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Summary

Recent activity in resonant extraction of the circulating proton beam at the Bevatron spurred interest in accurately measuring the radial betatron oscillation frequency. Calculations indicated that it would be practical to use the existing RF system tuned to the betatron-oscillation frequency for excitation of the desired oscillations. Measurement of the proton rotational frequency and the betatron oscillation frequency has been carried out with the aid of a small digital data processor. The system we have used allows dynamic on-line presentation of beam radius, betatron frequency, and rotational frequency to precision of approximately one part in 10 000.

Introduction

Whenever new equipment is being planned for installation in an accelerator, the cost versus need and the space used in the accelerator must be considered. Our choice of using the existing RF accelerating system to drive radial betatron oscillations for diagnostic work took no additional space in the Bevatron, and the cost was minimal because all the hardware already existed except for the necessary circuitry to program the RF. The only disadvantage is that radial tune measurements cannot be made while the guide field is rising, as during normal acceleration of the beam.

The Bevatron acceleration system is a two-gap system consisting of two ground planes and a drift-tube electrode mounted in the north straight section. The signal from a tuned master oscillator is amplified by a wide-band driver which drives the final amplifier stage. The electrode is the capacitive part of the tuned LC circuit of the final amplifier. The energy gain of the proton is equal to the net voltage difference in crossing the two gaps. The maximum energy gain per turn is about 5 keV. The energy gain in crossing the electrode system also produces a small radial betatron oscillation, which will build up if the RF system is tuned to the radial-betatron-oscillation frequency, f_β. Detectable growths of amplitude can be observed by monitoring beam spills on a target just radially clear of the normal circulating beam.

Circuit Design and Equipment

Hardware generation for the excitation and measurement of radial ν value included the design and building of just two items, a modulator of frequency and amplitude, and one attachment for a CMC 727B counter that would allow measurement of the duration of a specific number of cycles of the $\approx$ 2.5-MHz RF voltage.

Since the Bevatron coarse-frequency programming is done by an inductance change of a winding on a saturable reactor, it seemed reasonable to manipulate the saturating current through the reactor to achieve the desired shift to f_β. The normal programming of the reactor current is obtained by integrating a voltage proportional to $\dot{B}$. By placing a feedback loop around the integrator, as shown in Fig. 1, we are able to have the reactor current, and the frequency of the oscillator, follow a voltage impressed at the "betatron program" point on Fig. 1.

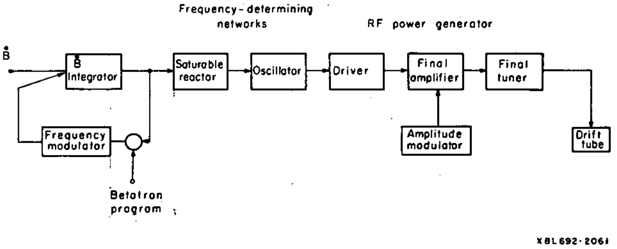

Fig. 1. Block diagram of Bevatron RF system, showing frequency control elements and amplitude modulation input. "Vernier program" is an input routinely used for small frequency adjustments.

Amplitude modulation of the Bevatron RF system was already possible, as it has been a routinely used technique for spilling beam. We use this system to cut off the RF voltage during the time of frequency change. The only difficulty we encountered was re-establishment of the final amplifier tuning after the large frequency change. Careful adjustment of the self-tuning circuit overcame

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the difficulty. External preset and gating circuits are applied to a CMC 727B counter, which counts a certain number of RF cycles and then shuts off. The identical gate is used to start and stop a Nano 100 counter, which counts a precision 10-MHz pulse train and displays a count linearly related to radius. The 10-MHz clock in use is the time-base generator for the CMC counter. For the accuracy and resolution desired we count for 18 535 RF cycles, corresponding to about 75 000 10-MHz pulses. The display counter BCD output is sent to a PDP-8 digital processor, which calculates (on-line) radius, frequency, ν, and other quantities of interest at the time. Start and reset pulses from the processor control the measurement system. A block diagram of this system is shown in Fig. 2.

System accuracy is determined primarily by the number of RF cycles being counted and approaches 1.25 parts in 18 000, corresponding approximately to ± 0.052 in. radius.

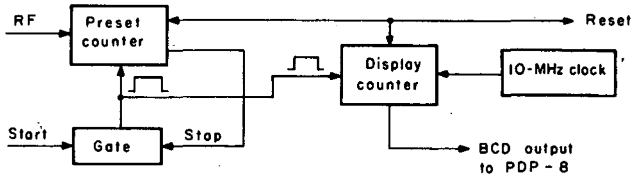

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Fig. 2. Block diagram of frequency-measuring system.

Measurement of Radius and ν Value

The scalers may be gated on at any time to measure radius. The radius value is determined from a calculation involving the closed-orbit geometry, beam velocity, and measured duration of 18 535 cycles. The choice to measure RF period rather than frequency and the particular number of cycles was made so that with nominal conditions near 600-in. radius (aperture center line), a radial beam shift of 1 in. corresponds to 100 counts at the 10-MHz rate. The PDP-8 computer is programmed to accept data on the field strength, and calculates the radius value. For greatest accuracy the Bevatron field may be held constant during the measurements.

The constant field is essential for the measurement of ν value, for in this case the RF is turned off before the frequency shift and the beam must circulate at constant radius until radial blow-up is observed. Field variation is held within about 0.01%. At the start of a ν measurement, the scalers measure a time period as for a radius measurement. The RF voltage is then turned off, the frequency lowered to near the betatron frequency (about 0.6 of the rotational frequency, f_o), and the voltage turned on again. The shifted frequency is adjusted to produce beam loss on a target placed at the edge of the circulating beam. Figure 3 shows the signals monitored on an oscilloscope during a measurement. The loss is made to occur at a preset time (at 600 ms in Fig. 3) when the counters are gated to make a second measurement of RF period. The ν value is calculated as the ratio of the two RF periods measured, and is displayed by the digital system.

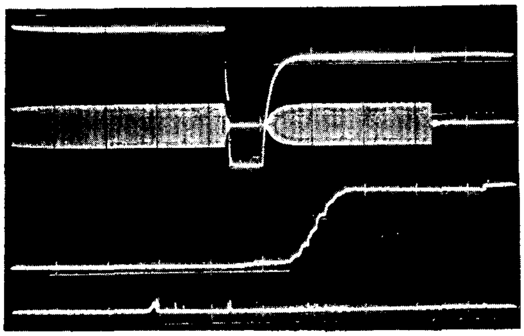

Fig. 3. Oscilloscope picture showing betatron oscillation exciter in operation. Top trace: RF amplitude modulation waveform. 2nd trace: RF waveform. 3rd trace: integrated output of Cerenkov counter. 4th trace: direct output of Cerenkov counter. Sweep speed: 100 ms/cm.

The betatron frequency determined is that of the particles with amplitude sufficient to reach the target. If the ν value varies with betatron amplitude, information on this variation may be obtained from measurements with the target placed at various radial distances from the closed orbit. This application has been of value in studying effects of guide-field nonlinearities.

Acknowledgments

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