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INSTRUMENTATION AND OPERATION MODES FOR THE COMMISSIONING PHASE OF THE SEALAB SRF PHOTOINJECTOR

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Abstract

Superconducting radio-frequency (SRF) photoinjectors offer a broad range of electron beam parameters and are therefore suitable for many applications such as energy recovery linac (ERL) driven lightsources, particle colliders, or for ultrafast electron scattering experiments. We are now nearing completion of the setup a SRF photoinjector with a SRF gun and SRF booster linac at the SEALAb accelerator test facility at HZB. The goal here is to realize an electron source with high brightness and high average current. In this work, the general planning for the commissioning phase, the operation modes and investigations into the diagnostic tools for achieving the expected beam parameters will be presented. The focus of the instrumentation is to provide information on the beam parameters at large dynamic range and on mechanisms for beam loss generation.

INTRODUCTION

The commissioning phase is important for high-brightness and high-current SRF machines in order to achieve stable beams that meet a wide range of specifications. Our laboratory is called Sealab which is a Superconducting RF Electron Accelerator Laboratory. From ERL to other applications of the machine, we need different machine modes with a strong machine protection system and reliable diagnostic tools. The general layout of the whole machine can be seen in Figure 1. The booster and main SRF cavity are not yet ready, and the booster section has been replaced with three quadrupole magnets. All the necessary technical infrastructure and installation of major components for the warm machine has been completed. The initial commissioning of the machine will focus on the injector, the first meter linac, and the diagnostic line through the low-power dump.

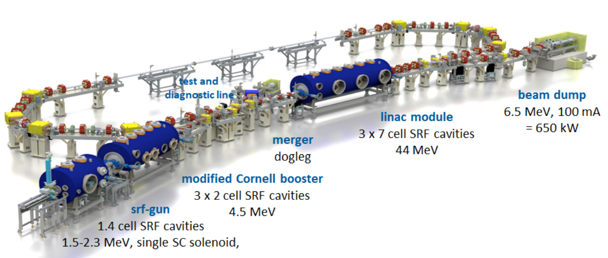

Figure 1: The initial layout of the machine. The booster was replaced with 3 quadrupole magnets until the booster module was ready for assembly.

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Before beginning the initial beam commissioning, it is important to ensure that specific components have undergone their own commissioning processes, such as the high-level RF system. Currently, the accelerator is in the final stages of assembly and commissioning for the diagnostics, cryoplant, SRF modules, and photocathode laser system [1]. The refurbishing of the SRF photoinjector has been completed, and the first RF tests are currently ongoing. The initial beam is expected to be available at the end of 2023.

To ensure successful initial commissioning, the average beam current should be kept below the threshold current of approximately 0.5 uA, which is necessary due to diagnostic tool restrictions, specifically from the viewscreens. Therefore, we have set our initial average current to 0.35 uA. The charge will begin at 7 pC per bunch and increase to 77 pC in the secondary phase. The initial parameters for 7 pC and 77 pC with continuous wave and macro pulse are detailed in Table 1. We will start with continuous wave during the first phase to avoid synchronization issues which comes from the viewscreens. For the second phase, we plan to switch to macropulses, which are better suited for the first meter diagnostic tools. To transition from 7 pC to 77 pC, we will use the same beam parameters but with a decreasing number of macro pulses down to 10.

Table 1: The initial beam parameters. L is the length and f_{rep} is the repetition rate

Parameter	**CW/7pC**	**Macropulse/7pC**
$f_{\mathrm{rep(micropulse)}}$	50 kHz (20 us)	50 MHz (20 ns)
$f_{\mathrm{rep(macropulse)}}$	CW	10 Hz
$L_{\mathrm{macropulse}}$	-	20us
$L_{\mathrm{micropulse}}$	2 to 6 ps RMS	2 to 6 ps RMS
Micropulse energy	1.7nJ	1.7nJ
Spotsize on cathode	0.7 mm	0.7 mm
# of micropulse	-	100

Regarding cathode current measurements, the work in progress about increasing the macropulse repetition rate for smoothing the measured signal using an RLC network. However, a 10 Hz repetition rate is crucial for compatibility with the viewscreen stations. The design of new electronic circuits and exploration of different options for cathode current measurements is still ongoing.

MPS SYSTEM

The machine protection system (MPS) is essential for high-brightness and high-charge accelerators as it protects

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the accelerator structures from unexpected damage. The MPS aims to detect beam losses using beam loss monitors and analyzing the signals with set thresholds. When the signal exceeds the threshold, it sends a signal to the relevant components to stop the beam. [2] The most effective way to stop the beam is to shut off the laser to prevent the creation of the electron bunch. When necessary, the main controller sends a closing signal directly to the laser shutter. The response time is very fast in cases of significant beam loss, which is below 10 us.

The general working scheme of the MPS system can be seen in Figure 2. The MPS main board takes signals from BLMs, which use visible light pin-diode sensors, processes the signal according to the configuration files, and sends an output signal to the laser. The main board is an FPGA unit that digitally checks every input signal (0 or 1). Additionally, by connecting the main controller to the EPIICS control system, the MPS can send an alert to the control room, notifying operators of beam loss situation.

In addition to the beam loss monitors, the MPS system also includes other safety features for protecting the accelerator,also it serves as a personal protection system (PPS). First one is the interlock system, which is triggered when the BLMs detect a signal above the set threshold. The interlock system stops the beam and initiates a series of safety protocols to ensure that the accelerator is safe to operate. Also, our system is open to add other imput signals from the different components or other safety protocols.

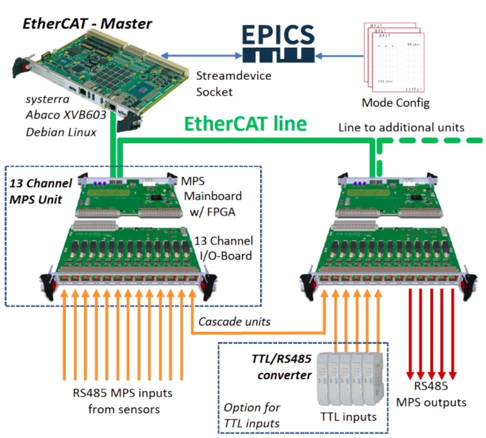

Figure 2: General logic of the MPS system [3]

There are two different types of BLMs in the Sealab accelerator: circular and stripline. The stripline BLMs can provide position information about beam losses. The BLMs were tested in the BESSY Injection Line using single pulse and macro pulses (5 micro-pulses) with charges of 300 pC and 1500 pC, respectively, at 50 MeV. The beam was steered to the left and right to check the position of the losses. The position information can be accurately obtained from the stripline BLMs. In addition, the interlock system and threshold were tested during these experiments. The first test were performed with 300 pC single bunch beam which was steered to the left. The losses were below the threshold voltage we set on the interlock so it did not trigger. However, in Figure 3, the five-bunch beam with 1500 pC was steered to the left, which was higher than the threshold we set, and it triggered the interlock system.

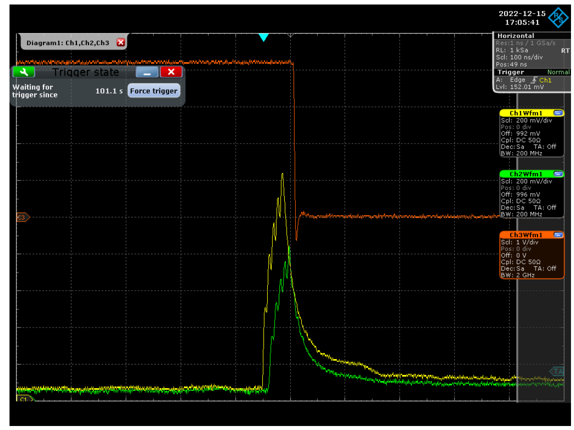

Figure 3: The yellow is the left sensor the green is the right. The orange is the interlock output. The beam is sterered to the left.The measurement were performed with 5 bunch with 1500 pC and interlock is triggered due to the high amount of losses on the beam pipe.

For the initial commissioning of the accelerator, 18 BLMs were installed along the beamline to detect and monitor any unexpected beam losses. The BLMs were also placed to facilitate easy calibration of the loss monitors. The cabling and connections for the BLMs have been installed and are ready for use. It's important to ensure that all connections and cabling are properly set up before proceeding with the commissioning process to avoid any issues that could compromise the safety and functionality of the accelerator.

As mentioned earlier, we are planning to start the initial commissioning phase using pin-based diode BLMs. However, we are also considering BLMs based on scintillators to add higher time resolution and dynamic range to the measurements. Investigations into different types of BLMs for high current usage in the accelerator are still ongoing.

OPERATIONAL MODES AND DIAGNOSTIC TOOLS

The operation of the accelerator will be limited by two operation modes: beam modes and machine modes. There will be various machine modes available for full operation [4]. However, the main machine mode for the initial commissioning will be the diagnostic mode with a current threshold of 0.35 uA, and the beam will go through the diagnostic line. In the beam mode, we expect to have two different modes: low and high charge modes. After the initial commissioning machine modes can be updated easily with respect to the planned operations of the accelerator.

As mentioned before, the primary goal is to obtain a stable beam with a wide range of operations. Therefore, verifying the beam parameters and stability is crucial for the initial commissioning. The main diagnostic tools and methods

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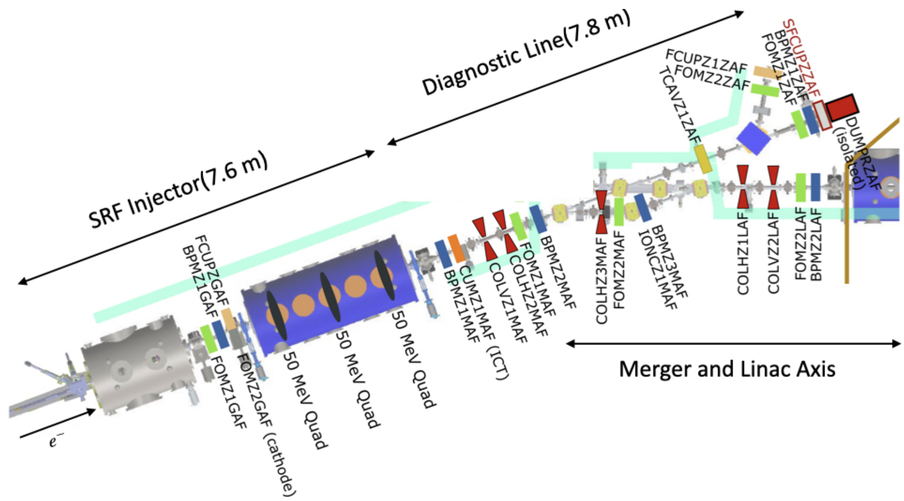

Figure 4: The planning full commissioning will start from the SRF gun and is expected to dump in the low power dump on the diagnostic line.

will be available for beam-based measurements during the initial commissioning include cathode current measurement, YAG view screens (FOMs), Faraday cups, stripline beam position monitors (BPMs), integrating current transformers (ICTs), DC current transformers (DCCTs), and a transverse deflecting cavity (TCav). The locations of these devices are shown in Figure 4.

The cathode current measurement will give information about the electron gun's performance. The YAG view screens and Faraday cups will be used for the measurement of the beam profile and intensity. The stripline BPMs will provide information about the beam position, while the ICTs and DCCT will measure the beam current. The TCav will be used for measuring the temporal beam profile. The data obtained from these diagnostic tools will be analyzed to verify the beam parameters and ensure the stability of the beam.

Also, it is planned to use the sum signal of the beam position monitors (BPMs) as a current measurement for the calibration of other devices and to cross-check the current measurement results. The sum signal from the BPMs is proportional to the beam current and can be used as a reliable and accurate reference for other current measurements. This will ensure that all devices are calibrated correctly and that the measurements are consistent across different systems. Additionally, using the sum signal of the BPMs for current measurements will reduce the need for additional sensors, which can simplify the setup and reduce the risk of errors. This approach is commonly used in accelerator facilities to ensure the accuracy and reliability of current measurements.

The initial commissioning will be performed in a step-by-step manner, starting with low beam currents and gradually increasing the beam current and charge. The diagnostics tools will be used to monitor the beam parameters and ensure the stability of the beam. Once the stable beam operation is achieved, the high charge mode will be activated, and the beam parameters will be verified and monitored using the same diagnostic tools.

During the initial commissioning phase, the signals from the BPMs and Faraday cups will be read using an oscilloscope and ammeter respectively. This is to eliminate any restrictions that may come from electronic readout modules and to ensure the widest range of measurement.

CONCLUSION

This paper presents a detailed discussion of the current status and initial commissioning of accelerator including the machine protection system (MPS), operational modes and diagnostic tools. As discussed in the paper, the MPS system must be updated to meet the requirements of higher current applications. The system can also incorporate additional input parameters, such as vacuum or RF failures, in addition to the beam loss monitors. Ongoing investigations aim to improve the MPS system's functionality. The diagnostic system and operational modes are ready to be tested, and further research is underway to utilize the diagnostic tools in other applications, such as ultrafast electron diffraction (UED) experiments.

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