INITIAL EXPERIENCE IN OPERATING THE SRF CRYOMODULES FOR ERLP

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Abstract

The Energy Recovery Linac Prototype (ERLP) is being commissioned at Daresbury Laboratory (UK) to develop and demonstrate energy recovery to produce IR-FEL radiation using SRF technology. The ERLP uses two identical Linac cryomodules, one as a booster cavity accelerating the beam to 8.35 MeV, the other as a linac module in the re-circulating loop with an energy gain of 26.5 MeV. Each module consists of two 9-cell cavities operating at a frequency of 1.3 GHz and at a temperature of 2 K. As there is no energy recovery in the booster it requires a peak power of 52 kW, whereas the linac module only requires 12 kW. The cryomodules are cooled to 2 K by a cryo-system consisting of a 4 K liquefier, 2 K recuperator with a JT valve and external vacuum pumps. In this paper we report our initial experiences in operating the SRF Linacs particularly with cryogenics and RF systems.

INTRODUCTION

STFC Daresbury Laboratory is proposing to build a 4th generation light source 4GLS [1], utilising ERL and FEL techniques. In order to develop and demonstrate these technologies, ERLP [2] is being constructed at Daresbury Laboratory in the UK.

Table 1: Design Parameters for ERLP

Parameter	Value
Operating temperature	< 2 K
RF Quality factor	5 x 10^9
Accelerating Gradient Booster Cavity 1	5 MV/m
Accelerating Gradient Booster cavity 2	3 MV/m
Accelerating Gradient Linac cavity 1	13.5 MV/m
Accelerating Gradient Linac cavity 2	13.5 MV/m
Peak RF Power in Booster Linac	52 kW
Peak RF Power in the main linac	12 kW

ERLP has all the basic features of the 4GLS: the laser excited photocathode electron gun, FEL insertion devices, ERL operation using SRF cavities and their associated synchronisation systems. Table 1 gives the design values

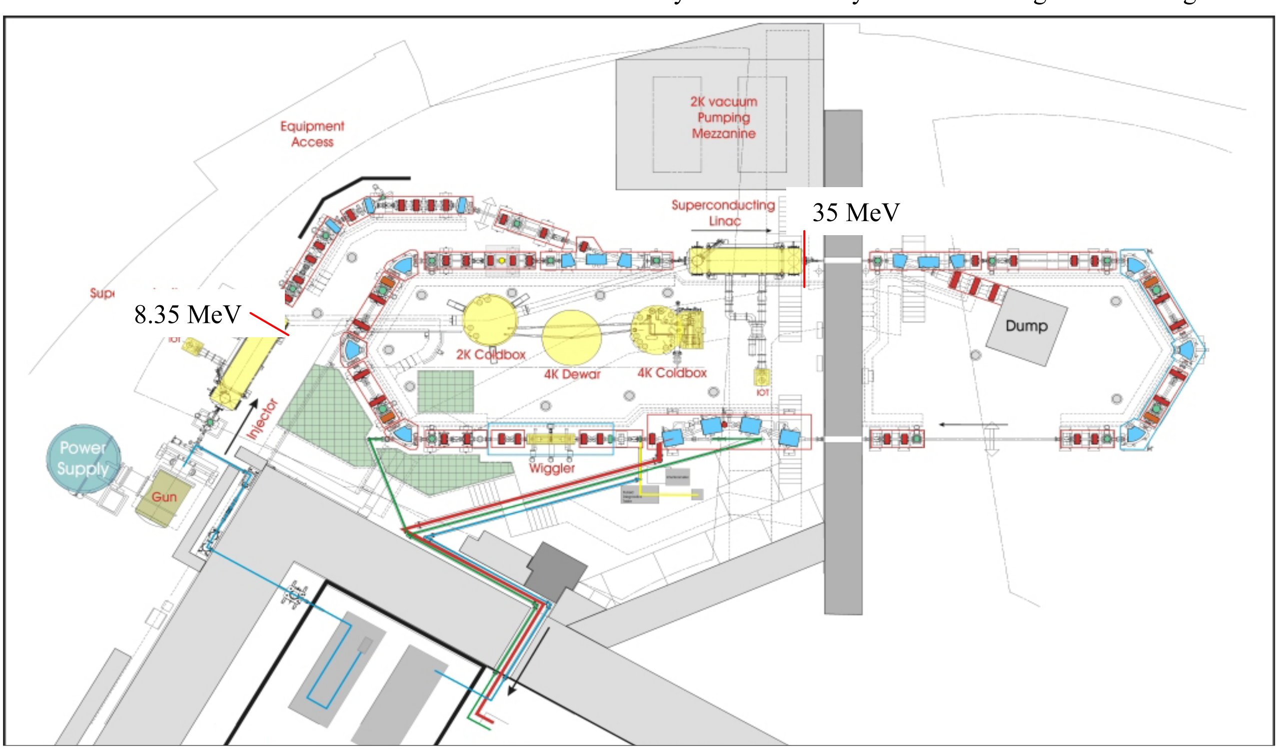


Figure 1: Energy Recovery Linac Prototype Accelerator layout.

of the operating parameters for the ERLP, relevant to the required RF systems. Figure 1 shows the layout of the ERLP accelerator; it uses two identical Linac cryomodules, one as a booster accelerating the beam to 8.35 MeV and the other as a linac module in the re-circulating loop, accelerating the beam further to 35 MeV. Each module (see Figure 2) consists of two 9-cell cavities, operating at a frequency of 1.3 GHz and at a temperature of 2 K. As there is no energy recovery in the booster it requires a peak power of 52 kW, whereas the linac module only requires 12 kW.

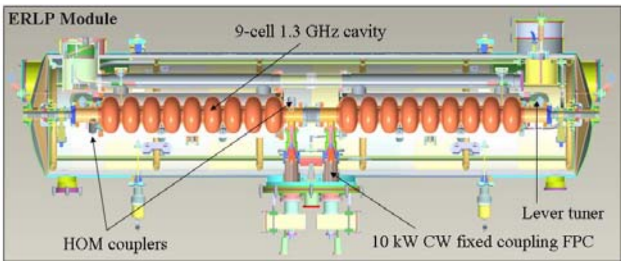


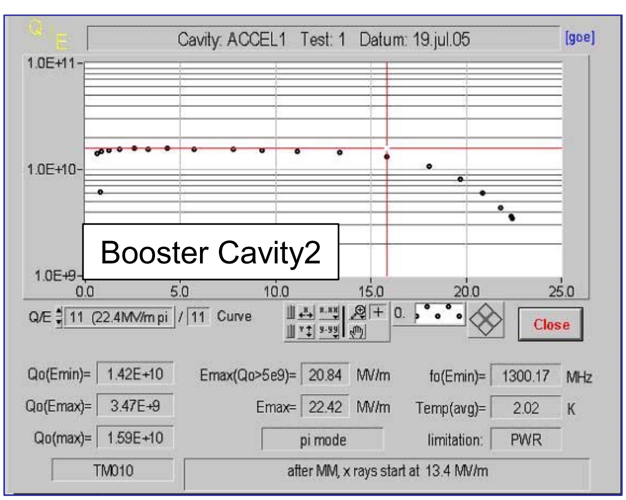
Figure 2: ERLP Cryomodule

PERFORMANCE

The ERLP accelerating modules have been procured from ACCEL Instruments GmbH in Germany. They are based on the FZD Rossendorf ELBE modules which ACCEL have commercially licensed. Delivery of both modules occurred in early 2006, with their subsequent installation taking place in June 2006. High power qualification and acceptance of the modules could not occur until the cryo system was fully commissioned, which happened in May 2007.

Prior to their integration into their respective cryomodules, each of the 9-cell cavities were tested at DESY to ensure operational conformance to the Daresbury design specification of $E_{acc} > 15$ MV/m and $Q_o > 5 \times 10^9$. The integrated module acceptance criterion was to have an energy gain of > 25 MeV.

Initial Test Results



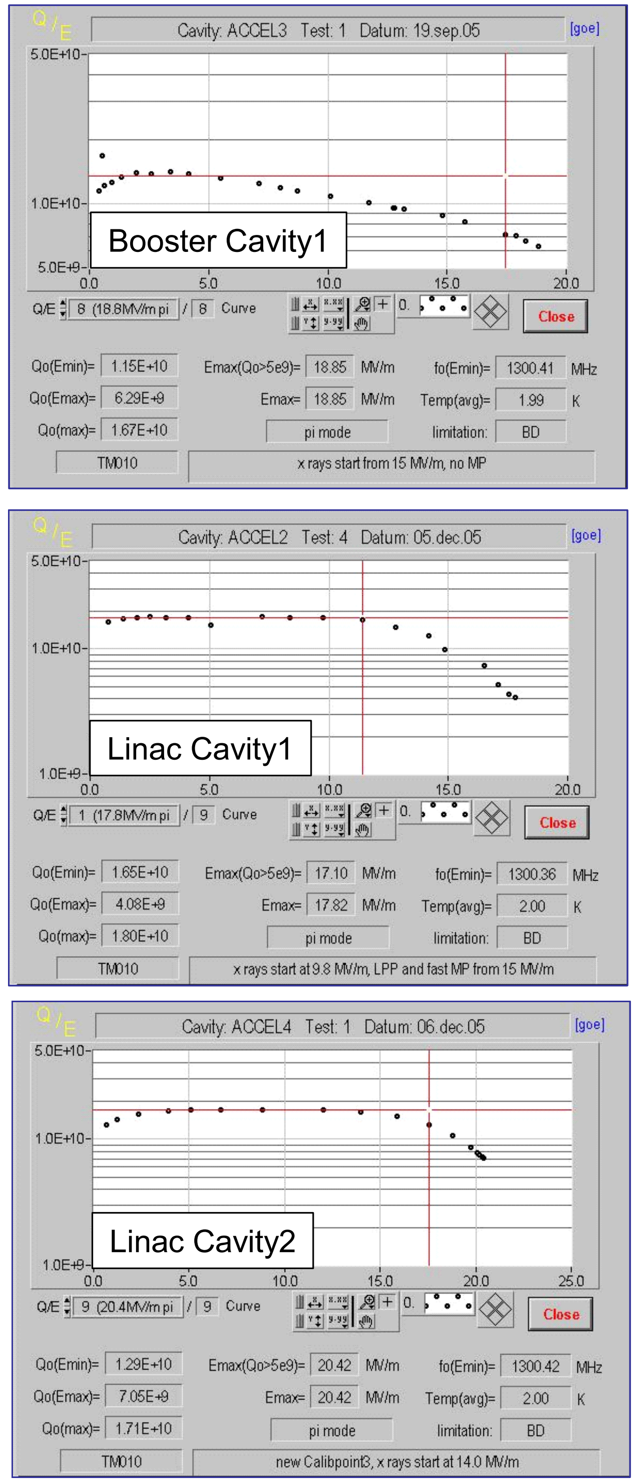


Figure 3: Q vs Accelerating Gradient for the ERLP cavities measured during the vertical tests at DESY.

The results of the vertical tests at DESY showed that all four cavities exceeded the Q value of 5×10^9 with accelerating gradients in excess of the required 15 MV/m at 2 K. Figure 3 shows the test results for each of the four cavities. Table 2 gives a summary of the performance of all the cavities measured during the vertical tests at DESY.

Table 2: Results of the Cryomodule in vertical tests

Cavity	Qo	Gradient (MV/m)
Booster cavity 1	> 5 x 10^9	18.9
Booster cavity 2	> 5 x 10^9	20.8
Linac cavity 1	> 5 x 10^9	17.1
Linac Cavity 2	> 5 x 10^9	20.4

RF system conditioning & Commissioning

The performance of the cavities in the final integrated module however, showed a large deviation from these initial vertical test results (see Table 3). Each cavity showed high levels of field emission during high power testing, with a low gradient onset of typically between 3 MV/m and 5 MV/m.

Table 3: Performance of the ERLP Cryomodule

Cavity	Q_o	Maximum Gradient (MV/m)	Limitation
Booster cavity 1	3.5 x 10^9 (@ 8.2 MV/m)	10.8	Field Emission
Booster cavity 2	1.3 x 10^9 (@ 11 MV/m)	13.5	Field Emission
Linac cavity 1	1.9 x 10^9 (@ 14.8 MV/m)	16.4	RF Power
Linac Cavity 2	7 x10^9 (@ 9.8 MV/m)	12.8	Field Emission

Figure 4 shows a typical conditioning characteristic, which was observed for all cavities, highlighting a significant radiation signature starting from low gradients. This is a surprising limitation for these cavities, considering that radiation was not observed in the vertical tests until gradients >13 MV/m were reached. The radiation monitor was positioned in the middle of the Linac module and a few cm away. The erratic nature of the radiation plot is due to the fact that the RF power was pulsed at a 10 % duty factor.

Each cavity experienced several quenches, indicating the fundamental gradient limit associated by field emission, although this was marginal for the Linac cavity 1. A quench could only be detected by observing a sudden pressure rise in the liquid helium tank. The recovery of the pressure to a stable value after a typical quench event took about an hour. Figure 5 shows the installation of the linac cryomodule with RF waveguides in the ERLP.

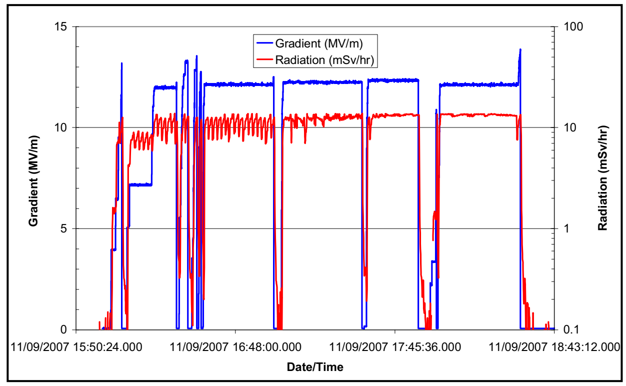


Figure 4: Linac Cavity 1 Processing Gradient as a Function of Field Emission Radiation

Figure 5: ERLP Cryomodule with RF waveguides

During high power conditioning the Linac module experienced problems arising from excessive heating in an input coupler. Figure 6 shows how both the warm and cold window temperatures for Cavity 2 started running away in temperature at high gradients. RF testing for this cavity was halted and a strip down of the input coupler initiated. On inspection it was revealed that the coax assembly had an RF spring that had become dislodged (see Figure 7). This then became excessively hot when RF power was applied and some damage to the coax was observed.

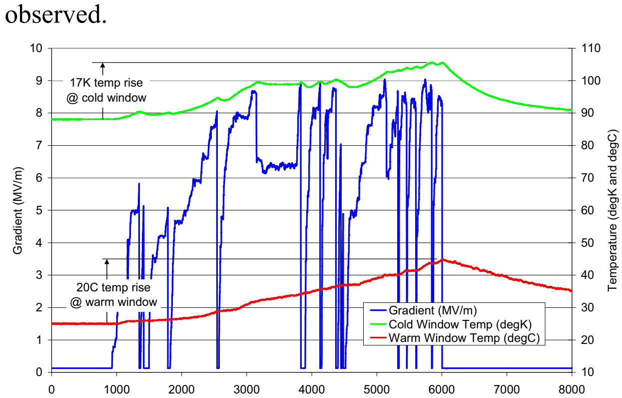


Figure 6: Linac Cavity 2 Coupler Heating

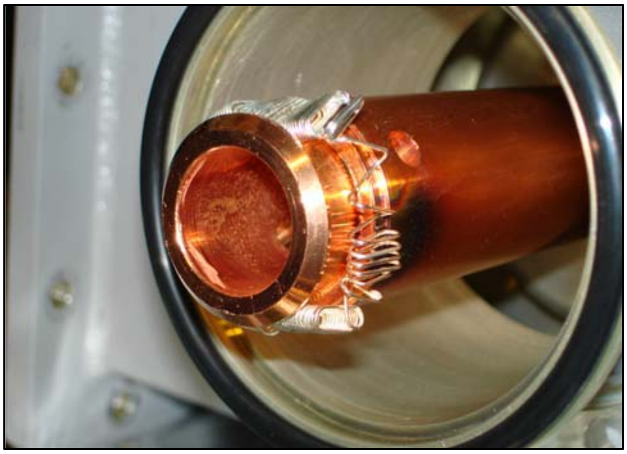


Figure 7: Dislodged Coax RF Spring

Another problem arose on Cavity 1 for the Linac module whereby, during high power conditioning, its tuner mechanism stuck. On inspection, it was found that the tuner drive rod mechanism had become excessively worn and had effectively seized on its carrier (see Figure 8). The rod and carrier mechanism was subsequently replaced and RF testing of both cavities resumed without further incident.

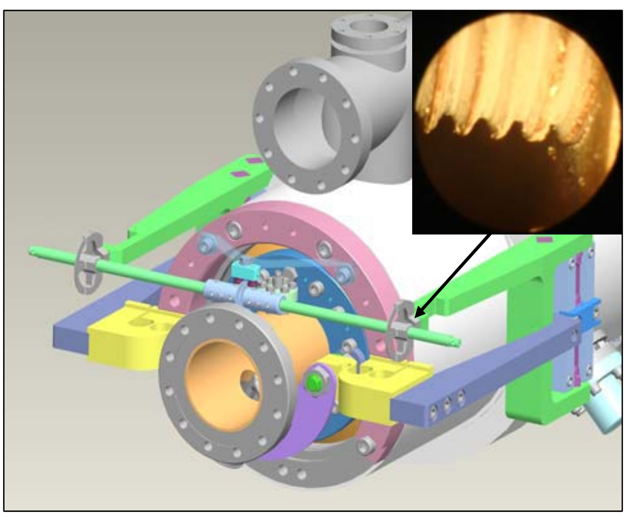


Figure 8: Worn Drive Rod Mechanism on Linac Cavity 1

Even though the cavities failed to meet the module acceptance criteria in terms of energy gain for the Booster module and the Qo specification for all cavities, the performance of both modules is sufficient for the operation of the ERLP which requires an overall energy gain of 35 MeV. The tests with beam will be conducted in the next phase.

CRYOGENICS

Details of the cryogenic system have already been reported elsewhere [3].

The Cryomodule Design

Both the cryomodules used on ERLP are of identical design that has been optimized for the operation in CW mode. The selected cryomodule design was originally developed by FZD for the ELBE accelerator. The larger size (diameter 85 mm) of the two phase line and the chimney connecting it to the helium bath compared to the corresponding pipes (diameter 54 mm) in the TESLA cryomodule enables higher heat transport as required in CW mode. The dynamic heat load is a dominant factor in the overall cryogenic load of the system and the need for a radiation shield at 5 K (as incorporated in the TESLA Cryomodule) was not considered necessary. The 80 K radiation shield in the ERLP is cooled by liquid nitrogen.

Microphonics

The design also minimizes microphonics generation which is a prime requirement for operation of these modules in CW mode. The pressure stability of ± 0.03 mbar could be easily achieved in the liquid helium tanks enclosing the SRF cavities. The microphonics level in both the cryomodules was found to be extremely low with corresponding peak to peak phase instability in the four cavities ranging between $\pm 0.3^0$ to 0.6^0.

Refrigeration system

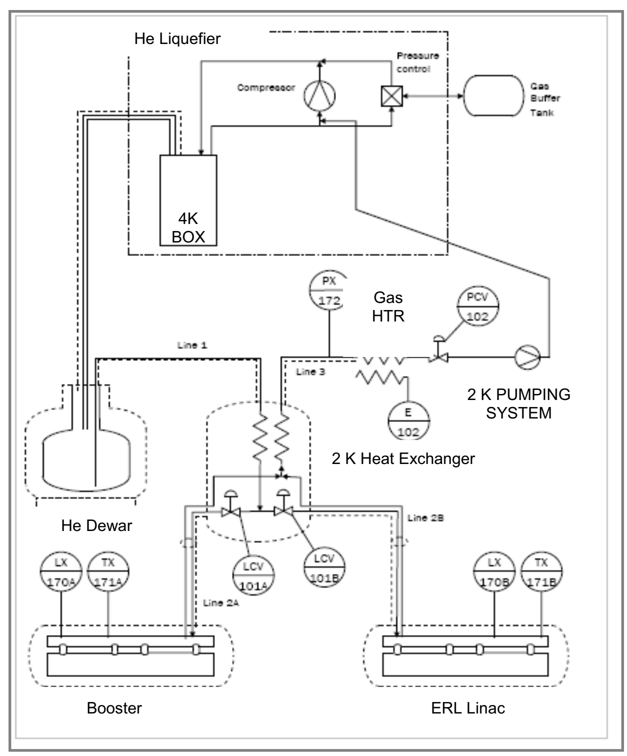


Figure 9: Schematics of ERLP Cryogenics

Overall cooling power required for the ERLP was estimated to be 180 W at 2 K, including a safety factor of 1.5**.** The Cryogenic system design is based on the combination of concepts from the two systems comparable in size with ERLP: ELBE (FZD) [4] and HoBiCaT (BESSY) [5] which are operating successfully. Figure 9 shows the cryogenics schematics for the ERLP.

It consists of a Linde helium liquefier TCF-50, a 1500 litres storage dewar, 2 K cold box with 2 K counter-flow heat exchanger as well as a distribution network to supply liquid helium to the two cryomodules via two compound transfer lines TL2A and TL2B. The vapour pressure in both the cryomodules is reduced using vacuum pumps with a total pumping capacity of 6000 m^3/hour at 18 mbar for helium. A 15 kW low pressure heater is used to heat cold returning gas to 300 K before it reaches the vacuum pumps. The choice of vacuum pumps instead of cold compressors was mainly driven by cost constraints. The overall capital and operational costs of the vacuum pumps outweighed the corresponding cost for the cold compressors because ERLP would be operated as an experimental facility for a limited time.

The cooldown of the cavities is fully automated and the cool down rates of ~12 K/hr for T > 150 K and ~ 2 K/minute (120K/ hr) for T< 150 K could be achieved. The system has a wide dynamic range of operation and can easily handle helium mass flow rates from 1 g/S to 8 g/S with a pressure stability of ± 0.03 mbar. The static heat load of the both the cryomodules together was measured to be less than 5 W. The system has shown a capacity to operate with a dynamic load of 118 W at 2 K under stable conditions.

Q measurements

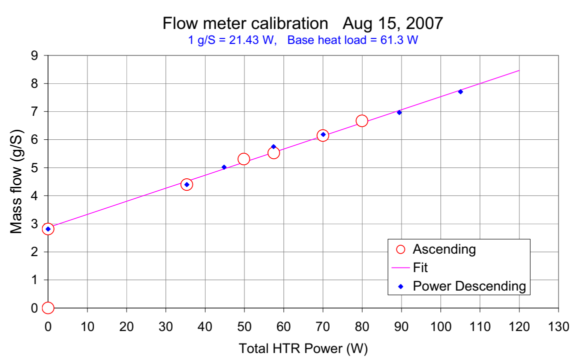


Figure 10: Helium mass flow calibration

A helium mass-flow meter was used to measure the dynamic heat load induced by the cavities. The mass flow-meter was calibrated (see Figure 10) for heat load using resistive heaters installed in the cryomodules. For RF operation a baseline mass flow of 5 g/S was maintained. The deviation in the mass flow on applying the RF power was correlated to the dynamic heat load and consequently to the Qo of the cavities.

SUMMARY

An Energy Recovery Linac Prototype is currently being constructed Daresbury laboratory (UK) to promote the necessary skills in science & technology to enable the construction of 4th generation light source - 4GLS. The cryogenics and the RF systems have been commissioned and the initial tests are underway. The michrophonic levels in the system are found to be extremely low. A good pressure stability of ± 0.03 mbar at the operating temperature of 2 K could be one of the reasons for low microphonics in the system. The cryogenic system has shown the capability to operate at 1.8 K. The demonstration of energy recovery in ERLP is scheduled in March 2008.

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