Progress on the commissioning of ALICE, the energy recovery linac-based light source at Daresbury Laboratory

PROGRESS ON THE COMMISSIONING OF ALICE, THE ENERGY RECOVERY LINAC-BASED LIGHT SOURCE AT DARESBURY LABORATORY

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Abstract

ALICE (**A**ccelerators and **L**asers **I**n **C**ombined **E**xperiments) is a 35 MeV energy recovery linac based light source. ALICE is being developed as an experimental test-bed for a broad suite of science and technology activities using electron acceleration and ultra-short pulse laser techniques. This paper reports the progress made in accelerator commissioning, describes the present status of the ALICE experimental facility, and includes the latest results on beam and terahertz (THz) radiation measurements. Near-future developments including the demonstration of the Compton Backscattering x-ray source and IR FEL commissioning are also presented.

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 within the 1-20Hz range.

In addition to the accelerator, several light sources are or will be available for conducting a variety of R&D projects, 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 that 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.

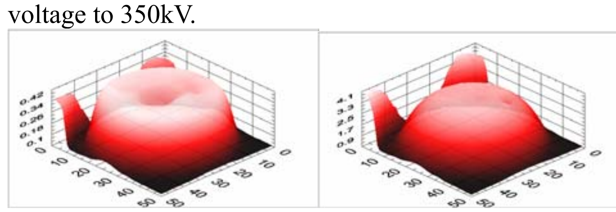

Figure 1: Typical QE maps at the end of the activation cycle before the re-caesiation (left) and after a full cathode activation including a heat cleaning treatment of the wafer (right).

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.

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].

Full energy recovery has been 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 attempted because of the beam loading effects in the injector SC booster cavities.

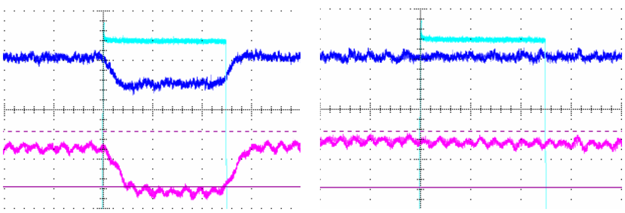

Figure 2: Main linac RF power demand signals: without (left) and with (right) energy recovery.

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 change in the beam mean energy during the train length. Tweaking the LLRF system and manipulating the external quality factors of the booster cavities allowed the operation of the machine at ~20pC bunch charge and up to 100μs train lengths. The problem of the beam loading is being resolved at present. This and other results from SC RF commissioning are reported in a separate paper in these Proceedings.

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. Increase of 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 latest commissioning periods. 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.

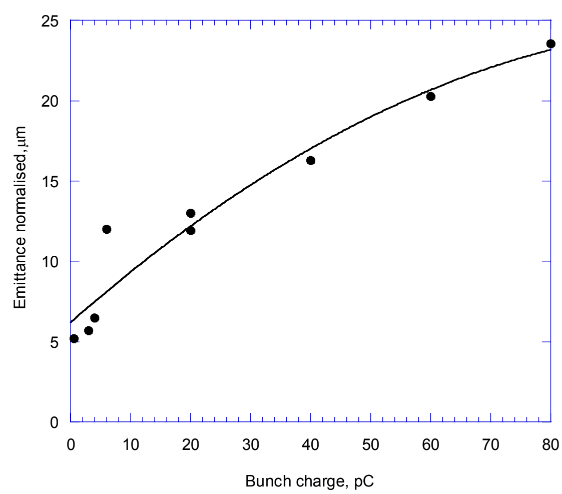

Figure 3: First estimates of the transverse emittance as a function of the bunch charge.

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

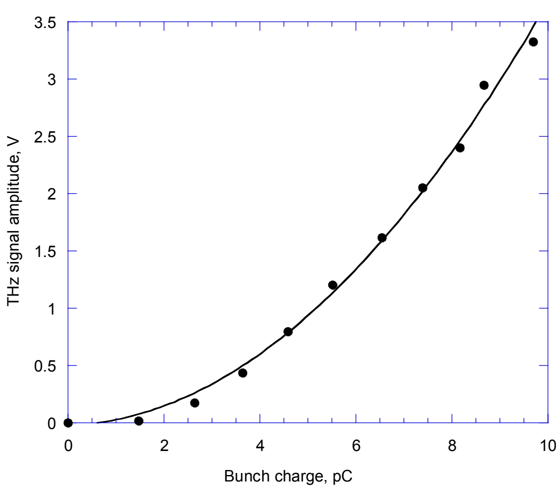

Figure 5: Dependence of the THz signal amplitude on the bunch charge.

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.

In these initial experiments the bunch charge has been limited by the RF system but it will be improved to run at 80pC per bunch in long 100μs trains.

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^o geometry. 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.

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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