Test Accelerator Facility for Linear Collider

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Abstract

KEK has proposed to build Test Accelerator Facility (TAF) capable of producing a 2.5 GeV electron beam for the purpose of stimulating R&D for linear collider in TeV region. The TAF consists of a 1.5 GeV S-band linear accelerator, 1.5 GeV damping ring and 1.0 GeV X-band linear accelerator. 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 in Phase-III, the damping ring will be completed. The construction of TAF Phase-I has started, and the 0.2 GeV S-band injector linac has been almost completed. The Phase-I linac is composed of a 240 keV electron gun, subharmonic bunchers, prebunchers and traveling buncher followed by high-gradient accelerating structures. The SLAC 5045 klystrons are driven at 450 kV in order to obtain the rf-power of 100 MW in a 1 μs pulse duration. The rf-power from a pair of klystrons are combined into an accelerating structure. The accelerating gradient up to 100 MeV/m will be obtained in a 0.6 m long structure.

Introduction

In 1986, the Community of High Energy Physics in Japan discussed a direction of the post-TRISTAN project. The Community decided to pursue the physics of energy frontier and to start the investigation of the feasibility of a TeV electron-positron linear collider. In 1987, an R&D group was organized in KEK in order to study the possibility of the TeV linear collider. Table-1 shows the parameters of the 1 TeV linear collider tentatively designed at KEK. In order to realize a linear collider in TeV region, many technical difficulties should be overcome. The following R&D programs are in progress at KEK;

1) theoretical works on parameters, beam dynamics, beam-beam disruption, beam-strahlung, final focuses and linac lattices.

2) experimental works on the development of high power rf-sources, high gradient accelerating structures, alignment system, instrumentations, control and final focus system.

A large number of advanced ideas have been proposed to solve the technical problems. However, the R&D by extending the conventional schemes seems to be the shortest way to realize the TeV linear collider. The R&D group has decided to build the Test Accelerator Facility (TAF) as a major experimental R&D program[1-3].

Test Accelerator Facility (TAF)

The TAF consists of a 1.5 GeV S-band linear accelerator, a 1.5 GeV damping ring and a 1.0 GeV X-band linear accelerator as shown in Fig. 1. The TAF project will be carried forward in three phases[2]. The S-band linac is constructed in Phase-I. After completing the high power

Energy		0.5 TeV + 0.5 TeV	
Linac length		5 km + 5 km	
Luminosity		$1\times10^{33}cm^{-2}sec^{-1}$	
RF-frequency		11.4 GHz	
Accelerating gradient		100 MeV/m	
Beam power		2.5 MW	
Disruption parameter		2	
Aspect ratio	1		100
Number of particles (per bunch)	1.9×10^{10}		4×10^{9}
Bunch frequency	1600		7800
Bunch height	0.17 μm		0.003 μm
Bunch length	1 mm		0.08 mm

Table 1. Parameters of the linear collider tentatively designed at KEK.

klystrons and accelerating structures at X-band frequency, the 1.0 GeV X-band linac will be constructed in Phase-II The S-band linac is used as an injector for the 1.5 GeV damping ring which will be constructed in Phase-III. Table 2 shows the parameters of the proposed TAF linacs.

	S-band linac Phase I	S-band linac Phase II	X-band linac
Eb(GeV)	0.2	1.5	1
Ea(MeV/m)	50	50	100
frf(GHz)	2.856	2.856	11.42
Prf(MW/structure)	200	200	50
Nk(Klystrons)	4	24	8
Ns(Structures)	2	12	16
Ls(m/Structure)	3	3	0.5
Ne(e-/bunch)	5×10^{10}	5×10^{10}	1×10^{10}

Table-2. The parameters of the TAF for the linear collider R&D at KEK.

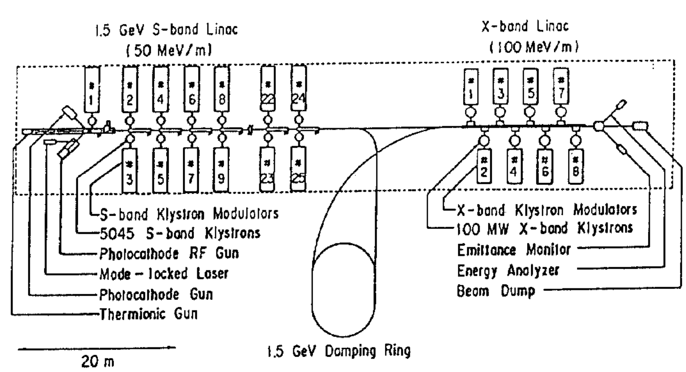

Figure-1 Test Accelerator Facility (TAF)

TAF Phase-I Linac

A linear accelerator with the energy of 0.2 GeV has been almost completed at the NIKKO experimental hall of the TRISTAN main ring[3]. As shown in Fig. 2, the linac consists of a 240 keV electron gun, subharmonic bunchers, prebunchers and TW buncher followed by high gradient accelerating structures. The Phase-I linac makes it possible to accelerate a single bunch of 5×10^{10} electrons and high-current multi-bunches by the accelerating gradient up to 100 MeV/m.

One of the crucial parameters of TeV linear collider is the maximum accelerating gradient that can be attained and be used stably in the structure, since the total length of the linear collider is determined by the accelerating gradient. In order to realize the 1 TeV linear collider with the length of 10 km, the accelerating gradient of 100 MeV/m should be attained in the practical beam acceleration. The R&D group has carried out the experiment of high gradient by means of the S-band resonant ring, and the gradient of 105 MeV/m has been attained[5]. The R&D group decided to continue the experiment of the high gradient by using the TAF Phase-I linac. The investigation will be performed to find the maximum gradient which makes it possible to accelerate the beam stably.

S-band Klystrons and Modulators

The rf-peak power of 300 MW/m is required in order to generate the accelerating gradient of 100 MeV/m in S-band structures. In the 0.6 m long structure of the TAF linac, the rf-peak power of 200 MW is required to generate the gradient of 100 MeV/m. The klystron modulators[3] have been developed in KEK to drive the 5045 klystrons supplied from SLAC. The modulator produces a 4.0 μs flattop pulse of 24 kV peak voltage in a 7 μs pulse duration. It also provides a 1.0 μs flattop pulse of 30 kV peak voltage in a 3.5 μs pulse duration. The SLAC 5045 klystrons are driven at 450 kV through a 1:15 step-up transformer so as to generate the 100 MW peak power. The rf-power from a pair of klystrons are combined with a 3 db coupler, and the rf-power of 200 MW peak is fed into the 0.6 m long accelerating structure. Figure 3 show the Schematic diagram of the rf-system to obtain the 200 MW peak power. The rf-power of 5 MW required to drive the buncher and the prebunchers is obtained with a 16 db divider.

S-band Accelerating Structures

The 0.6 m long accelerating structure is a $2\pi/3$ constant gradient traveling wave structure with 17 cells and 2 couplers. In order to obtain the gradient of 100 MeV/m at 195 MW input, the parameters of the structure are choosen as follows; Q_0 = 11600, τ = 0.37. The heat loss in the structure is estimated to be 5 kW at 25 pps. The multi-pipes are bored in the disk spacers so that the water can directly flow in the structure wall. The high efficiency of water cooling is expected to be obtained.

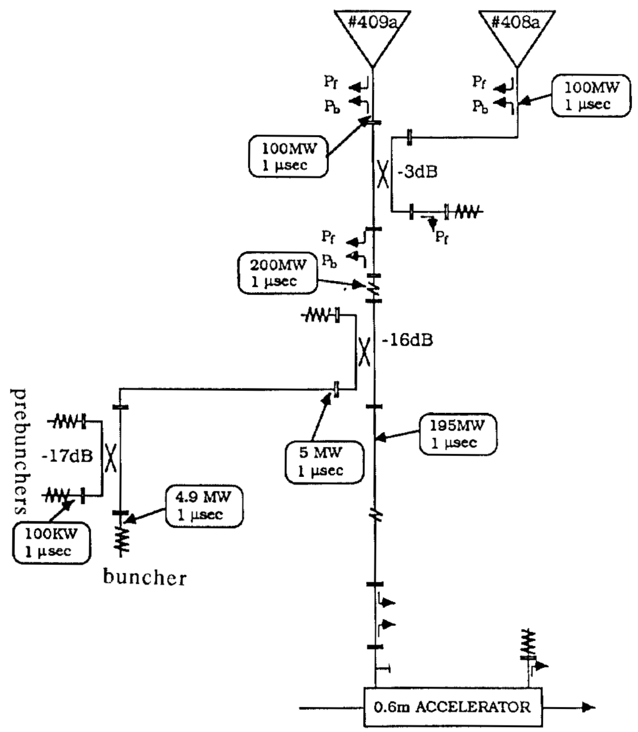

Figure 3. Schematic diagram of the waveguide system of the TAF Phase-I in order to obtain 200 MW peak power.

Electron Gun

As the electron source of TAF, the thermionic electron gun and the rf-gun are being studied.

The thermionic electron guns are constructed for the

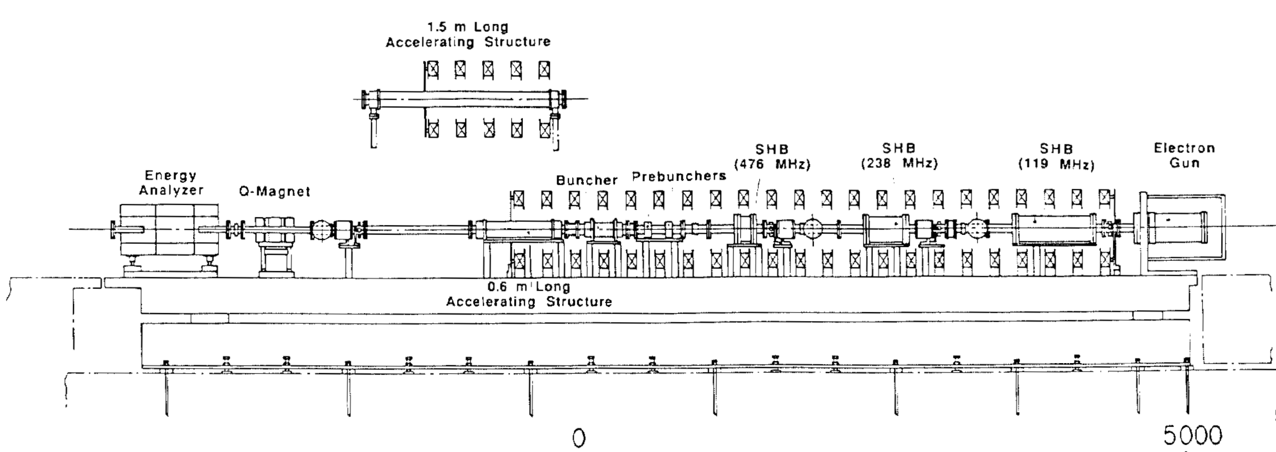

Figure 2. TAF Phase-I linac.

electron source of TAF Phase-I linac. The higher voltage makes it possible to produce a high current and low emittance beam from the gun. The two types of the thermionic guns, which can be operated at 240 kV, have been designed. One of the two types is a conventional triode with the EIMAC-Y796 cathode-grid assembly. The other type of the gun is a tetrode with a center electrode between anode and cathode. The optimum beam focus can be obtained by adjusting the voltage on the center electrode for various beam current. The power supply for the gun is a line type pulser with a PFN. The voltage up to 240 kV can be generated in a 1 μm pulse duration. The beam from the gun is focused by two magnetic lenses in order to control both the radius and the convergence of the beam from the gun at the entrance to the magnetic confined region.

An rf-gun with photocathode is a low emittance electron source, since the emitted electrons are accelerated by the high accelerating field generated in the cavity. The pulse structure of the emitted beam from the photocathode is determined by the fine structure pulses of the mode-locked laser. The rf-gun makes it possible to generate not only a single bunch but also multi-bunches. The bunch shape is determined by the shape of laser pulses. The bunch length of about 10 ps can be obtained without prebuncher and buncher. The bunch separation is also tunable by adjusting the mirror system of the mode-locked laser. The multi-bunchs separated by the subharmonic wavelengths are required to investigate the interactions between multi-bunch and cavities. At this point, the rf-gun is seems to be suitable for the TAF linac. The lasertrons[4] also generate electrons by means of photocathode and mode-locked lasers. The large portion of basic techniques obtained from the lasertron project in KEK would be applied to the R&D for rf-gun. The development of the rf-gun will start soon.

Subharmonic Bunchers and Solid-State Amplifiers

In order to produce a high current single bunch, a pulsed electron beam should be injected in the acceptance angle of the buncher. Therefore, the beam pulse shorter than 100 ps is required for S-band linear accelerator. The pulse length of the beam from the thermionic triode gun is limited by the time response of the grid pulser and cathode-grid assembly. The subharmonic bunchers (SHB) are necessary to produce a sub-nanosecond pulse beam by bunching a nanosecond beam from the thermionic gun.

The TAF Phase-I linac has three subharmonic bunchers to produce a single bunch and multi-bunches. The SHB are coaxial single gap cavities with rf-tuners. The optimum frequencies, location of the SHB cavities and gap voltages are determined by calculating the longitudinal space-charge debunching forces in the beam with two-dimentional disk model[5]. The 24th subhamonic frequency ($f = 119$ MHz, $1/f = 8.4$ ns) applied on the SHB-#1 is determined from the pulse length of the beam (2 ns) from the gun. The SHB-#2 is driven at the 12th subharmonic frequency ($f = 238$ MHz, $1/f = 4.2$ ns) and SHB-#3 is driven at the 6th subharmonic frequency ($f = 476$ MHz, $1/f = 2.1$ ns).

The rf-phases and rf-powers in the SHB cavities can be independently controlled to obtain the optimum bunching. The SHB cavities are driven by the 5 kW - 50 μs solid-state amplifiers. The amplifier is composed of 850 kW unit amplifiers, and the rf-power of 5 kW are obtained by combining 6 units. The rf-power can be increased by the extension of the unit amplifiers. The rf-phase at the cavity gap picked up by the loop is locked by the phase controller.

The SHB, prebunchers, buncher and accelerating structure are confined by the Helmholtz coils, which are independently connected with the power supplies. The axial magnetic field can be tapered from 150 Gauss to 700 Gauss so that the beam flows in Brillouin condition as the charge density increases due to beam bunching.

Support and Alignment System

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 experiment. The support system of the TAF Phase-I linac consists of a 9 m long and 0.67 m wide table made of SUS316-L. The flatness of the table surface is measured by using the laser system and evaluated to be 36 μm / 9 m. The components, such as electron gun, SHB, prebuncher, buncher, accelerating structure and beam monitors can be aligned within 50 μm. The Helmholtz coils, Q-magnet and energy analyzer magnet can be aligned within 100 μm.

Control System

The control system[3] for TAF linac consists of two DEC VAX computers (VAX station 3500 and VAX station II/GPX). The computers provide on-line execution of large programs and serve the interfaces to the machine operators in order to direct the overall efforts of the control system.

The serial CAMAC system is adopted as the interface, since many kind of CAMAC modules have been developed for TRISTAN control. The CAMAC crates are installed near klystron modulators, and they are connected by a serial highway to the computers in the TAF control room. The optical fiber cables are used for the serial CAMAC highway in order to obtain high reliability in a noisy environment.

The application programs written by FORTRAN77 are divided into the following categories. The CAMAC commands originated by the operator's consoles or the requests from basic I/O devices are the tasks activated by a non-periodic demand. The monitoring and logging tasks are periodically activated tasks. The complicated sequential control tasks for the system starting-up and shutting-down routines are quasi-periodic tasks. The general purpose consoles provide the man-machine interfaces for the TAF control. The improvement of the system can be achieved both by extending the general purpose consoles and by refining the control softwares.

X-band Klystrons and Accelerating Structures

The rf-frequency of the linear collider is chosen at 11.4 GHz. As a first step, a 30 MW X-band klystron so called XB-50 is under progress, and a test diode will soon be fabricated. As the second step, the design work of a 50 MW X-band klystron (XB-65) has been started.

As for the X-band structures, the basic fabrication techniques have been investigated and the prototype of $2/3\pi$ and $6/7\pi$ modes are tested at low power level.

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