The Control and Operation of the Programmable Wave Form Generator for the SSRL Injector*

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Abstract

A CAMAC-based programmable wave form generator is described which is used to control the quadrupole and sextupole trim power supplies for the new 3 GeV booster synchrotron injector for the electron storage ring SPEAR. This same type of unit is used to vary the cavity voltage of the RF system. Memory located in the CAMAC module is loaded with a wave form and output to the supplies with an internal clock. The wave form can be loaded either graphically using the X-windows-based control system or with an ASCII text file.

I. Introduction

We have recently completed the commissioning of a new 3 GeV booster synchrotron injector adjacent to the SPEAR storage ring[1]. The injector consists of a 120 MeV linac followed by a booster whose magnets are ramped using a White circuit. [2] The principle of the White circuit is that the dipole and quadrupole magnets in the booster are placed in series with capacitors so that an L-C oscillating circuit is produced. For the case of the SPEAR injector the resonant frequency is 10 Hz. With the dipoles and quadrupole currents being ramped in hardware the only magnet supplies which must be ramped using a programmable power supply are the quadrupole and sextupole trim coils. After 9 months of operation the sextupole magnets have not been utilized, so they will not be discussed further. The purpose of the quadrupole trim coils is to fix minor problems in magnetic field within the quadrupoles during the ramp. The specific shapes of the ramps for the focusing and defocusing quadrupoles are empirically determined. The other component of the injector which needs an external ramp is the radio-frequency (RF) cavity voltage. For this purpose one of several analytic functional forms are used to ramp the voltage. Thus to accomplish these functions a CAMAC-based programmable wave form generator (WFG) was selected.

II. Hardware Description

The hardware requirements are best met by a wave form generator which is capable of producing an arbitrarily shaped function. We have chosen a commercially available module[3] for this purpose. The package consists of two modules each occupying a single slot in the CAMAC crate. One module has the output connections and the timing input connections and is addressed by the computer. The second is the memory storage module and talks to the first via a buss connector along the top back edge of the units. The unit can produce 1, 2 or 4 output signals simultaneously using a 12-bit D-A converter. The analogue output signals are driven by two op-amps which are each capable of producing $\pm 5V$ signals with respect to ground, thus in floating mode $\pm 10V$ is possible, but for our system only a single $\pm 5V$ driver is used. Short circuit protection is achieved by temperature limitation of the output driver, which can get quite toasty if grounded.

One of the surprises of the module was a transient voltage spike which occurs each time the voltage is changed during a ramp. Since our application uses the module to generate a wave form that is 100 msec in length a low-pass filter with 1 kHz time constant is sufficient to smooth out the signal and has no effect on operation. It might be a problem for higher frequency operations.

The memory module contains 32K of static memory which can be parsed according to the number of signal channels. For our application a 1000 sample wave form was used, updating the wave form every 0.1 msec.

III. Initialization

The proper timing of the booster is critical to its functioning. Rather than have the WFG operate in free-running mode a master oscillator is used to synchronize all of the critical events. The WFG can operate either in continuously repeating mode or can output 1-15 repetitions of the form and then stop. As we have implemented the module it is set up in continuous mode with a start pulse sent by the master oscilator. In this mode the unit only completes a full wave form and restarts itself if a start pulse is missed by the master oscillator. The start pulse from the master oscillator ensures that the ramp is always synchronized to the rest of the booster operations.

To initialize the unit wave forms are loaded into the memory. Unfortunately this can not be done on the fly, rather the output of the unit must be turned off prior to loading wave forms. The loading procedure takes over a second to complete, occasionally causing time-out problems with our serial highway crate controller. One restriction on the flexibility of the unit is that each of the wave forms must be the same length. Once the wave forms have been loaded into memory the unit can be armed and the next time a start pulse from the master oscillator is seen the wave form will be unloaded from memory. A software start is also an option after the module has been armed.

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IV. Wave Form Creation and Loading

The user interface to the WFG is through the X-windows-based graphical user interface of the injector control system.[4] For the focusing and defocusing quadrupoles the inputs to the final wave form are 20 amplitudes adjustable on screen using sliders (a graphical input *widget* provided by X-windows). Each of the 20 sliders represents a different time with respect to the injection of the electron beam into the booster from the linac. There are additional sliders for adjusting the phase of the wave form, a constant offset and an overall amplitude factor. The program divides the 50 msec ramp time into 19 intervals and assigns the 20 slider values to the 20 interval borders. The total number of points in the wave form is 1000, so the first 500 are calculated as a linear interpolation between the slider values. The second 500 values are a smooth interpolation between the last and the first slider value while trying to keep the wave form amplitude low. We plan to replace the linear interpolation by a 3-point spline interpolation in the near future. The phase, offset and overall amplitude are applied to the total wave form before it is written to the data base and loaded into the WFG. A new wave form is calculated and loaded whenever one of the input parameters is changed.

The RF cavity voltage depends on a number of machine parameters such as the AC and DC offset voltages for the White circuit and the linac energy. There are also parameters for the rate of change of the magnetic field in the dipoles ($\dot{B}$) and overall phase, offset and scale parameters. The program converts the White circuit voltages into energy equivalents which are used to estimate the phase angle ϕ of the white circuit at which injection occurs. The 1000 waveform points (to cover the 100 msec period) are calculated by

$$f(t) = \dot{E}\, T_{rev}\, \dot{B} + E(t)^4\, U_0$$

where

$$\begin{aligned} E(t) &= ENERGY_{DC} + ENERGY_{AC}\, SIN(\omega t + \phi), \\ \dot{E} &= \omega\, ENERGY_{AC}\, COS(\omega t + \phi), \\ U_0 &= \text{Energy Loss per Turn}, \\ T_{rev} &= \text{Revolution time}. \end{aligned}$$

Again, the phase, offset and scale factors are applied to the 1000 waveform points before it is written to the data base and loaded into the WFG. A new waveform is calculated and loaded whenever one of the input parameters is changed. As an alternative, the program can accept as parameters the maximum booster energy and the ratio of the AC to the DC component of the magnetic field which it converts to the AC and DC voltage setpoint by using the calibration factors.

The control system for the injector includes provision for saving to an ASCII text file a particular parameter or set of parameters. These text files can be reloaded into the data base. Thus an arbitrarily shaped wave form can be calculated and written into a text file with the proper format and then loaded into the data base and the WFG module.

V. References

[1] H. Wiedemann, "3 GeV Injector Synchrotron for Spear." At this Conference.

[2] R. Hettel et al., "The 10 Hz Resonant Magnet Power Supply for the SSRL 3 GeV Injector." At this Conference.

[3] Model 5910 Function Generator, Bi Ra Systems, Inc. Albuquerque, N.M. 87107.

[4] C. Wermelskirchen et al., "The SSRL Injector Control System." At this Conference.