PRESENT STATUS OF THE C-BAND ACTIVITIES AT KEK

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Abstract

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 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 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 was successfully tested the output rf power up to 135-MW, 0.5-μsec pulse width and 50-pps repetition rate. 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.

1. INTRODUCTION

The C-band main linac has been developed motivated by the urgent and essential physics program at the linear collider. The C-band technology needs a minimum R&D towards early construction and reliable operation. It enables an early start to the physics program, so as to be as concurrent as possible with LHC operation. Once a new particle threshold opens, all angles of the new physics can be thoroughly studied in the clean experimental environment of e^+e^- collisions.

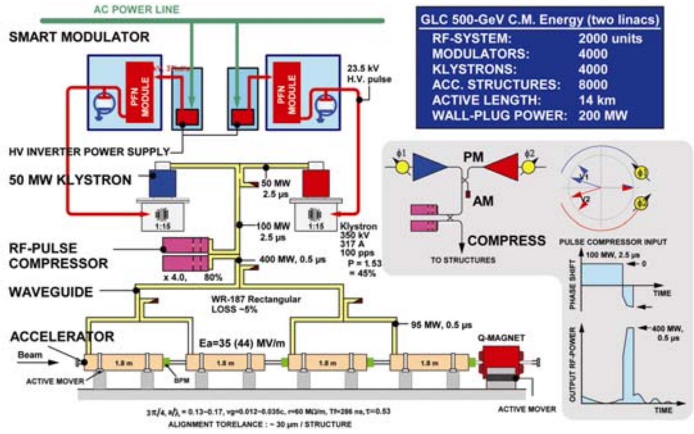

Figure 2: One unit of the C-band main linac.

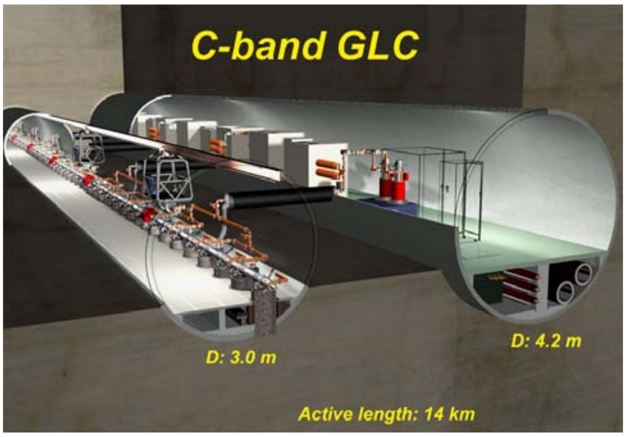

Figure 1: C-band main linac tunnels. The klystron gallery is 4.5-m in diameter and the linac tunnel is 3.0-m in diameter.

The main linac system is the heart of linear collider. It is a huge system, which is a repetition of thousands of common RF-units. Therefore, in order to realize a good physics program, these RF-units have to meet strict requirements for: (1) High reliability, (2) Simplicity, (3) Easy operation, (4) Reasonable power efficiency, and (5) Low cost.

This guiding principle provides boundary conditions for our design work. The C-band group has been working extensively along this line. Especially the first three items are crucial for the large system to be operated, prior to the detailed discussions on energy efficiency or upgradeability. The rf-frequency commonly used for various electron linear accelerators is the S-band (2.8-GHz). The S-band technology was established about 1/2 century ago, and it has had a long experience.

The C-band frequency is only two times higher than the S-band, hence the size of the accelerator structure is a half of the S-band. Therefore, the current technology for fabricating the components can easily meet the accuracy required for the C-band main linac. Consequently, this directly results in high reliability, simplicity, and hence low cost.

The total C-band main linac RF-system for 500-GeV C.M. energy includes about 2000 rf-units as shown in Fig 2. In total about 8000 accelerating structures and about 4000 klystrons with modulators are needed for the two main linacs. The number of

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each component is not large enough to induce a drastic cost reduction caused by the mass-production. Therefore, from the beginning of the designing of each component, the efforts toward cost reduction are absolutely necessary. For this purpose the C-band group was inventing novel ideas and executing special R&D's for cost reduction.

The cost for the main linac and that for the civil engineering were estimated with a help of industry. The total reduction factor of the current price over that for the mass production is currently estimated to be around 2.2, averaged over all the main linac components. The total cost is kept reasonably low, in spite of the low reduction rate. This is simply due to the efforts described above. In addition, the fabrication of the C-band components needs neither a number of advanced machines nor complicated processes.

Although the number of accelerator physicists in the C-band group is small, the R&D budget is not enough, and we are suffered from political oppressions in the past, the group has efficiently worked out the design lead by the guiding principles described above with a major collaboration with industry. The reason that there are so many supporters of the C-band group in the industry and in universities is simply because the C-band technology is easier than other technologies and it naturally fits the current technology level of the industry. Obviously, if an international team of accelerator experts extensively study the C-band main linac, they will certainly see the advantages of the technology and further improvements can be expected.

In this report, the rf-unit, klystron, modulator, pulse compression system, accelerating structure, alignment and support system for the structures and possible energy upgrade scenario for the C-band technology are described in each section.

2. RESULTS OF HARDWARE R&D

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

2.1 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 as shown in Fig 3. 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]. It was obtained an output power of 37-MW was generated with a 2.5-μsec pulse at a 50-pps repetition rate.

2.2 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) Much smaller in size than the usual modulator, (3) Use existing low-risk reliable circuit components such as thyratron tube for the PFN switching.

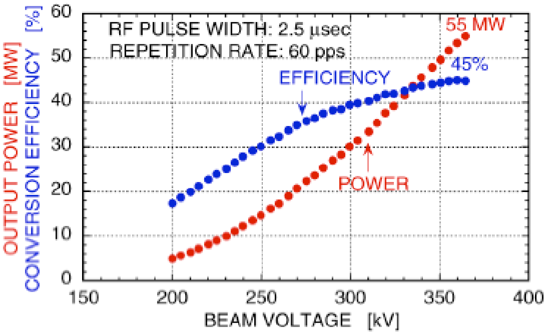

Figure 3: Typical efficiency and RF output power characteristics at saturation as a function of beam voltage.

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 GLC [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, and it was tested 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.

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 prototype model.

2.3 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 [11], 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 135-MW peak output power, 0.5-μsec pulse width at 50-pps repetition rate with a total multiplication factor of 3.0. The rf compressor provide the very good thermal stabilities, which is much better than conventional copper cavities. There is no unusual vacuum out-gassing found even at the high power operation as shown in Fig. 4.

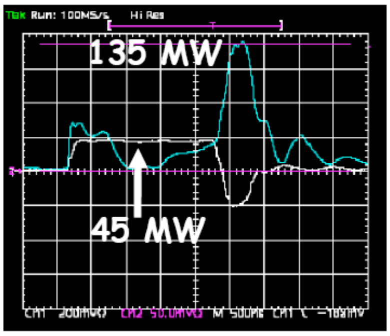

Figure 4: Typical pulse compressor cavity rf power waveforms.

2.4 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 be stared in July this year at Spring-8 [12].

2.5 Pulsed High-Voltage Monitor

We have developed a very stable and accurate high-voltage monitor, to be used for monitoring the klystron pulse voltage [13]. 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, see Fig. 5. For the moment, the maximum voltage in the CVD test was limited by the modulator output voltage.

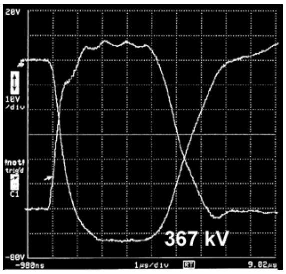

Figure 5: Measured voltage waveform at -367-kV.

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

There are no available 50-MW class rf loads for C-band frequencies in the world. Therefore we have constructed a new type rf load using SiC ceramic with an indirect water-cooling structure. We chose a circular mode TM_{011} chained cavities. 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.

3. FUTURE R&D

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. 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- to 10-nm wavelength. The first operation of the C-band linac at initial beam energy will be started range of 0.5- and 1-GeV [14].

4. REFERENCE

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