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C-BAND LINAC RF-SYSTEM FOR e^+e^- LINEAR COLLIDER

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A C-band (5712 MHz) rf system for a 500 GeV to 1 TeV e^+e^- linear collider is proposed. An accelerating gradient of 30 MV/m (including beam loading) is 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 the minimum of R/D studies.

I. INTRODUCTION

The choice of rf frequency for the main linac is one of the most critical issues for e^+e^- linear colliders. R/D work has been done at several frequencies ranging from L- to X-band, and even beyond to 30 GHz[1,2]. The principal theories required to design the linear collider have been well established, and the first order designs of these systems have been almost completed.

However, several important practical problems concerning the main linac have not yet been satisfactory solved: how to fabricate the accelerating structure with the tight tolerances required at the high frequencies; how to develop high-power klystrons with reasonable power-efficiency, life-time and focusing system; how to provide high voltage for klystron with reasonable efficiency; and most important at all: how to reduce the construction cost. These difficulties are intimately related to the detailed design of the hardware, which mostly depends on the choice of the rf frequency.

In 1992, we proposed a C-band system as the best solution for reaching 500 GeV center of mass (c.m.) energy, one that does not require critical technology[1]. In this paper, some advantages of the C-band system and details of the current design will be described.

II. ADVANTAGES OF C-BAND SYSTEM

From the point of view of structure efficiency, a higher frequency is desirable, since the shunt impedance scales with the frequency as

$$r \propto \omega^{1/2} \quad . \qquad (1)$$

This is the main reason for choosing a higher frequency than the traditional S-band frequency. For example at X-band, the shunt impedance becomes twice as high as at S-band, which means we can get the same accelerating gradient with half of the input rf power. However, when a beam is accelerated, the effective accelerating gradient is lowered due to beam loading. This effect is more severe in a higher shunt impedance structure, and thus the net accelerating gradient does not simply increase as eq. (1). To make use of the benefits of the high shunt impedance at higher frequency, we need to increase the peak input power per unit length proportional to eq. (1). Unfortunately, the peak power available from a klystron tends to go down at higher frequencies. For this reason, extensive long-term R/D programs are under way trying to realize very high power klystrons at the higher frequency bands.

Another difficulty at the higher frequency bands is the very strong single- and multi-bunch wakefield effects. Recent studies have almost solved the multibunch problem by means of damped and/or detuned structures. In our case, we plan on using the choke mode cavity structure[3] running at C-band. This structure strongly damps the higher modes, so that the multibunch instability should be no problem. However, still there is the single-bunch wakefield effect to consider, one that can cause single-bunch emittance dilution in the main linac. The alignment tolerance of the accelerating structure due to this effect scales, assuming the gradient and lattice fixed, as;

$$\Delta y_{structure} \propto \left(\frac{dW_T}{ds} \right)^{-1} \propto a^4 \propto \omega^{-4} \qquad (2)$$

where a is the beam hole radius and W_T is the single bunch transverse wake function. Equation (2) shows that the tolerance decreases dramatically as the frequency increases. In the case of X-band, the alignment tolerance of the structure becomes 256 times tighter than the S-band case.

As a compromise between the above considerations, we consider C-band to be the best choice of frequency. The shunt impedance can be as high as 55 MΩ/m (including 25 % degradation due to the damping structure) while the straightness tolerance is 30 μm, which is achievable using conventional brazing techniques[5].

If we look at the practical details of the rf system, we will find that, additionally, C-band has a big advantage in the power supply (modulator) that is needed for the klystron. The filling time of rf field into the disk-loaded structure is given by

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

where Q is quality factor, and τ is the attenuation constant of the structure, which is usually chosen close to 0.5. We see that the filling time becomes shorter at higher frequencies. Typically, it is 900 nsec at S-band, 300 nsec at C-band and 100 nsec at X-band. Assuming a compression ratio of 5 in the pulse compressor, and including a beam pulse length, the pulse length at the klystron output becomes 9 μsec at S-band, 3 μsec at C-band and 800 nsec at X-band. A pulse length 800 nsec at X-band is rather short, requiring the development of a special modulator which provides a high voltage (HV) pulse with a fast rise and fall time. On the other hand, in the case of S-band, to get a HV

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pulse of 9 μsec length from a conventional modulator, a long pulse forming network(PFN) line and a large volume transformer are required. The pulse length of 3 μsec in C-band is quite suitable to the conventional klystron modulators of a simple single-line PFN. Among the R/D programs, the major goal for the klystron modulator is quite simple: reduce its cost. For the C-band power supply, since it is not necessary to develop special technology, we can construct a reliable system at lower cost.

III. SYSTEM DESCRIPTION

The machine parameters of the C-band system are summarized in Table-1. In the 500 GeV c.m. energy case, we accelerate 72 bunches in one pulse, and operate the machine at 150 Hz to get a luminosity of 1×10^{34} /cm^2/s.

Fig. 1 shows the schematic diagram of the rf system. The output power of the klystron is enhanced by a factor of 3.5 by the SLED-II type compressor; this is fed into two structures to get a net accelerating gradient of 29.3 MV/m. We need 7.8 km of active length to reach a beam energy of 250 GeV.

A. Klystron Modulator (Pulse Module)

The HV pulse modulator generates a 310 kV and 2.4 μsec flat top pulse. Since this level of voltage and pulse length are normal in conventional modulators, no special R/D is required for the modulator. We assume a power efficiency of 80 %, which is a reasonable estimate considering existing klystron modulators.

B. Klystron

The C-band klystron is a 50 MW klystron. We assume a power efficiency of 45 %, which seems reasonable if we scale from existing S-band klystrons such as the SLAC 5045-tube: 50 MW peak output and 45 % power efficiency, or the Toshiba E3712 tube: 80 MW peak and 46% power efficiency[6].

It is well known that the energy capability of microwave tubes is lower for higher frequencies because the beam pipe diameter is smaller. In the case of pulsed klystrons, the output energy per pulse roughly scales as,

$$P \cdot t \propto \omega^{-2} \qquad (4)$$

The Toshiba E3712 tube can produce : 80 MW x 4 μsec = 320 Joules/pulse at S-band frequency. It scales down to 80 Joules at C-band. Our design is close to this value. Therefore no critical difficulty will be encountered in development of this class of klystron at a C-band frequency.

C. Pulse Compressor

The pulse compressor is a SLED-II type compressor. In order to reduce its physical length, we use a disk-loaded circular waveguide, whose group velocity is 0.056 of speed of the light. Since extra power will be dissipated on the disks, the attenuation becomes higher than in a simple waveguide delay-line.

Table-1. Machine Parameter of C-band Linear Collider

------------ Basic Parameters ------------			
Center of Mass Energy	GeV	500	1000
Number of particle per bunch	10^{10}	1.11	1.5
Number of bunches per pulse		72	72
Bunch spacing	nsec	2.8	2.8
Repetition frequency	Hz	150	50
R.m.s. bunch length	μm	120	120
Normalized emittance at damping ring (x/y)	μm.rad	3/0.03	3/0.03
------------ Parameters Related to Main Linac RF ------------			
Injection Energy	GeV	20	20
Nominal accelerating gradient	MV/m	40.0	57.6
Net accelerating gradient	MV/m	29.3	43.2
Active length of main linac per beam	km	7.8	11.1
Total average power into cavities for two linacs	MW	54.0	52.5
Wall-plug power for two linacs	MW	225	220
Assumed efficiency from AC to RF	%	24	24
------------ Parameters Related to FFS and IP ------------			
R.m.s. beam size at IP (x/y)	nm	260/3.0	372/2.2
Crossing angle	mrad	6.0	6.0
Disruption parameter	Dx/Dy	0.20/17.5	0.067/11.3
Number of beamstrahlung photons		1.5	1.4
Energy loss by beamstrahlung	%	5.3	8.0
Geometrical luminosity reduction factor		0.54	0.64
Pinch enhancement factor		1.6	1.5
Luminosity	10^{33} /cm^2/sec	9.1	6.3

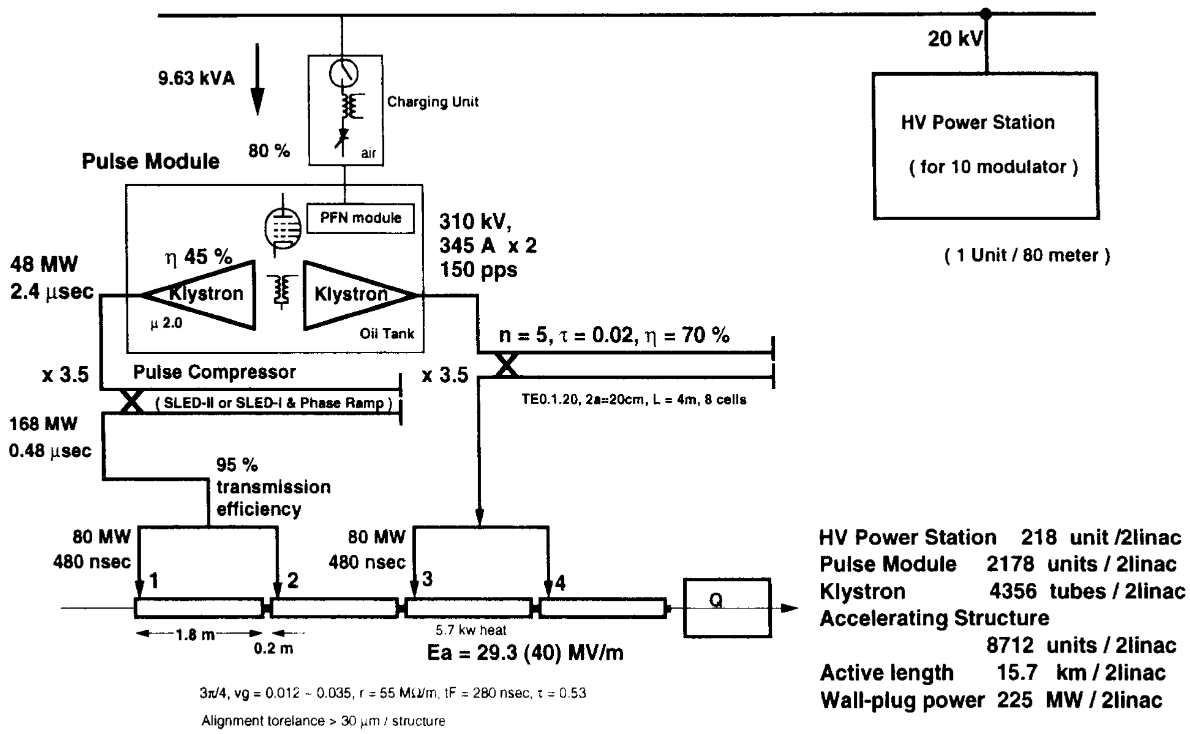

Fig. 1 C-band rf system for e^+e^- linear collider of 500 GeV c.m. energy

According to an analytical estimate, the TE0,1,20 mode inside a cylindrical cavity of diameter 20cm and cell length 50 cm, has a Q-value of 2.7 x 10^5. The attenuation parameter of this delay line becomes τ = 0.02. This compressor will provide a power gain of 3.5 and a power efficiency of 70%. In order to reduce its construction cost, the cavity will be made of steel with copper plating.

D. Waveguide

We do not need to use a special low-loss waveguide, which is sometimes required in the higher frequency bands. We use standard rectangular waveguide (EIA WR-187), whose loss factor is as low as 0.03 dB/meter.

E. Accelerating Structure

In order to avoid emittance dilution due to the multibunch wakefields, we use the HOM-free choke mode cavity structure[3]. Such a structure has been tested at high accelerating gradient at S-band[4]. Detailed discussion of the C-band version of this cavity is given in ref. [5]. The outside diameter of this structure at C-band is 140 mm, which is a suitable size for precise machining on a lathe and also for brazing. This is another reason to choose C-band.

IV. EXTENDIBILITY TO 1 TeV C.M. ENERGY

We can extend the system to reach a c.m. energy of 1 TeV by replacing the klystrons by 100 MW klystrons and extending the active length to 11.1 km/beam. By lowering the machine repetition frequency to 50 Hz, we can limit the wall plug power to 220 MW. Increasing the number of particles per bunch by a factor of 1.4 will allow us to obtain a luminosity of 0.6x10^{34} /cm^2/s.

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