RESULTS FROM HARDWARE R&D ON C-BAND RF-SYSTEM FOR e^+e^- LINEAR COLLIDER

T. Shintake, N. Akasaka and H. Matsumoto, KEK, 1-1 Oho, Tsukuba, 305 Japan
J.-S. Oh, PAL POSTECH, Pohang, Kyungbuk, 790-600, Republic of Korea
M. Yoshida, ICEPP, University of Tokyo, Tokyo, Japan
K. Watanabe, Tohoku University, Sendai, 982 Japan
Y. Ohkubo, H. Yonezawa, TOSHIBA Co., Tokyo, Japan
H. Baba, NIHON KOSHUHA Co., Ltd., 1119 Nakayama, Yokohama, 226 Japan

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 two 50-MW C-band klystrons (TOSHIBA E3746 #1, #2), the "Smart Modulator", the traveling-wave resonator (TWR) and the cold model of the rf-pulse compressor [1,2]. A C-band accelerating structure, which uses the choke-mode cavity, is under development. Its HOM-damping performance will be tested at ASSET beam-line in this year. Since the C-band system is designed to accelerate high-current beams at a high accelerating gradient of 36 MV/m, there are various applications in the future beside the linear collider. For example, we can build an injector for the SR-ring in a limited 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

The e^+e^- linear collider is a large-scale project. In the main linac for two beams, we need more than 7000 accelerating structures, 3500 klystrons and their pulse modulators. Therefore, the hardware has to meet the followings:

(1) Highly reliable,
(2) Simple,
(3) Low construction cost,
(4) Reasonably power efficient and
(5) Operationally ease.

The above list provides a guideline and boundary conditions to our R&D works. Among the system parameters, the choice of the drive rf-frequency plays the most important role concerning to the system performance as well as the hardware details. We proposed the C-band frequency as 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. The deigned value of the accelerating gradient in ref. [1] 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 was reduced to 1800 units (it was 2040 units).

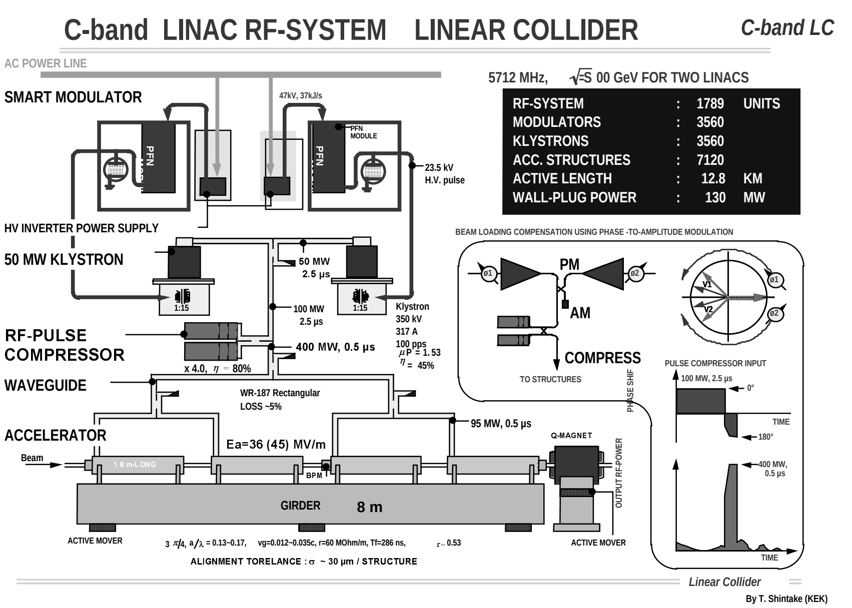

Fig. 1 One unit of the C-band RF system.

3 PROGRESS ON HARDWARE R&D

3.1 Waveguide Components

Since this is the first project to use the C-band frequency as the beam acceleration, no high-power waveguide component of vacuum-tight design was available in the market. We newly developed various waveguide components, including a ceramic window, at EIA-WR187 size (Fig.2). [3] We assembled a traveling-wave resonator (TWR), and tested it up to 90 MW of the accumulated power with 2.4 µsec pulse-width. No difficulty concerning to the high-power operation was found at this power level.

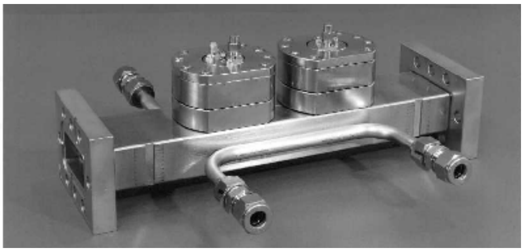

Fig.2 C-band waveguide component (Bethe holecoupler).

3.2 RF Pulse Compressor

The authors have proposed a new type RF pulse compressor in 1996 [4]. It can generate a flat output pulse from an energy-storage cavity of 1 meter long. It eliminated the long pipes required in SLED-II type compressor. To compensate ringing response associated with the multi-cell coupled cavity, the amplitude modulation is applied on the input RF power. In 1997, we demonstrated generation of a flat pulse using a cold model pulse-compressor cavity (Fig. 3, Fig. 4). The energy gain of 3.25 was obtained [5].

To improve the power gain, we started a study on a new idea: recovering rf-energy from the front part of the modulator pulse. A phase modulator is used to compensate a phase slip in the klystron. Since the pulse-compression cavity acts as the energy storage, the rf-energy in the front part is accumulated and contributes to the output energy.

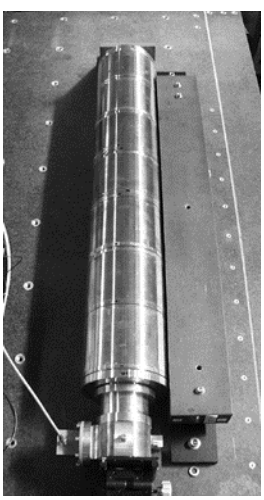

Fig. 3 Three-cell pulse compression cavity.

A tentative test showed enhancement of the power gain of 1.3 [6]. To apply this idea in the practical accelerators, we need to develop a RF feedback module (IQ-modulator and demodulator, a microprocessor and a solid-state RF amplifier of 500 W output level). This RF feedback module will be also useful in various accelerators to compensate the beam loading effects, such as in a beam buncher system or a rf-gun to generate a stable beam into FEL oscillators.

3.3 C-band Klystron R&D

In 1996 FY, we developed the first tube E3746 #1, which employed conventional design: the single-gap output structure and the solenoid focus. It generated 50 MW power into 1 μsec width at 20 pps repetition [7,8]. We continuously operated the klystron at C-band test-lab until the second tube being ready.

In 1997 FY, we developed the second tube E3746 #2. This is an upgrade version of the first klystron, in which the single-gap output structure was replaced with a newly developed 3-cell traveling-wave output structure shown in Fig. 5. The second tube generated 54 MW peak power in

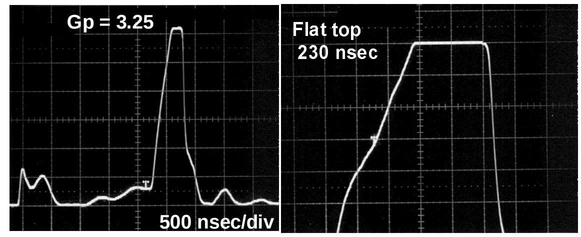

Fig. 4 Flat-top rf pulse compression using 1-m long 3-cell delay-line.

2.5 μsec at 50 pps. The power efficiency was improved to 44%. Fig. 6 shows the output waveform from the second klystron. Details are reported at this conference [9].

Recently we have developed an advanced calorimetric method for the absolute rf-power measurement. To eliminate uncertainty in flow-rate measurement of cooling water, we introduced an electric heater in the cooling water system. Since we can accurately determine the dissipation power on the heater by VI product, this method enables to determine the absolute power accurately.

3.4 Smart Modulator (Klystron Power Supply)

The C-band klystron uses a high-voltage pulse of –350 kV peak and 3.5 μsec width. The conventional PFN line-type pulse-modulator is suitable to generate this pulse, and no essential difficulties are expected. Therefore, R&D work was focused on reducing cost and improving reliability. In 1993, Prof. M. H. Cho and Prof. H.

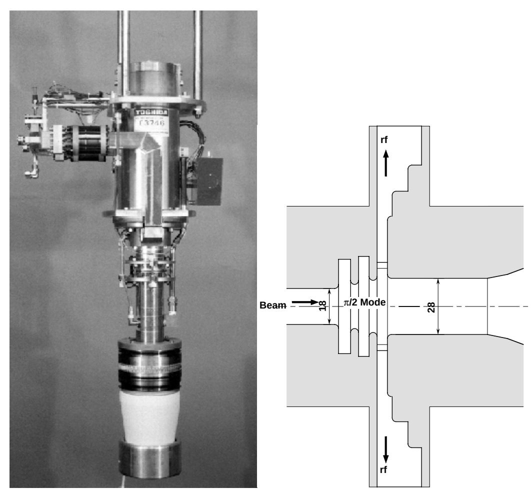

Fig. 5 The C-band klystron: TOSHIBA E3746 #2, and its traveling-wave output structure..

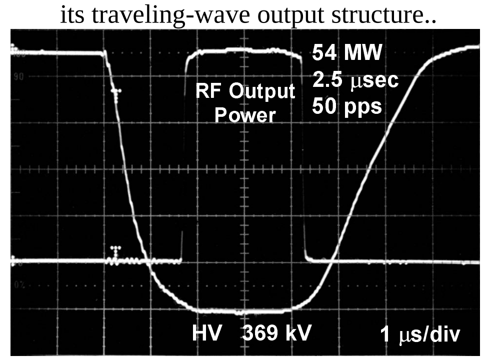

Fig. 6 RF output power of the second E3746 C-band klystron.

Matsumoto proposed a concept of "Smart Modulator", which is an ideal modulator: simple, compact, reliable and low cost. As the first step, we developed a prototype of the smart modulator, which is

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. 7. The main cabinet size is 1600x2000x1200 mm only, which is now running daily driving the 50 MW klystron [10,11,12].

Fig. 7. The smart-modulator (white box at upper-right), the C-band klystron (middle), and the C-band members.

3.5 Accelerating Structure

A C-band accelerating structure is under development at MITSUBISHI heavy industry [13]. It uses a special rf cavity called the choke-mode cavity, which strongly damps all higher-order-modes using microwave absorbers made by SiC [14]. The rf power for the beam acceleration is confined in the main cavity by means of a choke-filter. Figure 8 shows the structure under fabrication. It uses Matsumoto-coupler for symmetric field at input/output coupler. To align beams on its center, two RF-BPMs will be mounted at both ends, and one HOM pickup will be used at middile. The basic performance of the RF-BPM was tested at FFTB-beam line, and 25 nm of resolution was measured [15]. The RF-BPM in Fig. 8 is the upgraded version, which does not have the common-mode leakage. The HOM damping performance will be tested at ASSET beam line of SLAC in this year.

4 FUTURE R&D

The first stage of the R&D was successful. For the next step, in order to examine the system performance under a realistic situation, one-unit of the C-band system has to be installed and tested with beam in an existing machine, such as KEK-B injector. Daily operation will tell us what we should do next.

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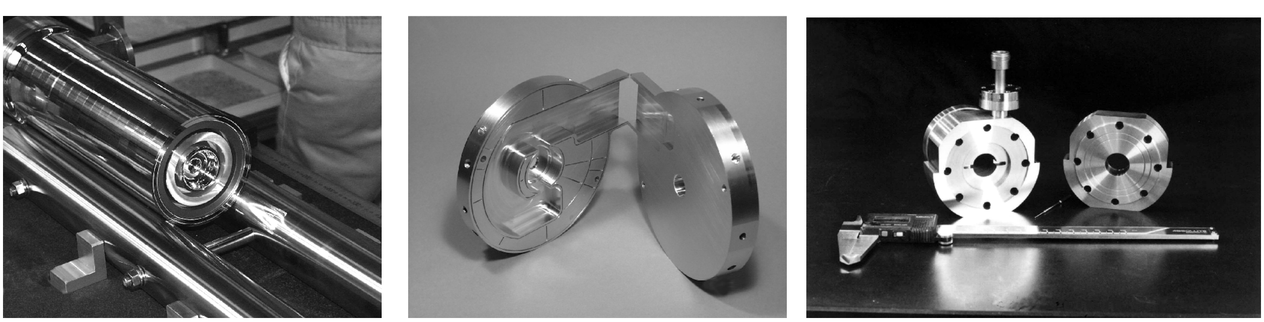

Fig. 8 C-band accelerating structure fabrication.
(left)choke-mode cell with SiC ring, (middle) Matsumoto-coupler and (right) common-mode free RF-BPM.