DESIGN OF L-BAND SUPERCONDUCTING CAVITY FOR THE ENERGY RECOVERY LINACS

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Abstract

For the energy recovery linacs (ERLs), strong higher-order-mode (HOM) damping is indispensable to achieve high current operations. For this aim, we have designed L-band superconducting cavity which is optimized for the ERL operations. New cavity cell shape is designed. The HOMs are damped with microwave absorbers mounted on large beampipes. A new idea of eccentric fluted beampipe is proposed. Design concepts and estimated HOM characteristics are described in this paper.

INTRODUCTION

The ERLs are considered as promising future light sources which can provide excellent synchrotron radiation lights. The ERL project in Japan has been started with the cooperation of KEK, JAEA, ISSP and other SR institutes, with an aim to realize 5 GeV class ERLs [1]. For this aim, we have started to develop superconducting accelerating cavities for the main linacs, which are key components of the ERLs.

Accelerating gradient of 15 $\sim$ 20 MV/m is required to achieve high energy electron beams. For this purpose, multi-cell cavity is inevitable. A most challenging issue, which comes from a requirement of high current CW beams, is a strong suppression of HOMs excited in accelerating cavities. Dipole HOMs can cause current limitation due to the beam-breakup (BBU) instabilities. Even quadrupole HOMs can be problematic and lead to the quadrupole BBU instabilities. Typical simulation results, calculated by the Cornell university, show that the dipole and quadrupole HOMs should be damped to $(R/Q)Q/f < 1.4 \times 10^5$ $(\Omega\mathrm{cm}^{-2}\mathrm{GHz}^{-1})$ and $(R/Q)Q/f < 4 \times 10^6$ $(\Omega\mathrm{cm}^{-4}\mathrm{GHz}^{-1})$ respectively, for 100 mA operation [2], where f is the resonant frequency, Q is the quality factor, and R/Q is the ratio of the impedance and the quality factor. Monopole HOMs are also harmful. They are damped by HOM absorbers and could become significant heat load on cryo-modules. The frequencies of monopole HOMs should not be around multiples of 2.6 GHz to avoid resonant excitation.

The TESLA cavity is known as a representative L-band superconducting cavity. However, it is not adequate for the ERLs, because its HOM damping ability is not enough for high current operations. Furthermore, it is known that the loop-type HOM couplers, which are adopted for the TESLA cavity, have a heating problem for the CW operations [3]. Therefore, we decided to develop 1.3GHz superconducting cavity which is optimized for the ERL operations, especially for HOM damping. We have designed new cavity cell shapes, applied large beampipes on which microwave absorbers are mounted, and adopted a new idea of an eccentric fluted beampipe. Details of the design concepts and its HOM characteristics are discussed below.

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HOM SUPPRESSION BASED ON TESLA SHAPE CAVITY

At first, we start discussion based on the TESLA shape cavity. Subjects are concentrated on the effectiveness of the large beampipes and a number of cells

Large Beampipe

In order to investigate the HOM damping capability of the large beampipes with microwave absorbers, we designed the KEK-ERL model-1 cavity. In this model, cavity cell shapes are basically the same as the TESLA cavity, but one side of beampipe diameter is enlarged from 78 mm to 108 mm. All monopole and dipole modes, except TM010, propagate through the beampipe and are damped by the absorbers. From simulation results, it was found that the large beampipe damper is from several to ten times more effective than the loop-type HOM couplers, as shown later in Figure 4. Here, HOM impedances of the TESLA cavity are quoted from the data shown in [4, 5] and those of the KEK-ERL model-1 cavity are calculated using MAFIA. External Q (Q_{ext}) of the beampipe is estimated and used for the plot. For the KEK-ERL model-1 cavity, the value of $(R_t/Q)Q_{ext}/f$ is just below the 100mA threshold. Considering the fact that loaded Qs of absorber could be somewhat larger than the estimated Q_{ext}, further suppression of dipole HOMs is required.

Number of cells

One method to decrease the HOM impedances is to reduce number of cells per one cavity [6]. We attempted a seven-cell cavity with the KEK-ERL model-1 strategy. The HOM impedances are lowered around half, but the effect is not so drastic. The shunt impedance (R_{sh}) of the accelerating mode is also lowered more than 20 %. From this result, we decided to keep nine cells.

DESIGN OF THE KEK-ERL CAVITY

With the aim of strong HOM damping, we have designed a new cavity cell shapes which have larger iris diameter. As

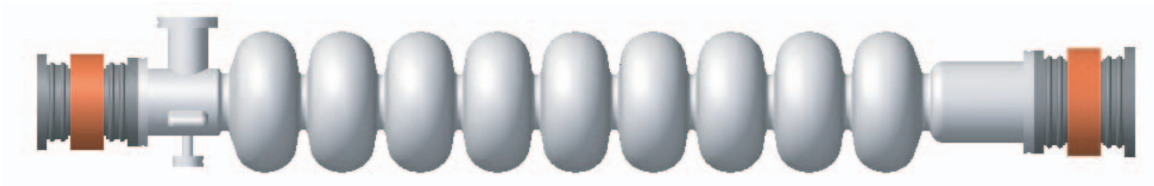

Figure 1: Conceptual view of the KEK-ERL model-2 cavity.

a measure against the quadrupole HOMs, the idea of eccentric fluted beampipe is introduced and its damping ability is discussed in this section.

Cavity Cell Shape

We have designed cavity cell shapes with the following strategy; impedances of dipole HOMs should be as small as possible, frequencies of monopole HOMs should be sufficiently far from multiples of 2.6GHz, and R_{sh}/Q of the accelerating mode should be kept as high as possible.

First, we investigated the possibility of a larger iris diameter, which strengthens the cell-to-cell couplings. It was found that it can significantly lower the impedances of HOMs even in the case of nine-cell cavity, but as expected it reduces that of the accelerating mode. In view of above strategy, we selected 80 mm as the iris diameter. Next, we considered about a cavity diameter. The frequency of TM020 mode is close to 2.6 GHz and depends on it. Therefore, we have to select cavity diameter carefully. Considering the characteristics of TM020 mode and a typical fabrication precision, we required that the all of frequencies of TM020 pass-band should be more than 40 MHz apart from 2.6 GHz. As a result, the cavity diameter was decided as 206.6mm, which was same with that of the TESLA cavity.

Large beampipes, whose diameters were chosen as 120 mm and 100 mm, were adopted so as to propagate TE111 and TM011 mode effectively. Microwave absorbers were mounted on both sides of beampipes. The eccentric fluted beampipe, which is described below, was attached to the side of the input coupler port. The cavity described above is called as the KEK-ERL model-2 cavity. The conceptual view is shown in Figure 1.

Table 1: Parameters of the accelerating mode for the KEK-ERL model-2 cavity and TESLA cavity

	KEK-ERL model-2	TESLA
Frequency [MHz]	1300	1300
Iris diameter [mm]	80	70
Cavity diameter [mm]	206.6	206.6
Rsh/Q [Ω]	897	1030
$Q_0 \times R_s$[Ω]	289	270
E_p/E_{acc}	3.0	2.0
H_p/E_{acc} [Oe/(MV/m)]	42.5	42.6
Coupling [%]	3.8	1.9

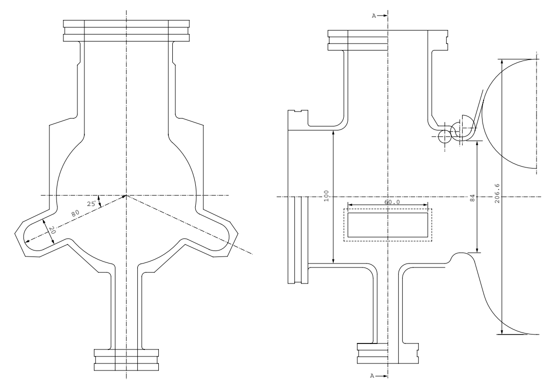

Figure 2: The schematic views of the eccentric fluted beampipe.

Main parameters of the accelerating mode are shown in Table 1. Since the cavity design is focused on the HOM damping, the accelerating mode is sacrificed to some extent. Its R_{sh}/Q is lowered around 900 and E_p/E_{acc} is raised to 3.0.

Eccentric Fluted Beampipe

Another challenge is the damping of the quadrupole HOMs. Because their cut-off frequencies are generally high, their damping is difficult. For this purpose, we propose the eccentric fluted beampipe. The schematic views are shown in Figure 2.

The eccentric fluted beampipe acts as a mode transformer. Due to its asymmetric shape, the quadrupole modes can be partly transformed into dipole modes. Then, they propagate through the beampipes and are absorbed by the dampers. The length of around 6 cm is enough to transform the modes. Angle of the flutes is chosen to couple with both polarizations of the quadrupole modes. The effect on acceleration mode was checked and found to be negligible.

HOM CHARACTERISTICS

The HOM characteristics of the KEK-ERL model-2 cavity were estimated using MAFIA. The results are shown below.

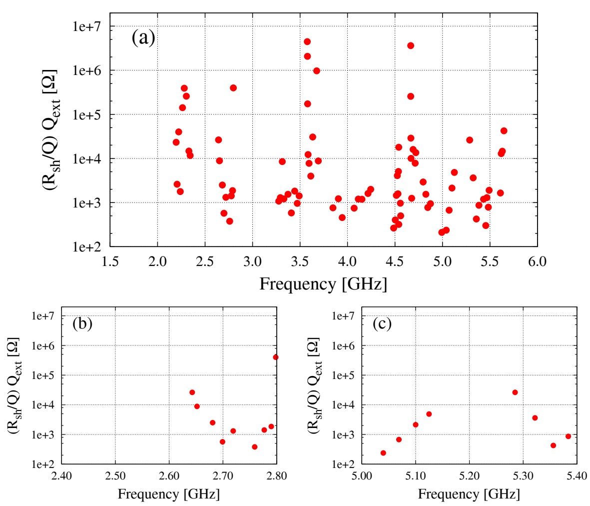

Figure 3: (a) Spectrum of the monopole HOMs and that for (b) around 2.6 GHz and (c) around 5.2 GHz for the KEK-ERL model-2 cavity.

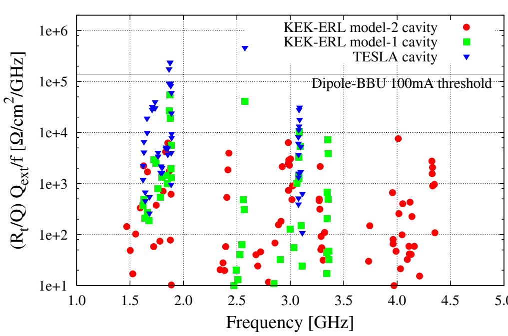

Figure 4: Spectrum of the dipole HOMs. The values of $(R_t/Q)Q_{ext}/f$ are plotted for the TESLA cavity, KEK-ERL model-1 cavity and model-2 cavity.

Monopole Modes

The impedances of monopole HOMs were calculated up to 5.6 GHz and shown in Figure 3. No HOMs exist around 2.6 GHz and 5.2 GHz. It is noted that when ERL is operated with lower frequency of beam repetition, its frequency should be selected carefully not to excite the monopole modes of high impedances.

Dipole Modes

The impedances of dipole modes were calculated up to 4.5 GHz. In Figure 4, the values of $(R_t/Q)Q_{ext}/f$ for KEK-ERL model-2 cavity are plotted and compared with the TESLA and KEK-ERL model-1 cavity. Impedances for the KEK-ERL model-2 cavity are about one order smaller than those for the model-1 cavity. The BBU simulations performed by JAEA indicate that the BBU threshold reaches to more than 600 mA for the KEK-ERL model-2 cavity even without randomization of HOM frequencies [7].

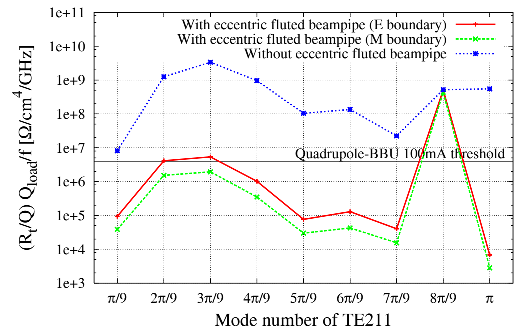

Figure 5: Impedances of the TE211 modes for the KEK-ERL model-2 cavity, for the case with and without the eccentric fluted beampipe. The results for both polarizations are plotted.

Quadrupole Modes

The impedances of the TE211 were calculated for KEK-ERL model-2 cavity with the eccentric fluted beampipe. The values of $(R_t/Q)Q_{load}/f$, assuming ideal absorbers, are plotted in Figure 5. At present, the design of the eccentric fluted beampipe is not yet optimized for the KEK-ERL model-2 cavity, but it shows a promising damping ability. High impedance of $8\pi/9$ mode results from an asymmetry of its field. After optimization, it is expected that 100 mA quadrupole-BBU threshold can be satisfied.

SUMMARY

We have designed the 1.3 GHz superconducting cavity, for the ERL main linacs, which is optimized for the ERL operations. With the goal of the strong damping of HOMs, we designed new cavity cell shape and adopted large beampipes with microwave absorbers. Quadrupole HOMs are damped with the eccentric fluted beampipe. Although some optimization is needed for the eccentric fluted beampipe, our cavity design satisfies the conditions for 100 mA CW operations. At the moment, nine-cell Nb KEK-ERL model-2 cavity is in production. Its performance will be evaluated in the near future. We also proceed the development of components such as an HOM damper, an input coupler and a frequency tuner.

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