APT LLRF CONTROL SYSTEM MODEL RESULTS *

A. Regan, Los Alamos National Laboratory, LANSCE Division, Los Alamos, NM, USA and
C. Ziomek, Z-TEC, Albuquerque, NM, USA

Abstract

The low-level RF (LLRF) control system is an essential component of the RF system for the Accelerator Production of Tritium (APT). Requisite for good performance at a reasonable cost is system modeling prior to actual hardware build. Models have been created to help establish the LLRF control system baseline design. These models incorporate common signal processing functions and control functions as well as mixed continuous and discrete-time analysis. Components include klystron saturation curves, waveguide delays, realistic resonant cavity equivalents, and LLRF proportional, integral, and differential (PID) control transfer functions. They predict the performance of the LLRF system in the presence of beam noise, excitation of non-fundamental modes which occur in the superconducting cavities, and pulsed beam situations. This paper will describe the basic model and will present results for a variety of operating scenarios.

1 MODEL DESCRIPTION

The functionality of the low-level RF (LLRF) control system for the APT was described in reference 1. In order to best design this system we have relied on computer modeling to predict system response to a variety of inputs during different operational scenarios. The software used is MATRIXX™, a graphical modeling and analysis control system program. In MATRIXX™, common signal-processing and control functions such as transfer functions, limiting, dead band, etc. are all available. It allows both linear and nonlinear functions, as well as mixed continuous and discrete-time analysis (e.g., digital control of a continuous-time plant) and it provides iconic programming (functional blocks, signal flow connectors). We have developed LLRF control system models for a variety of reasons: 1) specification of RF components; 2) verification of system design and performance objectives; 3) optimization of control parameters; and 4) testbed for exploratory control system development. This modeling has been utilized and proven on a number of LLRF control system designs: GTA; AFEL; Boeing's APLE; University of Twente's FEL. It is now being used as a tool for the design of the APT LLRF control system.

The graphical modeling approach allows the model to be built as a combination of "superblocks," each representing the transfer function of its individual components. The overall system model schematic is represented by the top-level block diagram shown in figure 1. Represented as baseband in-phase and quadrature signals, the model includes an ideal current-source beam with noise, a multi-mode accelerator cavity (single gap), a non-linear klystron (with saturation and ripple), waveguide and transmission line delays, and a LLRF controller with feedback and feedforward characteristics. The level of detail available to represent individual components within the RF system (including the accelerating cavity) can be significant. With such a model, we have been able to predict how a particular LLRF control system design will react to a variety of operational scenarios. These include the presence of beam noise, klystron high voltage power supply ripple, and beam pulsing or fault shutdown.
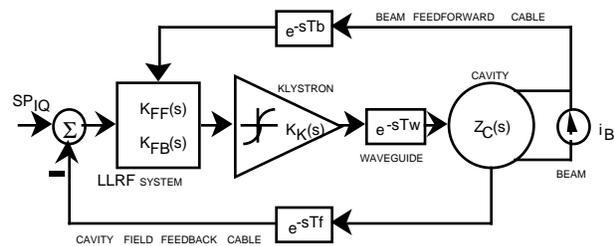
Figure 1. LLRF control system model block diagram.

2 MODEL RESULTS

Model analysis provides for certain parameters to be modified depending on the scenario being tested. These external parameters allow easy modification of the core model to investigate different operational cases. Figures 2 through 6 show the results of modeling the case of normal turn-on of the RF into the cavity followed by turn-on of the beam, as well as the case of rapid beam shutdown (due to pulsing or a beam abort).

As seen in figure 2, there is an initial RF turn-on transient in the cavity field and a spike in the field amplitude and phase errors. Figure 2 shows the type of field amplitude and phase errors we can expect for this turn-on/ CW operation. As seen, the beam turn-on causes a +1/-2% field amplitude error and a +1/-0.5° field phase error. The LLRF control system in this model utilizes just a cavity field feedback signal. An optional beam feedforward feature for tighter control is discussed at the end of this paper.

Figure 3 shows that the klystron saturates until the field gets close to its nominal value when the loop achieves control and the cavity field and klystron forward

---

amplitude settle to their nominal levels (ready for beam). Field errors are now close to zero. Reflected amplitude is identical to the forward amplitude without beam, indicating the large mismatch due to strong overcoupling without beam. When the beam is turned on, at t = 500 μs, the klystron forward output increases to compensate for the beam loading and the klystron saturates once more. Again, the cavity field and klystron forward amplitude eventually settle to their nominal levels.

Since any beam noise will drive modes other than the fundamental in the superconducting cavities, we wanted to study the effects of these other modes. Figures 3 and 4 show the results when we include the two modes nearest to the fundamental. The klystron output does not match perfectly to these other modes in the cavity, and consequently, the reflected signal (figure 3) does not drop to zero as expected when the beam is present. Note the relative magnitudes of the plots in figure 4. Because the steady-state magnitude of the fundamental is approximately 3400 times that of the 698 MHz mode and even greater than that of the 681 MHz mode, their effects are fairly minimal. With a 2 MHz filter built into the feedback control system (to eliminate the possiblity of attempting to control a fedback mode signal which would have the wrong phase and thereby cause the control system response to blow up) the transient-induced modes damp out over time.
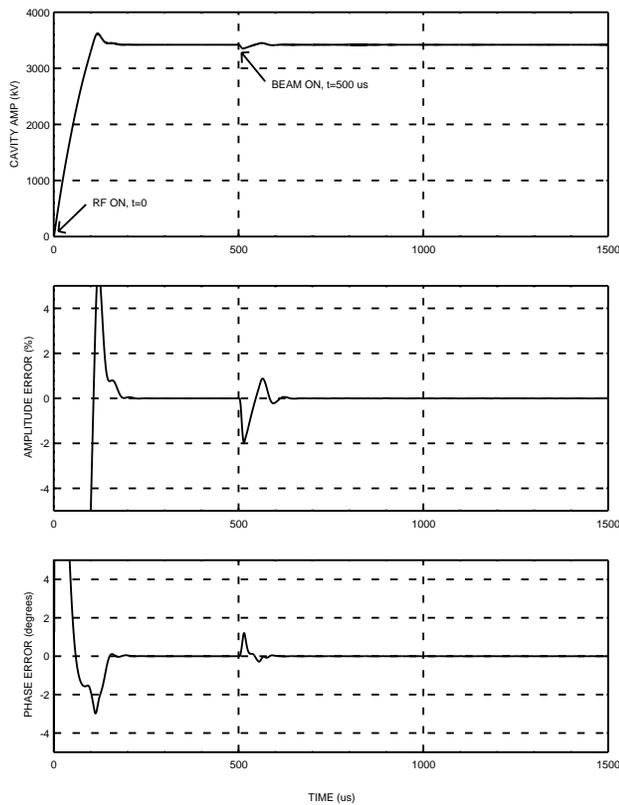
Figure 2. Normal RF and beam turn-on. Cavity field, amplitude and phase errors.
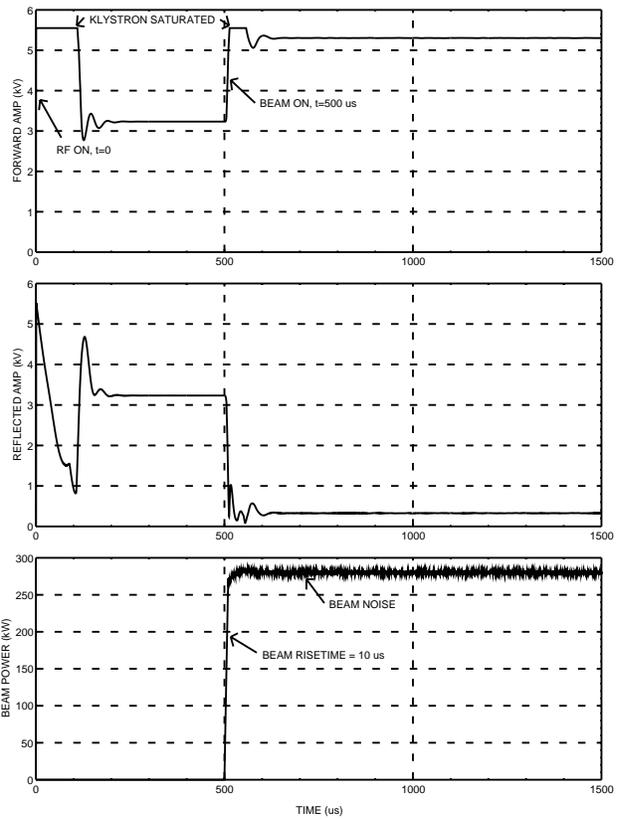
Figure 3. Normal RF and beam turn-on. Forward signal out of klystron, cavity reflected signal, beam power in the cavity.
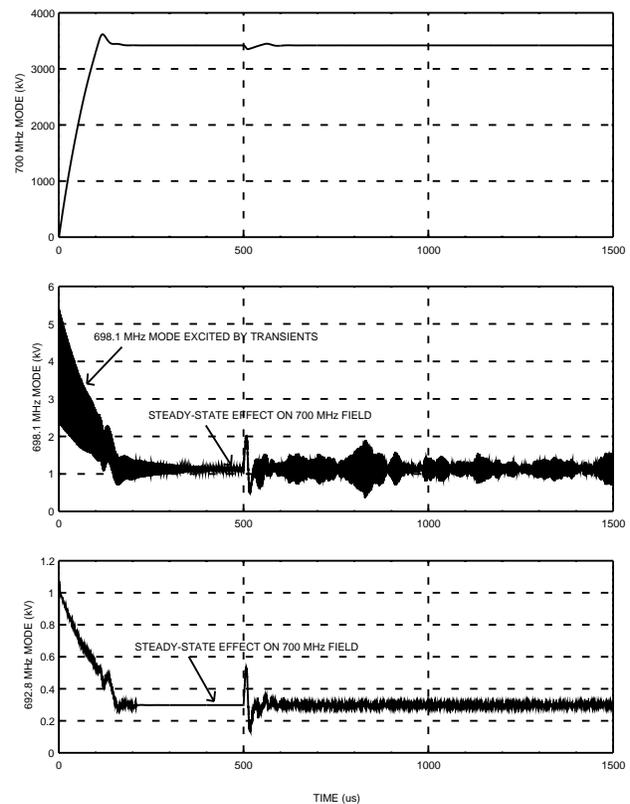
Figure 4. Normal RF and beam turn-on: cavity modes excited.

Another case investigated with the model was the effect of rapid beam shutdown. This might occur intentionally due to pulsing of the beam, perhaps for cavity conditioning, or unintentionally, due to a beam abort caused by some system error requiring fast beam shutdown. As seen in figures 5 and 6, without beam feedforward, there is a large transient when the beam is turned off, while the RF remains on. However, this transient is short-lived and should not cause any problems to the cavities.

When the beam is off and the transient passed, the cavity and the klystron return to the states they were in prior to the beam turn-on, and are ready for beam re-introduction. This model indicates that if the beam is turned off, the control system requires it to remain off for at least 50 µs before turning it on again in order to reach a controlled steady-state field in the cavity.
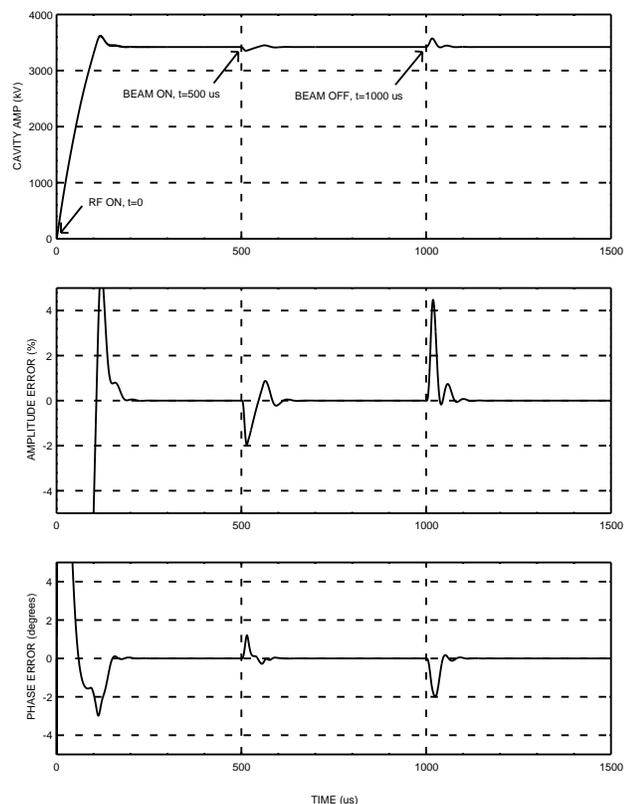
Figure 5. Beam turn-off effect on cavity field, error signals.
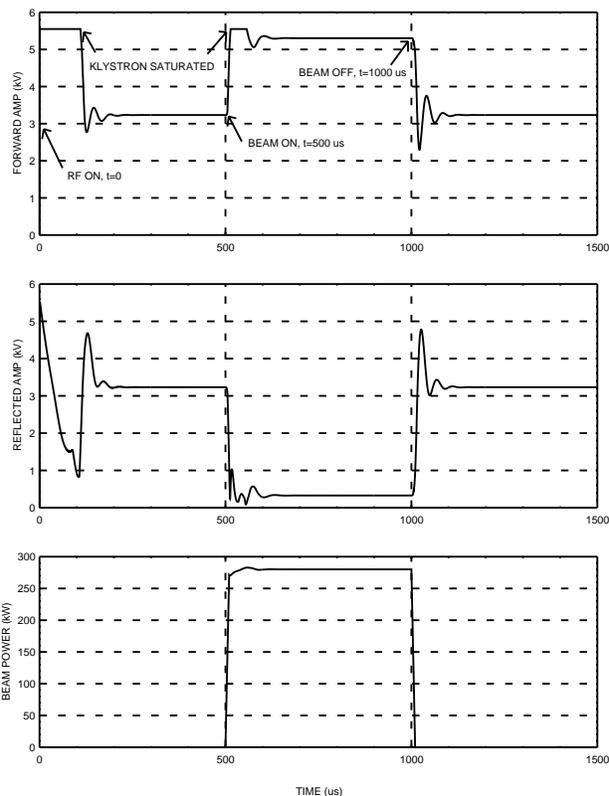
Figure 6. Beam turn-off effect on forward signal out of klystron, cavity reflected signal. Beam power shown.

We have also done some modeling to predict the effectiveness of a beam feedforward feature in the LLRF control system. These models predict that we can reduce the turn-on and turn-off transients that occur in the amplitude and phase errors to +1/-0.5% and +0.3/-0.5° respectively.

3 CONCLUSIONS

The modeling effort has been extensive for the APT project. The basic LLRF control system model has been proven on past projects and gives a solid foundation upon which to base our LLRF control system design. We are now in the process of developing VXIbus modules which perform the control functions defined by the models.

REFERENCES

[1] Regan, A.H., et al, "APT LLRF Control System Functionality and Architecture," Linac96 Proceedings, Geneva, Switzerland, August 1996, pp. 225-227.

[2] Ziomek, C.D., et al, "Low-Level RF Control System Issues for an ADTT Accelerator," ADTT Conference Proceedings, Las Vegas, NV, July, 1994.

[3] Cheo, B.R. and Jachim, S.P., "Dynamic Interactions Between RF Sources and Linac Cavities with Beam Loading," submitted to IEEE Trans. Elec. Dev., 1990.