EFFICIENCY AND GAIN ENHANCEMENT OF RF-PULSE COMPRESSOR FOR C-BAND RF SYSTEM

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Abstract

In order to make use of the additional energy in the front part of the modulator output pulse, the phase modulation system was proposed for the efficiency enhancement in various RF system. The phase modulation system compensates the undesirable phase rotaion associated with the rising power of the klystron to store the additional energy in the RF-Pulse Compressor. This idea leads the enhancement of the RF-Pulse Compressor in both respect of the power efficiency and gain which are keys of the $\mathrm{e}^+\mathrm{e}^-$linear collier.

To demonstrate the efficiency and gain enhancement of the RF-Pulse Compressor, we confirmed the complete phase compensation of the klystron and observed the gain enhancement of 125% using the cold model of the RF-Pulse Compressor in the C-band RF system.

1 INTRODUCTION

In the oridinary RF system with the RF-Pulse Compressor in the electon linear accelerator, only the flat top of the modulator pulse is used. The conventional modulator using the line-type PFN(pulse forming network circuit) with the thyratron switch usually generates a pulse with the considerable settling time(Fig. 1), and it is technically difficult to reduce this time. The front part of the pulse contains a large amount of energy. However this useful energy cannot be used due to the undesirable phase rotation associated with the rising voltage of the modulator output pulse.

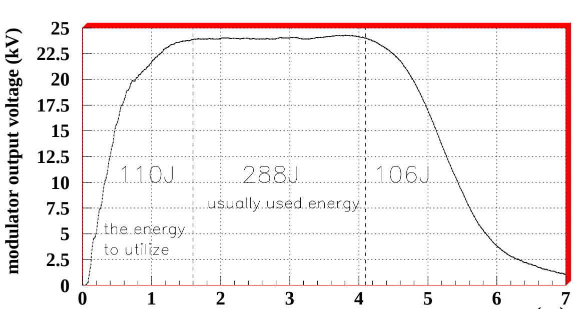

Figure 1: The modulator output voltage on dummy load

If we can utilize the energy in the front part of the modulator output pulse, the gain enhancement factor of $1.38(=(110+280)/280)$ will be roughly estimated in the ideal case. Considering the klystron efficiency, this factor becomes to $1.32(=(40+126)/126)$. If we assume 30% of the energy loss in the RF-Pulse Compressor, the gain enhancement factor of $1.22(=(40\times0.7+126)/126)$ is finally expected.

To do this, we employ the phase modulation system to compensate the phase rotation in the klystron. Then the integrated energy of the front part can be stored in the pulse compression cavity, which contributes to increase the power gain of the compressed output pulse.

Furthermore this phase modulation system with the adaptive feedback may be used as a multipurpose apparatus as follows.

- A compensation of the ringing response of the RF-Pulse Compressor associated with the coupled-resonator circuit.
- A beam-to-rf phase adjustment.
- An energy gain adjustment.
- A frequency locking by rotating the phase: $\Delta f = \frac{1}{2\pi}\frac{d\phi}{dt}$ where Δf is the frequency shift and ϕ is the phase.

2 PHASE MODULATION SYSTEM

The schematic diagram of the phase modulation system for the C-band RF system [1, 2] is shown in Fig. 2.

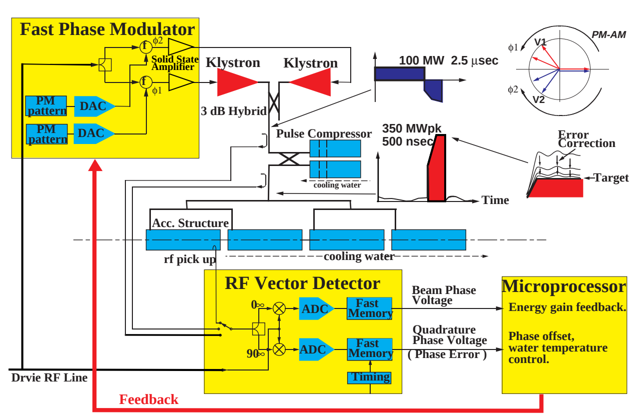

Figure 2: The schematic diagram of the phase modulation system.

It consists of the fast phase modulator, the vector rf voltage detector, the solid-state driver amplifier and the feedback control computer.

In this system, the vector-rf-voltage detector monitor the power flow at the several points; klystron output, pulse compressor output and the output coupler of the accelerating structure. The software computes errors from the target value and stores the phase modulation pattern to the memory in the fast phase modulator. This feedback loop is repeatedly applied on the successive pulses to maintain a constant energy gain. The feedback is automatically controlled corresponding to the various situation: some system failures, temparature change and timing drift etc.

In the two klystrons system as shown in Fig. 2, the Phase-to-Amplitude conversion is performed to flip the input voltage of the RF-Pulse Compressor. The single klystron configuration is also possible, but it is more difficult than the two klystron system because the klystron is usually operated in the saturated region for the high effiency and the stability, and furtheremode the non-linearity must be compensated.

3 SIMULATION

To find the optimized parameters of the RF-Pulse Compressor, the computer simulation was performed using the measured data of the C-band modulator [3] pulse and the klystron characteristics. The C-band RF-Pulse Compressor was designed for the multi-bunch operation in the future e^+e^- linear collider. The concept is: (1) the multi-cell coupled cavity is used to delay the energy output, (2) the input pulse is controlled to obtain a flat-pulse output.

In the simulation, we used a 3-cell non-uniform coupled cavity pulse compressor whose characteristics had been measured in 1997 using the cold model [4].

Fig. 3 shows the simulated output from the RF-Pulse Compressor. The dashed line shows the normalized input voltage, the light solid line shows the gain for the square input pulse, and the dark solid line shows the gain for the extended input pulse with the phase compensation. The phase compensation started at the period of 50% peak power.

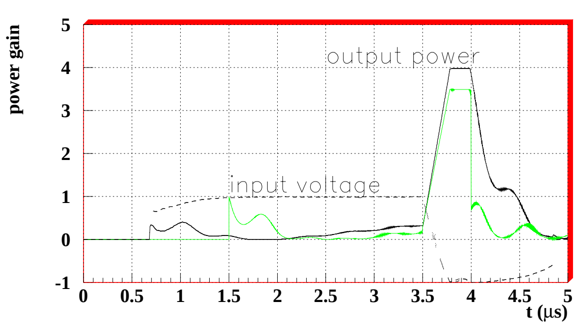

Figure 3: The simulated RF-Pulse Compressor output. Vertical axis is the normalized power gain.

The rf energy from 0.7 to $1.5\mu sec$ in Fig. 3 was stored additionally in the RF-Pulse Compressor. Futhermore we found that the lower side band through the smooth input contributes to reduce the reflection power so that the power gain reached to 4.0.

As described in Section. 1, the gain enhancement factor of 1.32 and the the maximum gain of 4.6 is expected in the ideal case. The optimization will enhance the gain.

4 EXPERIMENTAL TESTS

To demonstrate the efficiency and gain enhancement of the RF-Pulse Compressor, we performed the experimental test with the single klystron configuration using the cold model of the C-band RF-Pulse Compressor, the 50MW klystron(Toshiba, E3746) and the pulse modulator(Nihon Koshuha, KLY-M-104). The phase modulation system mainly consists of double balanced mixer(Stellex, M14A), CAMAC 100MHz 8bit Flush-ADC, VME 250MHz Programable Pattern Generator, VME 12bit DAC, VME board computer(force CPU 5V), and the feedback software which was written in Perl with SWIG, Perl/Tk, Perl/MesaGL and C++. Fig. 4 shows an experimental setup.

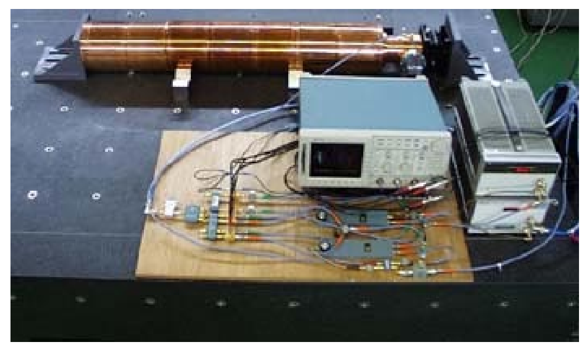

Figure 4: An experimental setup.

4.1 Phase Compensation of Klystron

At the first step, the undesirable phase rotation in the klystron associated with the rising cathode voltage was compensated by the feedback loop. The procedure of the phase compensation is as follows.

- Timing Adustment: It is important to adjust the timing of the fast phase modulator and the vector-rf-detector because it seriously affects the accuracy of the adaptive feedback. To correct the timing, we used a step pulse modulation and detecteted the timing of the rising edge.
- Calibration: The vector modulator invariably has the in-phase and quadrature (called I-Q) errros and the amplitude error. The I-Q errors affect only the settling time of the feedback, but the amplitude error causes the error in controlling the klystron output voltage. A few times of measurement was enough to determine the vector errors by setting the manual phase shifter at various phase points.
- Feedback: The vector rf voltage detector monitors the I-Q components and the amplitude of the klystron output. In the software, the I-Q sampled data is used to compute the phase correction data. Considering the characteristics and errors of the system, the software generates the I-Q modulation pattern from the phase correction data. The AM modulation pattern for the RF-Pulse Compressor must be also considered in this time. Then the I-Q pattern is stored to the memory of

DACs. When the next pulse is triggered, DACs generates the I-Q modulation waveforms.

This feedback loop is repeatedly applied on the successive pulses to maintain a constant energy gain.

In this experiment, the quadrature component of the klystron output was reduced to the noise level after 4 times feedback processes.

The Fig. 5 shows the the I-Q components of the vector demodulator versus time for the klystron output, and their X-Y(I-Q) display is shown in Fig. 6. We can interpret the I-Q display by $A(t)e^{j\phi(t)}$ where $A(t)$ and $\phi(t)$ is the amplitude and phase of the klystron output respectively, so we find that the phase rotates to the positive direction associating with the rising amplitude.

The Fig. 7 and 8 show the temporal display and I-Q display of the klystron output with the phase compensation.

It was found that the phase rotation of both the rising and falling part was completely compensated.

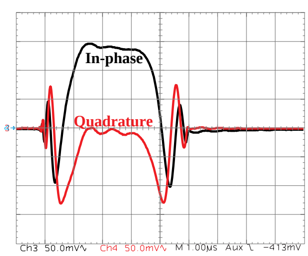

Figure 5: I-Q demodulator pulse without the phase compensation

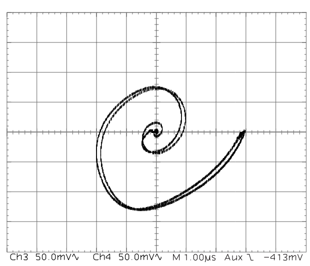

Figure 6: I-Q display without the phase compensation

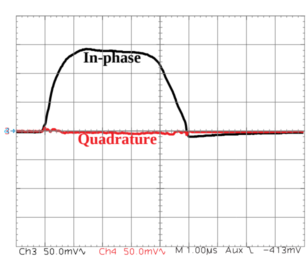

Figure 7: I-Q demodulator pulse with the phase compensation

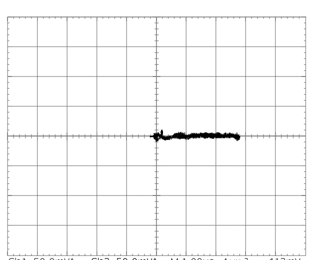

Figure 8: I-Q display with the phase compensation

4.2 *Gain Enhancement of RF-Pulse Compressor*

Using the monitor signal from a Bethe-hole coupler at the klystron output, the pulse compression was demonstrated with the phase compensation of the klystron. The RF-Pulse Compressor in this measurement was the cold model of the C-Band RF-Pulse Compressor with a 3-cell non-uniform coupled cavity and we used the single klystron configuration. As the pulsed klystron modulator had been already tuned up to generate the $2\mu s$ flat pulse, the expected gain with the phase compensation was 3.5.

For the AM modulation to control the RF-Pulse Compressor output, we must consider the non-linear characteristic of klystron, not only for phase but also for amplitude.

Fig. 9 shows the power gain of the RF-Pulse Compressor output. The light line shows the gain for the square input pulse, and the dark line shows the gain for the extended input pulse with the phase compensation. We observed the gain enhancement factor of 1.25 and obtained the power gain of 3.5. It should be noted that the $2.5\mu s$ flat pulse was required for this power gain without the phase compensation.

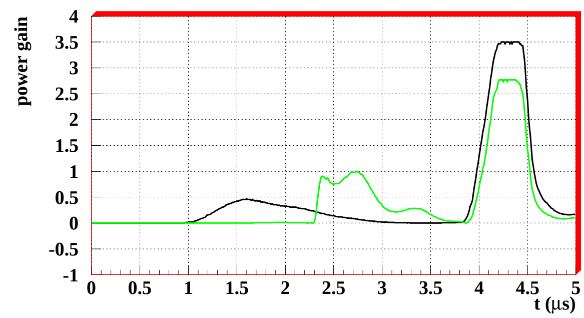

Figure 9: The power gain of the RF-Pulse Compressor.

5 DISCUSSION

We successfully demonstrated the phase modulation system. We confirmed that this phase modulation system provides a important gain enhancement with no hardware modification in high-power components.

For the further R&D, it is neccessary to optimize the parameters of the C-band RF-Pulse Compressor for a higher gain and to develop the phase modulation module for common uses. Especially, the solid-state RF amplifier is an important R&D task to drive each klystron at 500W level. It must be compact, minimum phase walk and low cost. A pulsed-class-A amplifier will be suitable for this purpose.

6 ACKNOWLEDGMENTS

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7 REFERENCES

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