THE CURRENT STATUS OF THE ALICE (ACCELERATORS AND LASERS IN COMBINED EXPERIMENTS) FACILITY.

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Abstract

ALICE (Accelerators and Lasers In Combined Experiments), a 35 MeV energy recovery linac based light source, is being commissioned and developed as an experimental R&D facility for a wide range of projects that could employ synchronized ultra-short (<1ps) electron bunches and light pulses. A suit of light sources includes an IR FEL, Compton backscattering (CBS) X-ray source, high power THz source and a multi-TW femtosecond laser. The full energy recovery and coherently enhanced, due to shortness of the electron bunches, THz radiation have been already demonstrated on ALICE. Completion of the first phase of the CBS x-ray source experiment and first lasing of the IR FEL are expected before the end of 2009. Status of ALICE experimental facility and latest results on FEL, THz, and CBS development are reported in this paper.

INTRODUCTION

ALICE, formerly known as ERLP [1], is a new R&D facility currently being commissioned at Daresbury Laboratory. The accelerator is an energy recovery superconducting (SC) linac operating at the nominal beam energy of 35MeV. The high voltage DC photoelectron gun operates at nominal voltage of 350kV and bunch charge of 80pC. The bunch trains can be of variable length from a single bunch regime to 100µs with a bunch repetition frequency of 81.25MHz within the train. The train repetition frequency can also be varied from 1-20Hz.

In addition to the accelerator, several light sources will be available for conducting a variety of R&D research, including pump-probe experiments. These are (i) an IR FEL with wavelength of ~4µm; (ii) a THz source with coherent enhancement of the radiation intensity due to sub-picosecond bunch lengths generated by ALICE; (iii) a Compton Backscattering (CBS) X-ray source with photon energy of 15 or 30keV depending on the collision angle between the photons and electrons. The CBS source is powered by a terawatt IR femtosecond laser that can also be used as a stand-alone light source for a variety of experiments.

PRESENT STATUS

Full energy recovery and demonstration of the coherently enhanced THz radiation were successfully achieved on ALICE by the beginning of 2009. The injector can now reliably deliver beams with bunch charges well in excess of 80pC and with the design bunch structure, i.e. 81.25MHz bunches in trains up to 100µs, repeating at 1-20Hz. However, due to a number of mostly technical problems, some of the other ALICE design parameters have not been achieved at present.

The gun operating voltage of 350kV was initially used for gun commissioning [2] but, after several failures of the high voltage insulating ceramics [3], it was necessary to install a more robust but smaller inner diameter ceramic, which was loaned to us by Todd Smith at Stanford University, which reduced the maximum gun operating voltage to ~250kV. Furthermore, a field emitter on the GaAs cathode wafer located close to its centre necessitated a reduction of the gun voltage down to 230kV. This field emitter is likely to be responsible for a hole in the quantum efficiency map of the cathode. This hole becomes more pronounced towards the end of the cathode activation cycle but virtually disappears after the cathode re-caesiation (Fig.1). An improved 500kV ceramic insulator is currently being developed and manufactured in collaboration with Jefferson Laboratory and Cornell University that will restore the ALICE gun nominal voltage to 350kV.

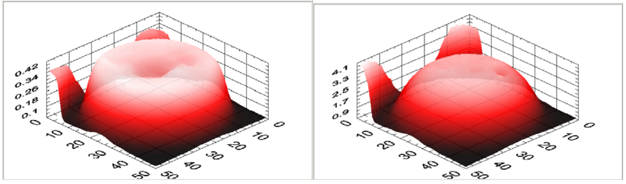

Figure 1: Typical QE maps at the end of the activation cycle before the re-caesiation (left) and after a full cathode activation including a heat cleaning treatment of the wafer (right).

Due to excessive field emission from the main linac module, designed to bring the beam energy to 35MeV [3], the beam energy was reduced to 21MeV for the machine commissioning conducted to date. The corresponding beam energy after the injector was 4.8MeV to allow injection and extraction chicanes to operate correctly. Recent work on extensive SC linac cavity conditioning, improvements in the cryogenic system and optimisation of the linac operating parameters would allow ALICE to operate at a higher beam energy of 25-27MeV in an energy recovery mode and up to ~30MeV in a nonenergy recovery mode (the latter will be used for the CBS experiments).

ENERGY RECOVERY AND BEAM CHARACTERISATION

The gun was commissioned and the 350keV electron beam was fully characterised at a range of different bunch charges of up to 80pC. The results are reported in [2,4].

Initially, full energy recovery was established at 21MeV beam energy and several bunch charges up to 20pC. This is illustrated by the RF power demand signals from the two superconductive cavities of the main linac (Fig.2). Higher bunch charges were not not possible to achieve because of the beam loading effects in the injector SC booster cavities.

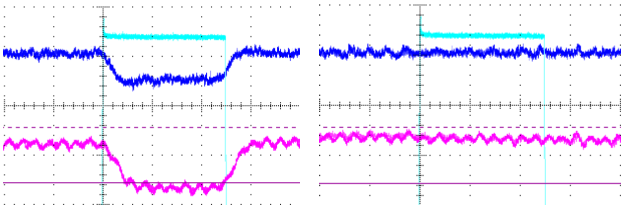

Figure 2: Main linac RF power demand signals: without (left) and with (right) energy recovery.

Beam loading in the booster cavities was clearly visible on the LLRF signals at train lengths of a few tens of microseconds and bunch charges above 10pC. The major impact of this on the beam was that the beam energy towards the end of the macropulse was lower than at the beginning by a few percent. The effect of beam loading was also observed on the Faraday cup located in a dispersive section of the injector beam line. In the presence of the beam loading, the current measured by the Faraday cup is not constant because the beam sweeps across the cup aperture due to such change in the mean energy during the train length. Extensive work on optimisation of the LLRF system response and external quality factors of the booster cavities allowed extended operation of the machine to ~40pC bunch charge and up to 100μs train lengths in an energy recovery regime.

Towards the end of the latest commissioning period, after elimination of a minute vacuum leak detected in the gun vacuum vessel followed by a full cathode activation, the achieved cathode quantum efficiency was reliably ~4%, and the cathode dark 1/e lifetime exceeded 800 hours. This will ensure ALICE operation at nominal bunch charges of 80pC for prolonged periods of time, expected to be 2-4 weeks, between cathode re-caesiations.

The field emitter on the cathode wafer remains a serious problem especially at levels of quantum efficiency above 3% when the flow of field emission electrons becomes too intense after acceleration in the booster. Replacing the wafer in the current gun design is a complicated and time consuming procedure and, based on experience, may lead to vacuum, HV and cathode problems. Increasing the field of the first solenoid, next to the gun, disperses the field emission electrons within the gun beamline and only a smaller fraction is picked up by the booster cavities and accelerated further. At lower bunch charges, this increased solenoid field is too high, leading to a transverse cross-over and correspondingly larger beam emittance. It is close to the optimal setting for higher bunch charges of ~80pC.

Beam characterisation and optimisation was not a priority during this latest commissioning period. Only a limited number of emittance measurements were made in the injector beamline using quadrupole and slit scans. Provisional results are shown in Fig. 3 where the emittance for various bunch charges was measured using a slit in the injector beamline. No attempts were made to minimise the emittance for each bunch charge. This and the existence of the field emission current, probably accounts for significantly larger emittance values compared to that expected from the ASTRA model (~3μm at 80pC). A systematic optimisation of the injector settings is planned and a significant improvement in overall beam quality, including the transverse emittance, is expected.

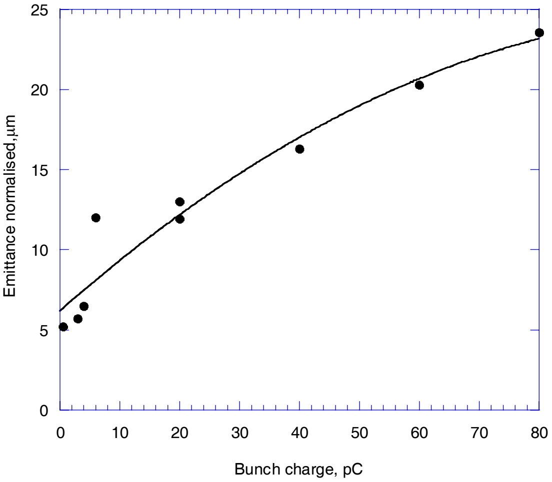

Figure 3: First estimates of the transverse emittance as a function of the bunch charge.

THZ GENERATION STUDIES

Coherent enhancement in the synchrotron radiation from short electron bunches produces high power THz radiation at high repetition rates. This radiation provides a useful diagnostics tool for the accelerator, but will also allow new photon science developments.

The final dipole in the compression chicane is the source of THz radiation. A plane mirror within this vessel deflects radiation through a 38mm aperture CVD wedged diamond window. The overall acceptance of the beamline is 70 x 70mrad. The window separates the accelerator vacuum from the THz beamline which transports the radiation to a diagnostics laboratory. The beamline was optimised by extensive modelling with the wavefront propagation code SRW [5]. There are two intermediate foci in the 17m optical path to the diagnostics laboratory. The beam can then be directed into a nitrogen purged diagnostics enclosure which includes a custom high-aperture, step-scan Martin-Puplett interferometer, or further transported on to a suite of THz exploitation laboratories including a tissue culture facility (TCF), see Fig. 4. Here the beam is condensed by a Winston cone through a TPX exit window where live human tissue cells can be irradiated.

Figure 4: Tissue culture laboratory where THz radiation can be condensed into living human tissue cells

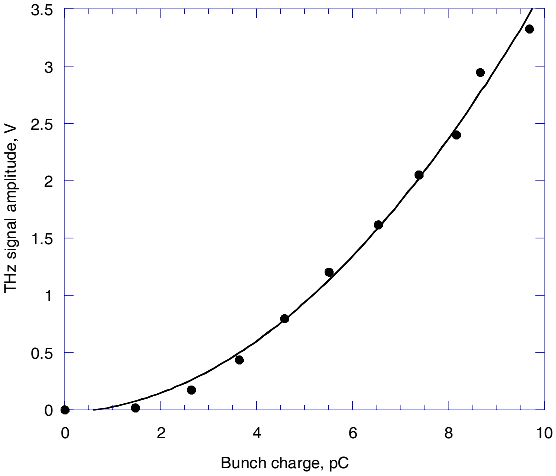

Figure 5: Dependence of the THz signal amplitude on the bunch charge.

Monitoring the intensity of the radiation at the diagnostics enclosure allowed the accelerator RF system to be tuned to put the optimum energy chirp onto the electron bunch to give maximum compression in the chicane.

Under these conditions a linear dependence on THz detector signal on the bunch train length was observed at constant bunch charge, and a clear quadratic dependence on bunch charge was observed at constant train length, as shown by the fitted line in Fig 5. This is indicative of coherent emission.

The latest observations of the THz intensity at the bunch charge of up to 40pC indicate that the THz pulse energy can reach several tens of μJ.

FUTURE DEVELOPMENTS

The ALICE R&D facility faces several exciting challenges in the years 2009-10. First, the Compton Backscattering experiment will be conducted with a head-on geometry that is less demanding in terms of laser/electron beam synchronisation compared to a side-on 90° geometry. ALICE will be able to deliver electron bunch charges in excess of 80pC to the laser-electron beam interaction point tightly focussed to a less than 100μm spot and with the beam energy close to 30MeV. At the same time, an extensive programme of THz studies is planned including the first experiments at the TCF to determine the safe limits of human exposure to THz radiation. This will be followed by installation and commissioning of the IR FEL. Towards the end of 2009 experiments with EMMA, the first non-scaling FFAG [6], will commence and continue throughout 2010. Three major upgrades are also expected including installation of the load-lock system on the photogun, extension of the gun beamline to include diagnostics for full beam characterisation before the booster, and installation of the new improved SC linac module that is currently being constructed and is a result of a multinational collaboration [7].

In conclusion, ALICE commissioning has reached the point when it is now becoming a true R&D facility capable of accommodating and testing novel ideas, and conducting proof-of-principle experiments.

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