

# BEAM TEST OF INITIAL BEAM LOADING COMPENSATION FOR ELECTRON LINACS

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## Abstract

For the high-intensity electron linacs, one of the noble schemes to get a sufficient intensity is to accelerate the multi-bunch beam in an RF pulse generated by the klystron. It is very useful technique for FEL linacs and/or to increase the injection rate for the storage rings. Furthermore, it can realize the high energy transfer efficiency of the RF power to the beam. In the multi-bunch operations, however, it has also a troublesome defect called “Initial-Beam-Loading” effect, which causes the large energy spread along the bunch train within the beam pulse. The initial-beam-loading effect can be considered as a sum of the single-bunch beam loadings. Since it may cause serious beam loss in the linacs and the beam lines to follow, it should be corrected to the tolerable level by using the some suitable method. We have developed the initial-beam-loading compensation system, which can modulate the phase and amplitude of the low level RF signal [1,2]. Beam test using this system was carried out at the 125-MeV 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 beam test.

## 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 beam pulse. Because the heavy loading gives rise to a large energy spread that may cause serious beam loss, 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  $\Delta\Phi$ -A method (the amplitude modulation or  $\Delta T$  method), which can completely correct 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 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 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 because of its simple setup (Fig. 1).

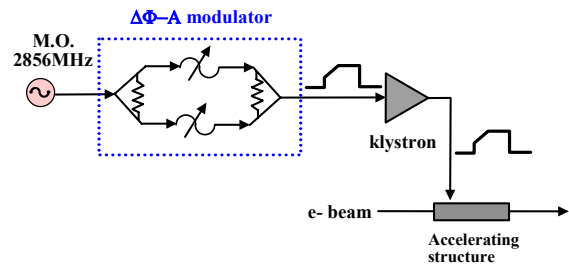


Figure 1: Schematic drawing of the low-level RF  $\Delta\Phi$ -A modulation method.

## 2 COMPENSATION SYSTEM

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

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of a  $\Delta\Phi$ -A modulation system and an I/Q (Inphase/Quadrature) detector.

The  $\Delta\Phi$ -A modulator we developed consists of two fast variable phase shifters and two 3-dB power dividers. The hybrid-coupled type using the 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, and each of them has a 12-bit resolution and a rising time less than 5-nsec. The 100-MHz pulse generator is used for the common time base of two arbitrary waveform generators in order to avoid the relative jitter, which may deteriorate the accuracy of the output RF control in amplitude and phase. The modulator can achieve the maximum attenuation more than 20-dB, and it can transform the input CW signal into the pulse.

The I/Q detector as 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

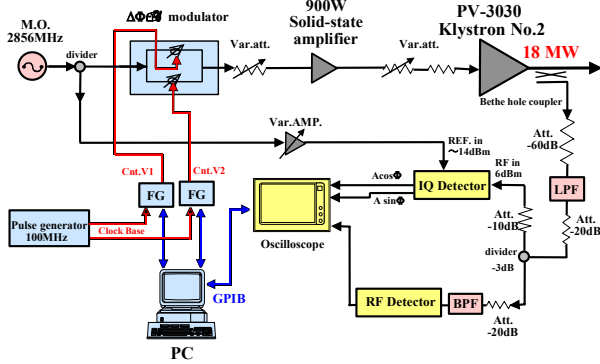


Figure 2: Block diagram of initial beam loading compensation system.

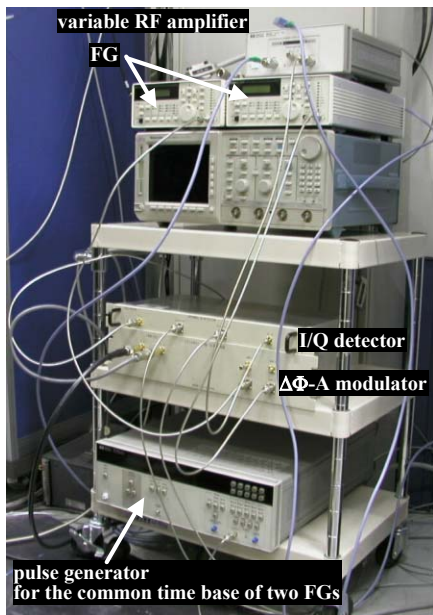


Figure 3: Photograph of initial beam loading compensation system.

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, the ordinary RF detector was used for the amplitude measurement.

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

### 3 RESULT OF BEAM TEST

The beam test of initial beam loading compensation was carried out at LEBRA of Nihon University. 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 the energy compensation of two accelerating structures (Acc2 and Acc3), the  $\Delta\Phi$ -A modulation system is installed in the upstream of the solid-state amplifier No.2 driving the 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 parameter of beam test is shown 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 remaining the energy spread after compensation is that the initial-beam-loading effect is not compensated at Acc1.

### 4 SUMMARY & FUTURE PLAN

The  $\Delta\Phi$ -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  $\Delta\Phi$ -A modulation system is also installed in the klystron system No.1 and the 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  $\Delta\Phi$ -A modulation scheme of the low-power RF is powerful tool for the initial-beam-loading compensation.

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

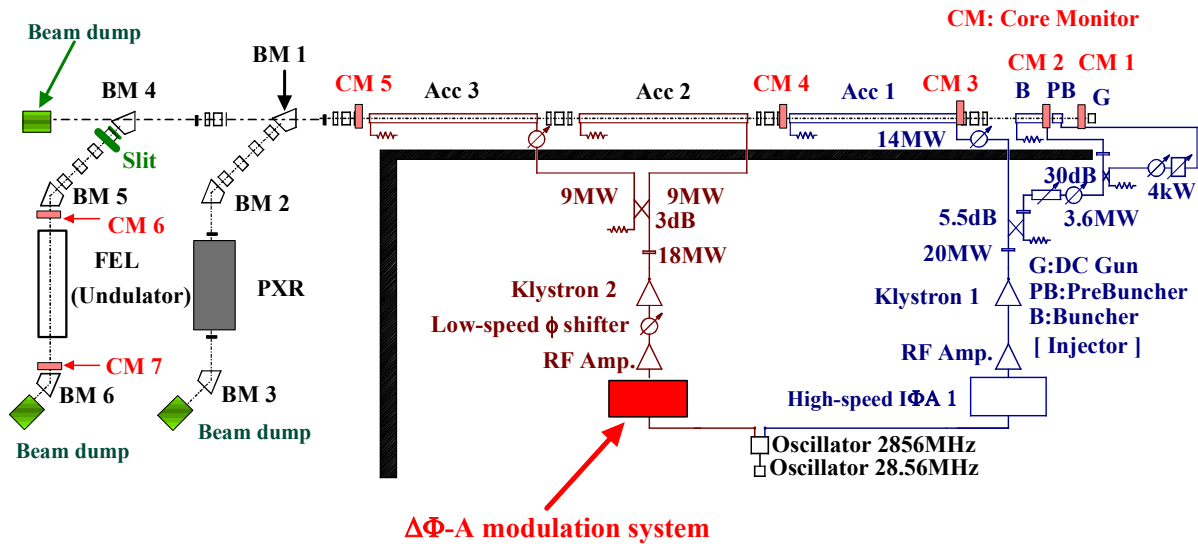


Figure 4: Experimental setup for  $\Delta\Phi$ -A initial beam loading compensation system.

Table 1: Main parameter of beam test

Beam energy gain of steady-state	
with compensation	89 MeV
without compensation	100 MeV
Beam pulse width	2.3 $\mu$ sec
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

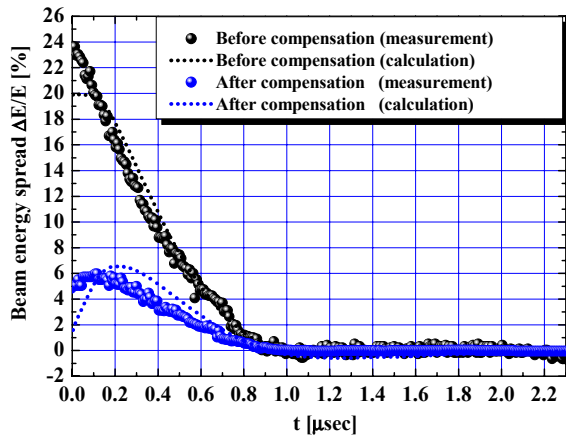


Figure 5: Measured beam energy before and after the initial-beam-loading compensation.

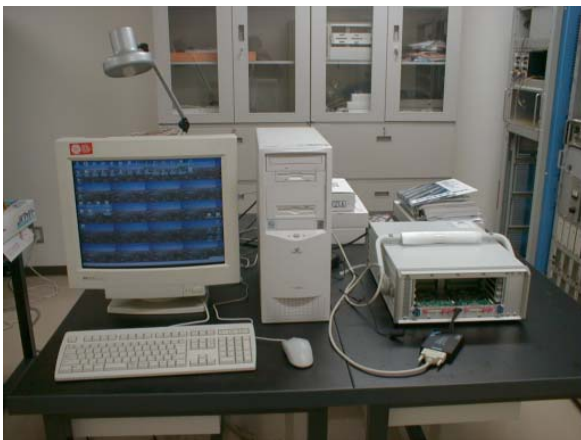


Figure 6: Photograph of a new  $\Delta\Phi$ -A control system under development.

## 5 REFERENCES

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