RF SOURCE OF COMPACT ERL IN KEK

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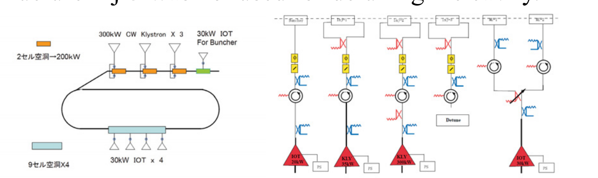
Abstract

The Compact Energy Recovery Linac (cERL) project at KEK has been in progress since 2007. As the pre-stage of the 5-GeV ERL, a 65-MeV test machine, called cERL, has been planned; the preparations for the construction of this system have been made. Because of a budget reduction, the energy of cERL was decreased to 35 MeV in 2009 and redesigned to meet the requirements of the new scheme. The RF source of cERL has been developed in these three years. A 300-kW CW klystron and an associated power supply for an injector linac, an IOT, and a 35-MW CW klystron were developed. The key waveguide components such as the 150-kW circulator were also developed. The test stations required for processing the couplers for superconducting (sc) cavities have been in operation since 2009. Now, the plan to develop the RF test station at the new site is in progress. In this paper, the RF source status for cERL is reported.

INTRODUCTION

At KEK, the 5-GeV Energy Recovery Linac (ERL) is considered to be the future plan. In order to research difficult technical elements, an R&D accelerator called a compact ERL with an energy of 65 MeV was planned at KEK. The design details of this system are described in CDR [1]. According to the original plan described in CDR, a 100-mA beam is accelerated up to 10 MeV in the injector linac; the main linac consists of three cryomodules having 2 sc cavities each. The frequency is selected to be 1.3 GHz in order to utilize common technology with STF in KEK [2]. The original scheme of the RF system in the 65-MeV cERL is shown in Figure 1-(1). The required RF stability in the cERL was an rms amplitude of 0.1% and a degree phase of 0.1. Although these requirements were not more severe than the target ERL requirements, stabilization with the LLRF feedback was inevitable. If the operation point was selected to be 70% of the klystron saturated power, which was in the linear range of the P_{in} vs. P_{out} characteristics, an operation point of 250 kW corresponded to a saturated output power of 270 kW from the klystron. Therefore, a 300-kW CW klystron is required in the injector RF source [3]. Towards the end of 2009, the energy of cERL was decreased to be 35 MeV because of a budget reduction, and the RF scheme was changed to the layout shown in Figure 1-(2). The detailed RF parameters corresponding to Figure 1-(2) for the reduced cERL are given in Table 1. This table shows the six required accelerating structures and corresponding RF parameters and RF sources used. Since energy and current were reduced in this scheme, the structure Inj-3 was not used for detuning the cavity.



(1) (2)

Figure 1: RF layout. (1) shows 65MeV plan of cERL and (2) shows the 35MeV reduced version.

RF SYSTEM FOR INJECTOR

300kW CW Klystron

We developed the 300-kW CW klystron of the injector linac to agree with the original CDR plan. We ordered it to Toshiba Corp. in 2009; the specifications of this klystron are given in Table 2. This klystron (Toshiba E37750) achieves an output power of 305 kW with an efficiency of 63% at a voltage of 49.5 KV and a beam current of 9.75 A. This klystron has been used for processing a pair of couplers with a 150-kW power level from March 2010 at the PF Power Supply Station. From June, the test station will move to the East Counter Hall in KEK where cERL is to be constructed. The performance of this klystron is shown in Figure 2.

Table 1: RF parameters for the cERL of the reduced energy scheme

Item	Unit	Buncher	Inj-1	Inj-2	Inj-3	ML-1	ML-2
Structure		NC	SC	SC	SC	SC	SC
Gradient	MV	0.14	1.5	3.5		15	15
Ql			$8x10^5$	$2x10^6$	Detuned	$2x10^7$	$2x10^7$
Beam phase	degree	-90	-15 to -30	-10		0	0
Power Required	kW	4.5	20	55		11	11
Power Output	kW	6.2	27	76		30	
RF source		IOT	Klystron	klystron		IOT	
Power Available	kW	20	35	300			

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Table 2: Specifications of 300kW CW Klystron

Item	Unit	Specification
Perveance	$\mu A/V^{3/2}$	0.89+-0.9
Beam voltage	kV	52>
Beam Current	A	11>
Frequency	MHz	20
Klystron Type		Diode
Output Power	kW	>270 (Goal 300)
Efficiency at Sat.	%	>50 (Goal 60)
Gain at Saturation	dB	>37
Cavity Number		5
Cooling		Water Cooling

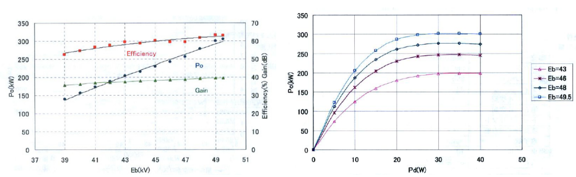

Figure 2: Characteristics of 300-kW klystron. Left: Applied voltage vs. output power (black), gain (green) and efficiency (red).Right: Input power vs. output power in various applied voltage.

Power Supply for 300kW CW Klystron

The power supply for the 300-kW CW klystron was manufactured in FY2009. The main specifications of the power supply are as follows: a maximum output voltage of -52 kV, a maximum output current of 11 A, a ripple of an output voltage of less than 0.5% (p-p), and the stability of an output voltage of less than 0.5% (P-P). Stabilization was achieved by the well-established thyristor phase control. For the protection of the klystron, a fast IGBT switch goes active when it has an arcing to maintain an energy of less than 10 J in the tube.

Waveguide System

We prepared the components of the WR650 system to be similar to those of STF since the operating frequency was the same. In FY2009, we developed a circulator with three ports; this circulator has the capability of the CW 150-kW klystron since the original CDR employs two couplers in one cryomodule that consists of two sc cavities. In order to be small, the ferrite parts consisted of four layers. An insertion loss of less than 0.3 dB and an isolation of more than 20 dB were achieved. The block diagram of the RF system for one cryomodule and the planned power distribution system are shown in Figure 3. This circulator has been used for the coupler test stand since the end of FY2009.

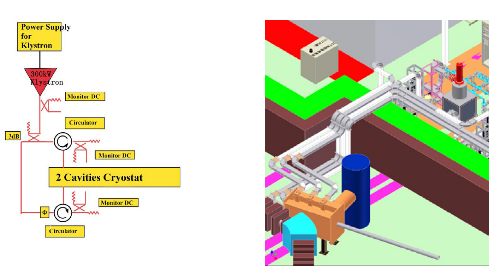

Figure 3: Left: Block diagram of the RF system for the 2-cavities cryostat. Right: Power distribution layout of the injector of cERL.

RF SYSTEM FOR MAIN LINAC

We prepared two types of RF sources for the main linac: one was a 35-kW IOT (VKL-9130, CPI), and the other was a 35-kW klystron (E3750, Toshiba). Even though E3750 had a good efficiency of 60% at the saturation points, when these two sources were operated in the unsaturated power range under the LLRF feedback, the operating efficiency of an IOT was expected to be higher than that of a klystron. We will compare the performance of the two sources and make a choice for the future project. We had all power supplies for these two sources. One was manufactured in FY2009, and the other two power supplies were transferred from Japan Atomic Energy Association (JAEA). These will be installed and tested in FY2010 at the East Counter Hall in KEK.

COUPLER TEST

In order to perform the high-power test of the injector couplers, which have a transmission power of 150 kW, before the manufacturing of all components, we developed a test bench to evaluate the coupler in the Photon Factory (PF) Power Supply Hall by utilizing the old power supply of the PF klystron. The layout and the photographs of the test stand are shown in Figure 4. The power transmission test of up to 150 kW of a pair of couplers was successfully performed in May 2010. This station will be closed soon, and all HLRF components except for the old power supply will be moved to the East Counter Hall where the cERL will be constructed.

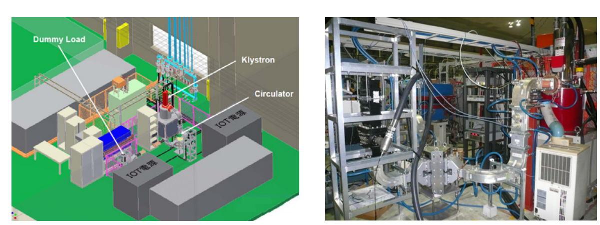

Figure 4: Left: Schematic drawing of the test station Right: Photograph of the RF source in the PF Power Supply Hall.

LAYOUT OF COMPACT ERL

The cERL will be constructed at the East Counter Hall in KEK. The layout of the entire cERL is shown in CDR. The layout of the RF source for the original 65-MeV cERL is shown in Figure 5. In accordance with the energy

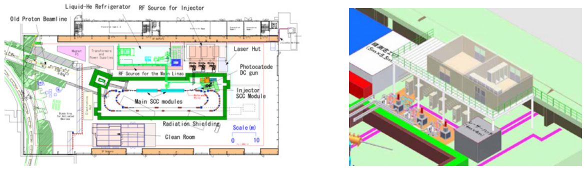

Figure 5: Left: Layout of 65MeV cERL. Right: 3D drawing of RF source in East Counter Hall in KEK.

reduction, all power supplies and RF sources are gathered near the injector section. At the same time, two coupler-test stands for the injector linac and the main linac coupler are developed next to the power supplies. There are some ambiguities since the structure of the radiation shield is not precisely designed.

LLRF

The stability requirements are an rms amplitude of 0.1% and a degree phase of 0.1 at the cERL. In order to satisfy these requirements, a digital LLRF system has been developed [4]. The block diagram of the LLRF is shown in Figure 6. The LLRF consists of a digital control, an RF amplifier, an RF monitoring system, a tuner control, and a component safety system (MPS). Because of the budget limitation, we built the RF amplifier, the RF monitoring system, and the MPS, which is the same as the J-Parc one, in FY2009.

A micro-TCA system is adopted, and the new FPGA board (AMC module) has four 16-bit ADCs and four 16-bit DACs. Down-converted RF signals (IF: ~10 MHz) are connected to ADCs. Simple PI feedback with a feed-forward will be applied inside the FPGA on the basis of the previous experiences at STF in KEK [5]. The cavity detuning control will also be carried out by this new FPGA board. The FPGA board will be an EPICS IOC, and all the controls and data acquisition will be via EPICS. The fast arc detector employs an optical fiber with a diameter of 0.6 mm and a photo-diode/multiplier system. The control board for the digital control was manufactured in FY2009. The AMC module is employed on the cabinet since this module is widely used in the field of telecommunications.

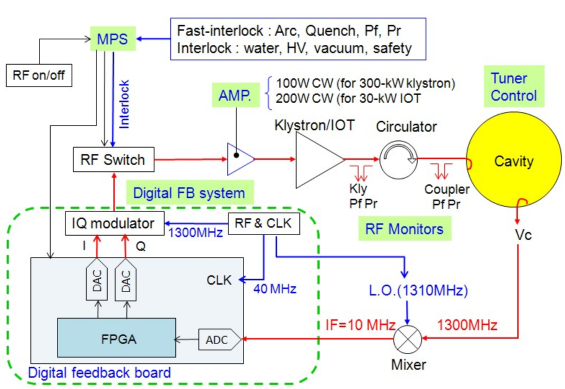

Figure 6: Block diagram of LLRFL.

RF SOURCE SCHEDULE FOR COMPACT ERL

After the evaluation test of couplers in the PF Power Supply Hall, all components will be moved to the East Counter Hall. In FY2010, the installation of the 300-kW klystron and the power supply will be carried out. The operation of the 35-kW IOT is also planed next to the 300-kW RF source. Because of the budget reduction, except for the 20-kW IOT for the buncher section, we have made the necessary components shown in Table 1. In FY2010, the coupler test of 150 kW for the injector linac and the coupler test of 30 kW for the main linac are scheduled. Since the construction of cERL will be completed in 2012, we will procure an IOT of the buncher in FY2011. The waveguide components will also be procured in FY2011, and we will begin the construction of the power distribution system shown in Figure 3 in FY2012.

SUMMARY

KEK began the development of the cERL in 2007, and an RF source has also been developed. The recent development for the RF source, including HLRF and LLRF, is presented in this paper. The general development of the recent cERL is described in this conference [6]. In 2009, the 300-kW CW klystron and its power supply for the injector linac were manufactured. The 300-kW klystron was operated for the coupler test of 150 kW successfully. A newly developed 150-kW circulator was employed in this test stand and operated. RF sources, such as the 35-kW IOT and the 35-kW klystron, for the main linac were also procured. Their power supplies were prepared. All these components were installed at the East Counter Hall, the cERL site. The development of LLRF is also in progress.

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