OPERATIONAL EXPERIENCE OF THE SUPERCONDUCTING RF SYSTEM ON ALICE AT DARESBURY LABORATORY

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Abstract

ALICE (Accelerators and Lasers in Combined Experiments) is a proof of concept energy recovery linac (ERL) accelerator, which incorporates two superconducting radio frequency (SRF) cryomodules each with two identical 9-cell cavities. The first cryomodule, the Booster provides the acceleration for the injected beam into the ERL section of the accelerator where the second module, the Linac accelerates the beam to its required energy. The conditioning of these SCRF cavities has previously been reported; this paper describes the experiences gained during the commissioning of ALICE.

INTRODUCTION

The layout of the ALICE facility is shown in Fig. 1, where the Superconduting RF (SRF) system consists of 2 cryomodules, manufactured by ACCEL, both of which contain two identical 9-cell cavities based on the Rossendorf design. The first cryomodule, the Booster (or injector), is designed to accelerate the 350 keV electron beam received from the photo injector, by 8 MeV. The Linac cryomodule then accelerates the beam up to 35 MeV. The SRF cavities operate at 1.3 GHz and are powered by 5 Inductive Output Tubes (IOTs) along with an analogue low level RF (LLRF) system which maintains the amplitude and phase stability of the cavities during operation. Booster cavity 1 is powered by 2 e2v IOT116LS IOTs, Booster cavity 2 has a CPI CHK51320W IOT, Linac cavity 1 has an e2v IOT and Linac cavity 2 has a Thales TH713 IOT. The basic operating parameters for the IOTs are shown in Table 1.

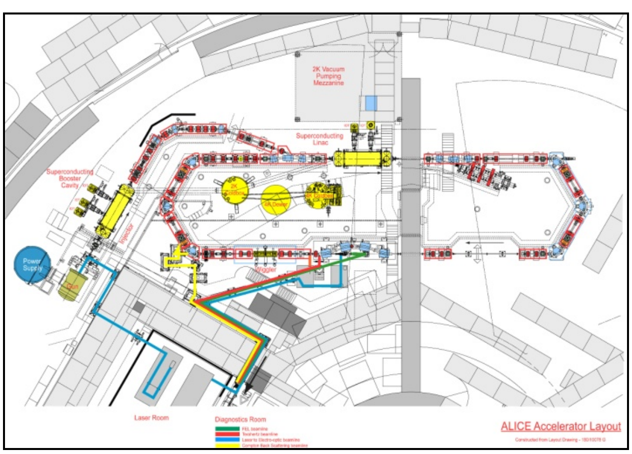

Figure 1: Layout of the ALICE system.

Table 1: IOT Parameters

Parameter	Units	e2v	CPI	Thales
Frequency	GHz	1.3	1.3	1.3
Max CW Power	kW	16	30	16
Gain	dB	>20	21	20.9
Beam Voltage	kV	25	34	25
Bandwidth	MHz	>4	4.5	>5
Efficiency	%	>60	63.8	60.4

ALICE when fully operational is designed to operate with a 350 kV, 80 pC (6.5mA) beam, as shown in Table 2. However, to date during the first commissioning phase of ALICE, the accelerator has only been operated up to accelerating gradients of 20.8 MeV with a beam voltage of 240 kV and a beam charge just in excess of 20 pC (1.6 mA).

Table 2: ALICE Operating Parameters

Parameter		Units
Nominal Gun Energy	350	keV
Injector Energy	8.35	MeV
Circulating Beam Energy	35	MeV
RF Frequency	1.3	GHz
Bunch Repetition Rate	81.25	MHz
Nominal Bunch Charge	80	pC
Maximum Train Length	100	µs
Maximum Train Repetition Rate	20	Hz
Maximum Average Current	13	µA

CAVITY CONDITIONING

Tests of both the Booster and Linac cavities were performed at DESY in a vertical test stand in 2005 and proved that they were all capable of meeting the specified accelerating gradient of 15 MV/m. However, subsequent conditioning of the cavities at Daresbury Laboratory in 2007 [1] following installation on ALICE showed a reduction in the levels of accelerating gradients obtainable. The accelerating gradient for 3 of the cavities was limited by field emission quenches, and the fourth cavity was limited by the level of RF power available. Additionally, ionising radiation dose levels of 15 mSv/h were measured at some distance away from the Linac cavities at accelerating gradients of 12 MV/m. Calculations predicted that for at 9 MV/m the LLRF electronic equipment located in a rack 2.5 m from the module would see 100 mSv/h and have a lifetime in the order of 1000 hrs. Thus a 100 mm lead wall was positioned around the Linac cavity, so as to provide some protection to the local electronic equipment.

The Booster and Linac cavities were both re-conditioned under pulsed conditions with a pulse length between 1 mS and 18 mS at a frequency repetition rate between 5 and 10 Hz. Attention was paid to the maximum accelerating gradients obtainable and the levels of ionising radiation seen at the LLRF electronics. The conditioning process for each of the cavities is shown in Figures 2 and 3. It was noted that early on in the conditioning process that at RF input levels of around 1.5 kW that the majority of the conditioning events that occurred were isolation vacuum events. Measurements of the radiation levels at the Linac electronics rack under similar conditions to the previous predictions showed that the level had been reduced to 5 mSv/h by the addition of the lead wall, and that the predicted lifetime of the LLRF electronics would be greater than 10,000 hrs. However the future longer term plan is to replace the Linac cavity with a new 7-cell design, which is discussed in these proceedings [2].

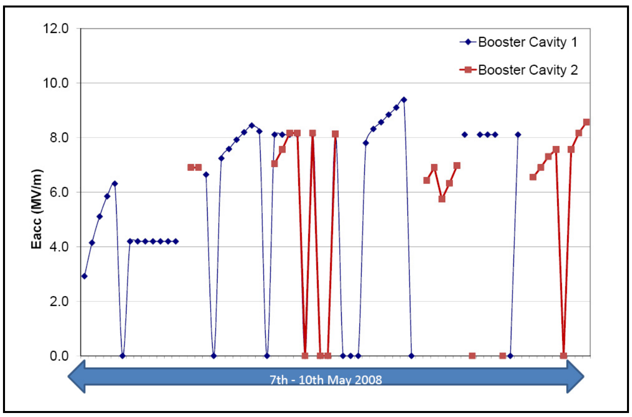

Figure 2: Booster Cavity Conditioning.

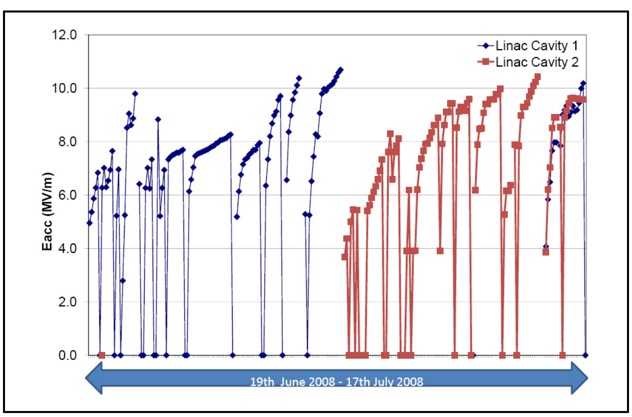

Figure 3: Linac Cavity Conditioning.

Investigations into the limitation of the accelerating gradients were postponed by the failure of numerous ancillary power supplies within the high voltage power supply (HVPS). The RF system incorporates a single line-commuted HVPS, which is used to power all 5 IOTs and is located in an outer hall. There are long high voltage cable runs (in some cases greater than 60 m) between the IOTs and the HVPS. Thus in the event of a fault there is additional stored energy due to the inductance of the cables to be considered. The various types of IOT have different requirements, such as filament settings, and ion pump reference point (cathode and body), which meant that the wiring to the individual tubes could not be standardised. Thus a long program of work to improve the reliability of the power supply system was undertaken, initially involving extensive crowbar testing of individual IOTs, and final crowbar testing of the complete system. It was observed that reliable operation could only be ensured if the grid and heater supplies were referenced to the HVPS at the power supply. Plus a spare HT cable with in-line ultra fast diodes added to control the energy discharge from the long cable lengths. The grid power supplies were replaced with an in house built power supply incorporating improved output isolation to prevent failure from reverse voltages. Also protection diodes were connected at both ends of the grid supply, along with spark gaps across the cathode and grid at the IOT junction box end. It is recommended for future solutions that either individual HVPS are used or all HV auxiliaries are referenced locally to each IOT.

Further delays were then encountered due to the failure of the isolation vacuum Rexolite window on Booster cavity 1 (Fig. 4), shortly after the application of a few 100's Watts of RF power into each cavity. An inspection of the failed window suggested that higher RF power levels were likely to have been involved; however the history data available did not support this theory.

Figure 4: Booster Cavity 1 Window Failure.

An inspection of the couplers and the cold cavity windows for both Booster cavities failed to highlight an obvious reason for the failure. The couplers, the cold cavity windows and the waveguide system were cleaned and the failed window replaced. Numerous arc marks were discovered on both the inner conductors, which could be explained by the numerous isolation vacuum events seen during the early stages of the conditioning process for each cavity. As a precaution a visual inspection was performed on the Linac cavity coupler assembly.

CAVITY OPERATION

Improvements were made to the interlock systems on the isolation vacuum system and broadband RF detectors added to the reflected power monitoring to add extra protection to the system. The cavities were once again conditioned and the cavities were successfully operated from the end of November 2008 to the beginning of February 2009 as shown in Figures 5 and 6. Maximum accelerating gradients achieved for the Linac cavities were 12.6 MV/m and 13.4 MV/m for cavities 1 and 2, respectively. During this period of commissioning one of ALICE's main goals was achieved; energy recovery at a level of 20.8 MeV [3].

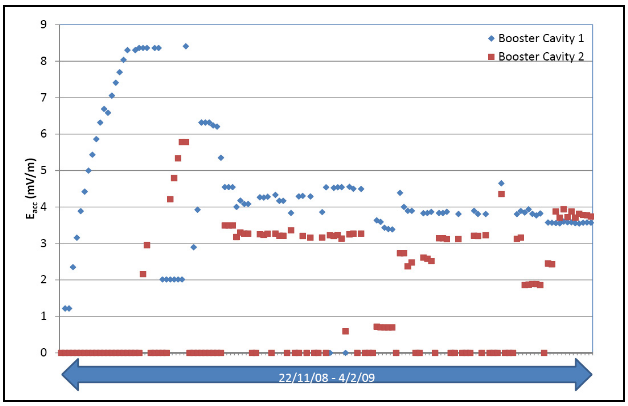

Figure 5: Booster Cavity Operation.

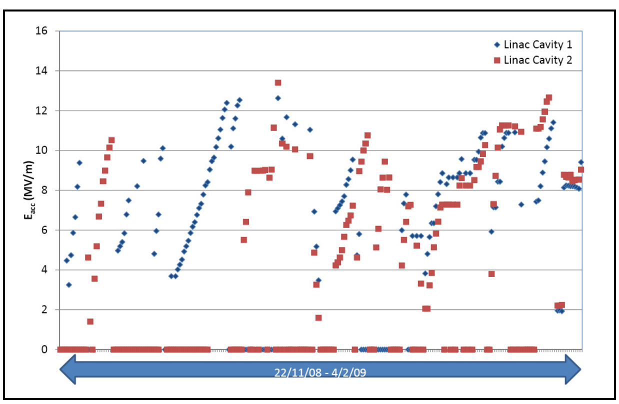

Figure 6: Linac Cavity Operation.

During the initial commissioning of the ALICE machine with a bunch charge of 6 pC, beam loading in the Booster cavities was observed. To resolve this the external Q's of both of the Booster cavities were adjusted via 3 stub tuners on the waveguide system, so as to optimise the ability of the analogue LLRF system to compensate for the amplitude and phase of the RF system when the beam is present in the cavities. For Booster cavity 1 the external Q was reduced from 2.48×10^6 to 5.20×10^5, and cavity 2 the external Q was adjusted from 2.61×10^6 to 8.97×10^5. As the bunch charge level was increased it was found to be necessary to adjust the gain levels within the LLRF system to remove an oscillation seen on the gradient set response. However, for increased train lengths approximately greater than 50 µS and bunch charges above 10 pC beam loading was again noted at the end of the macropulse. The gain levels of the LLRF system were adjusted further in an attempt to improve the optimisation of the system; however issues still remain especially with bunch charge levels of 20 pC and pulse train lengths of upto 100 µS. Thus when the cavities are next conditioned it is planned to adjust the LLRF filter responses within the amplitude and phase feedback loops in an attempt to improve the LLRF system performance. In addition, a feed forward system has been successfully bench tested and will also be investigated in the future.

Early on in this commissioning period there was a failure of a grid power supply, which was believed to possibly be due to a weak component stressed during the crowbar tests. However, since then the HVPS system has operated without any issues.

FUTURE WORK

The SRF cavities are about to be cooled down to 2 K to progress further commissioning of the ALICE machine. In the short term the external Qs are to be adjusted for the 80 pC levels and further conditioning work is to be undertaken on the cavities to discover whether the quench point of each of the cavities has in fact been met. Also a programme of work to investigate the limitations of the LLRF system is to be performed. In the long term it is planned to install a new Linac cryomodule to resolve the issue of high levels of field emission induced radiation.

SUMMARY

The lifetime of the LLRF electronics within the Linac rack has been extended with the introduction of a 100 mm lead wall around the Linac module, however the future longer term plan to resolve the issue is to replace the Linac module completely. Issues have been encountered with the LLRF system at the higher bunch charge levels with long pulse train lengths, though these are to be investigated shortly. Overall, improvements made to the high voltage power supply system and conditioning work performed on the SRF cavities has enabled energy recovery at 20.8 MeV to be achieved, one of the main objectives of the ALICE program.

REFERENCES

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