COMPENSATION OF INITIAL BEAM LOADING FOR ELECTRON LINACS

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Abstract

Serious initial beam loading effect may generate beam loss in the electron linac of the VSX 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). We have developed a phase-amplitude (Δϕ-A) modulation system using two fast phase shifters, which is put before a klystron and operated at low power level. In this paper, we report the performance of the test system.

1 INTRODUCTION

In the S-band (2856MHz) electron linac of the VSX light source project, initial beam loading is expected to be heavy, especially for the mode of slow positron production. 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.

Figure 1 shows the beam energy gain per accelerating structure of the linac. A square pulse of rf is input to the accelerating structure at t=0. The bold line shows the case that the electron beam is injected at $t=\tau_F$; at the time, the head of rf pulse arrives at the end of the accelerating structure. The parameters used in this calculation are summarised in Table 1. The beam energy gain is 61MV at the rise of beam pulse and 48MV in the steady state, for the parameters of Table 1.

One method for compensating the energy spread is to use ECS (Energy Compensation System) that consists of four bending magnets and accelerating structure. But it is hard to compensate a large energy spread by the ECS method. One of the other methods is to adjust the injection timing. The thin line in Fig. 1 shows the beam energy gain in the case that the electron beam is injected at $t=\tau_F$-0.27μs. The energy spread reduces to 11% at maximum, although it can not be fully compensated by this method. A few other methods of compensation have been recently proposed and investigated [2,3,4].

We have developed a Δϕ-A modulation system using two fast phase shifters which is operated at a low power level. We have carried out a high power test of klystron using the Δϕ-A modulation system.

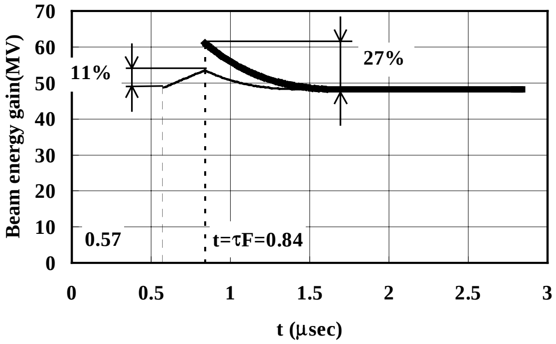

Figure 1: Beam energy gain per accelerating structure.

Table 1:The parameters used in this calculation.

Beam pulse width	2μs
Beam current	0.3A
RF input power per accelerating structure	30MW
RF frequency	2856MHz
Shunt impedance	60MΩ/m
Accelerating structure length	3m
Attenuation parameter τ	0.57
Filling time τ_F	0.84μs
Q	13000

2 COMPENSATION METHOD OF INITIAL BEAM LOADING

Figure 2 shows the electric field distribution of an accelerating structure in the steady state of beam loading. The energy spread due to beam loading becomes zero if input rf power in the transient state is controlled so as to keep the electric field at the same level as in Fig. 2. Input rf power required is shown in Fig. 3(a) and the beam energy gain in this case is shown in Fig. 3(b).

If we can obtain such an input rf power by adjusting the Δϕ-A modulator, the energy spread is expected to be completely compensated.

3 Δϕ-A MODULATOR

The Δϕ-A modulator developed here consists of two phase shifters and two 3dB power dividers. The block diagram of the Δϕ-A modulator is shown in Fig. 4. RF input signal to the modulator is divided in half and then combined again after the phases are modulated by the phase shifters. The output of the modulator is mainly modulated in phase if both phases of the phase shifters have the same sign, while the output is mainly modulated in amplitude if these phases have the opposite signs. Each phase shifter is controlled by a 100MHz programmable function generator with a control voltage from 0 to 10V. The controllable range of the amplitude and phase is shown in Fig. 5. The phase of a phase shifter can be changed in the range of ±110deg. Actually the output amplitudes of two phase shifters depend on the control voltages and the output phases do not linearly depend on the control voltages. Thus we have taken the mapping data of the phase and amplitude to the control voltage. From the mapping data, the desired values of control voltage can be obtained.

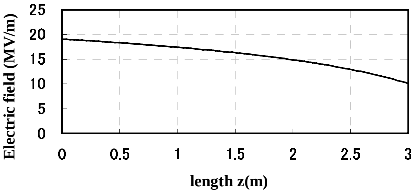

Figure 2:The electric field distribution of an accelerating structure in the steady state of beam loading.

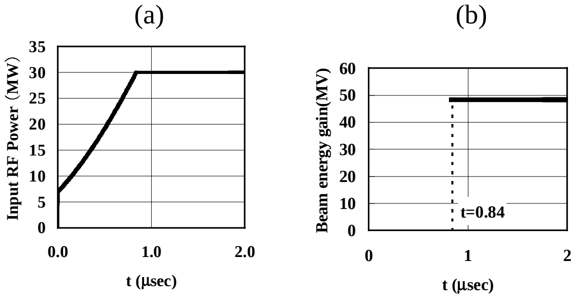

Figure 3: (a) RF input power required to completely compensate the initial beam loading. (b) Beam energy gain in the case of (a).

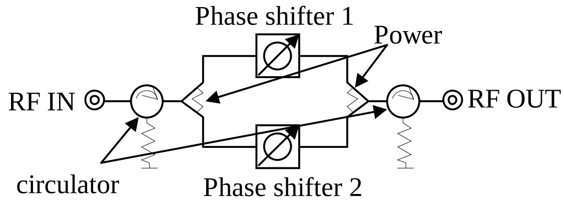

Figure 4: The block diagram of the Δϕ-A modulator

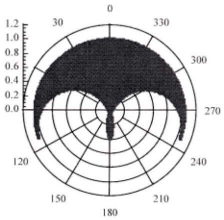

Figure 5: Controllable range of the phase and amplitude.

4 KLYSTRON HIGH POWER TEST

The klystron high power test using the Δϕ-A modulation system has been carried out at the klystron test bench of TOSHIBA Corporation. Figure 6 shows the block diagram of the experimental setup. The 2856MHz rf signal is amplified by a solid state amplifier and fed to TWT (Travelling Wave Transformer). The rf power is amplified by TWT up to 600W and then fed to TOSHIBA E3712 klystron. The peak power of the klystron output is 40MW in this test.

At first, we have measured the total response curve of the amplification system; the solid state amplifier, TWT and the klystron. A ramped rf signal generated by the Δϕ-A modulator is input to the amplification system. The measured response curve is shown in Fig. 7.

Next we have calculated the control voltages of two phase shifters using the response curve and the mapping data of the Δϕ-A modulator. The output amplitude of the Δϕ-A modulator is shown in Fig. 8. For the first trial value of the control voltage, we have obtained the klystron output as shown in Fig. 9. The target value for the complete compensation of beam loading is also shown in Fig. 9.

Using the inverse function of response curve, $V_m=f(V_k)$ indicated in Fig.7, we can get ΔV_m, the correction value of the output amplitude of the Δϕ-A modulator, as follows;

$$\Delta V_m=f'(V_k)\,\Delta V_k,$$

where ΔV_k is the difference between the measured and target values of the klystron output. Using the mapping data, we obtain the corrected trial values of the control voltages, for which the klystron output is measured again. Repeating the above procedure as well as a similar iteration for the phase of klystron output, we have obtained the final results of klystron output as shown in Figs. 10 and 11. The amplitude error is less than ±3% except at the rise of the rf pulse and the phase error is less than ±5 deg.

Assuming that the klystron output of the final result is input to the accelerating structure, we have estimated the beam energy gain for the parameters in Table 1. As shown in Fig. 12, it implies that the energy spread can be decreased from 27% to less than 1% with the Δϕ-A modulation system developed here.

We have recently developed a fast phase detector in order to compensate the beam loading more accurately. This phase detector is being calibrated and a high power test using the sub-booster klystron of KEK-LINAC is being prepared. In future, this Δϕ-A modulation system will be tested in the fully saturated region of klystron.

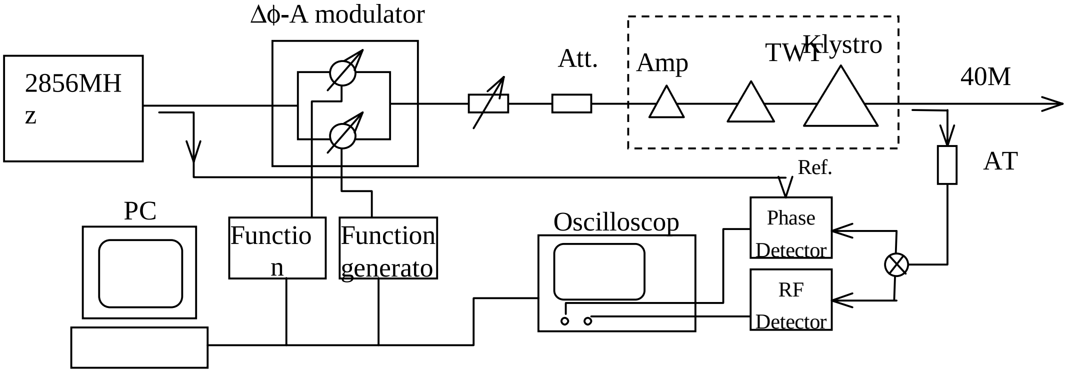

Figure 6:The block diagram of high power test.

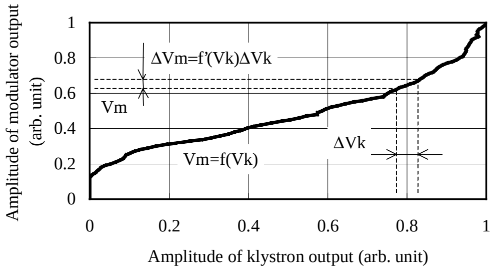

Figure 7:Δϕ-A modulator output vs. klystron output (amplitude).

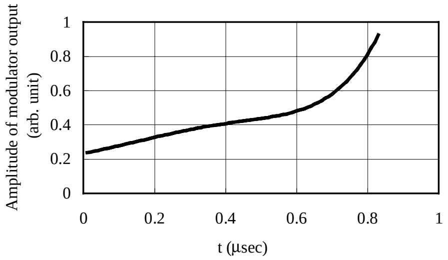

Figure 8:The first trial value of amplitude of the modulator output.

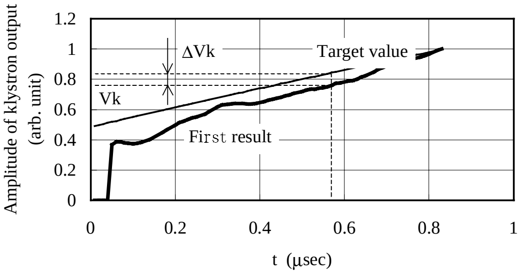

Figure 9:The first result of klystron output (amplitude).

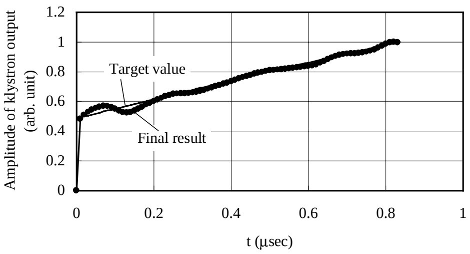

Figure 10:The final result of klystron output (amplitude).

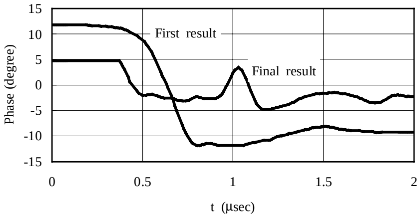

Figure 11:The first and final results of klystron output (phase).

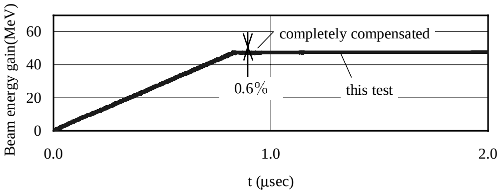

Figure 12:Beam energy gain estimated from this high power test.

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