MAGNETIC FIELD NEAR THE CENTER ON THE BABY CYCLOTRON

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Summary With the AVF cyclotron, the relative distribution of magnetic field changes when the magnitude of the field varies for a wide range. This change is large in the central region. The change of the relative magnetic field, however, may be suppressed in magnitude by employing a physical configuration that alleviates local saturations of iron at the magnetic pole surfaces. This paper covers a recently generated magnetic field featuring the relative field distribution in the central region of a type 3015 baby cyclotron that has successfully been held more or less steady from a 1.5 Tsl below 1.0 Tsl in average magnetic field.

Introduction

In earlier times, baby cyclotrons were used to produce short half-lived radio isotopes of ^{11}C, ^{13}N, ^{15}O and ^{18}F. At that time, protons and deuterons were accelerated with 2nd and 4th harmonics mode, respectively, and a narrow range magnetic field at 1.5 Tsl served the purposes well. However, for applications other than the above such as for chemical analyses or research on material science, variable energy is often demanded. For such purposes, the energy of particles need not be continuously variable, and a step-wise variation will suffice. Then a wide range magnetic field has to be employed for step-wise variable energy outputs. Table 1 shows the accelerating particle, energy, magnetic field, and other parameter of type BC-1710 [a fixed energy type] and type BC-3015 [a step-wise variable energy type].

The accelerating electrodes of both types are 45 degrees two-dee for push-push RF excitation. In the central region, angle of the dees is narrowed to 35 degrees.

When the averge magnetic field is at 1.5 Tsl, its hill is near 2.0 Tsl, so that surface edges of the pole iron for generating hills are liable to suturate. For this reason, the relative field distribution at 1.5 Tsl will change when a lower magnetic field is employed. In our case, by utilizing the law of similarity and backed by our experience, we have easily achieved the required relative field distribution at 1.5 Tsl with our very first design. But the physical configuration of poles has had to be improved to meet the requirement at a lower average magnetic field. Our related efforts and achievements are presented below.

Pole Configuration vs. Magnetic Field Distribution

Effect of Pole Edges for Hill Located outside Central Region The physical configuration employed first for the magnetic poles for a hill is showen in Fig. 1, and its center plug in Fig. 2. Fig. 3 shows the relative field distribution at 1.5 Tsl and 1.0 Tsl. In this figure, only two cases are involved but all other relative field distributions at lower magnetic field than 1.5 Tsl have been found to approximate to the distribution at 1.0 Tsl. Accordingly, in the discussions that follow, we will have the relative field distribution at 1.0 Tsl represent all the other distributions than that at 1.5 Tsl.

At 1.5 Tsl, the cone field terminates at a 12 cm radius, and thereafter evolves into an isochronous field. At 1.0 Tsl, on the other hand, the cone field persists up to a nearly 30 cm radius, a large phase slip manifests itself to necessitate further enhanchment of the magnetic field.

We have therefor shaved iron edges off the poles for a hill as shown in Fig. 1, in anticipation lowered magnetic fields ranging from about 20 cm to 30 cm in radius. The results obtained through this process are shown in Fig. 2 and 3. Influences of shave-off have extended to the central region, and their magnitude is slightly greater at 1.0 Tsl than at 1.5 Tsl. By denoting with R_1 the radius at which a cone field terminates and evolves into an isochronous field, the pre-shave R_1=30 cm has substantially been reduced to a post-shave R_1=22 cm by the above process. The R_1 reduction with 1.5 Tsl, on the other hand, has only been from 12 cm to about 10 cm, a much smaller variation in proportion.

Flutter variations due to the shave-off process have been extremely slight. The post-shave F*F versus radius is shown in Fig. 4.

Effect of Center Plug Shape At a low magnetic field, the cone field still extends to a large radius R_1 that should preferably be reduced to about as in the case with 1.5 Tsl. Edges of the cylindrical center plug easily saturate. To confine such saturations within a small range, we have reduced the radius of the center plug from 6 cm to 5cm, and extended the iron shims for a hill 1 cm further toward the center. In addition, we have slightly tapered the flat surface of the center plug to a gradual slope. Then thus modified pole configuration is shown in Fig. 5, and the relative field distribution gained thereby in Fig. 6 and 7. In the figure , an isochronous field for each particles is generated by the aid of circular trimming coils and the center plug spacing has also been held constant.

As evident from Fig. 6, the cone field terminated at a 12 cm radius, and has therafter evolved into an isochronous field. On these magnetic field distribution, ions are accelerated with sufficient stability both in the holizontal and the vertical plane. In the holizontal plane, the phase slip of the ions are small enough to arrive at isochronous field and in the vertical plane, ions are focused magnetically with radial gradient induced by the cone field accompanied with the electric focusing.

The computer studies in the vertical plane are descrived in the next section.

Vertical Particle Trajectory

In both median and vertical plane, particle trajectories have been calculated by mini computer. The electric field used in the program is a simple Gaussian distribution which is a function of the gap between dee and dummy-dee and aperture of dee, as same as that of van Nieuwland, J.m. and Hazewindus, N[1].

The cyclotron operating parameters used for the calculation in the vertical motion which are the position of the ion source, dee voltage and starting RF phase, are selected by the results from the calculation in the holizontal motion. Initial conditions are as follows, a unit distancd apart from the median plane, parallel to the median plane and step of starting phase by 10 RF degree (0 degree is peak of RF voltage).

Calculated results are shown in Fig.8 a) at 2nd and b) at 4th harmonics, respectively.

In the figures, the amplitudes are larger on the high magnetic field than that on the low magnetic field. The magnetic vertical focuss caused from the cone field is larger in the high field than that in the low field. The particles at the starting larger RF phase than 40 degrees have large vertical amplitudes and will be lossed.

Conclusion

An example interrelationship of the physical configuration of magnet poles in the central region of a variable energy AVF cyclotron versus the magnetic field distridution has been presented. The BC-3015 cyclotron has already passed acceptance test at the factory, and is scheduled to start operation at Univ. of Pennsylvania at the end of 1986.

References

1) J.M. van Nieuwland and N. Hazewindus, "Some Aspects of The Design A Cyclotron Crntral Region " Philips Res.Repts 29, 528 (1974)

Table 1. Particles, Energies, and Harmonic Modes

BC-3015 type

B (Tsl)	1.54	1.32	1.16	1.03	0.98
p (MeV)	32 [2nd]	23 [2nd]	----	14 [2nd]	----
d (MeV)	15 [4th]	----	----	----	----
α (MeV)	30 [4th]	23 [4th]	----	14 [4th]	----
$^3He^{++}$ (MeV)	42 [2nd]	----	23 [4th]	----	17 [4th]

Radio Frequencies: 47 MHz, 40 MHz, 31 MHz (step-wise)
Magnet Pole Gap: Hill 107mm, Valley 199mm, Mean 139mm
Extruction Radius 515mm

BC-1710 type

B (Tsl)	1.55	1.43
p (MeV)	----	17 [2nd]
d (MeV)	10 [4th]	----

Radio Frequencies:
47 MHz(d), 44MHz(p)

Magnet Pole Gap:
Hill 70mm
Valley 130mm
Mean 91mm
Extruction Radius 415mm

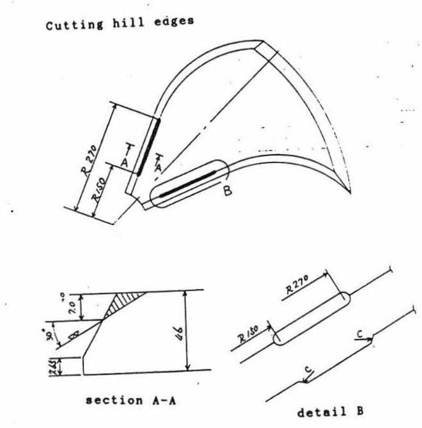
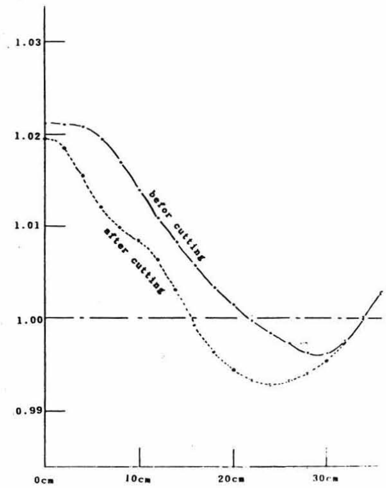


Fig. 1: Pole iron for hill "cutting hill edges" see text



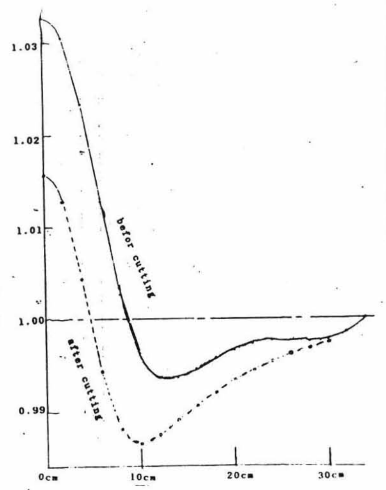


Fig. 2 :(1.0 Tsl) Fig. 3 :(1.5 Tsl)
Relative field distribution
before(real line) and after(broken line) the cutting

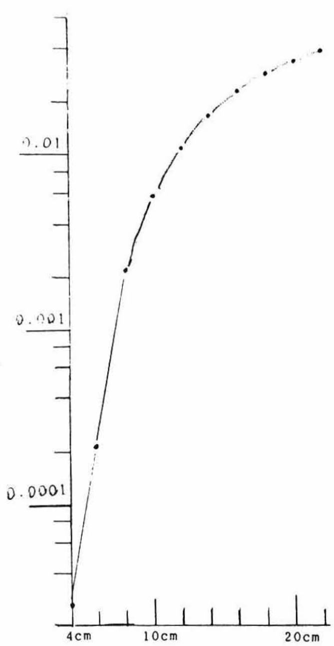


Fig. 4 : Flutter squared vs. radius

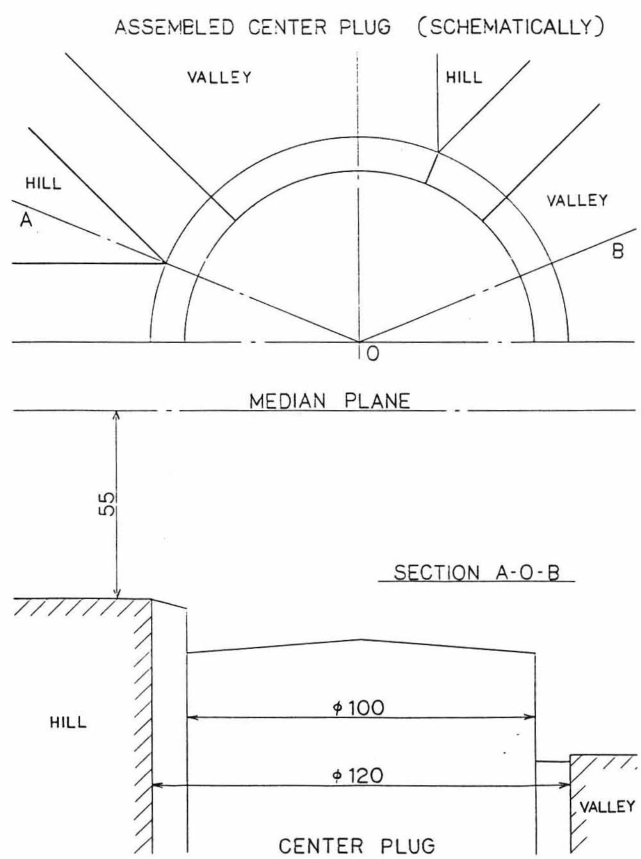


Fig. 5 : Improved center plug

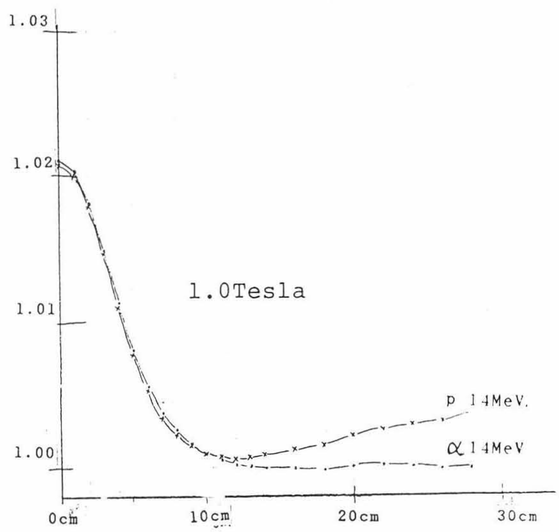


Fig. 6 :Relative field distribution for each particles (1.0 Tsl)

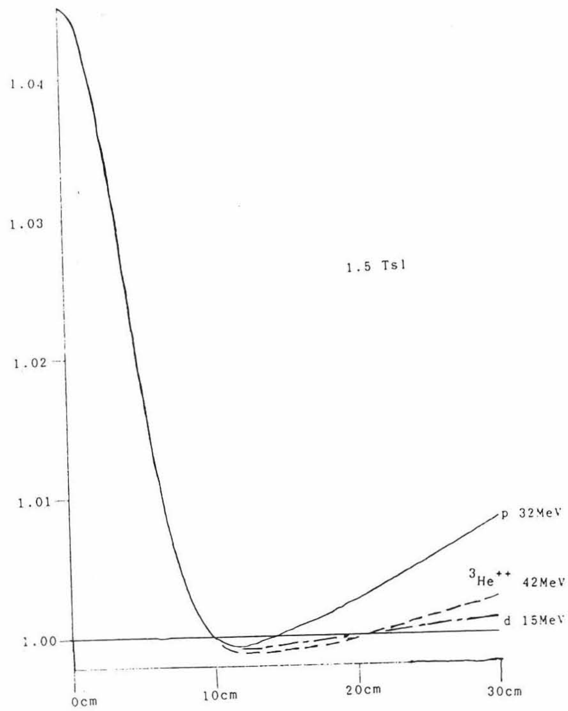
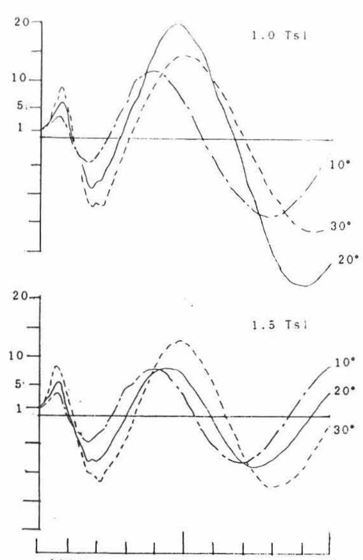


Fig. 7 :Relative field distribution for each particles (1.5 Tsl)



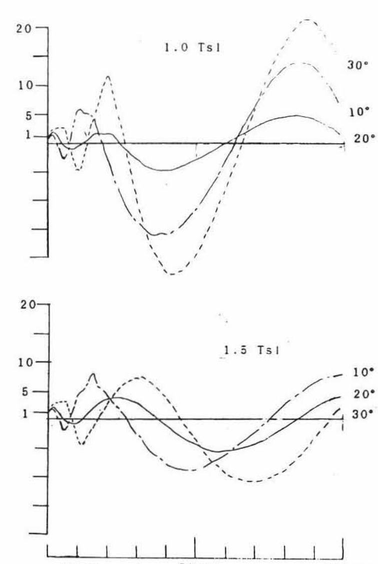


Fig. 8-a (2nd harmonic mode) Fig. 8-b (4th harmonic mode)
Computer results for axial amplitude vs. azimuth rays leavig the source at various times