HIGHER HARMONIC MODE OPERATION IN BABY CYCLOTRON

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The main items of J.S.W Baby Cyclotron are to produce the short lived Radio Isotope, carbon-11, nitrogen-13, oxygen-15, and fluorine-18. The features are compact size and reliable operation. High magnetic field used to make the cyclotron small and higher harmonic mode accelerations are adopted to accelerate both proton and deuteron with same magnetic field and shorten the resonator. The performances are listed on table 1. Plane view of Baby Cyclotron is shown Fig.1.

Both 2nd and 4th acceleration modes are used for proton and deuteron respectively to the prototype and the first commercial cyclotron. Two 45-degree dees in push-push excitation are used and their geometrical configuration is symmetrical.

Prior to acceleration test, orbits were traced by a computer for both modes in the magnetic field distribution measured on the electro magnets of cyclotron. In the course of computer studies, we found that there exist a large displacement of orbit center at 4th harmonic mode acceleration. It is well known that an orbit center of an ion is displaced by the first harmonic in the magnetic field. At the higher harmonic mode acceleration, orbit center displacement is caused by occurrence of asymmetries of both the magnetic field and the acceleration field. The later is generated by phase difference of the ion arriving at the acceleration gaps.[1] We express the displacement of the center by the poller coordinates, (ρ,φ), and variation of ρ and φ per revolution by $\Delta\rho$ and $\Delta\varphi$, respectively.[2] For the displacement caused by the asymmetry of the electric acceleration field in addition the magnetic field, the following equations hold for the 4th harmonic mode acceleration,

$$\Delta\rho = 2\sqrt{2}\,V/E\ \rho\sin\theta\sin2\varphi + \pi r C_1 \sin(\varphi-\psi_1)$$

$$\Delta\varphi = -4V/E\ \sin\theta(1-1/\sqrt{2}\cos2\varphi) + \pi r/\rho\, C_1\cos(\varphi-\psi_1) + 2\,(\nu_r-1)$$

Where V is half of the peak to peak R.F voltage, E is the energy of an ion at the radius r, θ is the phase of an ion from the peak of RF frequency. C_1 and ψ_1 are the amplitude and phase of the first term in a Fourier expansion of the azimuthal variation in the magnetic field. ν_r is the radial betatron oscillation frequency.

As the result of computation of the orbit center displacement for different positions of the ion sourse, a small change of the ion source position is responsible for a large displacement of the orbit center.

It is known from the equation that the smaller the value of $\sin\theta$ is, the smaller the displacement is. The reduction of the value of $\sin\theta$ can be achieved by the high relative magnetic field near the center of the magnet. In order to reduce the displacement of the center of the ion orbit further, we installed two pairs of harmonic coils at proper positions on the pole faces of the magnet. The harmonic coils generate the first harmonics of the magnetic field at arbitrary azimuth. The first harmonics generated by the coils could reduce the displacement caused by the asymmetries of both the electric acceleration field and the magnetic field.

On the prototype adopted the methods mentioned above, they are very important for reducing the displacement of the orbit center after searching for an optimum accelerating condition using shadow technique.[3] Specially, the good efficiency of the harmonic coils became clear not only for the orbit center problem but also for the beam extraction.

So the first commercial cyclotron was designed by detailed numerical calculations and experimental study, we could make a displacement of the orbit center small in the initial stage. Now, we can get stabilized extracted beam and sufficient amount of Radio Isotope by Baby cyclotron.

Table 1. Performances of Baby Cyclotron

Model / Item	Prototype		1st commercial type	
	proton	deuteron	proton	deuteron
Energy (MeV)	9.4	4.7	10	7
Extraction radius (cm)	24		30	
Average magnetic field(T)	1.85		1.52	1.8
RF frequency (MHz)	56		46.5	55
Harmonic mode	2	4	2	4

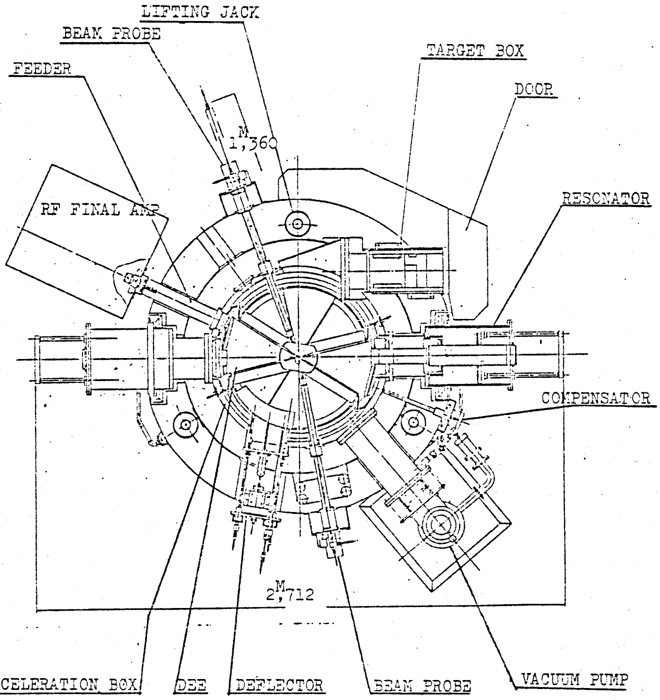

Fig.1 Plane view of Baby Cyclotron

References

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