TEST OF THE PHOTOCATHODE COOLING SYSTEM
OF THE 3½ CELL SRF GUN

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Abstract

This paper presents results of the photocathode cooling system test of the 3½ cell SRF gun at the Forschungszentrum Rossendorf. The SRF gun will produce short electron pulses with high bunch charges and low transverse emittance. The requirement for the superconducting electron linear accelerator in Rossendorf (ELBE) is to provide a low emittance electron beam up to 1mA current and 9.5 MeV energy. Additionally, it will easily operate in continuous wave (cw) mode because of the low RF power losses in the superconducting material. Therefore, the normal conducting copper cathode must be cooled by liquid nitrogen in order to preserve the temperature of the cavity at 2.2 K. The estimated power input from the RF field into the cathode could be more than 10 W [1]. First results of temperature measurements of the photo cathode respectively from the cooling system at a heat load up to 30 W are presented.

INTRODUCTION

For future FEL light sources and high energy linear accelerators a high current electron gun with high brilliance is absolutely essential. Thus, an innovative superconducting RF photo injector (SRF gun) is under development at the Forschungszentrum Rossendorf (ELBE), which is a collaboration of BESSY, DESY, MBI and FZR and supported by the European Community.

A first test of a superconducting photo gun designed as a half-cell cavity was succeeded [2]. During 200 hours operation time there were no significant change of the beam properties or the quality factor of the cavity. A preliminary study to cool the normal conducting copper photo cathode with liquid nitrogen (LN$_2$) [3] was done. For the new 3½ cell SRF gun a special photo cathode system was designed in order to dissipate the heat power input by cooling and, in addition, to preserve the cavity cleanness by particle abrasion.

This paper presents test results of the new photocathode cooling system by temperature measurements at heat loads of up to 30 W at significant points of the system.

$3^1/_2$ CELL SRF-GUN

Fig.1 shows the cryogenic module of the SRF gun including the resonator which is comprises a half cell containing the photo cathode and three acceleration cells with TESLA shape [4]. The red circle denotes the photo cathode system cooled by LN$_2$. The new system will minimize the heat load of the cavity which originates from the normal conducting photo cathode.
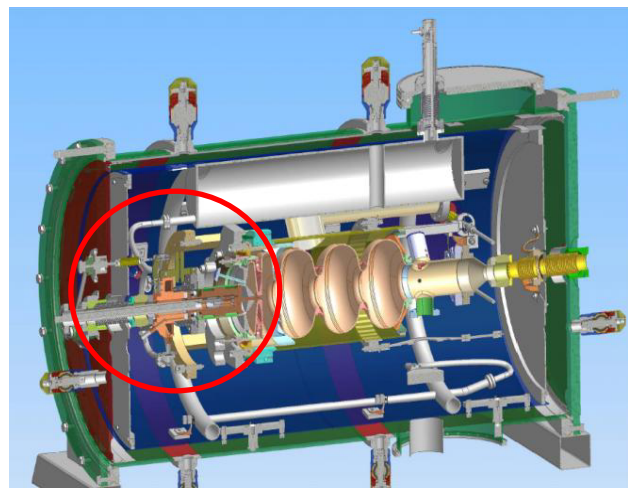

Fig.1: Cryogenic module with $3^1/_2$ cell cavity and photocathode unit

A surrounding LN$_2$ shield and an isolation vacuum inside the cryostat vessel preserve the super fluid liquid helium temperature of the cavity at 2.2 K. The tip of the cathode is evaporated with an active photo electrical Cs$_2$Te layer. The electrons will be ejected by incident high power UV-laser light. Short laser pulses in the range of 5 ps to 20 ps and a high peak field inside the cavity facilitate a high quality electron beam with an extremely small emittance and a high energy up to 9.5 MeV and 1mA beam current. Three useful operation modes are scheduled, the standard

ELBE FEL mode with 77 pC and 13 MHz pulse repetition, the high charge mode for neutron physics at ELBE and ERL studies (1 nC, 1 MHz), and the BESSY FEL mode (2.5 nC, 1 kHz) [5].

PHOTOCATHODE COOLING SYSTEM

In Fig.2 the assembled photocathode cooling system is shown. The front part of the copper cathode is visible as a thin tip (position 1). The back part is enclosed by a cooling body (position 2). A touched conical aligns by contact the photocathode to the center of the cooling body. The cooling body is connected to the LN_2 reservoir (position 3).
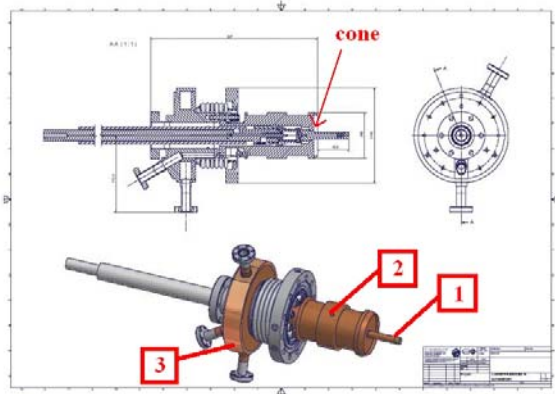

Fig.2: Assembled photocathode cooling system with three selected temperature sensor positions

A bayonet socket system locks the cathode by pushing and a following rotation. A spring determines the contact strength and only a stainless steel tip transfers the force to the cathode in order to minimize the production of particles through rubbing inside the superconducting cavity. The thermal resistance depends on the cotact area which is commonly reduced to three points and the contact pressure. Therefore, an excellent thermal conductivity of the contact area requires precise conical shapes.

Fig.3 shows the mounted photocathode cooling system test-bench. The end flange of the system is joined with a titanium spoke ring to the flange of the test chamber. A small cross section of the titanium spokes guarantees a negligible heat transfer from the test chamber with room temperature to the LN_2 reservoir. The heat cartridge is mounted into an intermediate piece and adapts to the photocathode tip. The heater is connected via an electrical feed through with a common electrical power supply.

The time derivative of the intrinsic energy Q is given by $dQ/dt = (\lambda/\delta) \cdot A \cdot \Delta T = P$, where P is the electrical heat power, $\delta=0.05\ m$ the length of the cathode tip, $A=15.7\ cm^2$ the cross-sectional area and λ the specific

thermal conductivity. $\Delta T = T_{cath} - T_{coolbody}$ is the temperature difference which can be measured. With this equations we can calculate the temperature of the photo cathode $T_{cath} = (P \cdot (\delta/A)\ /\ \lambda) + T_{coolbody}$.

Fig.3: Photocathode cooling test-bench with temperature sensors and electrical heater on the top

The measured temperature plotted in Fig.4 exhibits the thermodynamically stationary plateaus due to the discrete power input levels.
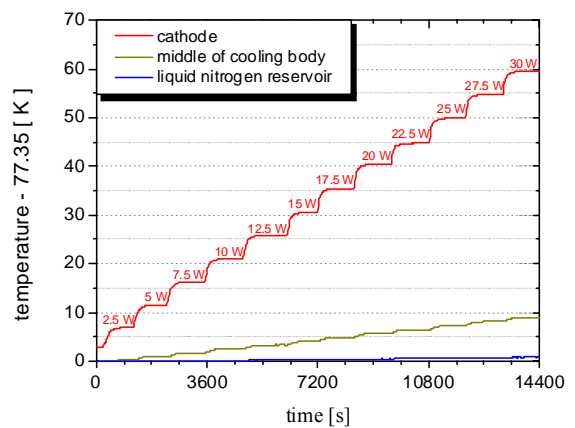

Fig.4: Measured temperature history for different power input levels

In Fig.5 the stationary temperatures depending on the discrete power input level is shown. The behavior of the temperature $T(P)$ is fitted linear by $T(P)=m \cdot P+b$ where b corresponds to the deviation of the starting LN_2 temperature due to an imperfect temperature sensor

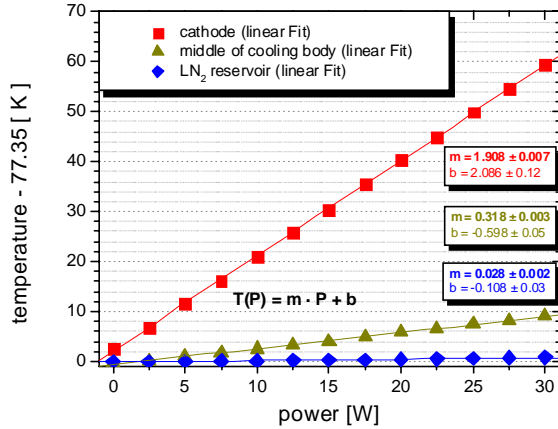contact. *P* is the electrical heat power and *m* the slope of the linear fit curve.

Fig.5: Measured temperatures for different power inputs at the three tagged positions of the cathode system

The temperature behavior of the cathode system fits the thermal conductivity for copper at LN_2 temperature very well.

Now, when the SRF gun will be operated the temperature of the cooling body will be measured. Consequently, the real power input into the photo cathode from the photo laser and the RF system can be estimated due to the measured temperature data.

HEAT TRANSFER TO THE CAVITY

The calculated radiation power from the photocathode to the cavity as black body radiation by the Stefan-Boltzmann law is shown in Fig.6. The diameter of the cathode is 10cm and the length of the cathode tip is 50cm.
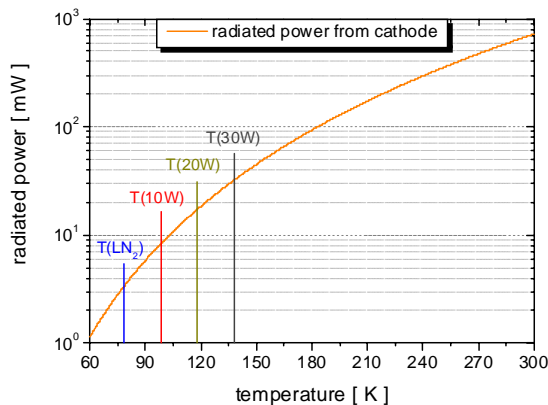

Fig.6: Radiated power from the photo cathode with regard to the photocathode temperature

Therewith, the absorbed power density to the cavity can be calculated. Due to the enlarged surface of the cavity the absorbed power density correlates to roughly 86 % of the radiated power density from the photo cathode. In the worst case when we assume 30 W power input to the photo cathode the power density burden the cavity with 1.7 mW/cm^2 respectively an integrated power of 31 mW. The helium cooling installation can provide the SRF gun with roughly 30 W to 50 W cooling power.

CONCLUSION

The cooling system for the photo cathode of the SRF gun is working very well up to 30 W heat load. The measured temperatures at the cathode tip and the coupled radiation power are some order of magnitudes smaller than the provided cooling power of the helium installation. Therewith, the heat load of the photo cathode could be neglected.

By monitoring the cooling body temperature the magnetic RF power losses due to the Cs_2Te layer could be estimated for the first time, because no investigations about the magnetic permeability μ_r of this semiconductor are done. The RF power losses due to the electrical permeability ε_r of copper and the power input of the photo laser are well known. Thus, the residue heat power originating through the magnetic permeability of Cs_2Te and consequently μ_r can be calculate.

ACKNOWLEDGEMENT

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