FIRST CONDUCTION COOLED PHOTOINJECTOR STATUS*

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Abstract

SRF photoguns become a promising candidate to produce highly stable electrons for UEM/UED applications because of the ultrahigh shot-to-shot stability compared to room temperature RF photoguns. SRF technology was prohibitively expensive for industrial use until two recent advancements: [1] and conduction cooling [2]. SRF gun can provide a CW operation capability while consuming only 2W of RF power which eliminates the need of an expensive high power RF system and saves a facility footprint. Euclid is developing a continuous wave (CW), 1.5-cell, MeV-scale SRF conduction cooled photogun operating at 1.3 GHz. In this paper, we present the current status of the project up to this date including results of the gun-cavity cool-down in the newly developed conduction cooled cryomodule.

INTRODUCTION

The use of SRF photogun brings certain benefits compared to normal conducting guns such as: unprecedented repetition rates and reduced almost to zero RF losses. As long as beam current is very low for UED/UEM applications, MW-level RF power source is not required and can be as low as several Watts. However, SRF was not user-friendly because it requires sophisticated cryomodules, experienced personnel for operation and expensive cryogenics until recent proof of principle of conduction cooling at Fermilab [2] and Jlab [3].

Euclid is developing a CW, 1.5-cell SRF photogun operating at 1.3 GHz for UED/UEM applications. The design of the gun was based on an standard Tesla single cell geometry with an additional half-cell, the back wall of which is used for photo-emission. The half-cell geometry was optimized using CST, which was bench marked by ASTRA code [4]. The beam parameters were optimized for UED/UEM applications. Beam energy out of the gun is 1.65 MeV which requires field on the cathode of 20 MV/m (E_{acc}=10 MV/m). Power dissipation in the cavity at the expected Q_0=1.1E10 should be around 1 W which is within cooling capacity of one commercially available cryocooler, for example Sumitomo RDE-418D4 can provide 2 W of cooling at 4.2 K. The gun in a cryomodule is cooled conductively through high conductive 5N AL links bolted to the Nb rings welded on the equators and can be seen on Fig. 1.

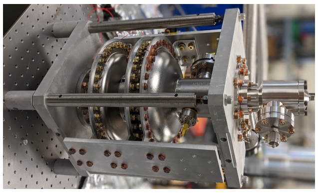

Figure 1: 1.5 cell Nb SRF gun with cooling rings welded.

Cavity Tests in Liquid Helium

After the cavity fabrication, several tests in liquid helium has been conducted for cavity performance estimation at Fermilab Vertical Tests Stand (VTS). The cavity obtained standard 200um BCP processing. E_{acc}=10 MV/m was achieved during the first pure Nb gun cavity with quite low quality factor of Q_0=2.5E9 at low fields which indicated insufficient DI water high pressure rinsing (HPR) due to the one side access only (the cavity has only one beam pipe). The results are presented in Fig. 2.

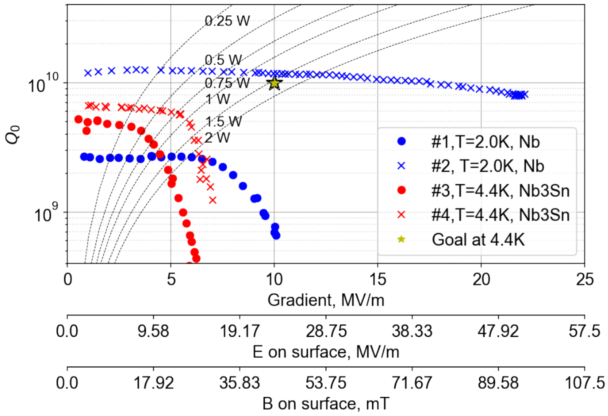

Figure 2: Four cavity tests in liquid helium Vertical cryostat

The HPR system nozzle was adjusted to address the issue. The second test of pure Nb cavity demonstrated processing procedure improvement. The cavity reached E_{acc}=22 MV/m and pretty flat Q_0=1E10 which is standard for BCP only processing. This result concluded the QC process of the cavity to proceed with Nb_3Sn deposition and testing. The cavity was coated with Nb_3Sn at Fermilab and tested in liquid helium at 4.4 K. Unfortunately, it was obvious before the test by resonant frequency change that the cavity was deformed during the cavity cage assembly which cracked brittle Nb_3Sn coating. E_{acc}=6 MV/m was achieved with significant Q degradation with low field Q_0=5E9. The cavity was re-coated and tested again, and was found out later deposition furnace contamination event happened before, which affected several cavities being coated. Nevertheless, the results of the test #4 showed better performance with low filed Q_0=7E9 with slight degradation up to E_{acc}=6 MV/m. The more details on the tests in liquid helium are available in [5].

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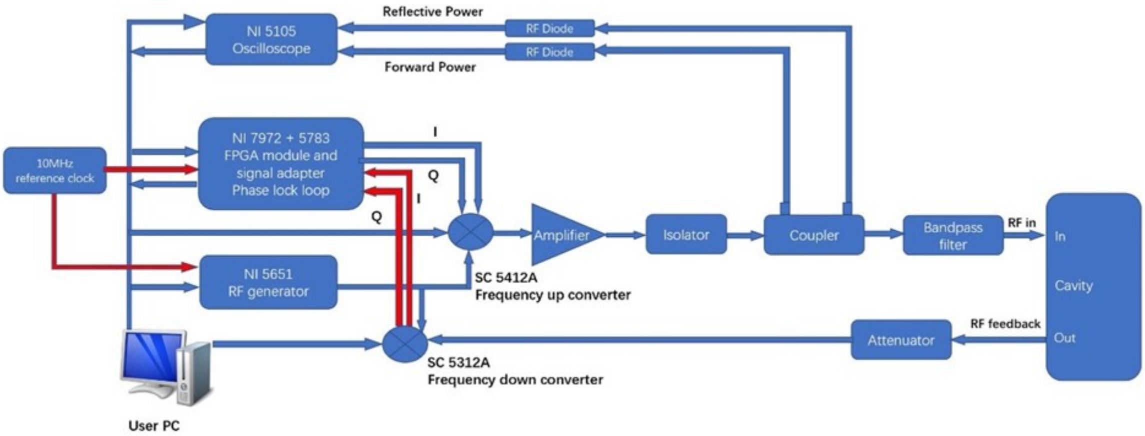

Figure 3: Schematic layout of the LLRF system.

We believe our goal parameters are achievable with the next coating round, but the decision was made to proceed with the horizontal test and to take risks if any with the current cavity coating other than with the best performing one. Even though the cavity did not reach the target gradient, electron beam with decent energy can be obtained with the current state. Cavity integration and beam generation processes will be rehearsed and there will be less risk with the re-coated cavity in the future.

CRYOMODULE COMMISSIONING UPDATES

A compact conduction cooled cryomodule (24" in diameter and 24" long) has been developed by Euclid to accommodate the SRF photogun. The cryomodule design and first commissioning has been discussed in [6]:

- Magnetic screen performance was measured at room temperature. Magnetic field was as low as 10 mG after a series of leakage improvements.
- The 2nd stage of the cryocooler achieved min possible temperature of 2.5 K with no load indicating adequate thermal screen performance.
- The thermal screen achieved temperature of 50 K while the first stage of the cooler which was used to cool down the screen was at 28 K, indicating a loose connection.

Since then, the magnetic screen was further improved reducing magnetic field at the cavity location down to 5 mG which was measured in the cooled cryomodule. THe thermal screen connection to the 1st stage was redesigned eliminating the temperature difference between the 1st stage and the screen. MLI was installed in the cryomodule to reduce thermal radiation to the screen and consequently its temperature since the cooler temperature is not constant and is a function of power load to each stage. At the end, the screen temperature achieved 30 K corresponding to 2 W of load to the 1st stage, meeting the design spec values. The cavity, cooled by the 2nd stage, reached slightly below 4 K and zero RF load, with the 2nd stage temperature of 3.5 K corresponding to 1.3 W of load. This is higher than expected load will be investigated in future. LLRF system has been developed and successfully used for the data collection described in the following section. The LLRF schematic layout is presented in Fig. 3 along with the components used for the system.

CAVITY TEST IN CONDUCTION COOLED CRYOMODULE

Despite moderate results during test #4 in liquid helium due to the cavity contamination during Nb_3Sn deposition, we decided to proceed with the horizontal test in the conduction cooled cryomodule in order to gain experience with the cavity integration and the cryomodule operation. The whole testing site with the cryocooler, the cryomodule and the control rack with electronics cab found in Fig. 4.

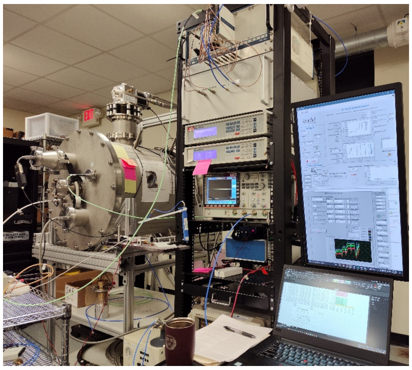

Figure 4: Conduction cooled cryomodule along with LLRF control rack and electronics at Euclid's facility.

It took a while to commission the whole system mostly due to LLRF system until the cavity was locked and the power finally got into the cavity, however, residual gas breakdown was discovered due to the degraded vacuum level (the cavity was sealed for the VTS#4 test and never pumped again). The cavity was taken out of the cryomodule and evacuated at Euclid's clean room which resolved the gas discharged issue. The cavity couplings were left intentionally unchanged for direct comparison with VTS#4 test and were Q_{ext1} =1E10 and Q_{ext2} =1E11 for the main and the pick up couplers correspondingly, meaning that decent RF power will be reflected from the cavity due to the unmatched coupling. Full QvsE curve has been collected, the results are presented in Fig. 5.

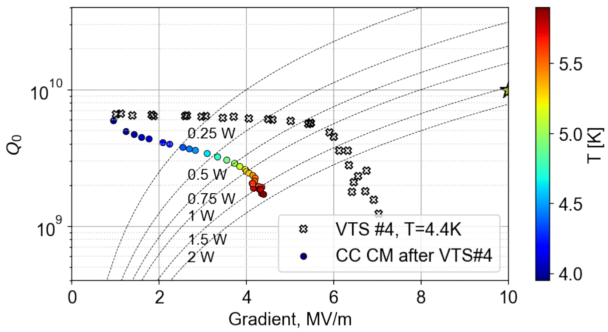

Figure 5: VTS4 test results in liquid helium at compared with the horizontal test in conduction cooled cryomodule.

As one can see from Fig. 5, low field quality factor was as high as Q_0=6E9 almost the same as during the test VTS#4 in liquid helium, but the cavity temperate was slightly below 4 K. The second stage of the cryocooler was only 0.3-0.6 K lower at min and max accelerating gradient. Such a high quality factor benefited from controlled cool down during the transition temperature on Nb_3Sn at around 18.8 K. Magnetic flux expulsion was clearly observed. As the power was increased to get higher accelerating gradient the cavity temperature was also trending up as one can see from Fig. 5. Each point was taken once the temperature of the cavity has been stabilized, stretching the data collection to several hours. Nevertheless, the cavity reached accelerating gradient around E_{acc}=4.3 MV/m at 10 W of forward power, while the power dissipated in the cavity reached 1.8 W. Up to 75% of power was reflected, contributing significant power dissipation in the power cable load to the 2^{nd} stage of the cooler and the cavity temperature, which can be eliminated by coupling adjustment in future. The cavity was stable with no field emission or quenching. The test was limited because of cable power limit and cryocooler capacity. It was worth mentioning, that the project goal is 10 MV/m at Q_0=1E10 which will correspond to 1 W of RF dissipated power in the cavity. While we believe a new coating with no contamination should provide the required performance, as of now, the cryomodule successfully handled even a higher load of 1.5 W from the cavity. 420 keV electrons can be generated at the achieved accelerating gradients which will be attempted later this year.

FUTURE PLANS

The final goal of this project is the development of MeV-scale electron microscopy user facility in Brookhaven National Laboratory in ATF-II bunker, for example [7]. Once the gun performance is demonstrated the whole system will be delivered to BNL. Currently, the gun was shipped to AWA facility at Argonne National Laboratory for beam generation using a UV laser. The beam will be characterized to cross-check with the expected simulation results. In order to get the design beam parameters a higher accelerating gradient of 10 MV/m is required. In order to get them, the contaminated cavity coating will be stripped away for a new re-coat of Nb_3Sn followed by the next conditioning cycle of cool down and beam generation and measurements.

CONCLUSION

Several key milestones towards UED/UEM facility based on conduction cooled SRF photogun have been accomplished:

- The gun cavity with no coating has been tested in liquid helium and obtained 22 MV/m of accelerating gradient proving the processing procedure for a one side only open cavity.
- The gun cavity was coated with Nb_3Sn providing operational parameters for further experiment.
- The conduction cooled cryomodule has been conditioned and met the design parameters: magnetic field 5mG, thermal screen temperature 30K.
- The cryomodule LLRF system has been developed and successfully used to lock the cavity resonance.
- The gun cavity passed the horizontal test in Euclid’s conduction cooled cryomodule.
- The whole experiment has been moved to AWA facility at ANL and is being prepared for the beam generation.

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