DESIGN AND STUDY OF SUPERCONDUCTING COMPACT CYCLOTRON

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ABSTRUCT

We have studied a superconducting compact AVF-cyclotron that is a prototype with a pole of 31 cm in diameter. The magnetic field is 3.2 T at the central region for 10 MeV protons. In this paper will be reported the general view of the magnet and the field design for static and dynamic stability of the beam orbit.

INTRODUCTION

A superconducting magnet will provide many advantages on accelerators. Consumed power and size can be much reduced of an accelerator by using a superconducting magnet. The compactness of an accelerator is very useful for radiation shield and space-limitation. We can moreover expect the higher energy beam. It is very important to develop an AVF- or a ring-cyclotron with a superconducting main magnet. In some places, superconducting AVF-cyclotrons have been constructed and in plannning. The bending limit K_b is 500-800 MeV for much of these cyclotrons. For the medical treatment, an AVF-cycrotron will be developed instead of other types of accelerator which may provide 250MeV protons. Compact cyclotrons of a few ton are very useful for many applications but scarce; there will be seen only one or two examples in the world. It is interesting to study a compact cyclotron with a superconducting magnet.

Design of the cyclotrons has already been established in principle. Some problems, however, are remained in practical design of superconducting compact cyclotrons. Severe problems will appear in the condition of beam stability and injection/extraction of the beam because of the strong field in the small gap in the accelerating region. The lower extraction efficient requires radiation shield more strict, and the cyclotron compactness will be lost. It is important to calculate the beam characteristics with high accuracy in the design.

A prototype will be constructed with a superconducting magnet[1,2] of 31 cm pole radius for 10 MeV protons. The magnet was made by a group of one of authors at Kyoto University in 1981. The calculation has been carried out to design the magnetic field and to examine the beam properties. It is also interesting for a school education to study a system based on the superconducting technology in a theoretical and experimental approach.

MODEL MAGNET

The superconducting magnet was made at Kyoto University in 1981. The design parameters of the magnet are listed in Table 1. In Fig.1 are shown the shape and geometrical size of the yoke and coil. The magnetic field has been calculated with the code 'TRIM'[3] in the case without a pole-tip. The pole-tip is a 3-sector type and has no spiral. The radial shapes of the hill and the valley have been determined to let the field come near isocronous[2] by the least squares method with the code 'SATDSK'.[4] Figure 2 shows the determined shape of the hill and the valley.

Table 1 Design parameters of the cyclotron

Coils		
inner radius	40.0	cm
outer radius	47.0	cm
magnetic motive force	8.5×10^5	AT
central field	32.5	kG
Pole-tip		
radius	15.5	cm
number of sector	3	
minimum hill gap	3.0	cm
maximum valley gap	58.0	cm
Yoke		
hight	114.0	cm
inner radius	98.0	cm
outer radius	110.0	cm
weight	4	ton

BEAM ORBIT ANALYSIS

1. Equilibrium Orbit

A program code has been developed based on ref.[5] to calculate the radius, the time of one revolution and the betatron frequency of the equilibrium orbit.

The time to complete one revolution is shown in Fig.3 in which time of zero means just a cycle of the equilibrium orbit of each energy. The accuracy of isocronous may be 0.58 % in this calculation.The betatron frequency is calculated by the smooth approximation[6]. The diagram of the resonance parameters are shown in Fig.4. Some resonance lines may be acrossed by the accelerated beam in the proton energy region between 7.5 MeV and 10 MeV. This problem will be resolved by high accelerating voltage.

2. Accelerated Orbit

The stability of the accelerated orbit is examined by the equation of ref.[7]. The beam conditions are set at r = 0.35 cm and E = 0.6MeV as initial values. The accelerating condition is 300 kV of the voltage per turn and 3×49.5 MHz of the frequency.

The calculated radius is 14.5 cm for 10 MeV protons under these conditions. The phase space of the beam has been calculated at the center of a hill, θ=0, in order to examine the orbit stability. The radial phase space (r, Pr) is shown in Fig.5 at every turn of the orbit. The maximum radial spread is about 5 mm at 33 turn for extraction. Good properties will be expected on the beam focusing of the accelerated orbit. The response of axial phase has also been calculated, and the radial dependence of the maximum displacement is shown in Fig.6 for three initial values; Z= 1, 2 and 3 mm. The beam injection condition has been examined for the extraction condition. Figure 7 shows the resultant phase at one turn which may be allowed at the injection point.

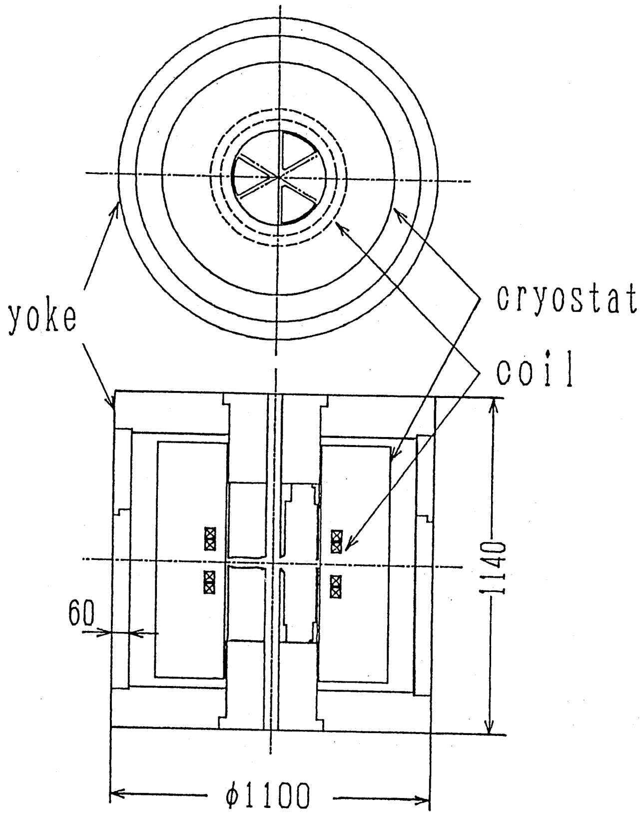

Fig. 1 The structure of yoke and coil.

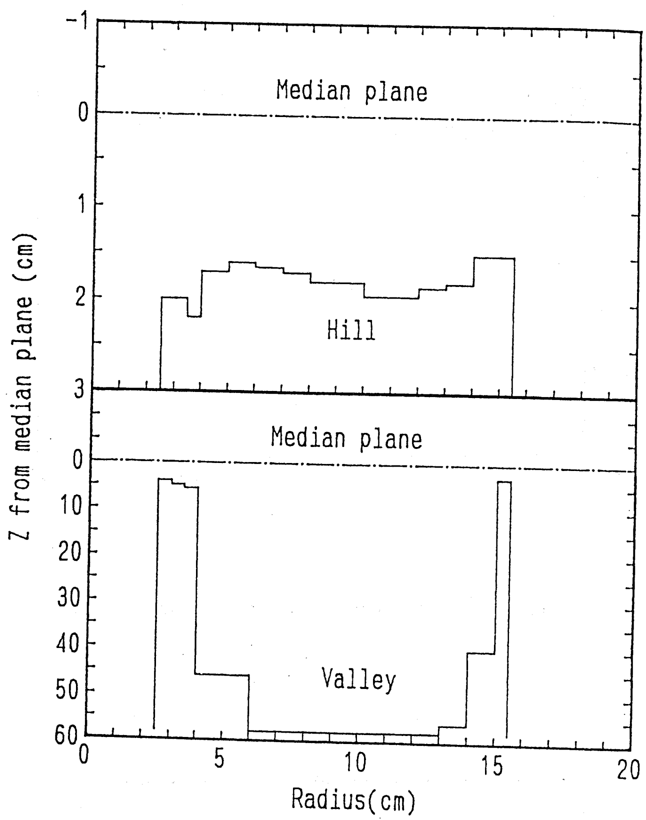

Fig. 2 The hill and the valley sector.

SUMMARY

A compact AVF cyclotron has been studied for 10 MeV protons with a superconducting magnet. The magnetic field has been calculated to design the optimum condition for isocronous and focusing. High accuracy is needed for the design because of high magnetic field of about 3 T. On the determined field have been examined the static and the dynamic beam properties. The calculation shows good stability of the beam with the present design.

From now on, the prototype will be constructed to study more closely. A field-measurement system will be developed with flip-coils. The other problems will also be discussed on RF cavity, beam injection / extraction, thermal condition and so on. The study can be applied to the design of a larger cyclotron for 200 MeV protons

The present research has been carried out by students for their graduation study at Kyushu University. The cyclotron is a good example to study a system with a superconducting magnet.

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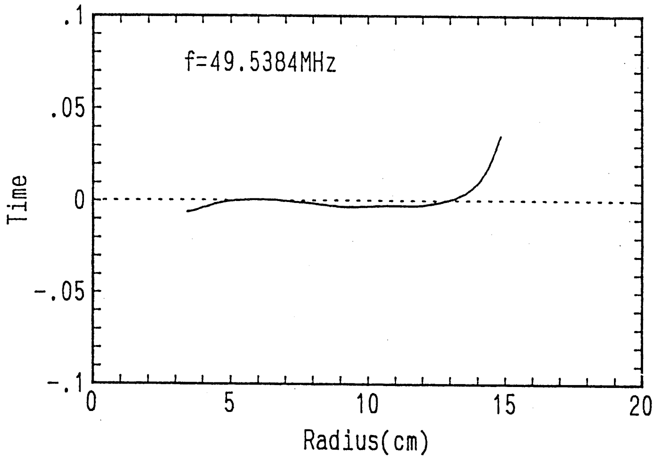

Fig. 3 Time to complete one revolution for the equilibrium orbit.

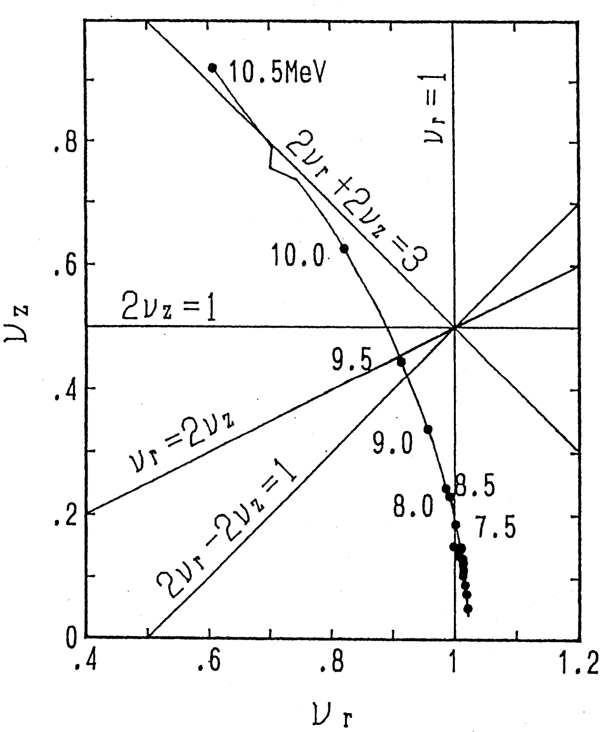

Fig. 4 The operational diagram of resonance parameters.

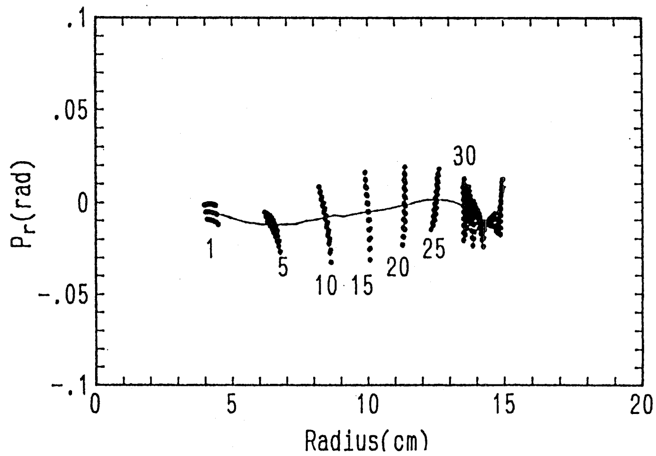

Fig. 5 The radial phase space. The number of turn is indicated in the figure.

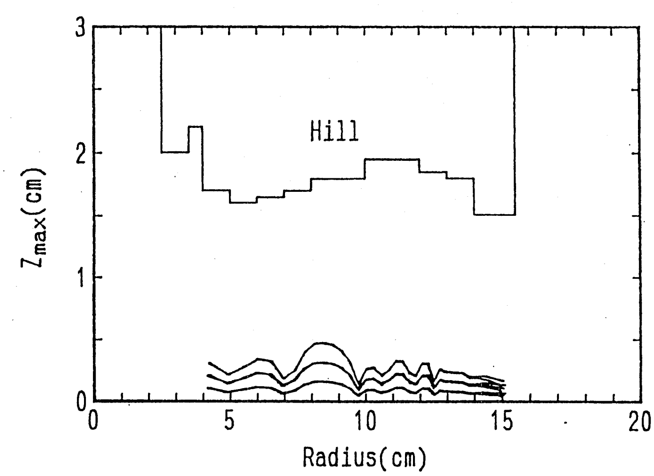

Fig. 6 The maximum displacement of the axial phase response.

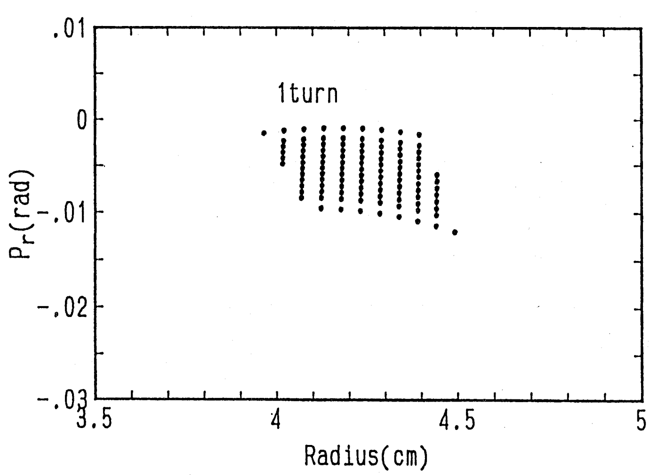

Fig. 7 The phase space in the central region.