STATUS OF 1.54 GeV ATF LINAC

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Abstract

Accelerator Test Facility (ATF) consists of a 1.54 GeV S-band linac, a beam transport line, a damping ring and an extraction beam line. A beam commissioning of the linac was performd in November 1995. A single bunch and multi-bunch beam were accelerated up to 1.43 GeV at the end of the beam transport line. The beam experiments on high-gradient acceleration, structure BPM and multi-bunch energy compensation were performed after the beam commissioning. The operation of the linac was suspended from April 1996 for the construction of the damping ring. The operation of the linac was restarted from December 1996, and the beam commissioning of the damping ring was carried out in January 1997.

1 INTRODUCTION

The 1.54 GeV ATF linac is designed to accelerate multi-bunch of electrons for the injection to a low-emittance damping ring. However, the ATF linac is designed not only as an injector of the damping ring but also as a test-stand for the linear collider technology such as multi-bunch acceleration, high gradient acceleration, beam loading compensation and instrumentations.

The required specification of the linac is as follows: A multi-bunch consists of a train of 20 bunches with a bunch spacing of 2.8 ns and a bunch population of 2×10^{10} electrons. The maximum energy spread of 90 % of multi-bunch electrons is 1.0 % full width, and the normalized emittance at the end of the linac is less than 3×10^{-4} m·rad (1σ).

Table 1 shows the specification of the 1.54 GeV ATF linac. The construction of the linac was completed except some improvements of rf system in order to obtain the design specification of the linac.

2 80 MEV PRE–INJECTOR LINAC

A 200 kV thermionic electron gun consists of an EIMAC Y646-E or Y796 grid-cathode assembly. A train of 20 pulsed-beam with a pulse width of 1 ns FWHM and 2.8 ns pulse spacing is produced from the gun by applying an rf-voltage to the grid. Each pulse beam contains more than 2×10^{10} electrons. The buncher section consists of two 357 MHz subharmoinic bunchers (SHB) and a 2856 MHz travelling wave buncher. A high current multi-pulse beam produces a cumulative loading voltage in the SHB cavity, which distorts the cavity voltage. A small induced voltage and high generator voltage provide a small phase shift caused by successive bunches. Therefore, low R/Q cavities, which reduce the beam-loading voltage are utilized. The bunching and transmission rate were checked by using the PARMELA simulation code. The resultant bunch length was less than 12 ps (FWHM), even after 20 bunch loading with greater than an 87.3% transmission rate. However, the present 5 kW solid-state amplifiers are not sufficient in order to compress a pulse beam to short bunch length without long tail. The bunch with long tail increases energy spread and results in the beam loss in a linac. Two 25 kW amplifiers are now in under fabrication to obtain the sufficient bunching in the SHB cavities.

A Type-E3712 klystron produces 100 MW peak power of 1.0 μs pulse duration for the travelling buncher and a 3 m-long accelerating structure. The peak power of 5 MW divided from the klystron is supplied to the buncher, and that of 60–95 MW is supplied to a 3 m-long constant gradient accelerating structure.

The bunch-by-bunch beam instrumentations are installed in the 80 MeV pre–injector linac. These ae composed of amorphous core monitors, wall current monitors, phosphor screen monitors, button BPMs, optical transition radiation (OTR) monitors and a wire scanner. The bunch length is observed by an OTR monitor and a streak camera. The emittance of the bunch is evaluated from the beam size observed by an OTR monitor combined with the Q-magnet. The emittance of each bunch is also measured by a wire scanner with fast-gate gamma detection.

3 RF SYSTEM

At the ATF linac, nine Toshiba-E3712 klystrons and two SLAC-5045 klystrons are used for the rf system. A type-E3712 klystron is used for the 80-MeV pre–injector descrived above. The accelerating section consists of eight tpe-E3712 klystrons. Each klystron is connected to two accelerating structures via a SLED cavity and operated in the long-pulse mode to produce a rectangular pulse waveform of 80 MW rf peak power in 4.5 μs pulse duration. At 3.5 μs after feeding into the SLED cavity, the rf phase is made to reverse during a 1.0 μs pulse duration. The extracted rf peak power from the SLED cavity is multiplied to 400 MW. Terefore, an accelerating structure is driven at 200 MW of peak power. When the pulse front of non-rectangular rf

Table 1: Required specification of the 1.54 GeV ATF linac.

Beam energy for DR	1.54 GeV
Energy spread	
(Full Width of 90%beam)	$<$1% (each bunch at 1.54 GeV)
Total length	85 m (from gun to linac end)
Accelerating structure	$2\pi/3$ mode, constant gradient
Total length	3 m
Total number	16
Accelerating field	
Maximum peak	52 MV/m
Nominal	33 MV/m
RF frequency	2,856 MHz
Feed peak power	200 MW/structure
Klystron	
Klystron peak power	80 MW/klystron
Pulse length	4.5μs
Total number	8
Pulse compression	Two-iris SLED
Power gain	5.0 (average)
S-band pre–injector	
Beam energy	80 MeV
Number of bunches	20
Bunch population	2.0×10^{10}
Bunch separation	2.8 ns
Bunch length (FWHM)	$<$10 ps
Normalized emittance	$<3\times10^{-4}$rad m (1σ)

waveform reaches an output coupler, the accelerating field distributes from 38 MeV/m to 52 MeV/m along the structure. The design accelerating gradient of 33 MeV/m can be achieved at 65 MW of average peak power. Seven klystron modulators in the accelerating section are connected to a 25-kV common HV power supply with HV common-bus. Three of them were designed to reduce a size of modulator. Self-healing type capacitors with long lifetime are utilized to decrease the size of pulse-forming networks. This capacitor consists of a metalized film with thin Zn-electrodes (300 Å in thickness) which form a series of microscopic capacitors. The case volume is less than third of the conventional type of capacitor.

Two 5045 klystrons are operated in a short-pulse mode to produce a rectangular rf pulse with peak power of 50 MW in 1.0 μs pulse duration. These klystrons produce the 2856$\pm$4.32727 MHz rf frequencies for the energy-compensation system.

4 ACTIVE ALIGNMENT SYSTEM

The support tables of the accelerator section of the linac have an active mover mechanism and wire-position sensors to align linac components with a tolerance less than 20 μm r.m.s. The 91 m-long wires are stretched in both sides of the linac from the gun to the end of the linac. One end is fixed to the pre–injector stage, which does not have an active mover mechanism, and the other end is stretched by tension weights 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 center position of a pair of induction coils is pre-calibrated on the calibration stand. The sensors are installed at four corners of the support table for Q-magnets and beam monitors, and accelerating structures. The wire position is detected by a synchronous detection of the signal from the differential coils using a 60-kHz, 100-mA AC current on the wire. The resolution of the position sensor is 2.5μm. The dynamic range of the sensors is $\pm$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 $\pm$10μm. The left side of the support table has a reference line parallel to the beam axis. The accelerating structures, Q-magnets and beam monitors are aligned to the reference line with an accuracy of less than $\pm$10μm. Each sensor installed on the left side of the linac has two pairs of induction coils to detect the vertical and horizontal positions from the wire. These sensors are aligned along the sag of the wire with a vertical offset. Therefore, the reference line is aligned in a straight line. Each sensor installed on the right side of the linac stages has a pair of induction coils for measuring only the vertical position. As a result, the support tables are vertically and horizontally aligned with an accuracy of less than 20μm r.m.s. The experiment of structure BPM has been carried out by using active alignment system of an accelerating structure.

5 $\pm\Delta$F 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, since the variation of bunch spacing is not acceptable in the damping ring. The proposed $\pm\Delta$f energy-compensation system is a new idea to compensate the multi-bunch energy by keeping the bunch separation synchronized with the rf frequency. When a multi-bunch pass 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 a different energy gain caused by the phase shift. The energy spread of a multi-bunch can be compressed to a small value required by the damping ring. The compensation energy depends on the position of electrons in a bunch, since the bunch has a bunch length and the compensating 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 klystrons. The advantages of the $\pm\Delta$f ECS system are as follows: simple system, high flexibility, highly efficient compensation, and without any effect to the single-bunch beam-loading.

The system in the ATF linac comprises two klystrons and two 3 m-long accelerating structures designed at two different rf frequencies. In order to simplify the timing system, the rf frequency deviation was chosen to be 4.32727 MHz, which is twice a damping ring revolution frequency, and is also the 660th subharmonic frequency of the 2856 MHz fundamental frequency. Therefore, an accelerating structure is driven at 2856+4.32727 MHz while another accelerating structure is driven at 2856−4.32727 MHz. The maximum peak power from the klystron is 50 MW at a 1.0μs pulse duration. One unit of the system can compensate an 80 MeV energy difference among the multi-bunch. Therefore, the system can compensate an energy difference of 160 MeV at the maximum among the multi-bunch. The maximum compensated beam-loading is estimated to be about 10 %.

Figure 1 shows the multi-bunch energy spread with and without ECS. The observation of the beam energy was performed by using BPM installed after a bending magnet of the transport line. The multi-bunch signal from the BPM was observed by a digital oscilloscope of 1 GHz bad width. The effect of the ECS is successfully demonstrated in the cases of 10 bunches with a bunch population of 4×10^9 electrons and 20 bunches with that of 7×10^9 electrons. The energy spread among bunches could be reduced to $\pm0.5\%$ peak to peak. Figure 2 shows the single bunch energy spread with and without ECS.

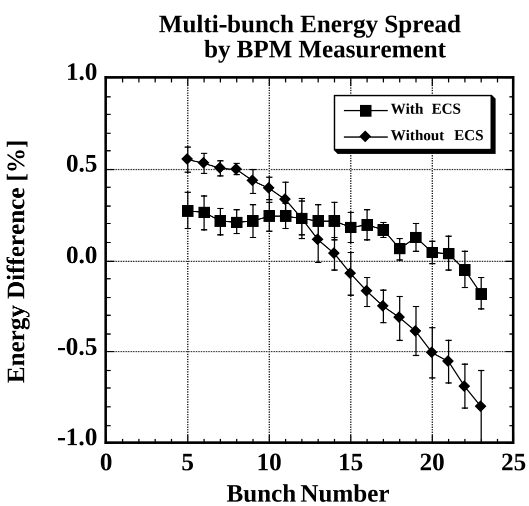

Figure 1: Multi-bunch energy spread with and without ECS.

6 INSTRUMENTATION

The beam-diagnostic system, except for the position monitor is installed in the linear accelerator in order to measure the characteristics of each bunch in a multi-bunch. The beam current is measured by an amorphous core current transformer(CT) and wall current monitors(WCMs). The beam profile (transverse and longitudinal) is measured by optical-transition radiation monitors(OTRMs). The beam-profile measurement of each bunch is performed by using a fast gate camera and OTR monitors. The beam emittances of each bunch is measured by a wire scanner(WS) and a gated photo multiplier tube(GPMT). These monitors have the capability of multi-bunch measurements and were described in the pre–injector section.

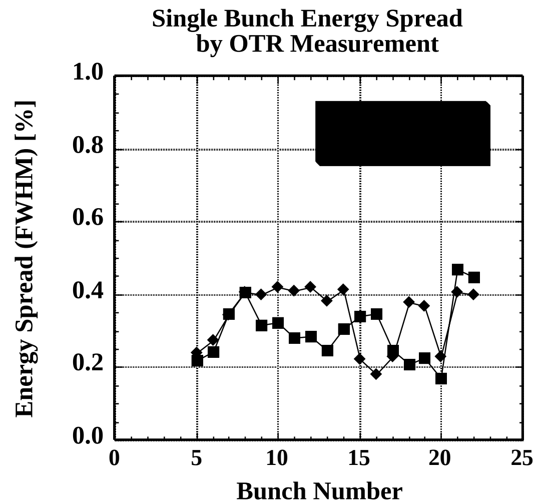

Figure 2: Single bunch energy spread with and without ECS.

7 TROUBLE SHOOTING OF THE LINAC

After restarting linac-operation for the beam commissioning of the ATF damping ring, it was found that the pre-fire in the tyratron tubes during a DC-charge to a pulse-forming network produces an over voltage to the thyratron tube. The source of the over voltage is a resonance between the high capacity DC power-supply connected to seven klystron modulators and a pre-fired modulator. In order to avoid the damage of the thyratron tubes, the seven klystron modulators were forced to operate at lower voltage. Therefore the output rf power from seven klystrons were limited to 30–35 MW, and then the beam energy was limited to 1.0 GeV. The protection circuit to decrease the resonant voltage and an interlock system were installed in the DC power supply and modulators. After that the beam energy could be increased to 1.44 GeV. After rf processing of SLED cavities and accelerating structures, the beam energy would be increased to 1.54 GeV.

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9 REFERENCES

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