C-BAND RF MAIN LINAC SYSTEM FOR e^+e^- LINEAR COLLIDER AT 500 GeV TO 1 TeV C.M. ENERGY

T. Shintake, N. Akasaka, K. Kubo, H. Matsumoto, S. Matsumoto, Shigeru Takeda,
K. Oide and K. Yokoya : *KEK Tsukuba Japan,*
P. Pearce : *CERN, Geneva, Switzerland*, H.S. Lee and M.H.Cho : *PAL, Pohang Korea,*
K. Watanabe : *Tohoku University,,* O.Takeda : *TOSHIBA Co*., H. Baba : *NIHON KOSHUHA Co.*

Abstract

A hardware R&D for the C-band (5712 MHz) rf system for a linear collider started in 1996 as a KEK research program. The first high-power test is scheduled for 1997. An accelerating gradient of 31 MV/m (including beam loading) will be generated by 50 MW C-band klystrons in combination with an rf-compression system. The klystron and its power supply can be fabricated by conventional technology. The straightness tolerance for the accelerating structures is 30 µm, which is also achievable with conventional fabrication processes. No critical new technology is required in a C-band system. Therefore, a reliable system can be constructed at low cost with a minimum of R&D studies.

1 INTRODUCTIONS

The e^+e^- linear collider is a large-scale machine. In the main linacs for two beams, we use more than 8000 accelerating structures, 4000 klystrons and pulse modulators. Therefore, the system must meet the followings demands:

(1) High reliability

To provide beams with reasonable availability, the system must be highly reliable; that is, the fault rate must be negligibly small and the lifetime of the key devices must be sufficiently long. To achieve this, we eliminate any critical parameter or excessive stress in the hardware components.

(2) Simple

For the same reason as (1), the system must be simple. This will also help to lower the construction cost and to make hardware maintenance easier.

(3) Lower construction cost

We should try to reduce the construction cost while not sacrificing the system performance and reliability.

(4) Reasonable power efficiency

We assume that the maximum limit on the whole wall-plug power in a site is 200 MW. To meet this requirement, the rf system must efficiently accelerate the beam. However, since an actual rf system needs axial power in addition to the wall-plug power to generate rf, we must optimize the total system, not a hardware piece only.

(5) Easy to operate

The machine operation should be easy. In the actual machine operation, the system must have flexibly to accelerate various pattern of the beam current. The tuning procedure must also be simple and easy.

The above list provides a guide-line and boundary conditions to our design work. Among the system parameters, the choice of the drive rf frequency plays the most important role concerning the system performance as well as the hardware details. We proposed the C-band frequency as being the best choice to meet all of the demands listed above[1,2]. The way that can we realize such a reliable system is described in this paper.

Discussions on a frequency scaling and parameter optimization among C- and X-bands are described in a ref. 3, in which it is shown that both the C- and X-band can achieve 1 TeV C.M. energy with sufficient beam-acceleration efficiency.

2 OVERALL PARAMETER

The overall parameter is listed in Table-I of ref.[3] for 500-GeV and 1-TeV C.M. energy linear colliders. In the 500-GeV case, an accelerating gradient of 31.9 MV/m is generated by a 50-MW klystron in combination with rf pulse compression; thus, an active length of 7.3 + 7.3 km is sufficient to reach 500 GeV C.M. energy. The gradient includes a beam lading effect, phase advance for a single-bunch energy slope and BNS-damping. A luminosity of 6.6 x 10^{33}/cm^2/sec can be obtained at a 100 pps repetition rate using a 150 MW wall-plug power.

3 SYSTEM DESCRIPTION

Figure 1 shows a schematic diagram of one unit in the main linac rf-system. Two 50 MW klystrons are driven by two high-voltage pulse modulators independently, followed by a 3dB hybrid power combiner and pulse compressor to generate 350 MW peak power, which drives four accelerating structures. The pulse-compression action is performed by rotating the phase of the input rf-signal in opposite directions in each klystron. By combining two powers at 3-dB hybrid, the phase modulation (PM) is converted to the amplitude modulation (AM) of the ramp-waveform, which compensates the beam loading effect in the accelerating structure. The energy-storage cavity consists of three coupled cavities using a low loss TE01n mode.

We use a standard rectangular waveguide: EIA187 (47.55mm x 22.15 mm, 3.95-5.85 GHz), whose attenuation constant is 0.03 dB/m (5% loss/8meter).

Figure 2 shows the important keys concerning the C-band, which make the system simple and reliable. Those keys are:

3.1 Klystron Power Supply & Pulse Transformer

The filling time of the accelerating structure scales as

$$t_F = \frac{2Q}{\omega}\tau \propto \omega^{-3/2}.$$

At the C-band, it becomes 280 nsec. Including the pulse-length of the beam and a compression factor of five in the rf-compression system, the rf-pulse at the klystron becomes 2.5 µsec. Including the rise- and fall-times, the pulse-length of the high-voltage applied to the electron-gun of the klystron becomes 3 µsec or longer, which is quite suitable to the conventional power-supply consisting from a PFN: Pulse Forming Network and a step-up pulse-transformer. This type of power supply has been used in many linear accelerators, owing to its high reliability and good efficiency.

To charge high voltage into the PFN capacitors, we use an inverter power supply. Such a high-voltage power supply has been widely used to drive pulsed lasers for a long time. Modern technology for power-semiconductor devices has improved the power efficiency by better than 95%. Using this power supply, we can simplify our modulator design, separating in module-to-module according to their functions: the inverter power supply (DC block), the PFN module (pulse forming block), and the pulse-transformer tank (matching block to a klystron). It becomes easier to reduce the cost, improve the reliability and ease maintenance. In the case of a failure, we simply replace any broken block with a new one and send the old one to a factory for repair.

3.2 C-band Klystron

Since the drift-tube diameter is proportional to the rf wavelength, we can use an electron beam with a larger diameter than higher frequency bands. It also makes it easier to design an electron gun with a larger cathode to extract a higher beam current. Therefore, we can design the beam voltage as low as 350 kV, which enables the PFN voltage as low as 43 kV. At this voltage level, it is easy to obtain suitable PFN-capacitors from various company products.

3.3 RF Pulse Compressor[4]

We use a three-cell coupled-cavity pulse-compressor instead of a delay-line type pulse-compressor. The cavity is compact, having a length of 800 mm, and its diameter is 160 mm. Therefore, it will be easier to fabricate at lower cost. A computer-simulation code was made to simulate the time response of the coupled-cavity system, which has shown a maximum efficiency as high as 70%. The details are reported in ref. 4.

3.4 PM-to-AM Modulation[4]

If we simply flip the input rf-phase for pulse compression, it emits a sharp-peaked triangle waveform followed by a large amplitude swing for one-cycle. To make a flat pulse, we apply AM modulation on the input rf wave. In our system, we keep the input rf level constant, but control the phase and combine the rf-power from two klystrons by a 3dB hybrid combiner. By rotating the phase into the opposite direction to each other, the phase modulation (PM) is converted to amplitude modulation(AM). The vector sum goes to the pulse compressor, and the vector difference (quadrature component) goes to a dummy load attached to the hybrid.

3.5 Accelerating Structure[5]

We use a choke-mode cavity structure, in which all of the higher-order modes are heavily damped. Therefore, the multi-bunch wakefield and any associated instability will not harm the beam emittance. The only concern is the single-bunch emittance dilution due to the short-range wake-field, which is a strong function of the iris aperture. We use relatively large iris-aperture: average <2a>=16 mm. As a results, the straightness tolerance for one structure becomes 30 µm or larger. This is a controllable level in conventional fabrication techniques of the disk-loaded structure. To eliminate any stress and make the structure further straight, a low temperature brazing technique will be adopted[6]

To align the structure with beam, we use an RF-BPM attached to the structure[7]. This type of RF-BPM was tested using the FFTB beam line at SLAC in December 1995[8]. It demonstrated a very high resolution of 44 nm for a single bunch. Three RF-BPM were assembled in one block, and the misalignment between them was measured with electron beam. It was only 3 µm. This is a quite promising result for a structure-alignment procedure.

The dark-current problem due to a field-emission under the high accelerating gradient has been studied using computer simulations[9]. From which, no serious contributions to the background in the detector at IP is expected at C-band frequency.

4 HARDWARE R&D PROGRAM

In January, 1996, the hardware R&D has been started as a KEK research program. In 1997-1998, we will construct one unit of rf-system. Since we use one klystron, the input rf will be directly AM modulated to demonstrate the flat-top output from the compressor. The first klystron tube will be available in 1997.

REFERENCES

[1] JLC Group, "JLC-I", KEK Report 92 - 16, December 1992, A/H/M

[2] T. Shintake, *et al.*, "C-Band Linac RF-System for e^+e^- Linear Collider", Proc. 1995 Particle Accelerator Conf. and Int. Conf. on High-energy Accelerators, May, 1995, Dallas, Texas, U.S.A., KEK Preprint 95-49

[3] K. Oide, *et al.*, "C-band Linear Collider with C.M. Energy 500 GeV to 1 TeV", presented at this conference.

[4] T. Shintake and N. Akasaka, "A New RF Pulse-Compressor using Multi-Cell Coupled-Cavity System", presented at this conference.

[5] H. Matsumoto, et al., "C-band Choke-Mode Accelerating Structure for the Linear Collider", presented at this conference.

T. Shintake, *et al.*, "HOM Free Linear Accelerating Structure for e+e- Linear Collider at C-band", Proc. 1995 Particle Accelerator Conf. and Int. Conf. on High-energy Accelerators, May, 1995, Dallas, Texas, U.S.A., KEK Preprint 95-48

[6] H. Matsumoto, *et al.*, "Low Temperature Brazing Technique for the Accelerators", presented to this conference.

[7] K. Kubo, *et al.*, "Alignment Issue for C-band Linear Collider", presented to this conference.

[8] The experimental results on RF-BPM will be published soon.

[9] N. Akasaka, "Dark Current Simulation in High Gradient Accelerating Structure", presented to this conference.

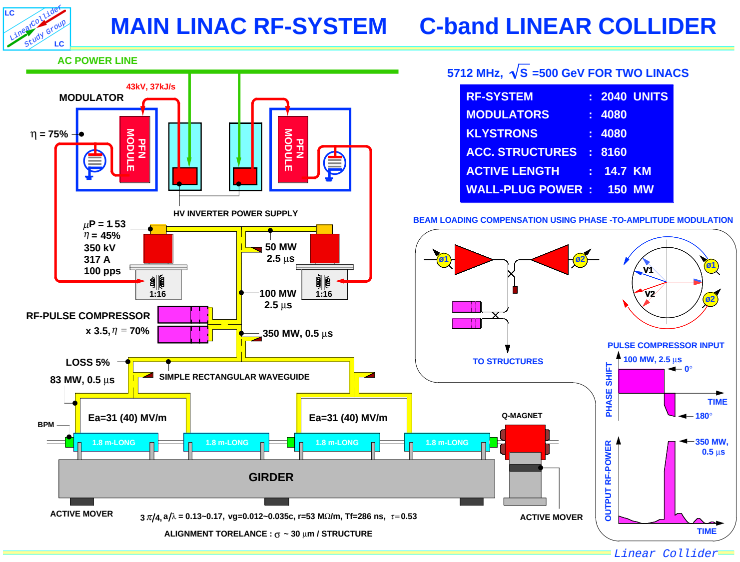

Fig. 1 One unit of the C-band RF system.

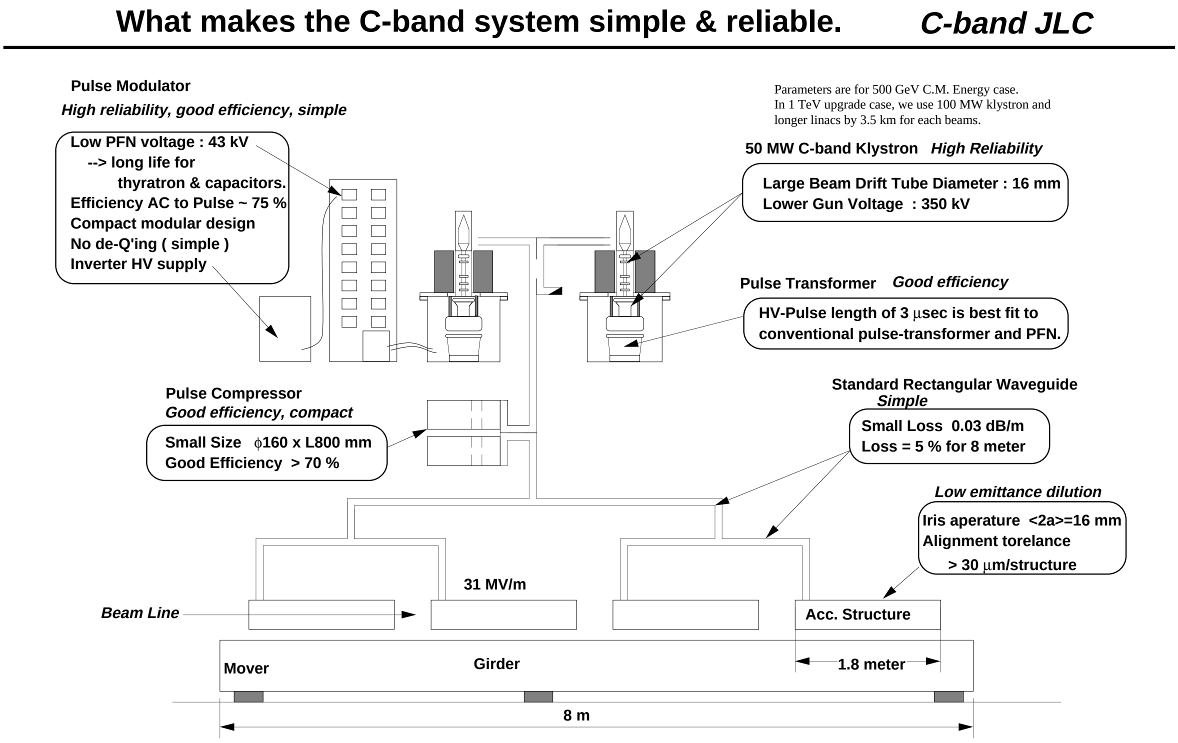

Fig. 2 What makes the C-band system simple and reliable. The key points in the C-band rf-system.