A single-cavity buncher has been developed that resonates at both the fundamental and twice the fundamental frequency to form a nearly ideal bunching voltage waveform in the gap. The cavity utilizes the TM020-like mode as the first harmonic of the fundamental TM010-like mode. Field distributions on or near the axis, which are seen by the beam, are essentially identical for the two modes. Many beam bunching applications require two buncher cavities with the harmonic buncher being physically as close as possible to the fundamental frequency buncher - the buncher described here accomplishes this property with a single cavity and excitation of two modes. Calculated parameters for cavity designs with a fundamental frequency of 0.45 GHz are presented for different cavity lengths which represent a range of interest for accelerators and rf tubes. Means of tuning and fabrication are described. A geometry chosen for PIGMI is described in more detail.

Cavity Geometry

The ratio of the TM020 and TM010 mode frequencies in a right circular cylinder is 2.1. Only small changes in the geometry should be required to make this ratio exactly two. However, for the buncher cavity to have a reasonably high effective shunt impedance, ZT2, and to be of suitable length, a drift tube nose is required close to the beam axis. After studying various geometries, the one shown in Fig. 1 was selected. The radius at which the outer protrusion (with gap g2) ends was found optimum at 0.6 R. This radius produces a maximum frequency shift as a function of g2 for the TM020-like mode while the TM010-like mode experiences an almost maximum frequency shift of the opposite sign. A 30" drift tube nose was selected to improve rf efficiency. For a 0.45 - 0.9 GHz cavity, R1 was 0.15 cm.

Calculations with a representative cavity gave the following fractional frequency shifts of the (TM010, TM020) modes for the variables shown in Fig. 1.

\[ \frac{f_{g2} - f_{g1}}{f_R} = (-0.2, 0.1) \]
\[ \frac{f_{g2} - f_{g1}}{f_R} = (-1, -1) \]
\[ \frac{f_{g2} - f_{g1}}{f_R} = (0.1, 0.1) \]
\[ \frac{f_{g2} - f_{g1}}{f_R} = (-0.1, -0.1) \]

For half cavity length, l, with beam bore hole, R1, and gap, g1, changes to the outer cavity radius, R2, and g2 produce the required resonance conditions.

Calculations

Tables 1 to 4 summarize some of the calculated results for different buncher geometries. A large range of geometries can be selected for the electron beam case, whereas choices are limited for low beta proton beams. Large L geometries do not have transit time factors listed for low beta proton beams because rf fields change sign as the proton beam traverses the cavity. Small R2 and L are desirable for low beta proton beams. Different ratios of ZT2 between the TM010-like and TM020-like mode can be selected for different applications by inspection of the tables.

Geometrical parameters listed in the first few columns of the tables are defined in Fig. 1. Results of calculations for the rf properties are found in the last eight columns. The first four rf properties are resonant frequency in GHz, quality factor, Q, for the mode, shunt impedance, Z, in W, and the ratio between the maximum electric field on the cavity metal surface to the average on-axis electric field, Esurf/E avg. Transtime factors given in the last four columns for particle beta of 0.0231, 0.04, 0.332 and 0.741 were determined using the calculated on-axis electric field distribution. ZL for a particular velocity particle can be determined using the sixth last column with a transit time factor, T, from one of the last four columns. For example, to impart 16 keV at 0.2 GHz and 4 keV at 0.4 GHz to a 750 keV de proton beam, peak powers of 319 and 29 watts, respectively, are required for a buncher with dimensions scaled from those given for L = 2 cm, R1 = 0.25 cm and g1 = 0.08 cm in Table 3. The buncher would have a 1.13 cm beam bore hole diameter and would be 114 cm in overall diameter.

R1 and g2/L are plotted as a function of g1/L in Fig. 2 for various L and R1 combinations of an 0.45 - 0.9 GHz buncher. Figure 2 can be used to specify geometries not listed in the table by interpolation between the curves. A survey calculation showed that an axially symmetric mode at three times or at four times the fundamental frequency could not be excited for the geometries studied, hence these geometries are limited to double frequency operation. Electric field distributions for the TM010 and TM020 modes of an L = 8 cm, R1 = 1 cm and g1 = 2 cm cavity are shown in Fig. 3.

While converging to the geometry with desired frequencies by adjusting g1 and R2 for subsequent SUPERFISH calculations, fractional frequency shifts \( \frac{f_{g2}}{f_{g1}} \) and \( \frac{f_{g2}}{f_{g1}} \) were (-0.221, 0.6877) and (-0.939, -0.879), respectively, for the (TM010, TM020) modes.

*Visitor from Chalk River Nuclear Laboratories, Chalk River, Ont., Canada, K0J 1J0
A double-frequency aluminum buncher has been built for a Pion Generator for Medical Irradiation (PIGMI) being prototyped at LASL, using a geometry similar to that given in Table 3. Figure 4 illustrates the geometry selected and field distributions for the two modes. The buncher is symmetrically loaded near the beam prototyped at L&L, using a geometry similar to geometric selection and field distributions for the two modes. For a Pion Generator for Medical Irradiation (PIGMI), designed to bunch a 250 keV proton beam in an 80 cm drift distance. This requirement corresponds to a peak energy gain of 2.2 keV from the fundamental mode and 0.8 keV from the second harmonic mode. With proper phasing between the two modes, the resultant rf wave will be almost linear over 220 degrees of phase space. Table 5 lists relevant parameters for the PIGMI buncher.

Transit time factors were evaluated using the on-axis electric field distribution. Average rf powers were based on one percent duty factor.

The buncher design shown in Fig. 4 incorporated a pair of vanes for fine tuning. Each 2 cm wide vane is mounted on a radial rod that can be rotated for tuning purposes. - the two vanes are strategically located to perturb the two modes differently. The lower or inner vane is centered at the TM010-like mode electric field minimum. Rotation of this vane out of the buncher plane increases the TM010-like mode frequency. The upper or outer vane is located to have virtually no effect on the TM010-like mode frequency. Rotation of this vane out of the buncher plane lowers the TM010-like mode frequency. Perturbations from the vanes were studied using SUPERFISH - the mid-range position is illustrated in Fig. 4.

Table 3

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<th>Frequency (MHz)</th>
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<th>E3 (kV/m)</th>
<th>E4 (kV/m)</th>
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Table 4

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<th>Frequency (MHz)</th>
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Discussion and Conclusions

A family of geometries has been determined for single-cavity double-frequency bunchers. Based on particular applications, the data presented can be used to select an optimum geometry. Having two modes excited in the same cavity with virtually identical rf fields in the beam bore hole is a novel method for producing a double bunching scheme. Besides saving space on the beam line, the single cavity reduces fabrication.

A single-cavity double-frequency buncher has been built for PIGMI. Performance of the buncher with beam and high power from will be determined shortly. Since the cavity can be excited exactly at twice the fundamental frequency, precautions have to be taken to isolate the rf drive properly from the resonant load.

An accelerating structure could be made from a chain of rf cavities using geometries determined for the single-cavity buncher. RF coupling between the cavities could be done on the web with slots located between 0.6 R and the drift tube nose. The structure could then be operated as a "harmonic accelerator" with a fundamental mode frequency and a harmonic at twice the fundamental. With proper amplitude and phase control the rf accelerating wave could be linearized over a large range.

References

Fig. 1. Cavity geometry selected for the single-cavity double-frequency buncher. (One-quarter section of cavity.)

Fig. 3. Electric field distribution for a single-cavity double-frequency buncher with L = 8 cm, R_H = 1 cm and g_1 = 2 cm.

Fig. 2. Outer cavity radius, R_C, and g_2/L as a function of g_1/L for various L and R_H combinations.

Fig. 4. Double-frequency buncher for PIGMI showing tuning vane locations and field distributions for the two modes with the vanes simulated by cylindrically symmetric perturbations.