# RF FEED-FORWARD CONTROL EXPERIMENTS FOR THE 50 MEV LINEAR ACCELERATOR AT TLS

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*Abstract*

Performance of an electron linear accelerator is very important for synchrotron light source application. Its performance will determine the reproducibility of filling pattern in the booster synchrotron. The filling pattern of the booster synchrotron will then affect filling pattern control of the storage ring. The RF feed-forward control can effectively improve performance of linear accelerator. Design consideration and details of the implementation will be summarized in this report.

## INTRODUCTION

Beam quality of the 50 MeV linear accelerator is positively associated by flatness of rf field amplitude and phase. Both parameters will primarily depend upon the klystron modulator performance. Well tune of the pulse forming network, which cannot be achieved easily, are essential for good microwave pulse for the linear accelerator [1]. To eliminate tedious tuning process of the pulse forming network, RF feed-forward might be another alternative solution to accomplish the same mission. Not only beam loading effects can also be compensated but effects of slow drift due to various reasons can be removed by rf feed-forward control [2]. A feasibility of the rf feedback control was studied recently at the linear accelerator of Taiwan Light Source (TLS). Purposes of this study are as side products of revised of low level RF system of the linear accelerator. Preliminary test was done during the second quarter of 2007 shown a promising result. The efforts will be continued as R&D topics to study control algorithm, and hardware development. Future accelerator research program of NSRRC might benefit form this rf feed-forward study. Improvement of the operation performance of the injector to support top-up operation of TLS requires further exploration.

## LINAC RF SYSTEM

The pre-injector of the TLS is consists of a 140 kV thermionic gun and a 50 MeV travelling wave type linear accelerator system. Synoptic view of the pre-injector is shown in Fig. 1. The microwave system was composed of multiplier that derivates 2998 MHz from 499.654 MHz, a 1 kW GaAs solid state RF amplifier, and a high power klystron amplifier. The high power klystron is powered by an 80 MW PFN based modulator. The PFN is charged by a switching power supply. An analogue vector modulator is placed in front of the GaAs amplifier to control the amplitude and phase of the RF field feed into the linear accelerator. An analogue vector demodulator is used to detect the rf signal of outlet of inlet of linear accelerator.

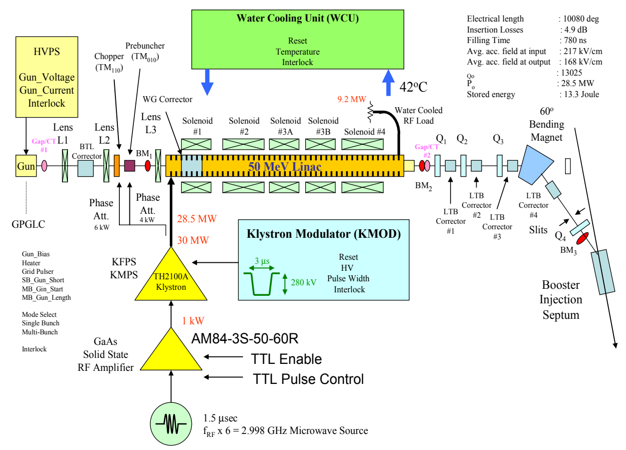


Figure 1: Synoptic of the 50 MeV linear accelerator system components of the TLS.

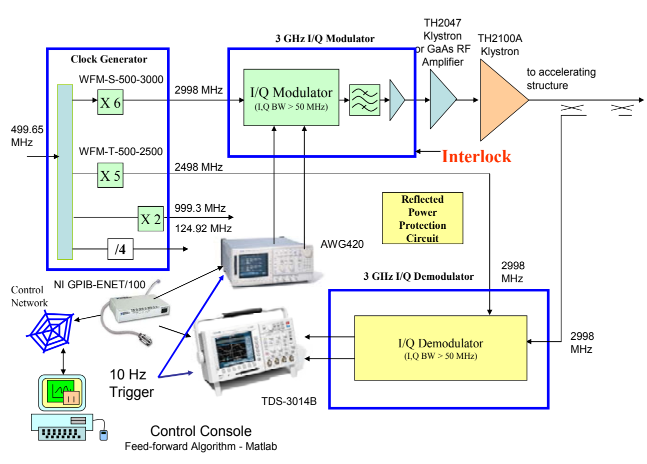


Figure 2: The block diagram of the updated low level RF system for the 50 MeV linear accelerator. It is a feed-forward enable system.

The updated functional block diagram of the low level rf for the linear accelerator of the TLS is shown in Fig. 2. This system consists of the clock generator, AWG 420 arbitrary waveform generator, analogue type vector modulator, GaAs solid state RF amplifier, high power klystron and klystron modulator, analogue type vector demodulator, and oscilloscope. The arbitrary waveform generator is use to generated quadrature (I and Q) control waveform as an input of the vector modulator. The vector modulator and a 1 KW solid state rf amplifier, klystron

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and klystron modulator can provide a stable high micro power for linear accelerator. The vector modulator from rf LINAC output through oscilloscope obtain in-phase and out of phase (I and Q) information of rf field of the LINAC. The LINAC amplitude and phase can be acquired by simple calculation form I and Q signal.

The AWG and the oscilloscope are connected to the control system via GPIB-Ethernet adapter. Access of the AWG and the oscilloscope can be done in the Matlab environment where all experiment can be accomplished.

## CORRECTION ALGORITHM

Assuming rf feed-forward control is a time invariant system and it has an input x(t) and an output y(τ), this system can be assumed separable a non-linear instantaneous part function f(x) and a linear part with an impulse response function g(t). According to convolution thermo can expressed output of the system as Eq. 1:

$$y(\tau)=\int_{-\infty}^{+\infty} f(x(t))g(t-\tau)dt \qquad (1)$$

The increment function Δx added to the input signal $x_o(t)$, the output of the system can response a increment Δy(τ). If assumed function f(x(t) is differentiable then relationship between input and output increment can be written as an Eq. 2:

$$\Delta y(\tau)=\int_{-\infty}^{+\infty} \frac{d}{dx} f(x_0(t))\Delta x(t) g(t-\tau)dt \qquad (2)$$

Eq. 2 can be written in matrix form as follows :

$$\begin{pmatrix}\Delta y(\tau_1)\\ \Delta y(\tau_2)\\ \vdots \\ \Delta y(\tau_n)\end{pmatrix}=\begin{pmatrix}T_{11} & T_{12} & \cdots & T_{1n}\\ T_{21} & T_{22} & \cdots & T_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ T_{n1} & T_{n2} & \cdots & T_{nn}\end{pmatrix}\begin{pmatrix}\Delta x(t_1)\\ \Delta x(t_2)\\ \vdots \\ \Delta x(t_n)\end{pmatrix} \qquad (3)$$

The matrix T elements can be obtained by measurement. According to causality, the transfer matrix elements must satisfy $T_{ij}=0$ when $i<j$ and making transfer matrix T triangular :

$$\begin{pmatrix}\Delta y(\tau_1)\\ \Delta y(\tau_2)\\ \vdots \\ \Delta y(\tau_n)\end{pmatrix}=\begin{pmatrix}T_{11} & 0 & \cdots & 0\\ T_{21} & T_{22} & \ddots & 0\\ \vdots & \vdots & \ddots & 0\\ T_{n1} & T_{n2} & \cdots & T_{nn}\end{pmatrix}\begin{pmatrix}\Delta x(t_1)\\ \Delta x(t_2)\\ \vdots \\ \Delta x(t_n)\end{pmatrix} \qquad (4)$$

With the desired change in output Δy known and the matrix T calibrated, the elements of the correction vector Δx are get by solving Eq. 5.

$$\Delta x_i=\frac{1}{T_{ii}}\left[\Delta y_i-\sum_{j=1}^{i-1} T_{ij}\Delta x_j\right] \qquad (5)$$

Where $i$=1, 2, 3, …, n. $\Delta y_j = y_j - y_{tj}$, $y_{tj}$ is target value.

Flow chart of the feed-forward correction is shown in Fig. 3. First, a transfer matrix which can be obtained by measurement must be generated. Iterative correction can be done after response matrix available.

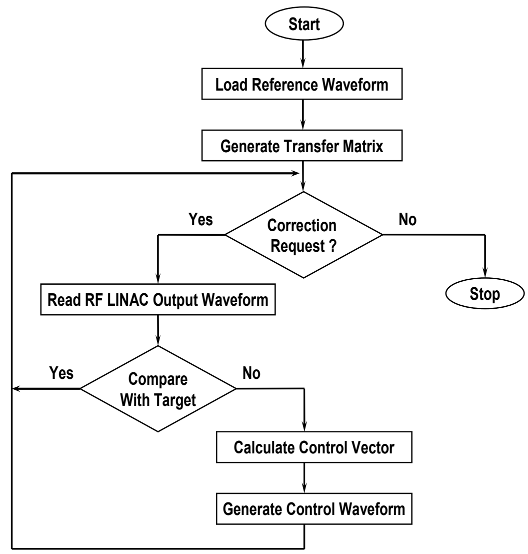


Figure 3: Flow chart of the feed-forward correction.

## RESPONSE MEASUREMEMT

The response matrix element can be measurement by experiment. Add a perturbation signal to the control I, Q control vector, measure the response difference without and with perturbation can extract the matrix elements of the response matrix. Where the perturbation vector is step function (calibration pulse) is applied in the I channel and Q channel, I/Q signals responses are observed by the oscilloscope of the IQ demodulator of linear accelerator rf output and their amplitude and phase response of the LINAC can be calculated from measured I/Q signal. The perturbed I signal response shown as Fig. 4 and Fig. 5 shown perturbed Q signal response.

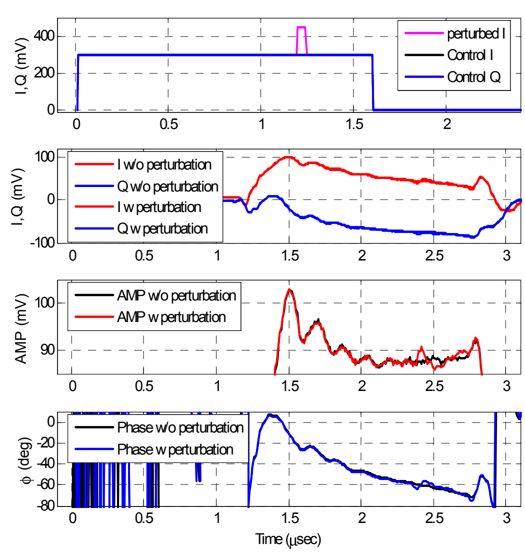


Figure 4: RF amplitude and phase response measurement, the perturbation is applied to I channel. This measurement is without beam.



 

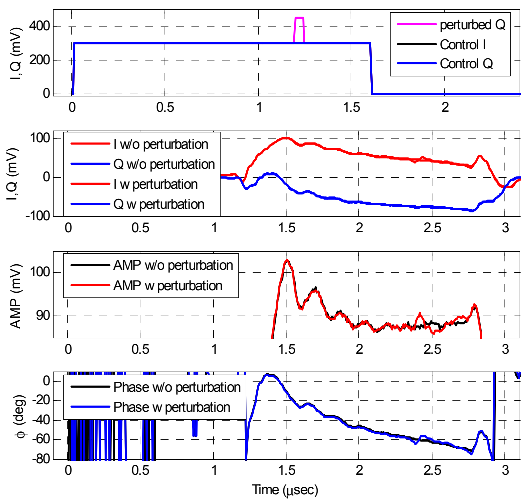


Figure 5: RF amplitude and phase response measurement, the perturbation is applied to Q reference channel. This measurement is without beam.

## PRELIMINARY CORRECTION TEST

We performed several correction tests of the RF feed-forward control. Present a simple for feed-forward control method to compensate variation of the RF field. Simple correction can improve flatness of amplitude and phase of the RF field. RF amplitude and phase waveforms before and after correction without beam are shown in Fig. 6 and we can observe that flatness of amplitude and phase are visibly improved. The RF amplitude and phase response measurement after corrected I signal applied without and with beam condition shown as Fig. 7. Figure 8 shows RF amplitude and phase waveform before and after correction with beam. Both of amplitude and phase are smoothed simultaneously. Flatness of the amplitude and phase has been improved slightly.

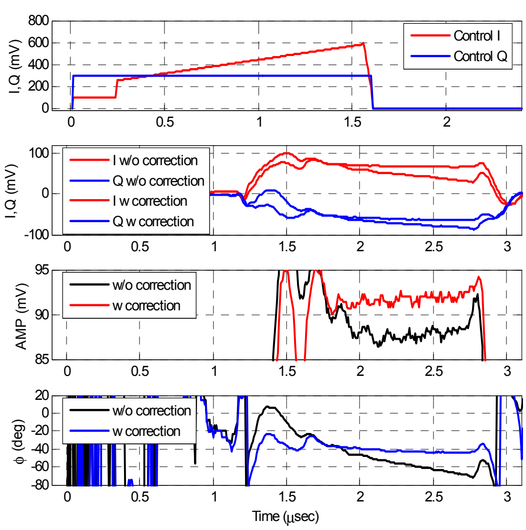


Figure 6: RF amplitude and phase waveform before and after correction I signal without beam, flatness of amplitude and phase are improved.

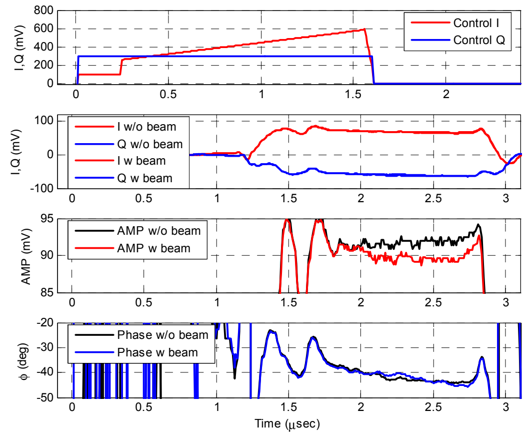


Figure 7: The RF amplitude and phase response measurement after corrected I signal applied without and with beam condition.

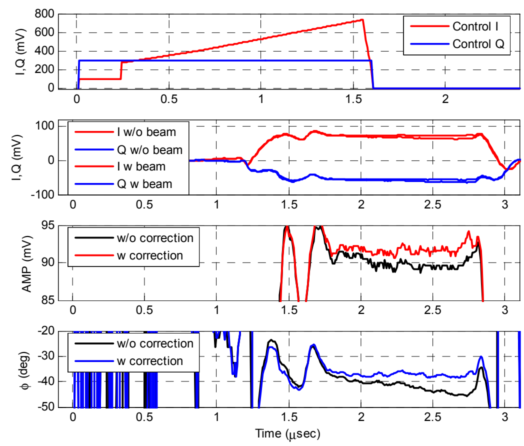


Figure 8: RF amplitude and phase waveform before and after correction with beam, both amplitude and phase are corrected simultaneously.

## SUMMARY

Preliminary rf feed-forward test is performed at the 50 MeV linear accelerator of TLS. The flatness of amplitude and phase of the linear accelerator rf pulse can be improved after simple RF feed-ward correction. Iteration of the correction procedure is developed to make performance of feed-forward more operative. Continuous efforts on control algorithm improvement, rf electronics and data acquisition improvement are on going. The rf feed-forward can flat rf pulse amplitude and phase of the linear accelerator to provide high beam quality.

## REFERENCES

[1] T. Asaka, et al., "Stabilization of the rf system at the SPring-8 linac", Nucl. Instr. and Meth. A 488 (2002) 26-41.

[2] Y. Liu, D. Cline, I. Ben-Zvi, X. J. Wang, J. Sheehan, K. Batchelor, R. Malone, M. Issapour, "A modified feed-forward control system at the Accelerator Test Facility", Rev. Sci. Instrum. 68(2), February 1997.