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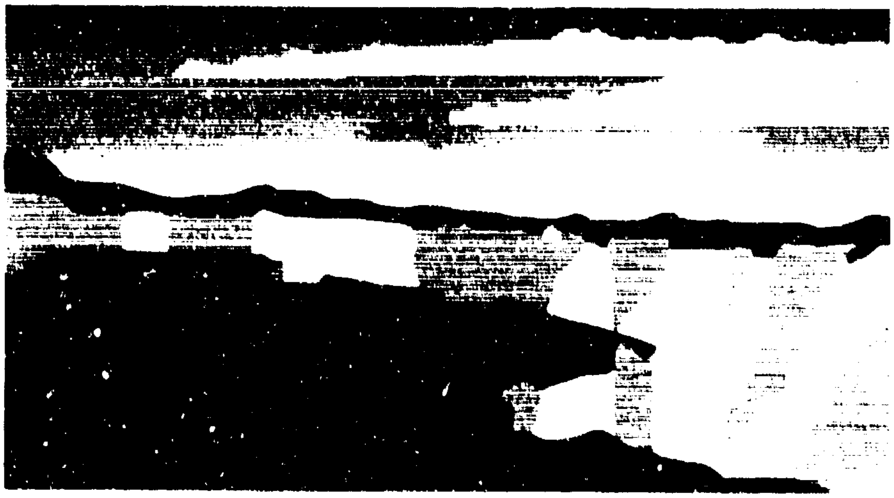

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Results Of Adaptive Feedforward On GTA*

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Abstract

This paper presents the results of the adaptive feedforward system in use on the Ground Test Accelerator (GTA). The adaptive feedforward system was shown to correct repetitive, high-frequency errors in the amplitude and phase of the RF field of the pulsed accelerator. The adaptive feedforward system was designed as an augmentation to the RF field feedback control system and was able to extend the closed-loop bandwidth and disturbance rejection by a factor of ten. Within a second implementation, the adaptive feedforward hardware was implemented in place of the feedback control system and was shown to negate both beam transients and phase droop in the klystron amplifier.

I. INTRODUCTION

The GTA control system uses feedback to control the RF field in the accelerating cavities. A simplified block diagram of the GTA RF control system is depicted in figure 1.

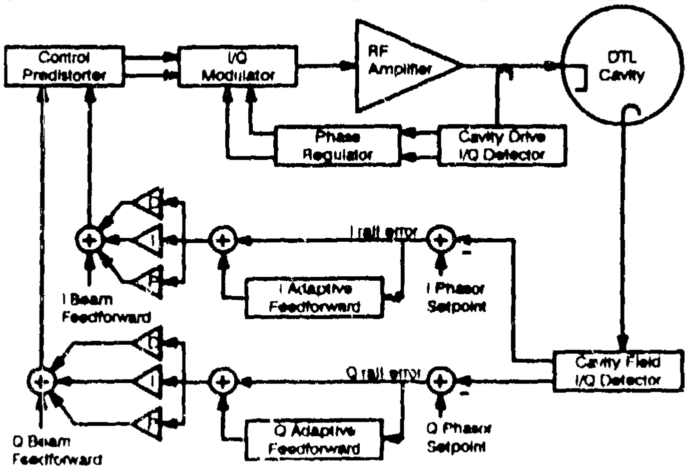

Figure 1. Simplified block diagram of GTA control system

Closed-loop bandwidths of a few hundred kHz have been demonstrated by the GTA RF control systems [1]. These bandwidths are limited by the physical properties of the high-Q cryogenic cavities, the high-power amplifier responses, and the long propagation delays caused by the large physical distances between equipment. The amplitude and phase disturbances to the RF field that are beyond the closed loop bandwidth cause error in the accelerating field parameters. One significant error that occurs with every RF pulse is the beam turn-on transient. A fast risetime on the beam causes the accelerating field to droop before the feedback system can compensate. The beam turn-on disturbance causes transient errors in the field amplitude and phase for a few microseconds as the feedback loop recovers. Due to the repetitive nature of the beam transients, the feedforward correction function can be inserted into the drive signal that will predict the beam transient affects. This correction function is adaptively updates as the accelerator operates to determine and track the optimum correction function to negate the repetitive disturbances. The detailed theory of operation is described elsewhere [2-4]. This paper will focus on the experimental results of the hardware functioning on first drift tube linac (DTL) cavity of GTA.

II. ENHANCEMENT TO FEEDBACK

As depicted in figure 1, the adaptive feedforward hardware was designed to operate as a modular addition to the feedback control system. This figure shows the experimental setup for the adaptive feedforward tests on the first 850 MHz DTL cavity of GTA. The operating conditions for the DTL were a gap voltage of 2.1 MV, a beam current of 50 mA with a -30° synchronous phase, and copper losses of 33 kW. From this, the beam loading calculates to be 73%.

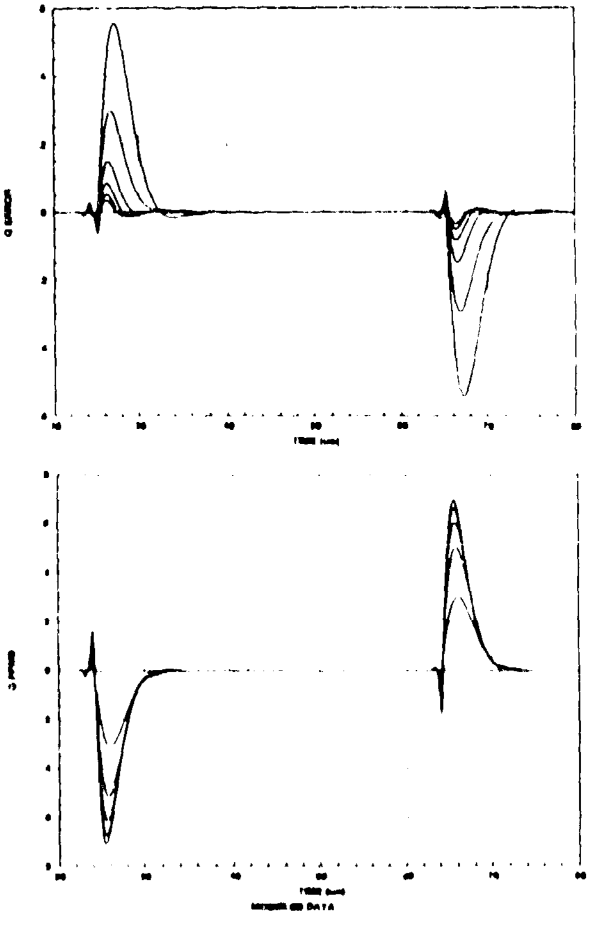

Figure 2. Modelled results of feedforward as enhancement

Figure 2 shows the expected performance from the modelled system performance with similar operating condi-

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tions. This figure shows five traces that depict the feedforward adapting from zero over the course of a 50 pulses. In addition, the corresponding error signals are shown to be reduced by the insertion of the correction function. These traces show the quadrature channel only, but the in-phase errors are adaptively reduced simultaneously.

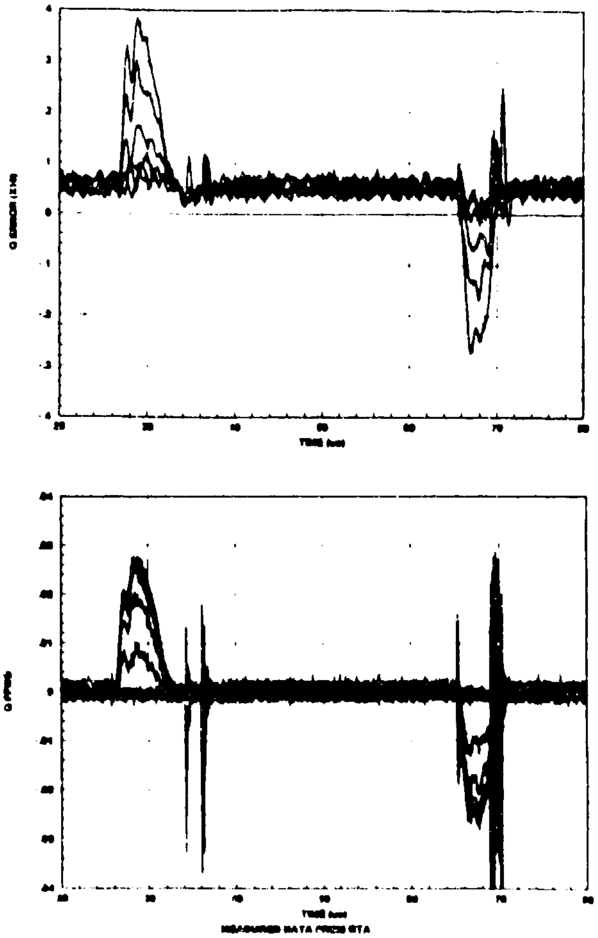

Figure 3. Measured results of feedforward on GTA

Figure 3 shows the measured data from the experiment on GTA. Again five traces in a sequence of 50 pulses are shown. As the system operation progresses, the correction function improves and the error signal is reduced. Notice that the measured data closely matches the modelled data. The experimental results in figure 3 show that a 1% error in the field quadrature cause by the beam turn-on transient could be reduce to less than 0.05% with feedforward.

III. REPLACING FEEDBACK

In addition to the intended implementation of the adaptive feedforward module, a second configuration for the adaptive feedforward module was evaluated. Instead of using the device as a feedforward enhancement to the feedback control system, the device can be used as an adaptive controller, replacing the feedback control system. Figure 4 shows the topology of this configuration, where the control output is driven by the adaptive devices. The measured field parameters are used to correct the control output as the system parameters vary over time. Any changes in the system

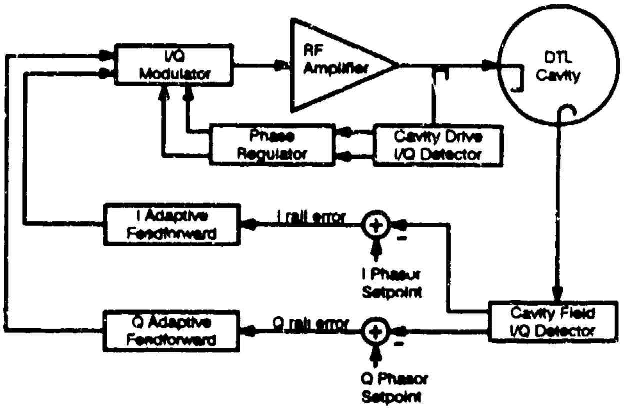

Figure 4. Diagram of control system with only feedforward

are tracked by the adaptive controllers which will track slow changes that occur over hundreds of milliseconds. With a fixed RF system configuration, the field amplitude and phase can be precisely maintained. One drawback is that the feedforward function takes a number of pulses to adaptively determine the correct control output, and while it is adapting, the field parameters are not held at the operating point. But once the hardware has a chance to adapt, the field amplitude and phase can be maintained at the operating point.

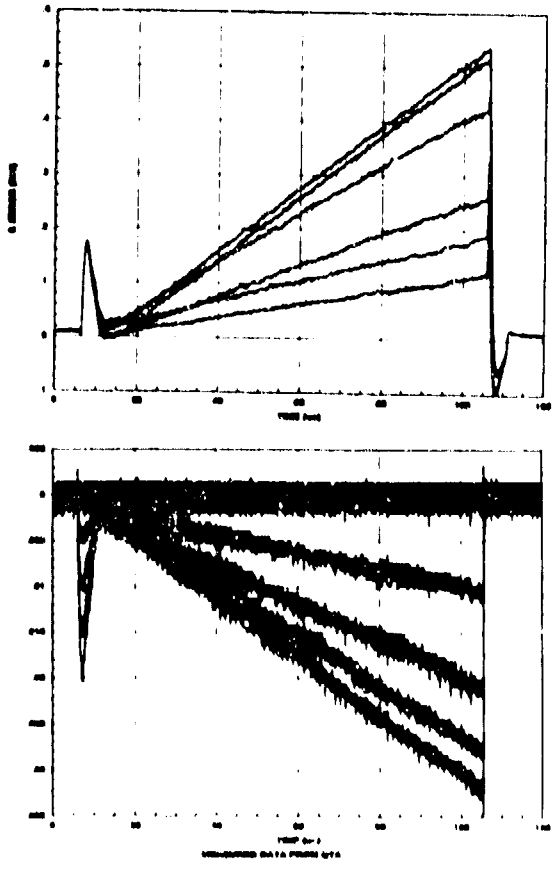

Figure 5. Measured results of feedforward only

Figure 5 shows the measured results of using the device as an adaptive controller to maintain the amplitude and phase of the RF field in the accelerating cavity. Any instantaneous changes in the system require a few seconds for the feedforward control function to adapt, but the system does track slow changes very closely. During this experiment, the adaptive controller was able to hold the RF field parameters within 0.5% of the operating point for many minutes of operation.

IV. FUTURE WORK

These experiments proved extremely successful and verified the concept of adaptive feedforward as a viable solution to improving the field control for pulsed accelerators. In addition, some possibilities for additional work in the future were identified. As shown in figure 3, there are transient glitches that grow slowly as many pulses are accumulated. These glitches are a result of the adaptive algorithm used that accumulates the error functions for all past pulses with no way of eliminating some of the past data. Consequently, any circuit or computational glitches will eventually grow to become significant. Consequently, a revision that incorporates a forgetting function has been designed. The algorithm governing the adaptive process remains

$$f_N(t) = \sum_{i=0}^{N-1} k_i \cdot e_i(t + \Delta T) \quad . \qquad (1)$$

but whereas in the original implementation all the k_i values were identical, the revision incorporates exponential k_i values, creating a forgetting function. This forgetting function provides a sliding window that is used to weight a finite number of past data values for accumulation into the correction function. Consequently the algorithm for the revision is described by the equation

$$f_N(t) = g \cdot f_{N-1}(t) + k \cdot e_{N-1}(t + \Delta T) \quad . \qquad (2)$$

In this algorithm, the gain, k, corresponds to the adaptation gain which affects the sensitivity and adaptation time for the device. The gain, g, provides the forgetting function that is used to discard old data with a exponential decay. The preliminary tests with the new design show that by including the forgetting function, g, the adaptation gain, k, can be increased significantly. Thus, the new design allows more input sensitivity (more dynamic range) and provides a faster settling and tracking time.

The success of the adaptive controller configuration enables the extension of this type of device to additional applications. An adaptive, stand-alone controller could be useful for many accelerator RF applications where conventional feedback control is impractical. For example, short pulse length accelerators typically do not have time for feedback corrections. The adaptive controller could adaptively predict the correct control output.

Currently, there is significant interest in evaluating the usefulness of the current design for other accelerator applications. Adaptive feedforward tests are scheduled for LANSCE II, University of Twente FEL, AFEL, and APLE. Each of these accelerators require control bandwidths greater than a feedback system can provide. The adaptive feedforward is a viable solution to this common accelerator RF demand.

VI. REFERENCES

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