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ELECTRON LINAC OF TEST ACCELERATOR FACILITY FOR LINEAR COLLIDER

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Abstract KEK has proposed to build a Test Accelerator Facility (TAF) capable of producing a 2.5 GeV electron beam for the purpose of stimulating R&D for the JLC (Japan Linear Collider) project. The TAF consists of a 1.54 GeV S-band linac, 1.54 GeV damping ring and 1.0 GeV X-band linac. The TAF project will be carried forward in three phases. Through phase-I and phase-II, the S-band and X-band linacs will be constructed, and the damping ring will be completed in phase-III. The construction of TAF phase-I has been started, and a 0.3 GeV S-band linac has been almost completed.

INTRODUCTION

As a post-TRISTAN project, KEK has proposed a new project to pursue the energy frontier physics by using an electron-positron colliding machine.[1-2] It presently be considered that the Japan Linear Collider (JLC) project should be started at the center-of-mass energy around 400 GeV, which seems to be the optimum in order to start experiment till the end of this century.[3-4] At the first stage of JLC project, the JILC (Japan Intermediate Energy Linear Collider) will be constructed at 400 GeV center-of-mass energy, which is two times higher than that of LEP-II. The energy can be increased up to 600 GeV by extending the rf power system. At the final stage of the JLC project, a 1 TeV linear collider will be constructed by extending the total length of the linacs.

Table 1 shows the design parameters of 400 GeV JILC. It should be noted that these parameters are tentatively obtained. The parameters will be changed by the detailed design studies carried out for each major sub-system, for example the main linacs, damping rings and final focus systems. The JILC is installed in the straight tunnel with the total length of 10 km, which is required to increase the energy up to 600 GeV. The multi-bunches of electrons are generated by an rf-gun and they are accelerated up to 1.54 GeV by an S-band injector linac for a damping ring. The damping ring contains 8 bunch trains of 10 bunches each. One bunch train is kicked out every shot, after reducing the beam emittance. The bunches from the damping ring are compressed by the first bunch compressor from 4.5 mm to 350 μm. The bunches are re-accelerated by an S-band preacceleration linac up to 10 GeV and they are re-compressed to 60 μm by the second bunch compressor. The bunches are accelerated by an X-band main linac up to 200 GeV. The electron and positron bunches are focused by the final focus system and they are collided at the interaction point.

Table 1. Design parameters of 400 GeV JILC

Beam energy	E	200 + 200 GeV
Luminosity	L	3.1×10^{33} cm^{-2}sec^{-1}
Total length of the linacs		10 km
Number of particles/bunch	N	1.0×10^{10}
Repetition frequency of linacs	f_{rep}	200 Hz
Number of bunches/rf pulse	N_b	10 bunches
Number of bunches /sec	f_b	2000 bunches/sec
R.m.s beam size at IP		
Horizontal	σ_x^*	290 nm
Vertical	σ_y^*	2.2 nm
Aspect ratio	$R = \sigma_x^*/\sigma_y^*$	132
R.m.s. bunch length	σ_z	60 μm
Disruption parameter	D_x/D_y	0.103/13.5
Pinch enhancement factor	H_D	1.5

TEST ACCELERATOR FACILITY (TAF)

The following theoretical and technical R&D programs have been in progress by the study group:[4] design of linacs and damping rings,[5,14] beam dynamics in linacs and damping rings, studies on the interaction region, such as beam-beam interactions,[6-7] design of final focus system,[8-9] high power rf sources to generate high accelerating gradients,[10-12] accelerating structures capable of producing high gradient of 100 MeV/m,[13] beam monitors, controls ,[15-16] alignments, [17] intense electron and positron sources.

As for the linear collider, the beam should stably be accelerated so as to collide the sub-micron beams at the interaction point. Therefore, the R&D for the stability of both the linacs and the damping rings is highly required. The study group has decided to construct a test facility as a major R&D program. The proposed Test Accelerator Facility (TAF) consists of a 1.54 GeV S-band linac, 1.54 GeV damping ring and 1.0 GeV X-band linear accelerator. Therefore the major part of the JILC can be tested by using the test facility. The S-band linac is an injector of the damping ring, and a high current single bunch and multi-bunches are accelerated up to 1.54

GeV. The low emittance beam from the ring is compressed by the bunch compressor and it is re-accelerated by the high gradient X-band linac up to 2.5 GeV. The beam from the X-band linac will be utilized to test a prototype final focus system.

The TAF project will be progressed through three phases. The S-band and X-band linacs will be constructed through phase-I and phase-II, and the damping ring will be completed in phase-III. Table 2 shows the parameters of the linacs of the TAF. The 0.3 GeV S-band linac is under construction at the TRISTAN Nikko experimental hall. A new building with an accelerator tunnel has been proposed in order to install linacs.

Table 2. Design parameters of the linacs of TAF

Linac	S-band		X-band
Phase	I	II	II
E_b(GeV)	0.3	1.54	1.0
E_a(MeV/m)	40 - 50	40 - 50	70 - 100
f_{rf}(GHz)	2.856	2.856	11.424
P_{rf}(MW/structure)	200	200	50
N_k(Klystrons)	4	24	10
N_s(structures)	2	12	20
L_s(m/structure)	3	3	0.5
N_e(electrons/bunch)			
Single bunch	5×10^{10}	5×10^{10}	5×10^{10}
Multi-bunches	1×10^{10}	1×10^{10}	1×10^{10}

1.54 GeV S-BAND INJECTOR LINAC

The JILC is composed of the following S-band linacs: two damping ring injectors of 1.54 GeV each, two pre-accelerating linacs of 10 GeV each, and a 10 - 30 GeV linac for positron generation. The R&D for the high gradient linacs in S-band frequency is also required.

The JILC is designed to collide the bunches at the repetition rates of 2000 pps. The linacs are operated at 200 Hz and 10 bunches are accelerated per shot. The bunch separation in a bunch train is chosen as 16 buckets of 11.424 GHz, since the longer bunch separation suppresses the multi-bunch instability. An rf-gun with a photocathode is a low emittance and high current source, since the emitted electrons are accelerated by high accelerating fields generated in the cavity. The pulse structure of the emitted beam is determined by the fine structure pulses of the mode-locked laser. The rf-gun makes it possible to generate multi-bunches with longer bunch separation, since the bunch separation can be tunable by adjusting the mirror system of the laser. The lasertron is a DC-gun with a photocathode and mode-locked laser. The large portion of the basic techniques established by the lasertron project[18] in KEK can be applied to the rf-gun. The rf-gun generates 10 bunches with the bunch separation of 4 buckets of 2.856 GHz. The number of electrons in a bunch is 1×10^{10} for the multi-bunches.

The structures of the linac consists of 3 m-long constant gradient structures of $2\pi/3$ mode. In order to produce the gradient of 40 - 50 MeV/m in a 3 m-long structure, the rf power of 200 MW should be required. The rf power from a pair of two SLAC-

5045 klystrons are combined by a 3db coupler and the rf power of 200 MW, 1 μs can be obtained. Table 3 shows the parameters of the 1.54 GeV S-band injector linac.

Table 3. Design parameters of 1.54 GeV injector linac

Beam final energy	E_{fin}	1.54 GeV
RF frequency	f_{rf}	2.856 GHz
Accelerating gradient	G_{acc}	40 - 50 MeV/m
Bunch spacing	t_b	4 buckets = 1.4 ns
Number of bunches	N_b	10 bunches
Normalized emittance	$\gamma\varepsilon_0$	1.0×10^{-2}
R.m.s. bunch length	σ_z	3 mm
Accelerating mode		$2\pi/3$
Structure length	L_s	3.0 m
Attenuation parameter	τ	0.50
Filling time	t_f	600 nsec
Normalized elastance	S_0	0.8 Vm/pC

1.54 GeV Damping Ring

Table 4 shows the parameters of the damping ring design for JILC. The normalized emittance required for the damping ring is 2.5 μmrad. The required damping time should be less than 2.5 msec. In order to achieve these extremely low emittance and short damping time, the wigglers with the total length of 76 m is combined to the ring. The 7.6 m-long wiggler unit is composed of the permanent magnets, and the designed wiggler field is 1.8 Tesla, which seems to be a limit by the conventional permanent magnets.

Table 4. Design parameters of the 1.54 GeV damping rings

Type		$FODO_{arc}$ + Wiggler
Beam energy	E_b	1.54 GeV
Circumference	C	176.0 m
Bending magnet	B_0	1.15 T
Bending radius	r_b	4.46 m
Normalized emittance	$\gamma\varepsilon_0$	2.1×10^{-6} rad·m
Damping time	τ_x/τ_y	2.5/2.5 msec
Repetition rate	f_{rep}	200 Hz
Rf frequency	f_{rf}	1.428 GHz
RF peak voltage	V_{rf}	0.92 MV
Bunch spacing	t_b	2 buckets=1.4 ns
Number of bunches	N_b	10 bunches
Number of bunch train	t_b	8
Bunch current	I_b	3.35 mA
Total current	I_{tot}	218 mA
R.m.s. bunch length	σ_z	4.5 mm
Energy spread	$\Delta E/E$	0.76×10^{-3}
Momentum compaction factor	α_p	2.2×10^{-3}
Number of FODO cells in arc		54
Wiggler length	L_w	76 m = 7.6 m/unit x 10
Wiggler field	B_w	1.8 T

The arc is composed of 27 separated function FODO cells since the simple lattice makes it possible to obtain simplicity. The rf-frequency of ring cavities is chosen as 1.428 GHz in L-band since the bunch length is 4.5 mm in the ring. The bunch separation of each bunch is two buckets of the rf-frequency in the ring cavity. The ring contains 8 bunch trains of 10 bunches each. One bunch train is kicked out every 5 ms, after the bunches circulate in the ring during 16 damping times.

In order to decrease jitter, the following two extraction systems are designed: a double kicker system and a feed-forward system. The extraction kicker consists of a pair of two kickers driven by the same pulser. The systematic error due to the jitter of the kicker-pulser will automatically be cancelled by two kickers. For random error correction, the bunches are monitored by a position monitor installed at the exit of the extraction kickers. The random error between bunches in a bunch train is corrected by the additional kicker installed at the injection part of the preaccelerator linac. For the feed-forward system, the longer beam line is required in order that the control signals can catch up the bunches.

1.0 GeV X-band Linac

The tentative parameters of the 1.0 GeV X-band linac are listed in Table 5. The structure is a conventional $2\pi/3$ mode, constant gradient disk-loaded structure. A cold model has been tested and prototypes of the structure for high-power test will be constructed. The other type of structures are also studied to investigate the possibility of these structures, for example damped cavities of higher order modes and the structures of the other modes.

The rf sources for X-band klystrons are under developing. A 20 MW X-band klystron so called XB-50 is under progress and the design work of a 50 MW X-band klystron (XB-65) has been started.

Table 5. Design parameters of X-band linac.

Beam final energy	E_{fin}	2.5 GeV
Beam injection energy	E_{inj}	1.54 GeV
RF frequency	f_{rf}	11.424 GHz
Accelerating gradient	G_{acc}	100 MeV/m
Bunch spacing	t_b	16 buckets=1.4 ns
Number of bunches	N_b	10 bunches
Accelerating mode		$2\pi/3$
Structure length	L_s	0.866 m (99 cell)
Attenuation parameter	τ	0.50
Filling time	t_f	90 nsec

TAF PHASE-I LINAC

Phase-I linac is constructed at TRISTAN Nikko experimental hall. The rf-gun is under developing and a 240 kV thermionic gun is utilized as an electron source for the phase-I linac. The linac consists of three subharmonic bunchers, prebunchers, TW buncher and accelerating structures. The rf power from a pair of two SLAC-5045 klystrons is fed into one accelerating structure. The following gradient will be obtained in the structures: 100 MeV/m in 0.6 m-long structure, 70 MeV/m in 1.5 m-long structure, and 50 MeV/m in 3 m-long structures. The pulsed electron beam from the gun is compressed by three sub-harmonic bunchers to generate a high current single bunch. The single bunch is utilized for the wake field experiments and R&D for the beam monitors. The rf frequencies of the SHB are 119 MHz, 238 MHz and 476 MHz respectively. The number of electrons up to 1×10^{11} can be produced in a single bunch.

The requirement for the support and alignment system of the TAF differs from the ones for the accelerators in routine use. The components of the test accelerator should be easily replaced for the experiments. The support system of the phase-I linac consists of a 9 m long and 0.7 m wide table made of SUS-316L. The flatness of the table surface is adjusted and it is evaluated to be 36 μm/9m. The components, such as electron gun, beam monitors, structures can be aligned within 50 μm by putting on the table. The large components such as Helmholtz coils , Q-magnets and energy analyzer magnet can be aligned within 100 μm.

Figure 1. The Test Accelerator Facility (TAF)

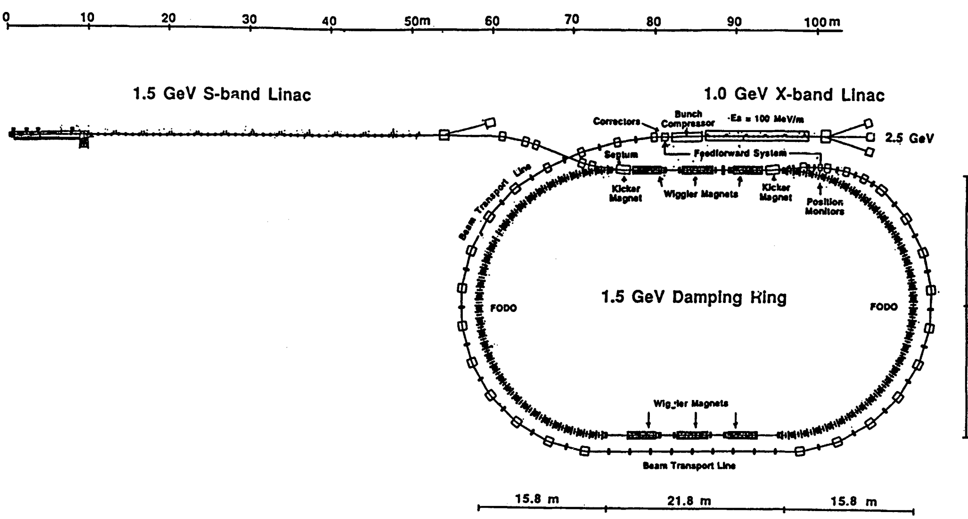
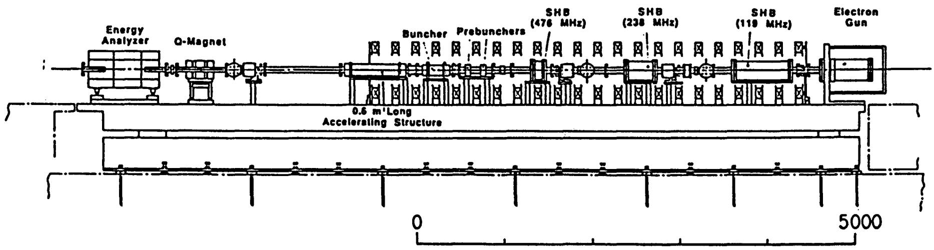


Figure 2. TAF phase-I linac



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A number of contributions to this conference contain more specific and detailed reports on the various aspects of the Test Accelerator Facility.

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