KLYSTRON RF STABILIZATION USING FEEDFORWARD CIRCUIT

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Abstract

Klystron rf stability in the linac of ATF, Accelerator Test Facility at KEK, is important to make beam injection into the damping ring stable. The current pulse-to-pulse fluctuation of the output rf is 0.4% peak-to-peak in the amplitude and 1.5degree in the phase. The linac beam energy is correlated with rf amplitude fluctuation directly. In order to make more stable beam injection, storage and extraction in the damping ring, pulse-to-pulse jitter of injected beam energy should be reduced to half of it. By the analysis of rf fluctuation, the amplitude and the phase jitter are correlated with a charging voltage of the modulator. The charged voltage of the modulator is also correlated with the slope of charging rise cycle. The peak of the charging waveform slope which is a few ms in advance of a deQ trigger control gives a possibility of a feedforward to stabilize the charged voltage. We developed a new deQ circuit with a feedforward function which reduces a charged voltage fluctuation into about a half of it. The rf fluctuation of the klystron and the feedforward circuit test are described.

1 INTRODUCTION

ATF[1] is a test-stand of key components to realize a linear collider such as multi-bunch beam generation, high gradient acceleration, low emittance beam generation and its instrumentation development. ATF consists of 1.54GeV S-band Linac[2], damping ring[3] and extraction beam line[4]. The main purpose of the damping ring is to develop an extremely low emittance beam($1\text{x}10^{-11}$ m for vertical). After the commissioning on end of January 1997, single bunch operation and development were performed continuously. The emittance performance was confirmed as $1.3\text{x}10^{-9}$ m for horizontal $3.6\text{x}10^{-11}$ m for vertical with 1.29GeV energy and maximum $1\text{x}10^{10}$ electrons of single bunch storage. It is comparable with the design value within a few factor difference. One of the problem to be solved in ATF operation is extracted beam intensity fluctuation of pulse-to-pulse. The required specification for the intensity fluctuation in the linear collider is less than 1%, however, ATF beam is fluctuating more than 10%. This is coming from the injection efficiency fluctuation which is caused by the energy jitter and the wide energy spread expanded into whole damping ring acceptance of 1% full width. The energy spread will be reduced to half of it by the bunching section upgrade in this summer. The energy jitter of pulse-to-pulse has been studied by measuring correlation with various possible sources. The results of the correlation measurements showed that the most strong source was rf amplitude jitter of the klystron output. It is directly connected with driving pulse voltage jitter supplied by a klystron modulator. In order to reduce the energy jitter pulse-to-pulse, a stabilization of the klystron modulator output is essential. This paper describes a new deQ circuit with feedforward compensation to stabilize the output pulse amplitude of the existing modulator for the pulse klystron.

2 ATF KLYSTRON MODULATOR PERFORMANCE

In the ATF linac, 9 klystrons are in operation with 25Hz repetition. The first klystron which is used for the bunching section is operated with 70MW 1µs rf pulse output. The rest of them which are used for 8 regular accelerating unit are operated around 56MW 4.5µs rf pulse output with rf pulse compression. The average accelerating gradient is 25.6MV/m which gives 1.3GeV beam energy at the end of linac. There are two type of klystron modulators; one is a conventional resonant charging type from AC 200V. The other is a common DC power supply type with resonant charging. In both case, a deQ circuit stabilize the charged voltage less than 0.2% peak-to-peak. The charged voltage of the PFN capacitor is around 43kV in the operation. The following pulse trans makes about 340kV 7.5µs HV pulse which is applied to the klystron. The operational parameter of the modulator and klystron are summarized in Table.1. Also, the simplified diagram of the modulator is shown in Fig. 1.

Klystron	Toshiba E3712
frequency	2856MHz
output rf power	56MW, 4.5µs
cathode voltage	340kV, 7.5µs
Modulator	
PFN & pulse trans	12stage, 2 para., 3.0Ω, 1:16
PFN charged voltage	43kV with deQ
repetition	25Hz
pulse flatness	<1%p.p.
pulse amplitude jitter	<0.2%p.p.

Table.1 operation parameter of ATF klystron modulator

Since the AC line stability is not good by a conflict with the other accelerator operation and other power supply operation, there is a few % voltage fluctuation in the input AC line. By using a deQ circuit for PFN charging and an AC line synchronized thyratron trigger, the PFN charged voltage is well regulated less than 0.2% peak-to-peak which is the design value of the modulator. In this condition, the correlation measurement between PFN charged voltage and the klystron output rf has been done using digital oscilloscope with offset function and vertical axis expansion. The results of this correlation are shown in Fig. 2. The amplitude and the phase of klystron output rf are well correlated with the PFN charged voltage.

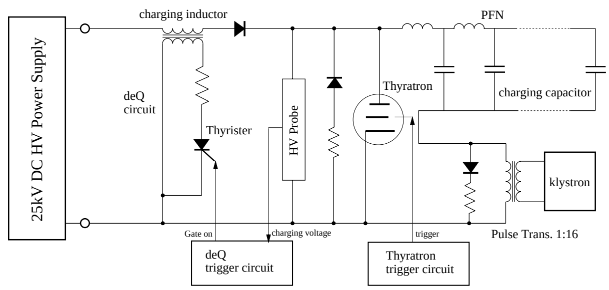

Figure 1: The simplified diagram of the modulator

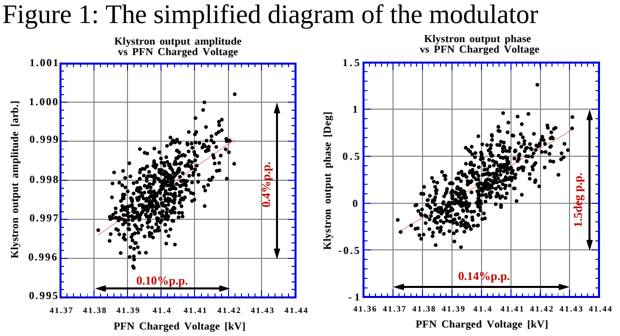

Figure 2: correlation plot between an amplitude and a phase of klystron output rf and PFN charged voltage

3 FEEDFORWARD FUNCTION FOR DEQING STABILIZATION

The deQ circuit of the ATF modulator consists of charging inductor which is a part of resonant charging circuit, its secondary winding circuit including a thyrister and a resister, PFN voltage monitor and thyrister trigger circuit, as shown in Fig. 1. The thyrister trigger circuit outputs 20V trigger pulse to make it on-state when the PFN voltage reached the set reference voltage. The charging current into the PFN capacitor is cut by this close action of the inductor secondary circuit. In this way, the charged voltage is stabilized.

Since there is a small time delay from the deQ trigger timing to charged voltage equilibrium, a small change of charging voltage slope at the reference voltage will make small overshoot or undershoot for the equilibrium. In this case, a change of the charging voltage slope is correspond to an amplitude fluctuation of the AC line which is slow compared to 25Hz. The correlation plot between a charging voltage slope and charged voltage equilibrium shows a good correlation relation as shown in Fig.3. The charging slope is detected by differentiating the charging voltage electrically.

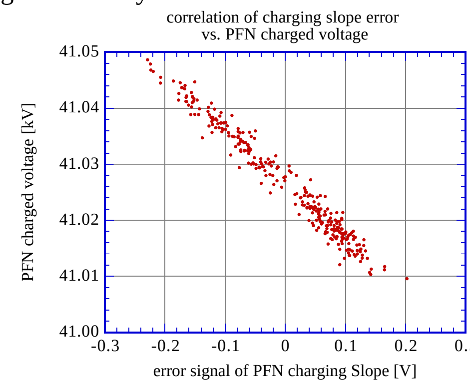

Figure 3: correlation plot between a charging voltage slope and charged voltage equilibrium

The maximum of the charging voltage slope is about 5ms in advance to the deQ trigger timing in case of the ATF modulator. Therefore, there is a possibility of feedforward from the slope information to the timing of deQ trigger in order to compensate overshoot and undershoot charging. A 5ms time duration is enough long for determination of the feedforward amount by a digital calculation or an analog circuit.

4 FEEDFORWARD TEST CIRCUIT

Using this slope detection, a feedforward test circuit was designed and built by the analog circuitry. The conversion function from the slope change to the delay of the deQ trigger was assumed to a linear for the circuitry simplicity. The charging slope detection circuit, the slope error signal generation, the amplifier for feedforward gain adjustment and deQ trigger delay circuit were added to the existing deQ circuit. The block diagram of the circuitry is shown in Fig. 4. The slope detection is done by a sample/hold at the peak signal of the differentiated charging waveform. A comparator outputs an error signal voltage from the reference which is coming from the deQ

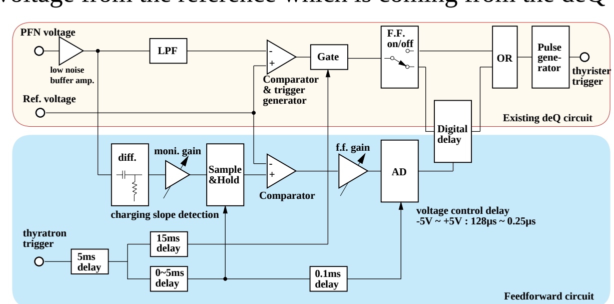

Figure 4: The block diagram of the feedforward circuitry

reference voltage. The error signal level is adjusted by the following amplifier and converted into a digital signal. The digital error data is converted to a time delay which is used for a deQ trigger delay. The amount of the delay is 0.25 to 128μs for +5 to -5V error voltage. By adding this delay circuit, the deQ trigger has an offset delay of about

60µs for the nominal control compared to the case of without feedforward.

5 RESULTS OF FEEDFORWARD TEST

The test of the feedforward circuit has been done using one of the ATF modulator which is the first modulator used for the bunching section. The charged voltage was 41kV which generated 328kV of the klystron cathode voltage and 49MW 1µs rf pulse. The measurement of the charged voltage and the klystron output rf has been done using the digital oscilloscope(Tektronics TDS684B) with offset function and vertical axis expansion into its maximum. The bit resolution is about 2 order small compared with the measured fluctuation width. In order to remove high frequency noise coming from a thermal noise and a thyratron noise, 20 sequential sampling points were averaged. The acquisition bandwidth of 20MHz was used only for the charged voltage measurement.

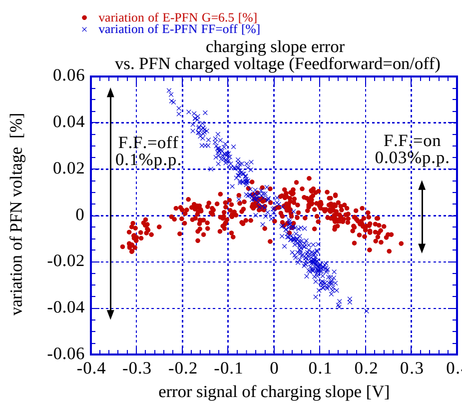

Figure 5: correlation between a charging voltage slope and charged voltage equilibrium with feedforward on/off

After the adjustment of the feedforward gain, the PFN charged voltage fluctuation was measured together with the error signal of the charging slope. The read-out time from the oscilloscope into PC was around 3 seconds for one correlation. The total number of the data points is 300 for each plot which is correspond to about 15 minutes duration. The plot shown in Fig.5 includes the correlation of the PFN charged voltage with feedforward and without feedforward. It shows the fluctuation is reduced from 0.1% to 0.03% peak-to-peak by the feedforward. As for the output rf stability shown in Fig. 6, the effect on the output rf is about factor 2 reduction, that is, from 0.3% to 0.13% peak-to-peak in amplitude and from 0.8degree to 0.5degree peak-to-peak in phase. A residual fluctuation in phase still remains. It seems that it may come from a noise conflict for the phase measurement and from the phase noise of the drive input rf of the klystron.

6 CONCLUSION

In order to reduce the energy jitter pulse-to-pulse, the stabilization of klystron modulator output has been tested by using new deQ circuit with feedforward compensation. The achieved performance on the PFN charged voltage stability was 0.03% peak-to-peak which was about factor 3 reduction from the existing deQ circuit. The rf stability of the klystron outputs were 0.13% peak-to-peak in amplitude and 0.5degree peak-to-peak in phase which were about factor 2 reduction. This method will provide easy modification of an existing deQ circuit and more than factor 2 reduction for an rf amplitude fluctuation.

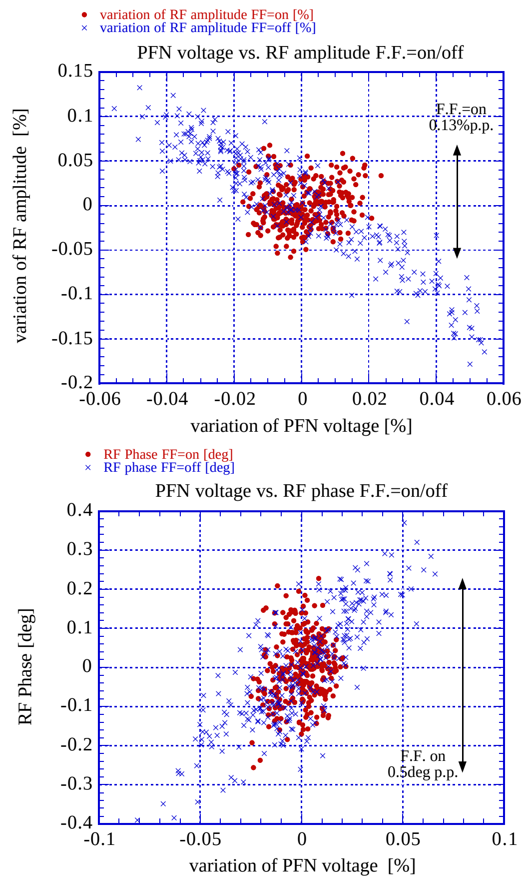

Figure 6: correlation between a charging voltage slope and klystron output rf with feedforward on/off

7 ACKNOWLEDGMENT

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