# DEVELOPMENT OF A C-BAND ACCELERATING MODULE FOR SUPERKEKB

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## *Abstract*

A C-band accelerating module has been constructed in KEKB/PF linac, and beam acceleration tests have been performed during 10-month operation. The purpose is to investigate C-band feasibility and stability of acceleration in the region beyond 40MV/m. The C-band accelerating module is expected to be promising for accelerating positrons up to 8GeV instead of 3.5GeV for both of the present KEK B-factory and SuperKEKB project in order to upgrade the luminosity. Last summer a 1m-long C-band accelerating section installed in the KEKB/PF linac. Accelerating field corresponding to 41 MV/m was successfully achieved in October in a beam test. Present status of C-band accelerator development is reported.

## INTRODUCTION

The KEK-B factory is making highest luminosities ($>1.3\times10^{34}$ cm$^{-1}$s$^{-1}$) in the world, where 3.5-GeV electrons and 8-GeV positrons are colliding. Toward higher luminosities a future project SuperKEKB is under consideration, of which target luminosities arise in the order of 1-5 $\times10^{35}$ cm$^{-1}$s$^{-1}$ [1]. In order to put into practice such a high goal, requirements to the injector linac should inevitably become severe for all values such as beam intensities, energies and emittances etc., as are listed in table 1. Some schemes of linac upgrade have been considered what should be improved to meet the requirements as well as possibility and feasibility, and consideration is still going on.

Table 1: Upgrade requirements

| | | KEKB | SuperKEKB |
|---|---|---|---|
| Beam energy | e+ | 3.5 GeV | 8.0 GeV |
| | e- | 8.0 GeV | 3.5 GeV |
| Stored current | e+ | 2.6 A | 4.1 A |
| | e- | 1.1 A | 9.4 A |
| Linac beam | e+ | 0.6 nC x 2 | 1.2 nC x 2 |
| | e- | 1.0 nC x 1 | 2.5 nC x 2 |
| Smaller emittance to fit IR&C-band structure aperture | | | |
| Faster e+/e- mode switching for continuous injection | | | |

Among the requirements, there has been a subject useful not only SuperKEKB but also for the KEKB. It is a plan to exchange energies of electrons and positrons: positrons become 8GeV instead of 3.5GeV, and electrons become 3.5GeV from 8GeV. The purpose is to avoid positron instability in the ring due to electron cloud, of which influence depends on the positron energy: higher the energy, smaller the effect. Therefore 8GeV positrons would be useful and desirable also for the KEKB instead of the present energy 3.5GeV. The requirement and importance of the beam seem to be growing, especially so under the present status in which beam intensities are still kept rising in both KEKB rings to increase luminosity.

Then exchange of energies would be more urgent issue that should be realized quickly, if possible, before the SuperKEKB project starts. It would have an important role to escape the influence of the electron cloud effect on positrons. Our strategy to get 8GeV positrons is basically simple [2].

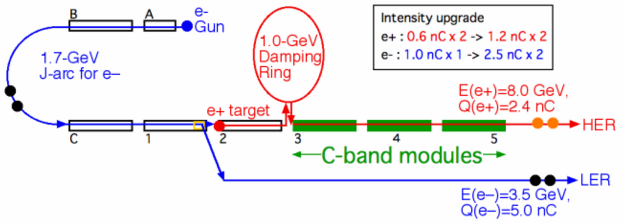
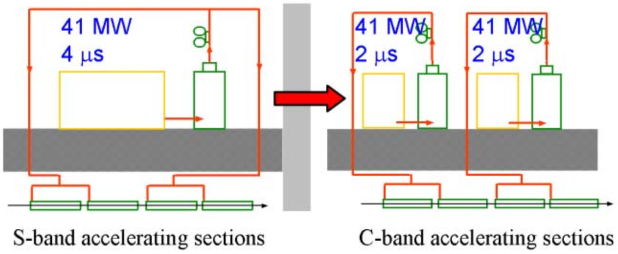


Figure 1: Layout of an upgrade scheme of the KEKB/PF linac

Presently positrons are produced at a production target which is installed halfway of the KEKB/PF linac, as is shown in Fig.1, and then accelerated up to 3.5 GeV in the following half of the linac. The most simple and feasible way to get 8-GeV positrons would be increasing the accelerating fields in the second half of the linac. This scheme is direct method and does not request any new buildings; however, the accelerating field strengths should be increased double from the present value of 21MV/m to 42 MV/m. How can we realise such a high accelerating field, that is the question to be solved. It is obvious that such a high field could not be obtained without increasing



S-band accelerating sections C-band accelerating sections

Figure 2: Layouts are showing how to replace accelerating modules from S-band to C-band.

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the accelerating frequency of S-band. Otherwise RF power of four times higher than the present value 41MW would be necessary. That would be impossible due to lack of powers of electricity and cooling water, and lack of space for the extra klystrons and modulators in the klystron gallery.

The only way we can take seems to be introducing a higher accelerating frequency instead of S-band. From the practical points of view, the frequency was automatically decided on C-band (5712MHz), of which accelerating structures could be expected to give apertures large enough for accelerating positrons with large emittances, at least, at high energy region. Furthermore a C-band klystron has been fortunately already developed, and is commercially available.

In order to achieve the average accelerating field of 42MV/m, it is not enough merely to replace accelerating structures to C-band ones, but also necessary to double the RF powers for each accelerating section This means that one accelerating module with a S-band klystron should be replaced, for instance as is shown in Fig. 2, with two C-band modules, each of which has a C-band klystron.

Outline of our energy upgrade is shown in Table 2: in the second half of the linac after the positron production target, most of the S-band Accelerating modules should be replaced by C-band ones, except for the beginning part following the target, where the positron beam emittance is still so large that the beam size is not small enough for accelerating in the C-band structures.

Table 2: Energy upgrade scheme with C-band accelerating sections

| | S-band section | C-band section | e+ energy gain |
|---|---|---|---|
| Acc. field | 21 MV/m | 42 MV/m | - |
| Present | 231 m | 0 | 4.8 GeV |
| upgrade | 46 m | 185 m | 8.0 GeV |

## DEVELOPMENT OF C-BAND MODULE

We decided in 2002 to start investigation of C-band accelerating structures how would be operational stability and reliability at accelerating fields as high as 42MV/m for both of KEKB and SuperKEKB. We started developing from April 2002 a C-band accelerating module to fine difficulties, if any, as quick as possible.

Although almost of all elements necessary for the C-band module should had been designed from the beginning except for the klystron, until July 2003 minimum elements, such as those listed in Table 3, had been prepared for making an acceleration test except for an RF pulse compressor [3]. Then after confirming high power performances in the test stand, we installed them in the KEKB/PF linac at the #44 unit where was empty and ready for C-band. The relevant main items that have been developed for C-band are listed in Table 3 with maximum values achieved in high power test operations. Most of the values exceeded successfully specifications.

Table 3: C-band R&D main items and maximum values achieved in test operations.

| Klystron E3746 | 43MW, 2μs, 50pps |
|---|---|
| Compact Modulator (1/3size) | 45kV, 2μs, 50pps |
| Sub-booster | 400W, 2μs, 50pps |
| RF window | 300MW, 2μs, 50pps |
| Accelerating section | 41MV/m, 0.5μs, 50pps |
| Dummy load | 100MW, 0.5μs, 50pps |
| 3-dB hybrid power divider | 200MW, 0.5μs, 50pps |
| Wave guide flange | 200MW, 0.5μs, 50pps |
| Pulse compressor, SKIP | 200MW, 0.5μs, 50pps |

*Accelerating Section*

A first prototype accelerating section of C-band was designed basically as a half size of the present 2-meter long S-band section that is used in the KEKB/PF linac [4]. Therefore it is 1m long with a quasi-constant field gradient. By comparing with S-band values, we could determine with confidence precise sizes of each cavity from a few test cavities

After RF processing of totally 300 hours, which was performed at the test stand with 0.5 μs RF pulses, the acceleration field reached to the level of 41.8 MV/m. Then the C-band accelerating section had been installed in the KEKB/PF linac in September 2003. RF power from a C-band klystron fed into a single 1m-long section during the first 10-month operation without a pulse compressor, which was still under investigation last year, but installed recently August 2004 [5].

After the 10-month operation at 50 pps with 0.5 μs RF, we opened and directly observed the couplers and aperture disks August 2004, and found that the input-coupler iris was discoloured at peripherals and there were many discharge spots especially at the aperture corner of the first disk. This observation is consistent with other measurements such as analyses using the reflection and transmission waves or acoustic sensors. It is obvious that the iris is the main source of discharges. In the second prototype accelerating section, the coupler structure will be changed so that it will have a thicker and wider iris without sharp edges in order to avoid discharge due to RF heating.

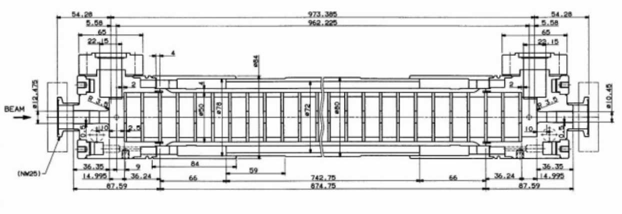

Figure 3: The first prototype 1m-long C-band accelerating structure.

### *Dummy Load*

A dummy load was developed for C-band based on the S-band one which is used in the KEKB/PF linac. The dummy load that consists of 13 pairs of SiC buttons have been tested up to 100 MW peak and 2 kW average powers.

Figure 4: Photograph of a dummy load for C-band.

### *First Acceleration Test*

During 10-month operation, the accelerating field strengths of the C-band section have been measured by analysing beam-energy gains as a function of the accelerating phase. A field gradient of 41.2 MV/m was achieved with the klystron output power of 43.8MW, which was almost our goal.

Figure 5: The first prototype 1m-long accelerating section installed in the beam line of the KEKB/PF linac.

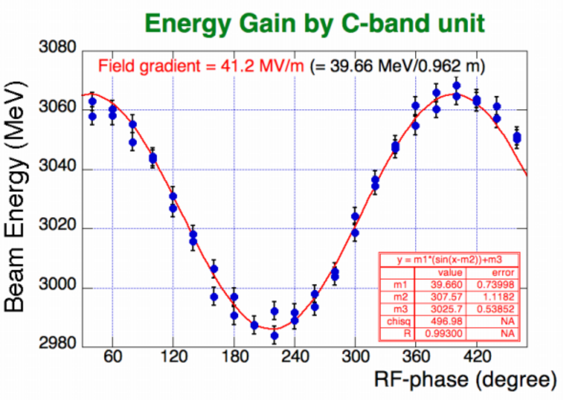

Figure 6: A result of beam acceleration.

### *Pulse Compressor （SKIP）*

We have manufactured this year a C-band pulse compressor “SKIP”, which stands for SuperKEKB Injector Pulse Compressor. After 170-hour RF processing, the peak output power attained 200 MW at a repetition rate of 50 pps for 43 MW input. SKIP has been installed in the C-band module in the linac for long time operation with beam acceleration.

Although SLED-type RF pulse compressors are used in the KEKB/PF linac, we adopted a different mode cavity for the C-band pulse compressor [5]. That is TE$_{038}$-mode used in the LIPS [6], because a Q factor much higher than100,000 is necessary to achieve the same field-multiplication factor as the S-band pulse compressors. This requirement comes from a difference of RF pulse lengths: C-band RF pulses have a half-length of the S-band. Although SKIP has many more nodes in the cavities than SLED, the C-band wavelength is half of S-band one. Therefore Mechanical sizes of SKIP become about the same as the S-band SLED.

Table 4: Comparison between KEKB-SLED and C-band SKIP

| | KEKB-SLED | C-band SKIP |
|---|---|---|
| Frequency | 2856 MHz | 5712 MHz |
| RF pulse length | 4.0 μs | 2.0 μs |
| Resonance mode | TE$_{015}$ | TE$_{038}$ |
| Length | 33.59 cm | 30.72 cm |
| Cavity diameter | 20.51 cm | 23.28 cm |
| Q value (Q$_o$) | 90,000 | 130,000 |
| Coupling | 6.4 | 6.6 |

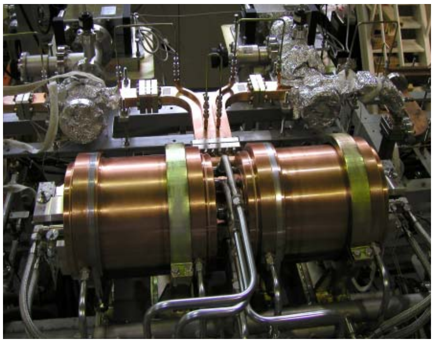

Figure 7: Photograph of SKIP at test stand.

## ACKNOWLEDGEMENT

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