FIRST BEAM TEST OF Δϕ-A INITIAL BEAM LOADING COMPENSATION FOR ELECTRON LINACS

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Abstract

The initial beam loading effect may cause serious beam loss in the electron linac of the Super SOR light source [1]. Because of the large energy spread, it is difficult to compensate the beam loading with ordinary methods, such as the adjustment of injection timing and ECS (Energy Compensation System). A phase-amplitude (Δϕ-A) modulation system has already been developed and tested. First beam test using this system was carried out at the 125MeV electron linac of Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University. Its result shows that our system well corrects the energy spread due to initial beam loading effect. In this paper, we report the results of first beam test.

1 INTRODUCTION

In high-intensity electron linacs, such as the Super SOR electron linac in the mode of slow positron production, a long bunch train is accelerated on each RF pulse. In such a case, the negative longitudinal wake potential increases along the bunch train during one filling time of the accelerating structure, and it makes an energy spread within beam pulse. Its effect is called initial beam loading (transient beam loading) effect. Because the heavy loading gives rise to a large energy spread that may cause serious beam loss in the linac and the beam lines to follow, it should be compensated with some correction method. Initial beam loading effect can be compensated to a certain extent by using the adjustment of beam injection timing and/or ECS. However, these methods are not very effective for a large energy spread amounted to several tens percent.

We adopted the Δϕ-A method (the amplitude modulation or ΔT method), which can completely correct initial beam loading effect on each accelerating structure[2,3,4]. In this scheme, pre-filling of the structure

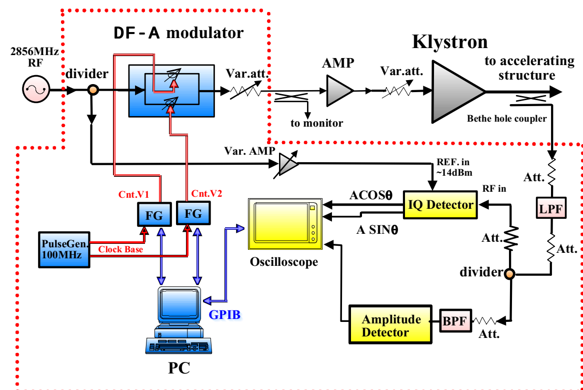

Figure 1: Block diagram of the Δϕ-A modulation system for initial beam loading compensation.

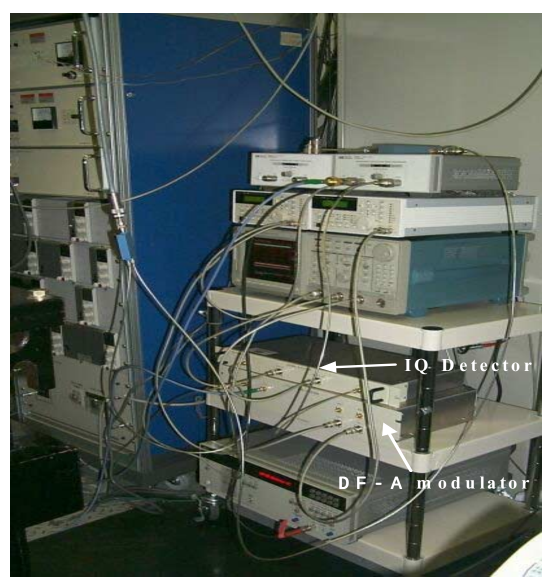

Figure 2: Photograph of the Δϕ-A modulation system.

with RF before beam injection can be done so that energy gain of each bunch during the transient period is equal to that of each bunch of steady state. The characteristic of our method is that the RF amplitude and phase are

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simultaneously modulated at a low power level by using the response curve of the amplification system; the solid state amplifier and klystron [5]. A merit of our system is that it can be easily installed in and removed from the RF amplification system because of its simple setup.

We have developed a Δϕ-A modulation system using two fast phase shifters which is operated at a low power level. Figures 1 and 2 show the block diagram and photograph of the Δϕ-A modulation system respectively. The system has already been tested at the klystron test bench of KEK-LINAC. At that experiment, the accuracy of phase measurement is not satisfactory because the response of phase detector is more than 150nsec. For this reason, a fast phase detector has been developed and used for the beam test.

2 FAST PHASE DETECTOR

The fast phase detector has been developed in order to compensate the beam loading more accurately. It is based on the IQ (Inphase/Quadrature) technique[6]. It consists of two DBMs (Double-Balanced Mixer), two low pass filters, a power divider and a 90° hybrid that splits the signal into inphase and quadrature components. The block diagram of the phase detector is shown in Fig. 3.

When the reference and test RF signal are input to the different ports, two DC signals are obtained. One is proportional to ACOSθ(=Vi) and another is to ASINθ(=Vq), where “A” and “θ” are the amplitude of test RF and the phase difference between test and reference RF respectively. Therefore, we can simaltanesouly obtain

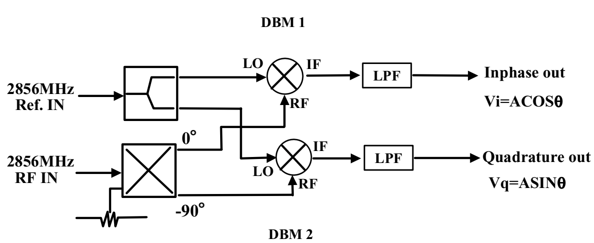


Figure 3: Block diagram of the fast phase detector (IQ detector).

the amplitude and phase of test RF signal by using the follwing equations.

$$A = \sqrt{V_q^2 + V_i^2}, \quad \theta = \tan^{-1}\left(V_q / V_i \right) \qquad (1)$$

The performance tests of this phase detector are carried out at a low and high power level. The results show that the response time is less than 10nsec. It is an enough performance for our purpose.

3 BEAM TEST

The first beam test of initial beam loading compensation using the Δϕ-A modulation system have been carried out in the LEBRA electron linac of Nihon University. The LEBRA s-band linac consists of two klystrons and 3 accelerating structures in order to achieve FEL, which covers from infrared to ultra violet region. Figure 4 shows the RF system of this experiment. The Δϕ-A modulation system is installed before the solid state amplifier in the #2 klystron unit. The 2856MHz RF signal is amplified by a solid state amplifier up to 400W and fed to MITSUBISHI ELECTRIC CORP. PV-3030 klystron. The peak power of the klystron output is about 20MW in this test. Table 1 shows the parameters in this experiment.

At first, the klystron output was controlled to be close to the target value. Its results are shown in Fig. 5 to 8. The amplitude error is within ±3% and the phase variation is within ±2° except at the rise of the RF pulse.

Next, the klystron output of the final result is input to the accelerating structures. Figure 8 shows the electron beam waveforms measured on several timings of beam injection. Figure 8-(b) shows the case of beam injected after the first filling time. Figures 8-(a), (c) and (d) are the case of beam injected timing being delayed to the first filling time for –150nsec, 225nsec and 450nsec respectively. In the case of (b), the pulse width of beam before bending magnet (CH2) is comparable to one after bending magnet (CH3 and CH4). It means that initial beam loading is well compensated, and that the beam energy spread is much reduced.

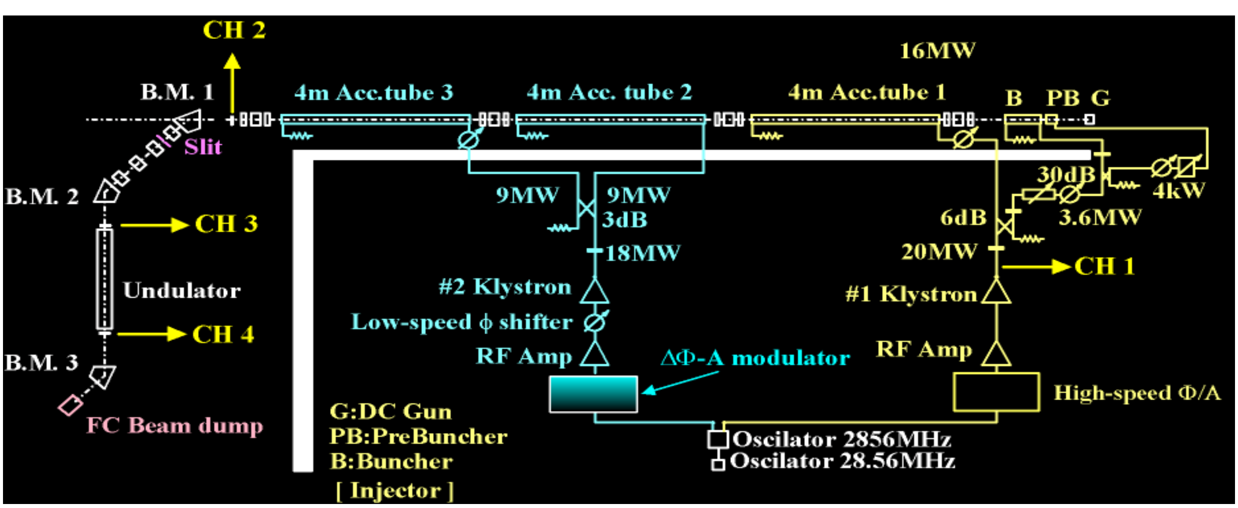


Figure 4: Experimental setup for Δϕ-A initial beam loading compensation system.

4 SUMMARY & FUTURE PLAN

The first beam test of energy compensation is performed by using a low level RF $\Delta\phi$-A modulation system. The initial beam loading effect is well compensated, and as a result the beam energy spread is considerably reduced. In the near future, the software for the $\Delta\phi$-A modulation system will be improved in order to control the RF waveform more accurately at the rise of pulse. The energy spread within beam pulse will also be measured accurately.

Table 1: Parameters of this beam test.

Beam energy	86.8 MeV
Average beam current	100 mA
Beam pulse width	10 μsec
Repetition rate	2 pps
Output power of #1 klystron	20 MW
Output power of #2 klystron	18 MW
RF frequency	2856 MHz
Shunt impedance	60 MΩ/m
Accelerating structure length	4 m
Attenuation parameter τ	0.627
Filling time t_f	935 nsec
Q	13000

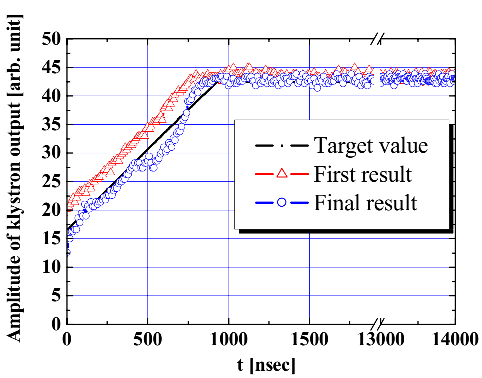


Figure 5: Result of klystron output (amplitude).

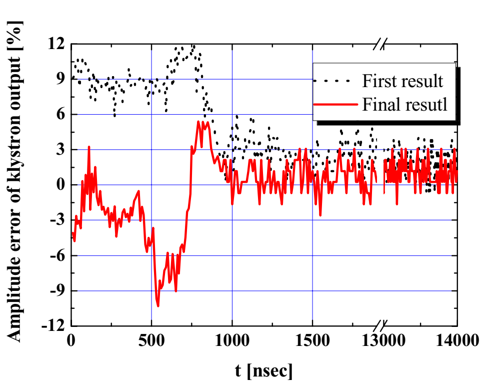


Figure 6: Result of klystron output error (amplitude).

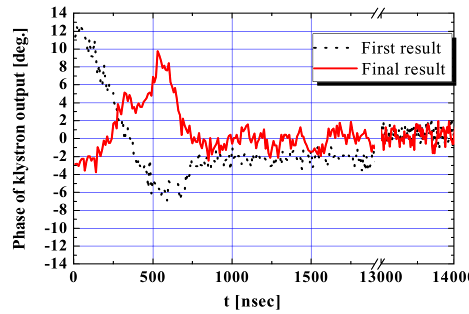
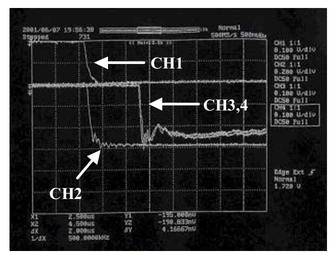
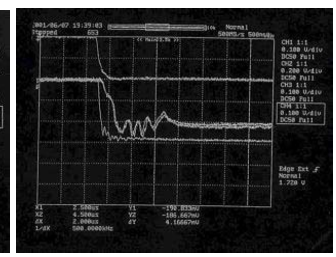


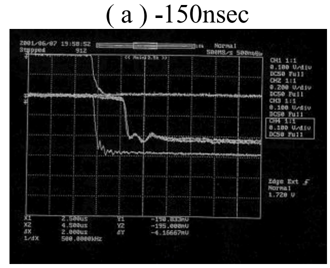
Figure 7: Result of klystron output (phase).



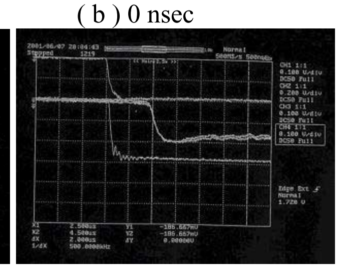
(a) -150nsec



(b) 0 nsec



(c) 225 nsec



(d) 450 nsec

Figure 8: Measured beam pulse waveform with different injection timings. CH1 shows the amplitude of #1 klystron output. CH2 shows the beam waveform at the end of straight section. CH3 and CH4 show the beam waveform before and after the undulator respectively. Electron beam is injected after one filling time (b). (a), (c) and (d) are the case of beam injected timing being delayed to the first filling time for –150nsec, 225nsec and 450nsec respectively.

5 REFERENCES

[1] K. Harada et al., “The effect of the Insertion Devices at the Super SOR light source”, in these proceedings.

[2] K. A. Thompson and R. D. Ruth, “Simulation and Compensation of Multibunch Energy Variation in NLC”, Proceedings of the 1993 Particle Accelerator Conference, p.3693 (1993).

[3] I. V. SYRACHV and T. HIGO, “Numerical Investigation of Transient Beam Loading Compensation in JLC X-band Main Linac”, KEK Report 96-8 A (1996).

[4] S. Kashiwagi et al., “Beam Loading Compensation using Phase to Amplitude Modulation Method in ATF”, ATF INTERNAL REPORT 98-27 (1998).

[5] M. Satoh et al, “COMPENSATION OF INITIAL BEAM LOADING FOR ELECTRON LINACS”, Proceedings of the Seventh European Particle Accelerator Conference, Vienna, p.2462 (2000).

[6] Y. Ohtake, KEK Report 95-18 A, p.256 (1996).