C-BAND LINEAR COLLIDER WITH C.M. ENERGY 500 GEV TO 1 TEV

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Abstract

An electron/positron collider using C-band micorowave for acceleration, proposed several years ago, has been investigated as a possible choice for the Japan Linear Collider. The R&D status is reported in several papers in these proceedings. In the present paper a revised parameter set to be used as the working parameters for the next stage study is presented.

1 INTRODUCTION

The JLC (Japan Linear Collider) group has been investigating the possibility of using the C-band (5712MHz) microwave since 1992 in addition to the study of X-band (11.4GHz).

The major advantages of the C-band compared with higher frequencies are:

- Klystron technology is easier because of the lower current density,
- The efficiency of the modulator is higher owing to the longer pulse length,
- The fabrication/alignment tolerance of the structures is less tight.

An apparent disadvantage of the higher power consumption is solved by choosing a relatively low accelerating gradient. Our design study showed that the luminosity per unit wall-plug power is quite insensitive to the choice of accelerating frequency in the range from S-band to X-band. (The studies of early stages are summarized in [1].)

Although the idea of using C-band was set forth several years ago, actual R&D of hardware and detailed design study progressed slowly and became realistic only in the last couple of years mainly due to the limited man power. In fact the parameter set related to the beams has been almost identical to that of the X-band.

The purpose of the present paper is to give an overall view and the parameter set chosen so as to fit the C-band system.

The present paper is the summary (or header) of all the papers on C-band submitted to this conference. See THP087G, TUP066G, TUP067G, TUP069G, TUP072G, WEP056L, WEP060L for detail.

2 CHOICE OF THE PARAMETERS

One of the most important parameters is the accelerating gradient. It is basically determined by the trade off between the power consumption and the linace length. We chose 40MeV/m as the unloaded gradient.

The r. m. s. bunch length is chosen to be σ_z=200μm, which is about twice that in the previous parameter set. This is to ensure the controllability of the single-bunch energy spread without requiring too large off-crest angle. Because of this choice, the effective transverse wake function becomes twice which makes the structure fabrication/alignment tolerance tighter by factor of two. Thus, after a preliminary study (see[2]), we decided to make the iris aperture larger: $a/\lambda \sim 0.15$ so that the tolerance to suppress the emittance growth within 25% becomes about 30μm. (The long-range wake is not an issue since we choose the choke-mode structure. The distance between bunches 2.8nsec (16 buckets) is large enough.)

The basic structure parameters are determined by a/λ together with the attenuation parameter $\tau \sim 0.5$. As a result, we obtain the required peak power of klystron 50MW. We assume the klystron efficiency 45%. These klystron parameters are fairly conservative.

With the basic parameters above, we constructed the parameter set to maximize the luminosity under the following conditions.

- Total AC power consumption be less than 200MW. (Actually, the luminosity per power is optimized. The actual total power is determined by the choice of the repetition frequency.
- Number of electrons (positrons) per pulse be less than 80×10^{10}. According to the design study of X-band JLC, this limit (coming from the positron production) is marginal by the present technology.
- Relative decrease of the accelerating gradient from the unloaded one (including the effect of off-crest phase) be less than 20%. This value is somewhat arbitrary. A larger value will make the tolerances tighter (such as the pulse-charge fluctuation, accuracy of the beam loading compensation, etc.)
- The single bunch energy spread after correction be less than 0.35% (peak-to-peak).
- Average energy loss due to the beamstrahlung be less than 8%.
- The beta function at the interaction point $\beta_x^* > 10$mm, $\beta_y^* > 0.1$mm.

- Growth factor of the beam offset at the interaction point due to the multi-bunch crossing instability be less than two.

Some of these constraints are irrelevant in the energy range $0.5 < E_{CM} < 1$TeV but play a role at lower or higher energies.

We obtained the parameter set shown in Table.1, after adjustment of some parameters which do not change the luminosity significantly. The parameters of the damping ring, the intermediate linac, etc., are not yet ready.

The proper value for the injection energy to the main linac, which is tentatively listed up as 10GeV, is not known yet. (E_{inj}=20GeV is used in[2]. This is the value adopted for the X-band study and has been used for C-band too for simplicity.) It involves not only the dynamics in the main linac but also the design of the bunch compressor and the intermediate linac. In the case of X-band JLC, we probably need two stage bunch compression with an intermediate linac in between. The compressor design for C-band is slightly easier because of the longer bunch length. Therefore, the problem of one stage or two stages and of the frequency choice of the intermediate linac is still an open question. It might even happen that the intermediate linac is not necessary at all with the first stage acceleration after damping ring done by modifying the C-band structure slightly.

Because of the longer bunch, we now definitely need the crab crossing. Once we decide to adopt the crab crossing, the crossing angle is determined by the trade off between the backbround and phase tolerance of the crab cavity. The value in the table (full crossing angle 8mrad) is according to the earlier study of the background and may have to be revised.

3 ENERGY UPGRADE TO E_{CM}=1TEV

For the possible extension to $E_{CM} = 1$ TeV, we are thinking of an upgrade of klystron upto 100MW by using a low perveance and a higher voltage with a higher efficiency ~70%. The linac must still be lengthened by a factor of about $\sqrt{2}$.

Because of the higher gradient, we can in principle put more particles (By factor of $\sqrt{2}$) in a bunch with the same relative loading. However, the total pulse charge is limited by the positron production. Thus, if we fix the total pulse charge and increase the bunch charge N (by deceasing the number of bunches), the luminosity increases linearly in N. This is not true, however, because of the beamstrahlung. We have to increase the horizontal beta function to minimize the beamstrahlung. Therefore, for higher luminosities, we should think of an improvement of the positron source. The parameter set in Table.1 assumes an improvement of 25%. If we use the same bunch charge and the same number of bunches as at 500GeV, the luminosity at 1TeV would be 5.44×10^{33}/cm^2/sec (with $\beta_x^* = 21$mm). This is increased to 6.98×10^{33} by 25% improvement of the positron source. Therefore, upto this level, the luminosity increases nearly as positron intensity squared. Further improvement brings about only a slow increase of luminosity. (The full improvement of factor $\sqrt{2}$ gives only 7.56×10^{33} with $\beta_x^* = 39$mm.)

4 REFERENCES

[1] JLC-I, JLC group, KEK Report 92-16, Dec. 1992, Tsukuba.

[2] K. Kubo, these proceedings (TUP067G).

Table.1.
C-Band JLC Parameters for E_{CM} = 0.5 and 1.0 TeV

The items left blank for E_{CM}=1TeV are identical to those for 500GeV.

===== BASIC PARAMETERS =====				
Beam energy	E	GeV	250	500
Number of electrons per bunch (at damping ring exit)	N	$\times10^{10}$	1.11	1.39
Number of bunches per pulse	m_b		72	
Number of electrons per pluse	Nm_b	$\times10^{10}$	80.0	100.
Bunch separation	t_b	nsec	2.80	
Repetition frequency	f_{rep}	Hz	100	50
Rms bunch length in main linac	σ_z	μm	200.	
Invariant emittance (DR exit) hor.	ϵ_x	rad·m	3×10^{-6}	
ver.	ϵ_y	rad·m	3×10^{-8}	
longitudinal emittance (DR exit)	$\sigma_E\sigma_z$	eV·m	8.00	
Length of one linac (cavity packing factor 80%)		km	9.42	13.19
===== RF RELATED PARAMETERS =====				
Rf frequency	f_{rf}	GHz	5.712	
Rf wave length	λ_{rf}	mm	52.485	
Nominal accelerating gradient	G_0	MeV/m	40.0	56.0
Effective accelerating gradient[1)]	G_{eff}	MeV/m	31.9	46.4
—– Total Power —–				
Average stored power (2 linacs)		MW	34.6	46.8
Wall plug power (2 linacs)[2)]		MW	153.	133.
Assumed efficiency from AC to structure		%	22.6	35.2
Average beam power (2 linacs)	P_B	MW	6.41	8.01
—– Beam Loading —–				
Loss parameter	k_1	V/C/m	4.86×10^{13}	
Single bunch extraction efficiency	η_1	%	.865	.772
1-Effective/Nominal gradient	$(G_0 - G_{eff})/G_0$	%	20.3	17.1
—– Accelerating Structure —–				
Number of cavity units per beam	N_c		4184	5864
Total length of cavities per beam	L_{active}	km	7.53	10.55
Structure type	constant gradient choke mode			
Accelerating mode			$3\pi/4$	
Length of a unit structure	l_c	m	1.80	
Iris radius/wavelength (average[4)])	a/λ		.148	
Max (at entrance)			.173	
Min (at exit)			.125	
Filling time	T_f	nsec	286.	
Average group velocity /c	v_g/c		.023	
Average Q-factor	Q		9670.	
Attenuation parameter CG	τ		.53	
Shunt impedance	R_s	MΩ/m	53.1	
Elastance	s	Ω/m/sec	1.95×10^{14}	
Peak power per cavity		MW	84.3	165.
—– Pulse Compressor —–				
Compression scheme	multi-cell coupled cavity			
Pulse compression ratio			5	
Pulse compression efficiency		%	67.	
—– Klystrons —–				
Klystron peak power (2 cavities/klystron)	P_{kly}	MW	50.3	98.6
Efficiency	η_{kly}	%	45.	70.
Number of klystrons per beam	N_{kly}		2092	2932

Required klystron pulse length		μsec	2.44	
—– Modulators —–				
Number of modulators per beam			1046	1466
Efficiency from AC to pulse		%	75	
===== LINAC BEAM DYNAMICS =====				
Injection energy of main linac	E_{inj}	GeV	10.0	
—– Energy Spread —–				
BNS energy slope $\langle(\sigma_z/E)(dE/dz)\rangle$		%	-0.41	-0.52
Energy slope $\langle(\sigma_z/E)(dE/dz)\rangle$ due to wake[5)]		%	-0.57	-0.50
Phase delay of rf crest[3)]	ϕ_{rf}	deg	14.5	10.0
Single bunch full energy spread at linac exit		%	0.35	0.28
Energy error of last bunch by 1% error of Nm_b		%	-.20	-.18
R.m.s. energy error of the last bunch by 1% r.m.s. random error of N		%	.026	.023
—– Transverse —–				
Beta function scaling constant $\beta=\beta_1\sqrt{E(\mathrm{GeV})}$	β_1	m	2.0	
Total betatron phase advance/2π			79.0	82.2
Transverse wake[5)] at $z=2\sigma_z$		V/C/m^2	4.64×10^{15}	
Structure misalignment tolerance (r.m.s.)		μm	30.	
===== FINAL FOCUS SYSTEM =====				
Distance from IP to the first quad		m	2.2	
Beta function at IP	β_x^*	mm	15.0	30.0
	β_y^*	μm	200.	200.
Invariant emittance at FFS exit	ϵ_x	rad.m	3.3×10^{-6}	
	ϵ_y	rad.m	4.5×10^{-8}	
===== BEAM-BEAM PARAMETERS[6)] =====				
Number of particles/bunch at IP (assume 10% loss in linac and FFS)	N^*	$\times10^{10}$	1.00	1.25
Rms beam size at IP	σ_x^*	nm	318.	318
	σ_y^*	nm	4.29	3.04
Aspect ratio	σ_x^*/σ_y^*		74.2	104.6
Crossing angle (crab crossing)	ϕ_{cross}	mrad	8.00	8.00
Beam diagonal angle	σ_x^*/σ_z	mrad	1.59	1.59
Disruption parameters	D_x		.225	.141
	D_y		16.66	14.75
Amplitude blowup factor of multibunch crossing instability			1.41	1.21
—– Background —–				
Detector solenoid field	B_{sol}	Tesla	2.0	2.0
Distance from IP to mask tip		m	.66	.66
Required mask angle	θ_{mask}	rad	.072	.082
Average number of beamstrahlung photons per electron	n_γ		1.42	1.61
			[1.64]	[1.78]
Average energy loss by beamstrahlung	δ_{BS}	%	3.87	8.38
			[4.72]	[8.58]
Upsilon maximum	Υ_{max}		0.187	0.451
Upsilon average	Υ_{avr}		0.0787	0.189
—– Luminosity —–				
Nominal luminosity[7)]	$\mathcal{L}_{00}$	10^{33}/cm^{2}s	4.20	4.63
Geometrical reduction factor			.863	.863
Pinch enhancement factor	H_D		1.82	1.75
e^+e^- Luminosity	$\mathcal{L}_{e^+e^-}$	10^{33}/cm^{2}s	6.58	6.98
			[8.46]	[8.42]
$\gamma\gamma$ Luminosity[8)]	$\mathcal{L}_{\gamma\gamma}$	10^{33}/cm^{2}s	[2.43]	[2.88]
$e^-\gamma$ Luminosity[8)]	$\mathcal{L}_{e\gamma}$	10^{33}/cm^{2}s	[3.79]	[4.28]

1) Energy gain divided by structure length, including beam loading, its compensation efficiency, single-bunch wake, and the loss due to off-crest compensation.
2) Includes only the accelerating power for the main linac.
3) Weighted according to the contribution to the short-range transverse wake, namely, $[\langle(a/\lambda)^{-c}\rangle]^{-1/c}$ (c=3.5).
5) Following longitudinal and transverse wake Green functions (per unit structure length) are used.

$$W_L(z) = 5.967\times10^{14} - 1.504\times10^{16}\sqrt{z} + 1.235\times10^{17}z \quad \text{(V/C/m)}$$
$$W_T(z) = z(1.579\times10^{19} - 2.346\times10^{20}\sqrt{z} + 1.258\times10^{21}) \quad \text{(V/C/m}^2\text{)}$$

(z in meters)

4) Average through the entire linac. It must be smaller near the linac entrance for providing the BNS damping.
6) The numbers in the square brackets [ ] are obtained using a new beam-beam simulation code CAIN. Others are those from simple formulas used in a parameter optimization program. The latter is used for comparing different parameter sets. Thus, the numbers in [ ] should be used. The difference is (possibly) mainly due to the horizontal disruption which is not negligibly small.
7) $f_{rep}m_bN^2/4\pi\sigma_x^*\sigma_y^*$.
8) Luminosity involving the beamstrahlung photons.