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1.54 GeV ATF Injector Linac

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Abstract

This paper describes the present status of 1.54 GeV S-band injector linac of the ATF(Accelerating Test Facility) for JLC.

1 INTRODUCTION

The ATF (Accelerator Test Facility) project was started in 1988 in order to stimulate the R&D work for the JLC project [1]. On the first stage, the accelerating gradient of 93 MeV/m has been achieved by an S-band linac [2, 3]. The project has been extended to construct an accelerator system as a proto-type machine of the JLC [4].

As shown in Figure 1, ATF consists of five major accelerator-parts: an S-band injector linac [5], a beam transport-line [6], a damping ring [7], a bunch compressor, and electron/positron sources. ATF generates, accelerates, damps, and compresses a train of 20 bunches with 2×10^{10} electrons/bunch and 2.8 ns bunch spacing. The amount of total number of electrons in a bunch-train is approximately half that of the JLC-I machine. The multi-bunches are accelerated by the accelerating gradient of 33 MeV/m which is approximately same that of the JLC-I machine on the initial stage. The goals of the vertical and horizontal beam emittance to be achieved are 3×10^{-8} m·rad and 5×10^{-6} m·rad, respectively. The goal of the bunch length is 100 μm with a one-stage compressor with a large (1/50) compression ratio. The amounts of both the beam emittance and the bunch length are same those of the JLC-I machine. ATF will verify the multi-bunch scheme of linear colliders in all parts from the injector linac to the bunch compressor.

2 1.54 GeV ATF Linac

The 1.54 GeV ATF injector linac was designed to accelerate multi-bunch electrons for the injection to a low-emittance damping ring [8]. The injector linac consists of an 80 MeV preinjector linac, 8 units of regular accelerator section, and an energy compensation system. The parameters of the 1.54 GeV ATF injector linac are summarized in Table 1.

3 80 MeV Preinjector Linac

The required specification of preinjector results from the energy acceptance and dynamic aperture of the damping ring [9]. Although the energy spread among the bunches will be compensated by a special accelerating structure in the 1.54 GeV ATF Linac, the energy spread within a bunch is determined by the bunch length at the exit of the preinjector. Also, the dynamic aperture of the damping ring determines the maximum emittance of the Linac beam. Assuming no emittance growth in the linac, the specification of the maximum emittance will be applied to the preinjector. As shown in Figure 2 the preinjector consists of a thermionic electron gun, two sub-harmonic bunchers, four single cell bunchers, an accelerating structure, a matching section of beam lattice, an energy analyzer and beam instrumentations.

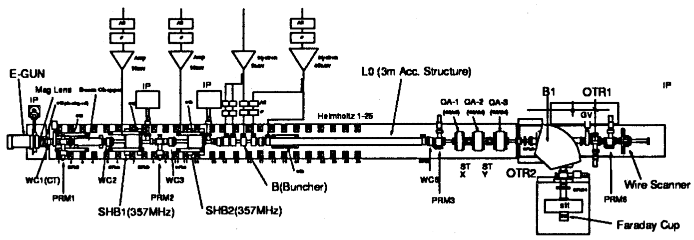

Figure 2: Schematic drawing of the 80 MeV preinjector.

The thermionic gun system consists of a triode with type EIMAC Y646-E or Y796 grid-cathode assembly [10]. The HV pulser provides maximum pulse voltage of 240 kV with 3 μs pulse duration. Grid pulses with pulse separation of 2.8 ns are produced by gating the output of a 357 MHz signal generator synchronized with sub-harmonic bunchers. The multi-bunch from the gun has a bunch length of 1 ns FWHM. Each bunch contains 3×10^{10} electrons. The bunch population is larger than the specification of the linac beam because of an about 70 % transmission efficiency in the buncher section.

To avoid a phase shift of the bunching voltage due to the beam-loading, low R/Q cavities, which reduce the beam-loading voltage, are used. To obtain more flexibility for buncher tuning, four single-cell standing-wave cavities with low R/Q for the buncher are applied as well as low R/Q Sub-harmonic bunchers.

The accelerator section of the 80 MeV preinjector is a 3 m-long constant-gradient accelerating structure. The geometrical dimension and rf specification are identical to the structures of the 1.54 GeV linac. The energy spread of the multi-bunch due to the beam-loading is evaluated to be 5 % in full width at the bunch population of 2×10^{10}. The OTR (Optical Transition Radiation) monitor is used to observe the bunch-by-bunch profile and length. The bunch-by-bunch energy spread can be observed by the OTR monitor and a bending magnet as shown in Figure 3. The energy spread is evaluated to be 1.24 % in full width at the bunch population of 0.5×10^{10} electrons [11].

A wire scanner is routinely used for bunch-by-bunch emittance measurement in the ATF preinjector. A MCP-PMT with gate technology detects gamma generated from the fire by colliding the beam electrons.

4 Accelerator Section of 1.54 GeV Linac

The role of the accelerator section of the injector linac is the acceleration of multi-bunch from 80 MeV to 1.54 GeV with a minimum energy spread and a minimum emittance growth. It consists of eight rf units, two energy compensation units, a linac lattice, and beam monitors. The beam-transport line is located between the 1.54 GeV ATF linac and an injection kicker of the damping ring.

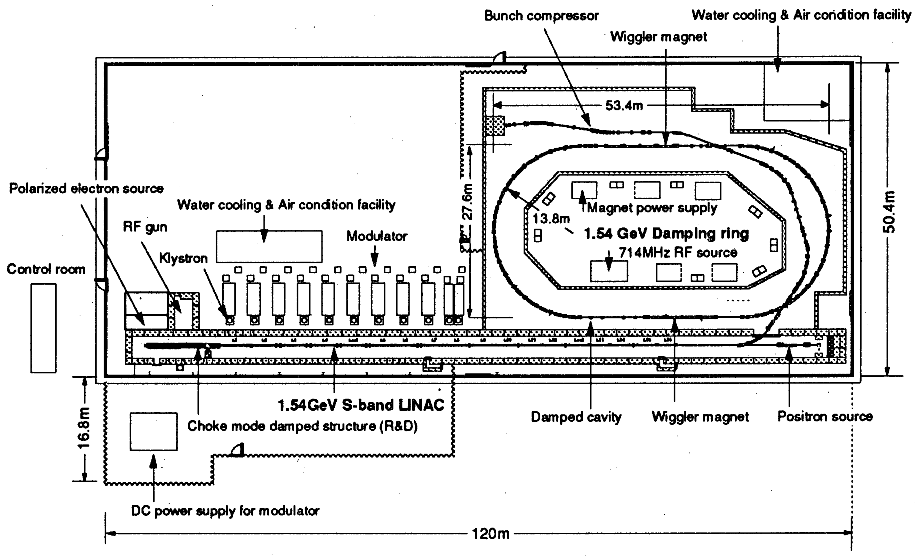

Figure 1: Schematic diagram of ATF (Accelerator Test Facility).

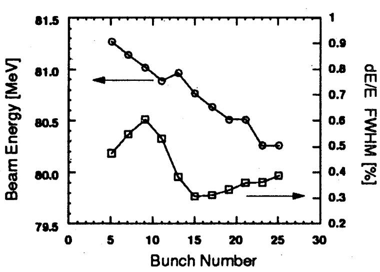

Figure 3: Bunch-by-bunch energy and spread observed by an OTR monitor. The bunch population is 0.5×10^{10}.

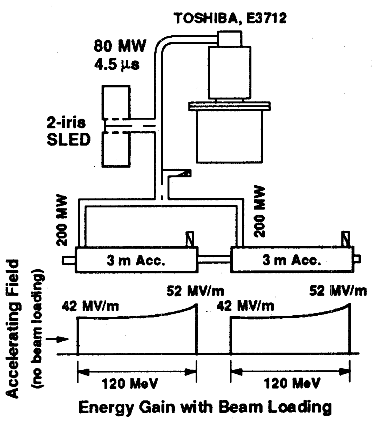

Figure 4: RF system for the regular section of the linac.

4.a RF System

The rf unit of regular section consists of an E-3712 klystron, a modulator [12], a dual-iris SLED cavity [13], rf waveguides, two 3 m-long accelerating structures [14] and rf dummy-loads as shown in Figure 4. The klystron produces the rf peak power of 80 MW with a pulse duration of 4.5 μs and supplies to a dual-iris SLED cavity. The rf phase is reversed at 3.5 μs and the peak power of 400 MW is extracted from the SLED cavity with a pulse duration of 1.0 μs . The rf power is divided into two rf waveguides in order to supply a peak power of 200 MW into a 3 m-long accelerating structure.

The accelerating field distributes from 52 MV/m at the downstream of the accelerating structure to 42 MV/m at the upstream of the structure. The energy gain of the first bunch among twenty bunches is 119 MeV in an structure. The energy spread is evaluated to be ±2.6 % at the bunch population of 2.0×10^{10}, since the energy gain of the last bunch is 112.54 MeV in an structure with beam-loading.

4.b Alignment System

In order to avoid any emittance growth in the linac, the accelerating structures should be aligned to less than 200 μm r.m.s. of the vertical and horizontal directions. The support tables of the accelerator section of the linac have an active mover mechanism and wire-position sensors to align the linac components with a tolerance of less than 20 μm r.m.s. of the vertical and horizontal directions. The 91 m-long wires are stretched in both sides of the linac from the preinjector stage to the end of the linac. One end is fixed to the preinjector stage, which does not have an active mover mechanism; the other end is stretched by a tension weight of 33.5 kg. Each position sensor consists of a pair of induction coils electrically connected in series, and mounted on a vertically movable offset stage fixed at a support stage. The sensors are installed at four corners of the support table for Q-magnets and beam monitors, and a short support table for an accelerating structure. As for the long support table for the two accelerating structures, six sensors are installed at four corners, and both sides of the center of the table. The wire position is detected by a synchronous detection of the signal from the differential coils using 60 kHz, 100 mA AC current on the wire. The resolution of position sensor is 2.5μm. The dynamic range of the sensors is ±2.5 mm, which is determined by the gap length between two induction coils. The linac support tables are machined with an accuracy of less than $\pm10\mu$m. These sensors are aligned along the sag of the wire with a vertical offset. As a result, the support tables are vertically and horizontally aligned with an accuracy of less than 20μm r.m.s..

Table 1: Parameters of 1.54 GeV ATF injector linac

Beam Energy	1.54 GeV
Bunch Population	2×10^{10} electrons/bunch
Bunches/Train	20
Bunch Spacing	2.8 ns
Repetition Rate	25 pps
Energy Spread (Full Width	<1.0 %
Beam Emittance	$<3\times10^{-4}$ m·rad (1σ)
Total length	88 m
Pre-injector	18 m
Linac	70 m (active length: 48 m)
80 MeV Pre-Injector	
Gun Voltage	200 kV [240 kV achieved]
Beam Energy	80 MeV [105 MeV achieved]
Number of Bunches	20
Bunch Population	2×10^{10} electrons
Bunch Separation	2.8 ns
Population tolerance	$\leq \pm1.0\%$
Bunch length (FWHM)	<10 ps
Normalized emittance	$<3\times10^{-4}$ rad m (rms)
Regular Accelerating Sections	
Accelerating Structure	$2\pi/3$ mode constant gradient
Total length	3 m
Total number	16
Accelerating Field	
Maximum Field	43 MV/m [52 MV/m achieved]
with Beam-loading	33 MeV/m [40 MeV/m achieved]
RF Frequency	2.856 GHz
Feed Peak Power	200 MW/Structure
Klystron	
Klystron Peak Power	80 MW [85 MW achieved]
Klystron Pulse Length	4.5 μs
Number of Klystrons	8
RF Pulse Compression	Dual-iris SLED
Power Gain	5.0 at peak
Klystron Modulator	
Total Number	8
Energy Compensation System	
Accelerating Structures	
RF Frequency	2856 + 4.32727 MHz
RF Frequency	2856 − 4.32727 MHz
Klystron	
Total Number	2
Klystron Peak Power	50 MW
Klystron Pulse Length	1.0 μs
Klystron Modulator	
Total Number	2

4.c *Energy compensation System*

In the damping ring the variation of bunch spacing is not acceptable, the energy compensation system by using four dipole magnets is not applicable. The proposed Δf energy-compensation system (ECS) is a new idea to compensate for the multi-bunch energy by keeping the bunch separation synchronized with the rf frequency. By passing the multi-bunch through an accelerating structure driven at an rf frequency which is slightly larger or smaller than the fundamental frequency, the multi-bunch would be obtained the different energy gain caused by the phase shift. As a result, the energy spread of the multi-bunch is compressed to a small value, which is required from the damping ring. The compensation energy depends on the Z-position of the electrons in a bunch, since the bunch has a bunch length and the compensated field has a slope of the part of sinusoidal wave. If the bunch is compensated by both a negative slope and a positive slope, the effect of the slope is canceled and the bunch would be accelerated or decelerated by a flat-top field. The system has high flexibility for bunch populations from zero to 4×10^{10} electrons/bunch by adjusting the rf power of the klystrons. The system consists of two klystrons and two 3 m-long accelerating structures designed at two rf frequencies; $2,856\pm4.32727$ MHz [15]. The energy spread of the multi-bunch compressed by the ECS would be smaller than that of a single bunch.

4.d *Lattice*

The lattice of the 1.54 GeV linac has been designed by using SAD simulation code. The beam acceptance of the linac is set to 7×10^{-3} m, which is $\pm4.8\sigma$ of the incoming beam from 80 MeV preinjector. The result of a simulation of emittance blow-up due to the wakes of cavities under misalignment of accelerator components with an orbit correction using the beam position monitors. The simulation is performed by assuming the injection error $\Delta_x=\Delta_y=1$ mm, and skew rotation error of quads is 0.2 mrad. The single bunch energy spread at the exit is σ_ϵ = 0.3 %, and $|\Delta p/p| \leq 0.75$ %. These results show that a misalignment of less than 500 μm r.m.s. is not serious after a simple orbit correction.

5 Acknowledgement

The authors would like to thank Prof. Y. Kimura and Prof. K. Takata for their encouragements and discussions during the work. They wish to thank to Mr. S. Morita for his help during the construction of the linac. They also wish to thank to the ATF group for their useful discussions and kind collaborations.

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