PRESENT STATUS OF R&D FOR JLC PROJECT

Seishi Takeda

National Laboratory for High Energy Physics
Oho 1-1, Tsukuba, Ibaraki 305

Introduction

The R&D of Japan Linear Collider (JLC) project was started from 1987 to construct the machine by the end of this century[1][2]. In past four years the R&D has been made remarkable progress [3][4]. The present target of R&D is concentrated upon the design of the real machine beyond the conceptual one. The sub-accelerator systems are under developing such as electron positron sources, injector linac, damping ring, kicker magnet, bunch compressors, high power klystons, high power klystron modulators, high gradient accelerating structures, high power rf components, beam instrumentations, computer control, final focus system and precise alignment system. In order to prove the total specification of those accelerator systems, the project to construct the Accelerator Test Facility (ATF) has been started in the TRISTAN Assembly Hall. The ATF consists of electron sources, 1.54 GeV S-band injector linac, 1.54 GeV damping ring to obtain the vertical emittance of 3×10^{-8} rad m, bunch compressor, final focus system to obtain 30 nm of vertical beam size, nanometer alignment system, nanometer beam size monitor, 1 GeV X-band linac, positron target and computer control system. The R&D for JLC will reach the design goal after the construction of ATF which will be completed in 1992.

Parameters of JLC

The JLC has three stages of center-of-mass energies. At the first stage, JLC will be started at 0.5 TeV in the center-of-mass energies and it will be increased to 1.0 TeV and to 1.5 TeV by increasing accelerating gradient of main linac. The total length of JLC is fixed at the energy upgrade.

The design parameters should be consistent with theoretical requirements and accelerator technology. Therefore the parameters have been evaluated for not an ideal case but a realistic machine which is taken into account the decreases of luminosity due to multi-bunch instabilities, misalignment of accelerating structures, misalignment of monitors and ground motions. The parameters were determined by the simulation code to obtain the highest luminosity at 1.5 TeV in the center-of-mass energy system. Table 1 shows the global parameters and Fig. 1 shows the schematic layout of JLC.

Center of Mass Energy	E (TeV)	0.5	1	1.5
Luminosity	L ($cm^{-2}s^{-1}$)	2.4×10^{33}	8.8×10^{33}	1.3×10^{34}
Total Length of JLC	L (km)	25	25	25
RF Frequency	f_{rf} (GHz)	11.424	11.424	11.424
Accelerating Gradient	G_a (MeV/m)	40	80	120
Repetition Frequency	f_{rep} (Hz)	150	150	150
Particles / Bunch	N	1.3×10^{10}	2.0×10^{10}	2.7×10^{10}
Bunches / RF pulse	N_b	20	20	20
Wall Plug Power	P_{AC} (MW)	30	120	240
Average Beam Power	P_b (MW)	3.0	9.7	19.3
Invariant Emittance at Interaction Point	ε_{xn} (rad·m) / ε_{yn} (rad·m)	5.5×10^{-6} / 7.5×10^{-8}	5.5×10^{-6} / 7.5×10^{-8}	5.5×10^{-6} / 7.5×10^{-8}
Beam Size at IP	σ_y / σ_x (nm)	4.5 / 335	3.2 / 372	2.9 / 561
R.M.S. Bunch Length	σ_z (μm)	152	113	95
Energy Loss by Beamstrahlung	ΔE/E (%)	5.6	15	15

Table 1. The global parameters of JLC

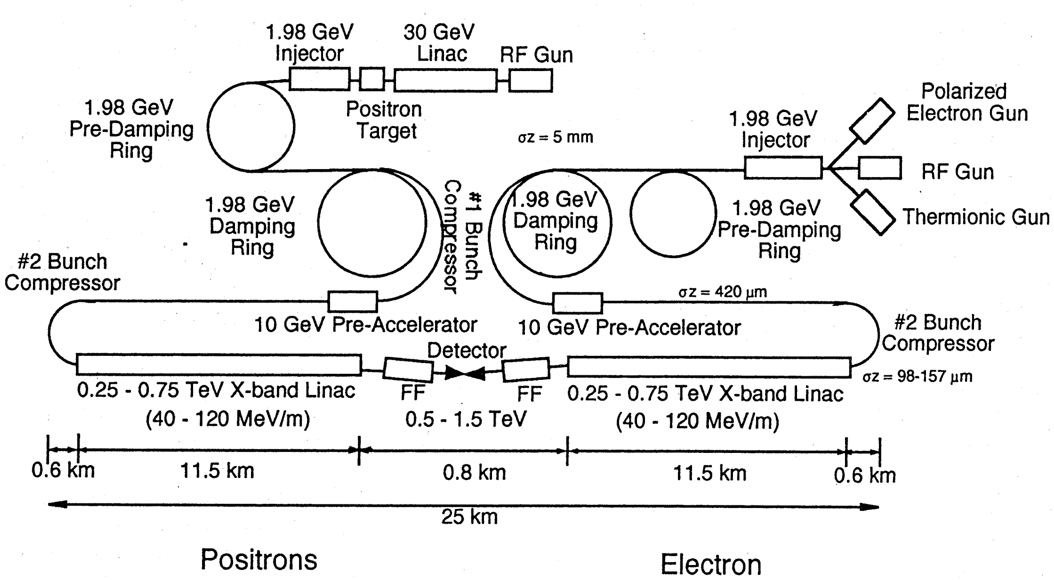

Figure 1. The schematic diagram of JLC

Electron and Positron Sources

The multi-bunch acceleration gives rise to both the high luminosities due to high repetition rate of collisions and the high efficiency due to heavy beam loading. A bunch train contains 20 bunches, and each bunch contains $1.3 - 2.7 \times 10^{10}$ particles. The bunches are accelerated every sixteen rf buckets of 11.424 GHz rf frequencies to decrease the effect of multi-bunch instabilities and to maintain the low beam emittance. The bunch separation between the first bunch and last one is 26.6 ns. The charge fluctuation in the bunches should be less than $\pm 2\%$ to obtain design luminosity. Considering with the beam loss in the injector, damping ring and beam collimator, the electron sources should generate the bunches containing $2 - 4 \times 10^{10}$ electrons. The following three types of electron sources are developing for JLC.

Thermionic Gun

The thermionic gun with sub-harmonic bunchers is one of the most conventional and reliable electron sources. The multi-bunches with bunch separation of 1.4 ns are generated by means of a grid control and 714 MHz sub-harmonic bunchers. A thermionic gun, 240 kV gun-pulser and grid pulserhave been developed. The beam current monitosr with an amorphous core have been developed to measure current waveform of the beam with time resolution less than 60 ps. The thermionic gun system will be installed in the injector linac of the ATF.

Photocathode RF Gun

As one of the advanced electron sources, a photocathode rf gun is developing to generate multi-bunches of low emittance. The photocathode is irradiated by the fine structure light pulses from a mode-locked laser and hence the short bunches are produced from the photocathode surface. The bunch spacing can be selected to be 16 buckets of rf frequencies by the optical system. The bunches are accelerated by high accelerating field in the rf cavity. This scheme produces low emittance multi-bunches without any buncher system due to the increase of beam emittance. The technique of the production of photocathode has been established. The laser, rf source, rf cavity and beam diagnosis systems have been completed. The rf gun will be installed in the injector of the ATF.

Polarized Electron Gun

A polarized electron source by using a GaAs-AlGaAs super lattice has been developed. The superlattice is fabricated by the MEB (molecular-beam epitaxy) method. The thickness of the AlGaAs and GaAs is controlled by a monomolecular layer accuracy and the optimum thickness of the superlattice is chosen in order to obtain the polarization of the beam as high as 80%. By a preliminary cathode test the maximum polarization of 74 % has been obtained at room temperature at the thickness 21 $\AA$ and 33 $\AA$ of GaAs and AlGaAs respectively.

A polarized electron source by using a strained GaAs layer with a lattice-mismatch heterojunction has been developed by Nagoya group. The polarization of 85 % has been obtained at the test stand. The final target of the R&D is the polarization higher than 80 % and cathode-life of 1 week.

The next step of the R&D is focused to the design of the polarized electron guns for JLC. A 100 kV polarized electron gun is preparing to produce the beam with the polarization as high as 80 %. The gun will be installed in the ATF injector.

Positron Source

For the positron source, the design of positron target is carrying out by modifying the computer code EGS4. The normalized yield from electrons to positrons is estimated to be 0.05 e^+/e^-/ GeV. Assuming that the beam loss is 50 %, the number of positrons should be $2x10^{10}$ in a bunch and hence the energy dissipation per pulse is evaluated to be 640 J at the target. The machine is operated at 150 Hz and then the cooling system for 100 kW beam power is required. The wire target has an advantage of high efficiency to capture the slow positrons. We are designing the wire target including flux concentrator and capture section. A prototype of positron target will be installed in the 1.54 GeV ATF injector to investigate the normalized yield of the system.

S-band Linacs

The S-band linacs of JLC are composed of 1.98 GeV damping ring injectors, 30 GeV linac for positron production and 10 GeV pre-accelerators. The total beam energies for those S-band linacs are 54 GeV, which is same as the energy of SLC linac. The optimum accelerating gradient should be chosen to minimize the cost of construction. The accelerating gradient of 33 MeV/m can be obtained in constant gradient structures of 3 m-long at 100 MW rf peak power. The S-band klystrons (type-E3712) have been developed to produce 100 MW peak power in 1 μs pulse duration. This klystron also produce 85 MW peak power in 4.5 μs pulse duration. The energy doubler will be utilized to reduce the cost of construction. The SLC utilizes the SLED cavities to produce the rf peak power of 300 MW from 65 MW peak power in 3.5 μs pulse duration. The maximum peak power from the SLED cavity is limited by the rf breakdown around the coupling iris. New type of SLED cavities with two coupling irises have been developed to reduce the electric field around the irises. The dimensions have been obtained by URMEL code for both the fundamental mode (TE_{015}) and restriction mode (TE_{115}). The electromagnetic fields in the two-irises SLED cavity were estimated by MAFIA code to compare with the SLED cavity of SLC. The peak power of 450 MW can be produced from the 85 MW klystrons with the pulse duration of 4.5 μs. If two 3 m-long structures are driven by one klystron with energy doubler, the accelerating gradient of 33 MeV/m can be obtained. A high power test will be carried out to install in the ATF injector linac. The coupler design for the structures have been performed by MAFIA code. The design of constant gradient S-band structures of 3 m-long have been completed.

The rf windows at S-band frequency have been designed for 100 MW peak power. The material of the rf window has been improved. The gap between grains of Al_2O_3 is one of the origins where the rf breakdown is generated on the ceramics. If the ceramic plate is processed by HIP (Hot Isostatic Pressing) at 2000 $°C$ of temperature and 2000 kg/cm^2 of pressure, the grains are closely pressed and gap distance is closed. It gives rise to reduce the out-gassing and rf breakdown. The second type is an rf window of single mode to reduce the rf field across the ceramic window. The third one is the tapered type with large rf window. The design work has been started by the simulation code MAFIA and the high power tests are carrying to estimate the specification. The dummy loads by using SiC material without water leakage have been developed. Those high power rf components will be installed in the ATF injector linac.

Damping Rings and Bunch Compressors

The design work of the damping rings and bunch compressors has been carried out to obtain the bunches suitable for main linacs. The one of the main targets is to obtain vertical emittance of 3×10^{-8} rad m. The design of the damping ring has been completed and the present work is focused to the R&D of precisely aligned FODO magnets, wiggler magnet of long length, auto-alignment system to control the vertical position within ± 10 μm, smooth vacuum pipes with low beam inductance, double kicker system to cancel jitters and rf system to damp higher order modes.

The bunch length in main linacs should be 95-152 μm to control the adverse effects caused by the transverse wake field. The bunch of this length is not readily obtainable from the damping ring and hence the bunch compressors are required. For the bunch extracted from the damping ring the momentum spread Δp/p is estimated to be 0.08 % with the bunch length of 5 mm. By the first bunch, the bunch is compressed in length to 0.4 mm while the momentum spread is increased to 1 %. By the second bunch compressor with 2 % energy spread compresses the bunch length to 95-152 μm although 5 % particles spread out beyond $2\sigma_z$.

X-band Klystrons and Modulators

The klystrons of 150 MW peak power is needed for the center of mass energy of 1.5 TeV, the final goal of JLC. At the center of mass energy of 0.5 TeV, 30 MW of peak power is needed to produce 40 MeV/m of accelerating gradient. As the first step of the R&D, a 30 MW klystron (type XB-50K) has been designed by using the FCI simulation code. The rf peak power of 11 MW was obtained with 70 ns pulse duration. The maximum rf peak power was limited by the troubles of half-wavelength aluminum ceramics in rf window. The peak power of 18 MW was obtained by replacing the rf window to a pill-box type. The design of the 100 MW X-band klystron (type XB-72K) has been completed by using the FCI simulation code. The XB-72K generates the rf peak power of 100 MW at 550 kV and 150 MW at 600 kV of applied voltage. The Shintake Cavity is applied for the output cavity to decrease the rf field and avoid the rf breakdown in the output gap. The first tube will be tested in Nov. 1991.

The X-band klystron modulators for XB-72K klystrons have been completed. A conventional PFN type klystron modulator generates peak voltage of 550 kV in 400 ns of pulse duration. As the advanced klystron modulator, the design study of MPC (Magnetic Pulse Compression) scheme with an amorphous core has been carried out. The peak voltage of 600 kV could be obtained in 100 ns pulse duration.

X-band Accelerating Structures

The R&D of main X-band accelerating structures has the following two items; the fabrication technique of the structures in X-band scale, the design studies of the damped structures and detuned structures.

The technical R&D of machining and brazing for 1/4 scale of conventional S-band structures has been started for JLC. Two types of ultra-precise lathes have been developed in the KEK Machine Center to finish the surface of the cells for X-band structures.

As a prototype structure, a constant impedance disk-loaded structure with 20 cells and 2 couplers has been developed. The disk aperture is 6 mm to obtain the maximum accelerating gradient of 100 MeV at 30 MW input rf power. The average accelerating gradient of 85 MeV/m would be obtained in a structure.

The multi-bunch acceleration gives rise to the high luminosity due to high repetition rate of collisions and then twenty bunches would be accelerated in one rf pulse. To preserve the low emittance along the linac, the structure design should be taken into account the multi-bunch instabilities due to the wake field excited by the bunches in the structures. The transverse wake field, especially TM_{110} like mode, excited by the preceding bunches should be damped below 1 % when the successive bunch passes through the same structure. At present there are two candidates to reduce the multi-bunch instabilities; damped structures and detuned structures.

The study was started from the estimation of the transverse wake fields in the disk-loaded structures by using URMEL, TBCI codes. The design of damped structures has been carried out by MAFIA codes and Slater's formula to minimize the external Q-value for the TM_{110} mode. The slot dimensions have been optimized to minimize the external Q-value for the TM_{110} mode. It was found that the external Q-value for the TM_{110} mode could be reduced to the required value of 15 with large width of iris while the Q-value of accelerating modes are also reduced to 5600, which is 75 % of the one without damping waveguides. The detuned structure with proper distribution of the dipole modes of all the cells in the structure would cancel the effective wake field felt by the successive bunches. The fundamental design has been carried out by means of the equivalent circuit model.

Final Focus and Alignment System

The design study of the final focus has been almost completed. Trough the design of a flat-beam final focus, K. Oide proposed that the vertical size is limited by the synchrotron radiation in the final focus quadrupole doublet with the chromatic effect of a quad. At present, the study is concentrating to the R&D of the quadrupole magnets, support and alignment system. A 10 cm long quadrupole magnet with a bore radius of 2 mm was constructed with vanadium permendur in 1989. The bore radius is 4 times larger than the quad for JLC. The measurements by a small Hall probe show that the quad produces a 700 Tesla/m field gradient in the region where the radius less than 1/3 half aperture without any serious field deformation due to saturation effects. The results from the measurements suggest the validity of the design calculation. We are designing the final focus quad for ATF.

As for the alignment of final focus quads, the low frequency components of the vibration displacement can be controlled by the feedback system while the high frequency components should be suppressed less than vertical beam size. The techniques for precise measurement of displacement have been developed involving laser interferometers and laser photodetector methods. As a preliminary experiment, a prototype of the alignment system for the load of 10 kg was developed and the vibration displacement could be suppressed to 30 nm.

KEK attends the international collaboration for the FFTB project in SLAC to obtain the vertical beam size of 60 nm. A prototype final quadrupole magnet has been completed and the measurement of magnetic field distribution has been carried out. A prototype of alignment system for FFTB final focus quads has been completed. The design of the final Q-magnets (QX_1, QC_1 and QC_2) and alignment system for FFTB have been completed and they will be installed at the exit of a straight line of SLC in 1992

Beam-Beam Effects and Background

At the interaction point, positrons and electrons in the bunch radiate photons (beamstrahlung) due to the deflection by the very strong electromagnetic field produced by the opposing bunch. In the same electromagnetic field, created low energy e^+e^- pairs are deflected by large angles and collide final focus magnet in the detector. This gives rise to a potential source of the background problem. The estimation of background has been carried out for the pair creations by coherent and incoherent processes. The numbers of pairs through these processes are estimated to be 8×10^4 per collision. Particles below 1 GeV will be trapped by the solenoidal magnetic field in the detector and will not cause the background. The horizontal deflecting angle of the particles higher than 10 GeV is less than 5 mrad and the vertical deflecting angle of the particles higher than 20 GeV is less than 5 mrad. If the crossing angle is 5 mrad, the e^+e^- pairs can pass through the space between the poles of final focus quads. The secondary background problem. The estimation of background has been carried out for the pair creations by coherent and incoherent processes. The numbers of pairs through these processes are estimated to be 8×10^4 per collision. Particles below 1 GeV will be trapped by the solenoidal magnetic field in the detector and will not cause the background. The horizontal deflecting angle of the particles higher than 10 GeV is less than 5 mrad and the vertical deflecting angle of the particles higher than 20 GeV is less than 5 mrad. If the crossing angle is 5 mrad, the e^+e^- pairs can pass through the space between the poles of final focus quads. The secondary background caused by the photoneutrons and backscattered photons is dominant. As the result of the simulation, the background can be avoided by the mask even with a small angle of 5 mrad without any crab-crossing scheme. The probability of miss-trigger due to the background is estimated to be 1 %.

ATF (Accelerator Test Facility) Project

The ATF project has been started to construct an accelerator test facility in the TRISTAN Assembly Hall. The project will be complete in 1994. The ATF consists of the following major accelerator components; 1.54 GeV S-band injector, damping ring, bunch compressor, final focus test facility, 1 GeV X-band linac and positron target.

The 1.54 GeV S-band injector linac consists of a 50 MeV electron injector, 1.5 GeV linac and beam transport line to the damping ring. The following electron sources will be installed; a conventional thermionic gun with 714 MHz sub-harmonic bunchers, rf gun with mode-locked laser and polarized electron gun.

The ATF damping ring is a test facility to obtain the beam with the vertical emittance of $3 \times 10^{-8} rad.m.$ The design of the ATF damping ring has been completed and the prototypes of the following components will be completed in 1992; a unit of FODO magnet, unit of wiggler magnet, unit of vacuum system and beam line. A double kicker system has been completed. The rise time and fall time could be obtained 35 ns and 25 ns respectively. The Assembly Hall was not built for accelerator construction and hence the thickness of the floor is not enough to install the damping ring which requires the vertical alignment tolerance of ± 10 μm. An auto-alignment system is designed to adjust the vertical and horizontal positions of all the units of damping rings. The R&D of a 1.428 GHz damped cavity and CW klystron for the ATF damping ring will be started.

The final focus test facility is utilized to confirm the demagnification factor of 1/300 and the specification of the auto-alignment system. A new type of beam monitor by using compton scattering with laser beam will be installed to measure the beam size of 30 nm in vertical direction.

The 1.0 GeV X-band linac will be constructed to study on the rf sources, rf pulse compression and accelerating structures as the prototype of main linacs. The XB-72K klystrons will be utilized for rf sources. The accelerating structures would be the JLC-like damped structures or detuned structures to accelerate the multi-bunches in the range from 40 to 120 MeV/m of accelerating gradient.

The construction of Accelerator Test Facility will lead us to believe that the design goal of JLC is close at hand since the ATF is realy a prototype of linear collider.

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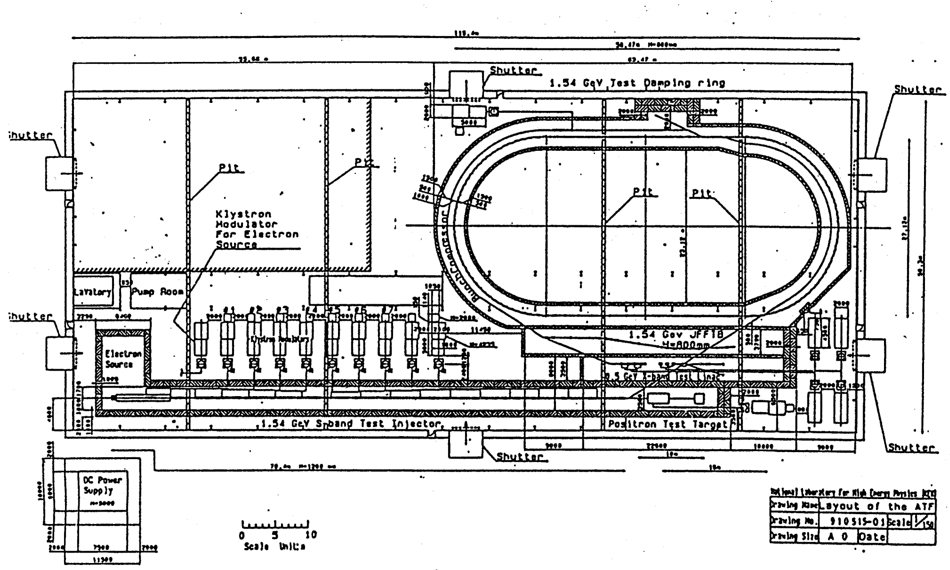

Figure 2. The Accelerator Test Facility