BASIC RESEARCH ON THE 1.3 GHZ SUPERCONDUCTING CAVITY FOR THE ERL MAIN LINACS

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Abstract

Feasibility study of the superconducting cavity for 1.3 GHz ERL (Energy Recovery Linac) main linacs has started under the collaboration of KEK, JAEA and University of Tokyo. The development effort was concentrated to optimize the cavity shape to sufficiently suppress the beam instabilities for the desired accelerating beam of 100 mA with the recovery beam of 100 mA. Our final shape has a 9-cell structure with beam pipes of a large diameter on both sides. BBU simulation on dipole modes showed the BBU current limit of more than 600 mA without any randomize of HOM frequencies. HOM power absorbed by the dampers is estimated as 100 W for monopole modes. For the damping of quadrupole modes a new idea of mode conversion using an eccentric fluted beam pipe (EFB) is proposed and simulated. This simple way can take out the quadrupoles to the beam pipe easily. For the establishment of a manufacturing process and the performance of the cavity shape, two single cavities one of which has the EFB have been fabricated and measured. Shape optimizing study, fabrication and some measurement results will be presented.

INTRODUCTION

An ERL project has been organized since 2005 under the collaboration of KEK, JAEA, University of Tokyo and other SR institutes in Japan aiming to discuss on a 5 GeV , 100 mA class ERL for the future synchrotron light source. The project is now planning to construct a demonstration ERL of 60-200 MeV with a beam of 100 mA in cw (continuous wave) mode to establish the key technologies such as dc photocathode gun, 1.3 GHz driving laser, superconducting (SC) rf cavity and its cryogenics. A schematic drawing and the main parameters of this test ERL are shown in Fig. 1 and Table 1[1].

For the SC rf system, two kinds of 1.3 GHz SC linacs are under investigation, i.e., the injector linac and the main linac. In the injector linac, the power delivering of 1 MW in cw is required and the power coupler is the main issue in its development. On the other hand, the SC cavities for the main linac have to provide the high accelerating fields of 15-20 MV/m in cw with sufficiently high Q factor suppressing the HOM impedance so as not to excite the beam instability caused by the high intensity accelerating and recovering beams. Optimization of the structure based on the TESLA cavity has been made in several laboratories by reducing the number of cells[2,3].

In this study, we began the optimization again from the TESLA shape by using the HOM damping scheme that was used in KEKB, CESR and other high intensity storage ring SC[4,5]. As a result, we proposed a new 9-cell cavity which had the beam pipes of large diameter on both sides, and also had a mode converter, EFB, so as to propagate out the quadrupole modes[6,7].

In order to establish the fabrication and treatment procedure of this new 9-cell cavity, two single cell cavities have been built, which have the same cell shape of the central and the end cell of the 9-cell cavity, respectively. The end-single cavity also has the large beam pipes and EFB. The summary of the shape study and the first cold test of the single cavity will be described in this paper.

Table 1: Main parameters of the test ERL

Beam energy	60 - 200	MV/m
Injection energy	5- 10	MV
Circumference	68.8	m
Max. beam intensity	100	mA
Normalized emittance	0.1 - 1	mm-mrad
Bunch length	1 – 0.1	ps
RF frequency	1.3	GHz
Accelerating gradient	10 -20	MV/m

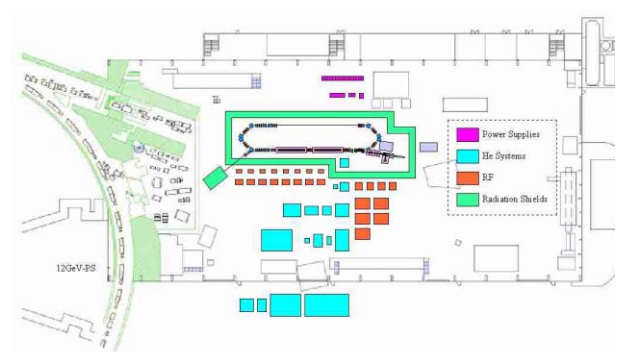

Figure 1: A layout of the test ERL at KEK.

SHAPE STUDY OF THE 9-CELL CAVITY

In the application of the TESLA cavity to a 100 mA class ERL, two problems have to be considered; a HOM impedance around 2.5 GHz and the heating up of the HOM couplers due to the high intensity and cw beam operation. To solve these difficulties, we consider the HOM damping scheme using beam line absorbers instead of the HOM couples.

KEK-ERL model-1cavity

KEK-ERL model-1 cavity has the same shape as the TESLA cavity except for the HOM couplers and a beam pipe of one side that has a diameter of 108 mm so as to lower the cut-off frequency of TE11 and TM11 to 1.63 GHz and 2.11 GHz, respectively. This small change can reduce the highest HOM impedance by a factor of ten.

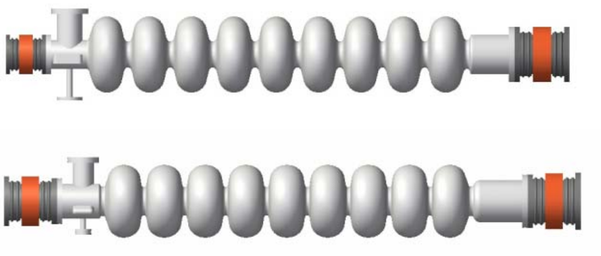

Figure 2: Comparison of the KEK-ERL model-1 (upper) and model-2 cavity (bottom).

KEK-ERL model-2cavity

To improve the damping of dipole modes, the diameters of the iris between cells and also the beam pipes were increased to 80 mm and 100/120 mm as shown in Fig. 3. This modification improves the impedance again by one order (Fig. 4). Fig. 5 shows the simulation results of the BBU threshold current on these cavities. The threshold of model-2 is pushed up to 600 mA without any randomization of the HOM frequency[8].

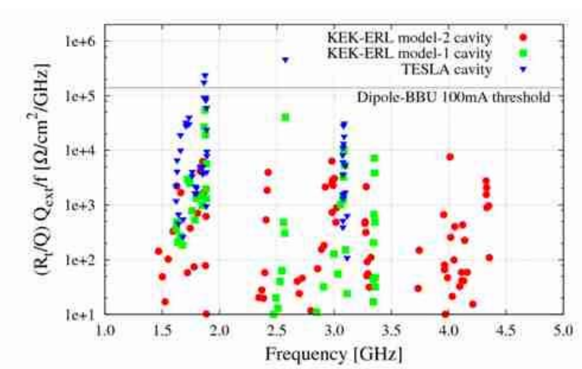

Figure4: Comparison of the dipole mode impedances of each cavity shape.

The geometrical parameters of model-2 are listed in Table 2. Because of the deep penetration of the accelerating field into the beam pipe, the R/Q decreases to 897 ohm. The Esp/Eacc of 3.0 is 50% higher than that of the TESLA shape but it does not become the disadvantageous factor so much, because the operation field of ERL is 15 – 20 MV/m even if high. A large cell-to-cell coupling of 3.8% has an advantage of the large frequency tolerance of each cell to obtain a flat-pi mode.

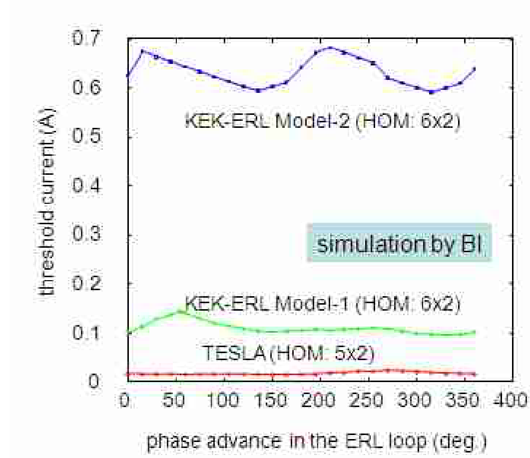

Figure 5: Simulation results of the BBU threshold current for the various cavities assuming the perfect HOM absorption by the beam line damper.

Table 2: Geometrical parameters of model-2

	KEK-ERL model-2	TESLA
Frequency (MHz)	1300	1300
R/Q (ohm)	897	1030
Geometrical factor (ohm)	289	270
Esp/Eacc	3.0	2.0
Hsp/Eacc (Oe/(MV/m))	42.5	42.6
Cell coupling (%)	3.8	1.9
Iris diameter (mm)	80	70
Beam pipe dia. (mm)	100/120	78
Cavity length (mm)	1328	1256

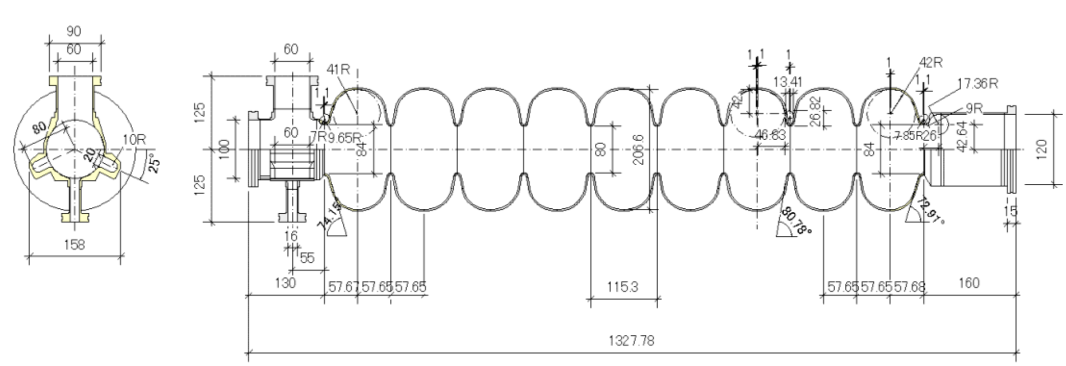

Figure 3: A drawing of the KEK-ERL model-2 cavity.

QUADRUPOLE MODE DAMPING

By increasing a diameter of the beam pipes, the HOM of both monopole and dipole modes can be extracted and damped sufficiently but this diameter is not enough to propagate the quadrupoles toward the beam line absorbers. To obtain the damping of quadrupoles, an asymmetric fluted beam pipe is proposed and simulated. MAFIA simulation shows that by giving the offset grooving on the beam pipe, the beam pipe, named as eccentric fluted beam pipe (EFB), works as a mode converter and a part of the quadrupole propagates out as a TE11 mode. Fig. 6 shows the mode change in EFB. This mode damping was measured using a 3-cell Cu model cavity.

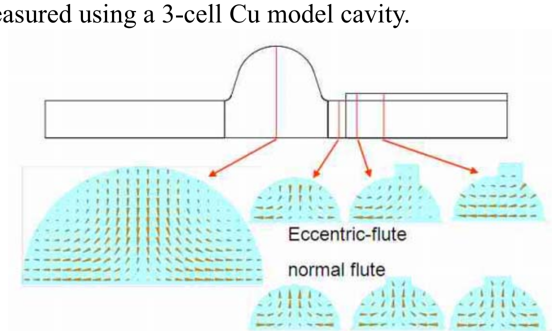

Figure 6: Mode conversion in the EFB. The quadrupole mode converts to TE11 in the offset-grooved beam pipe.

COLD TEST OF C-SINGLE CAVITY

For the test of a fabrication and treatment procedure two single-cell cavities have been fabricated; one has a cell shape of the central cell of model-2, and the other of the end cell with EFB (Fig. 7).

Figure 7: Nb test cavities of C-single and E-single.

Fabrication procedure of these cavities is as follows.

- Hydro-forming of half cells.
- Electron beam welding(EBW) on the equator.
- Grind the inner seam of the equator welding.
- EBW of the beam pipes and grinding the inner seam.
- Barrel polishing (60µm)
- Electropolishing(EP) (100µm).
- Annealing in vacuum at 750°C for 3 hrs.
- Final EP (20µm)
- Ultrasonic cleaning (50°C×1 hr) and high pressure rinsing(80 bar×1.5 hrs).

The cold test of these cavities has started and Fig. 8 shows the Q-E of the center-single cavity. The first 9-cell test cavity (model-2) is under fabrication in the same procedure of these cavities.

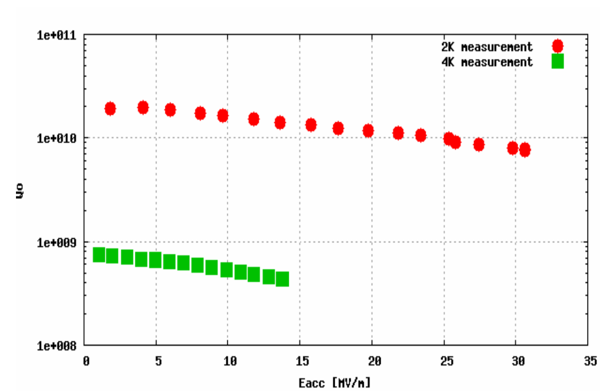

Figure 8: The Q-E of the C-single cavity. Field limitation of 4.2K was due to the available rf power, and that of 2K was the temperature rise caused by a poor capacity of a He pumping system.

SUMMARY

Basic research of the superconducting cavity for ERL has started under the collaboration of KEK, JAEA and University of Tokyo. New 9-cell cavity was proposed for the main linac that had an enough margin of a BBU current limit and had damping of quadrupole modes. A single cell cavity for the fabrication test showed the gradient of more than 30 MV/m that is enough for the ERL use.

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