AN 80MEV INJECTOR FOR ATF LINAC

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**DESY

Abstract

Accelerator Test Facility(ATF) consists of 1.54GeV S-band Linac and damping ring for linear collider R&D. The role of the injector of S-band Linac is to make an ATF bunch train which is 20 bunches of $2x10^{10}$ electrons and 2.8 ns bunch spacing. The bunch train is produced from the conventional thermionic gun by applying the rf burst pulse to the grid. The buncher system is required to make the 1ns width bunch short enough to accelerate up to 1.54GeV by 2856MHz rf. In order to avoid the phase shift in the buncher caused from the heading bunch loading, low R/Q bunching cavities are developed and tested. After the acceleration to 80MeV, the bunch length, beam energy and energy spread of each bunch were measured and compared with the results of the simulation code "PARMELA" in the preliminary beam test.

Introduction

The Injector(preinjector) of 1.54GeV ATF Linac consists of the thermionic gun, two of sub-harmonic bunchers(SHB), buncher cavities and a 3m long accelerating structure. It makes 20 bunches of $2x10^{10}$ electrons beam which has 2.8 ns bunch spacing. The bunch length is required to have less than 10 ps (FWHM) for every bunch. The main issues of this injector are a generation of multi-bunch from the thermionic gun and a bunching of the multi-bunch beam. The multi-bunch of ATF beam is generated by applying burst rf voltage to the grid. The half cycle of the rf voltage contributes to the beam emission which is 1ns(FWHM) and 3A peak current with 200kV kinetic energy. The frequency of the rf voltage is 357MHz which is the same frequency as the SHB's and is fully synchronized with it[1]. The problem on the bunching of the multi-bunch comes from beam loading voltages which rotate a buncher voltage from a proper phase of bunching. In order to avoid this phase shift, low R/Q structure for bunching cavities was chosen to reduce the magnitude of loading voltage. In this paper, we describe the preinjector design relating on a bunching issue of multi-bunch and the preliminary beam test of cavities and monitors.

80 MeV Preinjector of LINAC

History and background

The preinjector which was built as a test linac of Linear Collider R&D at Nikko-hall during 1987-91 was designed to make single bunch and high current beam. In the linac, 119MHz SHB, 238MHz SHB, 476MHz SHB, two of 2856MHz standing-wave prebunchers and 0.3m traveling-wave buncher were used for bunching. At the design of Damping Ring of new test facility ATF, bunch structure was decided to 2.8ns spacing of multibunch(20 bunches). The bunching system had to be modified to generate such a beam for 1.54GeV Linac and Damping Ring. Since an RF-gun with a photo-cathode which will be used in future is now under development, an ordinary thermionic gun and buncher cavity system is adopted for a first ATF beam generation.

The movement of the preinjector from Nikko-hall to TRISTAN Assembly-hall was done from fall 1992 to summer 1993. At that time, all SHB cavities were removed except pre-bunchers and buncher, and the frequency of the SHB power amplifier was modified to 357MHz. The R&D study of bunching scheme was begun.

Specification and Design

The required specification of preinjector comes from the energy acceptance and the dynamic aperture of Damping Ring. The energy spread between bunches will be compensated by the special accelerating structure in ATF Linac, however, the energy spread within a bunch is determined by the bunch length at the exit of the preinjector. Also, the dynamic aperture of Damping Ring determines the maximum emittance of the Linac beam. Assuming no emittance growth in the linac, the specification of maximum emittance will be applied to the preinjector. Table 1 summaries the requirement of the beam.

Beam Energy	80 MeV
Number of Bunches	20
Bunch Population	$2x10^{10}$ electrons
Bunch Separation	2.8 ns
Bunch Length(FWHM)	< 10 ps
Normalized Emittance	< $3x10^{-4}$ rad.m(rms)
Energy Spread(FWHM)	<1%(each bunch @1.54GeV)

Table 1 required specification of the preinjector

In order to meet these requirements, the development was focused on the generation of multi-bunch from the thermionic gun and on the bunching by multi-bunch loaded cavities. The extraction of the multi-bunch was done by applying an rf voltage to the grid. The beam has 1ns FWHM of bunch length. Each bunch contains $2x10^{10}$ electrons which is relatively high current produces cumulative loading voltage which distorts the cavity voltage in the bunching cavity. To avoid a phase shift of the bunching voltage by a beam loading two schemes were proposed and studied. One was a frequency shift operation of bunching cavities. The amount of frequency shift should be chosen to meet proper bunching phase for every bunch. The other was use of low R/Q cavities which reduce a beam loading voltage. A small induced voltage and high generator voltage operation can avoid a big phase shift by successive bunches. Considering on complicated frequency shift operation which needs complicated timing system, we adopt low R/Q buncher system which needs only big generator power to get proper voltage. Further more, to get more flexibility for buncher tuning, we introduced four single cell standing-wave cavities of low R/Q for buncher as well as low R/Q SHB cavities. The bunching and the transmission rate were checked by using PARMELA. The resultant bunch length was less than 15ps (FWHM) even after 20 bunch loading with greater than 85% transmission rate.

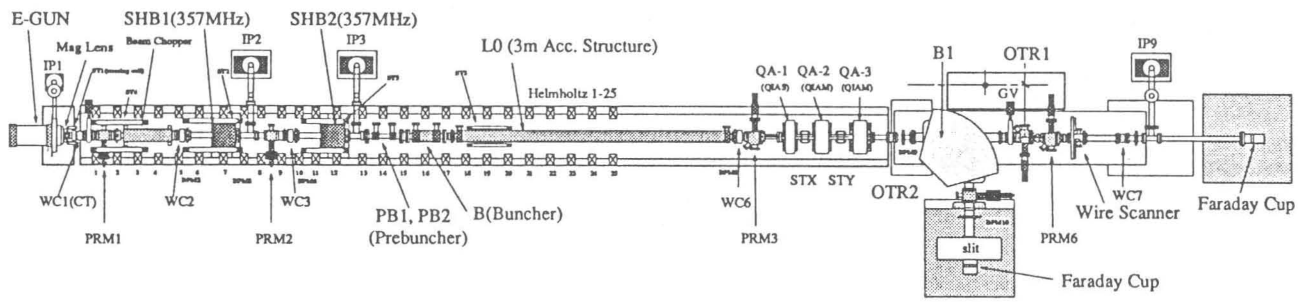

Figure 1. the preinjector setup of this beam test

Preinjector Beam Test on Summer '94

Preinjector Setup and Beam Test

The first beam test to make ATF bunch train was done in August '94. Two SHB cavities were processed and installed into the preinjector. Since the buncher cavities, however, are under development, the old standing-wave prebunchers and traveling-wave buncher were used with the same wave guide system of the single bunch design. The measured R/Q of the new SHB was 50Ω. It was fairly agreed with the design value of 65Ω. However the Q_0 was 2000 which was very small than the expected value of 8000. The reason was seemed to be existing of a gap in the cavity wall. The maximum voltage of the SHB was limited to 18kV with 5kW power amplifier from this reason. Since the beam test was carried before a restoration of the SHB, and since the other buncher cavities were not for heavy beam loading, the beam of preinjector exit was expected not to meet the specifications. Figure 1 shows the setup of the preinjector for this beam test. The current monitor at the exit of gun measures a generated beam current and the wall-current monitors at several locations measure the transmission rate of beam. Three of screen monitor are for position and size measurements. The BPMs which was installed in several locations were not used this time, because the electronics was under fabrication. After the acceleration to 80MeV, streak-camera using OTR for measurement of bunch length, wire scanner and gated PMT for beam size and emittance measurement are used. With the bending magnet, the beam energy and its spread are analyzed by gated camera using OTR. These monitors are for bunch by bunch measurement will judge the beam quality and tuning goodness.

Multi-bunch Generation and Buncher Tuning

The generated multi-bunch beam was 26 bunches with slow rise and fall shown in fig.2. The number of electron in each micro-bunch at the flat top was $8x10^9$ with 150keV energy and 1ns (FWHM) width. With maximum gap voltage of SHBs, the beam was bunched into S-band prebunchers. The setting of voltage and phase of bunchers were searched with monitoring transmitted current shape and bunch length by the streak-camera. The streak-camera was set its timing delay to catch the fifth bunch which is head of flattop. The settings of the solenoid coils were also searched from the initial setting which was gotten experimentally. After several iterations, we reached a point of minimum bunch length. However the tuning was seemed to be not so good, we stopped the tuning at this point and measured the beam parameter bunch by bunch.

Multi-bunch Beam Monitors

wall-current monitor

In order to get good response from 1ns to 10ps beam, we use a register loaded wall-current monitor as a beam current monitor. The monitor has 4 output port from the register of symmetrical position. These output are combined together to cancel out a beam position dependence. The response coefficients were measured before the installation using 500ps and 50ps pulser. The lower trace in fig.2 shows a transmitted current after 3m structure. It shows low transmission at the latter half of the bunches which comes from phase shift of buncher voltage.

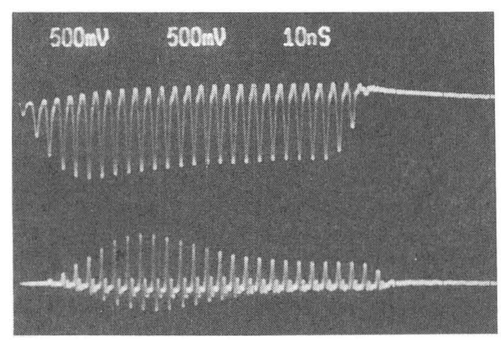

Figure 2. Extracted multibunch beam from gun (up)
Transmitted current through the 3m structure (down)

OTR monitors

Because a transition radiation occurs from each electron in the bunch, it carries the information of bunch structure. We use OTR monitor for bunch by bunch profile measurement[2] and bunch length measurement. Together with bending magnet, profile measurement is correspond to an energy spread measurement. The OTR was generated by 1mm thickness of polished steal. The 3 ns gated camera was used for profile measurement. The streak-camera which has a maximum resolution of 0.6ps was used for bunch length measurement. Since OTR was not so strong enough, we did not use band-pass filter for wave length selection. So the measured bunch length was made a correction of dispersion effect. Figure 3 shows a bunch length of each bunch and figure 4 shows an energy and its spread of each bunch. The bunch length was optimized in the part of flat-top head and increased at the tail. The energy spread tended to opposite to the bunch length. The beam energy was decreased gradually by the beam loading in spite of sitting on the front crest of rf.

Wire Scanner for Multi-bunch

The wire scanner is routinely used for an emittance measurement in ATF[3]. To resolve each bunch, we introduced an MCP-PMT with gate function for gamma detection. The supplied gate was 3ns width was adjusted to select one of bunch signal. By the fixed gate, the wire was scanned for many pulses of the beam. It takes about 40 sec for a beam size measurement and 5 min. for an emittance measurement. Figure 5 shows the emittance of each bunch which is no strong dependence on the bunch order considering its big error of a few 10%.

Comparison with Simulation Results

A confirming calculation was done by PARMELA after the experiment. The input of this code was the current of all focusing magnets and amplitude of each cavities. A search of the parameter was done for the phase of each cavities to get minimum satellite bunch, maximum transmission current and minimum bunch length. Since the code calculates only single bunch without beam loading, the comparison with one of multi-bunch is not adequate in the point of view of beam loading. The cavity voltage would change slightly by head bunch loading. However, the comparison which is summarized in table 2 below shows a good agreement with measurements on the 5th bunch except transmission rate. The measurement of transmission by wall-current monitor was not so accurate at that time, so the measurement by the faraday cup was put on the table as an average.

	PARMELA	measurement
total transmission	89%	25%(average)
bunch length (FWHM)	17ps	19 - 23ps
energy spread (FWHM)	0.4 MeV	0.4 MeV
normalized rms emittance	3.6×10^{-5}	$4.0 - 7.0\times10^{-5}$

Table 2 comparison of beam with PARMELA

Summary

The study of multibunch generation in the preinjector of ATF was begun on August '94. Only the low R/Q SHBs were used for the bunching test. The multibunch beam monitors which were also developed and tested were confirmed to work. The comparison of beam measurements with PARMELA gave a good agreement except transmission rate. The further study will be continued with new bunchers of low R/Q.

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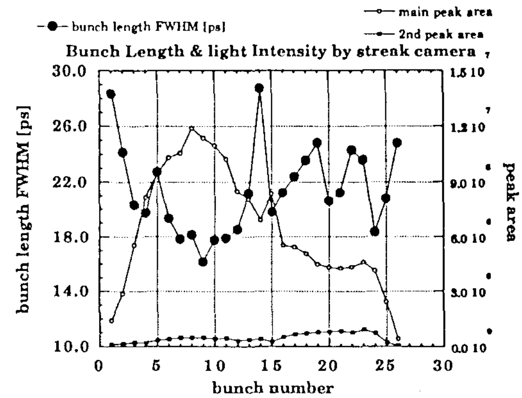

Figure 3. Bunch length measurement of each bunch by the OTR and streak-camera.

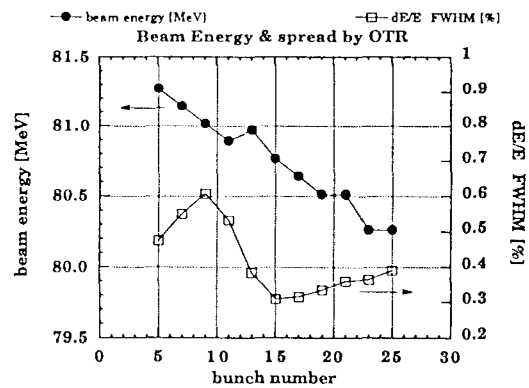

Figure 4. Energy and energy spread measurement of each bunch by the OTR and gated camera.

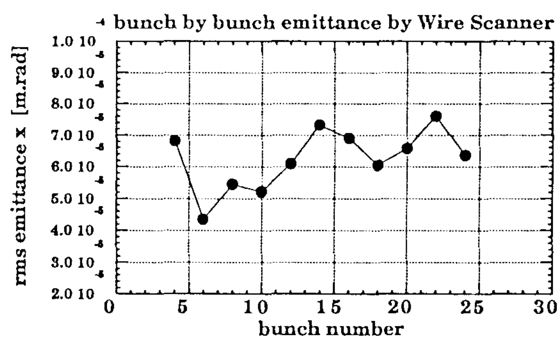

Figure 5. Emittance measurement of each bunch by the wire scanner and gated PMT.

References

[1] T. Naito, M. Akemoto, T. Asaka, H. Hayano, H. Matsumoto, S. Takeda, J. Urakawa, and M. Yoshioka "Multi-bunch Beam with Thermionic Gun for ATF", in this conference

[2] T. Naito, T. Asaka, H. Hayano, H. Matsumoto, and S. Takeda "Bunch by Bunch Beam Monitor for ATF Injector Linac", in this conference

[3] T. Asaka, H. Hayano, M. Kikuchi, T. Naito, J. Urakawa, M. Yoshioka, T. Nakazato, M. Oyamada, S. Urasawa and T. Yamakawa "Wire Scanner System of ATF Linac", Proc. of the 19th Linear Accelerator meeting in Japan, July 1994, p269.