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# COMMISSIONING OF THE ERL CRYOMODULE ON ALICE AT DARESBURY LABORATORY

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*Abstract*

The ERL cryomodule with two identical 7-cell, 1.3 GHz cavities developed as part of an international collaborative program has been installed in the linac stage on the ALICE (Accelerators and Lasers in Combined Experiments) facility at Daresbury Laboratory replacing the existing 9-cell cryomodule. The cavities have been cooled to 2 K and commissioning of the cryomodule is underway. This paper describes the conditioning and the characterisation tests performed on the two superconducting RF cavities.

## INTRODUCTION

The ERL cryomodule development is an international collaboration consisting of ASTeC, Cornell University, DESY, FZD-Rossendorf, LBNL, Stanford University, TRIUMF (2009) which commenced in 2006. The objective of the programme of work was to fabricate a new CW Energy Recovery Linac (ERL) cryomodule incorporating two identical 7-cell, 1.3 GHz niobium superconducting RF (SRF) cavities (Fig. 1) and to validate the operation of the module with beam. As part of the programme it was defined that the cryomodule should have the same footprint along with the same cryogenic and RF interconnects as is on ALICE (Accelerators and Lasers in Combined Experiments) facility at Daresbury Laboratory, so that it was 'plug compatible' with the existing cryomodule as best as possible.

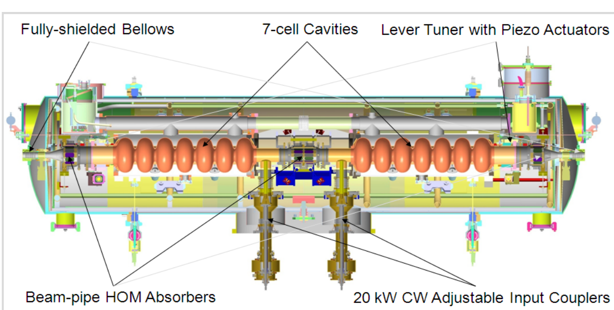


Figure 1: Developmental CW-ERL cryomodule.

The aim of installing the cryomodule on ALICE was to increase the operating beam energy from 27 MeV, limited by the current linac cryomodule, to 35 MeV, whist establishing the gradient and $Q_0$ performance for each of the cavities, the Lorentz force detuning at high gradient, evaluating the operational performance with piezo tuners and characterising the effects of beam loading. The operational parameters for the original two 9-cell cryomodule versus the new 7-cell are shown below.

Table 1: Specification for the Original ALICE and the New ERL Cryomodules

| Parameter | Current Linac | New ERL |
|---|---|---|
| Frequency (GHz) | 1.3 | 1.3 |
| Number of Cavities | 2 | 2 |
| Number of Cells per Cavity | 9 | 7 |
| Cavity Length (m) | 1.038 | 0.807 |
| Cryomodule Length (m) | 3.6 | 3.6 |
| R/Q (Ω) | 1036 | 762 |
| $E_{acc}$ (MV/m) | 12 - 15 | >20 |
| CM Energy Gain (MeV) | 27 | >32 |
| $Q_o$ | $<5 \times 10^9$ | $>1 \times 10^{10}$ |
| $Q_{ext}$ | $4 \times 10^6$ | $4 \times 10^6 - 10^8$ |
| Max Cavity Forward Power (kW) | 10 SW | 20 SW |

The new cryomodule requires the HOM (Higher Order Mode) absorbers, the thermal intercepts for the high power RF couplers and the radiation shield to be cooled with gaseous helium instead of liquid nitrogen. Thus the existing 120 W, 2 K cryogenic infrastructure on ALICE required modification to meet these additional requirements and to provide the intermediate cooling an additional system called COOL-IT [1] was developed and integrated into the cryogenic system.

The cryomodule was successfully assembled and extensive offline cryogenic tests were initially conducted with liquid nitrogen and then with liquid helium at 4.2 K to assess cryogenic performance of the module and to verify the functionality of the tuners and monitoring telemetry. Measurements showed that all the basic parameters were within specification and were in line with the current linac [2]. The cryomodule was installed on ALICE, successfully cooled to 2 K and initial low power RF characterisation measurements were performed [3], [4].

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## RF CONDITIONING

High power RF conditioning was commenced initially using a self-excited loop, with external Qs for the cavities set to $6.4\times10^6$ and $8.3\times10^6$ for linac cavity 1 and linac cavity 2, respectively, similar to the original linac cavities. Conditioning progressed well with gradients of 10.8 and 12.5MV/m being achieved. However, when the loop was closed using the analogue LLRF (low level RF) system on ALICE it was discovered that the phase set control was struggling to maintain the measured phase in both of the cavities, as shown by Fig. 2 and Fig. 3, where for a gradient of 0.8 MV/m on linac cavity 1 to maintain the measured RF cavity phase, a phase set variation of $40^0$ was needed and for a gradient of 7.0 MV/m in linac cavity 2 to a phase set variation of $60^0$ was required, which is on the limit of the system.

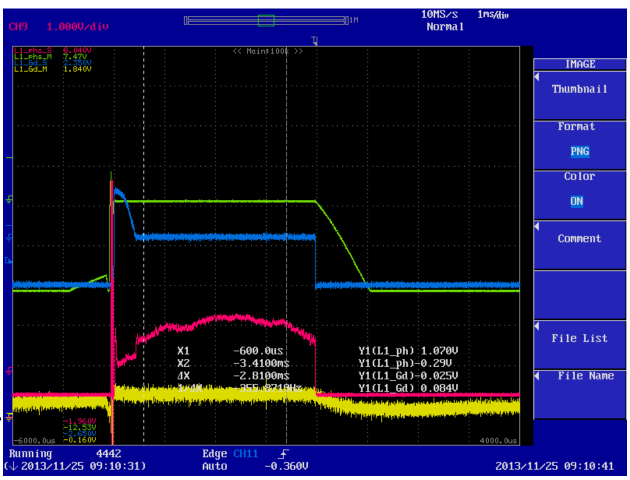

Figure 2: Linac cavity 1 LLRF responses for a gradient of 0.8 MV/m (Pink – Phase set, Green – Phase measure, Blue – Gradient set, Yellow – Gradient measure).

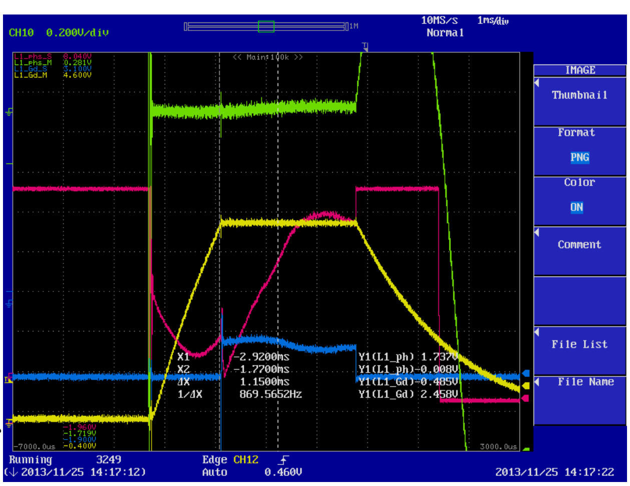

Figure 3: Linac cavity 2 LLRF responses for a gradient of 7.0 MV/m.

Typically with the previous module for an accelerating gradient greater than 10.0 MV/m a phase set variation of no more than $40^0$ was required to maintain the RF phase in the cavity. Thus it could be seen that even for very low gradients the LLRF system was struggling to maintain the cavity phase. Analysing the LLRF phase set control under CW conditions revealed a 71 Hz microphonics oscillation, which was seen on both linac cavities and confirmed by performing a FFT (Fast Fourier Transform) as seen in Fig. 5.

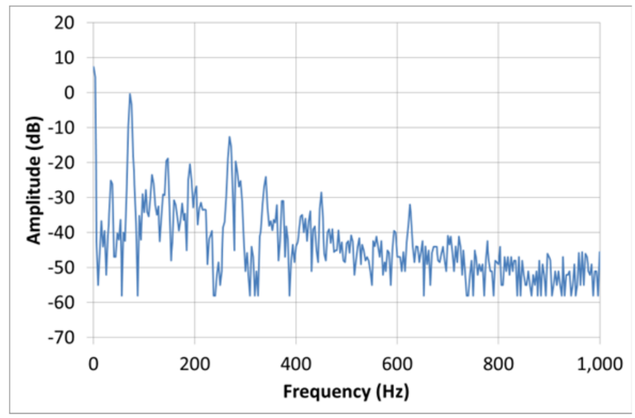


Figure 4: Linac cavity 1 FFT showing the microphonics of the system.

## MICROPHONICS INVESTIGATION

Seismic measurements performed on the floor next to the linac cryomodule and pumping platform for the vacuum pumps for 2 K operation, showed that there had been greater than an order of magnitude degradation seen since the plants original installation in 2005. For a specific vibrational resonance at 71 Hz, the amplitude of the vertical displacement in 2005 was $<10^{-7}$ $\mu m^2$/Hz, however, the level had increased to $10^{-6}$ $\mu m^2$/Hz in 2013 (Fig. 5).

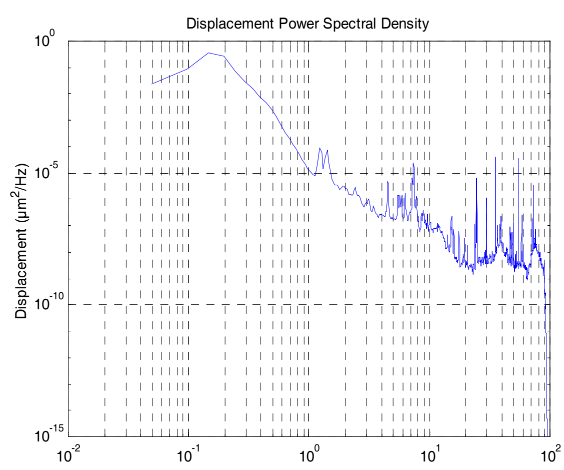


Figure 5: Seismic measurements performed on ALICE next to ERL cryomodule and the 2 K pumping platform.

Further investigations were performed with accelerometers on and around the 2 K cryogenic pumping platform and on the cryomodule. Pumps for the cryogenic system were switched off and on and it was identified that

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the source of the vibrations was the cryogenic backing pumps of the 2 K system (Fig. 6 and Fig. 7).

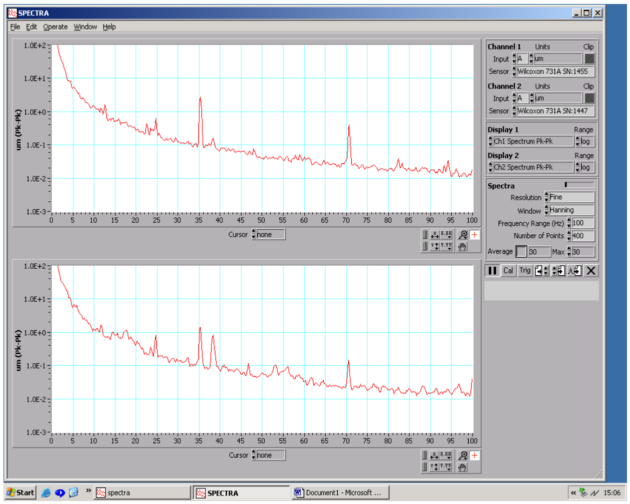

Figure 6: Accelerometer measurements performed on the 2 K pumping platform with the 2 K cryogenic pumps on.

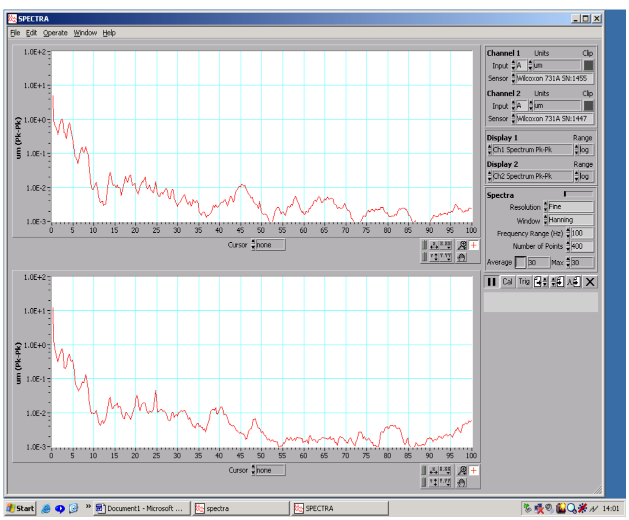

Figure 7: Accelerometer measurements performed on the 2 K pumping platform with the 2 K cryogenic pumps off.

An analysis of the shock absorbers for the vacuum pump platform identified that the pressure in the pump housing shock absorbers had decreased from 6 to 4 bar and that there was a distortion on the of platform floor shock absorbers with shock absorbers nearest the linac module being found to have deformed most likely due to radiation damage. These shock absorbers were replaced. In addition the bearings on the backing pump were replaced. A repeat of the seismic and accelerometer measurements showed an improvement with the amplitude at 71 Hz of vertical displacement being reduced to less than $10^{-6}\mu m^2/Hz$.

The cryomodule was once again cooled and low power RF measurements were performed with an in-house developed digital LLRF system [5] based around the LLRF4 development board, designed by Larry Doolittle at LBNL [6] to analyse the microphonics. Due to issues with the cryogenic system meant the thermal shield, the HOM absorbers and the coupler intercepts could not be cooled below 150 K. As a result the cavities experienced extremely high heat load of more than 100 W instead of 10 W at 2 K exceeding the desired operating conditions by an order of magnitude. Under such circumstances heat transport in the superfluid helium is via normal component of the liquid that may generate bubbling and boiling creating instability in the helium bath.

Due to a commitment to a scientific programme for ALICE it was necessary to discontinue the commissioning work, remove the ERL cryomodule and to replace it with the original linac.

## FUTURE PLANS AND SUMMARY

The CW-ERL cryomodule was successfully cooled to 2 K after installation on ALICE and the conditioning progressed well achieving the gradients of 10.8 and 12.5 MV/m for the two cavities respectively. However, due to the issues with microphonics and the cryogenic system it has not been possible to fully condition the two 7-cell cavities and to evaluate the cryomodule with an electron beam. A detailed analysis of the data collected and observations made so far is being undertaken mainly to understand the behaviour and sources of microphonics. This includes improving the diagnostics by introducing accelerometers, thermometry and developing methods for off-line tests and qualifying the module once again for the tests with beam on ALICE in about years' time.

## ACKNOWLEDGMENT

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