R&D STATUS OF THE LINAC UPGRADE PLAN USING A C-BAND SYSTEM FOR SUPERKEKB

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Abstract

We are developing a linac upgrade to increase the positron energy from the current 3.5 GeV to 8 GeV for SuperKEKB. In order to use the current infrastructure effectively, a C-band system is being considered to be introduced. One unit of a high-power RF source and an accelerator system were successfully tested, and an accelerator was installed in the beam line of the KEKB linac to conduct a beam acceleration test. A brief description of this project and the current R&D status are presented in this paper.

INTRODUCTION

The KEK b-factory (KEKB) has successfully achieved a goal luminosity of 1×10^{34} cm^{-2} s^{-1} and has been accumulating valuable data of B-meson physics. Recently, the SuperKEKB project, which aims to achieve a one-order higher luminosity, is being considered. A required major change for the linac in this project is switching the beam energy, i.e., the positron energy from 3.5 to 8.0 GeV and the electron energy from 8 to 3.5 GeV, in order to suppress positron beam blow-up caused by the electron-cloud in the ring. At the same time, positron and electron currents are required to be increased up to 1.2 nC and 5 nC, respectively. Among the several designs, it is presently being considered to replace the last 3 sectors (24 S-band klystron units) with the 6 sectors using the C-band system (48 C-band klystron units) [1]. Positrons after the conversion target are accelerated up to 8 GeV using forty-eight SLEDs and 50-MW klystrons. This is schematically shown in Fig. 1. The RF system is considered to be a

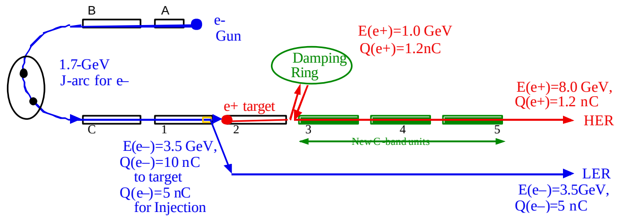

Figure1 Proposed scheme using C-band system

complex similar to the current S-band system, as shown in Fig. 2. In order to make use of the existing infrastructures, a modulator is changed to use a compact inverter power supply, which charges to the existing discharging circuits. This enables us to decrease the modulator size to one third of the existing one, as shown in Fig. 3, and to install 48 modulators in the existing klystron gallery. Klystron sockets, such as pulse transformers and oil tanks, are also planed to be reused. The currently designed RF system has a 100-kW sub-booster (SB) klystron that drives eight 50-MW klystrons to suppress the cost for the individual driver amplifiers. The accelerator guide is a half-scaled one of the current S-band structures, which has a 40-MV/m acceleration gradient; accelerator girders are also considered to be reused.

In order to obtain a 40-MV/m acceleration gradient, the 40-MW output power from the klystron is multiplied by a SLED (a power multiplication of 3.4 at a pulse width of 2 µs), and then fed to two 2-m long C-band accelerators, which are scale-downed versions of the S-band structure by one half. Assuming a filling time of 380 ns and an

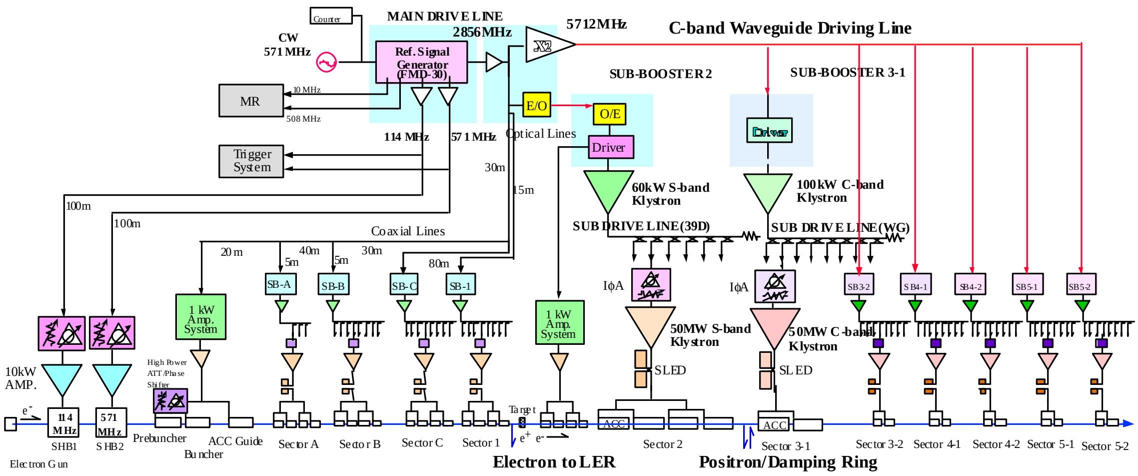

Figure 2 Block diagram of C-band System for SuperKEKB upgrade

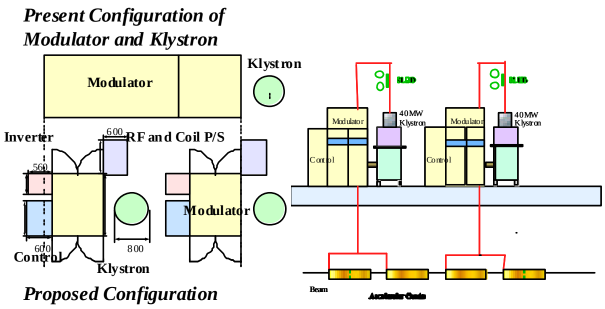

Figure 3 Comparison between the old and new modulator (left) and RF feeding scheme (right)

attenuation constant of 0.703, a peak power of about 59 MW at the entrance of the accelerator guide and an average acceleration gradient of 40 MV/m. have been obtained. The SLED is considered to be a CERN-LIPS type one, which uses the TE_{038} mode. This is almost the same size as the current S-band SLED and it is expected to utilize the manufacturing experience effectively.

C-BAND R&D STATUS

C band R&D started in the spring of 2002. The short-term goal was to install an accelerator guide in the EKEB linac of #4-4 (where no accelerator was installed) during the shutdown period of the summer 2003 and a beam test would be conducted in the autumn of 2003. We started by purchasing C-band components, since we had no components of the C-band frequency. Several important items for this project were designing and manufacturing the C-band accelerator, a SiC dummy load, a waveguide vacuum flange, the construction of an RF system including the development of an SB klystron, a high-power RF window and a compact modulator. Those components were successfully completed by the summer of 2003. A high-power test of the system, and processing of the accelerator guide were also completed, and the guide was installed to the beam line of the KEKB linac on schedule.

Compact Modulator

A compact modulator was a key issue in order to install all of the required units in the existing klystron gallery. A proto-type was manufactured using a dc inverter power supply, which charged the PFN. In the PFN, two circuits with 14 inductances (1.55 nH) and 14 capacitances (15.5 μF) each were placed in parallel. The designed flattop was 2μs and the characteristic impedance of the PFN was 5 ohms. A pulse transformer of having a 1:15 step-up ratio gave a 350 kV pulse at maximum to the high-power klystron. Though we faced many problems, which caused the IGBT to break down at the first stage, it has been stably operating for more than 1000 hours up to now.

50-MW klystron and driving system

A simple RF system was used in the test stand, which comprised a 2856-MHz signal generator, a frequency doubler, a pulse modulator, an 8W-transistor amplifier and a SB klystron. The SB klystron was manufactured by re-tuning a weather-satellite klystron. From the SB klystron, the output power was fed through a WR-5 waveguide to a Toshiba 50-MW klystron (E3746). The klystron socket was used in the same way as the S-band one, which was possible to use up to 350 kV.

High-Power RF Window

It was necessary to use the RF window to separate the vacuum system between the klystron and the accelerator guide. Although two windows were equipped in the high power klystron, because of the simplicity of the vacuum system, we developed a high-power RF window, which was capable of being used at the 50-MW power level. This was a mixed-mode window (TE_{11}+TM_{11}) proposed by Kazakov. Using the mixed mode, the field decreased at the ceramic surface and on the edge, where brazing was conducted.

SiC dummy load

It was necessary to develop a dry load, which absorbed the RF power at the exit of the accelerator guide. A SiC-dummy load was developed with loading the SiC cylindrical materials on the waveguide surface of the E-plane. Two SiC dummy loads set in parallel were successfully tested, as described below.

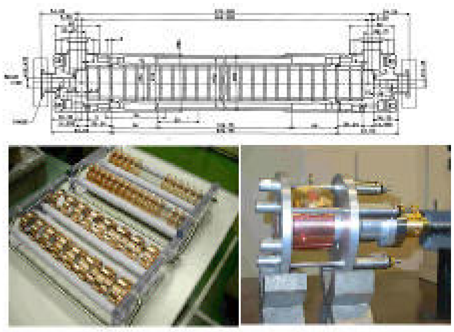

Figure 4 Cut-away view of accelerator (top), disks and cylinders (bottom left) and coupler (bottom right).

Development of an Accelerator Guide

Though the basic design was assumed to use a 2m-long accelerator guide, a 1-m long C-band accelerator guide, which was half scale of the current S-band one, was manufactured as a prototype. This structure had an electric property of the last half section of the 2-m long guide, and 2a was varied from 12.44 to 10.41 mm. The filling time was 234 ns and the attenuation constant was 0.434. With the condition of no SLED and 40-MW output power from the klystron, an acceleration gradient of about 39 MV/m was expected. The design was made using the HFSS and MAFIA-3D code. Disks and cylinders were manufactured at KEK and MHI (Mitsubishi Heavy

Figure 5 Birds-eye view of test hall (left) and waveguide system in test stand (right)

Industry) and electroplating of the regular cells and electron beam welding of the couplers were done at MHI. Fig. 4 shows a drawing and photos of the cell and coupler.

Test Bench and Test Results

A C-band test station was set in the accelerator assembly hall next to the S-band klystron test hall in the KEKB linac, considering that the distance from the RF source to the shielding room was short. In this stand, a modulator test was performed in February, 2003, and a C-band klystron test was conducted up to 42.5 kV of Es (PFN voltage) with a pulse repetition of 50 pps and a pulse width of 2 µs. An output power of 43 MW was measured with two water-loads. Then, the klystron output characteristics were measured. We also adjusted the pulse flat top by changing the PFN inductance. Tentatively, 1.3% flatness was obtained. Another adjustment led to a flatness corresponding to a phase variation of 2.6 degrees. Fig. 5 shows photos of the test hall. Fig. 6 shows various waveforms. A resonant ring test of an RF window up to a forward travelling wave of 160 MW was performed in March, 2003, which confirmed the high-power capability of a mixed-mode RF window. A high-power test of SiC dummy load up to 43 MW was successfully conducted in June, 2003 [2].

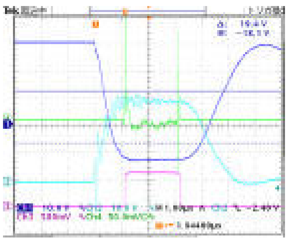

Figure 6 Wave forms; Voltage pulse (top), Phase (second), current (third) and output rf(bottom). Horizontal scale is 1µs/div.

The high-power processing of a 1m-long accelerator guide was conducted from July to August of 2003. This processing was performed under a pattern determined by the program. Interlocks of the internal pressure and the VSWR were used to process the accelerator guide properly. Data, such as the processing history, the dark current and waveforms of the reflected power, were automatically saved to memory to be used for an the analysis of this processing. A vibration sensor to detect the arcing position in the guide was set and data was also

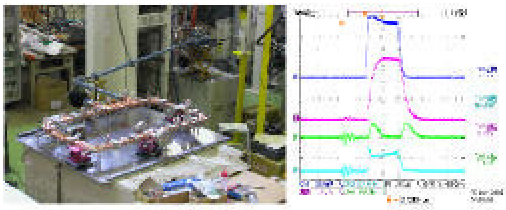

Figure 7 Resonant ring test and wave forms. Second waveform shows the forward travelling wave.

saved. Conditioning up to the 43.7 MW (corresponding to 42 MV/m) with 50 pps repetition and a 500 ns pulse width (this corresponds to the SLED power width) was successfully achieved with reasonable fault rate. Before installing to the beam line, phase shift measurements was performed to confirm no serious damage to the guide. Fig. 8 shows the processing history as a function of the pulse shot numbers. This accelerator guide was installed to the beam line of KEKB linac in September.

SUMMARY

The first test of the C-band accelerator unit, including the RF driving system, klystron, waveguide components and 1m- long accelerator guide, was successfully performed for the linac upgrade of SuperKEKB. We installed an accelerator guide to the KEKB linac beam line, and are now waiting for beam acceleration. Conditioning of the system in the klystron gallery is scheduled from October 1, 2003, and an evaluation of beam acceleration will be conducted. At the same time, we will prepare a new test stand to test the next accelerator guide and an RF compressor. We have a plan to install two 2m-long accelerator guides fed by a 50-MW klystron or four 2m-long accelerator guides fed by two 50-MW klystrons in the #4-4 station of the klystron gallery. This will give us important C-band operation experience as well as an energy contribution to the KEKB operation.

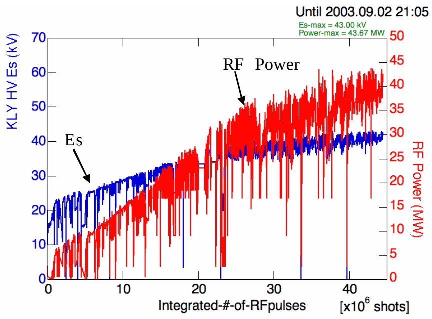

Figure 8 Processing history of accelerator guide with a function of shot numbers of rf pulse.

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