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C-band(5712 MHz) RF-System R&D Status

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Abstract A hardware R&D on the C-band (5712 MHz) rf system for the electron/positoron linear collider started in 1996 at KEK. R&Ds are running to develop a C-band 50 MW klystron, a vacuum-tight high-power waveguide system, an RF pulse compressor and a HOM free accelerating structure. In July 1997, the traveling-wave resonator, which is the first high-power device at C-band frequency, has been commissioned. The circulating power reached 90 MW and 2.5 μsec, which is enough energy to test the newly developed RF window. A 50 MW klystron was fabricated at Toshiba co., which is named E3746 and will be tested in August 1997. This paper will review our R&D activities.

1. Introduction

An 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 their pulse modulators. Therefore, the system must meet the following demands:

(1) High reliability,
(2) Simple,
(3) Lower construction cost,
(4) Reasonable power efficiency,
(5) Easy to operate.

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. System Description

Figure 1 shows a schematic diagram of one unit in the main linac rf-system [1]. We need 2040 units in the actual linear collider at 500 GeV c.m. energy. Two 50 MW klystrons are driven by two high-voltage pulse modulators independently, followed by a 3 dB 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 rf powers at 3 dB hybrid, the phase modulation (PM) is converted to the amplitude modulation (AM) of the ramp-wave form, which compensates the beam loading effect in the accelerating structure. The accelerating structure is the choke-mode cavity type, which strongly damps all of the HOMs (Higher Order Modes) to avoid multi-bunch beam instability in the long linac.

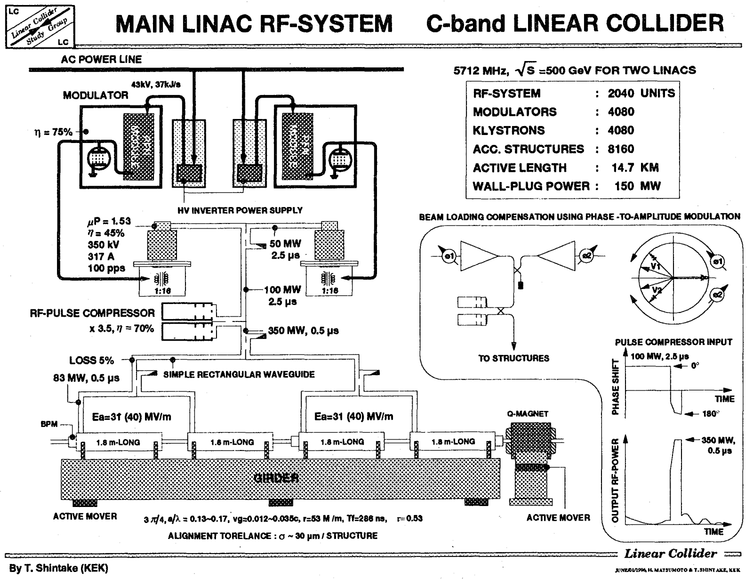

Fig. 1 One unit of the C-band RF system.

3. Hardware R&D Program

3.1 Waveguide Components

First of all we need the waveguide components to do any R&D studies at a new RF frequency. When we started this project at the C-band frequency, no high power waveguide components (vacuum tight) were commercially available. We developed new waveguide components, which is designed to stand for a very high peak power (a few hundred MW), and can be used in ultra-high vacuum condition. To meet these demands, a new type unisex waveguide flange, named MO-flange (Matsumoto-Ohtsuka type) has been developed to increase reliability and reduce cost [2].

At the C-band frequency, there are two choices for cross sectional dimension of the waveguide, that is, EIA-WR187 or EIA-WR159. To minimize Joule loss and reduce phase variation sensitivity due to thermal expansion, we choose the lower band size : EIA-WR187 (3.95-5.85 GHz). The theoretical rf transmission loss is –0.032 dB/m. This is comparable attenuation in the conventional S-band waveguide (–0.021 dB/m at 2856 MHz). The raw material is the OFHC (Oxide-Free High Conductivity) copper with a purity of >99.96%.

3.2 RF Window

To improve reliability of the ceramic rf-window (usually rf-window is one of the weakest point in an rf-system), a new rf-window was developed. It uses a simple long-pillbox housing to hold a ceramic disk in its center. The length and diameter of the pillbox was chosen to minimize the electric field on the ceramic surface, at the same time maximize the pass-band. We use an alumina-ceramic disk of 57 mm in diameter and 3.85 mm thickness. Since the electrical length inside the ceramic disk is chosen to a quarter wavelength, the reflections due to the machining errors are cancel-out. Therefore, this design has a large tolerance in mechanical dimensions.

Three windows were fabricated for the newly developed 50 MW klystron. During the tuning process of the fabricated window, the pillbox length was machined step-by-step with measuring VSWR. It was found that the dimension tolerance of the pillbox length was as large as 0.8 mm to keep the VSWR better than 1.05.

The high-power performance will be tested in the traveling wave resonator soon.

3.3 Traveling Wave Resonator (TWR)

To test the rf-window and waveguide components, a traveling wave resonator (TWR) was developed. TWR is composed of a directional coupler, a phase-shifter, a stub-tuner, an rf power monitor using Bethe-hole coupler, a vacuum pumping port, a viewing port, 90-degree E- and H-corners, all of them were newly developed in this R&D project.

The TWR operation was commissioned in July 1997. To drive TWR, we use a 5 MW C-band klystron (TH2067, 5 MW, 5710 MHz). Currently, the peak power reached to 90 MW with 2.5 μsec, this is enough energy to test the rf-window. The measured power gain was 18.1, which is good agreement with the design value of 18.8. The rf processing was progressed smoothly without any difficulties due to HV breakdown or gas desorbtions. Figure 2 shows a typical waveform of the circulating rf power. The demonstrated nicely flat waveform is promising the high feasible feature of C-band technologies toward the next generation of the pulsed-power RF-systems.

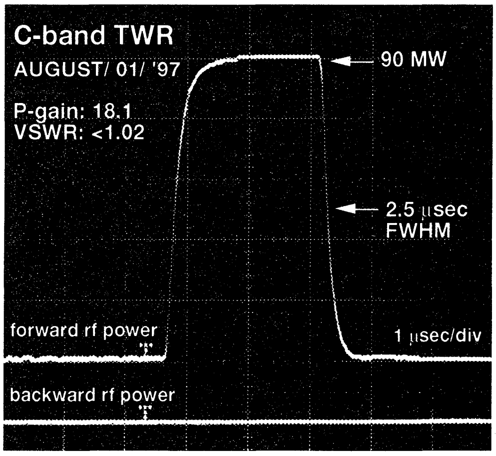

Figure 2. The circulating rf-power in the TWR.

3.4 C-band Klystron E3746 R&D

In order to ensure a high reliability in the C-band klystron, we designed the main parameter by frequency-scaling from existing S-band klystrons. We referred mainly two klystrons, Toshiba E3712-klystron (80 MW, 375 kV) and SLAC 5045-klystron (50 MW, 350 kV). We assumed the power handling capability will be scaled as

$$VI\tau \propto D^2 \propto \omega^{-2}$$

This is coming from a safety limit of the beam-power density in the drift-tube. From the operational experience in S-band klystrons, we found the safety beam-power at C-band will be 300~400 Joule/pulse. Considering the requested HV pulse length of 3.5 μsec, and assuming the power conversion efficiency as 45 %, we decided the target value of the output to be 50 MW. The electron gun voltage was determined to be 350 kV after optimizing the beam perveance and the surface electric field on the cathode and anode electrodes.

Design work on the interaction region was done by FCI-code. The designed klystron (named Toshiba E3746) uses five cavities, 1st and 2nd cavities are conventional reentrant-type cavity, 3rd and 4th (penultimate) use the nose-less pillbox cavity. The output structure is a single gap design, connected with two output waveguides, followed by two rf-windows in parallel, then two arms are combined to one output. FCI-code predicted the saturated output power will be 49.1 MW and the power efficiency 44.3 %. The design details are described in ref. [3]. The klystron will be tested in August 1997.

The No.2 tube of E3746 is under design, which will use a traveling-wave output structure to improve the power efficiency and lowering the surface electric field gradient.

3.5 Klystron Power Supply

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. By including the beam pulse and a compression factor of five in the rf pulse compressor, the rf-pulse at the klystron becomes 2.5 μsec. Including the rise- and fall-times, the pulse-length of the high-voltage at the klystron becomes 3 μsec, or slightly longer. To generate this pulse, we decided to use a conventional power-supply consisting of a Pulse Forming Network (PFN), a thyratron switching tube and a step-up pulse-transformer.

To charge a high voltage into the PFN capacitors, we use an inverter power supply. Merits to use this type of power supply are compact design, lower stored energy, good regulation (we do not need de-Qing circuit), command charging capability, and tightly interlocked.

The efficiency issue in C-band klystron modulator system was studied by J. S. Oh in 1996 [4]. Especially, the pulse efficiency (flat-top energy per total energy in the output pulse) was carefully studied, since it mainly limits the overall power efficiency in the modulator. The pulse transformer was modeled by an equivalent circuit, and the entire circuit of the pulse modulator was modeled using PSPICE code. According to the study, our klystron and modulator system can achieve power efficiency of 24 % using existing standard circuit components. This includes 45 % klystron efficiency, 85 % DC high voltage charging efficiency of the inverter power supply, and 70 % pulse efficiency using a transformer of step-up ratio 1 : 15 (we use a Stangenes transformer designed for SLAC 5045 klystron), and auxiliary powers for thyratron heater, klystron heater, focusing magnet, pulse transformer core-bias current, and etc.

3.6 RF Pulse Compressor

In order to accelerate the multi-bunch beam in the linear collider, we need a flat-pulse power from the rf pulse compressor. Additionally, to compensate the beam loading effect for various beam parameters, it must be capable of generating arbitrary waveforms.

To do this, we proposed a coupled-cavity pulse compressor with PM-AM modulation in 1996 [5]. We use a three-cell coupled-cavity pulse-compressor instead of a delay-line type such as used in the SLAC-NLCTA.

A cold model was fabricated and tested with a low power rf signal. The cavity is compact, having a length of 1 m, and its diameter is 160 mm. There was no difficulty in its fabrication. Figure 3 shows the waveform of the compressed rf signal from the cold model. Generation of a flat output pulse was well demonstrated. The power gain of 3.25 was achieved, which is 94% of the design value. The detailed discussions are given in ref. [6].

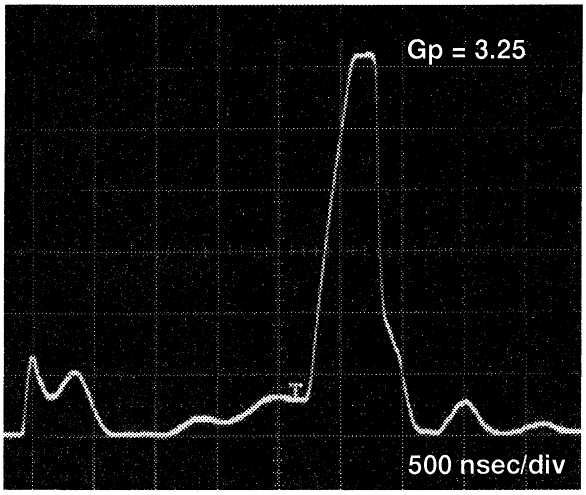

Fig. 3 Compressed RF output pulse (cold model test).

3.7 Accelerating Structure

We use a choke-mode cavity structure [7], in which all of the higher-order modes are strongly 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 result, the straightness tolerance for one structure becomes 30 μm or larger. This is a controllable value in conventional fabrication techniques of the disk-loaded structure. The first accelerating structure of this type at C-band will be fabricated in this year, and its HOM performance will be tested using intense electron/positron bunches in the ASSET facility at SLAC in May 1998.

3.8 High Resolution RF-BPM

To align the structure with beam, we use an RF-BPM attached to the accelerating structure. The RF voltage from TM110-mode provides very sensitive position information. This type of RF-BPM was tested using the FFTB beam line at SLAC in December 1995 and May 1996. The measured position resolution was 25 nm, this is much better resolution than any other BPMs about 2-decade magnitude. The misalignment between BPMs was only 3 μm. This is a quite promising result for a structure-alignment technique.

3.9 Miscellaneous R&Ds

We also keep running the following hardware R&Ds in the C-band project.
(1) Low temperature brazing R&D [8].
(2) Cooling water system study [9].

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