DESIGN STUDY OF ACCUMULATOR COOLER RING FOR MUSES

K. Ohtomo, Institute of Physical and Chemical Research (RIKEN), Wako, Saitama 351-01, Japan,
T. Katayama, Center for Nuclear Study, School of Science, Univ. of Tokyo, Tanashi 188, Japan

Abstract

An RI beam factory project is proposed by the Institute of Physical and Chemical Research (RIKEN) as a next new facility for nuclear physics. The accelerator system for this project, consists of main 2 parts, one is Super-conducting Ring Cyclotron (SRC) and the other is a storage ring system named MUSES. An Accumulator Cooler Ring (ACR) is a part of Multi-USe Experimatal Storage rings (MUSES). It is used for the accumulation and cooling of the radioactive isotope (RI) beams which are produced by the beam from SRC and pass through a fragment separator. The large momentum spreads of these RI beams will be significantly reduced by the electron cooling and stochastic cooling devices in the ACR. Devices for multi-turn injection and RF stacking are also prepared in order to increase the beam current. The simulations and designs of these devices are presented in this report.

1 LATTICE

1.1 Requirements for Lattice

Lattice of the ACR shall be designed by taking the following requirements into account:

1) Electron cooler requires a long straight free space (nearly 8 m) free from dispersion.
2) Stochastic cooling devices require a pair of dispersion-free space for a pickup and a kicker, and the phase advance of the betatron oscillation should be nearly $k\pi/4$ between them.
3) Multi-turn injection requires the sections where the phase advance of the betatron oscillation is nearly π, to arrange kickers and septum magnets.
4) RF stacking requires a dispersion in the multi-turn injection section and a space for tunable RF cavity.
5) Accumulation of high current beams requires a large acceptance in the horizontal plane (=125π.mm.mrad) and a large momentum spread ($\Delta p/p = \pm 2\%$).

1.2 Design of Lattice

Optimized design is shown in Table 1 and Figs. 1 and 2. The ACR lattice consists of two arc sections and two long straight sections, as shown in Fig.1 and is given as follows.

ACR = CELL--STRC--2CELL--STRC--CELL ,

where STRC denotes the long straight section and CELL the half of the arc section. A CELL is symmetric and decomposed into two half elements, HCELL.

Table 1 Lattice Parameters of ACR

Circumference	C=168.4836 m
Average Radius	R= 26.815 m
Max. Magnetic Rigidity	$B\rho$ = 8.0 T.m
Max. Beam Energy	E = 400 MeV/u (Z/A=1/2)
Momentum Compaction	α = 0.0402042
Transition Gamma	γ = 4.987
Betatron Tune Values	Qx/Qy = 4.555/3.540
Natural Chromaticity	Q'x/Q'y = -5.058/-6.571
Max. β-Amplitude	βx/βy= 18.33m/24.53m
Max. Dispersion	Dx/Dy= 4.518m/0.0m

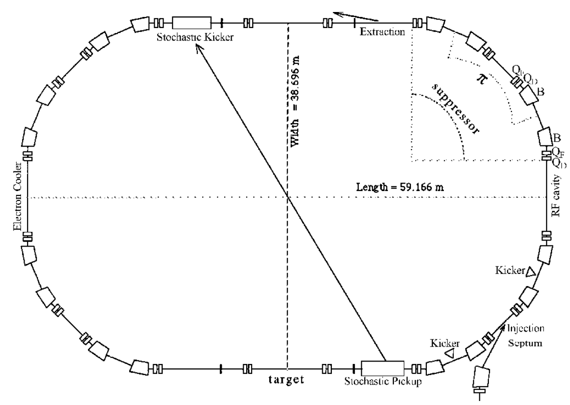


Figure: 1 The Layout of ACR.

CELL = (HCELL, -HCELL)

A HCELL is:

HCELL = -(Lr)--QD-QF--B--(Lk)--B--QD-QF--(Li)- ,

where QF and QD are the focusing and defocusing quadrupoles, B bending magnets, and L long drift space. Each CELL functions as a dispersion suppresser and makes the free dispersion space at Lr, where RF cavities or electron coolers are located. Horizontal and vertical beta functions are designed at nearly equal value because RI beam shape should match with cylindrical electron flow at an electron cooler. An injection kicker and septums occupy at Lk in one CELL, where the lattice has the maximum value of the horizontal dispersion. A couple of stochatic cooling devices are positioned at two Lr, set on opposite side in ring. The residual Lr sections are used for beam extraction devices.

The two long straight sections are given as follows:

STRC = ---QC---QD-QF--(Le)--QF-QD---QC--- ,

where Qc is a quadrupole for chromaticity correction. Le is a long drift space of 8 m for an internal target or for another experiment equipments.

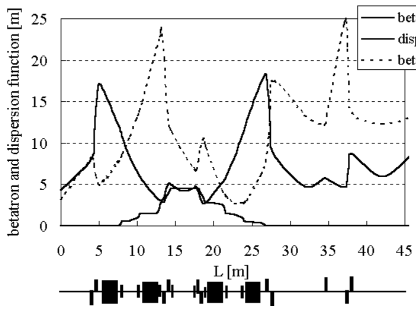


Figure: 2 β and dispersion functions in quarter of ACR

2 INJECTION

The multi-turn injection combined with RF stacking method is used in ACR. The local closed orbit is deformed by two bump magnets. The beam is injected onto an injection orbit, which has the momentum difference of +1% from the central orbit. After the multi-turn injection, the RF frequency changed gradually and the beam is stacked at the bottom orbit, which has the momentum difference –2% from the center. In a normal operation, the stacking period is 30msec and after 30 times of stackings the beam is extracted from ACR. The total repetition cycle is 1Hz, which is as same as an acceleration cycle of Booster Synchrotron Ring.

2.1 Pre-Debunching Devices

The momentum spreads of RI beam from the fragment separator is relatively large. The required RF voltage to capture them in RF buckets is proportional to the square of Δp/p. The value reaches 600kV on the assumption that Δp/p equals ±0.5% and the stacking efficiency is assured to be 80%.[1] This high voltage seems difficult to realize with ferrite loaded RF cavity. Then we are planning to install the debuncher cavities in the injection line just previous to the injection kicker.

Simulations in 6-dimentional phase spaces were performed and the typical result are shown in Fig. 3. Here the debuncher cavity are positioned at 100m downstream from the fragmet separator. The RF frequency of debunchers is 144-228MHz, 6-times higher than that of stacking cavity in ACR, and the total RF voltage of debunchers is set to be 3MV in the case of the beam energy of 400MeV/u. This voltage fulfills that the initial momentum spreads of ±0.5% is compressed to ±0.15%, which corresponds to the required RF voltage at stacking cavity of 70kV. It is achivable value with ferrite loaded cavity.

A type of debuncher cavities is a re-entrant λ/2 push pull and semi-tunable by changing the gap distance for various energy of RI beam. The structure is designed by superfish and the shape is cylindrical and the inner dimensions of cavity are 900mm in diameter and 600mm length with sliding nose for frequency tunability. The RF voltage is 800kV per a cavity and the number of cavity is 4.

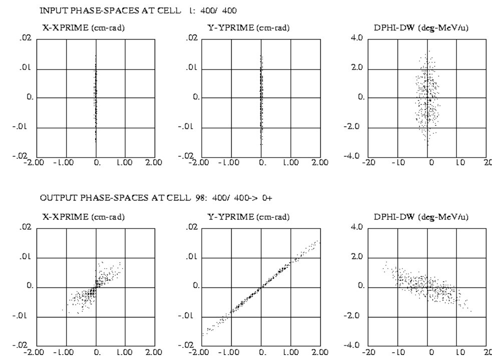


Figure: 3 De-bunching effects on phase space. The total RF voltage is set to be 3MV. Upper three figures are particles at the fragment separator and lower three are that after the debuncher.

2.2 Deflection Devices

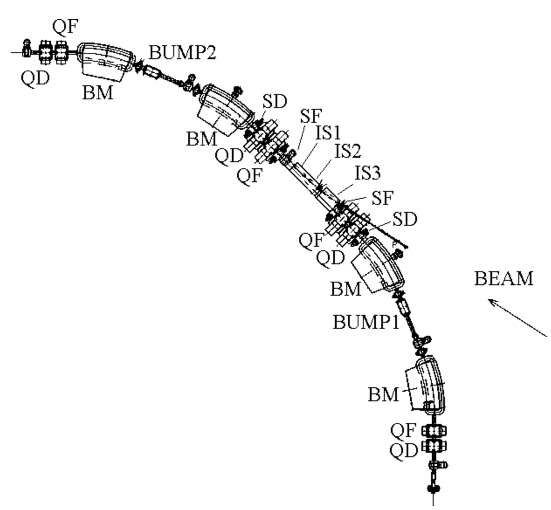
The devices for beam injection are located at half of arc section shown in detail in Fig. 4.

A couple of bump magnets are positioned apart from each other π in betatron phase. The magnetic field of these magnets are excited like a half-sine wave, of which a top magnetic field is 0.16 T corresponds to the beam of the maximum magnetic rigidity 8 Tm. The half period of half-sine is 300 μsec and a repetition cycle is 30 Hz.

The maximum displacement between the bump and central orbit is 104 mm at the first injection septum magnet. The deflection magnetic field of septum magnet is 1 T and the length is 500mm. Upstream of this, the second and third injection septum are set. The deflection magnetic fields are 1 T and 1.2 T and the lengths are 500mm and 625mm, respectively.

Some modification at the return yoke of the nearest Q magnet are required to make a clearance of the injected beam path from the debunchers.

Figure: 4 The layout of the injection devices.



2.3 Devices for RF stacking

The parameters of RF stacking cavity are listed in Table

2.

Table 2 Parameters of RF stacking cavity

Peak RF voltage	100kV
Initial Frequency Range	18-38MHz
Max. Frequency modulation width for RF Stacking	2.6%
Modulation Period	30msec
Max. Cavity free space	8m
Min. Q value	585
Max. Dissipation Power at Tuner Cavity	8kW
Max. Dissipation Power at Main Cavity	13kW
Max. Total Dissipation Power	21kW

A proposed cavity consists of two parts. The main cavity is a coaxial λ/4 and semi-tunable by changing the gap distance according to the energy of RI beam. The additional cavity is loaded with ferrites to change frequency rapidly for stacking . The frequency modulation method is based on the cavity of a proton booster synchrotron at Fermi Lab.[2] and the model cavity considered at TRIUMF.[3] A schematic drawing of the cavity are shown in Fig. 5.

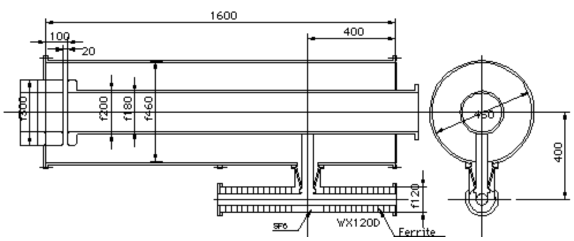


Figure: 5 The ferrite loaded cavity for RF stacking.

The length of the main cavity is 1600mm and the tuner cavity is connected directly with the inner duct of the main cavity at the position 1200mm apart from the gap. The length of the tuner cavity is 1400mm. The maximum frequency modulation width are attained with changing RF permeability ratio from 3 to 4. The dissipation power at the tuner cavity including ferrite is evaluated by superfish with complex module. The maximum power is 8kW and Q value is 585. The dissipation power at main cavity due to surface loss is also calculated as 13kW. The total dissipation power amounts to about 21kW.

Presently R&D works on the measurement of characteristics of real size ferrites are in progress.

3 CONCLUSION

The lattice design of ACR has been completed and the technical designing for basic devices such as magnets are now in progress. The model test for ferrite tuned stacking cavity is scheduled in this year.

REFERENCES

[1] Y.J. Yuan, et al.: 'Simulation of RF Stacking Combined with Cooling Effects', EPAC, 1996, p1338-1340.

[2] J.E. Griffen and Q.A. Kerns: 'NAL Main-Ring Cavity Test Results', IEEE Trans. On Nucl. Sci., NS-18, 241, 1971

[3] R.L. Poirier and T. Enegren: 'Status of RF Development work on a Ferrite Tuned Amplifier Cavity for the TRIUMF Kaon Factory', IEEE PAC, Washington D.C., 1987, p1499. (1987)