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DESIGN OF A CATHODE INSERTION AND TRANSFER SYSTEM FOR LCLS-II-HE SRF GUN*

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Abstract

Superconducting radio frequency photo injectors (SRF gun) offer advantages for operating in continuous wave (CW) mode and generating high-brightness and high-current beams. A new SRF gun is designed as a low emittance photo injector for LCLS-II-HE and a prototype gun is currently being developed under collaboration between SLAC, FRIB, HZDR and ANL. The aim is to demonstrate stable CW operation at a cathode gradient of 30 MV/m.

One of the crucial components for successful SRF gun operation is the photocathode system. The new SRF gun will adopt the HZDR-type cathode, which includes a cathode holder fixture (cathode stalk) developed by FRIB and a cathode exchange system designed by HZDR. This innovative cathode insertion system ensures accurate, particle-free and warm cathode exchanges. A novel alignment process targets the cathode to the stalk axis without touching cathode plug itself.

To commission the prototype gun, metallic cathodes will be used. A specifically designed vacuum system ensures vacuum pressure of 10^{-9} mbar for transport of a single cathode from the cleanroom to the gun.

INTRODUCTION

The LCLS-II high-energy upgrade aims to enhance the capabilities of the existing LCLS-II by increasing the energy of the electron beam. This upgrade will result in the production of X-rays with higher energy and brightness at the end of the superconducting linac [1]. To achieve this goal, one of the key technologies being employed is a new low-emittance injector [2].

The preferred solution for the low-emittance injector is a low-frequency SRF-Gun (Superconducting Radio-Frequency Gun) [3]. This system enables continuous wave (CW) operation with a high accelerating field and a quasi-DC field across the bunch. Currently, a collaborative project involving FRIB, HZDR, ANL and SLAC is underway to design and prototype a high-field SRF-Gun [4, 5]. The project incorporates a 185.7 MHz Quarter-Wave Resonator (QWR) [6] and a cathode system [7]. This new cathode system will be compatible with high-performance photocathodes operating at either cryogenic temperature (55-80 K) or warm temperature (300 K). Additionally, the prototype cryomodule will undergo testing with a metal photocathode.

The design requirements for this SRF-Gun are technically demanding. The operation of a QWR SRF-Gun with a cathode field at the 30 MV/m level has not been demonstrated before. Therefore, this project represents a significant challenge in achieving these objectives.

To facilitate precise, particle-free, and warm cathode exchanges, an ingenious cathode insertion system should be designed. We will utilize HZDR's well-established operational expertise with ELBE SRF-Gun [8] and modify the cathode insertion and load-lock system we have developed.

Furthermore, an ultra-high vacuum (UHV) transfer chamber is designed to securely transfer a singular cathode from the clean room to the gun, maintaining optimal cleanliness throughout the process.

The cathode insertion system must fulfill the following requirements: (1) safely and reliably insert a warm cathode into a cold cavity; (2) prevent the introduction of particles into the superconducting cavity; (3) maintain a high-quality vacuum level of less than 10^{-9} Torr ; (3) operate in a safe and reliable manner.

CATHODE AND MANIPULATION

The cathode plug incorporates the HZDR-type cathode shape, featuring a stem diameter of 10 mm and a bayonet structure for easy manipulation. This design offers the advantage of compatibility with various materials and surfaces. Additionally, the bayonet mechanism ensures that the cathode plug can be handled without direct contact with the plug.

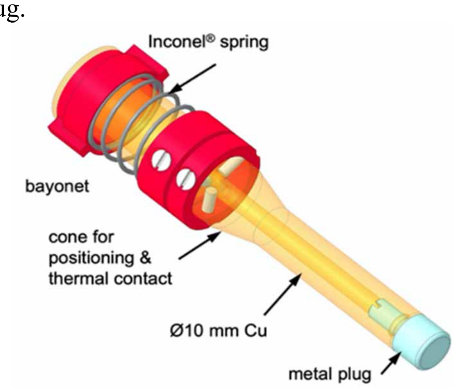

Figure 1: Cathode plug with plug tip, Cu body and bayonet structure.

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Cathode Plug Design

Figure 1 shows the photocathode specifically designed for the SRF Gun, where the cathode is isolated to the gun cavity. The cathode consists of a 10 mm diameter tip and a stem. The stem and conical cathode body are constructed from copper (Cu) due to its excellent thermal conductivity. The design allows for easy interchangeability of the tip.

Cathode Manipulation

Figure 2 illustrates the cathode manipulation process, which involves three distinct operations: (1) moving the tip to securely clamp the cathode from inside using ceramic balls. (2) moving the sleeve to compress and release the bayonet spring. (3) moving the sleeve to rotate the bayonet ring.

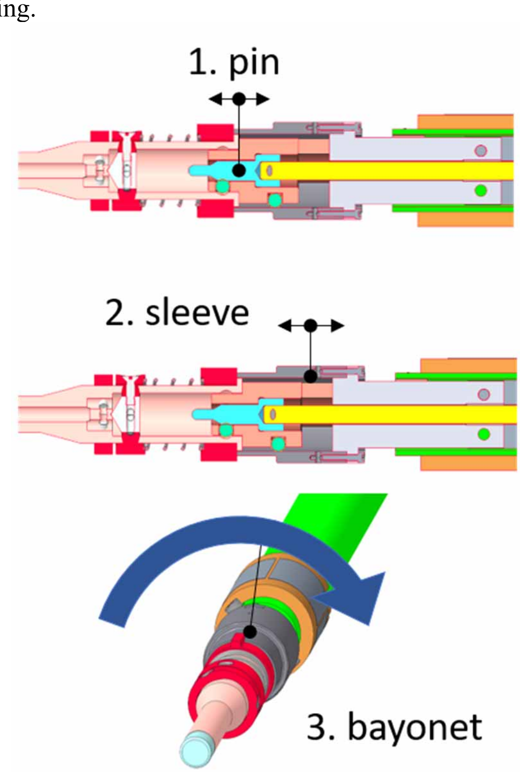

Figure 2: Three independent operations of cathode manipulation process.

The cathode stalk incorporates a Cu cone with a corresponding angle to accommodate the cathode plug cone, ensuring a perfect positioning and optimal thermal contact. Additionally, a stainless steel (SS) ring with two slits enables the bayonet ring fingers to pass through and securely lock the cathode when the ring is rotated using the sleeve.

To minimize particle generation, it is crucial to ensure that there is no sliding between the two cone surfaces during the insertion and operation of the cathode. This requirement is essential in maintaining a clean and particle-free environment.

CONCEPT OF FINE ALIGNMENT

The cathode insertion process requires precise transverse accuracy of 100 µm to ensure that the cathode is inserted into the stalk without scratching on the cone surfaces. To achieve this, a fine alignment system will be developed to accurately position the cathode with respect to the stalk axis. Figure 3 depicts the cathode insertion system along with the gun cavity. The total travel length for the cathode during the insertion process is 139 cm.

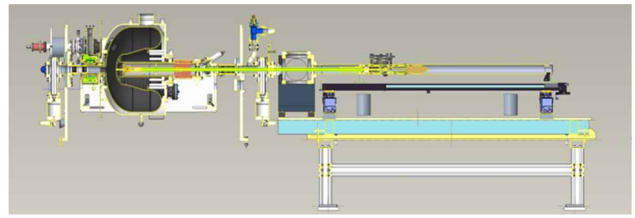

Figure 3: The cathode insertion system along with the gun cavity. In between there is a gate valve to separate the two vacuum spaces.

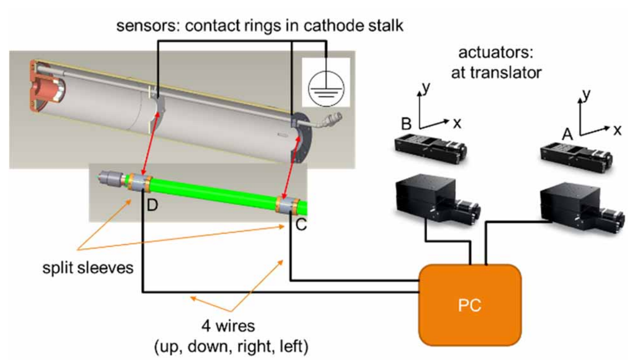

Figure 4: Fine alignment tools: two groups of precise µm meters, two groups of contact electrodes on the translator rod and two reference rings inside the stalk.

To ensure precise positioning, two sets of high-precision µm meters are utilized to adjust the x-y position and angle of the translator rod related to the stalk axis as shown in Figure 4. The alignment of the cavity/stalk axis is detected by employing two groups of contact electrodes on the translator rod, which contact two copper rings inside the stalk. These copper rings are meticulously aligned with the cavity axis to achieve optimal alignment and accuracy. The distance of the two rings is 280 mm, which can give good resolution of the angle measurement.

A control software will be developed to accurately calculate and execute the alignment process. Considering the length of the translator rod, which is 1.7 meters, it is necessary to take in account the sag bending caused by gravity. So, the bending of the rod due to the weight of the cathode will be factored into the motor control program to ensure precise alignment during operation.

TEST PLATFORM

At first, to validate the mechanism, a test platform has been constructed, featuring a shortened version hand-rod and a cathode stalk with identical cone shape and locking mechanism (see Fig. 5). The initial test results have confirmed the effectiveness of the manipulation mechanism, which operates reliably and smoothly, with no damage or scratching observed on the cathode or stalk cone.

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Figure 5: Test platform with a shortened version hand-rod and a cathode stalk.

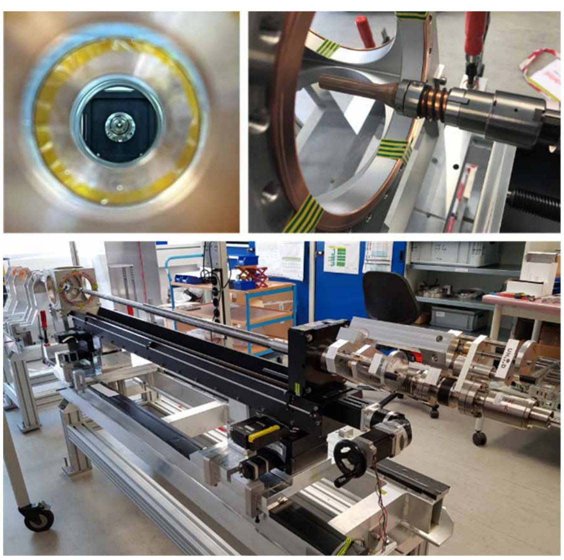
Figure 6: Test platform with real size manipulator and cavity/stalk mockup.

Secondly, a trial-setup of the real size stalk mockup and insertion system has been constructed (see Fig. 6). The mockup elements have been pre-aligned with a laser to establish an initially good alignment. The supporting frame has been aligned to the cavity/stalk mockup axis, and the holder angle and motors have been adjusted to ensure proper alignment of the cathode on the gun axis. At the end the trial assembly of the transfer system has been aligned with the mockup axis.

The cathode is manipulated using the bellow group and rotation feedthrough, simulating the operating in a vacuum environment. The cathode is held horizontally without any shaking or sagging and the locking mechanism demonstrates reliable and smooth operation, ensuring the stable position and secure placement of the cathode.

CATHODE TRANSFER CHAMBER

A vacuum chamber group has been designed, taking inspiration from the HZDR cathode system [9]. This system can transfer a cathode plug from the TP chamber (suitcase) onto the insertion manipulator in vacuum (see Fig. 7).

The purpose of the new system is to transport a metal cathode from the cleanroom to the SRF gun without venting the TF chamber and manipulator. The size of the system has been tailored to match the dimensions of the gun bunker at MSU. Additionally, the system has the capability to maintain a high-quality vacuum of better than 10^{-9} Torr, making it suitable for future use with semiconductor cathodes as well.

A jaws structure for sample transport has been designed to pick up the cathode, perform handover movements, and enable rotation within a vacuum environment. During the transfer process, only the cathode bayonet ring and its backside are touched, ensuring minimal particle generation.

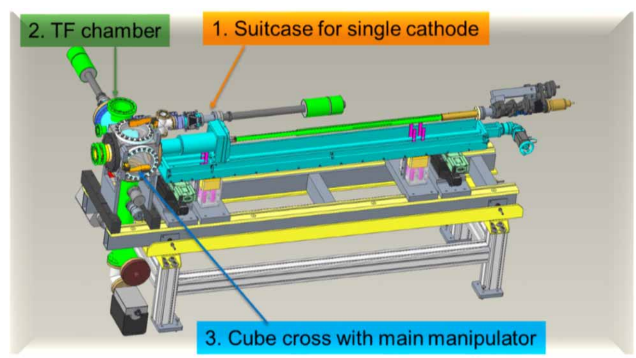

Figure 7: A vacuum chamber group has been designed to transfer a cathode plug from the TP chamber (suitcase) onto the insertion manipulator.

CONCLUSION

We are currently in the process of developing an advanced cathode insertion and transfer system, benefiting from the extensive operational expertise of HZDR SRF-Gun in this field. Our primary objective is to achieve precise and particle-free exchanges of cathodes in the cold cavity of the new LCLS-II HE low emittance SRF-Gun. To accomplish this, we have devised an ingenious cathode manipulation and insertion system. Additionally, we have designed an ultra-high vacuum (UHV) transfer chamber that ensures the transfer of a single cathode from the clean room to the gun while maintaining exceptional cleanliness throughout the entire process.

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REFERENCES

[1] "LCLS-II-HE Low Emittance Injector Conceptual Design Report", LCLSIIHE-1.1-DR-0418-R0, 14 Mar. 2022.

[2] J. Lewellen *et al.*, "Status of the SLAC/MSU SRF Gun Development Project," in *Proc. North American Particle Accelerator Conf. (NAPAC'22)*, Albuquerque, NM, USA, Aug. 2022, pp. 623-626. doi:10.18429/JACoW-NAPAC2022-WEPA03

[3] "LCLS-II-HE SRF Gun Technical Specification and SOW", LCLSII-HE-1.2-TS-0206-R2, Aug. 2021.

[4] T. Xu *et al.*, "Low-emittance SRF photo-injector prototype cryomodule for the LCLS-II high-energy upgrade: design and fabrication", in *Proc. IPAC'23*, Venezia, Italy, Apr. 2023, pp 912-915. doi:10.18429/JACoW-IPAC-23-TUPA028

[5] S. Miller *et al.*, "Status of the SLAC/MSU SRF gun development project", presented at IPAC'23, Grand Rapids, Jun. 2023, paper FRO007, this conference.

[6] S. H. Kim *et al.*, "Design of a 185.7 MHz Superconducting RF Photoinjector Quarter-Wave Resonator for the LCLS-II-HE Low Emittance Injector", in *Proc. North American Particle Accelerator Conf. (NAPAC'22)*, Albuquerque, New Mexico, USA, Aug. 2022, pp 245-248. doi:10.18429/JACoW-NAPAC2022-MOPA85

[7] T. Konomi *et al*., "Design of the Cathode Stalk for the LCLS-II-HE Low Emittance Injector", in *Proc. North American Particle Accelerator Conf. (NAPAC'22)*, Albuquerque, NM, USA, Aug. 2022, pp. 253-256. doi:10.18429/JACoW-NAPAC2022-MOPA87

[8] J. Teichert *et al.*, "Successful user operation of a superconducting radio-frequency photoelectron gun with Mg cathodes," *Phys. Rev. Accel. Beams*, vol. 24, p. 033401, 2021. doi:10.1103/PhysRevAccelBeams.24.033401

[9] R. Xiang *et al.*, "Cs_2Te normal conducting photocathodes in the superconducting rf gun," *Phys. Rev. Spec. Top. Accel. Beams*, vol. 13, p. 043501, 2010. doi:10.1103/PhysRevSTAB.13.043501