Multi-Harmonic Impulse Cavity*

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Abstract

A method that may enable very high gradient acceleration is proposed. A short impulse shape wave form can be generated by superposition of many harmonics. It is achieved by a cavity with multi-harmonic resonances, which may have ten or more modes excited simultaneously with proper phases. Such impulse wave form may achieve very high peak accelerating gradient. A preliminary result of a cold model cavity is presented.

1 INTRODUCTION

Acceleration or debunching (a.k.a. phase rotation) of secondary-beams such as pions or muons has to be very quick because of their short life times[1,2]. Because they are supposed to be initially bunched within very narrow time width, duration of the acceleration voltage can be very short (see Fig. 1). This impulse shape wave form can be achieved by a cavity with multi-harmonic resonances, which may have ten or more modes excited simultaneously with proper phases (see Fig. 2). Such impulse wave form may achieve very high peak accelerating gradient, because of the short duration of its peak. One more feature of this scheme may be the power consumption. Assuming that every mode has same order of shunt impedance, the total RF power is proportional to the number of modes that is also proportional to the acceleration gradient, while it is proportional to square of the acceleration gradient for a single mode cavity. This paper explains some ideas for Multi-Harmonic Impulse Cavity (MHIC).

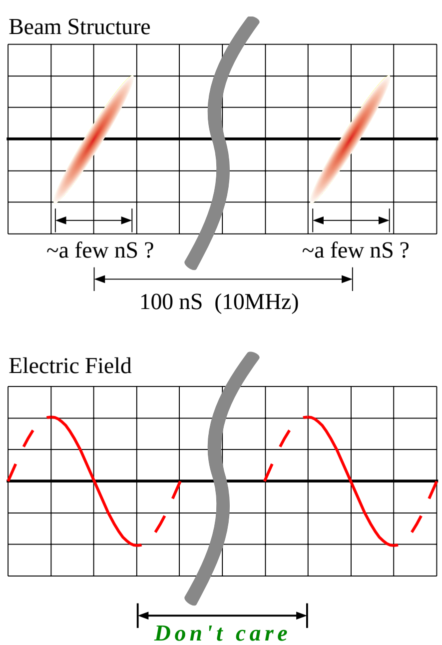

Figure 1: Time structure of a bunched beam and electric field for debunching.

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2 COAXIAL CAVITY

A simple example of such a cavity is a λ/2 coaxial resonator, which has harmonic integer resonances (see Fig. 3). Among the resonances, those with even harmonic number cannot be used because they have nodes of electric field distribution at the center. Effects of a beam hole in the conductor should be compensated for a cavity to have right resonant frequencies.

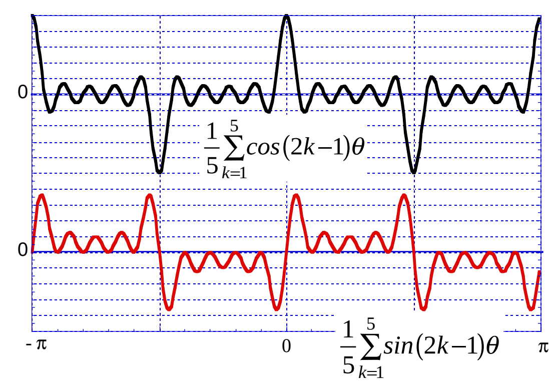

Figure 2: Superposition of harmonics to generate impulse train. Upper one is adequate for acceleration. Lower one is for (de-)bunching.

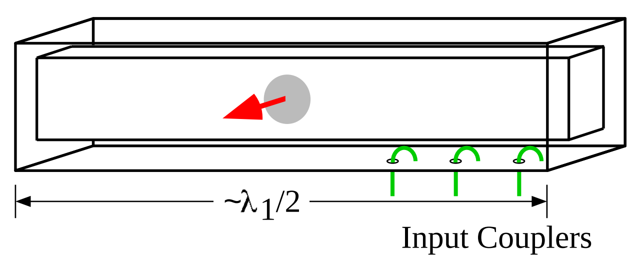

Figure 3: λ/2 coaxial resonator having many input couplers for harmonics.

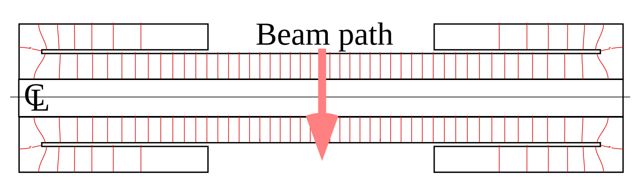

Figure 4: Folded coaxial resonator can reduce the cavity length.

Assuming that the fundamental frequency is 10 MHz, a length of a λ/2 coaxial resonator becomes 15 m, which is rather huge for a construction. Folded coaxial configuration (see Fig. 4) can be employed to reduce the cavity length (actually the width in this case). For a real application, these cavities are lined up on a beam axis. The folded coaxial cavities may have cross bar configuration for better space factor. Because there is a vacant space in the inner conductor, this space can be filled with nested cavities for higher harmonics as shown in Fig. 5. On the other hand, this location may be useful for a focusing device such as a Q magnet or a solenoid coil. For a higher order mode, the conductor surface of the peripheral area beyond the first node does nothing but power consume. Choke structures or low pass filters at these points may block power flows to the peripheral area and increase its shunt impedances.

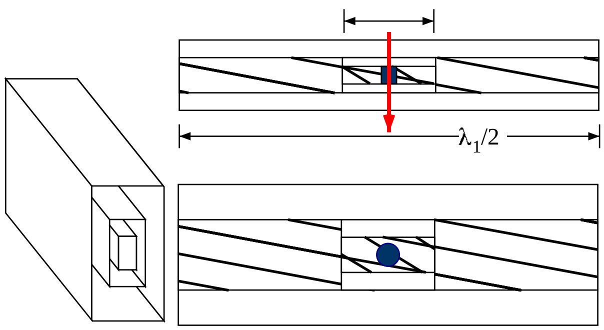

Figure 5: Nested coaxial cavity.

In very rough estimation assuming that shunt impedance of each mode is 4MΩ/m and 40kW/m is available for each mode, we can obtain 1MV/m for 120kW/m. With a naive scaling, operation of thirty modes achieves 10MV/m for 1MW/m. There should be a lot of difficulties achieving this level. One major problem is increase of mode density toward the higher frequency region.

In order to fine-tune the resonant frequencies, many frequency tuners are desired. An RF power feeding scheme should be established. Although a cavity with single RF coupler is simple, the RF circuit may be complicated because many harmonics have to be combined and matched to the cavity. On the other hand, installing multiple couplers on a cavity makes the fabrication complicated. Figure 6 shows a schematic drawing of a proof of principle (POP) model for a coaxial cavity geometry (CoaxPOP). Coupling scheme, frequency tuners and RF characteristics will be investigated. on this cavity. Experiments on the discharge properties are also possible so that it is designed as vacuum tight. Four of frequency tuners and coupling loops are prepared (see Photo 1). One antenna can be installed at the center port for measuring the electric field.

Figure 7 shows a preliminary data from the CoaxPOP, where RF power transmission is measured between a)

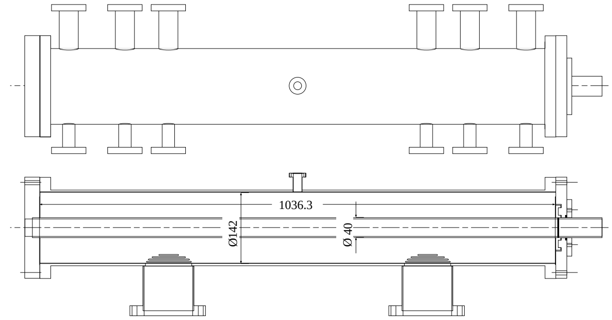

Figure 6: Proof of principle model for coaxial cavity.

Photo 1: CoaxPOP parts

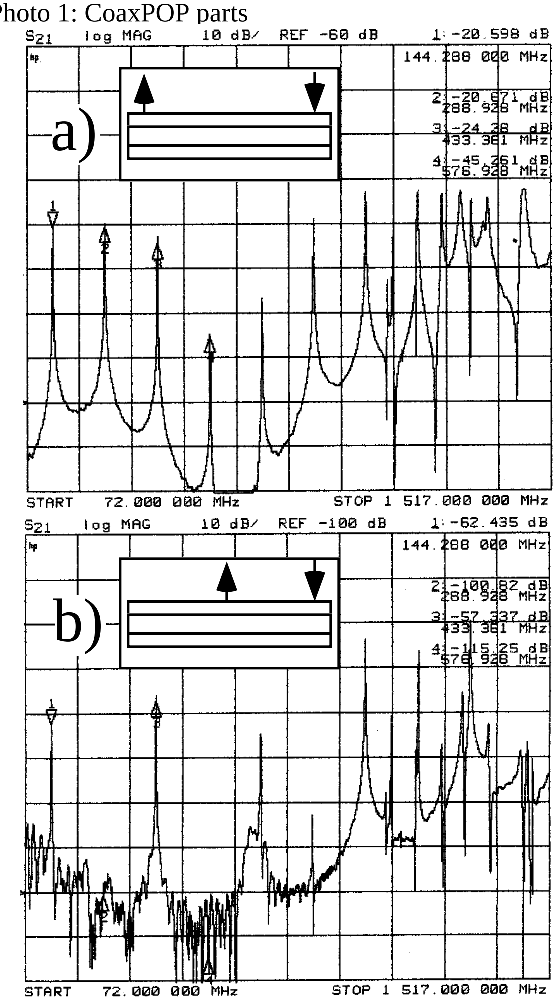

Figure 7: Measured transmissions between a) both end loops and b) from end loop to center antenna.

both end loops and b) from end loop to center antenna. The fundamental frequency agrees with the designed value of 144.5 MHz. Only harmonic modes are observed up to seventh harmonics. Even harmonics are much suppressed at the center antenna as expected. Further measurements are under way.

3 CYLINDRICAL CAVITY

Because a $\lambda/2$ coaxial resonator has two acceleration gaps, it has restrictions on designing a system: the axial length affects transit time factor and a bipolar wave form (single sine wave at least) is required. A single gap cavity using multiple modes such as "signal-cavity with double frequency buncher" [3] is preferred. Figure 8 shows the mode spectra of TMmn0 in a simple cylindrical cavity. Unlike the coaxial cavity, frequencies of higher order modes in a cylindrical cavity are not integral multiple of that of a fundamental mode. Adjustments are needed to satisfy such requirements.

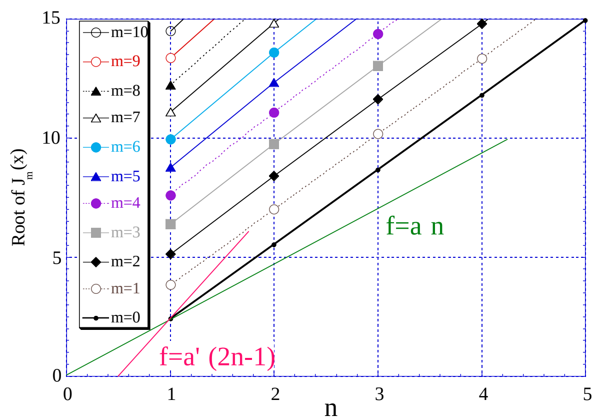

Figure 8: Mode spectra of TMmn0 in a simple cylindrical cavity.

Because the fundamental mode frequency is so low that the cavity diameter becomes too large. It is worse than the coax cavity case because a cylinder with large diameter takes larger volume than a pin point object with the same length. The diameter of a cylindrical cavity can be reduced by folding it radially. Figure 9 compares a size of a simple cylindrical cavity and that of a folded cylindrical cavity with a fundamental mode frequency of 30 MHz. The cavity radius can be reduced less than a half. The frequencies of these cavities are shown in Fig. 10. The lowest three or four frequencies have odd number proportions. The shunt impedance, however, is rather small (~1MΩ/m) and further work may have to be done for a practical use.

4 CONCLUSION

MHIC may enable CW operation of a room temperature cavity with fairly high field gradient because of the superposition of the electric field. It may achieve very

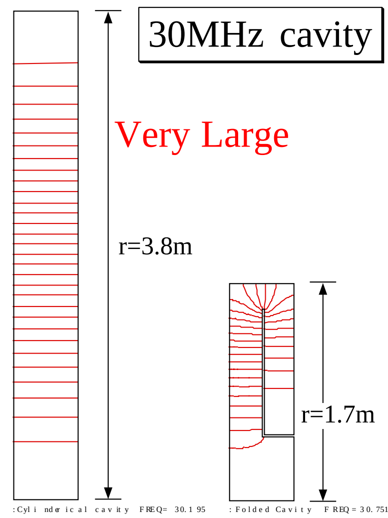

Figure 9: Comparison between a simple cylindrical cavity and folded cylindrical cavity.

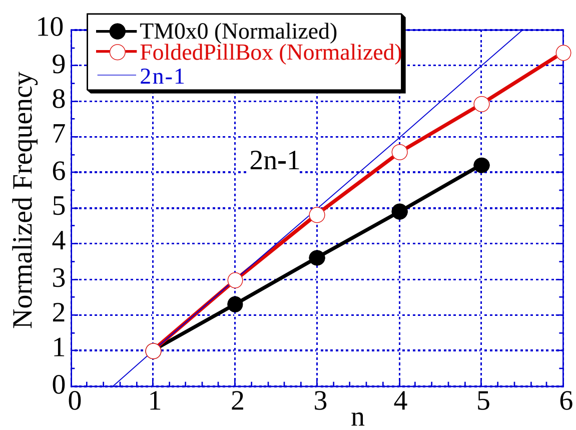

Figure 10: Frequencies in a simple cylindrical cavity and those of a folded cylindrical cavity.

high gradient field because of the wave form of the impulse shape (short time duration). Many power amplifiers with different frequency ranges required by this scheme makes the system complicated. Further work has to be done to realize this scheme.

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