# R & D STATUS OF C-BAND ACCELERATOR UNIT FOR SUPERKEKB

T. Kamitani*, T. Suwada, for the KEK electron/positron Injector Linac and
the Linac Commissioning Group, KEK, Tsukuba, Japan

*Abstract*

In an extensive luminosity upgrade of the KEK-B factory, considered as a future plan, the injector linac has to increase the positron acceleration energy from 3.5 GeV to 8.0 GeV. In order to double the acceleration field (from 21 to 42 MV/m), a design study of the C-band accelerating unit has been started. This paper reports on the R & D status of the C-band components for a high-power test and for a beam-acceleration test at the KEKB injector linac.

## INTRODUCTION

Recently, the KEK b-factory (KEKB) has surpassed its goal luminosity of $1\times10^{34}cm^{-2}sec^{-1}$. Though it is the world-highest luminosity ever achieved, an even higher luminosity ($10^{35}-10^{36}cm^{-2}sec^{-1}$) is desired for a deeper understanding of a B-meson physics. The design consideration of this extensive upgrade, called "SuperKEKB" [1], started in 2001, and R & D of the components are now underway. One of the major changes in this upgrade is the switch of the beam energies (from 8.0-GeV electrons and 3.5-GeV positrons to 3.5-GeV electrons and 8.0-GeV positrons). Raising the beam energy suppresses the positron beam blow-up caused by the electron-cloud inside the vacuum chamber.

The present KEKB injector linac accelerates electrons up to 8 GeV with 55 accelerator units, including a few stand-by units [2]. The electrons are injected directly into the High Energy Ring. For positron injection, the electrons are accelerated up to 4 GeV in the former half of the linac (26 units), and hit a metal converter target to produce positrons. Those positrons are accelerated up to 3.5 GeV in the latter half (29 units), and are injected into the Low Energy Ring. For the SuperKEKB, positron acceleration energy is required to be increased from 3.5 GeV to 8 GeV. The maximum energy gain by all of the present positron accelerating units is not sufficient (4.8 GeV) for 8-GeV injection. Since the positron intensity is proportional to the primary electron energy, the number of positron acceleration units cannot be increased by changing the target position at the cost of the units for the primary electron. The simplest way to realize this energy upgrade is to increase the acceleration field by about twice. It requires a four-times higher rf input power, if the present S-band accelerating structures are used. It is not realistic based on the limit of the capacity of the present klystron gallery and the input electricity power. Instead, the possibility to use C-band accelerating structures is considered. The upgrade scheme presently considered is shown in Fig.1. A damping ring (DR) is added for emittance reduction. The accelerator units after the DR are to be upgraded with C-band components to achieve 8-GeV injection. Another upgrade scheme using beam recirculation instead of the C-band units is also considered, but it is not mentioned here.

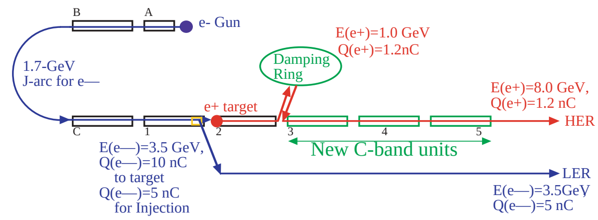


Figure 1: upgraded Linac with C-band units

## ACCELERATOR UNIT

The present S-band accelerator unit of the KEKB injector linac involves four 2-m accelerating structures fed by a klystron through a SLED-type rf-pulse compressor. The average accelerating field gradient is 21 MV/m with 41 MW output power of 4 $\mu$s pulse duration from the klystron and with rf-pulse compression. The energy gain by a unit is typically 160 MeV. In the upgrade to the C-band, an S-band unit is replaced by two identical sub-units; each is composed of two 2-m accelerating structures fed by a klystron through an rf compressor. The average accelerating field gradient is expected to be 42 MV/m with 40 MW output power of 2 $\mu$s duration from the C-band klystron and with a LIPS-type rf-pulse compressor [3]. The total energy gain by two sub-units is 320 MeV.

Compared with the S-band unit, the rf power source is divided into two. It is mainly because there is no C-band klystron available which can supply the 80 MW power necessary for the four accelerating structures. Instead, two 50-MW class klystrons are used. The modulator is also divided into two. A design comparison was made between the single modulator feeding two klystrons and the two modulators feeding a single klystron, respectively. In the case of the single modulator, it becomes too large to re-use the present components, like the capacitors, and requires complete renewal of the design to fit in the present klystron gallery, and costs too much. Finally, we decided to adopt a system composed of the two identical sub-units. It facilitates the design of the modulator and reusing the present components. What is more, by complete isolation of the sub-units, the operation is more flexible, since individual tuning is possible.

* takuya.kamitani@kek.jp

## RF SOURCE

The present S-band unit uses a 50-MW class klystron (Mitsubishi PV3050 or Toshiba E3730), which supplies 41 MW output power of 4.0 $\mu$s rf pulse duration. In the R & D work for the C-band linear collider, a 50-MW class klystron was developed by T. Shintake and H. Matsumoto [4] and is commercially available (Toshiba E3746). It is operated at 5712 MHz with a beam of 358 kV voltage and 320 A current in pulse repetition of 50 Hz. It needs 240 W of drive power and delivers an output power of 53 MW in 2.5 $\mu$s duration. In the C-band upgrade of the KEKB linac, this klystron is the first candidate. A klystron of this type has already been fabricated and used in a high-power test in a test stand since December 2002 and will be used in a beam acceleration test scheduled from this September.

The present line-type modulator produces a 4.0 $\mu$s long (flat-top) 306 kV high-voltage pulse for the klystron at a repetition rate of 50 Hz. In the upgrade to the C-band unit, two modulators for the two klystrons must be installed in the same space of the klystron gallery, as shown in Fig.2. To make the modulator more compact, the present high-voltage dc power supply and the charging circuit will be replaced by a compact inverter-type power supply. To generate a flat high-voltage pulse of 4.0 $\mu$s duration, two pararell pulse-forming-network (PFN) circuits, each composed of 20 capacitors (0.0146 or 0.0155 $\mu$F) and 20 inductors (0.67 $\mu$H), are used in the present modulator. In the C-band modulator, a pair of PFN circuits (14 capacitors and 14 inductors) is used to generate a pulse of 2.0 $\mu$s duration. Most of the components in the S-band modulators, like PFN capacitors, thyratrons, cabinets, pulse transformers and oil-tanks can be reused, which contributes to reduce the cost of the upgrade.

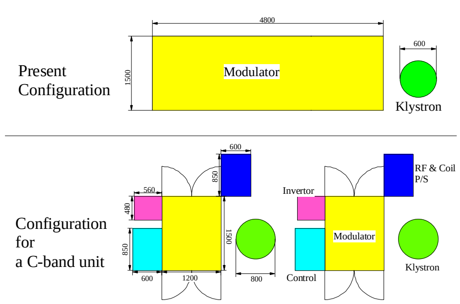


Figure 2: Modulator/Klystron layout

In the present rf drive system, an rf signal of 2856 MHz is transmitted from the main drive system to each sub-booster through phase-stabilized optical fibers. In the sub-booster, the signal is amplified by a 60-kW klystron and distributed to eight klystrons. In the sub-booster of the C-band unit, the frequency is doubled with a multiplier to 5712 MHz. Concerning the sub-booster klystron, instead of designing a brand-new one, an available 200 kW klystron operated in 5.3 GHz for radar (Mitsubishi PV-5101) is modified for 5712 MHz operation.

## ACCELERATING STRUCTURE

The accelerating structure used in the present S-band unit is a 2-m long, disk-loaded, traveling-wave structure operated at 30.0 deg C. The structure is composed of 54 regular cells and two (input, output) coupler cells, and the phase advance per cell is $2/3\pi$. The iris diameter is decreased linearly cell-by-cell to achieve a quasi-constant field gradient. The typical size of the iris diameter is 24.275 - 20.300 mm from the entrance to the exit. A total of five variant types of structures which have different iris sizes are used to distribute the deflecting mode of the cavities and prevent a beam break up from occuring during long-pulse operation. As shown in Fig.3, the first prototype C-band 1-m accelerating structure is designed as a scale-down model of the present S-band 2-m structure, which has the largest iris diameter within the five variants. The dimensions of the regular cells can be scaled precisely to half that of the S-band structure. They are already processed and the phase advances in respective cell are adjusted to 120 degree within an error of 2 degrees with the nodal-shift measurement. As has been done for the S-band structure, the disks and the cylinders processed individually are formed into an integral structure by an electroplating technique. Unlike the regular cells, the coupler dimensions (the iris width and the coupler cell diameter) have to be modified because the dimension of the wave-guide, which is connected to the coupler, is not scaled. The coupler dimensions are roughly optimized with the MAFIA-3D code to achieve the proper coupling strength and the minimum reflection, and further finely adjusted by milling and lathering step-by-step with the feedback from the measurement of the rf property. Fabrication of the couplers for high-power operation and electroplating of the regular cells are in progress. The couplers and the regular cells are to be connected later by electron-beam welding, and will be finished by the end of June.

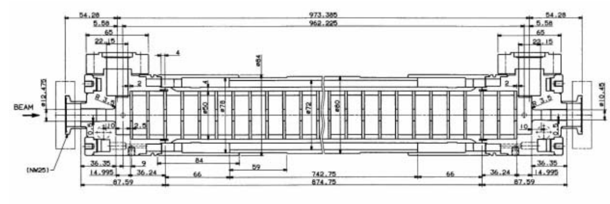


Figure 3: 1-m long C-band Accelerating structure

## RF COMPONENTS

In place of the WR-284 (WRJ-3) standard wave-guide (inner dimension; 72.1 mm $\times$ 34.0 mm) used in the S-band unit, the WR-187 (WRJ-5) standard wave-guide (inner dimension; 47.55 mm $\times$ 22.15 mm) is adopted for the C-band unit, considering the power loss and the contamination of the higher-order mode. An Merdinian-type flange for the wave-guide is designed and used at the test stand.

As an rf window to separate the vacuum of the accelerating structure and that of the region close to the klystron, a pillbox-type window is already available, which has been developed as a component of the C-band klystron. However, its maximum transmission rf power is 25 MW. A new type of an rf window, which can transmit 50 MW, is being developed to simplify the system in the C-band unit. Unlike the pill-box type window, it uses a mixture of two modes (TE11 and TM11) to generate a traveling-wave in the ceramic of the window. It lowers the electric field strength at the edge of the ceramic and reduces the electron emission, which results in a breakdown of the ceramic. With the high-power test performed using a resonant ring at the test stand, the new rf window has been confirmed to work without any problems at 160 MW rf power and a 2 $\mu$s duration at 50 Hz repetition.

A 3-dB high-power rf divider of the C-band has been designed by simulations using the HFSS code to determine the approximate dimensions. It does not have a button inside, which is often used for a fine adjustment to reduce the reflection, but sometimes causes discharging. Instead, the inner dimension is finely optimized by measuring the rf transmission properties of 16 candidate low-power test modules. Modules for high-power operation are under fabrication.

A high-power dummy load to fit for the WR-187 waveguide is being designed. Inside the wave-guide of the dummy load, cylindrical SiC blocks of 12 mm diameter stand in line with the gradually growing heights to absorb the rf-power uniformly. The heights and the positions of the blocks are optimized using the HFSS code. They are further optimized to achieve the least reflection by an rf-measurement using a low-power test module, in which the blocks are changeable and the positions are variable. The modules for high-power operation are being fabricated.

The rf pulse compressor for the C-band is still in the stage of conceptual design. Since the SLED-type cavity using TE015 mode [2] does not give a sufficient Q-factor and field multiplication at a frequency of C-band, an LIPS-type cavity using the TE038 mode [3] is being considered. A low-power prototype cavity will be fabricated this summer to optimize the coupling hole dimensions.

## TEST STAND AND BEAM ACCELERATION STUDY

For rf-conditioning and high-power test of the C-band components, setting up of a test-stand started in December 2002. The test stand has been used for conditioning the S-band accelerating structure, which is to replace the damaged structure after long use in the linac. The stand has also been used for a high acceleration field study of the S-band structure, which recorded a field of 40 MV/m with 41 MW supplied into a single 2m-long structure through a SLED-type rf compressor cavity. The stand has been re-arranged for a C-band study as shown in Fig.4. A unit test of the modulator, began in January 2003 with an coaxial dummy load. Initial tuning and the trouble shooting of the modulator has been performed. Later, a C-band klystron has been connected to the modulator as a proper load. After conditioning, a 43 MW output power of 2.0 $\mu$s duration from the klystron at 50 Hz repetition was achieved in April.

The accelerating structure, the 3-dB high-power divider and the SiC dummy loads will be installed in the test stand in June. Their rf-conditioning and a high-power test will be performed in July and August. In mid of August, the components of the C-band accelerator unit will be moved from the test stand to the location of the ”4-4” unit in the KEKB linac, which is temporarily vacant. The energy gain and the average acceleration field will be evaluated by measuring the beam energies of the electrons and the positrons in the beam study from September.

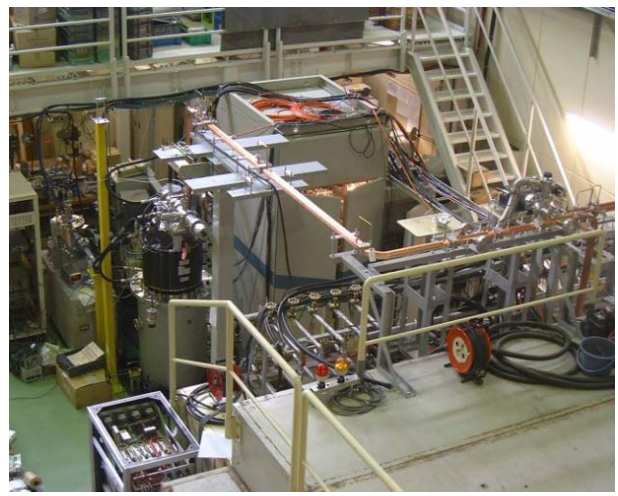

Figure 4: C-band High-power Test Stand

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