R&D Status of the C-band Linear Accelerator Technology for e^+e^- Linear Collider

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Abstract

Hardware R&D on the C-band (5712-MHz) RF-system for the e^+e^- linear collider started in 1996 at KEK. We developed three conventional and a periodic permanent magnet (PPM) type 50-MW class C-band klystrons (TOSHIBA E3746 series and E3748 series), a smart modulator, a travelling-wave resonator (TWR), a high power model of an rf-pulse compressor cavity is now under fabricating and the first HOM-free accelerator structure (Choke-mode type, full-scale high power model) [1], [2].

The c-band linac rf-system will use for the SASE-FEL (SCSS) project in the SPring-8 [3], which is actually make strings test of the main linac rf system for the linear collider.

Life test was carried out on the conventional klystrons over 6000 hours in total, where they showed highly reliable performance as high as conventional S-band klystrons. As a upgrading program to 1 TeV c.m. energy scale, we developed a new PPM klystron in 1999. The first PPM klystron was generated 37 MW with 2.5-μsec pulse width and 50 pps repetition rate [4].

The first high power model of an rf compressor cavity was used a low thermal expansion material (super Invar) to make stable operation with 200k of Q-value [5], and its high power test will on a early 2002 in KEK.

The electrical performance on the HOM-free accelerating structure was tested with beam at SLAC-ASSET facility in December 1998 [6]. The measured wakefield showed excellent performance on the HOM damping as exactly expected from the theory.

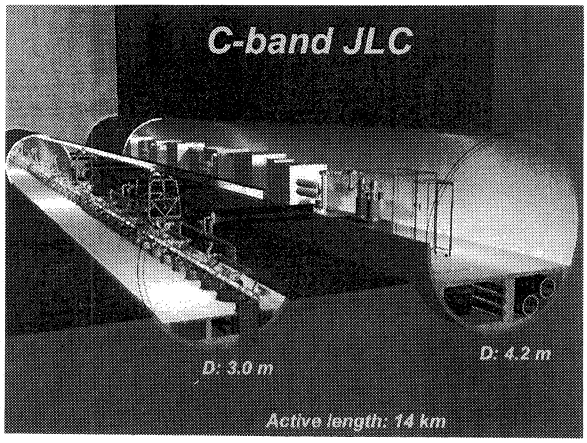

Fig.1: C-band main linac tunnels. It has diameter of 4.5-m for the klystron gallery and 3.0-m for the linac.

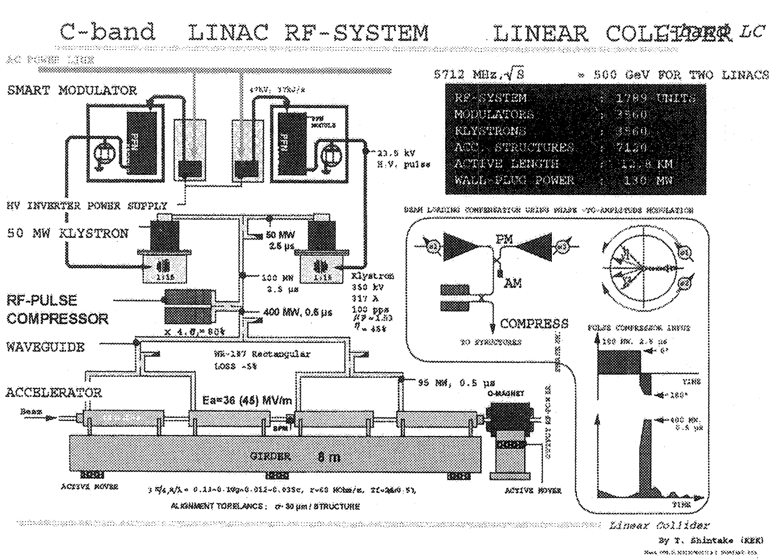

Fig. 2: One unit of the C-band main linac.

1 Introduction

The e^+e^- linear collider (500-GeV c.m.) will use more than 8000 accelerating structures, 4000 klystrons and their pulsed-modulator power supply. We have to maintain the beam operation stably for a long period in the physics run. Since 2000 units of the rf-system will be used in the main linac, each component has to be very reliable. And the power efficiency has to be high enough to lower the operation cost. Additionally, the construction cost has to be quite low. The main linac will be installed in two parallel tunnels with circular cross-section with diameters of 3-m and 4.5-m for the accelerator and klystron gallery, respectively shown in Figure 1. The tunnels will be constructed in a very stable stratum such as granite.

The key to succeed in developing such rf-system, which meets all of those demands, is the choice of the optimum drive rf frequency. The choice has to be made by compromising the following contradictions.

For the point of view of energy efficiency from rf to the beam in the accelerating structure, a higher frequency is desirable, since the shunt impedance becomes higher at higher frequency ($r \propto f^{1/2}$).

On the other hand, at higher frequencies, the technique required to fabricate accelerating structure becomes higher, and mass production becomes sever. Additionally, the peak output power from the klystron generally goes down as the frequency becomes higher.

We chose C-band 5712 MHz as the optimum frequency. It is twice higher than the

S-band 2856 MHz commonly used in conventional electron linear accelerators. The advantage in choosing the C-band frequency is that <u>we can obtain high accelerating gradient required for 500 GeV LC using existing technology</u>.

This paper will describe results of the hardware R&D on the C-band RF system and current status.

2 System Description

Each unit in the main linac rf-system is composed of two 50-MW klystrons, their pulsed modulators, one rf-pulse compressor, four 1.8-m-long Choke-mode accelerating structures and associated waveguide-system as shown in Figure 2. The accelerating gradient is 36-MV/m under the beam loading. The total number of the RF-system to achieve 500-GeV c.m. energy is 2000 units.

3 Results of Hardware R&D

In April 1996, we started hardware R&D, and up to now (April 2001) we have developed all of the hardware components and tested those performances, except the rf pulse compressor high-power model. They are summarized in Table-I.

3.1 The klystron R&D

We have successfully developed the 50-MW class klystron, which meets specifications of the 500-GeV linear collider. The R&D achievement level is 90%, the rest of 10% is that the klystron was tested at 50-pps, while the design parameter assumes 100-pps operation. This is limited by the maximum power of the inverter capacitor charger, which we purchased at the beginning of the project. At 100-pps, the heat load becomes twice higher at the beam collector in klystron. Since the present design has enough margins, we expect no serious problems in 100-pps operation. In Phase-II R&D, we have to refine the design details to reduce cost before starting the mass-production. As a part of the R&D program toward 1 TeV c.m. energy scale linear collider, we developed the first PPM klystron in 1999 as shown in Figure 3. We chose the NdFeB magnet (Model N40A, Shin-Etsu Co. in Japan), which has a residual flux density (Br) of 1.22 Tesla and a coercive force of 10.5 k-Oersted. Hot isostatic pressing (HIP) technique has been firstly applied to fabricate a magnetic circuit in a PPM klystron. Simply stacking disks of the magnetic stainless-steel (Mag-SUS) and oxygen-free-copper (OFC) alternatively, and, they were bonded in one block with diffusion bonding. No brazing-alloys were used in this process. An output power of 37 MW was generated with 2.5-μsec pulse width and 50 pps repetition rate.

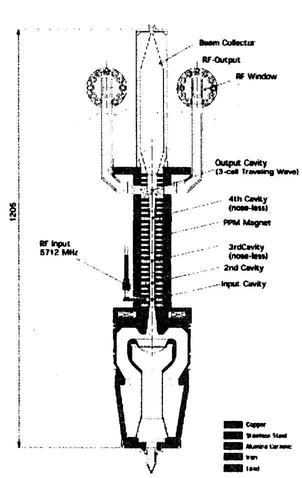

Fig. 3: Cut away view of the first C-band (5712-MHz) 50 MW-class PPM type klystrons (TOSHIBA-E3747).

3.2 The RF pulse compressor (cold model)

A new scheme was proposed as a flat-pulse rf-pulse compressor by T. Shintake in 1996, and the demonstrated generation of a flat-pulse in 1996 as shown in Figure 4. We have obtained the 3.25 of power gain with 65% of efficiency. The first high power model is using an invar metal as the rf cavity with copper plating, the temperature control system to the rf compressor will be simplified and contributes to reduce cost of the total system. The high power model is now under fabricating, and it will be tested end of this year (2001) in KEK.

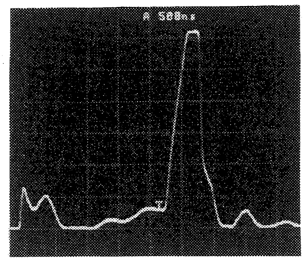

Fig. 4: A flat-pulse output waveform from rf pulse compressor

3.3 The C-band accelerating structure

The C-band Choke-Mode type damped structure was developed in 1998, its performance was tested with ASSET at SLAC as shown in Figure 5. The powerful HOM damping performance was proven. We found parasitic resonance at very high frequency around 23 GHz, which is caused by EM field trapping inside the cavity. It can be solved by changing the cavity dimensions by small amount. For the beam alignment, the cavity type RF-BPM was developed and its performance was tested with ASSET beam [7]. The position accuracy of 10-μm and the resolution of 1-μm were confirmed. High power test of the structure will start in middle of 2002 in SPring-8.

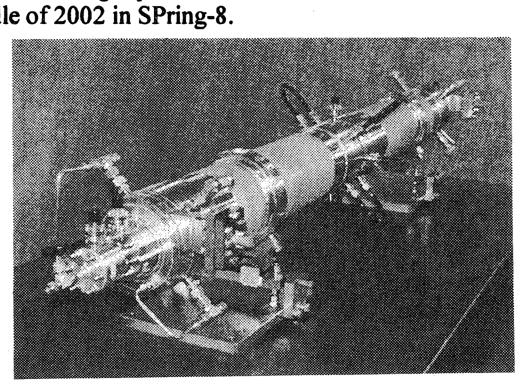

Fig. 5: The C-band accelerating structure of 1.8-m long, 91 cells.

3.3 Modulator power supply

Accordingly we focussed our R&D work on reducing the fabrication cost and improving the reliability. In 1993, the concept of the ì Smart Modulatorî was proposed by Prof. M. H. Cho and the author. As a first step, we developed a prototype modulator, whose features are: (1) Direct HV charging from an inverter power supply, (2) No deQ-ing circuit, (3) Much smaller size than the usual modulator and (4) Use existing reliable circuit components.

To reduce the modulator size and allow removing the deQ-ing circuit from PFN, we employed an inverter type DC-HV power supply: Model EMI-303L (Electric

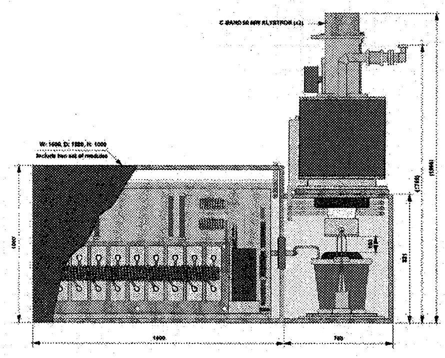

Fig. 6: First prototype Smart Modulator.

Measurement Inc. The smart modulator was installed in a metal cabinet of compact size 160 (w) x 200 (H) x 120 (D) cm as shown in Figure 6. It is now in daily use for driving the 50-MW klystron. The total run time has exceeded 6000 hours. The fluctuation of the measured output voltage was 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) for 4 hour run at 50 pps [8], [9].

The second step of the smart modulator will install into the insulation oil filled one box metal cabinet with very compact size 150 (W) x 100 (H) x 100 (D) cm as shown in Figure 6 [10]. It is now under deigning and will obtain middle of 2002.

4 Future R&D

Hardware R&D items, should be completed before the LC construction as following updating. Targets of those R&Dís are: (1) Reduce construction cost of machine. (2) Improve hardware reliability and (3) Reduce operation cost (improve power efficiency). Here we briefly explain the R&D subjects and expected solutions.

4.1 Klystron

One of the most costly parts in klystron is the processing time of the high temperature baking. This process will be also a bottleneck in the mass-production. To reduce baking time, we will refine the material quality used in the klystron, and also surface treatment after machining.

4.2 Modulator

In the mass production, circuit components will be delivered at quite low cost. The assembling process will be the bottleneck and most costly. The modular design will solve this problem. Dividing the modulator into blocks and fabricating them in different supplier, we can assemble them by simply plug-in to the modulator cabinet. This design also makes the machine maintenance faster, and the machine downtime shorter.

We have to also set up an R&D program to improve reliability and life-time of the thyratron-tube. Introducing high quality material in thyratron parts, such as, insulation ceramics, anode electrode, grid, and cathode, we expect that the tube lifetime will be dramatically improved.

4.3 RF Pulse Compressor

We need higher efficiency and easier operation. Using rising part of the modulator pulse, we can rescuer beam energy in the klystron, as a result the system power efficiency will be improved. To do this, we need a digital phase modulator, with intelligent feedback loop. It will also maintain a constant energy gain in the system.

4.4 Accelerating Structure

An optimizing the cavity dimensions, speed up the machining and refine the fabrication process. Automated machine for the cell machining will dramatically reduce the fabrication cost.

4.5 Waveguide and other components

The waveguide is a hidden item of the most costly parts in the rf-system. To reduce cost, minimize number of type of waveguide components, and simplify the design details, and introduce automated machining.

5 Test linac

To integrate developed hardware components, a test linac (at least 1-GeV) has to be constructed, and the system reliability has to be investigated with a long term of beam operation.

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

For the next step, in order to examine the system performance in a realistic situation, one unit of the C-band system has to be installed and tested with beam in an existing machine.

The c-band linac rf system now under fabricating for 1-GeV electron injector linac for the SCSS project (SASE-FEL) in SPring-8. Its comprises of 1-GeV injector include the buncher system and 20-m long vacuum type undulator can be applied the water-window with range of 1- and 10-nm of the light wavelength. The first operation of the c-band linac at beam energy of 500-MeV will start on a early 2004, second step will accelerates the beam energy of 1-GeV in a early 2007.

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