STATUS OF THE APEX BEAM DIAGNOSTIC AND FIRST MEASUREMENTS*

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Abstract

The APEX project aims to the construction of a high brightness high repetition rate photo-injector at LBNL. In its first phase a 750 keV electron bunch is produced at a maximum repetition rate of 1 MHz, with an adjustable charge per bunch spanning the pC-to-nC region. A load lock system is foreseen to test different cathodes without the need of breaking the vacuum and the downstream diagnostic is used to characterize the photo-emitted beam brightness. In the initial phase the main effort is directed toward the measurement of photocurrent, dark current, thermal emittance and electron beam kinetic energy. In a successive phase, diagnostic for full 6D phase space characterization of space charge dominated beams will be added to the beamline. We report and discuss the present diagnostic beamline layout, first beam measurements and future upgrades.

OVERVIEW

The APEX electron beam parameter space is summarized in Table 1. The project has been conceived as an R&D on MHz-class photo-injectors, particularly toward the possible application as driver for high repetition rate FELs [1]. A CW 187 MHz normal conducting rf-gun has been specifically designed and constructed for this purpose [2]. The low frequency and the peculiar design allow the power density on the walls to be within 25 W/cm^2 when running in CW at full power (100kW), and at the same time to sustain an adequate accelerating field (20 MV/m) at the cathode, a key parameter for high brightness beams generation. Furthermore, the low rf frequency allow to open big slots on the cavity walls without disturbing the field, that are used to increase the vacuum conductivity and make the system compatible with very high vacuum performances (10^{-12} Torr) [2]. Such a system, together with a load lock system is therefore a perfect environment to testing highly reactive cathode materials, with high quantum efficiencies and limited lifetimes.

As photocathode laser an Ytterbium-doped fiber laser system provides 700 nJ pulses at 1 MHz (0.7 W) at a wavelength of 1060 nm and pulse width of about 600 fs FWHM. Second and fourth harmonic are generated (respectively 250 and 80 nJ) and transported to the cathode, for different work function materials. Transverse and longitudinal pulse shaping allows for different electron beam densities and aspect ratios.

The wide range of measurable beam parameters make the diagnostic challenging. Fast sensors and readouts are needed for single bunch measurements, which are essential for jitter estimations. The high average power of the beam becomes an issue when invasive diagnostic is used (viewscreens, faraday cups, etc...), but the high repetition rate can on the other hand be used to enhance the signal-to-noise ratio and increase the overall dynamic range.

Table 1: APEX Beam Parameters

Parameter	Value	dimensions
Energy	750	keV
Charge	10^{-3}-10^{3}	pC
average current	1-10^{6}	nA
Emittance (rms)	<1	μm
repetition rate	1-10^{6}	Hz
Bunch length(rms)	1-60	ps

THE DIAGNOSTIC BEAMLINE

Full photo-injector characterization entails a deep understanding of the functional dependency of the beam quality out of the RF gun from all the variables listed above. In first instance the attention is addressed to the photocathode material choice and to the RF-gun performances. High Quantum efficiency materials are required to drive the accelerator at high repetition rate with present laser technology. Lifetime and the thermal emittance needs to be characterized in the RF environment, where cathode back-bombardment and partial vacuum pressures can seriously limit the performances. Accelerating rf field's amplitude and stability are very important to prove the Gun performances [3].

The layout of the present APEX beamline is shown in Fig.1. Two solenoids along the line keep the beam focused. Two beam position monitors and 4 magnetic correctors monitor and control the orbit. The solenoid's position can be remotely adjusted along 5 axes (no z adjustment) for beam based alignment. Two couples of skew and normal quadrupoles have been placed at the entrance and exit faces to compensate for eventual solenoid field errors due to lack of symmetry. The second solenoid ($z_{cathode}$=∼170 cm) is foreseen to be used in a later phase to match the beam into a Linac section. Its only use now is to help focusing the beam on the faraday cup (FC) at the end of the line.

Beam size, thermal emittance and beam alignment on the cathode can be measured at the first screen, 1.5 m downstream the cathode plug. Two different viewscreen materials are installed in the beamline: a Ce:Yag scintillator and a BeO ceramic. Ce:Yag scintillation screens 100 μm thick have a good resolution and a high photon yield (10^4 photons per MeV deposited). A thin aluminum layer creates

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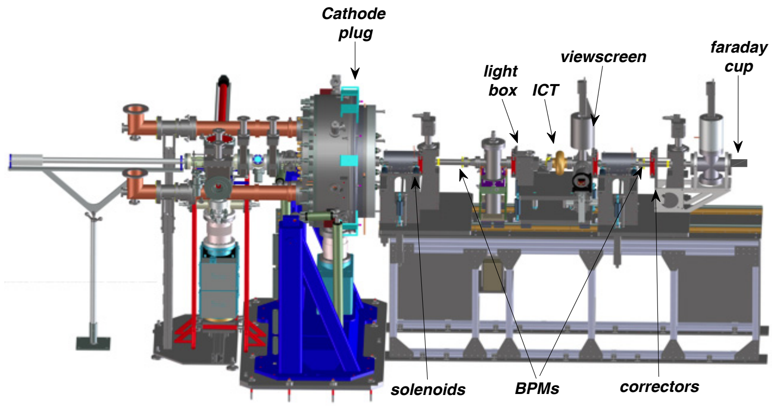

Figure 1: Present APEX beamline layout.

a path for electrons, preventing voltage build up in the insulating material. BeO have worst resolution, but higher saturation threshold, and will be used as back up option. A interlock on the beam power (10 W) has been implemented in the PLC-based equipment protection system (EPS). It will prevent invasive diagnostic to be inserted on the beam path during high power operations. Such power level is not limiting factor since present commercial cameras have frame rates of tents of Hz, allowing single bunch diagnostic only at low repetition rates.

The repetition rate is a major concern when designing the beam diagnostic. Deposited charge and energy may become critical and damage the diagnostic, cooling rates may become unfeasible. On the other side flexibility in the high repetition rate can improve the signal-to-noise ratio (SNR) and may increase the overall dynamic range of diagnostic tools. In the case of intercepting screens for example, very low beam charges can be detected increasing the repetition rate (see next Section), i.e. without changing the integrated signal in one readout cycle (∼ms) on the CCD and avoiding screen saturation.

Electronics

A complete source characterization implies both the measurement of average and standard of deviation beam parameters. As already said, a high repetition rate machine can take advantage of its average current, especially for very low charges. A single-bunch femto-coulomb charge is indeed hardly detectable, while the 1 nA current produced at 1 MHz repetition rate is easily measurable. Nevertheless an estimation of beam jitters requires bunch per bunch diagnostics, so for a full characterization both charge and current need to be measured. The range of charges and currents foreseen are summarized in Table 1. Beam charges below 1 pC may be present in particular cases if low QE cathodes are tested or beam transverse sampling for high resolution measurements. Different electronics is used to cover the full range of beam charge: a current transformer (ICT) (Fig. 1) ([4]) can detect single bunch charge in the 1 nC-10 pC range at ∼1 KHz. Low single bunch charges in the fC range can be measured with a chain of charge sensitive amplifier, Gaussian shaping amplifier , and high speed digitizer connected to the FC signal [5]. A VME QDC module module, with 25 fC minimum sensitivity, can also be used at bunch rates up to 100 KHz [6] with the FC.

For low charges a current measurement is more reliable. It can be extracted from the FC using a low noise picoammeter [7]. The instrument can be configured for 1 nA full scale measurements with intrinsic 10 fA resolution at ∼10 Hz readout rate. Faster rates are also possible by integrating over less than one line cycle at the expense of measurement resolution (∼10 pA baseline for 0.1 cycles integration). The first measurements performed and reported in Fig. 4 use instead a 200MHz lock-in amplifier locked at the beam rep rate.

Three stripline beam position monitors along the line will measure the centroid position. Each strip has a length of ∼14.5 cm and maximum sensitivity around 500 MHz. Simulated circuit response of in-house readout boards to a signal equivalent to 500 pC/30 ps beam already showed resolution on the order of 15 μm at 125MHz. For smaller charges, down to 10 pC/0.5 ps, simulations show noisy signals, still detectable with a resolution on the 100 μm scale. Those boards are now being adapted changing the working frequency from 125MHz to 260MHz, almost doubling the sensitivity.

FIRST MEASUREMENTS

At present time a dummy molybdenum cathode disk is installed in the cavity in place of a real cathode. We first wanted to verify the rf-gun performances in terms of vacuum and fields before placing reactive materials in the cavity. Nevertheless the molybdenum has a work function similar to that of copper and Ce_2Te, and the 266 nm laser pulse available is enough to extract electrons from the material with an expected quantum efficiency is on the order of 10^{-6}. A UV pulse of 25 nJ was delivered to the cathode, with a gaussian transverse laser spot of 500 μm rms size. The electron beam was focused on the downstream Yag screen and imaged on the CCD camera via a 105 mm focal length lens. The resolution was 18.4 μm/pix and the acquisition time was 100 μs. We integrated on the CCD about 100 electron beam shots, but also about 18700 dark current shots, since the rf-gun works in CW at 187 MHz. For such a long rf wavelength, the relative laser-rf injection phase for maximum energy is close to the crest (the phase slippage is very small), which is also the part of the rf wave where dark current is generated the most. When such a beam is focused on the screen, one gets to focus also the most part of the dark current because of the similar energy. To obtain Fig. 2 beam was injected slightly out of phase, lowering its energy enough to get a clear image of the beam while the dark current is under-focused.

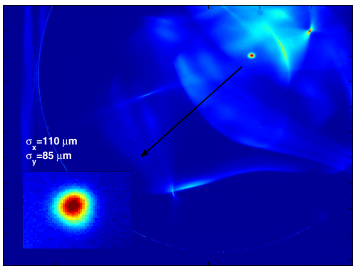

Figure 2: APEX Photobeam focused on the viewscreen by the first solenoid. The beam charge was about 10 fC.

Figure 3 shows an electron beam measurement performed at maximum energy injection phase. The beam centroid on the screen was recorded as function of the current of a corrector upstream. A linear fit of the measurement gives the beam energy. The cavity was running in CW at the nominal power of 100 KW. We measured an energy of 745 keV. Fine tuning of the injection phase has not been done yet, but this result is already showing that the accelerating field in the cavity is what we expected. The system is capable of running at nominal power levels for many hours without faults. The beam current has been measured with

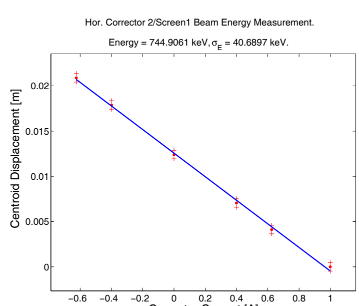

Figure 3: Electron beam energy measurements. Scan of the beam centroid with the upstream corrector field.

a lock-in amplifier a phase sensitive detector that gives as output modulus and a phase of the amplified input signal respect to the trigger. The instrument was triggered synchronous with the laser repetition rate (1.005 MHz). In order to change the laser-rf injection phase, the LLRF system acts on the phase of the signal driving the tetrodes of the high power amplifier, leaving the laser untouched. This explain why in Fig. 4 the dark current signal is changing with injection phase. The plot reports only the modulus of

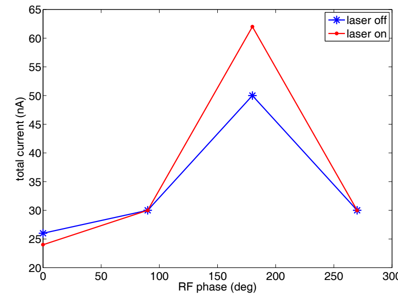

Figure 4: Phase scan measurement. Data collected with lock-in amplifier.

the signal and the dark current is in phase with the rf, while the instrument is in phase with the laser. We measured a photo-beam current of about 10 nA (10 fC at 1MHz) at 180 deg injection phase. The acquisition time on the instrument was about 300 ms, leading to an overall measured noise of about 2 nA (2 fC). The measured value is in agreement with 25 nJ of laser energy and a molybdenum QE of $2 \cdot 10^{-6}$. It shows the ability to characterizing very low beam charges. The dark current transported to the faraday cup is about 50 nA, meaning that for each rf cycle about 0.26 fC is transported to the faraday cup. Previous measurements performed with the farday cup right a the exit of the gun showed about 40 fC of produced charge per cycle ([3]).

Future Upgrades

The next phase of the project foreseen the installation of diagnostic for the full 6D phase space characterization. The transverse space space will be measured with the use of a double slit system and an insertable Faraday cup (FC), based on the Cornell design [8]. A quadrupole triplet will match the beam Twiss parameters for the subsequent longitudinal and slice emittance measurements, performed by a 1.3 GHz single cell deflecting cavity (RFD) [9] and a dipole magnet with 90 degrees bending angle [10].

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