference equations for axisymmetric fields were solved using a direct noniterative method. Resonance frequencies, fields and other quantities were found for the fundamental as well as higher modes for complex geometries as shown in Figs. 2 and 3. Figures 2 and 3 are slightly enlarged for greater clarity and are of the earlier version of the cavity (π drift space). The transmission line model and "Superfish" are in agreement to within 1%. The resonant sections were studied separately. The results for the 12.5 MHz section are shown.

Transit time factors for the cavity gaps were calculated from the electrostatic field distribution found by using the computer program POISSON. These results agreed with the calculations of the computer program WIDEROE.[8]

For a drift space of 3.64 m between buncher and first linac cavity, bunching voltages of 20.4 kV/gap and 16.22 kV/gap are required for maximum efficiency at 12.5 MHz and 25 MHz, respectively. The power requirements using the above transmission line model are 3.5 kW at 12.5 MHz and 1.4 kW at 25 MHz.

Conclusion

A compact harmonic buncher cavity has been designed for Argonne's low beta Xe^{+1} linac. The resonant sections are nested together to save beam line space. The cavity is approximately 1.5 m in height and at its maximum 0.4 m in outside diameter. It takes up only 0.22 m of beam line space. The computer program "Superfish" and a transmission line model of the resonator were used to calculate its properties. Considering the complicated geometry, excellent agreement (within 1%) was achieved.

Acknowledgement

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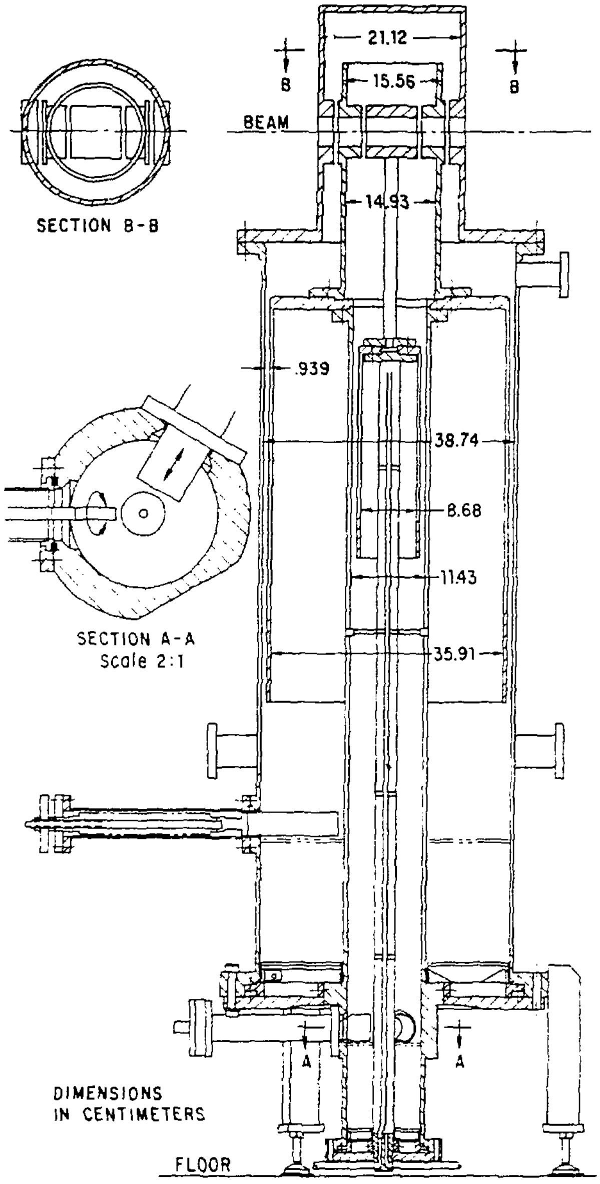

Fig. 1 Drawing of Harmonic Buncher Cavity

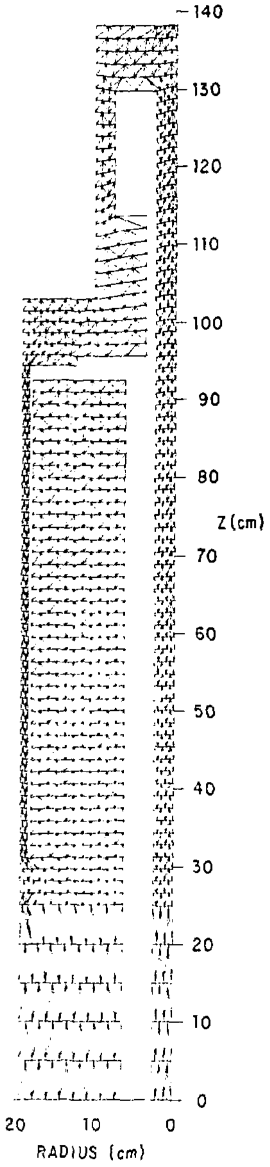

Fig. 2

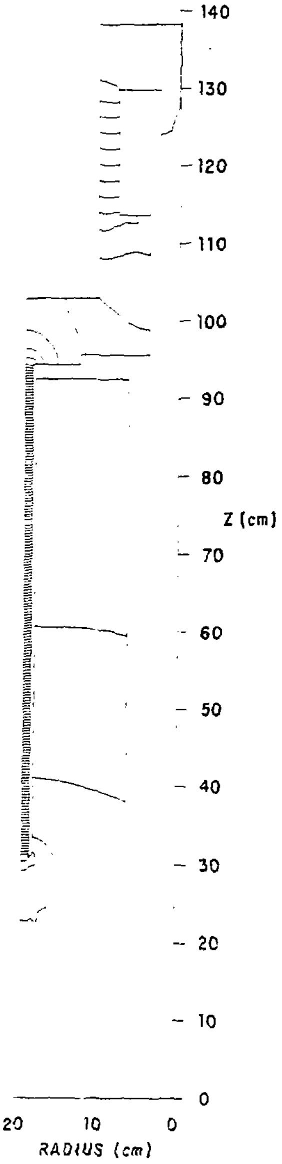

Fig. 3

Fig. 2 12.5 MHz Section Triangular Mesh

Fig. 3 12.5 MHz Section Electric Field Plot