BEAM TEST OF INITIAL BEAM LOADING COMPENSATION FOR ELECTRON LINACS

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Abstract

For high-intensity electron linacs, one of the noble schemes to obtain a sufficient intensity is to accelerate a multi-bunch beam in an RF pulse generated by a klystron. It is a very useful technique for FEL linacs and/or to increase the injection rate for storage rings. Furthermore, it can realize a high-energy transfer efficiency of the RF power to the beam. In multi-bunch operation, however, it also has a troublesome defect called "Initial-Beam-Loading" effect, which causes a large energy spread along the bunch train within the beam pulse. The initial-beam-loading effect can be considered to be the sum of the single-bunch beam loadings. Since it may cause serious beam loss in linacs and beam lines to follow, it should be corrected to a tolerable level by using the some suitable method. We have developed an initial-beam-loading compensation system, which can modulate the phase and the amplitude of a low-level RF signal [1,2]. A beam test using this system was carried out at the 125-MeV electron linac of Laboratory for Electron Beam Research and Application (LEBRA) of Nihon University. The result shows that our system well corrects the energy spread due to the initial-beam-loading effect. In this paper, we report on the results of beam tests.

1 INTRODUCTION

In high-intensity electron linacs, 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 the beam pulse. Because heavy loading gives rise to a large energy spread that may cause serious beam loss, it should be compensated by some correction method. Initial-beam-loading effect can be compensated to a certain extent by adjusting the beam injection timing and/or ECS. However, these methods are not very effective for a large energy spread amounting to several tens of percent.

We adopted the ΔΦ-A method (the amplitude modulation or ΔT method), which can completely correct the initial-beam-loading effect on each accelerating structure [3,4,5]. In this scheme, pre-filling of the structure with RF before beam injection can be done so that the 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 the phase are simultaneously modulated at a low power level by using the response curve of the amplification system: the solid-state amplifier and klystron. A merit of our system is that it can be easily installed in and removed from the RF amplification system owing to its simple setup (Fig. 1).

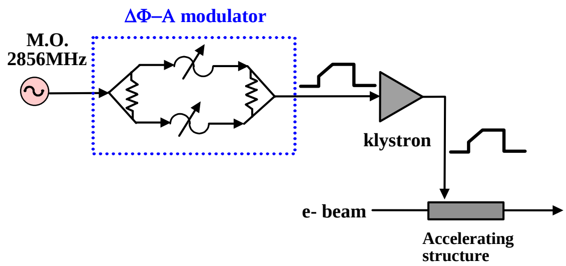

Figure 1: Schematic drawing of the low-level RF ΔΦ-A modulation method.

2 COMPENSATION SYSTEM

Figures 2 and 3 show a block diagram and a photograph of the initial-beam-loading compensation system, respectively. The compensation system consists

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of a ΔΦ-A modulation system and an I/Q (Inphase/Quadrature) detector.

The ΔΦ-A modulator we developed consists of two fast variable phase shifters and two 3-dB power dividers. A hybrid-coupled type using a varactor-diode was adopted for the fast phase shifter. Two 100-MHz programmable arbitrary waveform generators (Pragmatic Instruments, Inc. 2416A) with a control voltage from 0-V to 10-V are used for controlling two phase shifters, each of which has a 12-bit resolution and a rising time of less than 5-nsec. A 100-MHz pulse generator is used for the common time base of two arbitrary waveform generators in order to avoid any relative jitter, which may deteriorate the accuracy of the output RF control in both amplitude and phase. The modulator can achieve a maximum attenuation of more than 20-dB, and can transform the input CW signal into a pulse.

The I/Q detector as a fast phase detector we developed consists of two DBMs, two low-pass filters, a power divider and a 3-dB quadrature hybrid, which divides the RF signal into two equal outputs in amplitude with a 90-degree phase difference between them. In principal, it can simultaneously detect the amplitude and phase of the RF signal. In this beam test, an ordinary RF detector was used for amplitude measurements.

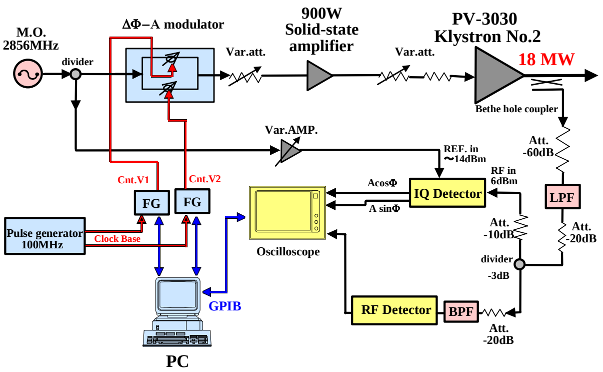

Figure 2: Block diagram of the initial-beam-loading compensation system.

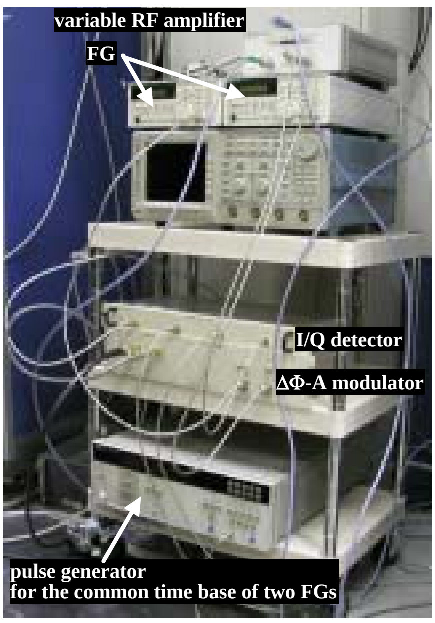

Figure 3: Photograph of the initial-beam-loading compensation system.

This compensation system has already been tested at the klystron test bench of KEK-LINAC without a beam, and its result showed a good performance of our compensation system.

3 RESULT OF BEAM TEST

A beam test of the initial-beam-loading compensation was carried out at LEBRA of Nihon University. The LEBRA facility has both a free electron laser (FEL) and a parametric X-ray (PXR) generation system based on the S-band (2856-MHz) 125-MeV electron linac. The electron linac consists of two klystrons, a DC gun, a pre-buncher, a buncher and three 4-m accelerating structures, each of which consists of 110 cells. Each klystron unit has an IΦA system and a 900-W solid-state amplifier (Class-C). The experimental setup of the beam test is shown in Fig. 4.

For energy compensation of two accelerating structures (Acc2 and Acc3), a ΔΦ-A modulation system is installed upstream of solid-stale amplifier No.2 driving klystron No.2, instead of the high-speed IΦA unit. Therefore, in this beam test, the energy spread caused by Acc1 is not compensated, and we aim to reduce the energy spread caused by only Acc2 and Acc3. The main parameters of the beam test are given in Table 1.

Figure 5 shows the measured and calculated beam energy spread before and after compensation. It shows that the energy spread is reduced from 24% to 6% by our compensation system. The reason for the energy spread remaining after compensation is that the initial-beam-loading effect is not compensated at Acc1.

4 SUMMARY & FUTURE PLAN

The ΔΦ-A modulation system and the I/Q detector have been developed for initial-beam-loading compensation. The first beam energy measurement was carried out using this compensation system.

When the same ΔΦ-A modulation system is also installed in klystron system No.1 and a more high-performance preamplifier, for example a Class-AB amplifier, is used for driving the klystron, the energy spread can be reduced to almost zero. Therefore, the result of this study shows for the first time that the ΔΦ-A modulation scheme of the low-power RF is a powerful tool for initial-beam-loading compensation.

To perform pulse-to-pulse feedback, a fast feedback control system based on a VMEbus is being developed and tested. Its photograph is shown in Fig. 6. Its performance and a detailed system description will be presented elsewhere.

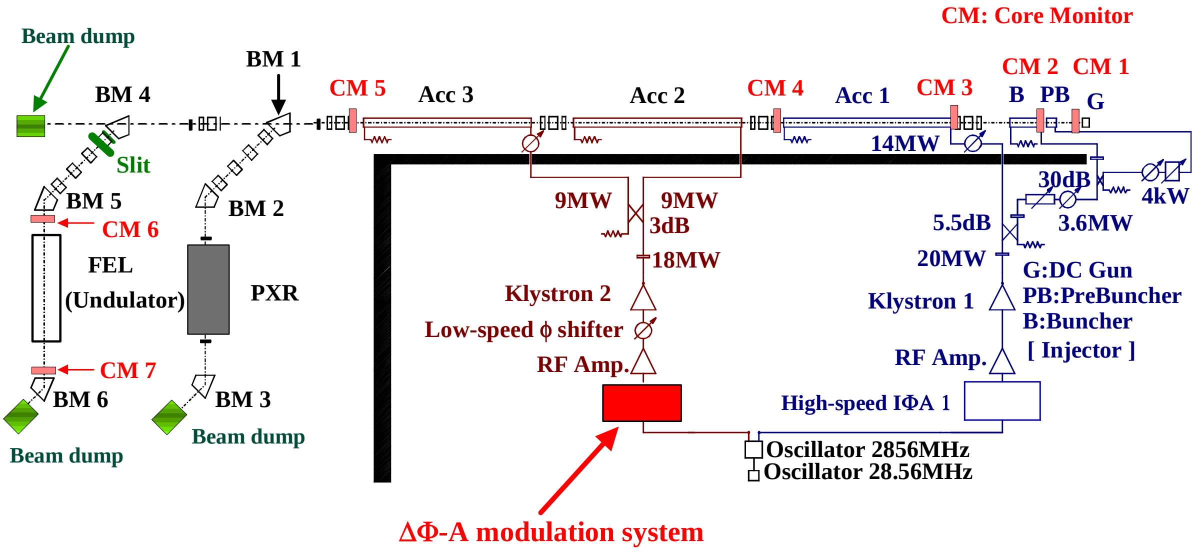

Figure 4: Experimental setup for the ΔΦ-A initial-beam-loading compensation system.

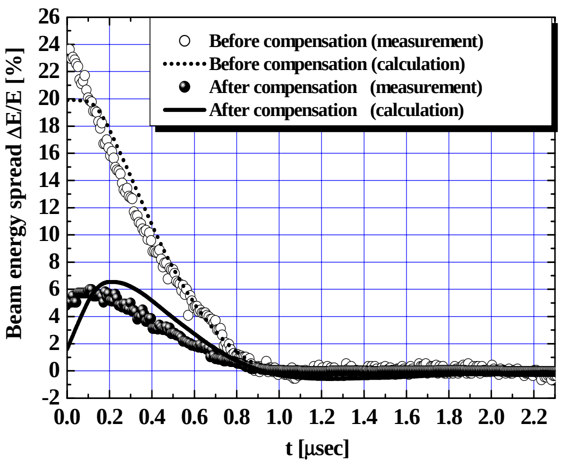

Figure 5: Measured beam energy before and after initial-beam-loading compensation.

Figure 6: Photograph of a new ΔΦ-A control system under development.

Table 1: Main parameter of the beam test.

Beam energy gain of steady-state	
with compensation	89 MeV
without compensation	100 MeV
Beam pulse width	2.3 μsec
Average beam current	
at the DC gun	180 mA
at the accelerating structure (No.1)	140 mA
at the accelerating structure (No.2 and No.3)	100 mA
Klystron output power	
Klystron No.1 (without compensation system)	20 MW
Klystron No.2 (with compensation system)	18 MW

5 REFERENCES

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