CW LINAC CRYO-MODULE FOR CORNELL'S ERL

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Abstract

Cornell University has proposed an energy-recovery linac (ERL) based synchrotron-light facility which can provide greatly improved X-ray beams due to the high electron-beam quality that is available from a linac. As part of the phase 1 R&D program, critical challenges in the design were addressed, one of them being a full linac cryo-module. It houses 6 superconducting cavities- operated at 1.8 K in cw mode- HOM absorbers and a magnet/ BPM section. We will present the design being finalized recently and report on the fabrication status that started in late 2012.

INTRODUCTION

The potential for excellent quality of X-ray beams, generated by a low-emittance electron beam, motivated the design of a 5-GeV superconducting energy-recovery linac (ERL) [1] at Cornell University. Starting with 10 MeV electrons produced by a photo-injector with currents of up to 100 mA [2], the beam will be accelerated in two main linac sections to 5 GeV before it enters several undulators feeding the X-ray beamlines. The existing CESR ring is then used to return the beam and inject it into additional undulators, before it gets decelerated to 10 MeV again inside the two main linac sections gain. A more detailed description can be found in [3]. This paper will focus on the Main Linac Cryomodules (MLC), designed and now fabricated under an NSF funded R&D phase, 64 of which will form the main linac of the proposed ERL.

GENERAL LAYOUT

The general layout of one linac cryomodule is shown in Fig. 1. The almost 10 m long module houses 6 superconducting cavities, operated in cw mode at 1.8 K. These 7-cells, 1.3 GHz cavities with an envisaged Q of $2*10^{10}$ will provide an energy gain of 16 MV/m. Each cavity is fed by a 5 kW power coupler. Due to the high beam current combined with the short bunch operation, a carful control and efficient damping of the Higher Order Modes (HOMs) is essential [4], leading to the installation of dampers next to each cavity. Each of these components will be described in more detail below.

The series linac module will have a quadrupole/ steerer section behind every 6 cavities, making the transition to the adjacent module. This section will be omitted in the prototype describe further on as it –in contrast to the other components- technically does not represent a challenge.

All components within the cryomodule will be suspended from the Helium Gas Return Pipe (HGRP). This large diameter (280 mm) titanium pipe will return the gaseous helium boiled off the cavity vessels to the liquefier and act as a central support girder. The HGRP will be supported by 3 support post, the middle one being fixed while the outer two slide by 7 and 9 mm, respectively.

CRYOGENIC COOLING SCHEME

The cryoscheme of the module consists in principle of 3 different loops. The cavities will be cooled by liquid helium obtained by a JT-Valve located at the module entrance. Sub-cooled to 1.8 K by pumping the He-atmosphere down to 16 mbar ensures an optimum operation regime for the superconducting cavities. To minimize the pressure drop over the whole linac string, a big aperture for the gas return pipe (HGRP) was chosen. In order supress pressure fluctuations a single chimney connects all cavities within one module to that return.

The second loop consisting of supercritical 5 K helium is used to cool the intercept all transitions to warmer temperatures in order to assure a minimal to the 1.8 K system. Finally, a 80 K loop provides cooling for the coupler intercepts, cools the thermal radiation shield of the module and removes the heat generated in the Higher

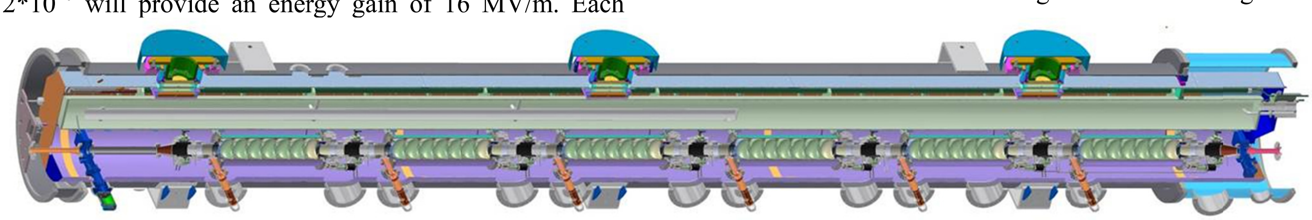

Figure 1: 3-D CAD model of the Main Linac Cryo-module (MLC) prototype, the fabrication of which has started recently. It houses 6 superconducting 7-cell cavities with Higher Order Modes (HOM) loads located between them. The overall length will be 9.8 m.

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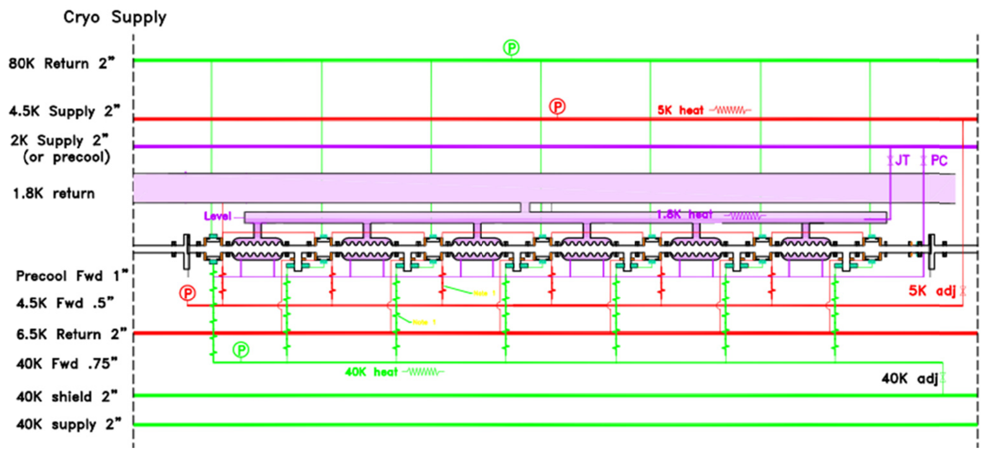

Figure 2: Diagram of the different cooling loops within the MLC: The 1.8 K loop feeds the cavities, the 5 K loop intercepts the cavity, coupler and HOM flanges and the 80 K loop cools the radiation shield, the HOM Absorbers and intercepts the power coupler.

Order Mode (HOM) absorbers- the operation temperature of the later was chosen for efficiency reasons.

The cryogenic scheme is visualized in Fig. 2, Fig. 3 gives the cross-section of the module showing the spatial arrangement.

HIGH Q CAVITIES

The 7-cell main linac cavity is optimized for a high R/Q of the fundamental mode and for strong HOM damping by optimizing the shape of the end and center cells [5]. Robustness of the obtained cavity design to small shape imperfections was verified by calculating HOMs in deformed cavity shapes, resulting in a tolerance specification for the cavity cell shape of ±0.25 mm. The BBU current calculated on this basis is above 300 mA, well above the 100 mA design specification.

According to the crucial role of shape variations, detailed measurements of the cell shape during various stages of the cavity fabrication are preformed, one of which is shown in Fig. 4 (a typical measurement of a cavity cup, taken with a coordinate-measuring machine - CMM). Our data on 7 prototyped cavities showed the maximum deviation being less than 200 µm.

These cups are pairwise welded on the iris leading to dumbbells. They are produced with excessive length and trimmed to the right frequency. The highly sophisticated procedure developed over the years is described in more detail in [6].

The field flatness of a cavity fabricated in that manner is shown in Fig. 5. Even though the field flatness (as a result of the dumbbell trimming) is pretty good, the whole cavity is tuned to field flatness after the chemistry process again. The first cavities fabricated following this procedure showed excellent performance, being reported in a separate paper [7]. At this time, 3 full cavities have been built, three more cavities with stiffening rings are being fabricated and are expected in June 2013.

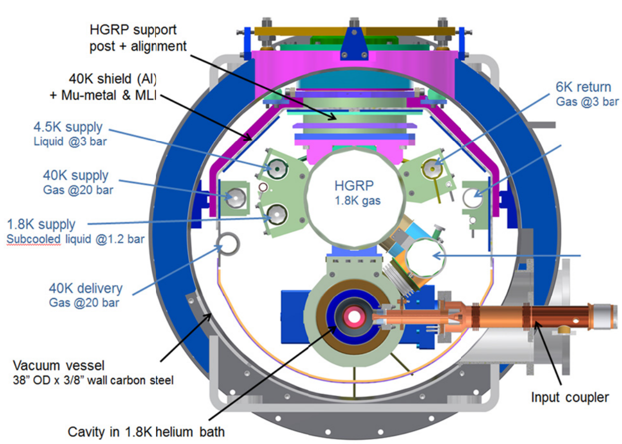

Figure 3: Cross-section of the MLC, giving more details on the piping and positioning of the components.

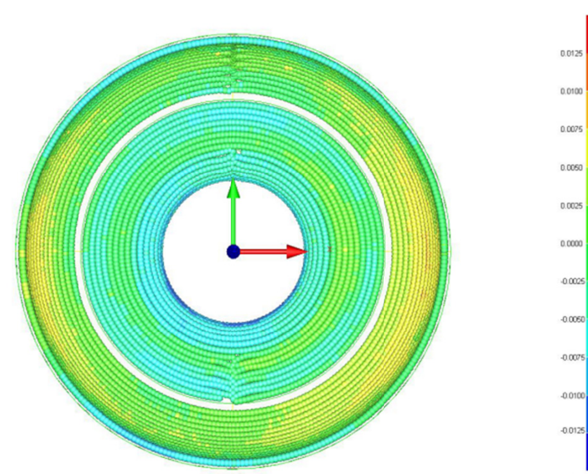

Figure 4: Overall accuracy of the cavity cup shape, measured with a coordinate-measuring machine (CMM). The deviation from the ideal shape is well below 200 µm, being better than required by the BBU limit estimated.

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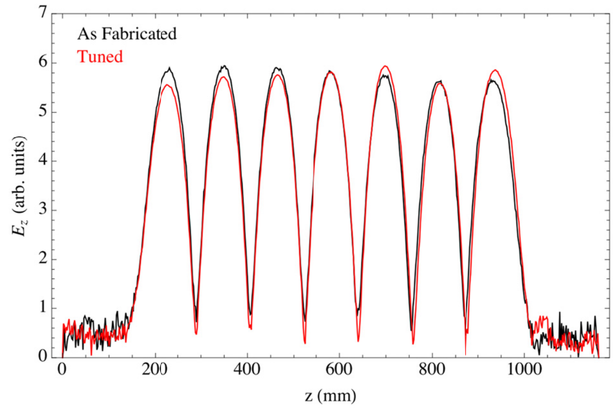

Figure 5: Measured field flatness of a cavity as welded and after field flatness tuning, measured with a bead-pull set-up.

ANCILLARY PARTS

Besides the cavities described above, the module currently under fabrication houses additional components which cannot be described in full detail within this paper (see [8] for details on the higher order mode absorbers). It is worthwhile to mention the power coupler shown in Fig. 6. Even though these ERL main linac input couplers only have to deliver up to 5 kW CW RF power to the cavities, the design is rather sophisticated: The design approach chosen for the whole module requires compensating the lateral movement between the straight mounting situation and the dog-leg geometry gained after cool-down (with an off-set of up to 1 cm).

The external Q of the coupler is $6*10^7$ (with the option to adjust it using a three-stub tuner) in order to minimize the RF power requirements taking into account the microphonics inside the module.

A first prototype of the coupler was successfully tested to 5 kW CW RF power under full reflection. This was done without any conditioning required to reach this power level using a commercial 5 kW solid state RF amplifier [9]. Meanwhile, the series has been ordered and delivery is expected for August 2013.

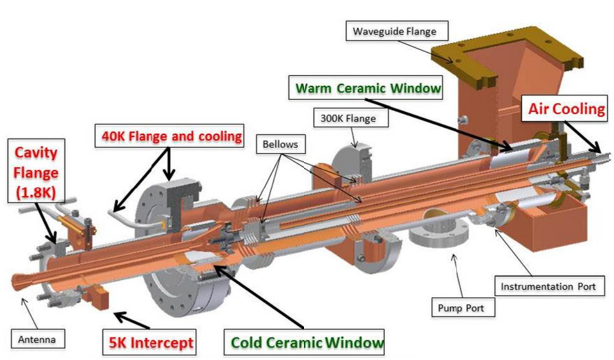

Figure 6: RF Power coupler. The coaxial transmission line has two bellows which allow for lateral movement during cool-down.

STATUS

The design phase of the MLC has finished late 2012. Since then, the fabrication has started; string assembly inside the clean-room will be done 2013. All major components have been ordered, the full cryomodule is expected to be assembled by the end of 2014.

SUMARY AND OUTLOOK

Cornell is currently building a prototype for the full linac cryomodule. In preparation for ERL construction, this allows us to verify the cost model of this cost-driving part of the full ERL. It allows high Q performance studies with significant statistics (6 cavities) as well as quantifying microphonics impacting operation. Using this module, the study of HOMs in a multi-cavity structure with imperfect cavities can be performed, which is the basis for the proposed small loop demonstrator. The fabrication is seen as a preparation step for future industry collaboration, defining key procedures and quality standards.

ACKNOWLEDGMENT

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