C-BAND MAIN LINAC RF SYSTEM FOR e^+e^- LINEAR COLLIDER OF 0.5 TO 1.0 TeV C.M. ENERGY

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Abstract

A hardware R&D for the C-band (5712 MHz) rf system for a linear collider started in 1996 at KEK. An accelerating gradient of 32 MV/m (including beam loading) will be generated by 50 MW C-band klystrons in combination with an rf-compression system. The klystron and its power supply can be fabricated by conventional technology. The straightness tolerance for the accelerating structures is 30 µm, which is also achievable with conventional fabrication processes. No critical new technology is required in a C-band system. Therefore, a reliable system can be constructed at low cost with a minimum of R&D studies. The first high-power test is scheduled for 1997.

Introduction

The e^+e^- linear collider is a large-scale machine. In the main linacs for two beams, we use more than 8000 accelerating structures, 4000 klystrons and pulse modulators. Therefore, the system must meet the followings demands:

(1) High reliability

To provide beams with reasonable availability, the system must be highly reliable; that is, the fault rate must be negligibly small and the lifetime of the key devices must be sufficiently long. To achieve this, we eliminate any critical parameter or excessive stress in the hardware components.

(2) Simple

For the same reason as (1), the system must be simple. This will also help to lower the construction cost and to make hardware maintenance easier.

(3) Lower construction cost

We should try to reduce the construction cost while not sacrificing the system performance and reliability.

(4) Reasonable power efficiency

We assume that the maximum limit on the whole wall-plug power in a site is 200 MW. To meet this requirement, the rf system must efficiently accelerate the beam. However, since an actual rf system needs auxiliary power in addition to the wall-plug power to generate rf, we must optimize the total system, not just the acceleration hardware.

(5) Easy to operate

The machine operation should be easy. In the actual machine operation, the system must have flexibility to accelerate various patterns of the beam current. The tuning procedure must also be simple and easy.

The above list provides a guide-line 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[1-4].

Overall Parameters

The overall parameters are listed in Table-I for 500-GeV and 1-TeV C.M. energy linear colliders. In the 500-GeV case, an accelerating gradient of 31.7 MV/m is generated by a 50-MW klystron in combination with rf pulse compression; thus, an active length of 7.3 + 7.3 km is sufficient to reach 500 GeV C.M. energy. A luminosity of 6.6 x 10^{33}/cm^2/sec can be obtained using a 150 MW wall-plug power. The details are described in ref.[3].

Table-I

CM Energy	TeV	0.5	1.0
Number of electrons per bunch	x10^{10}	1.1	1.4
Number of bunches per pulse		72	
Bunch separation	nsec	2.8	
Repetition frequency	Hz	100	50
Bunch length	mm	0.2	
------- RF-parameters -------			
RF frequency	GHz	5.712	
Peak input power at cavity	MW	83.0	165
Nominal accelerating gradient	MV/m	40.0	56.0
Effective accelerating gradient	MV/m	31.7	46.4
Wall-plug power for RF (2 linacs)	MW	150	133
------- Accelerating Structure -------			
Number of structures per beam		4080	5748
Total length of cavities per beam	km	7.3	10.3
Structure Type	CG with choke-mode		
Unit length of structure	m	1.80	
Iris radius/wavelength		0.13 - 0.17	
Shunt-impedance	MΩ/m	59.2 - 47.0	
------- Pulse-compressor -------			
Compression Scheme	multi-cell coupled cavity		
Pulse compression ratio		5	
Pulse compression efficiency	%	70	
------- Klystron -------			
Klystron peak power	MW	50.3	98.6
Efficiency	%	45	70
Number of klystrons per beam		2040	2874
RF pulse length	µsec	2.5	
------- Modulator -------			
Number of modulators per beam		2040	2874
Power efficiency from AC to pulse	%	75	
------- Beam Dynamics -------			
Injection energy	GeV	20	
Phase delay of rf-crest	deg	14.5	10.0
Structure straightness tolerance	µm	30	
------- Final focus -------			
Spot size at IP (horizontal)	nm	318	318
(vertical)	nm	4.3	3.0
Crossing angle (crab crossing)	mrad	8.0	8.0
Luminosity	x10^{33}	6.6	7.0

System Description

Figure 1 shows a schematic diagram of one unit in the main linac rf-system. Two 50 MW klystrons are driven by two high-voltage pulse modulators independently, followed by a 3dB hybrid power combiner and pulse compressor to generate 350 MW peak power, which drives four accelerating structures. The pulse-compression action is performed by rotating the phase of the input rf-signal in opposite directions in each klystron. By combining two powers at 3-dB hybrid, the phase modulation (PM) is converted to the amplitude modulation (AM) of the ramp-waveform, which compensates the beam loading effect in the accelerating structure. The energy-storage cavity consists of three coupled cavities using a low loss TE01n mode.

We use a standard rectangular waveguide: EIA187 (47.55 mm x 22.15 mm, 3.95-5.85 GHz), whose attenuation constant is 0.03 dB/m (5% loss/m).

Figure 2 shows the key points concerning the C-band, which make the system simple and reliable.

Klystron Power Supply & Pulse Transformer

The filling time of the accelerating structure scales as

$$t_F = \frac{2Q}{\omega}\tau \propto \omega^{-3/2}.$$

At the C-band, it becomes 280 nsec. Including the pulse-length of the beam and a compression factor of five in the rf-compression system, the rf-pulse at the klystron becomes 2.5 μsec. Including the rise- and fall-times, the pulse-length of the high-voltage applied to the electron-gun of the klystron becomes 3 μsec or longer, which is quite suitable to the conventional power-supply consisting of a Pulse Forming Network (PFN) and a step-up pulse-transformer. This type of power supply has been used in many linear accelerators, owing to its high reliability and good efficiency.

To charge high voltage into the PFN capacitors, we use an inverter power supply. Such a high-voltage power supply has been widely used to drive pulsed lasers for a long time. Modern technology for power-semiconductor devices (such as IGBT) has improved the power efficiency by better than 90%. Using this power supply, we can simplify our modulator design, making it modular according to the required functions: the inverter power supply (DC block), the PFN module (pulse forming block), and the pulse-transformer tank (matching block to a klystron). With this approach, it becomes easier to reduce the cost, improve the reliability and ease maintenance. In the case of a failure, we simply replace any broken block with a new one and send the old one to a factory for repair.

C-band Klystron

Since the klystron drift-tube diameter is proportional to the rf wavelength, we can use an electron beam with a larger diameter than higher frequency bands. It also makes it easier to design an electron gun with a larger cathode to extract a higher beam current. Therefore, we can design the beam voltage as low as 350 kV, which enables the PFN voltage to be as low as 43 kV. At this voltage level, it is easier to obtain suitable PFN-capacitors from existing ranges of various manufacturers.

RF Pulse Compressor

We use a three-cell coupled-cavity pulse-compressor instead of a delay-line type pulse-compressor. The cavity is compact, having a length of 1 m, and its diameter is 160 mm. Therefore, it will be easier to fabricate at lower cost. A computer-simulation code was made to simulate the time response of the coupled-cavity system, which has shown a maximum efficiency as high as 70%. The details are reported in ref. [5].

Accelerating Structure

We use a choke-mode cavity structure[6], in which all of the higher-order modes are heavily damped. Therefore, the multi-bunch wakefield and any associated instability will not harm the beam emittance. The only concern is the single-bunch emittance dilution due to the short-range wake-field, which is a strong function of the iris aperture. We use relatively large iris-aperture: average <2a>=16 mm. As a result, the straightness tolerance for one structure becomes 30 μm or larger. This is a controllable level in conventional fabrication techniques of the disk-loaded structure. To eliminate any stress and make the structure straighter, a low temperature brazing technique will be adopted[7]

To align the structure with beam, we use an RF-BPM attached to the structure. This type of RF-BPM was tested using the FFTB beam line at SLAC in December 1995[9]. It demonstrated a very high resolution of 44 nm for a single bunch. Three RF-BPM were assembled in one block, and the misalignment between them was measured with electron beam. It was only 3 μm. This is a quite promising result for a structure-alignment procedure.

The dark-current problem due to field-emission under the high accelerating gradient has been studied using computer simulations[10]. From which, no serious contributions to the background in the detector at IP is expected at C-band frequency.

Hardware R&D Program

In January, 1996, the hardware R&D has been started at KEK. In 1997-1998, we will construct one unit of rf-system. Since we use one klystron, the input rf will be directly amplitude modulated to demonstrate the flat-top output from the compressor. The first klystron tube will be available in 1997.

References

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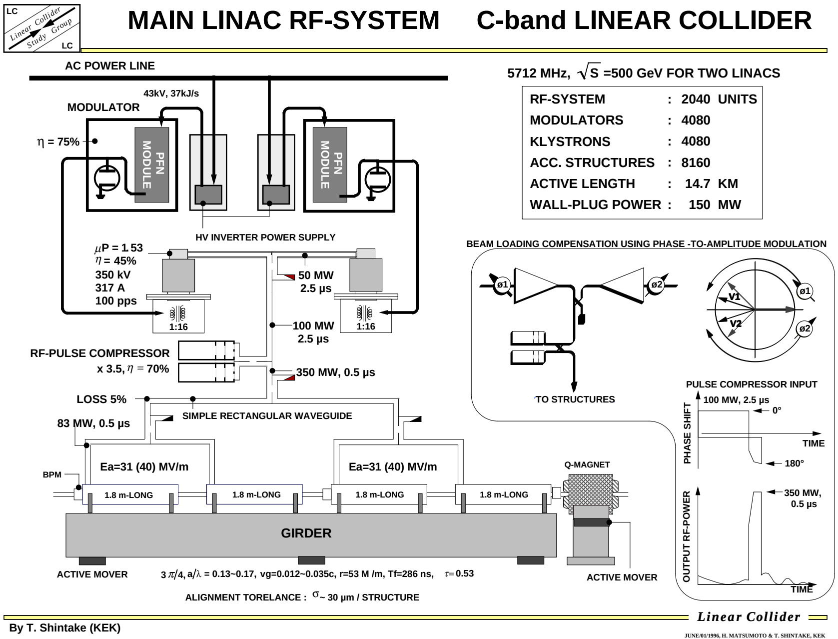

Fig. 1 One unit of the C-band RF system.

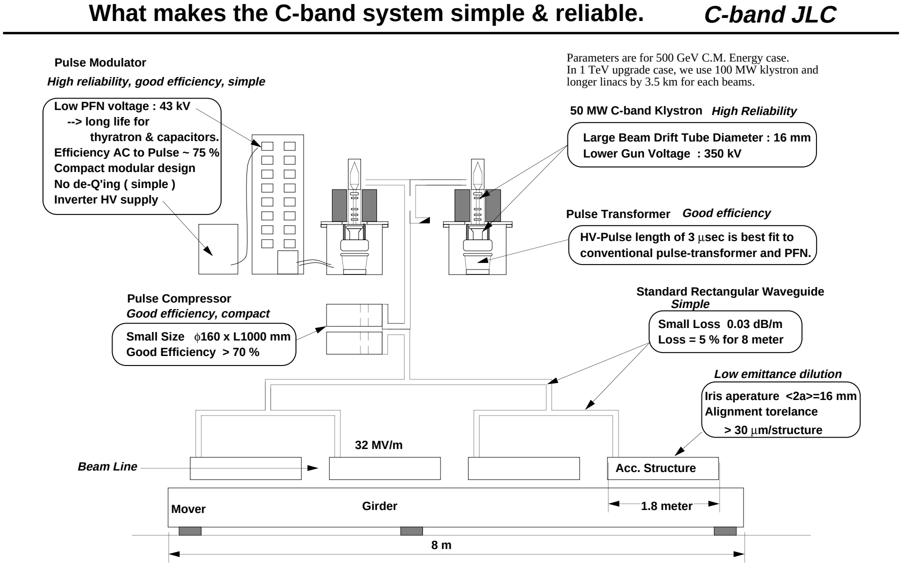

Fig. 2 What makes the C-band system simple and reliable. The key points in the C-band rf-system.