BEAM CONTROL AND RF STACKING IN ISR

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(presented in summary by M. J. de Jonge)

Abstract

This paper describes both the equipment and the different programs used for RF stacking in the ISR. Since the high-power part has been described earlier1) emphasis is put on the low level system.

Frequency and voltage programs, missing bunch phaselock5) and suppressed bucket system6) are described. Some of the results obtained during ISR running-in are discussed.

1. General Description of the Low Level RF System

A simplified block diagram is given in Fig. 1. A program generator provides the required modulation of the RF voltage on the cavities. The amplitude of the cavity voltage is controlled by a feed back system.

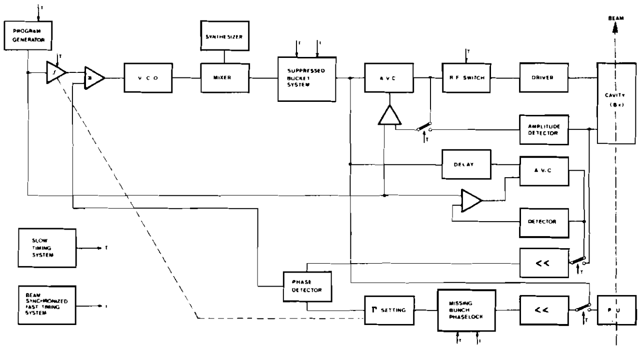

Fig:1_Simplified block diagram of low level R.F. system

The RF frequency is the mixing product of a single side band mixer. A frequency synthesizer and a voltage controlled oscillator are connected to the mixer inputs. The voltage controlled oscillator provides the necessary swing required for the acceleration across the vacuum chamber aperture (about $0.5 \cdot 10^{-3}$), the synthesizer provides the change in frequency as function of injection energy (0.5 %). In order to be able to trap the injected beam a phaselock system is incorporated.

Tuning of the cavities and the AVC amplifiers in the phase-lock system is done automatically via the injection frequency setting.

Several refinements, such as missing bunch phaselock and suppressed buckets systems are built into the system.

The operation of the system is governed by two timing systems, one delivers pulses derived from a free running 100 kHz clock, the other gives pulses synchronised with the beam. Both timing systems are started with a beam derived pulse.

2. The Amplitude and Frequency Program

The cavity voltage varies over a large dynamic range (300:1) during the stacking cycle. In order to be able to accomplish the stacking cycle in the available time between successive PS pulses, a high accelerating voltage (typically 20 kV) is required in the beginning of the cycle, to move the beam rapidly from injection orbit to a region close to the stack.

To obtain high stacking efficiency a very small voltage, typically a few hundred volts, (design value 50 V), is needed at the end of the cycle to form buckets that just contain the injected bunches2). To preserve the particle density in phase space the voltage reduction should be done adiabatically3).

The high precision required for the cavity voltage imposes the use of a closed loop feedback system, whereby the difference between the voltage of a program generator and the peak detected sum of the RF amplitudes of the cavity voltages is fed into a variable gain (AVC) amplifier.

The feedback system is non-linear due to the AVC amplifier (the loop gain of the feedback system depends on the gain of the amplifier). Rapid switch-on of the RF voltage on the cavities after injection can therefore only be achieved in open loop, which makes a second feedback system to control the AVC amplifier, before RF voltage is applied to the cavities, necessary. RF voltage is switched on in less than 5 μsec; 50 μsec after switch-on the main feedback loop is closed.

The parameters of the stacking process, (voltage at injection, adiabaticity of the voltage reduction and final voltage) can all be selected on the program generator, which also provides the rapid jumps in voltage shortly after injection for RF matching of the injected bunches to the ISR buckets.

The final frequency fed into the cavities is composed of a high frequency from a programmable synthesizer and a rather low frequency (55 - 60 kHz) of a voltage controlled oscillator. In this way the rather stringent requirements for the permissible f.m. noise 2,4) can be met. The low frequency has been chosen such that the unwanted sidebands of the mixing process do not coincide with integer and half integer multiples of the particle revolution frequency. A single side band mixer has been used to avoid the use of sharp band-pass filters that would have limited the response of the phaselock loop. The voltage controlled oscillator, a multivibrator type, uses as driving voltage, the integrated voltage program yielding a constant stable phase angle during the stacking cycle. Two types of stacking program are used : repetitive stacking (stacking at the top) and non-repetitive stacking (at the bottom).

In the stacking at the bottom program, the time during which the beam is accelerated rapidly, is shortened for each successive injected pulse. The correct timing for this scheme is generated by a precision frequency comparator (resolution better than 2 Hz) using a programmed synthesizer. A picture of a typical program is shown in Fig. 2.

With the program generator scanning buckets are generated that are used for the measurement of particle density distribution of the stacked beams. The signals, induced on an electrostatic p.u. electrode, due to the passage of the empty buckets through the stack are amplified and displayed on a memoscope. The analogue voltage driving the oscillator is used as horizontal sweep for this oscilloscope, and density is thus displayed directly as function of momentum. Typical RF scans are shown in Figs. 3 and 4.

A very flexibale timing system makes the selection of the different programs and modes of operation of the RF system very easy.

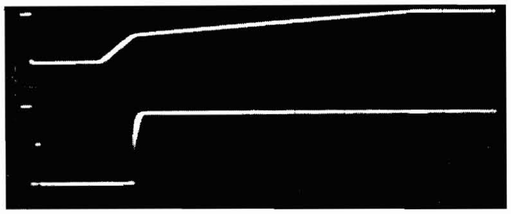

Figure 2

Typical voltage and frequency program

Upper trace : driving voltage oscillator

Lower trace : RF amplitude program

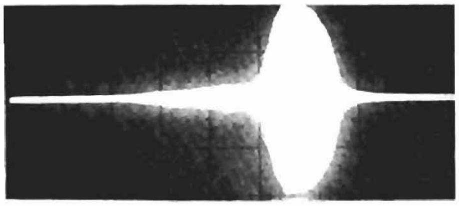

Figure 3

RF scan of stacked beam, 2.5 A stacked at the bottom in 38 PS pulses. 20 bunches, 22 GeV/c. 1 horizontal division corresponds with 10 mm radial shift.

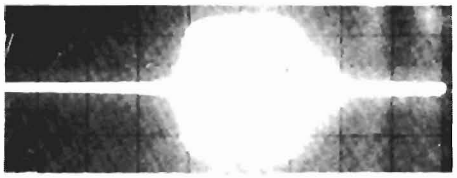

Figure 4

RF scan of stacked beam, 1.5 A stacked at the top. 4 bunches, 22 GeV/c. Signal less attenuated than in Figure 3.

3. The Phase-lock System

The beam input to the phase-lock system is a chopped wave consisting of a signal induced by the beam on an electrostatic P.U. The RF input is the sum of the RF cavity voltages. The signal from the P.U. is converted into a continuous wave by a high Q-resonance circuit, tuned to the RF frequency. The Q-factor chosen is about 100. The amplitude of the RF voltage on the cavities can vary as much as 1:300 and the phase detector must be able to handle this large dynamic range. An AVC amplifier, into which the ringing circuit is incorporated, gives an output variation in amplitude of ∿1:2.5 for an input variation of 1:300. The phase variation for the same dynamic range is about 2 degrees at 9.5 MHz. The AVC amplifier acts only on slow varying signals. A fast limiter in series with the AVC amplifier keeps the input signals to the phase-detector constant in amplitude, independent of fast or slow variations at the input of the system.

The two branches into the phase detector are identical as far as possible.

A dummy cavity and a phase reference signal keep the system locked, in the absence of a beam.

The output of the phase-detector goes through a variable gain amplifier and a hold circuit. The cut-off frequency of the phase-lock loop can thus be chosen to any setting between a few Hz and max. 5 kHz.

A timing pulse will open the loop via the hold circuit, and the output stays constant at the voltage it had when switched off. This enables us to switch off phase-lock during the stacking cycle. The fast timing system consists of an auxiliary f.m. oscillator locked on to the beam. Timing pulses firmly synchronised to one bunch are derived.

The missing bunch phase-lock system is a scheme that makes it possible to distinguish between the particles inside the bucket and those surrounding them. The signal from the modulation produced by the empty buckets on the stack, (Fig. 5) is subtracted from the signal from a bucket carrying particles. The resulting signal due to only the particles inside buckets is then used as a phase reference. The flexibility of the system permits one to take the difference between any number of "missing" and real buckets. The phase-lock system will operate locked on to any number of bunches down to one.

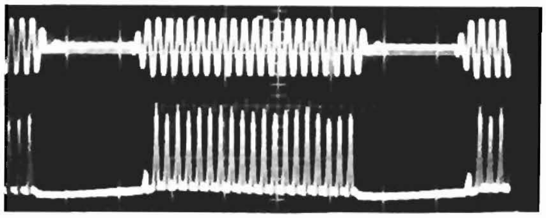

Figure 5

Upper trace : chopped RF wave with the suppressed bucket system working. V_{tof} = 500 V.

Lower trace : signal induced on a P.U. at the same moment. 10 out of 30 RF buckets are suppressed.

4. The Suppressed (missing) Bucket System

In order to avoid dilution of the stack due to empty RF buckets, the RF voltage is switched off once per revolution, during the time when no particles traverse the cavities. The number of RF cycles switched off, can be selected from 1 to 30. This switching only starts once the voltage has come down to about 600 volts per turn. A fast switch, synchronised to the fast timing system, chops the RF driving voltage. A signal compensating the ringing of the cavities is added to the driving voltage (Fig. 6).

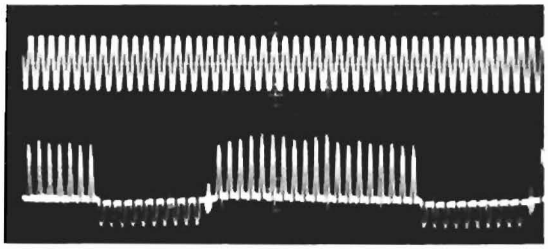

Figure 6

Upper trace : RF sum voltage on the cavities during a stacking cycle. V_{tof} = 500 V.

Lower trace : signals induced on a P.U. at the same moment. One notices the "negative nunches" due to the presence of a stack.

5. Performance of the System

The system described has been used extensively since the end of 1970 for both machine development and stacking for colliding beam experiments. An overall phase plane efficiency (from CPS to the final stack) of 70 % has been obtained.

The beam can be kept bunched for more than 10 minutes when the phase-lock system is used, for 2 to 3 minutes without the phase-lock system, which indicates that a very low noise figure has been achieved. The trapping range of the phase-lock system is sufficient to cope with injection errors of several mm.

First results with suppressed buckets indicate that the expected increase in stack density can be obtained. The scanning buckets generated with the present system have proven to be a valuable tool in the evaluation of the ISR performance.

6. Acknowledgements

We are very grateful for the many valuable comments and the constant encouragement of W. Schnell. The building, testing and installation of the equipment would not have been possible without the help of P. Brown, M. Disdier and M. Studer.

7. References

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