

# REALISATION OF A PROTOTYPE SUPERCONDUCTING CW CAVITY AND CRYOMODULE FOR ENERGY RECOVERY

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## Abstract

For Energy Recovery applications, the requirement for high-Q accelerating structures, operating in CW mode, at large beam currents, with precise phase & amplitude stability and modest accelerating gradients are all fundamental in achieving intense photon fluxes from the synchronised FEL insertion devices. Both Daresbury Laboratory and Cornell University are developing designs for advanced Energy Recovery Linac (ERL) facilities which require accelerating Linacs which meet such demanding criteria. The specification for the main ERL accelerator for both facilities dictates a modest accelerating gradient of 20 MV/m, at a  $Q_0$  of better than  $10^{10}$ , with a  $Q_{\text{ext}}$  of up to  $10^8$ . A collaborative R&D program has been set-up to design and fabricate a 'proof-of-principle' cryomodule (which is well underway) that can be tested on ERLP at Daresbury and also on the Cornell ERL injector. This paper details the new cryomodule design, provides an insight to the design solutions employed and reports on the present status of the project.

## INTRODUCTION

The fundamental requirements for a cavity and cryomodule that can facilitate ERL operation have been defined previously [1]. Our intention is to develop the design for such a cryomodule, based on the FZD Rossendorf ELBE [2] cryomodule design. The reason for choosing this module as a basis for this R&D project is to enable its installation on ERLP [3] at Daresbury to allow for full beam test validation on an operational ERL facility, albeit at relatively low average beam current ( $\sim 13 \mu\text{A}$ ). These tests will enable the evaluation of modest accelerating gradients (up to 20 MV/m) with an input coupler  $Q_{\text{ext}}$  reaching beyond  $10^8$ , at temperatures down to 1.8 K.

The microphonics sensitivity of the module at high  $Q_{\text{ext}}$  will be of particular interest when providing very tight phase and amplitude control for such ERL systems (anticipate needing  $0.01^\circ$  in phase and  $10^{-5}$  in amplitude). The ELBE module has already demonstrated a good peak microphonics sensitivity of only 6 Hz [4], which can hopefully be improved upon in this optimisation process. Additional tests are then planned at Cornell, on the ERL injector facility [5], which will allow for high current (up

to 100 mA) beam validation at similar gradients,  $Q_{\text{ext}}$  and cryogenic temperatures. On completion of these tests, the fundamental cavity and cryomodule challenges for both the 4GLS [6] and Cornell ERL facilities will then have been addressed and a common, generic solution identified.

## RF CAVITY OPTIMISATION

The cavity optimisation process has used as a baseline the TESLA 7-cell superstructure geometry developed at DESY [7]. Our design utilises the same 5 centre cells as the TESLA superstructure cavity, with optimisation of the end cells and enlargement of the beam pipes (see Figure 1) to match to beam-pipe HOM absorbers as developed by Cornell [8].

To reach the required  $Q_{\text{ext}}$  tuning range ( $10^7 - 10^8$ ), the position of the input coupler with respect to the cavity end cell has been analysed. Due to the physical size of the coupler employed (see later), its location is restricted to 113.1 - 133.1 mm measured from the coupler axis to the equator of the end-cell.

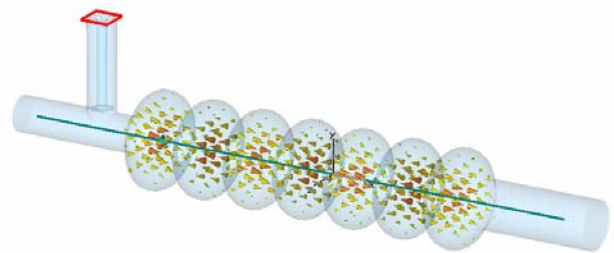


Figure 1: Plot of the E-Field Inside the ERL 7-Cell Cavity

The coupler antenna has a penetration adjustment of up to 15 mm and a full parametrisation of coupler distance from the end cell and its penetration has been assessed. The required range of  $Q_{\text{ext}}$  as a function of antenna penetration was achieved with the coupler located 123.1 mm from the end cell (see Figure 2). At a 123.1mm offset, the required  $Q_{\text{ext}}$  range is nearly obtained with a 15 mm variation in antenna penetration. The addition of a triple-stub tuner can be used to extend the upper range of the operational  $Q_{\text{ext}}$  to beyond  $10^8$  if required.

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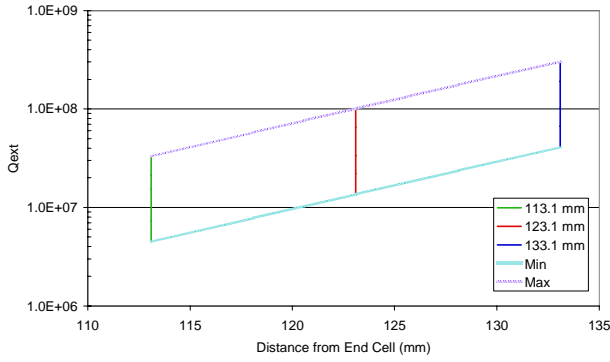


Figure 2: Variation of  $Q_{ext}$  with Antenna Extension and Position

## INPUT COUPLER

The chosen solution for a suitable input coupler that is capable of delivering 20 kW CW in standing wave, whilst also providing adjustability in terms of its  $Q_{ext}$  setting, is the Cornell ERL injector coupler (see Figure 3) [9]. CPI have successfully fabricated a number of these couplers and the power handling capability has been proven up to 50 kW CW in travelling wave. Tests are continuing to prove stable operation in standing wave for the Cornell ERL injector prototype module.

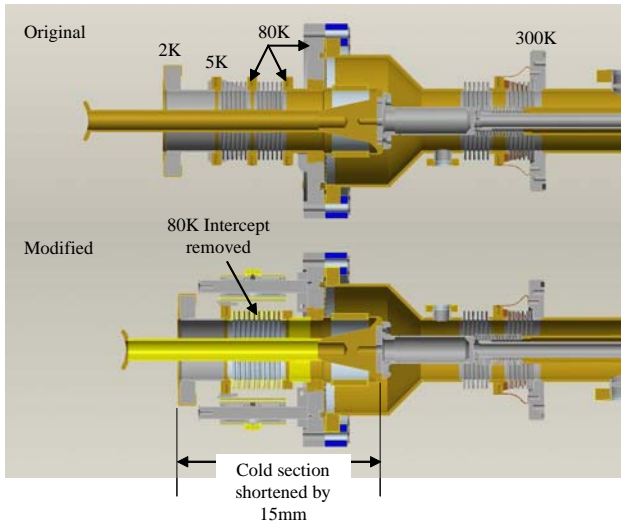


Figure 3: Original and Modified Cornell ERL Injector Coupler

To allow for the insertion of the cold part of the Cornell coupler and the modified cavity string into the cryomodule, its total length has been shortened by removal of the secondary 80 K thermal intercept which was fundamentally required for 50 kW operation. This has enabled the cavity string to be inserted into the cryomodule without interfering with the cryomodule vessel. There is still however a mechanical conflict with the original ERLP liquid nitrogen (LN2) skeleton (see Figure 4), which requires modification on one side as shown in Figure 5. The modified coupler heat loads due to the modifications are shown in Table 1.

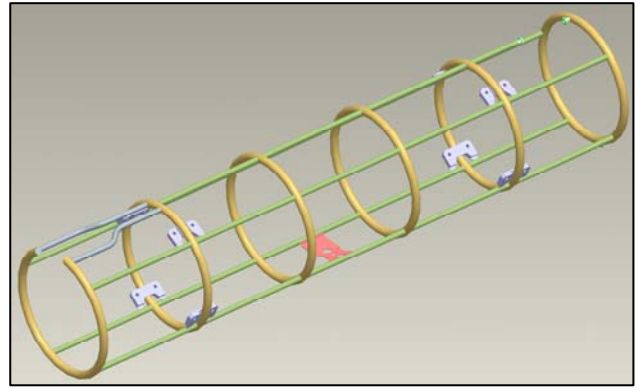


Figure 4: ERLP LN2 Skeleton.

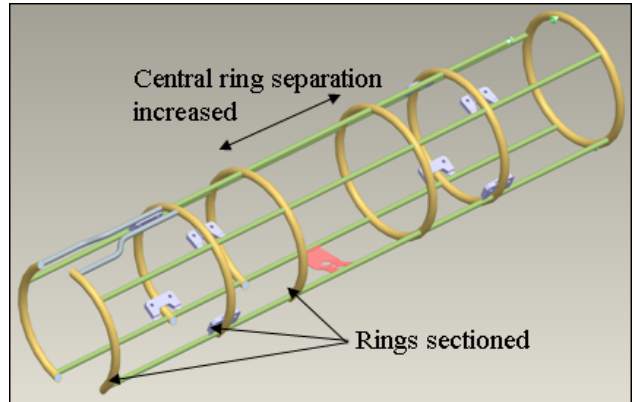


Figure 5: LN2 Skeleton Modifications.

Table 1: Modified Cornell Coupler Heat Loads

Parameter	Original	Modified
Max Power (kW)	50 TW	20 SW
Antenna Stroke (mm)	>15	<15
Heat Leak to 2K (W)	0.23	0.13
Heat Leak to 5K (W)	1.7	2.5
Heat Leak to 80K (W)	43	34

## TUNER

After examining different tuner alternatives it was decided to adopt a design based on the Saclay II tuner which was developed as part of the CARE project by CEA Saclay (see Figure 6). This design was chosen due to its compact size, its adaptability to the large beam pipe diameter of the 7-cell cavity and the promising test results observed when utilised to compensate for Lorenz force and microphonics detuning on a 9-cell cavity on CryHoLab at Saclay [10] and on HoBiCaT at BESSY [11].

The Saclay II tuner design must fit over the larger diameter beam tube (106 mm) of the 7-cell cavity. The piezo cartridge design of the tuner is being modified to allow the piezos to be pre-compressed without relying on the forces generated through tuning of the cavity string. Furthermore, we are replacing the low voltage piezo stack with a high voltage stack to achieve a higher degree of stiffness.

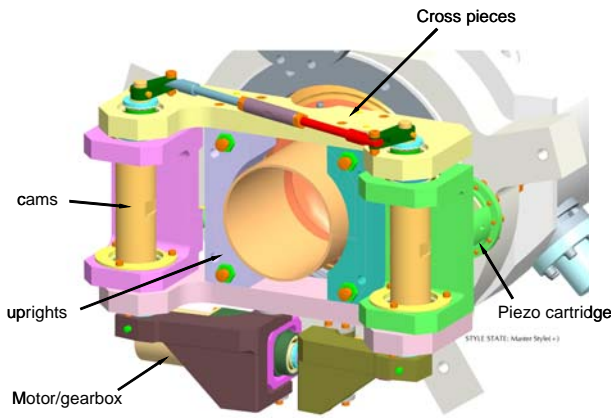


Figure 6: Adaptation of the Saclay II Tuner to the 7-cell Cavity

### HOM ABSORBER INTEGRATION

In its original configuration, the ELBE cryomodule does not have provision for the support of large beam pipe HOM absorbers, either between the two cavities or at its ends. Both the HOM absorbers and the Cornell input couplers require an additional 5 K thermal intercept which also complicates the support implementation in terms of its thermal isolation.

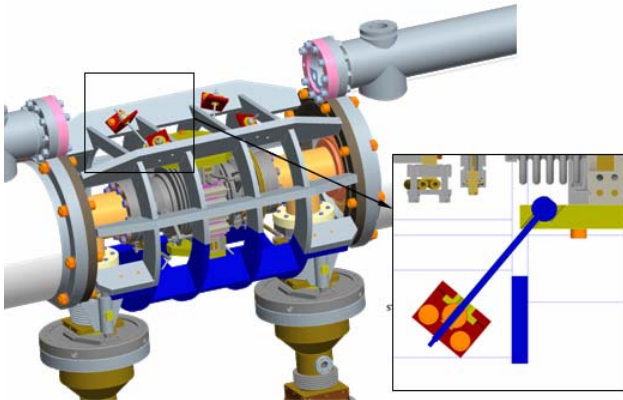


Figure 7: Central HOM Absorber Cage and Rod Support

The approach chosen is to incorporate a rigid support cage between the two cavities, which locks the longitudinal movement of both input couplers during cooldown. The HOM absorber, with its 5 K and 80 K cooling circuits is then thermally isolated from the caged support frame via thin (3mm diameter) titanium support rods, which are arranged to ensure precise longitudinal and transverse positioning and support (see Figure 7). The same rod support scheme has been adopted for each of the two end HOM absorbers with the support frame similarly attached directly to the 2 K cavity helium can (see Figure 8).

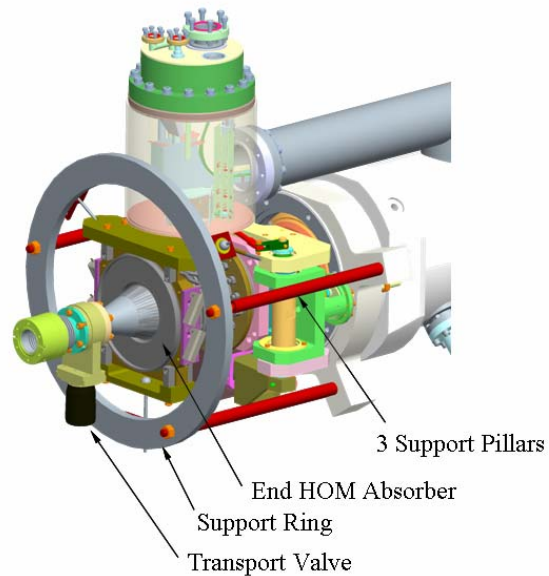


Figure 8: End HOM Absorber Ring and Rod Support

### CRYOMODULE MODIFICATIONS

Stanford University have provided a spare SCA cryomodule vessel, to be used as a basis for the modified cavity string. The size of this vessel is identical to that of the ACCEL fabricated ERLP modules [12], which is based on the FZD Rossendorf ELBE module (see Figure 9). The process of performing configurational changes and including new components to an existing cryomodule design, requires careful tracking of all interfaces that may be affected.

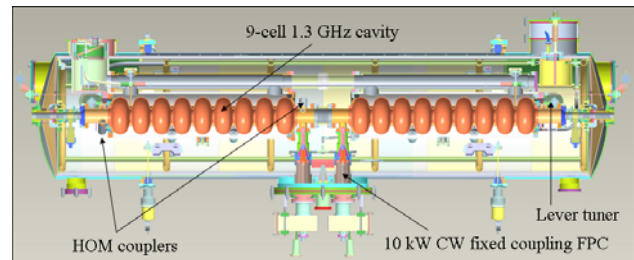


Figure 9: ERLP and ELBE Module

Utilisation of the FZD Rossendorf 3D assembly drawings has assisted this process tremendously to ensure that new fabrication drawings are not only accurate, but that the various inter-module dependencies are validated. The fundamental cryomodule changes required to be accommodated are:

- Replacement of the 2 existing TESLA 9-cell cavities with modified TESLA 7-cell superstructure cavities.
- Use of high CW power (>20 kW) input couplers.
- Use of beam-pipe HOM absorbers.
- Replacement of the existing tuner with one that incorporates piezo actuators for fast feedback.
- Provision for an additional 5 K cooling circuit for cooling the coupler and HOM absorbers.

Wherever possible we have tried to maintain the same mounting and location points for the cavity string within the original module to minimise additional R&D and fabrication costs. Retaining also as much of the original cryogenic cooling circuits is hoped to sustain this modules' quiet microphonics susceptibility. Figure 10 shows the modified module layout which now includes the 7-cell cavities, beam-pipe HOM absorbers, modified Cornell input couplers and Saclay II tuners.

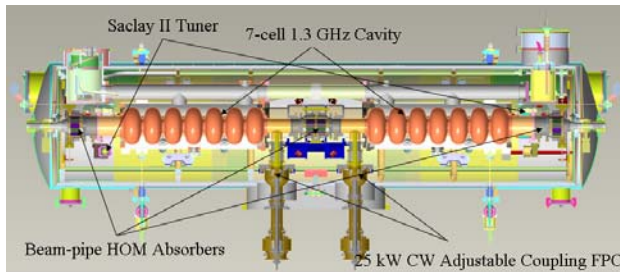


Figure 10: Modified Module Layout

## STATUS AND SCHEDULE

The cryomodule project is currently on track to have all components delivered on site by mid July 2008, including fabrication of all cryomodule sub-components. An additional 5 months is then scheduled to complete the cavity string assembly and module integration at Daresbury, ready for installation on ERLP in early 2009.

The Cornell HOM absorbers are expected to be delivered from ACCEL by end 2007. The modified Cornell RF couplers are on order with CPI and delivery is expected in March 2008. The modified Saclay II type tuner is fully detailed, with long-lead items already on order. RF simulations of the cavity shape are complete, and drawings of the required cavity shapes and helium tank are in progress. Milestone dates for this R&D project include:

• ACCEL HOM absorbers delivered	Dec 2007
• Module internal drawings complete	Dec 2007
• Saclay tuners delivered	Feb 2008
• Module centre section modified	Feb 2008
• CPI Couplers delivered	Mar 2008
• Tooling and fixtures fabricated	Mar 2008
• All module components available	Jul 2008
• Module assembled	Dec 2008
• Installation on ERLP	Early 2009
• Installation on Cornell ERL Injector	Early 2010

## CONCLUSIONS

This cryomodule R&D project has benefited greatly from the strong interaction between all collaborators. The vast amount of R&D that has been performed over recent years as part of the TESLA Technology Collaboration (TTC) has enabled the rapid realisation of such a cryomodule, which is capable of high gradient and high power CW operation, with the ability to compensate for

excessive microphonics to very tight phase and amplitude tolerances via its integrated fast piezo tuning. Building also on the experience gained at HEPL, FZD Rossendorf and more recently ERLP, the baseline 2-cavity cryomodule being employed for this R&D project shows great promise in terms of being able to achieve the challenging requirements for ERL operation. The R&D performed at Cornell for their ERL injector module has enabled proven components to be employed, thereby minimising the technical risks for this project.

The utilisation of a cryomodule that already possesses low microphonics susceptibility is hoped to be improved upon in the final design to maximise its efficiency when operated as an ERL module. The project is on track to enable low average beam current validation tests to be performed on ERLP in 2009, complimented by high current tests on Cornell's ERL injector prototype in 2010.

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