PRELIMINARY TEST OF +-ΔF ENERGY COMPENSATION SYSTEM

S. Kashiwagi , [1]H. Hayano , [1]F. Hinode, [1]K. Kubo, [1]H. Matsumoto, [2]S. Nakamura,
[1]T. Naito, [1]K. Oide, [1]K. Takata, [1]S. Takeda, [1]N. Terunuma, [1]J. Urakawa , [3]T. Okugi, [4]M. Kagaya
Department of Accelerator Science, School of Mathematical and Physical Science,
The Graduate University for Advanced Studies
1-1 Oho, Tsukuba, Ibaraki, 305, Japan
[1]National Laboratory for High Energy Physics
1-1 Oho, Tsukuba, Ibaraki, 305, Japan
[2]Depertment of Physics, Faculty of Education, Yokohama National University
156 Tokiwadai, Yokohama, Kanagawa, 240, Japan
[3] Depertment of Physics, Tokyo Metropolitan University
1-1 Minami-Osawa, Hachioji, Tokyo, Japan
[4]Tohokugakuin University
1-13-1 Chuo, Tagajo, Miyagi, Japan

Abstract

The 1.54 GeV S-band linac for the Accelerator Test Facility (ATF) accelerates multi-bunch beam. The beam has 20 bunches of $2x10^{10}$ electrons with 2.8 ns bunch spacing. When multi-bunch beam is accelerated in the linac, the beam has the energy deviation by transient beam loading. The 1.54 GeV S-band Linac is an injector of the damping ring (DR), and the energy acceptance of the DR is ±0.5%. This means that the beam loading compensation system is necessary in the linac for a successful injection of multi-bunch into DR. The system consists of a compensating section in addition to a regular accelerating section. The accelerating structures of compensating section are operated with slightly different RF frequencies of 2856±4.327MHz. This paper describes the principle of the beam loading compensation system and the results of energy compensating experiment.

Introduction

For future linear colliders, one of essential technique to get a sufficient luminosity is the ability to accelerate multi-bunch beam with small bunch spacing. As the pulse length of a multi-bunch beam is shorter than the filling time of accelerating structures, the energy gain of successive bunches drops by approximately linear function due to a transient beam loading in the accelerating structures. The energy loss (E_{bl}) at time t after the first bunch injection is

$$E_{bl} = \frac{r_0 i_0 L}{2}\left[\frac{2\tau e^{-2\tau}}{1-e^{-2\tau}}\frac{t}{t_f} - \frac{1-e^{-2\tau t/t_f}}{1-e^{-2\tau}}\right],$$

where t_b, r_0, τ_0, t_f are the instantaneous current of the beam and shunt impedance, the attenuation parameter and the filling time of the accelerating structures, respectively. The instantaneous beam current is expressed as

$$i_0 = \frac{e N_b}{t_{sp}},$$

where e, N_b, and t_{sp} are $1.6x10^{-19}$C, the total number of electrons per bunch and bunch separation, respectively. There are many methods to compensate transient beam loading, such as ΔT method, ΔF method and so on. The ΔT method is to inject a beam before an rf pulse has filled in an accelerating structure. The ΔF method is to have one or more accelerator structures running at slightly higher and lower than fundamental frequency and roughly in 90 degree out of phase from the acceleration.

Principle of ±ΔF Energy Compensation System

The ΔF Energy Compensation System (ECS) compensates for multi-bunch energy spread by keeping a bunch separation synchronized with an rf frequency. In this compensation system, compensating structures are installed between the regular accelerating structures. When a bunch train goes through the compensating structures driven at an rf frequency which is slightly higher and lower than the fundamental accelerating frequency, succesive bunches of the train ride on a different phase of the accelerating field (see Fig. 1). Due to this phase difference, the energy gain of the succesive bunches is different. As a result, the multi-bunch energy spread is compressed to a small value. When a bunch train enters the compensating structures of +Δf, the energy gain is lower for the bunch head and higher for the tail due to the fact that each bunch accelerates at a positive slope of the part of sinusoidal wave in the structure. To compensate for this single-bunch energy spread which is created in the compensating structures, two frequencies (f+Δf, f-Δf) are necessary in order to compensate it by both a negative slope and a positive slope.

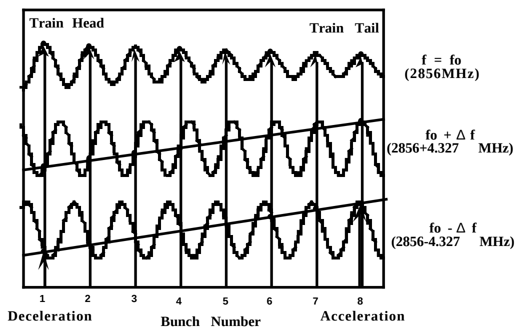

Fig. 1. Principle of the ±Δf energy compensation

This energy compensation system has a high flexibility for bunch population changes, the amount of compensation can be controlled by the input RF power applied to the compensation structures.

±ΔF Energy Compensation System in ATF

The 1.54 GeV S-band Linac of ATF accelerates a multi-bunch beam that consists of 20 micro-bunches with 2.8 ns spacing and the repetition rate of 25 Hz. After acceleration in the 1.54 GeV linac, the multi-bunch beam are injected into DR which generates extremely low emittance beams. The energy acceptance of DR is ±0.5%. As the multi-bunch beam with intensity of 2.0×10^{10} electrons/bunch is accelerated in the 1.54 GeV linac and a bunch train is injected after an rf pulse has filled in an accelerating structure, the multi-bunch energy spread of a bunch train is evaluated to be about 9.6% peak to peak without ΔT and ΔF compensation as shown in Fig. 2. Therefore, the beam loading compensation system is necessary in ATF for a successful operation of multi-bunch scheme. With the ΔF energy compensation system, the multi-bunch energy spread can be reduced to 0.27% with beam intensity of 2.0×10^{10} electrons/bunch.

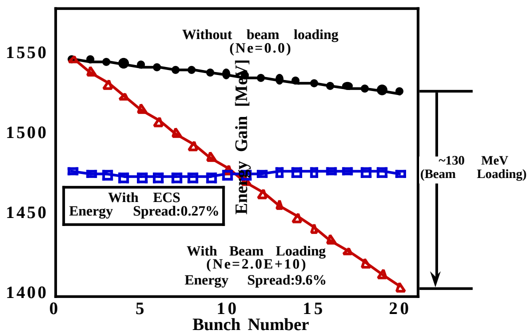

Fig. 2. Evaluated beam loading in ATF linac

Experimental setup

As shown in Fig. 3, the ATF rf system of the accelerator section consists of 8 regular rf units and 2 ECS rf units.

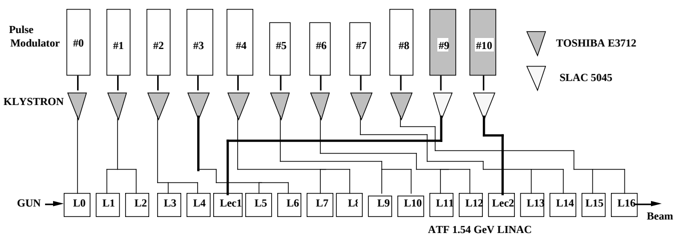

Fig. 3. Accelerator section of the ATF 1.54 GeV injector linac (L0-L16 regular sections, C1, C2 compensating sections)

The regular rf units consists of an E3712 klystron, a pulse modulator, a two-iris SLED cavity, rf waveguides, two 3 m-long accelerating structures and rf dummy loads. The ECS rf unit is composed of a SLAC-5045 klystron, a modulator, and a 3 m-long accelerating structure. The accelerating structures for the energy compensation system are designed for two frequencies (f_0±Δf). The rf pulse waveform from the two SLAC-5045 klystrons is rectangular with a width of 1.0 μs .

Timing system

In contrast to the regular accelerating section where the bunches are accelerated onto the crest of the RF wave, in the compensation section the bunches enter a phase where a slope of the part of sinusoidal wave. That is, a small jitter results in large uncertainty in the energy gain of bunches. In this reason, a very stable accelerating rf signal is required.

In the ATF, the fundamental frequency is generated using a 1428 MHz master oscillator, and the other necessary frequencies are generated from this reference signal using frequency multipliers and dividers. All the components are synchronized to this master oscillator. The sideband frequency for the compensation was selected to be 4.327 MHz signal, twice the revolution frequency of the DR, and 1/660 of the accelerating frequency. This frequency was decided by the bunch number (20 banches) and the DR revolution frequency. Two compensation signal (f_0±Δf) are generated by mixing the fundamental (2856 MHz) and the sideband (4.327 MHz) signal in the special module. Phase jitter was measured by generating two signals of the same sideband and feeding them into a mixer. The result of this measurement was 1.7 ps jitter at FWHM (sigma=0.8 ps)[1][2].

Measurement system of the beam energy

The beam energy of each bunch was measured from the strength of the bending field and the beam position after the bending magnet of the beam transport line. The measurement of the beam position for each bunch was performed by using stripline type BPM. The multi-bunch signal from BPM was measured by the digital oscilloscope of 2.5 GHz sample. The energy difference in a bunch train was calculated from the horizontal beam position and the dispersion function (η) at the BPM position. In this measurement, the position resolution of the BPM is limited by a sampling resolution and speed of the digital oscilloscope. The position resolution is evaluated to be 22.5 μm from the measurement range of the oscilloscope, the signal amplitude and the coefficient of sensitivity of the BPM. This value is sufficient to measure the beam position for each bunch, as the position resolution is converted into the energy resolution of 0.003%.

The dispersion function at the BPM was measured and compared to the calculated value by the program “SAD”[3] in the beam test. The measured value was 14% lower than the calculated value. The discrepancy is small compared to the DR energy acceptance. In the beam test of the ECS, the dispersion function of calculated value by the program “SAD” was used.

The beam profile were observed by a profile monitor using an optical transition radiation (OTR). A fast gated camera which has ~3 ns gate width, is used for the OTR monitor. The beam energy spread of each bunch was measured by the width (FWHM) of the profile at the beam transport line. The profile of each bunch was distinguished by changing the delay of the gated camera timing.

Preliminary beam test of the ECS

Adjustment of RF phase for the ECS

An adjustment of the RF phase for the ECS was performed by using the OTR monitor. At first, the gate timing of the OTR camera was set to the center of the bunch train. Then, the current of the bending magnet was adjusted that the bunch profile was seen on the center of the screen. An ECS phase was searched by a phase scan with 20 degrees step. Fig. 4 shows the beam energy dependence on the ECS phase. The optimum phase was decided from the result of a phase scan to find 90 degree apart from the accelerating phase.

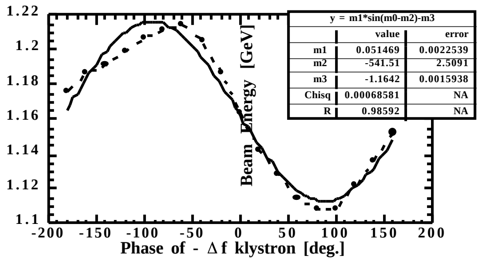

Fig. 4. ECS phase scan

The measurement of multi-bunch energy spread

In this experiment, the multi-bunch of 23 bunches/pulse accelerated up to 1.16 GeV with intensity of 3.2×10^{10} electrons/train. The bunch population of each bunch is shown in Fig. 5. After the adjustments of the ECS RF phase, the RF power of the klystrons were set to get a flat energy distribution for all bunches with 1.9 MW for +Δf and 1.5 MW for -Δf . The result of ECS on/off is shown in Fig. 6. The energy of each bunch distributed in about 1.5% without ECS, where the calculated energy difference was 2%. The ECS could compress it to about 0.5%. The energy decrease of the bunch train head seems to come from a BPM miss-reading by the beam loss of the collimator in front of the BPM.

Fig. 7 shows a single-bunch energy spread of each bunch with ±Δf ECS and +Δf only. The single-bunch energy spread with the ±Δf ECS was around 0.3% FWHM. When only +Δf

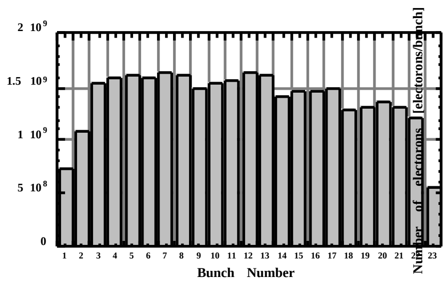

Fig. 5. Bunch population of the multi-bunch beam

ECS is applied on increase of single-bunch energy spread is expected. Although, there is no significant difference in this low compensation voltage. The detail of the single-bunch energy spread measurement is presented in elsewhere[4].

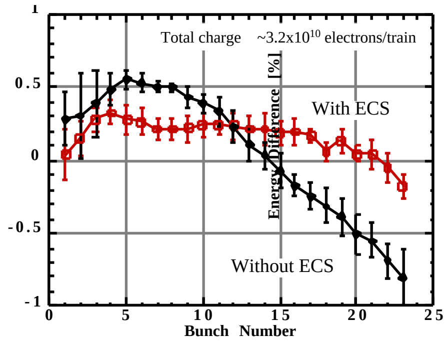

Fig. 6. multi-bunch energy spread

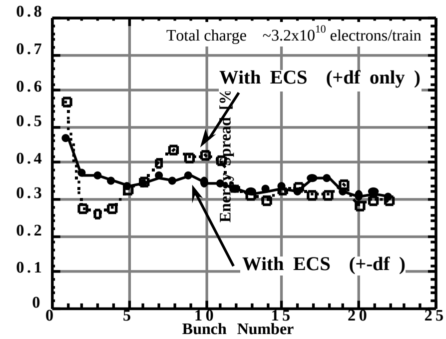

Fig. 7. Single-bunch energy spread

Summary

The beam test of the ECS was performed by using 2856±4.327MHz structures in the ATF linac. When the calculated energy difference by the beam loading was about 2%, the ECS could compress it to 0.5% by using rf power of 1.9 MW for +Δf and 1.5 MW for -Δf with 3.2×10^{10} total intensity.

Acknowledgment

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