STATUS OF THE INJECTION SYSTEM FOR THE CLARA FEL TEST FACILITY

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Abstract

A description is given of the high repetition rate injection system which is being developed for the proposed CLARA FEL test facility which is under construction at Daresbury Laboratory. The system comprises a 400 Hz High Repetition Rate photocathode Gun providing high brightness electron bunches with a charge of up to 250 pC and a linear accelerator section operating in either booster or bunching mode. The beam is delivered by an interchangeable metal photocathode illuminated with a UV laser.

INTRODUCTION

The Front End of 250 MeV CLARA FEL test facility [1,2] is now under construction at Daresbury Laboratory. The facility is a further development of the VELA electron accelerator which is now in operation [3]. Electron beam for this integrated facility will be provided by two normal conducting S-band photocathode guns: a 10 Hz 2.5 cell gun earlier used as the injector for the VELA machine, and a 400 Hz 1.5 cell High Repetition Rate Gun (HRRG) which has been recently successfully commissioned at Low Power RF.

The initial stage of CLARA will operate with the 10 Hz gun and the linear accelerator section. The beam will be deflected into the existing VELA beamline with an S-bend and directed to the spectrometer line for analysing beam properties or into one of the two VELA user areas. The HRRG will be installed on the VELA beamline for high power RF and beam commissioning with the VELA beam diagnostics suite. The HRRG is equipped with an interchangeable photocathode which allows for the investigation of different metals and to select the best at providing minimal beam emittance at highest quantum efficiency. After commissioning, the 400 Hz gun will be installed onto the CLARA beam line and the 10 Hz gun will be returned to the VELA beam line.

HIGH REPEPTITION RATE GUN

Photocathode Gun Cavity

The high repetition rate photoinjector for CLARA was developed to meet demanding requirements to the beam peak current and pulse duration at the CLARA FEL interaction area [4] and repetition rate required for VELA user experiments. The final design is based on a 1.5 cell normal conducting S-band RF cavity [5]. It has a dual feed RF input coupler with phase adjustment of each feed which has been shown in simulations to supress any dipole component in the coaxial coupler line.

For CLARA FEL experiments very high brightness beams are required. These can be delivered by a photocathode gun with as high value of the cathode surface field as possible. The practical limit in the described design has been set as 120 MV/m which is current state of the art for similar designs. For operation with the VELA beamline a repetition rate of 400 Hz is desired. As demands to the beam brightness are relaxed, a maximum surface field of 100 MV/m has been specified. These requirements imply power handling capabilities of 6.8 kW on the gun cavity. As operation at 400 Hz is not required for CLARA FEL experiments, the maximum cavity power is defined by operation in VELA mode.

Operation of the CLARA seeded FEL requires beam arrival time stability at the point of interaction between the seeding laser and electron beam of less than 64 fs rms [1]. Start to end simulation [1] has shown that to achieve this stability for the magnetic compression scheme the jitter of the beam launching phase in the gun should be better than 0.1° rms; that means that temperature of the cavity should be maintained with stability of better than 0.009° rms. RF amplitude stability must be better than 0.1 % rms [1,6]. To stabilise RF amplitude the gun cavity has a probe port in the second cell for feed-forward amplitude correction.

Cavity Cooling and Temperature Stabilisation

The thermal stabilisation of the gun cavity is achieved via 9 individual cooling channels as shown in Fig. 1, the flow through which can be controlled remotely and used to optimise frequency and field flatness under various operating conditions [5,7].

The cooling of the injector was investigated using advanced computational fluid dynamics techniques in ANSYS CFX. The cell radii are expected to increase by 5.6 µm due to the average steady state RF load of 6.8 kW at 400 Hz and 100 MV/m. This gives a detuning of the resonance frequency of -0.427 MHz which will be compensated for in the water temperature stabilisation system. High resolution thermo-stabilisation for the CLARA HRRG has been designed at Daresbury Laboratory, with

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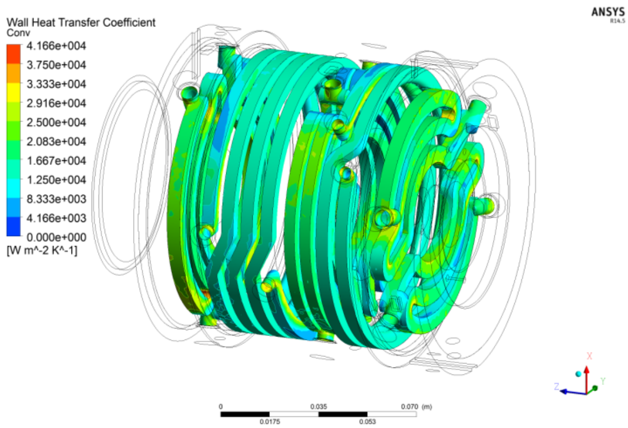

Figure 1: Wall convective heat transfer coefficient in High Repetition Rate Gun cavity as calculated with the ANSYS CFX technique.

the aspiration of controlling the operating temperature within a tolerance of ±0.025 °C or better. This deionised water compatible system has been designed to dissipate a maximum heat load of ~10 kW, with volumetric flow rates of approximately 2 m^3/hr.

The system comprises of two split units, interconnected by dedicated cabling and pipework. The flow control element is situated close to the gun; the temperature control element is approximately 30 m away located in an ancillary area outside of the accelerator, this is principally for ease of access during operation, but importantly also removes electronic components from the radiation enclosure reducing the risk of failure.

The operating temperature will be maintained by the mixing of hot and cold water, in a dual valve cascade. The water will be heated with an electronic process heater and the temperature maintained to within 1 °C, it will then be mixed with cold water via a 3-port control valve to approximately one degree below the required control temperature of about 50 °C. This water will then be mixed through a second 3 port control valve with hot water from the heated circuit to control to the set point.

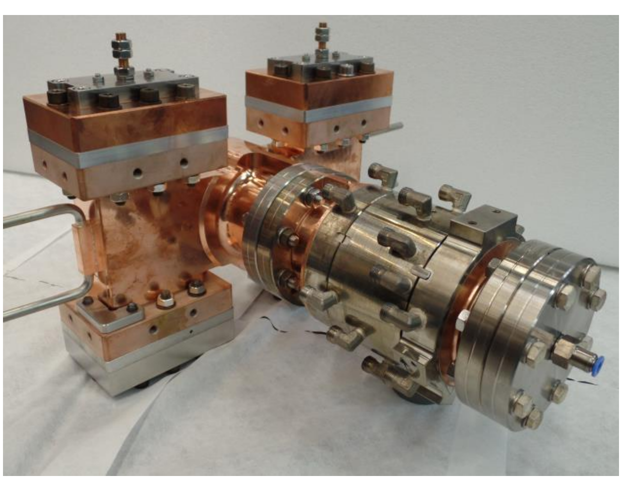

Figure 2: HRRG cavity after manufacturing.

Each channel on the gun has its own remotely operated flow regulating valve to separately control the flow giving the ability to match any variations in load around the gun shown by any of the eight PT100 temperature sensors.

The cavity was manufactured at Research Instruments GmbH and is shown in Fig. 2. A sophisticated cavity tuning procedure based on dimensions correction was developed to tune the field flatness and frequency before brazing [8]. Low-power tests have confirmed the cavity resonant frequency of 2.9985 GHz at 48°C operating temperature with a field flatness of 98±1%. The surface finish was carefully specified in order to achieve a high quality factor, Q_0,of 13350 ± 280 with Mo cathode plugs. This increases further to 14230 ± 120 using a Cu cathode plug.

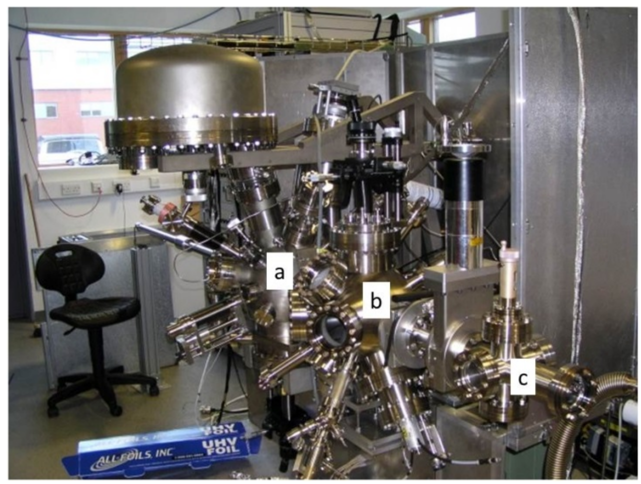

Figure 3: Photocathode Preparation System. a-Analysis Chamber, b-Preparation Chamber, c-Transport Vessel.

PHOTOCATHODE PREPARATION AND TRANSPORTATION SYSTEM

The electrons are emitted from interchangeable metal photocathodes illuminated with an UV laser [5]. The photocathodes, which are planned for use will either be a metal thin film deposited on a Mo plug or a metal tablet pressed into the plug. The photocathode will be loaded into the gun with a vacuum load-lock system permanently connected to the gun. The photocathodes, prepared in a Photocathode Preparation System (PPS), are transported to the accelerator hall inside a vacuum Transport Vessel that prevents oxidation of the photocathode surface during transportation. The plug design and its transport system are compatible with the ones used at DESY/LBNL/FNAL that also allow for the testing of different types of photocathodes.

The on-site photocathode preparation and characterisation facility is now under commissioning. This PPS comprises two separate chambers: (a) Analysis Chamber (AC) and (b) Preparation Chamber (PC) (see Fig. 3).

The AC benefits from three complimentary surface characterisation techniques: X-ray Photon-electron Spec-

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troscopy (XPS) which will provide information about surface composition and the chemical state of each element within the 10 nm of the surface, Auger Electron spectroscopy (AES) which will is alternative technique to provide surface composition and Ultra Violet Photon-electron spectroscopy (UPS) for measurement of surface work function. As well as the above techniques it also houses two further components: a UV laser which is used to determine the Quantum Efficiency (QE) of the photocathode and a Kelvin probe which provides another method to determine the surface work function. The above techniques are chosen to characterise the most important parameters of a photocathode which are its QE as a function of surface work function, composition and chemical state.

In order to achieve the desired QE, a separate Preparation Chamber (PC) is attached to the AC. It comprises of a hydrogen cracker source to remove hydrocarbon contamination, broad beam low energy ion source (500 eV) to remove oxide layers in cases where surface oxide can neither desorb nor diffuse into the bulk and two concentric magnetron sputtering sources fed with a pulsed DC power supply in order to be able to deposit metal and insulating material on the surface of the photocathode plug. These will allow for deposition of a thin film of low work function metal such as magnesium on top of a Mo plug. The PC is isolated from the AC via an all metal valve to reduce any cross contamination.

The optimised and characterised photocathodes can then be transported to the RF gun via a vacuum transport vessel which can be attached to the end of the preparation chamber. Four cathodes can be prepared at any time and be housed in the transport vessel.

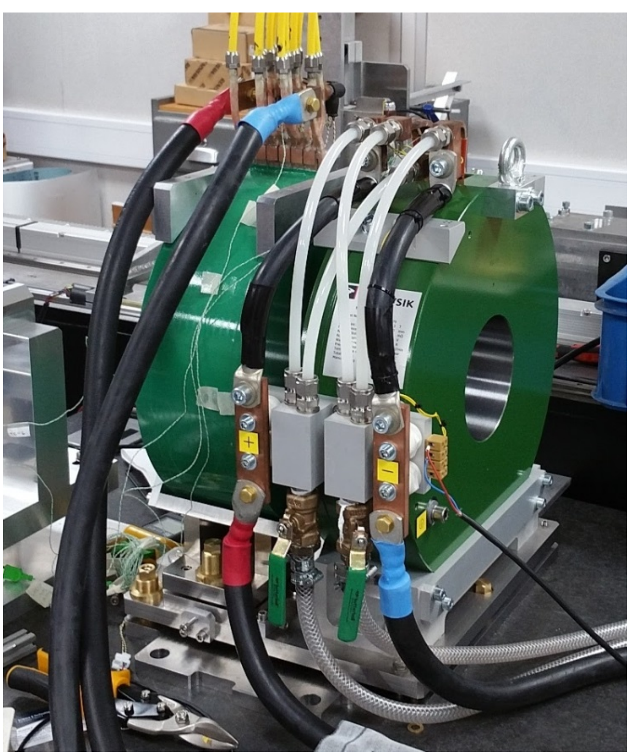

Figure 4: Magnetic system of the gun on the test stand.

The PPS will provide a rarely available capability to evaluate a wide range of different photocathode materials in accelerator environment.

BEAM FOCUSING SYSTEM

Beam focusing and emittance compensation are provided by a pair of coaxial, water-cooled solenoids mounted on one support frame as shown in Fig. 4, magnetized in opposite directions such that the fields they generate at the location of the cathode cancel each other out. The bucking solenoid is stationary and the main solenoid is capable of translation towards to the cathode plane and away from it. The magnetic system is operated at variable solenoid currents and at variable separation between the solenoids to produce optimum parameters of the emitted beam.

Whilst the main solenoid is a copy of the solenoid used at VELA, the bucking solenoid had to be designed, built and tested. It relies upon an asymmetric steel yoke that shifts the peak axial field away from its geometric centre towards the cathode to allow for a more efficient use of the available ampere-turns.

Before installation both solenoids were extensively tested both when operating alone and simultaneously and were found to perform exactly as expected.

CONCLUSION

All major components of the High Repetition Rate Injection system are either ready for installation, or in the commissioning stage. First high power RF commissioning of the HRRG on the VELA beam line is expected in early 2017.

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