# NEW LATTICE DESIGN OF ACCUMULATOR COOLER RING FOR MUSES

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## *Abstract*

Preliminary lattice design of the Accumulator Cooler Ring (ACR)[1] in Multi-USe Experimental Storage rings (MUSES), a complex of a synchrotron and storage rings for radioactive-ion experiments in the 2nd stage of RI Beam Factory (RIBF) project at RIKEN, has been improved on the efficiency of cooling of the RI beams.

In the RIBF, the Super-conducting Ring Cyclotron (SRC) accelerates primary beam up to the maximum magnetic rigidity of 8Tm, from 400MeV for fully-stripped light ion to 100MeV for $^{238}U^{78+}$ in terms of energy per nucleon. Secondary beam momentum spreads of ±0.5% after a fragment projectile separator (BigRIPS) will be reduced to ±0.15% by a debuncher cavity located at 80m downstream of BigRIPS.

In the ACR, devices for multi-turn injection and RF stacking are installed in order to increase the beam current. Resultantly growing emittance and momentum spreads of the beam should be cooled by the Electron Cooling (EC) and Stochastic Cooling (SC) devices. Also a slipping factor $\eta_{pk}$ and a betatron phase advance $\Delta\nu_{pk}$ between the stochastic cooler pickup and kickers should be optimized to shorten stochastic cooling time.

Lattice of the ACR had been designed by taking these constraints into account.


## 1 CONSTRAINTS FOR ACR

The ACR aims to accumulate low production rated short-life RI beam and build up its current as much as possible. The lattice should be designed in that cooling and injection devices function efficiently. Constraints derived from them are listed below:

$$\eta_{pk} = -\frac{\Delta\tau_{pk}}{\tau_{pk}} \bigg/ \frac{\Delta p}{p} = \frac{1}{\gamma^2} - \frac{1}{\gamma^2_{pk}}$$

1. The SC devices require a pair of dispersion-free space (over 6m long each) for a pickup and a kicker. The $\eta_{pk}$, which is defined as below,
 should be nearly zero, so that particles having different energy travel in isochronous[2]. The betatron phase advance of the from the pickup to the kicker should be nearly kπ/4 (k:odd).
2. The EC devices require a long straight section dispersion-free space (over 10m long). The horizontal betatron function should be less than 5m because an electron beam size covers the RI beam size.
3. The injection devices require a space (over 3m long). It is desirable that dispersion and horizontal betatron function should be large enough (over 5m each) to gain a good efficiency of multi-turn injection and RF stacking.
4. The RF stacking also requires a dispersion-free space (over 4m long) for a tunable RF cavity.
5. Efficient accumulation of RI beams requires a large acceptance in horizontal plane and momentum spreads.

## 2 LATTICE

### *2.1 Basic Strategy*

We designed two different typed lattices and connected each half of them at straight section to satisfy the constraint 1 which described in the last section. One lattice, we call it A-ring, has large dispersion to let faster particles travel along longer path. Another lattice, B-ring, has relative small dispersion.

The A-ring is described as follows:

A-ring = SC--B-B-QD2—QF2-B-QD1-B-QF1—(sym.)—QF1-B-QD1-B-QF2—QD2-B-B--SC,

where QF1,2 and QD1,2 are focusing and defocusing quadrupoles, respectively, B bending magnets, and SC a space for the stochastic cooling pickup or kicker. Between both SCs the horizontal phase advance $\Delta\nu_{pk}$ is nearly 3π/4 and partial transition $\gamma_{pk}$ is 1.72.

The B-ring is described as follows:

B-ring = QD3-QF3-B-B-QD3-QF3—(INJ)—QF3-QD3-B-B-QF3-QD3—(sym.)—QD3-QF3-B-B-QD3-QF3—QF3-QD3-B-B-QF3-QD3,

where QF3 and QD3 are focusing and defocusing quadrupoles, INJ the injection point, respectively. The injection point is located at the space where the dispersion is the maximum in the B-ring.

Table 1: Parameters of the ACR

| | |
|---|---:|
| Circumference [m] | 140.403 |
| Max. Magnetic Rigidity [Tm] | 8 |
| Max. Energy for A/Z=2.3 [MeV/u] | 400 |
| Injected Beam Emittance [πmm.mrad] | 10/10 |
| Injected Beam Momentum Spreads [%] | ±0.15 |
| Max. Beam Acceptance [πmm.mrad] | 125/10 |
| Max. Beam Momentum Spreads [%] | ±1.0 |
| Betatron Tune | 3.23/2.72 |
| Transition $\gamma$ | 2.65 |
| Transition $\gamma_{pk}$ and Transition $\gamma_{kp}$ | 1.72/5.66 |
| Max. Betatron Functions [m] | 25.2/46.5 |
| Max. Dispersion [m] | 14.6 |

The junction straight is described as follows:

J-straight = QD4-QF4—EC—QF5-QD5—RForEXT—, where QF4, QD4, QF5, and QD5 are focusing and defocusing quadrupoles, EC the electron cooler, RF the RF cavity, EXT the extraction point, respectively.

The ACR is described as follows:

ACR = A-ring—J-straight—B-ring— -J-straight,

The layout of the ACR is illustrated in Fig. 1. The twiss functions calculated by MAD[3] are shown in Fig. 2.

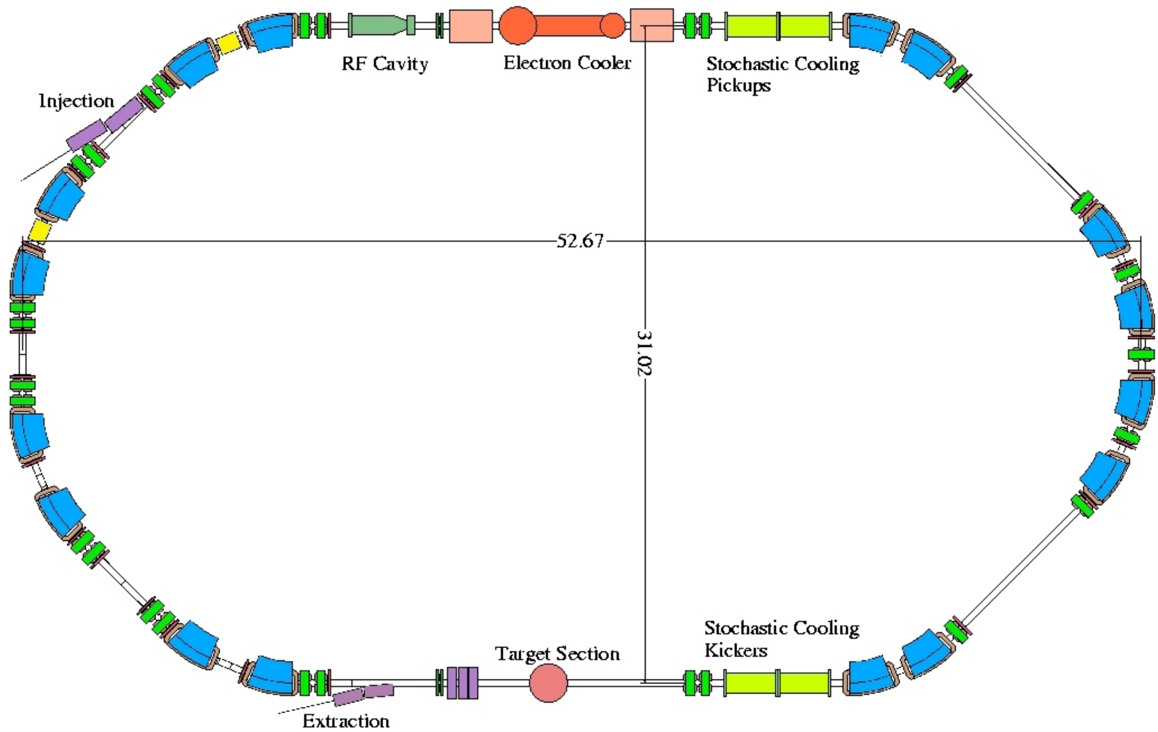



Figure 1: Layout of ACR.

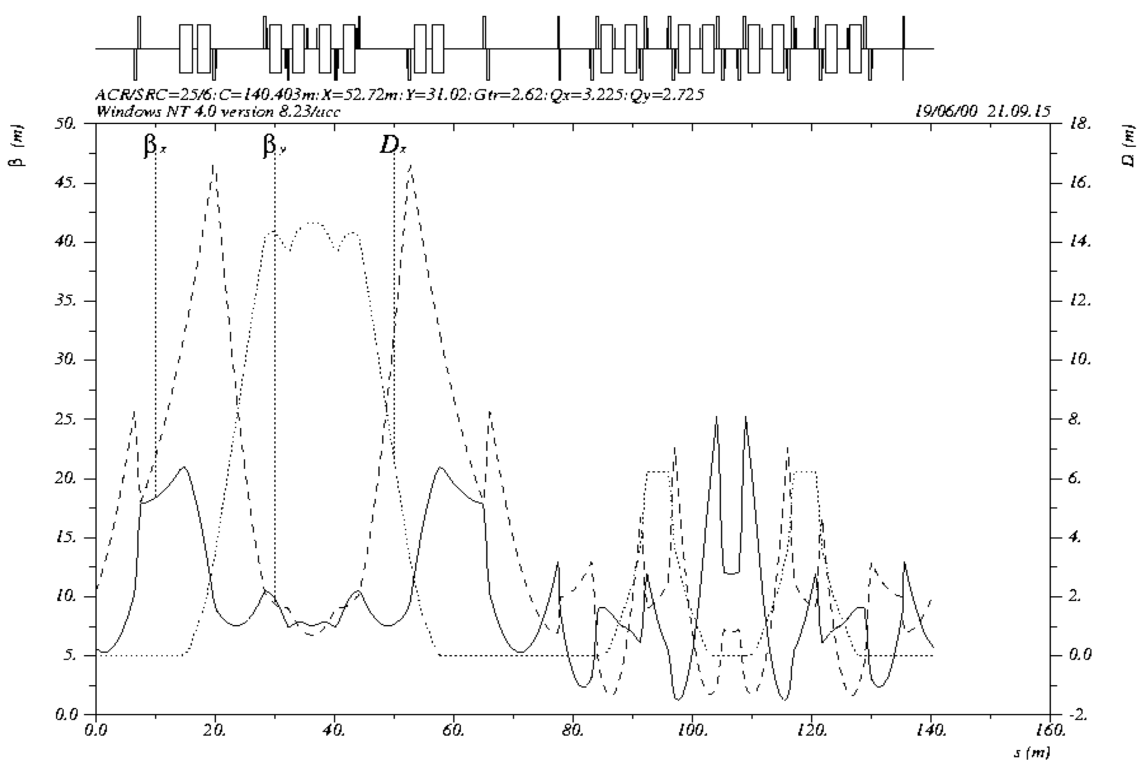



Figure 2: Twiss functions of ACR.

## 2.2 COD and Correction

The COD and its correction for the lattice were calculated by the MAD. All misalignments and field errors were supposed to distribute gaussian-like and the value of an 1σ were shown as below.

Bending magnets have 0.4mm of misalignments along horizontal, vertical, longitudinal axis, 0.2mrad of mis-rotations along 3 axis, and $5\times10^{-4}$ error fields of BL product, $1\times10^{-3}$ of K1L product, $1\times10^{-4}$ of K2L product.

Quadrupoles magnets have 0.2mm of misalignments along horizontal, vertical, longitudinal axis, 0.2mrad of mis-rotations along 3 axis, and $1\times10^{-3}$ error fields of K1L product.

The 19 of horizontal and vertical monitors and the 15 of horizontal and vertical kickers were supposed to install into the ACR ring. Trial COD calculations of 10 times and its corrections were performed. Maximum horizontal and vertical CODs were 10mm and 15mm, respectively. After the correction both distortions were reduced 1mm or less. It was found that maximum 0.6mrad of horizontal kicker force and maximum 0.8mrad of vertical kicker force were required. A typical COD before and after correction were displayed in Fig. 3.

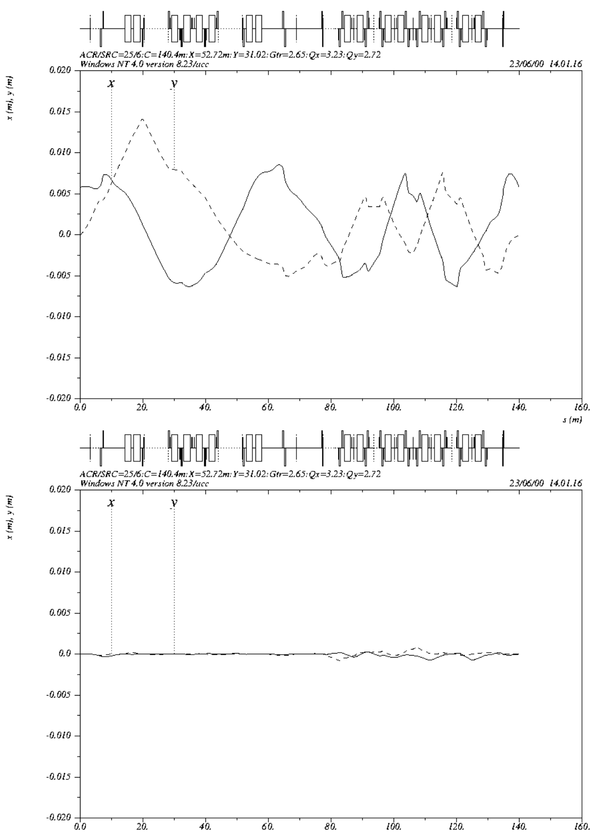
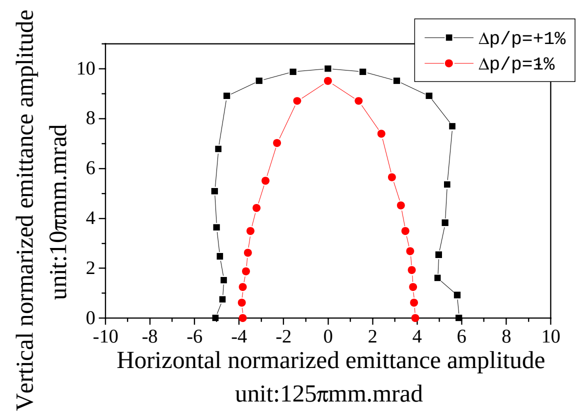


Figure 3: COD before and after correction.

## 2.3 Dynamic Aperture

The dynamic aperture after an optimization of sextupoles was also calculated by the MAD. It was supposed a bare lattice, which means no limitation derived from the duct hight and width, to use the calculation. The results were shown in Fig. 4, in which 2048 turns of tracking were performed in each point. The figure indicates large enough acceptance were reserved.

Figure 4: Dynamic Aperture for bare lattice of the ACR.




## 2.4 Injection and Stacking

RI beam are injected into the ACR with a multi-turn injection and cooling-stacking scheme up to $1\times10^{9}$ pps. The operation of the ACR are supposed in following manner:

1. The beams are injected by the multi-turn injection and the stored beam current is estimated to be about 10 times of injected beam current during 20μsec.
2. The beams are decelerated by the RF bucket and stacked to a bottom orbit. Then the multi-turn injection is repeated 3 or 4times so that the beam momentum spreads reaches to ±0.5%.
3. The beams are cooled by the SC and the EC during 100msec.
4. The cycle of above 1 to 3 is repeated 10 times and the beams are extracted by a fast kicker with synchronization to Booster Synchrotron Ring operation.

## REFERENCES

[1] K. Ohtomo and T. Katayama, "Injection Simulation Study at Accumulator Cooler Ring at RI Beam", p.2126, EPAC'98, Stockholm, June 1998.

[2] M. Wakasugi, et al., "Simulation Study of Stochastic Cooling for ACR at RIKEN MUSES", in this conference.

[3] H. Grote and F.C. Iselin, "The MAD program", CERN/SL/90-13.