Accelerator Test Facility for the JLC Project

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

Abstract

A brief description of the Accelerator Test Facility (ATF) for the JLC project is given. The ATF is a comprehensive machine to test the experimental feasibility of the accelerator sub-systems which are common to the JLC machine

INTRODUCTION

A five-year R&D program on the JLC (Japan Linear Collider) project was started in 1987 at KEK in accordance with the future plan proposed by High Energy Committee in Japan[1]. The target of the project is to construct an electron-positron linear collider of TeV energy region as a home-based machine by the end of this century. Table 1 shows the parameters of the JLC project. The present R&D aims to investigate the technical feasibility of the TeV linear collider and it has been progressed in the collaborations with the universities and with SLAC and CERN as the international collaborations for next generation of linear colliders. Through the FFTB project in SLAC, KEK is collaborating with INP-Protvino/Novosibirsk, DESY and LAL-Orsay to focus the beam to 60 nm of vertical diameter. The R&D for JLC project has been remarkably advanced in four years and many valuable results have been obtained. The construction of the ATF was proposed in 1987 in order to test the experimental feasibility of accelerator sub-systems developed by the five-year R&D program. As a first stage of the project the construction of the ATF phase-I linac was started from 1987 in the TRISTAN Nikko experimental hall and it was completed in 1990. The second phase of the ATF project was started in 1991 to construct a prototype linear collider in the TRISTAN Assembly Hall.

ACCELERATOR TEST FACILITY

The civil modification of floor in the hall will be started in August 1991 and the installation of the damping ring injector will be started in December 1991. The construction of ATF will be completed by late in 1994 and the first low emittance beam will be focused by the final focus system early in 1995. As shown in Figure 1, ATF consists of the major accelerator subsystems as follows; electron sources to produce multi-bunches of electrons and polarized electrons, 1.54 GeV S-band injector linac to accelerate multi-bunches at 35 MeV/m of accelerating gradient, beam transport line to the damping ring, 1.54 GeV damping ring to obtain the vertical beam emittance of 3×10^{-8} rad·m, bunch compressor, final focus test facility to focus the beam to 30 nm of vertical beam size, test station of positron source, and 1 GeV X-band linac to generate the accelerating gradient of 80 MeV/m.

Center of Mass Energy	E (TeV)	0.5	1	1.5
Luminosity	L ($cm^{-2}s^{-1}$)	1.8×10^{33}	8.2×10^{33}	1.3×10^{34}
Total Length of JLC	L (km)	25	⇐	⇐
Length of Linacs	L (km)	23	⇐	⇐
Particles / Bunch	N	0.9×10^{10}	1.4×10^{10}	1.9×10^{10}
Bunches / RF pulse	N_b	20	⇐	⇐
Repetition Frequency	f_{rep} (Hz)	150	⇐	⇐
Wall Plug Power	P_{AC} (MW)	25	100	200
Accelerating Gradient Nominal	G_a (MeV/m)	40	80	120
Effective	G_{eff}(MeV/m)	27	56	87
RF Frequency	f_{rf} (GHz)	11.424	⇐	⇐
Structure Length	L_s (m)	1.0	⇐	⇐
Iris Radius/Wavelength	a/λ	0.16	⇐	⇐
RF Power/Structure	P_{rf} (MW)	35	140	280
RF Pulse Width	t (ns)	100	⇐	⇐
Average Beam Power	P_b (MW)	1.15 x 2	3.8 x 2	7.5 x 2
Normalized Emittance	ε_{xn} (rad·m)	3×10^{-6}	⇐	⇐
	ε_{yn} (rad·m)	3×10^{-8}	⇐	⇐
Beam Size at IP	σ_y/σ_x (nm)	2.7/300	2.2/300	2.0/440
R.M.S. Bunch Length	σ_z (μm)	137	108	91
Energy Loss by Beamsrahlung	ΔE/E (%)	4	15	15

Table 1. The general parameters of JLC

ELECTRON SOURCES

The multi-bunch acceleration gives rise to high luminosity due to high repetition rate and high efficiency due to the heavy beam loading. To obtain 1.3×10^{34} of luminosity at 1.5 TeV center of mass energy, a bunch train containing 20 bunches will be accelerated by the JLC machine. As for the ATF, the damping ring has been designed for the bunch train with 10 bunches, and each bunch contains 1×10^{10} particles. The bunches are separated by 1.4 ns, which is the separation of 16 rf buckets at 11.424 GHz, to decrease the effect of multi-bunch instabilities. The length of a bunch train is 12.6 ns from the first

0-7803-0135-8/91$01.00 ©IEEE

bunch to the last bunch. The charge fluctuation in the bunches should be less than ±2% to obtain high luminosity. Considering with the beam loss in the injector and damping ring, the electron sources are designed to produce the bunch which contains 3 x 10^{10} electrons. The following three types of electron sources are being developed to install into the ATF injector.

A. *Thermionic Gun*

The thermionic gun is one of the most conventional and reliable electron sources. The multi-bunches with the bunch separation of 1.4 ns are generated by means of 714 MHz sub-harmonic bunchers. The major part of the thermionic gun system has been developed for the ATF phase-I linac. The thermionic gun and the HV power supply are designed to obtain the maximum beam energy of 240 keV. In the normal operation the beam energy is chosen to be 150-200 keV. The fast grid pulser was tested at Nikko ATF phase-I linac and a short pulsed beam with pulse length of 14 ns and peak current of 3 A could be produced[2]. The thermionic gun system will be installed in the 1.54 GeV S-band injector of the ATF.

B. *RF Gun*

As the advanced electron sources, an rf gun is being developed to generate the low emittance multi-bunches. The photocathode is irradiated by the fine structure light pulses from the mode-locked laser and hence the multi-bunches with short bunch length are directly produced on the photocathode surface. The bunch spacing can be controlled 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 which leads to the increase of beam emittance. The technique to produce photocathode has been established. The laser, rf source and beam diagnosis systems have been completed. The rf gun will also be installed in the 1.54 GeV S-band injector of the ATF.

C. *Polarized electron Sources*

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 90 %. By a preliminary cathode test the maximum polarization of 71 % has been obtained at a photon wavelength of 802 nm at room temperature by using GaAs and AlGaAs of 21 Å and 33 Å thickness respectively[3]

A polarized electron source by using a GaAs layer grown on the $GaP_{0.17}As_{0.83}$ base layer by the MOCVD method has been developed. The maximum polarization of 85 % was obtained at photon wavelength of 860 nm at room temperature[3].

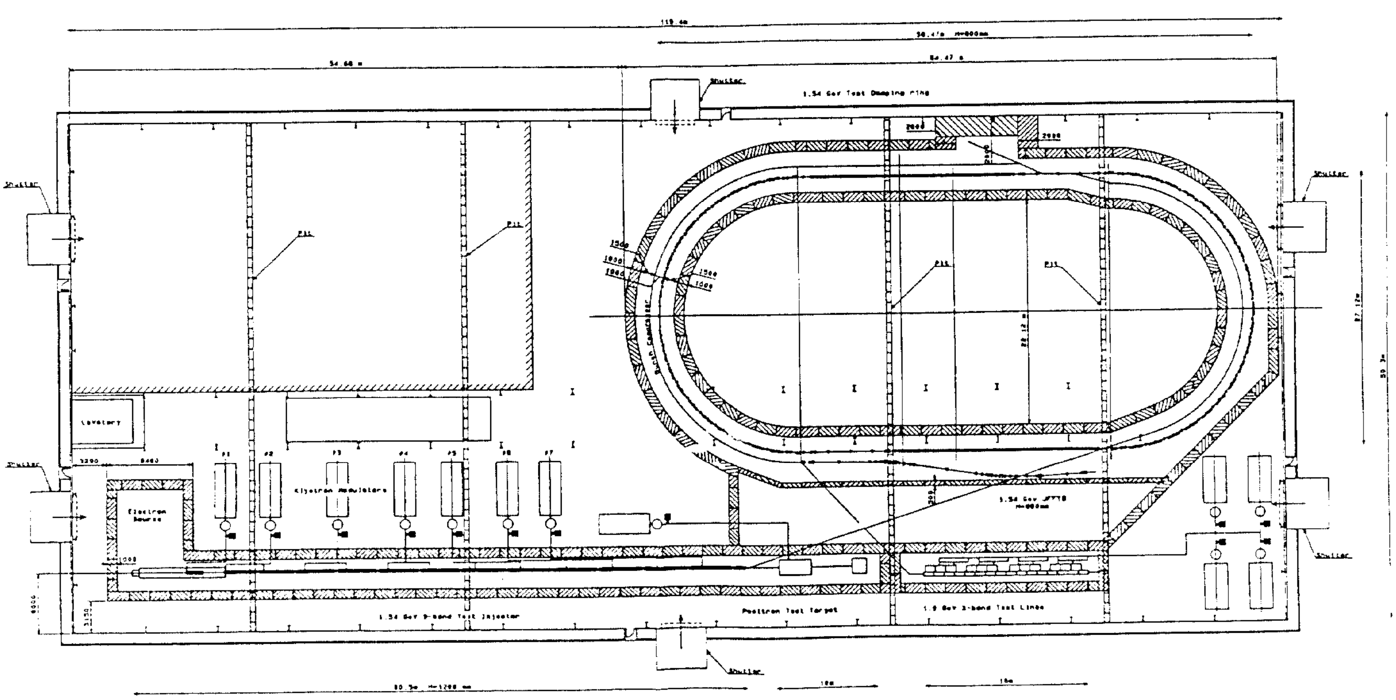

Figure 1. The Accelerator Test Facility (ATF) in the TRISTAN Asembly Hall at KEK

Two types of polarized electron guns are designing to produce 150 keV multi-bunches of electrons with the polarization as high as 90 %. The guns will be installed in the 1.54 GeV ATF S-band injector to establish the technique, such as long cathode life and maintenance-less required for the real operations.

S-BAND INJECTOR LINAC

For the JLC the several S-band linacs will be required for the damping ring injectors, linac for positron productions and pre-accelerators for bunch compressors. The total beam energies required for S-band linacs are estimated to be about 20-50 GeV. In order to reduce the cost of construction the accelerating gradient should be chosen to be optimum. The energy doublers will be utilized to reduce the cost of construction. The SLAC developed SLED cavities for SLC to produce the rf peak power of 300 MW from 65 MW and 3.5 μs pulse. The S-band klystrons (type-E3712) have been developed to produce the rf peak power of 100 MW of 1μs and 85 MW of 4.5 μs pulse duration. By using SLED cavity the peak power of 450 MW can be obtained from 85 MW and 4.5 μs rf pulse.

A. *SLED Cavity*

The maximum peak power from the SLED cavity is limited by the rf breakdown near a coupling iris. In KEK an energy doubler with two coupling irises has been developed to reduce the rf field around coupling irises. The dimensions of the cavity have been obtained by URMEL Code to calculate both the fundamental mode (TE015) and restriction mode (TE115). The electromagnetic field in the cavity has been evaluated with MAFIA code to compare with one-iris SLED cavities. The rf measurement of 1/4 scaled energy doubler has been completed. A high power model at 2.856 GHz rf frequency has been designed and the high power test will be carried out in June 1991. Two accelerating structures of 3 m-long will be driven by a klystron and energy doubler and then the accelerating gradient of 35 MeV/m will be obtained. Total beam energy of 1.54 GeV will be obtained by 16 accelerating structures, 8 klystrons and 8 discharge units of klystron modulator. The total length of 1.54 GeV injector is 78 m including electron sources and low energy section. The R&D has been started for the auto-alignment system of S-band linac with accuracy of ±50 μm. The technique would be extended to the auto-alignment system of the main X-band linac. The installation of S-band linac will be started in December 1991.

B. *High Gradient Experiments of S-band Structures*

The high gradient experiments have been carried out using ATF phase-I linac. The maximum accelerating gradient of 93 MeV/m could be attained in a constant gradient traveling type structure. The electron beam from the thermionic gun could be accelerated at 85 MeV/m of maximum accelerating gradient in March 1990. The recent experiments are focused to the dark current and rf breakdown phenomena. It was found that the dark current increases with the structure length and the dark current from a dust-less and dielectric-less structure is one order lower than the structures fablicated by a standard fablication process[4].

C. *Application of HIP (Hot Isostatic Pressing)*

The several accelerator components have been developed with materials produced by thermo-mechanical process, HIP (Hot Isostatic Pressing) technique for 100 MeV/m of accelerating gradient and 100 MW of rf peak power. For the accelerating structures, OFHC is preprocessed by HIP at 700-850 °C of the temperature in the pressurized Ar gas of 1200 kg/cm^2. For the ceramic plate of the rf window, Al_2O_3 is preprocessed by HIP at 2000 °C and 2000 kg/cm^2. The boundaries between grains of copper or Al_2O_3 are the origins of the rf breakdown. It is expected that the rf breakdown limit would be increased due to the reduction of out-gassing since the grain boundaries are closely pressed and distance between grains is closely reduced[5]. The accelerator components such as accelerating structures, SLED cavities, rf windows and dummy loads will be fablicated with material preprocessed by HIP for the ATF S-band injector.

POSITRON SOURCE FACILITY

The designs are being carryed out for positron production target, flux concentrator and capture section base on a simulation. The cascade shower is generated in the target by the EGS4 code. Then ray tracing is carried out for each positron where the effects of the electric and magnetic fields are taken into account. The positron yield is almost linearly proportional to the total energy of the incident electron beam. If the normalized yield is assumed to be 0.05 e^+/e^-/GeV, the primary electron beam with the total energy of 1.3 kJ/pulse is needed to satisfy the intensity requirement of JLC. This is about six times larger than the SLC design value, and the target would be damaged by the thermal stress. To overcome it, there are two ways: one is to reduce the thermal stress, and the other is to increase the capture efficiency. If the spot size of the incident electron beam can be enlarged without any loss of the positron yield, the thermal stress is decreased inversely proportional to the square of the shower size. The simulation shows that this reduction of the stress would be achieved if the accelerating structure with larger disk aperture is applied to the capture section. As a result, the higher capture efficiency would be obtained. The wire target has an advantage of high efficiency to capture the slow positrons. The optimum parameters are being searched for a wire target, better flux concentrator, and stronger solenoid field. A prototype will be fablicated and tested at the ATF using 1.54 GeV electron beam.

DAMPING RING AND BUNCH COMPRESSOR

The design work of the damping rings and bunch compressors has been carried out to obtain the low emittance short bunches[6]. The one of the main targets is to obtain the vertical emittance of 3×10^{-8} rad·m which is two orders lower than the conventional storage rings. The design of the damping ring has been completed and the present work is focused to the R&D of FODO magnets, wiggler magnets, vacuum system, double kicker, rf system and auto-alignment system to align the vertical position of the magnets within ± 10 μm. The ATF damping ring is a test facility to obtain the beam with the vertical emittance of 3×10^{-8} rad·m. The design of the ATF damping ring has been completed. The following components will be constructed in 1991; a unit of FODO magnet, unit of wiggler magnet, unit of vacuum system and auto-alignment system. A prototype of double kicker magnet and 40 kV pulser have been completed. The design values of the rise and fall times are 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 with precise alignment. We are designing an auto-alignment system to adjust the vertical and horizontal positions of all the units of damping rings. The R&D groups in KEK are developing prototype damped cavities of UHF, which can be applied to the TRISTAN Accumulator Ring and Photon Factory ring. We will start the construction of damped cavities after we obtain the results of their R&D. The development of 1.428 GHz CW klystrons has been started for the ATF damping ring. The design of the bunch compressor has been almost completed and design of the magnets and rf system will be started. The construction of the ATF damping ring will be completed in 1994.

X-BAND KLYSTRONS

As shown in Table 1, the klystrons of 80 MW rf peak power and 100 ns pulse duration are required for the first stage of the JLC. For the energy upgrade to 1-1.5 TeV the klystrons of 100 MW rf peak power and 400 ns pulse duration will be required. As a first step of the R&D, 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 the rf window. We are designing the pill-box type rf window for the second klystron tube to obtain 30 MW peak power. The high power test will be started in July 1991. The design of a 100 MW X-band klystron (type XB-72K) has been almost completed by using the FCI simulation code. The XB-72K generates the rf peak power of 120 MW at 550 kV and 150 MW at 600 kV of applied voltage. The Cavity without nose-corn 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 fabricated in July 1991.

X-BAND KLYSTRON MODULATORS

Two types of X-band klystron modulator have been developed for XB-72K klystrons to generate peak rf power of 120-150 MW.

A. *PFN Type Klyston Modulators*

The first one is a PFN type to generate 550 kV peak voltage with 1:15 pulse transformer in 500 ns flat top pulse. The rf peak power of 120 MW will be expected from XB-72K klystrons[7].

B. *Blumlein-Type Klystron Modulators*

The second one is a Blumlein-type MPC (Magnetic Pulse Compression) type klystron modulators to generate 600 kV peak voltage in 100 ns flat top pulse without any output pulse transformer which gives rise to the increase of the rise time[8]. The impedance of the conventional Blumlein is very low and then it is suitable to drive the rf sources of low impedace such as cross-field amplifier. The spiral electrodes are adapted as the inner electrodes to increase impedance and to reduce the length of Blumlein. The output impedance of the Blumlein is chosen to be 0.6 kΩ to drive two 150 MW klystrons by a MPC modulator. The rf peak power of 300 MW will be obtained per one MPC modulator by driving two XB-72K klystrons. The advantages of the MPC scheme are the reduction of not only the modulator size but also the total number of klystron modulators required for JLC. Two types of klystron modulators will be tested and installed in the 1.0 GeV X-band linac of ATF.

X-BAND LINAC

The 1.0 GeV X-band linac will be constructed to study on the rf sources and structures as the prototype of main linacs of JLC. The accelerating structures are traveling wave type damped structures to accelerate multi-bunches. The X-band linac accelerates the multi-bunches compressed in length by the bunch compressor. The experiments of beam acceleration will be carried out by the accelerating gradient of 40 to 120 MeV/m.

A. *Accelerating Structure*

The R&D program for main X-band linacs has the following two items; the fabrication technique for the structures in X-band scale and the design of damped structures and detuned structures. The technical R&D of machining, diffusion bonding and brazing for X-band structures has being progressed in KEK machine center.

The design study of the damped structures was started from the computer simulation by using ULMEL, TBCI and MAFIA codes. The estimation has been carried out by ULMEL and

TBCI codes for the transverse components of the wake fields in a disk-loaded structure. The structure design has been performed by using MAFIA code and Slater's formula for both the slotted disk-type damped structures and crossed waveguide-type damped structures. The slot dimensions have been optimized to minimize the external Q-value for the TM_{110} mode. We have obtained the external Q-values as low as 1 for 0-mode and about 20 for π-mode. The cold models at C-band frequencies have been prepared for the rf measurements[9].

B. *High Gradient Experiments of X-band Structure*

A constant impedance disk-loaded structure has been developed for the high gradient experiment at X-band frequencies. It consists of 20 cells and 2 couplers of 20 cm-long and the disk aperture is 6 mm. By using the 30 MW XB-50K klystron, the maximum accelerating gradient of 100 MeV/m can be obtained in the first cell and then the average accelerating gradient in the structure will be 85 MeV/m respectively. The high power test will be started in July 1991.

FINAL FOCUS FACILITY

The final focus test facility is utilized to prove the demagnification factor of 1/300 and the specification of the auto-alignment system. The design study of the ATF final focus facility has been completed. 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 bore radius of 2 mm was constructed with Vanadium Permendur in 1989. The bore radius is 4 times larger than the quad required 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 is less than 1/3 of half aperture without any serious field deformation due to saturation effects. The results from the measurements suggest the validity of the design calculation.

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 in 1989 and the vibration displacement could be suppressed to ±30 nm.

KEK is collaborating with SLAC for FFTB project and a prototype quadrupole magnet and alignment system have been completed. The measurement of magnetic field distribution was carried out in March 1991 at KEK. A prototype of alignment system for FFTB final focus quads was completed in April 1991. The test of the alignment system will be carried out to suppress the vibration displacement to ±50 nm of vertical direction with a load of 1.5 t weight.

The survey of the technical feasibility for a new type of beam monitor will be started to measure the beam size of 30 nm in vertical direction[10]. The present target for the development of the beam size monitor for ATF is in early 1995.

SUMMARY

The Accelerator Test Facility would be demonstrated as a prototype linear collider since the major accelerator sub-systems are common to the JLC real machine. The results obtained from this project would lead us to believe that the experiment using e^+e^- collision of TeV energy region can be realized by the end of this century.

Acknowledgments

This paper is the summary of the R&D work performed by the JLC study group. The author would like to thank Professors H.Sugawara, Y.Kimura, S.Iwata and K.Takata for their encouragements.

References

[1] Y.Kimura, "The Performance of TRISTAN and Accelerator Development at KEK", Proc. of 2nd EPAC (held at Nice, June 12-16,1990) p.23.

[2] T.Naito, J.Urakawa, M. Akemoto and H. Akiyama, "Single Bunched Beam Generation using Conventional Electron Gun for JLC Injector", Proceedings of this conference.

[3] T.Nakanishi, et al., "Development of Polarized Electron Sources using AlGaAs-GaAs Superlatice and using Strained GaAs", Proc. of this conference.

[4] S.Takeda, M.Akemoto, H.Hayano, H.Matsumoto and T.Naito, "High Gradient Experiments by the ATF", Proc. of this conference.

[5] H.Matsumoto, M.Akemoto, A.Miura, T.Naito and S.Takeda, "Applications of Hot Isostatic Pressing (HIP) for High Gradient Accelerator Structure", Proc. of this conference.

[6] K.Kubo,"Simulation of Multibunch Instabilities in the Damping Ring of JLC", Proc. of this conference.

[7] M.Akemoto, T.Shidara and S.Takeda, "X-band Klystron Modulator for the Accelerator Test Facility", Proc. of this conference.

[8] T.Shidara, M.Akemoto, M.Yoshida, S.Takeda and K.Takata, "Blumlein-type X-band Klystron Modulator for Japan Linear Collider", Proc. of this conference.

[9] T.Higo, M.Takao, K.Kubo and K.Takata, "X-band Accelerating Structure for Japan Linear Collider", Proc. of this conference.

[10] T.Shintake, "Proposal of Nano-meter Beam Size Monitor for e+e- Linear Colliders", (to be published in INFN Report).