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A NEW LOW LEVEL RF SYSTEM FOR THE FERMILAB BOOSTER

Keith G. Meisner, James E. Griffin, Edward F. Higgins, and Stephen P. Jachim*†

SUMMARY

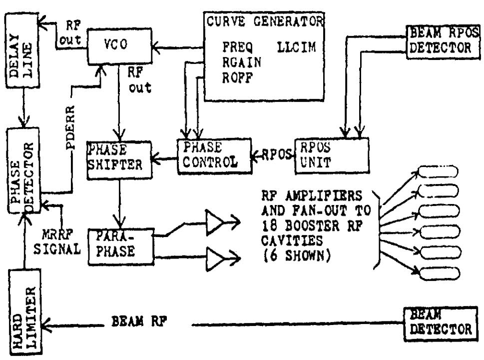
A new low level RF system featuring improved bandwidth, dynamic range, filtering, and signal processing has recently been commissioned in the Fermilab Booster. Two analog feedback loops lock the frequency and the phase angle of the RF accelerating voltage to the proton beam. Programmed curves such as frequency and gain can be corrected by a software feedback loop which processes digitized error signals. System performance and operational experience will be discussed.

INTRODUCTION

The reasons for building a new low level RF system are to provide a reliable, well documented electronic system which minimizes daily tuning requirements. Improvements are especially desired in the control of the beam radial position, in the stability of synchronous transfer process from Booster to Main Ring, and in stabilizing system performance over a wide range of Booster beam intensities as required by the Fermilab high energy physics program. These goals have been realized through careful attention to the noise and bandwidth requirements of each component and through the use of a flexible system of software and diagnostics.

SYSTEM COMPONENTS AND CONFIGURATION

FIGURE #1 LOW LEVEL BLOCK DIAGRAM



A 0 to 8 volt programmable, 28 to 54 MHz voltage controlled oscillator (VCO) produces the RF signal which is amplified and applied to resonant cavities to accelerate the Booster beam.[1] The VCO has a frequency modulation bandwidth capability of 2 MHz (-3 db point) and the output is filtered to reduce the worst-case second harmonic content by 30 db. One VCO output passes through a ± 10 volt programmable PHASE SHIFTER module with a range of ± 90 electrical degrees. The PHASE SHIFTER bandwidth is DC to 30 kHz (@ -3 db), and it provides a phase shift independent of RF frequency. The phase shifted RF signal is delivered to a paraphase module which controls the relative phasing of alternate RF cavities for adiabatic capture of the 200 MHz structured Linac beam into the 30.1 MHz injection RF buckets of the Booster.[2] The two paraphased RF outputs are amplified and distributed via fan-out modules to high power components which drive the Booster accelerating cavities. The modules discussed so far are sufficient to provide an RF voltage at the cavity gaps, but two feedback loops are needed to guarantee that this voltage provides the correct momentum gain per gap passage.

The first feedback loop corrects the approximate VCO frequency as programmed so that it matches the beam frequency during acceleration. A wide band (4 kHz to 300 MHz) coaxial current transformer detects the beam RF structure, which is then filtered (30 to 53 MHz band pass) and amplitude limited to less than 1 db variation by a HARD LIMITER module with a 40 db dynamic range.[3] A phase lock feedback loop coupled to the VCO compares this limited beam RF signal to the VCO output in a dual channel phase detector (PDET) module. The phase difference signal is filtered and delivered to the VCO as an error signal. The VCO input to the PDET channel is delivered through a heliax delay line of a length matching the total delay of the VCO drive signal to the beam plus delay of the detected beam RF signal back to the PDET.[4] The delay line is necessary to eliminate accumulative phase differences between the accelerated beam RF signal and the VCO output to which it is compared. Besides locking the VCO frequency to the beam during acceleration, the PDET is required to phase lock the beam to a reference RF signal from the Main Ring accelerator just before extraction. This allows synchronous transfer of Booster beam bunches into stationary Main Ring RF buckets. The second PDET channel is activated 1.5 msec. before extraction from the Booster and compares the MRRF signal phase to the VCO signal, filters the result, and adds this error signal into the VCO.

The second feedback loop begins with a single-turn ferrite loaded toroid divided into two halves radially. The toroid detects beam position in the form of two RF signals whose amplitudes are proportional to the radial displacement through the toroid. A RADIAL POSITION UNIT (RPU) with a dynamic range of 60 db in intensity converts amplitude to phase, then phase detects and produces an analog RPOS signal which is independent of beam intensity.[5] The RPOS signal is compared in the PHASE CONTROLLER module to a computer-derived radial offset curve (ROFF) which specifies a desired RPOS through the Booster cycle. Differences between RPOS and ROFF form an error signal (RPERR) which is filtered and multiplied by a gain specified by a second computer generated curve (RGAIN). The final processed error signal is delivered to the PHASE SHIFTER module and the resulting phase shifts cause slight changes in the net accelerating voltage per turn. In this way the average position of the beam is maintained at the desired radial offset (ROFF) position. The dynamics of this feedback loop are such that coherent synchrotron motion of the entire beam about the desired beam position is damped. It is necessary that the sign of the error signal in this feedback loop be reversed at transition.

The phase jump in beam to cavity gap voltage required at transition is initiated by two TTL level gates. One gate inputs to the PHASE CONTROLLER and produces a -1 multiplication in the PHASE SHIFTER drive signal. The second gate inputs to the PARAPHASE module and produces a 180 degree phase change in both of the RF outputs of this module. The net change in phase between beam and RF voltage is shown in Figure 2.

CURVE GENERATOR AND SOFTWARE SUPPORT[6]

Three computer generated digital curves are derived in CAMAC based waveform generators, and up to 1000 points of digital curve data are converted to analog waveforms in curve OUTPUT MODULES. Radial gain (RGAIN) and radial offset (ROFF) curves are used in

*Fermi National Accelerator Laboratory, P. O. Box 500, Batavia, Illinois 60510.

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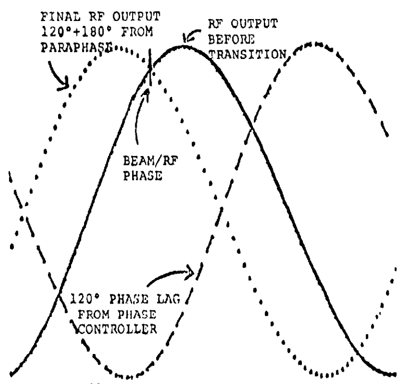
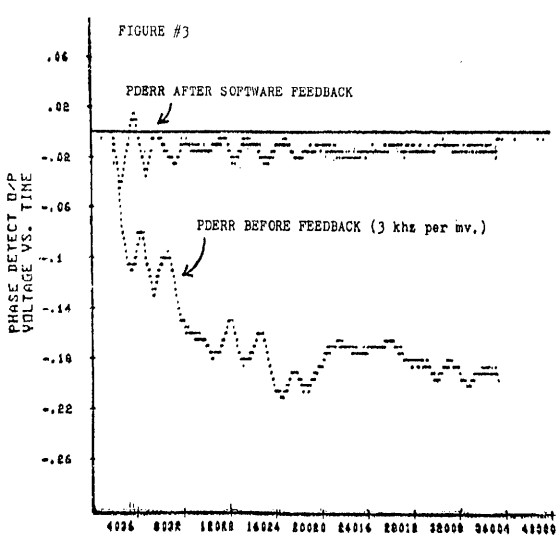


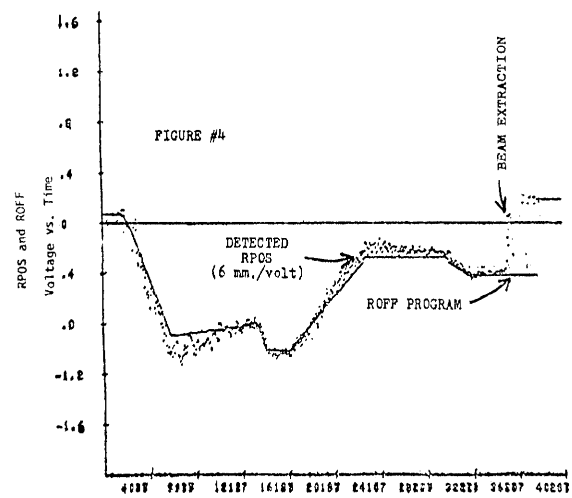
FIGURE #2- TRANSITION PHASE JUMP

the PHASE CONTROLLER for RPOS feedback as previously described. These are step function curves with fixed slew rates established in the OUTPUT MODULES. A frequency (FREQ) curve serves as an approximate program for the VCO and must be smooth and transient free to eliminate large, fast errors in the phase lock frequency feedback loop which can cause beam loss. To achieve the required smoothness the FREQ curve OUTPUT MODULE is programmed with time, value, and slope data and generates a waveform which vectors from point to point. A software option has been implemented which examines the FREQ curve point by point and performs a smoothing operation which over several iterations removes discontinuities. Direct sampling of the curves and related error signals is provided by a fast digitizing CURVE INPUT MODULE (CIM). The error signal output (PDERR) of the phase detector indicates differences between the FREQ curve and the actual beam RF frequency. An application program on the system host computer initiates sampling of the PDERR signal by the CIM, applies an appropriate algorithm to the CIM data, and corrects the FREQ curve as needed. Although the VCO frequency feedback loop tolerates large errors in the FREQ curve when beam is in the Booster, the VCO must also drive the Booster cavities at the correct frequencies when beam is not being accelerated. The software feedback feature provided by the CIM replaces painstaking FREQ curve tuning with two simple interrupt operations. Figure 3 shows FREQ curve software feedback results after one iteration of correction and smoothing. This feedback procedure took about one minute. Software feedback can be used in a similar manner in the RPOS feedback loop by digitizing the RPERR signal with the CIM and applying the data to modify the RGAIN curve.



SYSTEM PERFORMANCE

Use of the new low level system has shown improvement in several areas. Accurate control of beam radial position is an important tuning variable in minimizing transverse plane beam instabilities, and Figure 4 shows that the radial beam position closely follows the value specified by the programmed ROFF curve. Experience with the phase lock transfer process from Booster to Main Ring has been limited, but pulse to pulse phase and momentum errors of ± 3 degrees and ± .08% respectively have been achieved. The new system of curve generator hardware, diagnostics, and attendant software is reliable, easily tuned, and outputs reproducible waveforms. The new low level RF system accelerates beam with expected efficiencies, and with predictable results and easily controlled parameters.



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