# LINAC RF FEED-FORWARD DEVELOPMENT AT TLS

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*Abstract*

An electron linear accelerator is a very important for synchrotron light source operation. Its performance in amplitude and phase of the RF fields will decide the quality of the extracted beam. Applying the technique of RF feed-forward control is helpful to refine the amplitude and phase flatness of the linear accelerator RF field and effectively improve the energy spread of the extracted electron beam. Consequently, it will provide a high quality beam. Efforts of this preliminary study are summarized in this report.

## INTRODUCTION

Beam quality of the 50 MeV linear accelerator (LINAC) is determined by flatness of RF field amplitude and phase. Both parameters will primarily depend upon the klystron modulator performance and the beam loading effects. Well tuned pulse forming network cannot achieve easily which are essential to produce 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 achieve better performance. Not only beam loading effects can be compensated but also 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). This study is a side product of revised low level RF system of the linear accelerator recently, new low level RF system equipped with vector modulator and waveform generator which are essential part of RF feed-forward control. 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 RF control hardware development. Future accelerator research program of NSRRC might benefit from 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 consists of a 140 kV thermionic gun and a 50 MeV travelling wave type linear accelerator system. The synoptic view of the pre-injector is shown in Fig. 1. The microwave system was composed of a 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 pulse forming network (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 fed into the linear accelerator. An analogue vector demodulator is used to detect the RF signal of outlet of inlet of the linear accelerator.

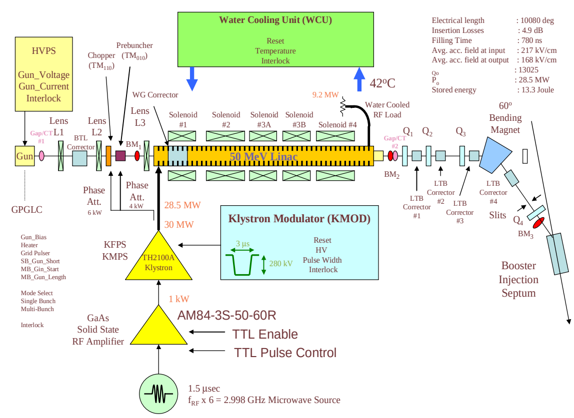


Figure 1: The synoptic of the 50 MeV linear accelerator system of the TLS.

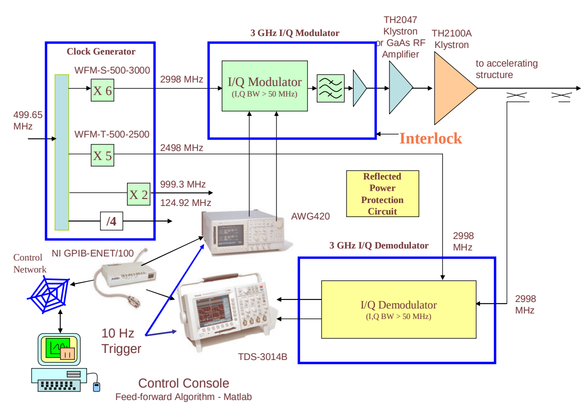


Figure 2: The block diagram of the updated low level RF system for the 50 MeV linear accelerator. It is a feed-forward enable system.

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

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klystron and klystron modulator can provide a stable high power microwave for the linear accelerator. The pickup RF signal at LINAC output is detected by the vector demodulator to obtain in-phase and out-of-phase (I and Q) components of the RF field. The RF 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 experiments can be accomplished.

## CORRECTION ALGORITHM AND RESPONSE MEASUREMEMT

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). The output according to convolution theorem can expressed output of the system as Eq. 1:

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

As the increment function Δx added to the input signal $x_0(t)$, 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:

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

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

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

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:

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

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

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

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.

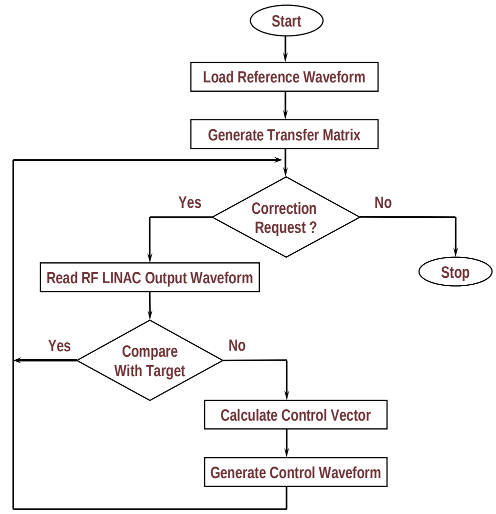


Figure 3: Flow chart of the feed-forward correction.

The response matrix element can be measured by experiment. Adding a perturbation signal to the control I, Q control vector, and then measuring 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 and Q signal response shown as Fig. 4.

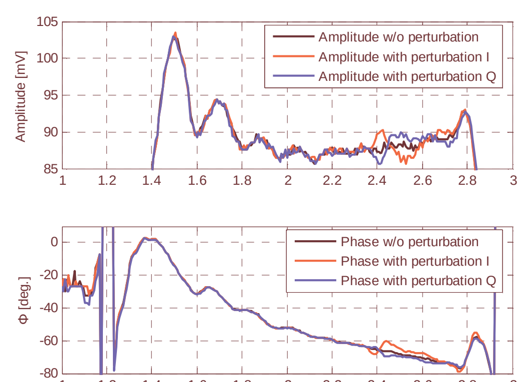


Figure 4: RF amplitude and phase response measurement, the perturbation is applied to I channel (red curve) and the perturbation is applied to Q channel (blue curve). This measurement is without beam.

## PRELIMINARY CORRECTION TEST

Several correction tests of the RF feed-forward control have been performed. A simple algorithm was applied to compensate variation of the RF field by the approach of feed-forward control. 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. 5. The flatness of amplitude and phase are improved. The RF amplitude and phase after corrected I signal applied without and with beam of 600 nsec bunch train is shown as Fig. 6. Droop due to beam loading are sensible at the amplitude response and phase response.

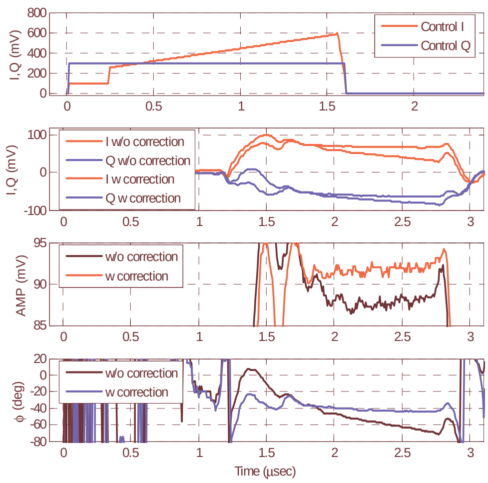


Figure 5: RF amplitude and phase waveform before and after correction I signal without beam, flatness of amplitude and phase are improved.

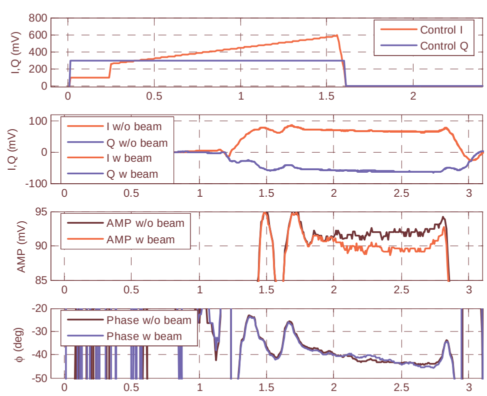


Figure 6: The RF amplitude and phase response measurement, after corrected I signal applied without beam and with 600 nsec bunch train of electron beam.

The Figure 7 shows as droop at amplitude and phase of the RF pulse induced by 600 nsec electron bunch train can be improved by further correction. Flatness of the amplitude and phase has been improved further.

Energy spread can be reduced drastically when correction is applied as shown in Fig. 8; energy spread can be reduced from 4 MeV (FWHM) to less than 1 MeV (FWHM) slightly after correction at exit of LINAC. Electron bunch train length is 300 nsec in this measurement.

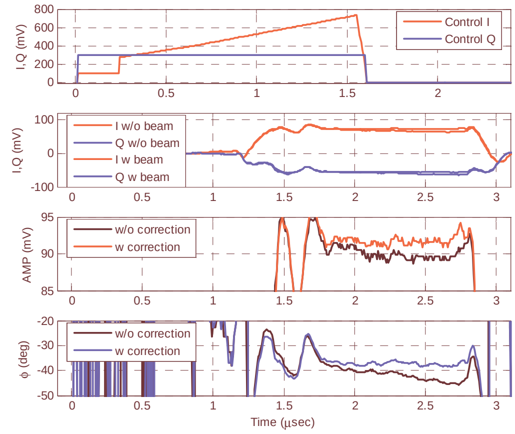


Figure 7: RF amplitude and phase waveform before and after correction with bunch train 600 nsec beam, both amplitude and phase are corrected simultaneously.

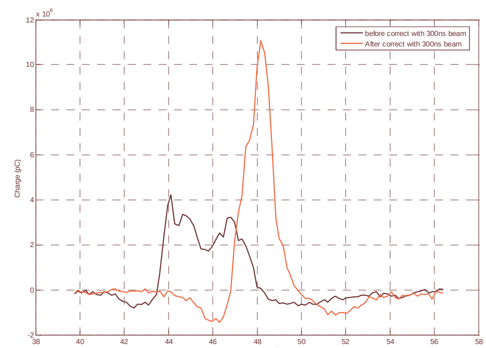


Figure 8: The RF amplitude and phase waveform before and after correction with bunch train length 300 nsec beam, energy spread is reduce simultaneously.

## SUMMARY

The preliminary RF feed-forward test-run has been 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 applying a simple RF feed-forward correction scheme. Iteration of the correction procedure is still in development. Continuing efforts on the improvement of control algorithm, RF electronics and data acquisition are on going. The study results show that the RF feed-forward technique can improve the flatness of the RF pulse amplitude and phase of the linear accelerator. The beam quality, in terms of energy spectrum, is also effectively improved.

## REFERENCES

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[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.