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# THE MAGNET AND POWER SUPPLY SYSTEM FOR THE COMPACT-ERL*

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*Abstract*

The recirculation loop of the cERL (compact Energy Recovery LINAC) was constructed in 2013. In this paper, we show the magnet and the power supply system for the recirculation loop of the cERL. The recirculation loop consists of the eight main bending magnets at the arc section, sixty quadrupole magnets and ten small bending magnets for the three chicanes of the injection, extraction and circumference adjuster. The four power supplies are used for the chicane bending magnets, sixty for the quadrupoles, forty-eight for the horizontal correctors, and thirty-three for the vertical correctors. The EPICS (Experimental Physics and Industrial Control System) was adopted to control these power supplies.

## INTRODUCTION

The cERL (compact Energy Recovery LINAC[1-3]) consists of the injector, merger, recirculation loop, extraction chicane, and the beam dump. The photocathode electron gun generates the electron beam. The beam goes to the recirculation loop after the acceleration by the injector cavities through the merger chicane. The main linac cavities accelerates the beam to about 20 MeV. After the recirculation loop, the main linac decelerate the beam to about 3 MeV. Finally the beam dump catches the "used" beam after the extraction chicane. In this paper, we show the magnet and power supply system of the cERL.

## MAGNETS

The layouts of the magnets of the cERL are show in Fig. 1. For the magnet names in the figure, "B..''s are the bending magnets, "Q.." quadrupole magnets. "ZH..''s are the horizontal correctors and "ZV.." the vertical correctors. The all correctors at the recirculation path are the correction coils of the bending and quadrupole magnets. The four sextupoles for the bunch compression and restoration will be installed at the arc section in this summer of 2015. The parameters are shown in Table 1.

### *Bending Magnets*

The bending angle of the main bending magnet at the arc sections (BMIF and BMIR in Fig. 1) are 45 degree. The parameters are shown in Table 1. The eight sector type magnets are connected to one power supply. The path of the magnetic power cable was fixed in order to avoid the large solenoidal loop. The picture of the magnet is shown in Fig. 2(a).

The magnetic core consists of the lamination of the silicon steel. The edge of the magnetic core was cut in order to form the sector shape after the lamination. The magnetic cables of 200 mm$^2$ cross section was used for the full energy operation of 245 MeV (800 A). With 20 MeV operation, the magnetic current is about 50 A and the capacity of the present power supply is 100 A/40 V. All bending magnets have the correction coils of fifty turns for the horizontal corrector. The hollow conductor was used for the main coil in order to 800 A operation. However, no water cooling was required for present 20 MeV operation.

The two ready-made bipolar power supplies of ±10 A/±40 V were used for the five small bending magnets of the merger chicane (Fig. 3(a)); the one connected to BMAG3-5 and the other BMAG1-2. (For the beam operation, the unipolar type power supplies were sufficient.) For the recirculation beam, the turn numbers of the coils of BMAG3-5 are adjusted to achieve the local bump orbit. For the injection beam, the edge angle of BMAG2 is fixed to eliminate the dispersion function at the entrance of the recirculation loop. The correction coils of these magnets are used for the precise adjustment of the

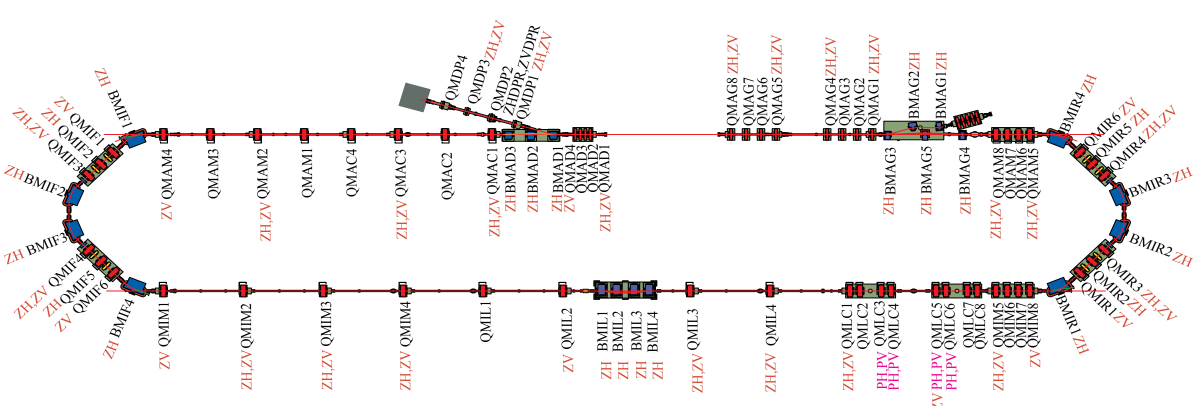

Figure 1: Magnetic Lattice of cERL.

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Table 1: Parameters of the bending magnets. The maximum magnetic fields are the measured effective magnetic field for the maximum magnetic current. The correction coils are used for the horizontal corrector.

| | Number | Core length [m] | Gap [mm] | | Maximum current [A] | Coil turn numbers | Maximum magnetic field [T] |
|---|---|---|---|---|---|---|---|
| Main bending magnet (BMIF1-4, BMIR1-4) | 8 | 0.82 | 60 | Main coil | 100 | 14 x 4 | 0.127 |
| | | | | Correction coil A | 5 | 50 x 2 | 1.812E-05 |
| | | | | Correction coil B | not used | 1 x 2 | 3.624E-07 |
| Circumference adjuster chicane (BMIL1-4) | 4 | 0.3 | 70 | Main coil | 30 | 184 x 2 | 0.248 |
| | | | | Correction coil | 5 | 40 x 2 | 8.991E-03 |
| Dump chicane A (BMAD1,3) | 2 | 0.3 | 70 | Main coil | 10 | 79 x 2 | 0.0351 |
| | | | | Correction coil | 5 | 8 x 2 | 1.777E-03 |
| Dump chicane B (BMAD2) | 1 | 0.3 | 70 | Main coil | 10 | 158 x 2 | 0.0701 |
| | | | | Correction coil | 5 | 16 x 2 | 3.551E-03 |
| Merger chicane A (BMAG1,3,4) | 3 | 0.2 | 70 | Main coil | 10 | 95 x 2 | 0.0456 |
| | | | | Correction coil | 5 | 10 x 2 | 2.400E-03 |
| Merger chicane B (BMAG2) | 1 | 0.2 | 60 | Main coil | 10 | 82 x 2 | 0.0498 |
| | | | | Correction coil | 5 | 10 x 2 | 3.034E-03 |
| Merger chicane C (BMAG5) | 1 | 0.2 | 70 | Main coil | 10 | 190 x 2 | 0.0925 |
| | | | | Correction coil | 5 | 20 x 2 | 4.868E-03 |

Table 2: Parameters of the quadrupole magnets. The maximum magnetic fields and field gradients are the measured effective magnetic field and gradients for the maximum magnetic current. The correction coils are used for the horizontal and vertical correctors.

| | Core length [m] | Bore diameter [mm] | | Coil turn numbers | Maximum current [A] | Maximum field gradient [T/m] | Maximum magnetic field [T] |
|---|---|---|---|---|---|---|---|
| 10cm QM (QMAG1-4, QMAD1-4) | 0.1 | 60 | main coil | 240/pole | 5 | 4.545 | |
| | | | correction coil A | 2/pole | 5 | | 9.174E-04 |
| | | | correction coil B | 2/pole | 5 | | 8.663E-04 |
| 20cm QM | 0.2 | 60 | main coil A | 25/pole | 100 | 8.310 | |
| | | | main coil B | 280/pole | 5 | 4.622 | |
| | | | correction coil A | 10/pole | 5 | | 3.074E-03 |
| | | | correction coil B | 10/pole | 5 | | 3.048E-03 |
| | | | correction coil C | 1/pole | 5 | | 2.868E-04 |
| | | | correction coil D | 1/pole | 5 | | 2.380E-04 |
| JAEA 10cm QM (QMAG5,8) | 0.1 | 102 | main coil | 398/pole | 5 | 2.709 | |
| | | | correction coil A | 4/pole | 5 | | 8.707E-04 |
| | | | correction coil B | 4/pole | 5 | | 8.324E-04 |
| JAEA 5cm QM (QMAG6,7, QMDP1-4) | 0.05 | 102 | main coil | 398/pole | 5 | 3.522 | |
| | | | correction coil A | 8/pole | 5 | | 2.434E-03 |
| | | | correction coil B | 8/pole | 5 | | 2.389E-03 |

beam orbit. The magnets are designed to achieve the maximum injection energy of 10 MeV (3 MeV at present).

The turn numbers of the coils of the extraction chicane (BMAD1-3, Fig. 3(b)) are also adjusted to achieve the local bump orbit for the recirculation beam. One power supply is used for these three magnets. These magnets are also designed to achieve the maximum injection energy of 10 MeV.

One power supply is used for the circumference adjuster chicane magnets of BMIL1-4 (Fig. 3(c)). The designed maximum energy of the recirculation loop was 125 MeV, and the indirectly water cooling type magnets were adopted. The main coils of the magnets were winded by the copper wire with water cooling pipe. For the 20 MeV operation, the water cooling was not required. In order to adjust circumference both positively and negatively, the bumped orbit of the half height was the initial orbit.

### *Quadrupole Magnets*

The quadrupoles between the injection and extraction chicanes (QMAG1-8, QMAD1-4) were optimized for the low energy (i.e. injection and extraction) beam. For these low energy quads, the core length of the magnets are 10 cm. The four old magnets of the JAEA FEL-ERL (17 MeV) were reused (QMAG5-8). All quadrupoles have two sets of the correction coils for the horizontal and vertical correctors. The power supplies were only connected to the correction coils of the magnets shown as “ZH..” and “ZV..”

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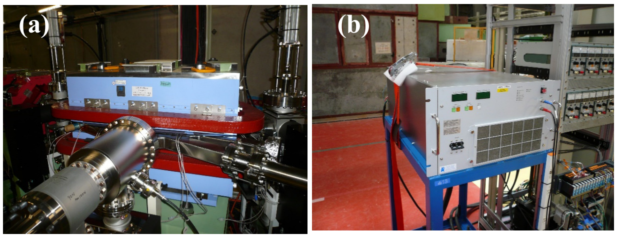


Figure 2: Main bending magnet and power supply.

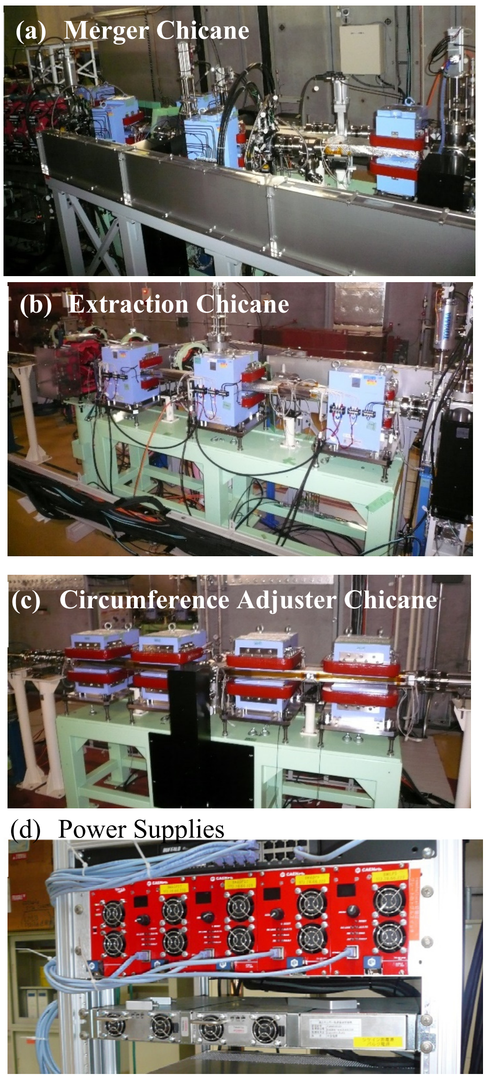


Figure 3: Chicane Bends and Power Supplies.

in Fig. 1. The quadrupoles at the dump line (QMAD1-4) were also old JAEA magnets. All quadrupoles for the low energy beams were designed to achieve B'L/B $\rho$=3 $m^{-1}$ for the maximum beam energy of 10 MeV.

The new quadrupoles of the core length 20 cm (Fig. 4(a)) were used for the recirculation path. The two type main coils were attached; the one was winded with the hollow conductor to achieve the maximum accelerated beam energy of 125 MeV and the other the copper wire for the initial commissioning with about 20 MeV beam energy.

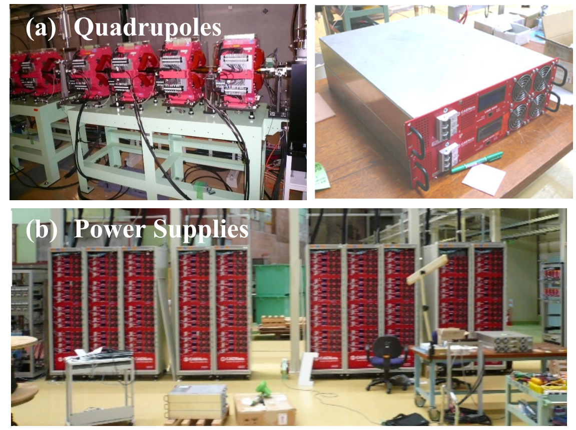


Figure 4: Quadrupoles and Power Supplies.

The wire coils were designed to achieve B'L/B $\rho$=3 $m^{-1}$ for 35 MeV operation, which was the estimated maximum beam energy of the recirculation loop with the present capacity of the cryogenic system and the superconducting cavities. The four sets of the correction coils were attached with all quadrupoles; the two sets of coils of ten turns for the usual horizontal and vertical correctors, and the two sets of one-turn for very precise adjustment. The power supplies for the quadrupoles, horizontal and vertical correctors were all the same power supplies with ±5 A/±60 V.

## POWER SUPPLIES

For the main bending magnets of the arc sections, we use the 100 A/40 V power supply (Fig. 2(b)) manufactured by Tokyo Electronics. The control interface was bit-I/O of the PLC (programmable logic controller) by Yokogawa Denshikiki. For the merger, extraction, and circumference adjuster chicanes, we use four modules of SY3634 series of ±10 A/±40 V (Fig. 3(d)) by CAENels. These modules have initially LAN based control interface.

The ±5 A/±60 V power supplies for the quadrupoles, horizontal and vertical correctors were LiAM6005 (Fig. 4(b)) by CAENels. We use 187 power supplies of this type including five spares.

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