# COMMISSIONING OF ELECTRON COOLING DEVICES AT HIRFL-CSR*

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*Abstract*

Electron cooling plays an important role in the Heavy Ion Research Facility of Lanzhou cooler storage ring (HIRFL-CSR). Two electron coolers were equipped in main ring (CSRm) and experimental ring (CSRe) in HIRFL-CSR respectively.

Two electron cooling devices have commissioned for twelve years since they were installed and completed in 2004.

The function and operation procedure of electron cooler were presented in this report. Their performance and the highlights of experiments results were described. Their commission and optimization were summarized here. The issues and troubles during the commission were enumerated and collected in this presentation. The future upgrade and improvement were suggested, and the new operation scenario and requirement were proposed.

## INTRODUCTION OF HIRFL-CSR

HIRFL-CSR (Heavy Ion Research Facility at Lanzhou---Cooling Storage Ring ) is multi-purpose accelerator complex [1], it is consisted two storage ring, the heavy ion beam with energy range 8-50 MeV/u from HIRFL—composed two existing cyclotron SFC(K=69) and SSC (K=450) is used as injector, will be accumulated, cooled and accelerated to the high energy range of 100—400 MeV/u in the main ring (CSRm), then extracted fast to produce RIB or highly charged heavy ions. The secondary beams will be accepted and stored by experimental ring (CSRe) for many internal target experiments or high precision spectroscopy with beam cooling, On the other hand, the beam with energy range of 100-900 MeV/u will also be extracted from CSRm with slow and fast extraction.

Accelerated ion beam from the CSRm through the radioactive beam separator line with the length of 100m was injected into the CSRe. Generally the CSRe operated with the DC mode. A gas jet internal target was installed in the opposite side of electron cooler.

## ELECTRON COOLING FOR CSR

In CSRm, the electron cooling device [2, 3, 4, 5, 6] plays an important role in the heavy ion beam accumulation at injection energy. The new state-of-the-art electron cooling device was designed and manufactured in the collaboration between BINP and IMP, it has three distinctive characteristics, namely high magnetic field parallelism in cooling section, variable electron beam profile and electrostatic bending in toroids.

Each ring was equipped an electron cooling device, the electron energy in the main ring is 35 keV and 300 keV for the experimental ring.

The electron cooling device plays an important role in HIRFL-CSR experimental ring for the heavy ion beam. Continuous electron cooling is applied to the stored ion beam for the compensation of the heating by various scattering. The most important is the ability to cool ion beams to highest quality for physics experiments with stored highly charged ions.

## STATUS OF HIRFL-CSR

In the past several years, more than 7000 operational hours was scheduled yearly for HIRFL-CSR, half of them were provided by the storage ring. Most beamtime was dedicated to the mass measurement experiments, recombination of ion with the free electron of cooler and the internal target experiments. The other beamtime was devoted to the cancer therapy and related experiments. More than 100 patients were treated in CSRm with the carbon beam. However, the extremely heavy ion beam like Bi and U were successfully cooled and accumulated with very low injection energy and weak intensity. A few times commission for accumulation of proton with the help of electron cooling were performed in CSRm, including instead of proton with $H_2^+$, these commission were not successfully completed carried out up to now due to the mismatching parameters between injector and storage ring.

## COMMISSIONING AND OPERATION OF ELECTRON COOLING IN CSR

About kind of ion beam was accumulated with the help of electron cooling in CSRm. The ion species from H to Uranium, and the energy range from to 1.2MeV/u to 21.7MeV/u. The experiments and operation results were reported in the workshop on the beam cooling and related topics from 2005 to 2013 [7, 8, 9, 10, 11] and RuPAC 2010 [12], RuPAC 2012 [13]. One can find the related papers in the references. Some investigation and optimization experiments [14, 15] were completed in CSR. Some accumulation experiments in CSRm, cooling force measurement, optimization of electron cooling and bunch length measurement in CSRe were implemented.

## WHAT WE HAVE DONE

### *Temperature Stabilization System*

During the operation, we found the tunnel temperature have the influence on the stability of high voltage output of cooler system, it presented a sine wave in the day and

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night. In order to decrease this effect, a special room was established to keep the constant temperature for the electronic system of the high voltage terminal of the electron cooler.

### *Electric and Magnetic Screen*

Due to the electronic system of the high voltage terminal of the electron cooler was placed in the outside of tunnel and some place as the other power supplies for dipoles and quadrupoles magnets etc. The spatial electromagnetic wave had the influence on the stability of high voltage output of cooler system. With the help of a special shielding room, the electronic system of the high voltage terminal of the electron cooler was well screened, and the stability of output was improved.

### *Electrical Network Voltage Stabilization*

Because of the CSRm ring operated in the pulse mode, a voltage sudden drop appeared during the ramping time in the input of power network due to huge load. A voltage stabilizer for the amplitude regulation was installed before the input of high voltage terminal.

### *Improvement of HV Stability*

In the initial design, there were some electronic elements with low temperature coefficient, these elements were replaced by some with the higher temperature coefficient.

### *Screen of Amplifier of BPM*

The signal from the beam position monitors in the cooler was influenced by the spatial electromagnetic wave from the power supplies of dipoles and other system, this noise became serious in the case of low intensity of stored ion beam. A screen box was designed and used for the preamplifiers of BPM systems the beam position measurement procession was improved.

### *CAMAC into NI Card in the BPM*

In the initial design, a CAMAC system was established for beam position monitor, this system was replaced by 8-Channel Digitizers NI PCI-5105 card, and a new measurement interface based on LabVIEW was established. This made the measurement more convenient.

### *Replace the Correction Coils Power Supplies*

There are twelve pair coils in the cooler in order to adjust the electron beam position and angle. These coils were powered individually. The current output stability had the influence on the measurement results of the electron beam position. The old analog electronics power supplies were replaced by the new digital controlled systems. The vibration of electron beam position was improved.

### *Drying of $SF_6$*

Due to there was water vapour in the $SF_6$, the higher voltage output was not approached because of spark, a special drying system was used to remove the water vapour in $SF_6$, 285kV output was achieved after high voltage training.

## ISSUES DURING OPERATION

### *Issues for Cooling Water*

The trouble from deionized water for collector cooling lasted for long time. This problem influenced the operation of the electron cooling devices. At the beginning, the cooler did not work at higher voltage due to lower resistance. After some period operation, the water tube had to be cleaned by special acidic liquid due to the residual oil form the copper winding wire of various coils in the storage ring. As a result, some components were corroded by this liquid. The leakage happened in some weaker position at the connector of cooling water system. Specially, in the ceramic insulator section, the surface of collector was covered by the ferrugineous rust caused by the leakage. During the period of operation, spark happened due to the worst insulation. The current load became bigger than normal situation, and the power supply of collector was destroyed finally.

### *Issues form Control System*

The control program for CSRm electron cooling devices was developed in the environment of Windows 98 system in the initial design. It was based on the LabWindows/CVI and LabVIEW. A special card named PCI-7841 was used for the communication between computer and electron cooling devices. The communication was based on the CAN bus. The PCI-7841 is a Controller Area Network (CAN) interface card. It supports a dual-port CAN's interface that can run independently or bridged at the same time. The built-in CAN controller of this card is Philips SJA1000, which provides bus arbitration and error detection with auto correction and re-transmission function. This needs special drive of DOS libraries and Windows DLLs (95, 98, NT, 2000, XP).

Up to now, the control system of electron cooling devices has not combined into the global control system of HIRFL-CSR. The electron cooling devices was controlled by the independent subsystem. As the upgrade of Windows system, The DOS libraries and Windows DLLs (95, 98, NT, 2000, XP) for PCI-7841 card had to been upgraded accordingly. At the same time, the different version of operation system existed small different. This factor made the operation inconvenient in the commission of electron cooling devices.

### *Issues form Beam Diagnostics System*

In order to measure the profile of ion beam in the storage ring, a magnesium vapour profile monitor was installed in the upstream of electron cooling device in CSRm. At the beginning of this monitor operation, the temperature was not controlled well, some magnesium vapour escaped form monitor chamber and entered the vacuum chamber of cooling section. As a consequence, the insulator surface of beam position monitor in the cooling section was polluted by the magnesium vapour,

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the insulation became weaker and worse. After some spark treatment, this situation became better, but the beam position monitor did not worked stably.

### *Issues of stability*

It was important for mass measurement high voltage stability of electron cooling devices, it determined the final resolution.

In the case of atomic physics experiment, the stability of electron beam position was required in some position sensitive experiments, especially recombination experiment.

In the experiments of recombination, the electron beam current stability was also a focus point.

The stability of high voltage will be an issue for long-term effort and related many aspects from point of view of improvement and upgrade in the aspects of performance of electron cooling devices.

## IMPROVEMENTS AND UPGRADE

- Real-time monitoring of ion beam position.
- Real-time monitoring of electron beam position.

In order to improve the performance of electron cooling system, a real-time monitoring system of the position of electron and ion beam was taken into account,

- Automatically ion beam orbit correction.
- Automatically electron beam orbit correction.

Based on the BPM real-time monitoring system, a automatically orbit correction of electron and ion beams was taken into account.

## NEW REQUIREMENTS

- Switch on and off electron beam momentarily.

The electron beam was required to turn on and off in the different period of the atomic physics experiments.

- Change the energy of electron beam momentarily.

The energy of the electron beam was required to change in the different cases of the atomic physics experiments.

- Energy modulation of electron beam.

The energy of the electron beam was required to modulate in the different cases of the atomic physics experiments.

- Density modulation of electron beam.

The radial density distribution of the electron beam was required to modulate in the different cases of the atomic physics experiments.

- Electron beam bunch

In order to demonstrate the cooling of bunched electron beam, the formation of electron beam bunch was taken into account recently.

## SUMMARY

From 2006, the electron cooler have operated well for ten years. Electron cooling, ion beam accumulation and electron cooling experiments were performed in HIRFL-CSR. Several physics experiments were completed with the help of electron cooling in CSR. The results show the electron cooling had well performance in the commission. In the future, the application of electron cooling should be extended according to the physics experiments. The performance of electron cooling should be improved carefully, and the reliability and stability of electron cooling should be upgraded in the future.

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