

CORRECTIONS OF KLYSTRON OUTPUT PULSE IN SW ACCELERATOR TESTING

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Abstract

Accelerator testing requires a good control over the shape of the used pulse. Usually a flat or stepped square pulses are used for testing. Producing a perfectly flat output pulse from the klystron can be challenging especially for testing standing wave (SW) accelerators. SW accelerator structures result in large reflections to the klystron and no isolator can withstand the reflected power level for ultra-high gradient operation. This results in a distorted output pulse from the Klystron. We developed a modulation technique that solves this problem using a negative feedback loop.

INTRODUCTION

Our technique performs corrections of the klystron output pulse using feedback loop. It can also overcome a poor modulator performance as well as some other system errors. The used pulse correction scheme resembles a general **process control system** [1,2]. Such systems are characterized by a desired output or any measured quantity that are set to a certain desired value, usually referred to as the **set point**, by adding a series of corrections to an input to the system using a negative feedback loop.

A basic process control system is shown in Fig. 1. In this system the **input** (x_i) is adjusted using a series of corrections. These corrections equal to the **error** signal (e_i) multiplied by a **scaling factor** (w). The error signal is defined as the deviation of the system output or **control variable** from some desired value or **set point** (D).

The intuition behind this is rather simple: a large (respectively, small) deviation between the output (y_i) and the desired value (D) results in large (respectively, small) errors, hence, significant (respectively, slight) corrections. Also, when the output converges to the desired value, the error converges to zero. The correction weights (w) should be optimized for best convergence. The system can be described using the following set of equations:

$$\begin{aligned} y_i &= H(x_i) & (1) \\ x_i &= x_{i-1} - w e_i & (2) \\ e_i &= y_{i-1} - D & (3) \end{aligned}$$

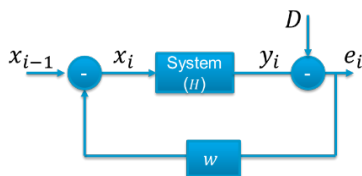


Figure 1: block diagram of a process control system. x_i is the input, y_i is the output, e_i is the error signal, w is the scaling factor, and D is the desired value or set point.

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This process can be illustrated using a simple example where $H(x_i) = 5x_i$. Let us assume that the initial value of the input (x_i) is $x_0 = 1$ while the desired value of the output (y_i) is $D = 10$. The initial value of x_i will result in $y_0 = 5$ which does not match the desired value of 10. However, as we follow (1 – 3) with a weight of $w = 0.1$, the output eventually converges to the desired value of $D = 10$ as shown in Fig. 2(a).

The same concept can still hold even if non-linearities are introduced to the system, however it is not guaranteed. An example is with $H(x_i) = 5x_i^2 + 6x_i + 1$. Using the same initial conditions and desired value as the previous example, the output converged to the specified desired value as shown in Fig. 2(b).

KLYSTRON PULSE CORRECTION

In what follows, we show that the klystron pulse correction problem resembles the aforementioned process control system. Namely, we may consider the input pulse to the klystron as (x_i), and the high-power output pulse from the klystron as (y_i). In contrast to the standard process control model presented above, the computation of the error term in our case is rather involving. In particular, we aim to remove any distortions in the pulse shape compared to the **desired** flat pulse shape as shown in Fig. 3.

So, our desired pulse shape (D) is the fitted version of the measured pulse to an ideal stepped (or flat) square pulse shape. Consequently, the block diagram for the control system can be modified as in Fig. 4.

Note that the pulse also has a phase component that

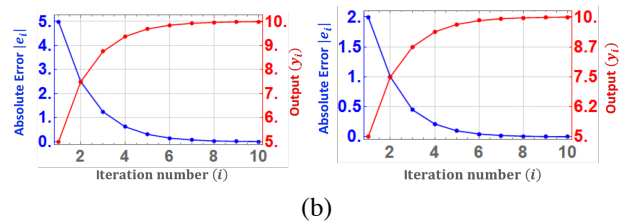


Figure 2: convergence of the (a) first and (b) second process control system examples

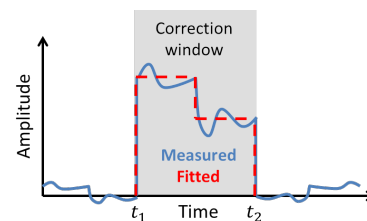


Figure 3: graph illustration of a measured distorted pulse in blue and the best flat fitted pulse in red as well as the correction window of interest in gray.

would need to be accounted for. Hence, complex $(a + jb)$ corrections will be essential as we explain next. Fig. 4 shows the basic block diagram for the used pulse corrections; however, more modifications are needed to extract (or obtain) a perfectly flat output pulse.

Intuitively, we shall only perform corrections within the duration of the pulse, since adding noise samples to the correction window results in a diverging behaviour. So, we perform edge detections for the output pulse of the klystron and perform the error extraction and corrections only within the specified window of the main pulse as shown in Fig. 3.

Second, we need to make sure that we are correcting for the actual klystron output pulse and that there is no added noise or distortion coming from the measurements. This can be performed by filtering all the noise outside the main frequency-band of the signal. This can be done by analysing the spectrum of the klystron output pulse and using a band pass filter (BPF) to filter any out-of-band noise.

Finally, we average the error across multiple samples before proceeding with the correction. In other words, we perform one correction step then average over N samples of the klystron output pulses for the next step.

As mentioned before, in our case, the forward signal should be flat both in amplitude and phase, so we will need to do complex corrections. The system is given in Fig. 5. Note that the averaging over N is not included in the plot just for simplicity but is still applied in a complex sense.

PRACTICAL EXAMPLE

A practical example of pulse correction is performed with the SLED-II pulse compressor which makes it more challenging in terms of amplitude and phase fitting and corrections [3]. However, our system still provides

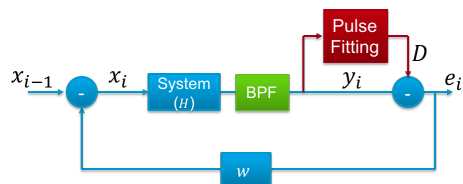


Figure 4: simplified block diagram of the process control system used in the klystron pulse correction. The system H represents the klystron while the input, x_i is the output of the function generator.

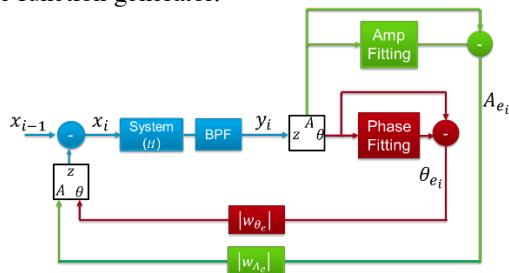


Figure 5: block diagram of the process control system used in the klystron pulse correction with the complex correction for amplitude and phase.

smooth and accurate corrections. With the SLED-II, the klystron have a wide pulse of $1.2 \mu s$ and there is a phase flip for the last 400 ns. The system is shown in Fig. 6. The starting pulse shape was distorted both in amplitude and phase, and after applying the correction, the resulted pulse shape was perfectly flat both in amplitude and phase as shown in Fig. 7.

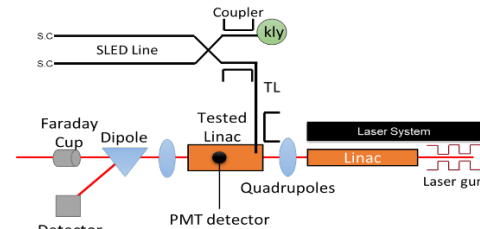


Figure 6: (a) The experimental setup for the linac testing at XTA test station at NLCTA at SLAC with the SLED line installed for pulse compression.

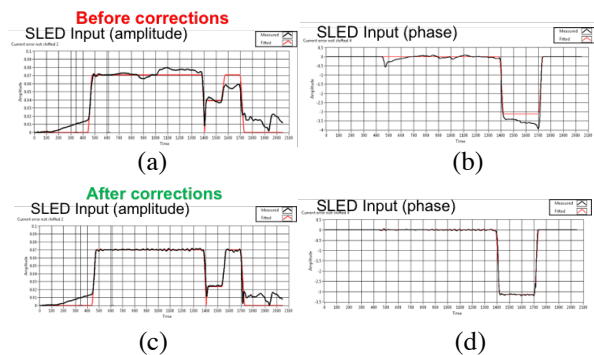


Figure 7: The waveforms of the klystron output pulse. Before using the correction program, the pulse is distorted in (a) amplitude and (b) phase. After using the correction feedback, the (c) amplitude and (d) phase are perfectly flat. Arbitrary units are used for the amplitude. The phase is in radian.

CONCLUSION

A pulse correction scheme was developed and applied to correct for klystron pulse distortion specifically for standing wave accelerator testing. The scheme was applied to a high-power testing at NLCTA at SLAC and proved efficient use even with the pulse compressor (SLED-II).

REFERENCES

- [1] S. Bhagade and G. Das Nageshwar, Process Dynamics and Control, PHI Learning, 2011.
- [2] B. Bequette, Process Control: Modeling, Design, and Simulation, Prentice Hall PTR, 2003.
- [3] S. G. Tantawi *et al.*, "Distributed Coupling Accelerator Structures: A New Paradigm for High Gradient Linacs," arXiv:1811.09925