DEVELOPMENT OF A PROTOTYPE MODULE FOR THE ERL SUPERCONDUCTING MAIN LINAC AT KEK

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Abstract

A prototype module including a couple of 1.3 GHz superconducting 9-cell cavities has been designed as the main linac of cERL which is the test facility to establish the basic ERL technology at KEK. The shape of 9-cell Nb structure is optimized to accelerate a CW beam of 100 mA with sufficiently damped higher order modes (HOM) which is achieved by adopting an eccentric fluted beam pipe and a cylindrical beam pipe of a large diameter of 120 mm. Extracted HOMs are absorbed by the ferrite cylinders bonded on the copper beam pipes by HIP process. A power coupler with double disk-ceramics has been developed to transfer an RF of 20 kW CW to the cavity in full reflection. The test results of fabrication, cooling and RF performance for these components are integrated as the prototype module of the main linac for cERL facility. R&D status of these components and module will be given in this paper.

INTRODUCTION

Feasibility study of a 5 GeV-class energy recovery linac (ERL) has been continued since 2005 under the collaboration of KEK, JAEA, University of Tokyo and other SR institutes in Japan. R&D of key components of electron gun, drive laser and superconducting cavity are in progress to construct a demonstrate ERL named compact ERL (cERL) at KEK (Fig. 1). Parameters of cERL are listed in Table 1 [1].

Beside the 2-cell superconducting (SC) cavities for injection, a prototype module of the main linac is to be installed in cERL. The module consists of two 9-cell cavities which have an optimized cell shape and beam pipes to suppress HOM impedances for an accelerating beam of 100 mA and another 100 mA of a recovering beam [2,3]. Ferrite HOM dampers are connected on both sides of each cavity to absorb the HOMs propagating out from the cavity. Since the dampers are cooled to 80K, thermal isolation from the 2K cavity is necessary as well as cooling of absorbed HOM of 150W. To satisfy this thermal condition, a bellows which has a comb-type RF bridge is adopted [4]. Absorption characteristic of the ferrite material was measured at 80K [5]. Coaxial type power coupler is used which has double ceramic windows of cold and warm. The CW-RF up to 20 kW is supplied to the cavity through these couplers under full reflection.

Because of CW operation at 10-20 MV/m, each cavity dissipates the RF loss of 40 W at 2K. To satisfy this huge load, design work of a new cryostat is in progress. Recent

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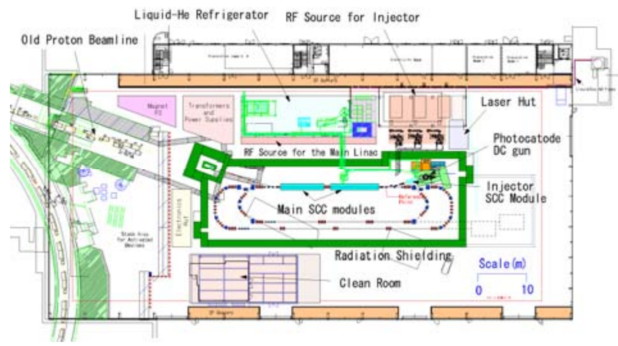

Figure 1: Layout of cERL with a 2-pass scheme.

Table 1: Main Parameters of the cERL

Parameter	Design Value	Unit
Beam energy	35 - 245	MV/m
Injection energy	5- 10	MV
Max. beam intensity	10 - 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

DEVELOPMENT OF KEY COMPONENTS

Vigorous efforts have been devoted to the development of the following key components.

9-cell Cavity for the Main Linac

KEK-ERL model-2 cavity for the main linac has a large iris diameter of 80 mm and beam pipes of 100/120 mm to extract HOMs toward beam pipes. As a result, this shape has a high peak field ratio as shown in Table 2. Vertical test of a prototype 9-cell cavity showed a strong field emission and Q degradation at >10 MV/m. To understand the phenomena in the cavity, temperature and radiation mapping system was developed, which can detect the distribution of temperature and X-ray by rotating the sensor array along the 9-cell cavity surface at 2K and obtain the electron traces (Fig. 2). Fig. 3 shows an X-ray mapping obtained at 2K and suggests the existing of an emission source on the iris. A small tip was observed on the welding seam at the iris by a CCD camera after warming up. By removing this tip and additional surface treatment, the accelerating gradient was improved to 25

MV/m and no X-ray was observed. However, it degraded again showing a new X-ray distribution after giving a persistent conditioning to the cavity [6,7]. Further investigation will be given to this degraded cavity as well as a new 9-cell cavity.

Table 2: Geometrical Parameters of Model-2 Cavity

Parameter	KEK-ERL Model-2
R/Q (ohm)	897
Esp/Eacc	3.0
Hsp/Eacc (Oe/(MV/m))	42.5
Cell coupling (%)	3.8
Iris diameter (mm)	80
Beam pipe dia. (mm)	100/120
Cavity length (mm)	1328

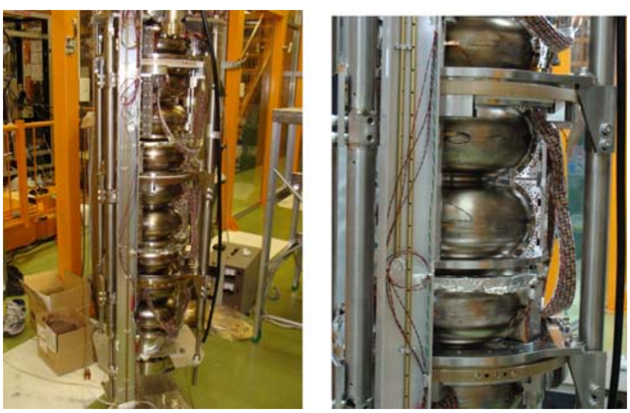

Figure 2: Setup of a 9-cell cavity for the vertical test with a rotating mapping system.

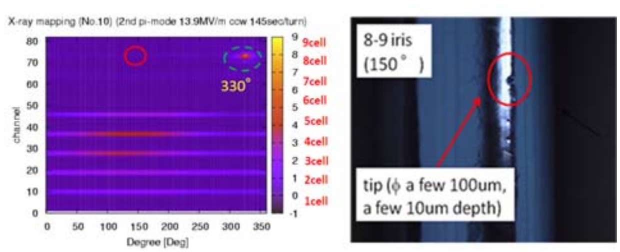

Figure 3: X-ray mapping obtained at 2K measurement (left) and a small tip observed by a CCD camera after warming up (right).

Input Coupler

A coaxial type power coupler with double ceramic windows is chosen as an input coupler of the main linac, where an RF power of 20 kW is supplied to the cavity in a CW mode under a full reflection. Impedance of the coaxial line is selected as 60 ohm aiming to reduce the RF loss of outer conductor which is located in the insulation vacuum of a cryostat. On the other hand, the inner conductor is cooled by the air of room temperature. Ceramic disks are made of 99.7% Al_2O_3 which has a sufficiently small loss angle. Both inner and outer conductors have the bellows to compensate the thermal shrinking and to obtain the variable coupling strength of 5×10^6 - 2×10^7. Schematic drawing is given in Fig. 4.

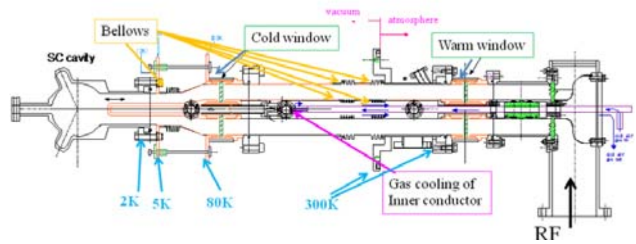

Figure 4: Schematic drawing of the input coupler for a main linac.

Unfortunately, the first model of this window was broken at 7 kW due to heating at the ceramic disk. This abnormal heating was happened when the peak magnetic field was positioned at the ceramic disk in a standing wave operation. Mode analysis using HFSS and MW-studio showed that the ceramic window including a choke structure had a TE mode resonance at a frequency close to 1.3 GHz. To avoid this resonance, a new window was designed of which the thickness of the ceramic disk reduced from 6.2 mm to 5.4 mm. This thickness reduction shifted the resonant frequency by 31.2 MHz. This second model was fabricated and showed the frequency shift of 30 MHz. An RF power of 27 kW was smoothly achieved without abnormal temperature rise. Fig. 5 and 6 show a power stand and the results of the new ceramic window [8.9]. Temperature rise and required cooling rate was measured on the bellows. Design work on thermal property and support mechanism is in progress.

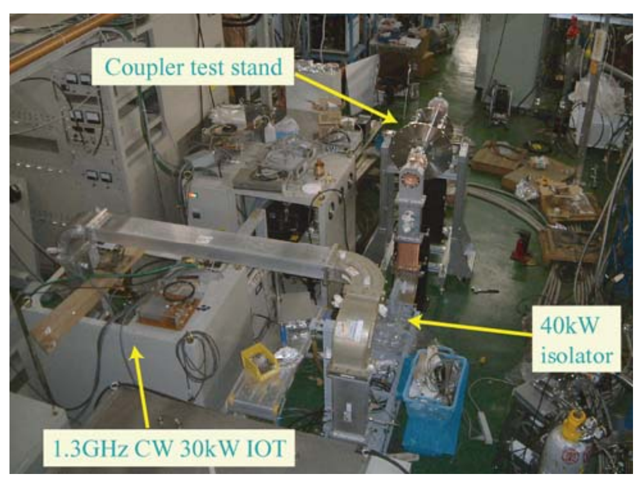

Figure 5: Coupler test stand with a 30 kW-IOT.

HOM Damper

A ferrite cylinder of 80 mm in length with a thickness of 2 mm is bonded on to the inner surface of a Cu beam pipe by HIP (Hot-Isostatic-Pressing). A bunched beam of 77 pC × 2.6 GHz including a recovering beam induces the

HOM of 150W per cavity that is cooled by LN_2.Therefore, IB004 ferrite have to be isolated thermally from the cavity using bellows with a comb-type RF shield. A model of this bellows was fabricated and measured the thermal resistance (Fig. 7) [10].

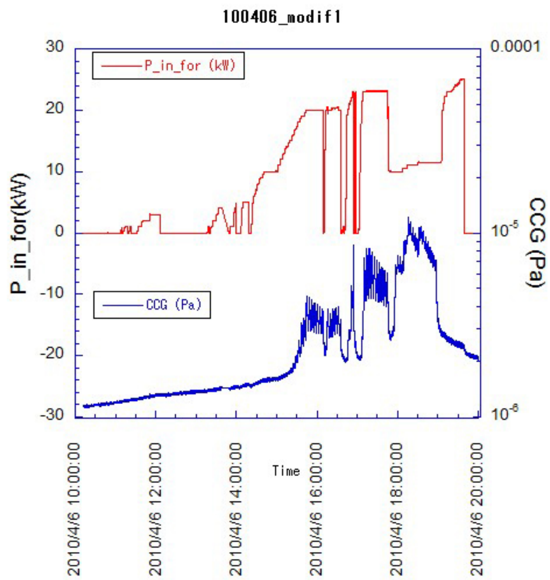

Figure 6: Results of a power test of new ceramic window; input power (red) and vacuum pressure (blue).

MODULE OF THE MAIN LINAC

Each 9-cell cavity is inserted in the Ti-jacket whose diameter is 300 mm. LHe is filled to 90% of the jacket keeping a space for evacuation in the jacket. These two cavities are fixed in the Ti frames and connected each other with the HOM damper. Slide-jack frequency tuners are fixed on one end of the He-jackets and expand the cavity length together with a piezo tuner. The total displacement of 3 mm corresponds to the frequency shift of 1 MHz. The Ti-frame is kept at 4K.

Two 9-cell cavities and He-jackets are fabricated in this fiscal year. A cryostat and other key components will be finished in the next year. Integration of these components as shown in Fig. 8 will be completed in spring of 2012.

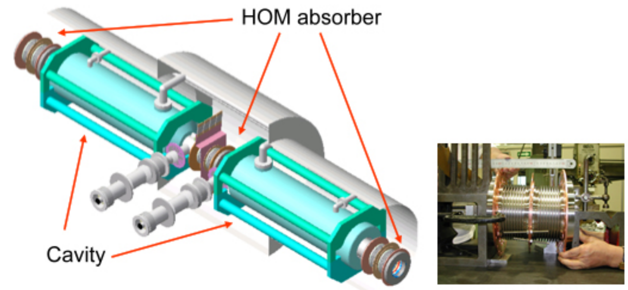

Figure 7: Layout of beam line HOM dampers.

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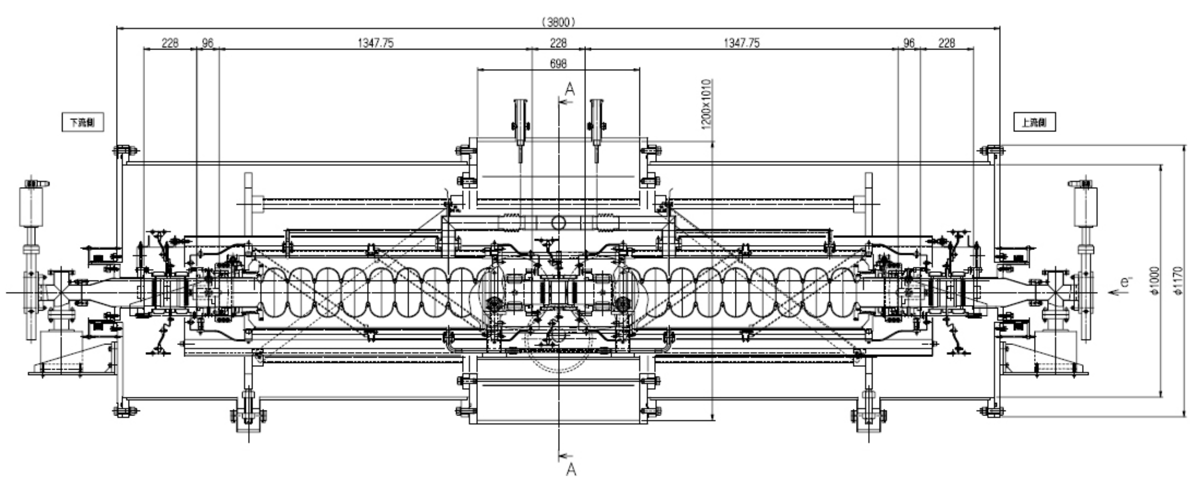

Figure 8: Prototype module of the main linac of cERL.