THE C-BAND (5712-MHZ) RF SYSTEM FOR e^+e^- LINEAR COLLIDER

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Abstract

Hardware R&D on the C-band (5712-MHz) RF-system for an e^+e^- linear collider started in 1996 at KEK. We have already developed three conventional and one periodic permanent magnet (PPM) type 50-MW class klystrons, a smart modulator, and the first HOM-free accelerator structure (Choke-mode type, full-scale high power model) [1], [2], [3], [4]. A very stable ceramic high voltage monitor was successfully tested up to 367-kV with a 4.5-µsec pulse. A very good agreement with the expected division ratio and signal waveforms was obtained from high power tests. A new C-band SiC type high power rf-load, advancing the power handling capability up to 50-MW is now being designed. It should have excellent mass production characteristics as it uses circularly symmetric TM_{011} chained cavities [5], [6]. The first high power test should be completed at KEK by the end of 2003. The first high power prototype of an rf compressor cavity made of a low thermal expansion material (super Invar) was designed to provide stable operation even with a very high Q of 200-k [7], it is now under high power testing at KEK. The C-band linac rf-system will be used for the SASE-FEL (SCSS) production project at SPring-8 [8], but SCSS will also serve to verify the design and components, which can eventually be deployed for the main linac rf system in a future linear collider.

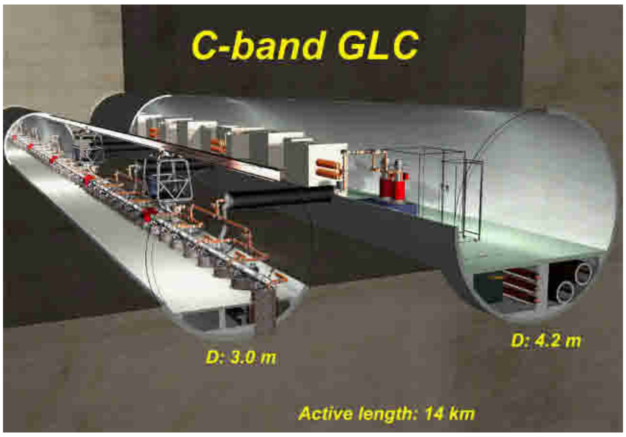

Figure 1: C-band main linac tunnels. The klystron gallery is 4.5-m in diameter and the linac tunnel is 3.0-m in diameter.

INTRODUCTION

To be interesting, an e^+e^- linear collider must be a very large-scale machine. For example, the e^+e^- collider under conceptual design now at KEK would have a main linac for each of two beams, and in total more than 8000 accelerating structures, 4000 klystrons and modulators would be used. Therefore, the hardware we develop has to meet very strict demands for: (1) High reliability, (2) Simplicity, (3) Reduced construction cost, (4) Reasonable power efficiency, and (5) Operational ease. This list provides a guideline and the boundary conditions for our design work. Of all the free system parameters that we may vary, the choice of the drive rf frequency plays the determinative role in setting the system performance as well as most other hardware details.

For reasons previously argued in [2], we propose that the C-band frequency is the best choice to meet all of the demands.

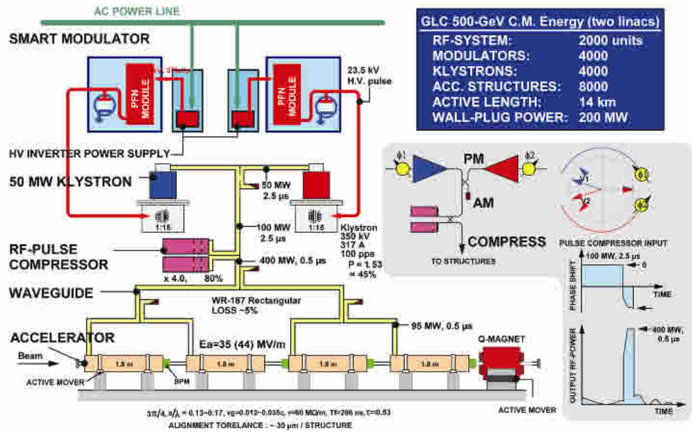

Figure 2: One unit of the C-band main linac.

SYSTEM DISCRIPTION

Each unit in the main linac rf-system is composed of two 50-MW klystrons, their pulse modulators, one rf-pulse compressor, four 1.8-m-long choke-mode accelerating structures and associated wave-guide-system as shown in Fig. 2. The accelerating gradient is 35-MV/m under full beam loading. This accelerating gradient was chosen as practicable after studying results from S-band frequency high gradient tests done between 1987 and 1994 at KEK. The total RF-system to achieve 500-GeV C.M. energy would be on the order of 2000 units.

RESULTS OF HARDWARE R&D

In April 1996, we started hardware R&D, and as of June 2003 we had developed most of the hardware components and tested their performances, with the exception of the high-power rf pulse compressor.

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Klystron R&D

We have successfully developed a 50-MW class solenoid focus type klystron (TOSHIBA E3746 series), which meets the required specifications of the 500-GeV linear collider. In Phase-II R&D, we have to refine the design details to reduce costs before starting mass-production. As a part of the R&D program aiming toward a 1-TeV C.M. energy scale linear collider, we developed the first PPM klystron (TOSHIBA E3748 series) in 1999 [4]. We chose a NdFeB magnet material (Model N40A, Shin-Etsu Co. in Japan). The Hot Isostatic Pressing (HIP) technique has been applied for the first time to fabricate the magnetic circuit for the PPM klystron. An output power of 37-MW was generated with a 2.5-μsec pulse at a 50-pps repetition rate.

Modulator Power Supply

We focussed our modulator R&D work on reducing the fabrication cost and improving the reliability. As a first step, we developed a prototype modulator, whose features are: (1) Direct HV charging from an inverter power supply, (2) No de'Q-ing circuit, (3) Much smaller in size than the usual modulator, (4) Use existing low-risk reliable circuit components.

To reduce the modulator size and allow removing the de'Q-ing circuit from PFN, we employed an inverter type DC-HV power supply (EMI-303L in U.S.A). A first model of the smart modulator was built in a metal cabinet of compact size 160 (W) x 200 (H) x 120 (D) cm. The fluctuation in the measured output voltage was measured to be lower than ±0.17% (at 3σ), which meets the energy stability requirement for the linear collider. The timing variation (jitter and drift) of the pulse output is around 2-nsec (at 3σ) over a 4 hour run at 50-pps [9].

The next step in the smart modulator development was to install everything except for the inverting H.V. supply in an insulation oil filled metal tank or cabinet of very compact size: 150 (W) x 100 (H) x 100 (D) cm [10]. The first prototype was developed by NICHIKON Co in Japan. Testing was begun in March 2003 at SPring-8. We obtained the results expected for the pulse wave shape, voltage and flatness, as well as verification of the operational repeatability and also markedly reduced EMI and noise generation.

Figure 3: A fist inverter type H. V. power supply (TOSHIBA).

A new prototype H.V. power supply was developed by TOSHIBA Co. in Japan and it was tested along with the rest of the modulator beginning in March 2003 at SPring-8. It is also very compact, being only 48 (W), 45 (H) and 63 (D) cm. It generates a maximum output voltage of 50-kV and provides an average power of 30-kW (or a peak of 37.5-kJ/sec); this supply can drive a 50-MW klystron at up to a 60-pps repetition rate giving a 350-kV beam voltage. We obtained an output voltage regulation of within ±0.1% with a test prototype as shown in Fig. 3.

Pulsed High-Voltage Monitor

We have developed a very stable and accurate high-voltage monitor, to be used for monitoring the klystron pulse voltage, see Fig. 4 [11]. Since it uses a ceramic material for the capacitive type voltage divider (CVD), the monitoring capacitance division ratio can be kept quite stable even under temperature changes, or changes in the set-up configuration, or mechanical stresses applied to the monitor port through the input lead. We successfully operated the monitor up to 367-kV, and 4.5-μsec pulse widths at a 50-pps repetition rate. The maximum voltage in the CVD test was limited by the modulator output.

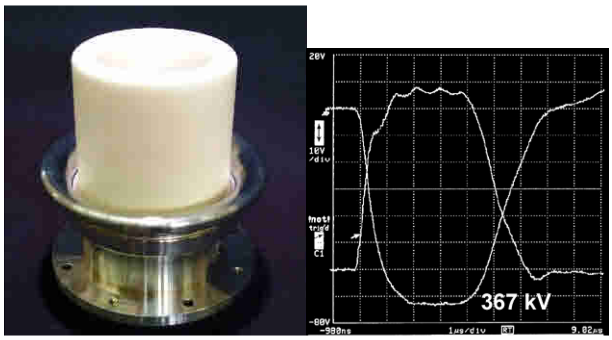

Figure 4: Ceramic high-voltage monitor. Left: A cup type monitor. Right: High voltage waveform at 367-kV and 4.5-μsec.

A New C-band 50-MW SiC Type RF Load

There are no available 50-MW class rf loads for C-band (5712-MHz) frequencies in the world. Therefore we have constructed a new type rf load using SiC ceramic with an indirect water-cooling structure, this upgraded the power handling density of the SiC material from 100-W per cc to 300-W per cc, allowing a much more compact size. Also, using circular mode TM_{011} chained cavities as shown in Fig. 5. One particular advantage is that since the main parts are completely axially symmetric, they can be machined on a turning lathe; thus this type of cavity has a big advantage in mass production because of its easier machining. For impedance matching between the waveguide and the cavity-chain of TM_{011} mode cavities, we chose an inductive iris-type coupler, which is structurally simpler than the doorknob-type coupler. The load is now at the detailed design stage, and we expect that high power tests at KEK will be completed by the end of 2003.

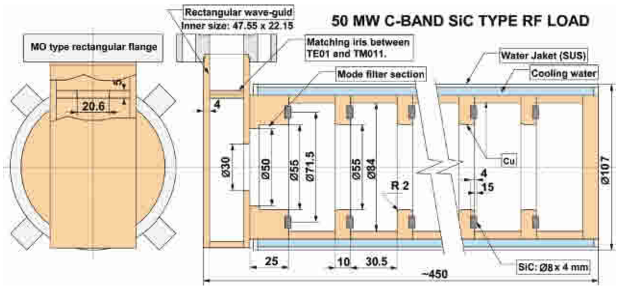

Fig. 5: First model of 50-MW SiC type C-band rf load.

RF Pulse Compressor

At the present the initial test of a high power model has begun at KEK. This prototype uses a copper plated invar metal for the rf cavity [12], this permits the temperature control system for the rf compressor to be simplified and thus contributes to reducing the cost of the total system. The current experimental result is a 90-MW pulse, 0.5-μsec wide at a 50-pps repetition rate with a total multiplication factor of 3.0. The rf compressor provide the very good thermal stabilities, which is better than conventional copper cavities. The test set up is shown in Fig. 6. There is no unusual vacuum out-gassing found even at the high power operation as shown in Fig. 7.

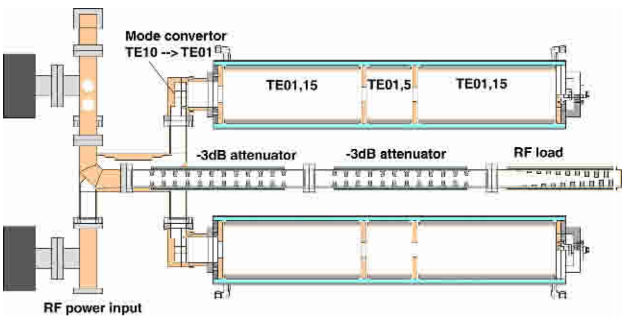

Figure 6: High power test stand for rf pulse compressor cavity.

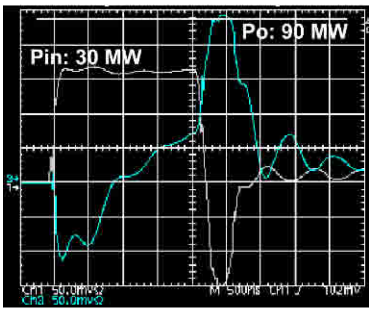

Figure 7: Typical pulse compressor cavity rf power waveforms.

C-band Accelerating Structure

A C-band Choke-Mode type damped structure was developed in 1998; its performance was tested with ASSET at SLAC. As expected, its powerful HOM damping performance was proven. We found parasitic resonance at very high frequencies around 23-GHz. The resonance was caused by EM fields trapped inside the cavity. This problem can be resolved by changing the cavity dimensions by a small amount. The new structure is fabricated by brazing. High power tests of the structure will begin at Spring-8 in Decmber 2003.

FUTURE R&D

The first stage of the C-band R&D between 1996 and 1998 was successfully completed. Beginning in 1999, the next priority is to develop a 50-MW class PPM type klystron with power efficiency of higher than 50%.

On a parallel track, in order to evaluate the system performance in a realistic situation, at least one unit of the C-band system has to be built, installed and beam tested in an operational machine.

To this end, a c-band linac rf system is now under fabricating for the 1-GeV electron injector linac for the SCSS project (SASE-FEL) at SPring-8 [13]. SCSS is comprised of a buncher system and 1-GeV injector followed by a 20-m long in-vacuum undulator. It should be able to produce X-rays in the water-window range of 1- to10-nm wavelength. The first operation of the c-band linac at initial beam energy of 500-MeV.

REFERENCE

[1] T. Shintake et al., “C-band Main Linac RF System for Linear Collider ”, KEK preprint 96-122, September. 1996.

[2] H. Matsumoto et al, “Fabrication of the C-band (5712 MHz) Choke-Mode Type Damped Accelerator Structure”, KEK preprint 98-143, September 1998.

[3] T. Shintake et al., “The first Wakefield Test on the C-band Choke-Mode Accelerating Structure”, KEK preprint 99-11, May 1999.

[4] H. Matsumoto et al., "DEVELOPMENT OF THE C-BAND (5712 MHz) 50 MW CLASS PPM Klystron (II)", 26th Linear Accelerator Meeting in Japan, Aug.01~03,2001, Tsukuba, Japan

[5] S. S. Win et. al., “A new C-Band 50 MW Class SiC RF load”, Proc. of 28th LINAC Meeting, July 30-August 1, 2003, Tokai, J-PARK.

[6] S. S. Win et. al., “A new C-Band 50 MW Class SiC RF load. II”, Proc. of 14th Symposium on Accelerator Science and Technology, November 11-13, 2003, Tsukuba Japan.

[7] M. Yoshida et al., "RF Pulse Compressor using Low Thermal Expansion Invar Material", 26th Linear Accelerator Meeting in Japan, Aug.1~3, 2001,

[8] T. Shintake et al., "The SPring-8 Compact SASE Source (SCSS)", SPIE2001, 29 July – 3 August 2001, San Diego, California, USA

[9] J-S. Oh et al, “Efficiency Analysis of the First 111-MW C-band Klystron–Modulator System for Linear Collider”, KEK Preprint 98-32, March 1998.

[10] H. Matsumoto et al., “Closed type Compact Modulator for 50 MW C-band Klystron”, Power Modulator Conference & High Voltage Workshop, June 30 – July 3, 2002, Hollywood, CA.

[11] Y. Takasu et al., “Pulsed High Voltage Monitor Using Ceramic”, 27th Linac meeting August 7-9, 2002, Kyoto.

[12] M. Yoshida et al., “RF Pulse Compressor System”, 27th Linac meeting August 7-9, 2002, Kyoto.

[13] T. Shintake et al., “Progress on the C-band Accelerator for the Spring-8 Cpmpact SASE Source”, proc. of PAC2003, May 2003, Portland, Oregon, USA.