C-BAND RF-SYSTEM DEVELOPMENT FOR e^+e^- LINEAR COLLIDER

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Abstract

Hardware R&D on the C-band (5712 MHz) RF-system for an electron/positron linear collider started in 1996 at KEK. During two years R&D, we have developed a 50-MW C-band klystron (TOSHIBA E3746), a "Smart Modulator", a traveling-wave resonator (TWR) and a cold model of the rf-pulse compressor [1]. A C-band accelerating structure, which uses the choke-mode cavity, is under development. Its HOM damping performance will be tested using short-bunch beams of ASSET beam-line at SLAC in this year. The C-band system is able to accelerate a high-current beam at an accelerating gradient higher than that in a conventional S-band system, therefore, there will be various applications in the future beside the linear collider. For example, we can build an injector for a SR-ring and for various physics experiments within a short site-length. Additionally, since the C-band components are compact, it has a big potentiality to be widely used in various medical and industrial applications, such as an electron-beam radiotherapy machine, or a compact non-destructive X-ray imaging system.

1 INTRODUCTION

An e^+e^- linear collider is a large-scale machine. In the main linac for two beams, we use more than 7000 accelerating structures, 3500 klystrons and their pulse modulators. Therefore, we have to develop the hardware as to meet the following demands:

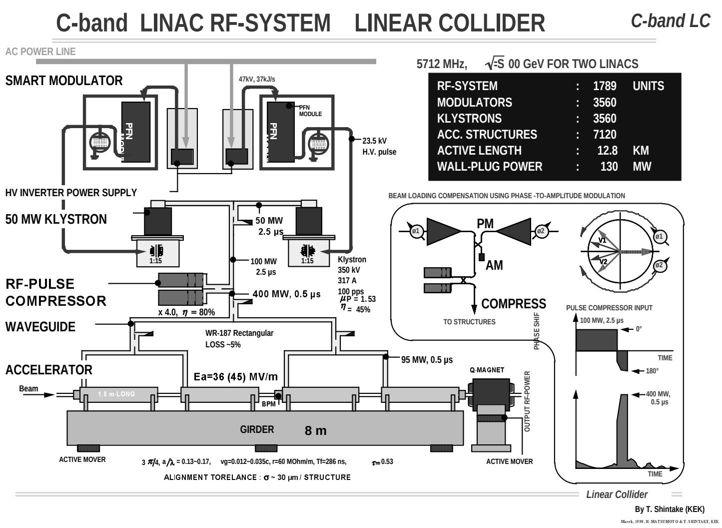

Fig. 1 One unit of the C-band RF system.

(1) High reliability,
(2) Simplicity,
(3) Lower construction cost,
(4) Reasonable power efficiency and
(5) Operational ease.

The above list provides a guideline 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 [2].

2 SYSTEM DESCRIPTION

Figure 1 shows a schematic diagram of one unit in the main linac rf-system. The accelerating gradient in ref. [2] was 32 MV/m. It is now 36 MV/m, which has been increased by a new idea concerning the RF pulse compressor (see later) and improved shunt impedance in the accelerating structure. The required number of unit for 500 GeV c.m. energy becomes about 1800 units (it was 2040 units).

In one unit of the RF-system, 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 400-MW peak power, which drives four accelerating structures. An accelerating gradient of 36 MV/m will be generated, with a beam loading.

3 PROGRESS IN HARDWARE R&D

3.1 Waveguide Components

At the beginning of the C-band R&D, a new-type unisex waveguide flange, named MO-flange (Matsumoto-Ohtsuka type) was developed. It ensures a high reliability and reduces production cost [3]. The waveguide size is EIA-WR187 (3.95-5.85 GHz). All of the required component such as a hybrid coupler, a 90 degree corner, a monitor *etc.* were newly developed. Figure 2 shows an example (a directional coupler).

3.2 TWR: Traveling-Wave Resonator (Resonant Ring)

To test the rf-window and waveguide components, a traveling-wave resonator (TWR)

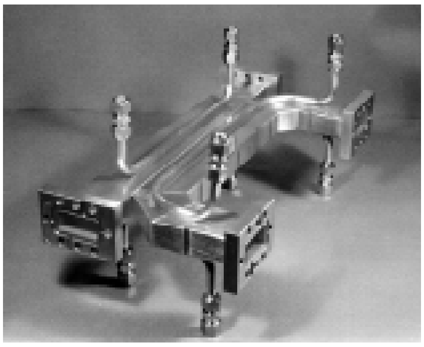

Fig. 2 C-band vacumme-tight high-power waveguide component (a directional coupler).

was developed. The TWR operation was commissioned in July 1997. To drive the TWR, we use a 5-MW C-band klystron (TH2067, 5 MW, 5710 MHz). After one week processing, the peak power reached 90 MW at 2.4 μsec pulse-width; this is enough power to test the rf-window. The measured power gain was 18.1, which is in good agreement with the design value of 18.8.

3.3 RF Pulse Compressor

A new type RF pulse compressor has been proposed by the authors in 1996 [4]. It applies AM modulation on the input RF power in order to obtain a flat pulse from the pulse compressor. To enhance the power efficiency, we use a three-cell coupled-cavity as an energy storage.

In 1997, we demonstrated generation of a flat pulse by a cold model cavity. Using a low power test signal, the flat pulse was generated as shown in Fig. 3. The energy gain of 3.25 was obtained. It corresponds to the power efficiency of 65%.

In order to improve the power efficiency, we started to study a new idea, which uses a front part of the modulator pulse. The phase slip due to the voltage variation in a klystron can be compensated by a phase modulator at the RF input to the klystron. A computer simulation predicted that it will be possible to obtain a power gain of 4.0 or even higher in C-band system.

To do this, we need an rf feedback module, which consists of a vector rf detector with IQ-demodulation, a vector rf modulator and a microprocessor to compute feedback corrections. Additionally, a solid-state rf driver is required to drive a klystron at 500 W level. It must be compact, minimum phase walk and low cost. A pulsed-class-A amplifier will be suitable for this purpose. R&D to develop those components will be started in 1998.

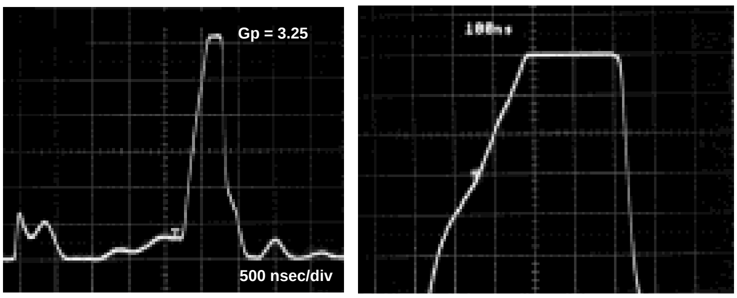

Fig. 3 Output pulse of C-band RF compressor and the magnified view of the flat top.

3.4 C-band Klystron R&D

Figure 4 shows the newly developed C-band klystron: TOSHIBA E3746 #1. It is the first high-power klystron at C-band for accelerator applications. E3746 #1 is a five cavity klystron, using a single-gap output structure and solenoid focus. The design details are described in ref. [6].

Figure 5 shows the output power at 46 MW peak and 2.5 μsec width. The tested maximum pulse repetition rate is 50 pps. The tested maximum output power is 50 MW, which is the target value required for the 500 GeV linear collider. The test results are described in ref. [7].

In klystron designs, we currently use the FCI-code (a particle-in-cell simulation code) to optimize the impedance of the interaction cavities [8]. The measured output power in the high-power test was lower than a prediction of the FCI by 3% only.

The No.2 tube of the E3746 klystron is under development, which uses a traveling-wave output structure to improve the power efficiency and to lower the surface electric-field gradient. A power efficiency of 48% is expected. It will be tested soon.

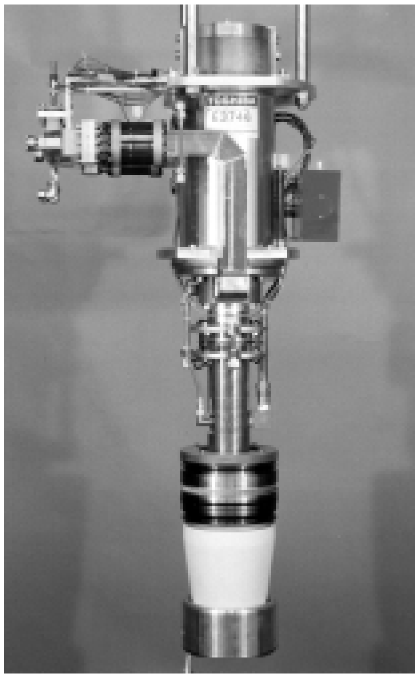

Fig. 4 The first high-power C-band klystron: TOSHIBA E3746 #1.

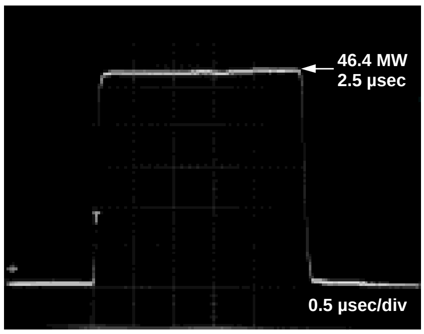

Fig. 5 RF output power from the first tube of E3746 C-band klystron.

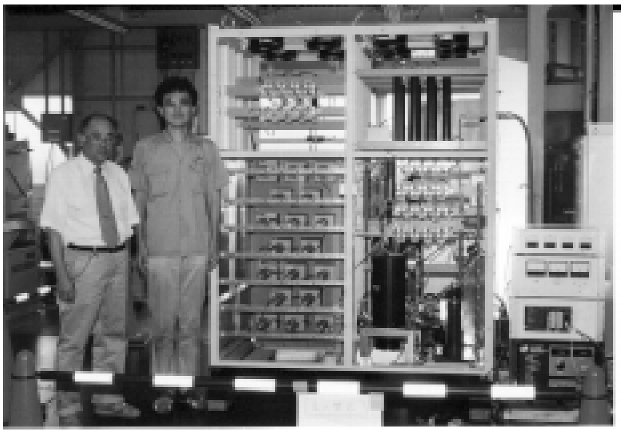

Fig. 6 The first model of the smart modulator developed at NIHON KOSUHA Ltd.

3.5 Smart Modulator (Klystron Power Supply)

The modulator power-supply (HV-pulse power supply for klystron) is one of the most expensive parts in the rf-system for the electron accelerator. It is sometimes the most unreliable and troublesome device, and occupies a large volume. Therefore, to develop an improved modulator will be a quite important R&D for the linear collider as well as for various scientific and industrial applications.

In 1993, Prof. M. H. Cho and Prof. H. Matsumoto proposed a concept of "Smart Modulator", which is an ideal modulator: simple, compact, reliable and low cost. As the first step toward the smart modulator, we developed the first model to demonstrate the high potentiality of the inverter power supply. The key points in the first model are:

1. Direct HV charging from an inverter power supply.
2. No deQ-ing circuit.
3. Much smaller size than conventional modulators.
4. Uses existing reliable circuit components.

The developed smart-modulator is shown in Fig. 6. The main cabinet size is 1600(W) x 2000(H) x 1200(D) only. The design details are described in separate papers [7,9,10,11].

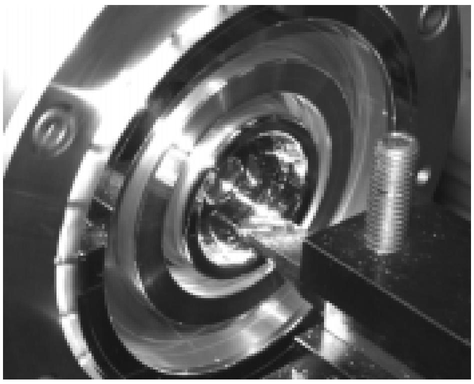

Fig. 7 A copper disk on a precision turning lathe. The main cavity part is machined with mirror surface using a diamond tip in order to maintain a high accelerating field. The choke-slot is sufficient with a standard machining. From center to outside: the beam hole, the main cavity, the choke-slot and a room for the HOM absorber (SiC ring).

3.6 Accelerating Structure

A C-band accelerating structure is under development at MITSUBISHI heavy industry. It uses a special rf cavity called the choke-mode cavity[13], which strongly damps all higher-order-modes using microwave absorbers made by SiC. The rf power for the beam acceleration is kept within the main cavity by means of a choke-filter. Figure 7 shows a copper cell under machining. After tuning the frequency, ring-shaped SiCs will be mounted, then total number of 91 cells will be assembled into one-unit by means of the electro-plating technique. The HOM damping performance will be tested at ASSET beam line of SLAC in this year.

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