BNL-100894-2013-CP

Progress with coherent electron cooling proof-of-principle experiment

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Presented at the 4th International Particle Accelerator Conference (IPAC 13)
Shanghai, China
May 12-17, 2013

Collider-Accelerator Department
Brookhaven National Laboratory

U.S. Department of Energy
DOE Office of Science

DISCLAIMER

PROGRESS WITH COHERENT ELECTRON COOLING PROOF-OF-PRINCIPLE EXPERIMENT*

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Abstract

We are preparing for the proof-of-the-principle experiment of coherent electron cooling (CeC), to test the technique with a potential of significant boost in luminosity of high-energy, high-intensity hadron colliders [1]. In this paper, we report on the progress with the procurement, testing and installing the experimental equipment, including the first tests of the electron gun and the magnetic measurements of the wiggler prototype. We describe the current design, the status of the project, as well as, our plans.

PROJECT OVERVIEW

Figure 1 shows the overall layout of the experiment [2]. The electron beam will be generated by a CsSb photocathode inside the 2 MeV 112 MHz SRF gun. Two 500 MHz copper RF cavities will provide energy chirp for ballistic compression of the electron beam. The compressed bunches will be further accelerated to 22 MeV by the 704 MHz 5-cell SRF linac.

The electron beam will merge with 40 GeV/u heavy ion beam after passage through a dogleg. The ions will “imprint” their distribution into the electron beam by modulating in the e-beam density in their locations. This modulation will be amplified in a high-gain FEL comprising of three 2.5-m-long helical undulators.

The ions will co-propagate with electron beam through the FEL. In the FEL, the ion’s average velocity is matched to that of the group velocity, e.g. to the propagation speed of the wave-packet of the e-beam density modulation. A three-pole wiggler at the exit of the FEL will be used to tune the phase of the wave-packet in such away that the ions with the nominal energy experience zero longitudinal electric field.

The time-of-flight dependence on the ion’s energy will then insure that the off-energy ions will be accelerated or decelerated, depending on the sign of their energy error. As the result of such interaction, the ion beam’s energy spread will reduce [1].

The used electron beam will be bent away from the ions’ path and is dumped.

RF SYSTEM

112 MHz RF Gun

Niowave has modified the 112 MHz SRF cavity into a

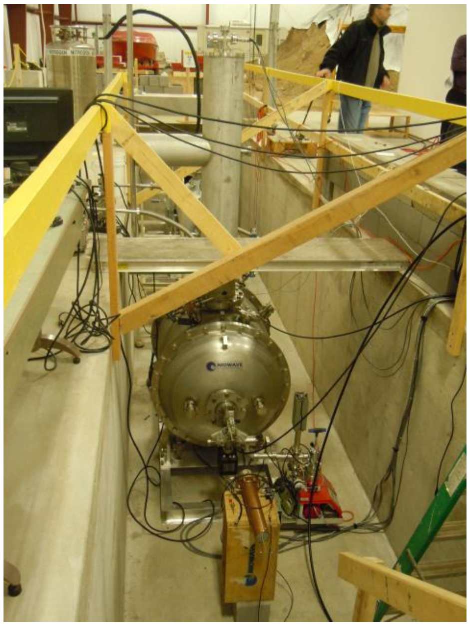

Figure 2: The 112 MHz cavity in the trench during the test at Niowave.

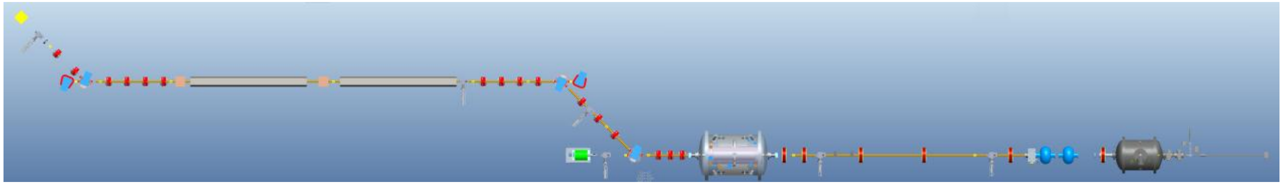

Figure 1: The layout of the CeC PoP experiment.

gun within a new cryomodule. One of the design modifications is addition of two manual tuners for coarse

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adjusting of the cavity's frequency close to be a harmonic of the RHIC's revolution frequency.

The cavity was tested at Niowave (Fig. 2) in February and delivered to BNL in April 2013. The cavity tests were performed utilizing two small antennas. In the final configuration the 112 MHz gun [3] will be equipped with a water-cooled fundamental power coupler shown in Fig. 3. It will be used to fine-tuning of the cavity's frequency. With the design accelerating voltage of 2 MV, during the test maximal voltage was limited to 1 MV due to the increasing radiation levels in a semi-open test environment. We plan to test the SRF gun at full accelerating voltage later this year after its installation into the RHIC tunnel during the shutdown. The 112 MHz 2 kW amplifier for the gun is in place.

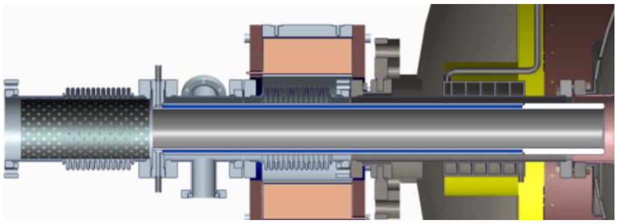

Figure 3: Design of a water-cooled fundamental power coupler for 112 MHz RF gun. Two bellows allow using the coupler as fine tuner of the cavity frequency. Focusing solenoid is placed over the bellow connected to the cavity vessel.

500 MHz System

We have refurbished two 500 MHz copper cavities, which are at BNL on a long-term loan from the Daresbury Laboratory, UK. Presently, the cavities are being conditioned, and will be installed into the RHIC tunnel during summer/fall of 2013 along with the gun.

Figure 4: Two 500 MHz cavities mounted on a common support before installation into the IP2 region.

704 MHz Accelerating Cavity

There are two 20 MV 5-cell accelerating cavities: one was fabricated by Advanced Energy Systems [4] and the other by Niowave. BNL will conduct the test of the both accelerating cavities in the vertical test facility this summer. Upon test completion, the best performing cavity will be chosen for placement into the cryo-module, which is under design by Niowave and BNL.

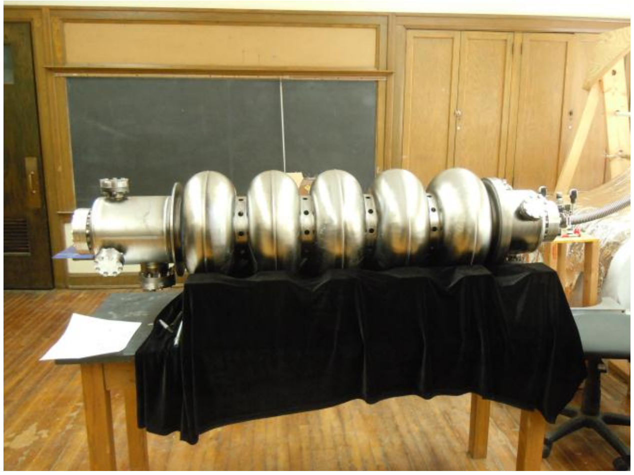

Figure 5: 704 MHz SRF accelerator cavity at Niowave after vacuum leak check.

LOW ENERGY SECTION

The low energy section of CeC accelerator (up to the 20 MeV linac) planned be installed during 2013 RHIC shutdown. A low power beam dump with Faraday cup at the end of the beamline will be used for low-current commissioning of the gin and the bunching cavities.

DIAGNOSTICS

The diagnostics for the CeC system [5] include nine beam position monitors (BPMs), two integrating current transformers (for measuring the current and beam transmission), four flags to measure beam sizes (as well as emittances and energy spread at 22 MeV), and one pepper pot (for measuring the emittance of the low-energy beam in the 2 MeV section). We will employ beam-loss monitors to control the beam losses in the CeC beam-line and the irradiation of the helical undulator. The longitudinal profile of ion beam will be observed using the existing RHIC wall-current monitor with 6 GHz bandwidth.

HELICAL UNDULATOR

We used BNL's LDRD funds to proceed with prototyping a helical wiggler. Figure 6 shows the 50-cm undulator prototype during the magnetic measurements at BudkerINP. The undulator was tuned to reach the requirements for CeC PoP project. The residual phase error is shown in Fig. 7.

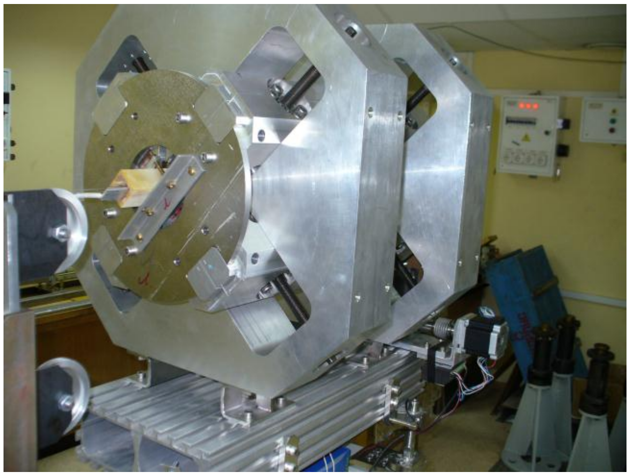

Figure 6: The prototype helical undulator undergoing magnetic measurements.

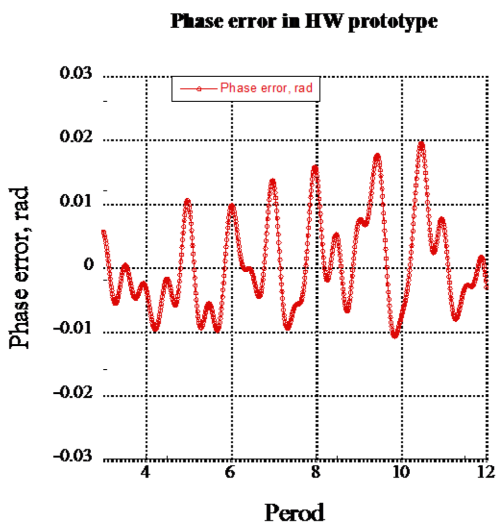

Figure 7: After the tuning, the measured phase error in the prototype helical undulator satisfies our requirements.

OTHER SYSTEMS

We are making steady progress with procuring the cryogenic system and the driver laser. The laser will generate flattop pulses of variable durations from 100- to 500-picoseconds, and with the leading- and the falling-edges below 150 picoseconds. The optical peak power should exceed 1 kW at 532 nm. The laser will be synchronized with RHIC timing system via a low-level RF system. The initial commissioning will also utilize a UV laser (4^{th} harmonic of 1.04 microns), which is on hands.

A significant part of other CeC equipment and manifolds had been installed in the buildings adjacent to the IP2 (see Fig. 8 and 9).

PLANS

We plan to commission the installed equipment, including the SRF gun, an generate first e-beam during RHIC's Run 14. The 20 MeV linac, the helical undulators, the high power beam dump, and the balance of equipment planned to be installed during RHIC shutdown in 2014.

Figure 8: 2K cryogenic equipment for CeC PoP

Figure 9: 500 MHz power amplifier for CeC PoP

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