AN ION SYNCHROTRON FOR MULTI-PURPOSES USE OF ENERGY RESEARCH CENTER, WAKASA BAY

Shunji Kakiuchi, Motokazu Maezawa*, and Yoshifumi Ito**
Hitachi Works, Hitachi Ltd., Hitachi shi, Ibaraki, 317 Japan
*Fukui Prefecture Government. 3-17-1, Fukui shi, Fukui, 910-80 Japan
** Energy Research Center, Wakasa Bay, Tsuruga shi, Fukui, 914 Japan

Abstract

A compact synchrotron for multi-purpose use is under construction at Tsuruga. The synchrotron has 8 bending magnets of 1.91m radius and 33.2m circumference. A tandem accelerator with terminal voltage of 5MV is utilized to inject the proton, helium or carbon beam to the synchrotron. Proton, helium or carbon beam is injected by multi-turn injection with the energy of 10MeV, 15MeV and 25MeV, respectively. The synchrotron accelerates the beam up to Bρ=2.15Tm, that is 200MeV for proton, 55MeV/u for helium and carbon, in repetition rate of 0.5Hz. The beam is accelerated using FINEMET core loaded untuned cavity with 0.61MHz to 5.1MHz. In this cavity, the impedance mismatching is improved by multi-feed coupling of the RF power to each FINEMET core separately, and then the higher gap voltage is achieved at the same input RF power. A low emittance beam can be extracted with newly developped extraction scheme keeping the separatrix constant. The transverse radio frequency perturbation with a certain frequency band width is applied to the beam to make it diffuse and exceed the separatrix of the resonance.

1 INTRODUCTION

In Fukui prefecture, a versatile accelerator project had been funded by the prefecture government in order to promote various high technology into regional community. In this project the accelerator complex will be intended to use as a tool for particle beam analysis, material physics, applications of mutation in agricultural and marine products industry and research of a malignant tumor treatment, respectively. So, it is important to accelerate various ion species from light to heavy ion and wide range of beam energy from about 1MeV to 200MeV to achieve above requests. The accelerator complex is now consisted of a tandem accelerator whose maximum terminal voltage is 5MV, low energy beam transport line (LEBT), ion synchrotron and high energy beam transport line (HEBT). The tandem accelerator will play an important role in this system both as an injector of the synchrotron for high energy use and as the main accelerator for low energy applications. The synchrotron had been designed to accelerate three kinds of ion of H^+, He^{2+} and C^{6+} whose charge to mass ratio (q/m) is more than 1/2. The beam energy of H^+ is from 10 to 200MeV and of He^{2+}, C^{6+} are from 2 to 55MeV/u. Ion pieces and energy of the synchrotron are shown in Table 1.

Table 1 Ion pieces and energy of synchrotron

ion pieces	input energy	output energy	output current
H^+	10 MeV	10 - 200 MeV	10 nA
He^{2+}	2 MeV/u	2 - 55 MeV/u	0.5 nA
C^{6+}	2 MeV/u	2 - 55 MeV/u	0.2 nA

A detailed features of the synchrotron system are described in this paper.

2 SYNCHROTRON

2.1 Lattice

In the present synchrotron, the ion beam is injected from a tandem accelerator to the synchrotron based on the multi turn injection scheme. The maximum beam energy reached is 200MeV for proton, 55 MeV/u for helium and carbon. The accelerated beam is extracted by the resonanat extraction in which the separatrix of the nonlinear resonance is kept constant and the RF perturbation with a narrow frequency band width is applied to make the beam diffuse to the separatrix [1]. The procedures of the injection, acceleration and

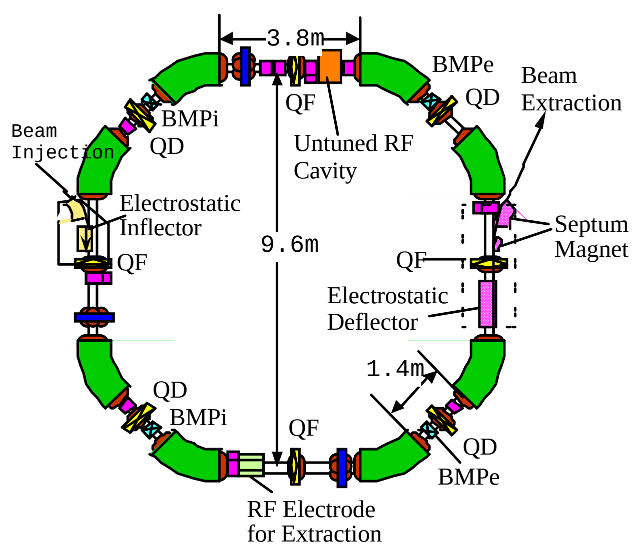

Fig. 1 The lattice of the synchrotron

extraction are repeated with 0.5Hz. Figure 1 shows the lattice of the designed synchrotron. The present synchrotron employs the separated function lattice of four superpriods. Each bending magnet is a sector type and has a curvature radius of 1.92m. The deflection angele of the bending magnet is 45 degrees. The maximum magnetic field of 1.12T is needed for the beam energy of 200 MeV for proton and 55MeV/u for helium and carbon. . The horizontal tune Qx and the vertical tune Qy are 1.75 and 0.85 respectively. There is no structure resonance near this operating point. The horizontal and vertical betatron functions are lower than about 6m and 12m, respectively, and the horizontal dispersion function is sufficently low. The momentum compaction factor is 0.31. Accordingly, the transition gamma is 1.79 and this value is much higher than the maximum gamma of the beam of 1.21.

2.2 Injection

The beam is injected from the electrostatic deflector. The dispersion function at the injection point of the transport system is designed to be zero. The beam stacking in the synchrotron is done by the so-callled multi turn injection scheme using two bump magnets. Assuming that the distribution of the injected beam from the tandem accelerator is assmed to be homogenious, the relationship between the effective injection turn number and the excitation time of the bump magnet in unit of the turn number was obtained by a numerical analysis. The results are shown in Fig. 2.

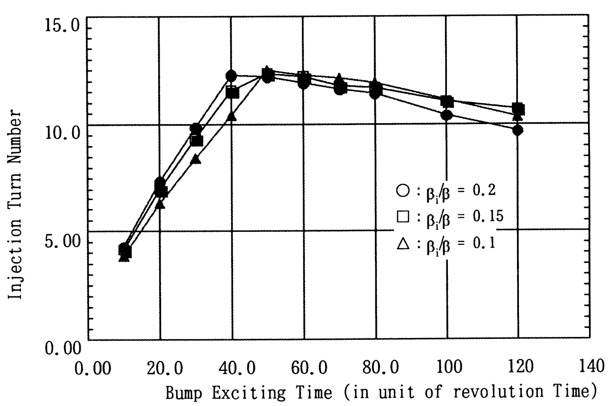

Fig. 2 Bump Exciting Time vs. Injection Turn Number

β_i and β in the figure are the betatron functions at the injection point of the injection transport system and the synchrotron, respectively. The design value of the effective injection turn number is 10. This value is realized by choosing the excitation time of the bump magnet in unit of the turn number larger than 30. Considering that the distribution of the beam ejected from the tandem accelerator shoould be gaussian, the effective injection turn number larger than 10 will be easily realized.

2.3 Acceleration

The beam energy is ramped in about 0.7s to the maximum value with the current of the bending and quadrupole magnets using the radio frequency (RF) accelerating cavity. The RF acceleration is done using the untuned type cavity which employs Fe-based Nanocrystalline FINEMET cores[2]. Since the untuned RF cavity does not need control of the resonant frequency, the acceleration can be simplified significantly. In general, the gap voltage of the untuned cavity is relatively low because of its small Q value in comparison with that of the tuned type cavity. Then, the gap voltage of the present RF cavity can be increased because the impedances of the power source and the ununed cavity can be matched due to respective feeding of the RF power to each FINEMET core. The gap voltage of the RF cavity of about 1.2 kV is necessary for the acceleration in the present synchrotorn. The high power test of the RF cavity using FINEMET core shows that the gap voltage higher than 1.0kV can be easily obtained by applying the RF power larger than 1.2kW, as shown in Fig.3. The figure also shows the data of the gap voltage with and without automatic voltage control (AVC).

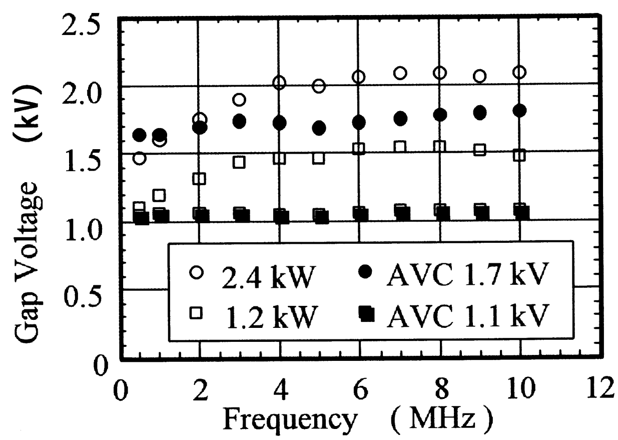

Fig. 3 The Gap Voltage of the Untuned RF Cavity

2.4 Extraction

The beam is extracted by the diffusion resonant extraction scheme in which the separatrix is kept constant and the narrow band RF noise is applied to make the beam diffuse to the separatrix [1]. The frequency of this RF noise ranges from 0.6fr to 0.7fr, where fr is the revolution frequency of the beam around the synchrotron. Since this frequency range of the applied RF noise covers the width of the frequencies of the betatron oscillations, which occurs due to the nonlinear effect and momentum spread of the beam etc., the beam diffuses due to the RF noise and the particles exceeding the separatrix are extracted by the third order nonlinear resonance. During the extraction, the intensity of the RF noise is slightly increased to obtain the constant spill.

The needed maximum voltage of the RF perturbation is lower than 100V for the proton beam energy of 200MeV. The particles are extracted horizontally through the electrostatic deflector and the septum magnets.

Because of the effect of the constant separatrix, the orbit gradients of the extracted particles at the deflector postion are constant without dynamic control of the magnets. As a result, the beam position does not change and the time integrated emittance can be kept very low.

3 CONCLUSION

We presented an ion synchrotron for multi-purpose use of Energy Research Center, Wakasa Bay. In the synchrotron, ions of proton and helium and carbon are accelerated to the energy of 200 MeV for proton and 55MeV/u for helium and carbon. The beam is accelerated by the untuned type RF cavity employing Fe-based Nanocrystalline FINEMET cores and extracted by the scheme using a transverse radio frequency perturbation of a narrow bandwidth under the contant separatrix.

Since the separatrix of the position and gradient of the extracted beam are constant, the present synchrotron can be applied to various irradiation schemes such as the double scatterer, the wobbller-scatterer and other scanning methods.

4 REFERENCES

[1] K. Hiramoto et al., Nucl. Instrum. Methods. A322, p154 (1992)
[2] K. Saito et al., Proc. of the 11th Symposium on Accelerator Science and Technol., p197 (1997)