THE STATUS OF ALICE, THE DARESBURY ENERGY RECOVERY LINAC PROTOTYPE

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Abstract

This paper provides an update on the progress with the building and commissioning of ALICE (formerly the Energy Recovery Linac Prototype - ERLP). The past year has seen a number of notable achievements as well as a number of obstacles to overcome. The detailed results from the gun commissioning work are described elsewhere at this conference. ALICE is a 35 MeV technology demonstrator being built as part of the UK's R&D programme to develop its next-generation light source (NLS). It is based on a combination of a DC photocathode electron gun, a superconducting injector linac and a main linac operating in energy recovery mode. These drive an IR-FEL, an inverse Compton Back-Scattering (CBS) x-ray source and a terahertz beamline.

The priorities for ALICE are to gain experience of operating a photoinjector gun and superconducting linacs; to produce and maintain high-brightness electron beams; to achieve energy recovery from an FEL-disrupted beam; the development of an electro-optic longitudinal profile monitor and to study challenging synchronisation issues.

ALICE will also act as an injector for what will be the world's first non-scaling, Fixed-Field Alternating Gradient (FFAG) accelerator called EMMA.

INTRODUCTION

ALICE (Accelerators and Lasers in Combined Experiments) experimental facility (known formerly as ERLP) is being commissioned at present. This machine includes a high DC voltage photoemission electron gun, superconducting linacs operating in energy recovery mode and a mid-IR free-electron laser (FEL). Originally conceived as a prototype test-bed for the key concepts and technologies expected to feature in the UK's next major light source project, the 4th Generation Light Source (4GLS), it now has a broader role as an accelerator physics and technology test facility and to develop fourth generation light source science. The period under review here covers both operation of the gun into its dedicated diagnostic beamline, and its subsequent removal and completion of the rest of the machine.

PROGRESS STATUS

Gun Commissioning

The first electron beam was obtained from the gun at 250 keV into a dedicated gun diagnostic beamline [1], in August 2006. The second and third periods of gun commissioning ended in April 2007, when the problem of a high level of field emission (limiting high voltage operation to 250 kV rather than the nominal 350 kV) and beam halo became insurmountable. A fourth period of gun commissioning took place in October and November 2007. Improved cathode activation produced a quantum efficiency (QE) of 3.5% and for the first time charge per bunch of over 100 pC was achieved, allowing the performance of the injector at high charge bunch to be measured. This was the start of several weeks of productive measurements of the properties of the gun, although in a presence of field emission (FE) from the cathode, until excessive current leakage within the gun became a problem again. Ref [2] summarises the measurements from this period. The highlights are:

- The gun can now be routinely conditioned up to 450kV;
- The beam was fully characterised (emittance, bunch length and energy spectra) in a wide range of bunch charges from 1 to 80pC;
- A good agreement between ASTRA simulations and the experimental data was found for the energy spread and bunch length measurements;
- A comparison of the bunch characteristics obtained with two different laser pulse lengths of 7ps and 28ps was made at 16pC bunch charge [3].

The latter is probably the first such experiment with a HV DC photogun. It shows that (at low $Q<20$pC) there is not much difference in bunch quality with two different pulse lengths. However the ASTRA model indicates that there should be an appreciable improvement in emittance with longer laser pulses at higher bunch charges, if a near-flat top laser pulse can be provided.

The emittance measured is much larger than in simulations, believed to be due to the fact that the model did not include several factors (like initial thermal emittance from GaAs photocathodes) and that the experimental conditions were not ideal (FE from the cathode, non-optimal setting of focussing magnetic fields and non-uniform QE map on the cathode).

Between periods of gun commissioning a number of issues interfered with continuous operation of the gun. These included:

- Vacuum leaks through the brazed joints at the end of the gun ceramic or large diameter joints exposed to several bake cycles;
- Poor vacuum due to suspected contamination of the gun;

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- Field emission due to mechanical defects or dust;
- Apparent current leakage along the ceramic surface – potentially due to detached particles of braze material.

Fig. 1 shows the gun ceramic with the copper brazing between the flange and ceramic.

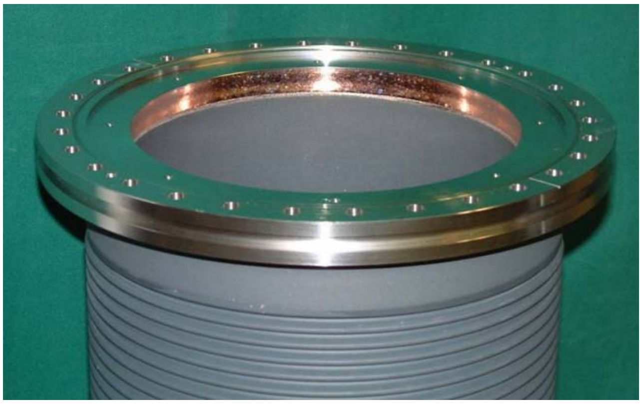

Figure 1: Gun ceramic showing copper braze between flange and ceramic.

Cryogenic System Commissioning

Following several months of commissioning work and the identification and rectification of a number of problems, the cryogenic system met its operational specification in May 2007. Over the following summer the cryogenics team have further optimised the system. This included pushing the system beyond its specified operational temperature of 2 kelvin, as part of a series of cryogenic tests aimed towards developing a thorough practical understanding of the change in superconducting cavity performance at lower operating temperatures. The initial tests were highly successful, with the team achieving stable operation at 1.8 kelvin with sufficient cooling capacity capable to sustain ALICE operation [4].

Superconducting Modules

During the initial phase of cavity conditioning, CW conditioning of the input couplers was clearly observed, resulting in a number of vacuum and arc events at >10 MV/m. Progress was then halted however due to a mechanical failure of the tuner mechanism, which were rectified in-situ by ACCEL during the cavity commissioning and acceptance tests. The test results are summarised in Table 1.

Table 1: Accelerating gradient results.

		Maximum measured	**Required**	
Booster	Cavity 1	10.8	4.8	MV/m
	Cavity 2	13.5	2.9	MV/m
Linac	Cavity 1	16.4	13.5	MV/m
	Cavity 2	12.8	13.5	MV/m

Note the maximum operational voltage is typically 90% of maximum measured voltage. Two of the four cavities failed to meet the specified Q value but the cryogenic system has the capacity to deal with the extra load. Processing to achieve the specification would take many months and is not guaranteed to be successful. In addition there were two significant issues that arose during commissioning:

- Failure to control phase and amplitude on both linac cavities simultaneously;
- Unexpectedly high radiation levels from the cavities, associated with low-field onset of field emission.

The first of these issues was dealt with by the installation of a second IOT on the linac module; initially it had been intended to power the linac with only one.

The second issue led to an extensive series of radiation measurements throughout the accelerator room. For example, at 7 m away from the linac module operating at a gradient of 7 MV/m, a peak radiation measurement of 9.2 mSv/hr was recorded. When the gradient is increased to 9 MV/m, the detector begins to saturate at 13 mSv/hr. It was decided that operation of the booster (which requires a considerably smaller gradient compared to the main linac) producing high radiation levels could be tolerated if some of the more sensitive equipment nearby was re-located. It was also decided to surround the main linac module with lead shielding to protect electronic components in the accelerator area and allow commissioning to continue. Construction of the lead shielding around the linac module can be seen in Fig. 2. More detailed results from the module commissioning can be found in refs [5, 6].

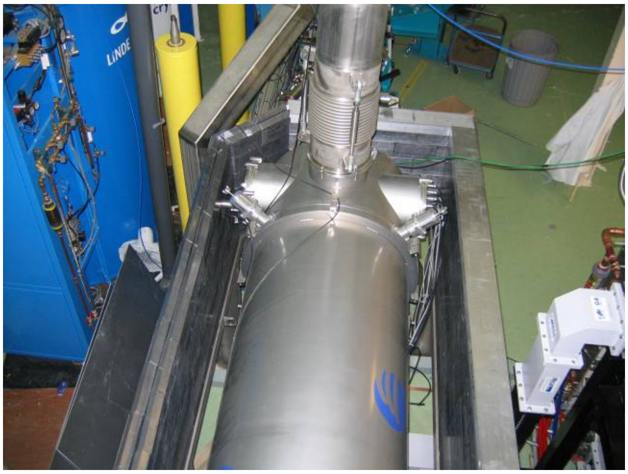

Figure 2: Lead shielding around the linac module under construction.

In addition a helium leak was detected in the booster insulation vacuum in October 2007, and it was determined that the leak location was such that the module would have to be returned to ACCEL for further investigation. The leak was subsequently determined to be a fault in a weld, which was ground off and repaired.

The reassembled module was cold-tested at ACCEL and returned to Daresbury in February 2008 and has been cooled to 4 kelvin successfully. The returned booster module has been re-installed in its final position; previously it had been canted out of position to make space for the gun diagnostic line.

RF System

All five IOTs (two for the main linac and three for the booster) have been run at high power and the final commissioning of the RF system to run all five IOTs into the linac and booster simultaneously is currently underway. Commissioning of a prototype capacitive system to prevent the droop in voltage has been tested successfully and the full system will be delivered and commissioned in July.

CONSTRUCTION PROGRESS

As already mentioned, up until now the gun has been beaming into a dedicated gun diagnostic beamline. This has now been removed and the electron beam transport fully assembled and under vacuum, requiring some of the diagnostic devices that were being used with the gun diagnostic beamline. Installation of photon beam transport systems required for the FEL output, Compton backscattering & electro-optic longitudinal diagnostic laser and terahertz beamlines are continuing.

FUTURE PLANS

HV conditioning of the newly-cleaned gun will commence in July. This will be the first time that the gun provides beam into the superconducting modules and into the rest of the accelerator. The first priority for this next period of operation is to demonstrate energy recovery. This will be followed by:

- Fine tuning of the machine (including injector tuning for minimum emittance, optimisation of energy recovery at nominal beam parameters, extensive beam measurements);
- A short pulse commissioning stage (concentrating on longitudinal dynamics, electro-optical diagnostics);
- Demonstrating energy recovery with the disrupted beam following installation of the FEL;
- Getting the first light from the FEL;
- The THz, IR-FEL and CBS phase I (head-on interaction geometry) research programmes will start, in parallel with the accelerator physics programme.

An exciting research programme using ALICE light sources (TW laser, IR-FEL, femtosecond tuneable laser, THz radiation, x-rays from CBS) is envisaged, mostly pump-probe experiments that will use a combination of one or more wavelengths and sources. The capabilities of ALICE will be further extended into bioscience after the completion of the Tissue Culture Laboratory (TCL).

Looking further ahead, a number of new developments of ALICE are planned in 2009:

- Gun upgrade by the installation of load-lock system that will allow cathode exchange without breaking the gun vacuum;
- Installation of an improved high-current ERL cryomodule;
- ALICE will also serve as an injector for the first non-scaling Fixed-Field Alternating Gradient (FFAG) accelerator, starting 2009/10 [7].

CONCLUSIONS

The prime motivation for the construction and operation of ALICE is to gain experience in designing and operating the technologies which are critical to the success of the future UK light sources. In the short period since the start of this project, a huge amount has been learnt, with much more still to come.

Once fully operational, ALICE will be one of the few true electron beam test facilities available in the world. It will be used for development of photoinjector guns, diagnostics, superconducting linacs, synchronisation and for benchmarking codes.

In addition to the IR radiation generated by the FEL and the x-rays produced by the Compton backscattering source, a third beamline to utilise terahertz radiation from a dipole magnet in the bunch compressor is being built.

A recent addition to this list is the Electron Machine with Many Applications (EMMA) project, which is a non-scaling FFAG technology demonstrator. This type of accelerator has many potential applications, for example for protons in radio-therapy and in neutrino factories. It will use ALICE as an injector.

REFERENCES

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