OVERVIEW OF THE CORNELL ERL INJECTOR CRYOMODULE

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Abstract

The Laboratory for Elementary-Particle Physics, Cornell University, in collaboration with Jefferson Lab is exploring the potential of a Synchrotron Radiation User Facility based on a multi-GeV, low emittance, Energy-Recovery Linac (ERL) with a 100 mA CW beam[1]. The ERL injector will accelerate bunches from the electron source from 0.5 MeV to 5 MeV with minimal emittance growth. The injector and main linac of the ERL will be based on superconducting RF technology to provide CW operation. There will be one cryomodule with five 1300 MHz 2-cell cavities, each providing one MV of acceleration, corresponding to an accelerating field of about 4.3 MV/m in CW operation. Besides standard features such as an integrated helium vessel and mechanical tuner, each cavity has two input couplers, symmetrically placed on the beam pipe to cancel kicks due to coupler fields. For a 100 mA maximum injected beam current, each coupler must deliver 50 kW of beam power leading to a Qext of 4.6 $x10^4$ for matched beam loading conditions. Antenna- and loop-based HOM couplers can disturb beam emittance through kicks. We plan to avoid the use of such couplers. Following the strategy for B-factory SRF cavities, the beam pipe aperture has been enlarged on one side to propagate all higher order modes out to symmetric ferrite beam pipe loads. These are positioned outside the helium vessel and cooled to liquid nitrogen temperature. Ferrite properties at 77 K have been measured and the corresponding damping evaluated. To explore the full capabilities of the injector, energy gains up to 3 MV per cavity will be considered at lower beam currents. For this flexibility, the input coupling needs to be adjustable by a factor of 9.

1 INTRODUCTION

Before committing to specific designs for a full energy ERL (a large machine with significant investment), it is essential that accelerator and technology issues be explored on a high current prototype machine. The first stage of the ERL project would be a 100 MeV, 100 mA (CW) prototype machine to study the energy recovery concept with high current, low emittance beams [2]. In the injector, a bunched 100 mA, 500 keV beam of a DC gun will be compressed in a normal-conducting copper buncher and subsequently accelerated by five superconducting (SC) 2-cell cavities to an energy of 5.5 MeV.

One attractive feature of a future linac-based light source is the low emittance beam from a high-brightness photo-emission electron gun. But the emittance must be preserved while the injector and main linac accelerate the beam. The goal is to have a beam with a normalized emittance of 2 mm·mrad. The injector system needs to deliver 500 kW to the beam through input coupling devices, typically antennae that protrude into the beam pipe. More than a hundred watts of beam induced power must be removed through HOM couplers. Both power delivery and extraction must be accomplished without introducing emittance-diluting asymmetries. At the same time, flexibility is necessary so that RF focusing and RF bunching can be accomplished without destroying space charge compensation. The high current beam must also remain stable against transverse and longitudinal multibunch instabilities. High average current and short bunch length beams excite significant higher order modes (HOMs) which result in cryogenic load. Our design goal is to allow a maximum emittance growth of no more than 10% total for five injector cavities [3].

The proto-ERL will require operation of superconducting cavities in two extreme regimes. In the injector, the high beam loading in the superconducting cavities requires a strong coupling to the fundamental mode coupler for high power transfer to the beam. In the main linac, the decelerated, re-circulated beam cancels the beam loading of the accelerated beam. Accordingly the main linac cavities must operate at a high external quality factor to minimize the RF power requirements.

To explore whether energy recovery is more favorable for smaller ratios of final and input energies, the injector cavities will be also be operated at three times the nominal gradient to deliver 15.5 MV total, but at lower current. Such studies will also open the possibility of better emittance preservation in the low energy part of the accelerator.

2 INJECTOR CAVITIES

Table 1 lists the properties of the superconducting 2-cell niobium structures, and Fig.1 shows the basic cavity/coupler design. The cavity design is fully discussed in [4].

One source of the emittance dilution is through interaction of the beam with high Q transverse higher-order modes (HOMs). Especially dangerous are the lowest frequency dipole modes with frequencies below the cut-off frequency of the beam pipes. With the cavity shape proposed, even the lowest dipole mode propagates into the beam pipe where it can be adequately damped by ferrite absorbers lining the beam pipe. The frequencies of

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all dipole and monopole modes are at least 10 MHz higher than the appropriate cut-off frequency of the beam pipe. Cornell [5] and KEK-B [6] employ a similar strategy against HOMs.

Table 1: RF properties of 2-cell superconducting cavities.

Frequency	1300 MHz
Number of cells	2
R/Q	218 Ohm
E_{pk}/E_{acc}	1.94
H_{pk}/E_{acc}	42.8 Oe/(MV/m)
Coupling cell to cell	0.7 %
Q_0 at 2 K	> 5×10^9
Twin-Input coupler Q_{ext}	4.6×10^4 / 4.1×10^5
Accelerating voltage	1 MV / 3 MV
Max. power transferred to beam	100 kW

Despite the presence of a large beam pipe to propagate out HOMs, the main cavity parameters are similar to those of the TESLA cavity. This was accomplished through the additional freedom of the cell length. The injector cavity has a thicker iris than in TESLA. The resulting cell-to-cell coupling is weaker (0.7 %), but still sufficient for two-cells.

The simulation code MultiPac [7] was used to check multipacting characteristic of the optimized cavity. This cavity shape is free of one-point multipacting. The familiar two-point multipacting exists but it is weak since the electron energies are about 35 eV.

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3 INPUT COUPLER

The external *Q* factor must be variable through the range from 4.6×10^4 to 4.1×10^5. Such strong coupling usually demands a deep insertion of the antenna into the beam pipe, which enhances the kick problem. A twin-coaxial coupler [9] for the 2-cell SC cavities offers two advantages: (1) Ideally there is zero transverse kick to the beam traveling along the cavity axis and (2) it reduces the power load for each of its arms by a factor of two. The outer diameter of the coaxial line is 62 mm and the impedance 60-Ohm to minimize heating of the inner conductor. The geometry of the antenna tip (Figure 1) is optimized to minimize penetration into the beam pipe.

One of the possible sources of emittance dilution is a kick caused by non-zero on-axis transverse electromagnetic fields of fundamental power couplers in superconducting cavities. This effect is especially strong in the injector cavities, where a high average RF power per cavity must be coupled to a vulnerable low-energy beam. The requirements here are far more demanding than in any existing system. A twin-input coupler reduces the kick ideally to zero. For a one mm offset between the two antenna locations, the kick is still more than a factor of 10 lower than the kick produced by a single coupler. Simulations show that a kick of this magnitude will be harmless to a low emittance beam [8].

A full description of the coupler is presented in [9]. The coupler will have two ceramic windows. One window is cold, tied to 80 K shield. This window with the "cold" part of the coaxial line will be attached to the cavity in a clean room thus sealing the cavity vacuum space. The "warm" coaxial line, waveguide-to-coaxial transition, and the "warm" ceramics will be attached in a process of the cryomodule assembly.

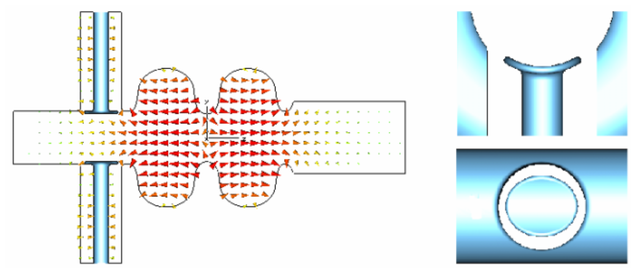

Fig. 1. Geometry of the cavity with the fundamental mode excited in it and details of the coupler.

4 HIGHER MODE COUPLERS

With the method described in detail in [4] and extended for circular waveguides, the value of Q_{ext} of the lowest frequency dipole mode was found as $Q_{ext,\,p} = 250$ for the parallel polarization. Due to the presence of the input couplers, the transverse polarization has lower frequency than the parallel one, but still propagates into the beam pipe and has $Q_{ext,\,t} \sim 1000$.

Strong damping of the HOMs is essential for beam stability and to reduce the HOM losses to a few hundred watts per meter. To achieve this demanding goal we plan to place RF absorbing material in the beam tubes between the cavities in the linac. However, this will require operating the HOM absorbers at temperatures below 80 K to simplify the thermal transition to the cavities at 2 K with low static losses to 2 K. One possible material candidate is ferrite, as it is used at room temperature in the HOM absorbers in the SC CESR cavities. Experiments performed to study the RF absorption properties of ferrite at cryogenic temperatures in the frequency range from 1 GHz to 15 GHz show that the material is even more lossy than at room temperature.

Using these ferrite properties in CLANS, first results show that the monopole HOMs are damped to Q values of less than 1000 with the exception of two modes near 5 GHz [10].

5 CRYOMODULE

For the injector cryomodule, our plan is to closely follow the design of the TESLA cryomodule. Constraints for the input coupler design will be similar to those of the TTF3 coupler. There will be heat intercepts at 4.2 K (cold He gas) and 80 K (either liquid nitrogen or cold He gas). The interface flanges, the length of the coupler as well as some other design features will be similar to the TTF3 coupler design.

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