# BEAM INSTRUMENTATION FOR THE COSY ELECTRON COOLER

E. Bekhtenev, V. Bocharov, M. Bryzgunov, A. Bubley, A. Denisov, G. Karpov,
V. Panasyuk, V. Parkhomchuk, V. Reva , BINP SB RAS, Novosibirsk, Russia
V. Kamerdzhiev, L. Mao, K. Reimers, FZ-Jülich, Germany
J. Dietrich, TU-Dortmund and HIM Mainz, Germany

*Abstract*

The report deals with beam instrumentation of the electron cooler for COSY storage ring. The electron cooler is an electrostatic accelerator designed for beam energy up to 2 MeV and electron current up to 3 A in energy recovery mode. The electron beam is immersed in longitudinal magnetic field so the electron motion is strongly magnetized. The control electrode in the electron gun is composed of four electrically isolated sectors. Applying AC voltage to one sector allows tracing of motion of that particular part of the beam. The electron beam shape is registered with the combination of 4-sector electron gun and the BPMs. This method allows observing both dipole and quadruple (galloping) modes of electron beam oscillation. Compass probe for measuring and tuning the direction of magnetic field in the cooling section is described. A monitor based on a few small Faraday cups for measuring the electron beam profiles is presented.

## INTRODUCTION

The 2 MeV electron cooler for COSY was built at BINP [1]. The design energy and good performance of the subsystems were demonstrated during electron beam commissioning in Novosibirsk. Further conditioning with electron beam is required to achieve electron currents above 200 mA at high energy. It will be done after the installation in COSY.

The electron beam is transported to and from the cooling section by two transport lines (see Fig. 1). This is due to the requirement of the HV system being installed outside the accelerator radiation shielding.

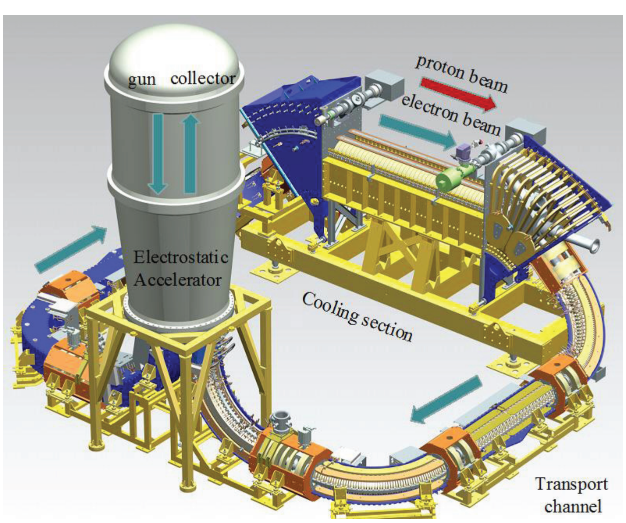


Figure 1: Layout of the 2 MeV electron cooler.

Lossless beam transport is essential for operation in the energy recovery mode. Beam position measurement and correction are necessary for beam loss minimization and accurate beam alignment in the cooling section. The design of the cooler includes numerous beam diagnostic systems. 12 beam position monitors (BPMs) provide position information in the electron transport lines and in the cooling section. The electron gun and its high voltage power supplies were designed having beam diagnostics in mind. Only electron gun features directly related to beam diagnostics are discussed in this paper. A Faraday cup array is used to measure the profile of the electron beam at low average current. Periodic verification of the magnetic field straightness in the cooling section is required to ensure best possible cooling.

## ELECTRON GUN

Beam position measurements require modulation of the electron current. This is done by applying AC voltage at 3 MHz and up to 10 V to the gun control electrode (see Fig. 2). Furthermore, the control electrode of the electron gun is composed of four electrically isolated sectors [2]. Applying AC voltage to one sector at a time allows the use of BPMs for tracing the corresponding part of the electron beam. Comparing the positions of each sectors from BPM to BPM or the sector positions in a single BPM at different currents in the corrector coils it is possible to analyze the optics in the transport line.

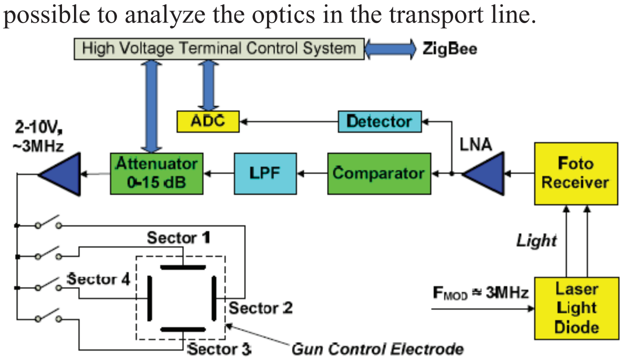


Figure 2: Diagram of the gun modulation electronics.

The modulation electronics is mainly located inside the HV vessel at potential of up to 2 MV. Modulation signal is transmitted to high voltage part by means of light [3]. Laser diode ADL-66505TL mounted on a viewport outside the HV vessel is used as optical transmitter. Its optical output power is stabilized at the level of 20 mW. Silicon PIN photodiode BPW34 located at 0.3 m distance from the laser diode is used as optical receiver. Combination of a low noise amplifier (LNA) and a comparator allows to have stable modulation voltage at

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the control electrode even if the optical transmitter is misaligned by up to 10 deg. Measuring the modulation voltage at the LNA output by means of a detector and an ADC allows adjustment of transmitter angle for maximization of optical power coming to the receiver.

## BEAM POSITION MONITORS

BPM signal processing electronics includes a preamplifier and a signal processor consisting of analog and digital boards [3]. The preamplifiers with high input impedance are located close to the pickups. Main parameters for the BPM system are shown in Table 1.

Table 1: Main Requirements for the BPM System

| | |
|---|---|
| Electron current | 0.1-3 A |
| Modulation amplitude of electron current | 0.3-1.5 mA |
| Proton current | 0.1-2 mA |
| Position measurement error | < 100 µm |
| Measurement rate | 0.1-1 s |

The principle of operation is shown in Fig. 3. The preamplifier is connected to the pickup via four 75 Ohm 1.2 m long cables. The switches used in the preamplifiers provide 4 connection combinations between 4 BPM electrodes and 4 signal processing channels. This approach allows eliminating measurement error caused by inequality of the channel transmission coefficients. After amplification the BPM signals with frequency $F_{SIGN}$ are mixed with reference frequency $F_{SIGN} + \Delta F$.

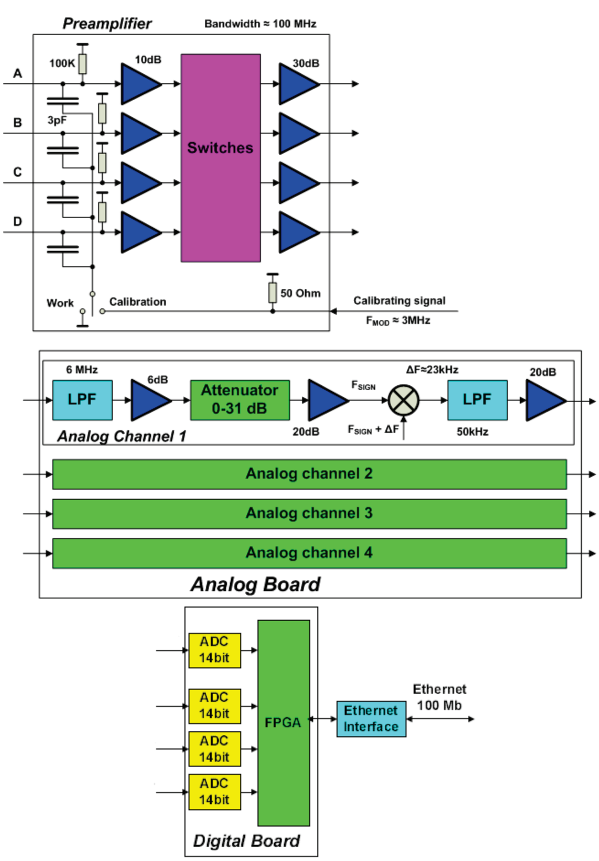


Figure 3: Block diagram of the BPM system.

The $\Delta F$ = 23 kHz signals are sampled by a 14 bit ADC after low pass filtering and amplification. The digital signals are sent to an FPGA where further processing is performed. It includes synchronous detecting and accumulation. A 3 MHz calibration signal can be applied to the preamplifier inputs via S1 switch. The BPM processor occupies one 1U 19" chassis. Each processor can serve two BPMs. The system was built and tested. It was in operation with electron beam at BINP since November 2011.

Table 2: Measured Accuracy of the BPM System

| | |
|---|---|
| Position variation for different beam modulation, $I_{MOD}$ = 0.3-1.5 mA | 4 µm |
| Resolution, $I_{MOD}$ = 0.3-1.5 mA | < 1 µm |
| Temperature dependence | 2 µm/°C |

To determine the position accuracy a sinusoidal 3 MHz test signal was used. It was applied via four-way splitter to four preamplifier inputs. Signal amplitude was changed in the range 0.2-1 mV corresponding to beam current modulation range 0.3-1.5 mA.

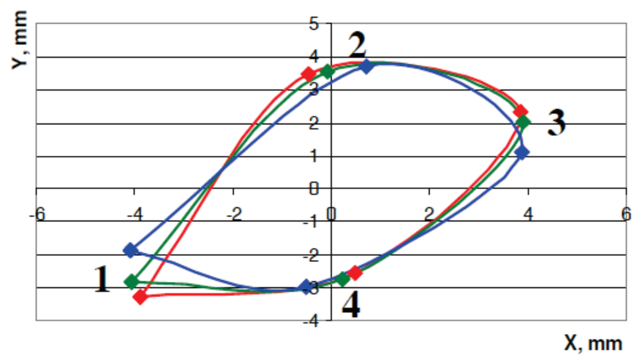


Figure 4: Beam positions measured by three different BPMs: BPM2 (red), BPM4 (green) and BPM10 (blue). The gun modulation was applied to one sector at a time.

The results of experimental evaluation for $K_X$=$K_Y$=43 mm are presented in Table 2. Figure 4 illustrates the electron beam shape measured at three different locations while driving the gun in the single sector mode as described in the previous section [3].

## PROFILE MONITOR

A detector consisting of six Faraday cups located in the transport line is used to measure electron beam profiles.

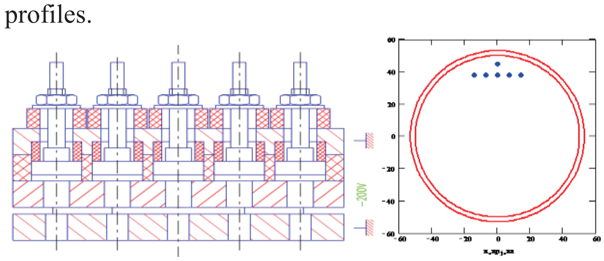

Figure 5: Design of the Faraday cup detector for profile measurements (left, 5 of 6 cups are shown) and its location within the beam aperture (right).

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The electron beam is deflected by a corrector magnet onto the detector and does not reach the collector. In order to minimize the load on the HV generator the cooler is operated in pulsed mode (5 μs pulse at 20 Hz repetition rate). The Faraday cup signals are recorded together with horizontal and vertical corrector currents while the beam is scanned across the detector.

## MAGNETIC FIELD STRAIGHTNESS

The efficiency of the cooling process strongly depends on the quality of longitudinal magnetic field in the cooling section. Magnetic field straightness of the order of $10^{-5}$ is required. That's why the cooling solenoid is composed of numerous short coils. The angle of individual coils can be adjusted. In order to measure magnetic field straightness a highly sensitive magnetic probe was designed and built. The basic idea of this probe is similar to the ones used at BINP and Fermilab for the same purpose [4]. However, the compass-based probe is installed on a guiding rail inside the vacuum chamber of the cooling section. This is done to improve the availability of the cooler. The light beam generated by a laser is reflected by a mirror attached to the compass. The reflected laser beam is then detected by a 4-segment photodiode. A feedback system using two differential signals from photodiode segments, controls currents in horizontal and vertical corrector coils. The value of this current corresponds to the transverse magnetic field in the cooling section. Figure 6 illustrates system operation. The important feature of the probe described is operation in vacuum. Therefore the gimbal suspension and jewel bearings were used instead of an organic polymers thread. This engineering solution decreased the accuracy of the probe but improved the mechanical strength of the device. The permanent magnets were replaced by needles made from a soft magnetic material. The field to be measured is strong enough so there is no loss of sensitivity. Furthermore, the probe should withstand baking at 200 ºC without losing its characteristics. Soft magnetic material is suitable for this purpose. For mechanical stability of the mirror surface it was made from polished molybdenum without any additional reflective layer.

Figure 7 shows the horizontal magnetic field in the cooling solenoid before and after coils adjustment. The rms ripple of the magnetic force line was decreased from $6 \cdot 10^{-4}$ to $2 \cdot 10^{-5}$.

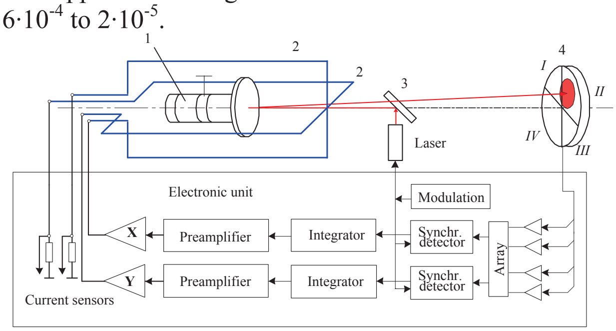


Figure 6: Illustration of the operating principle of the system monitoring magnetic field straightness. Magnetic sensor (1), corrector coils (2), beam splitter (3), photo-detector (4).

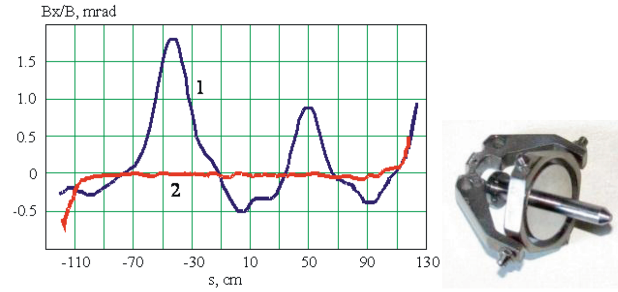


Figure 7: Horizontal magnetic field in the cooling solenoid before (1) and after (2) coil adjustment (left). Photograph of the magnetic sensor (right).

## SUMMARY

The 2 MeV electron cooler was designed, built and commissioned with electron beam at BINP. The design energy was demonstrated. Obtaining high electron currents at nominal energy requires further conditioning which will continue after the installation of the cooler in the COSY ring. Beam instrumentation is a vital part of the cooler. Several electron beam modulation techniques are implemented in the gun electronics enabling beam position and shape measurements. The novel gun design was shown to be very useful from the point of view of beam diagnostics. The four-sector technique allows observing both dipole and quadruple modes of electron beam oscillation. The BPM system was tested with electron beam. The position accuracy was determined to fulfil the requirements. A laser based system for measuring straightness of magnetic field in the cooling section without breaking vacuum was successfully used to optimize the field quality in the cooling section. A detector consisting of 6 Faraday cups was used to measure electron beam profiles at low average current. Beam instrumentation was extensively used during commissioning at BINP. Good performance of the subsystems described was shown·

## ACKNOWLEDGMENT

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