DIAGNOSTIC FOR A HIGH REPETITION RATE ELECTRON PHOTO-GUN AND FIRST MEASUREMENTS*

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Abstract

The APEX electron source at LBNL combines the high-repetition-rate with the high beam brigthness typical of photo-guns, delivering low emittance electron pulses at MHz frequency. Proving the high beam quality of the beam is an essential step for the success of the experiment, opening the doors of the high average power to brightness-hungry applications as X-Ray FELs, MHz ultrafast electron diffraction etc. As first step, a full 6D characterization of the beam is foreseen at the Gun beam energy of 750 keV. Diagnostics for low and high current measurements have been installed and tested, and measurements of cathode lifetime and thermal emittance in a RF environment are currently being commissioned. The recently installed double slit system will allow the measurements of beam emittance at full current (mA). Also a deflecting cavity and a high precision spectrometer are foreseen at low energy, allowing the exploration of the longitudinal phase space. Here we discuss the present layout of the machine and future upgrades, showing the latest results at low and high repetition rate, together with the tools and techniques used.

INTRODUCTION

The main design parameters of the APEX gun are reported in Table 1 [1]. A very good vacuum pressure is necessary to be able to run high quantum efficiency cathodes. Both absolute and partial pressure are important for high current operations, as the cathode degradation can be induced both by contamination (especially from water and CO_2) and ion back-bombardment (proportional to extracted current and total pressure). High accelerating field at the cathode is needed to produce high-brightness high-current beams, essential to drive FELs. The choice of a VHF frequency allow for CW operations without the need of special cooling techniques. Slots can be opened on the sidewalls of the cavity without distorting the field, increasing vacuum conductance with the surrounding anti-chamber, where 20 NEG pumps are installed. In this way we achieved the targeted vacuum level needed by semiconductor cathodes.

The laser system [2] is based on a Ytterbium doped fiber oscillator at 37.14 MHz. The oscillator pulses seed a chain of ytterbium doped fiber amplifiers. The repetition rate is reduced down to 1 MHz during amplification, and at the end of the chain we get about 0.7 W of average IR power, with single pulse length of 700 fs FWHM. The IR beam is then double in frequency, obtaining about 0.3 W of green pulses, and double again, producing 50 mW of UV light. Both UV and green are transported to the APEX gun, to be used with different cathode materials. A Pockels cell system allows to remotely control the laser repetition rate at the cathode, and a pulse shaping system

Table 1: APEX RF-Gun Critical Parameters

Parameters	VALUE
Frequency	185.7 MHz
Gap voltage	750 keV
Peak wall power density	25 W/cm^2
Field at the cathode	20 MV/m
Vacuum pressure	10^{-11} Torr
RF power	100 kW
Accelerating gap	4 cm

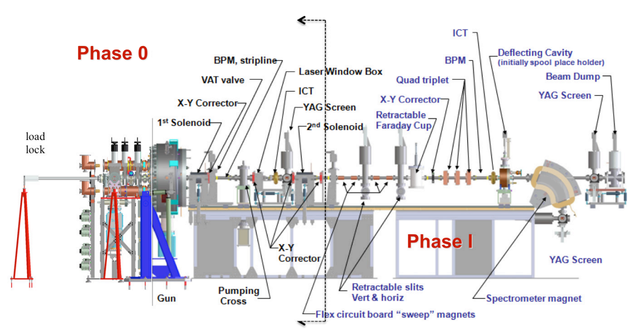

Figure 1: APEX layout for phase 0 and I.

based on pulse stacking via birefringent crystals [3] creates flat top longitudinal profile up to 60 ps long.

On the final table, a wedged optics samples a small percentage (around 3%) of the beam energy for energy and position monitoring.

ELECTRON BEAM DIAGNOSTIC

Figure 1 shows the layout of the first 2 phases (“Phase 0” and “Phase 1”) of the APEX project, with the dotted line showing the installed beamline elements for each of the two phases. The goal Phase 0 is the demonstration of the gun performances [4], in terms of accelerating electric field, vacuum pressure, and dark current. At the gun exit a solenoid lens is used to focus the electron beam to a 100

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μm thick Cerium doped Yag scintillator. Here the beam centroid and size can be measured as function of the solenoid field. A coaxial faraday cup at the end of the beamline (after an extractable beam dump) is used to measure the beam current. Depending on the particular measurement, fC to nC charges would need to be measured, with currents from nA to mA. A pico-ammeter and a lock-in amplifier have been already tested with very low currents, and we were able to measure down to few nA (Fig. 5). Electronics for charge measurement is also available, although not yet commissioned: a VME QDC (Caen V965) and a chain of charge amplifier/gaussian amplifier/14 bit digitizer from Cremat. Both systems can measure single bunch charge with few-fC resolution.

The Phase 1 beamline is currently being installed, and first tests will start before the end of the year. A double slit system with an extractable faraday cup will allow for transverse emittance measurements of space charge dominated beams. Two pairs of scanning coils before each slit assembly will be used to scan the beam over the slits at 100 Hz, so that phase space reconstruction within few seconds will be possible. A 90 deg. spectrometer magnet has already been installed at the end of the line. The beamline is designed to reach 10^{-4} energy resolution, and 500 eV energy spread resolution in the nominal case of 0.6 μm transverse emittance and 750 keV. A single-cell deflecting cavity at 1.3 GHz [5] is in production phase, for time profile and longitudinal phase space measurements. We foresee its installation on the beamline within the next 6 months.

FIRST RESULTS

The rf gun was conditioned to full power in less that 120 hours. Figure 2 reports a continuous run of 12 hours at nominal power without faults. At around 100 minutes the rf power was switched off for around 5 minutes due to tunnel access.

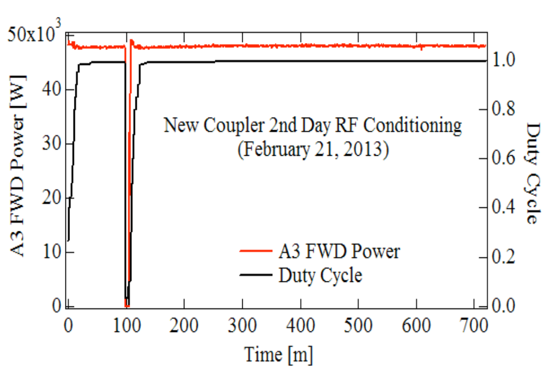

Figure 2: A 12-hour run at nominal power (50 kW each branch), showing no faults. The dip at 100 minutes was due to tunnel access.

The energy of the electron beam out of the gun can be measured by changing the field of a correcting coil and plotting the position of the beam centroid on the screen. The measurement in Fig. 3 shows an example of such measurement. The energy measured implies an accelerating field of 21.5 MV/m.

Dark current measurements were carried out as function of accelerating field in the cavity (Fig. 4). This was done before the installation of Phase 0 beamline, by placing a faraday cup directly at the exit flange of the rf gun. A comparison with dark current measurements from other facilities [6] confirms that indeed these values are within the expectations.

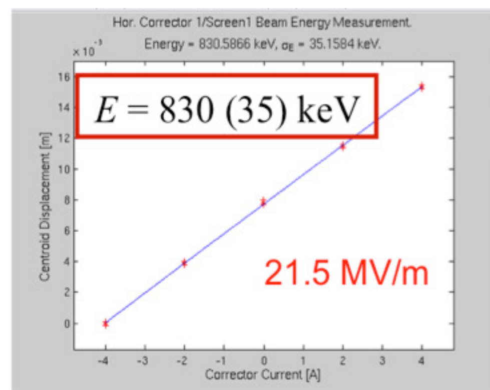

Figure 3: Electron beam energy measurement using a scanning coil.

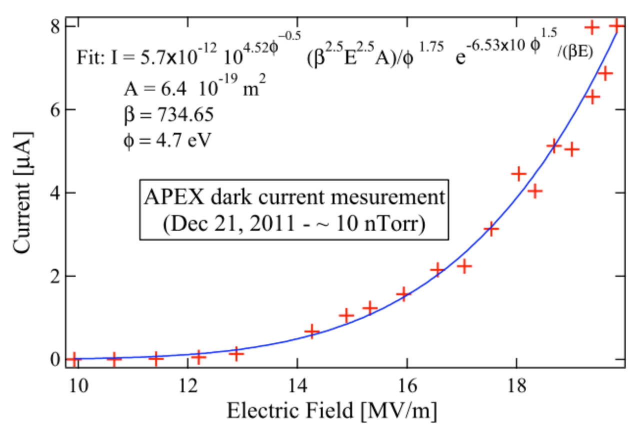

Figure 4: Dark current measurements as function of electric field in the gun.

The first beam tests after gun conditioning were carried out with a molybdenum cathode plug, with quantum efficiency of the order of 10^{-6} . This was done before the full cavity bake-out, with vacuum levels in the 10^{-8} Torr, not acceptable for reactive semiconductor cathodes. Nevertheless, we were able to commission the laser beamline and the electron diagnostic. Using the lock-in amplifier to read the signal from the faraday cup, we were able to measure about 10 nA of electron beam current, around 10 fC per bunch at 1MHz. It is worth noting that also the background (i.e. the dark current) changes by changing the phase of the rf, since the lock-in amplifier is

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a phase sensitive detector. The trigger to the lock-in was indeed derived from the laser trigger, so that when the laser was injected at the maximum accelerating phase, also the cark current was in phase with the reading.

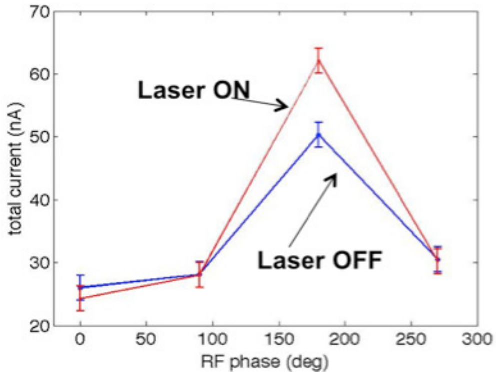

Figure 5: Measurements of 10 nA electron beam current using a lock-in amplifier.

In preparation for the high current runs we also developed a fast Equipment protection system (EPS). A thermal analysis indeed showed that a mA beam with a spot size smaller than 200 μm hitting the beam pipe at normal incidence would require around 2 ms to drill a hole. An in-house developed electronic box read the direct signals from the 2 current monitors in the beamline, and compares the difference with a threshold (5% of the full beam). A beam loss larger than the threshold would trigger a fast laser shutter. A test of the system showed a response time of about 1.7 ms. Figure 6 shows the first APEX long run with the Cs_2Te cathode at the nominal average current of 0.3 mA (300 pC, 1 MHz). The intial QE around 11% decreases during the 4 days of continuous operation down to around 4%, with a total extracted charge of 39.5 C. These first results are compatible with the typical cathode lifetime measured at FLASH [7], and suggests the degradation process to be dominated by the amount of extracted charge (i.e. ion back-bombardment), more than from cathode surface contamination. The oscillations of extracted charge during the run are due to slow drifts of the laser power with the temperature of the environment (bottom plot of Fig. 5), as the laser room is not temperature-stabilized yet.

During the last run a first attempt to measure the thermal emittance from the Cs_2Te cathode was done. The laser pulse at the cathode was about 250 μm rms, as reported in Fig. 7, and the charge per pulse was 900 fC. Measurements were done at 20 Hz, taking pictures of single bunches to avoid contribution from transverse beam jitters.The results of the solenoid scan are reported in Fig. 8. A first analysis gives a thermal emittance value of 0.54 μm/mm rms.

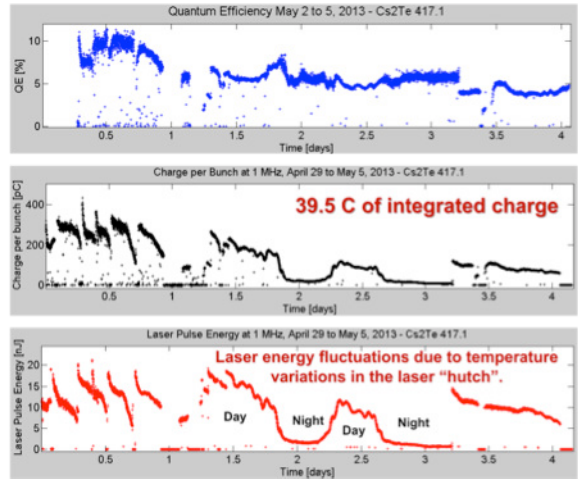

Figure 6: First measurement of cathode lifetime with MHz electron beam.

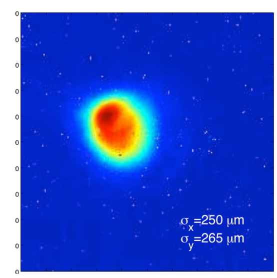

Figure 7: Transverse shape of laser pulse at the cathode for thermal emittance measurements.

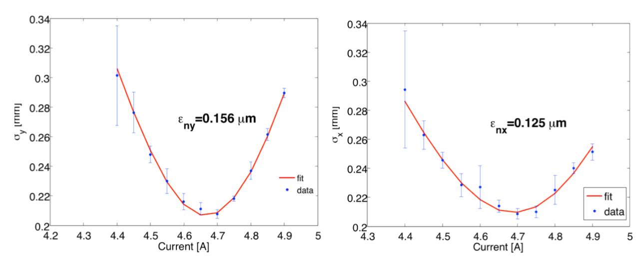

Figure 8: First thermal emittance measurement of Cs_2Te cathode.

CONCLUSIONS

We presented the first results from the APEX high repetition rate electron gun. The rf and vacuum performances have been achieved, with a final beam energy and accelerating field exceeding the targeted ones. Vacuum levels are at the level of what is needed to run semiconductor cathodes. We have been running a Cs_2Te cathode in the cavity for months without any sign of degradation due to contamination. The Phase 0 beamline was installed and commissioned. We were able to measure currents down to 10 nA, verifying the resolution of the readout electronics. Thermal emittance and beam

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energy were measured and analyzed. A first test of cathode lifetime has been performed at mA current, showing acceptable time constant (about a week). We are now installing Phase 1 hardware, that will allow to measure the transverse and longitudinal emittance at high charge, with a double-slit system, an rf deflector and a spectrometer dipole.

REFERENCES

[1] K. Baptiste, et al., NIM A 599, 9 (2009).
[2] D. Filippetto, et al., Proceedings of FEL2013, New York, USA, TUPSO19 (2013).
[3] S.Zhou, et al., Applied optics 46, (2007) 8488.
[4] F. Sannibale, et al., PRST-AB 15, 103501 (2012).
[5] S. Belomestnykh, V. Shemelin, K. Smolenski, V. Veshcherevich, Proceedings of PAC07, Albuquerque, New Mexico, USA, pp. 2331-2333.
[6] L. Monaco, et al., Proceedings of EPAC06, Edinburgh, Scotland, pp. 2493-95.
[7] S. Lederer, et al., Proceedings of EPAC08, Genoa, Italy, pp. 232-234.

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