BETATRON TUNE MEASUREMENT AND CONTROL IN THE PETRA PROTON RING

S. Herb
Deutsches Elektronen-Synchrotron DESY
2000 Hamburg 52 - Notkestrasse 85 - Germany

Abstract

The PETRA storage ring, modified for use as an injector to the HERA proton ring, requires active control of betatron tunes during the proton acceleration cycle. A tune measurement system based on a personal computer equipped with commercial data acquisition and analysis cards is used for both measurement and control of the tunes.

I. INTRODUCTION

PETRA was designed as an electron storage ring for 7-20 GeV electron beam energy; it now serves both the HERA electron and proton rings as an intermediate energy booster. For the proton service, beam is injected at 7.5 GeV and accelerated at about .3 GeV/sec to 40 GeV; it is planned to accelerate a train of 50-70 bunches spaced 97 nanosec apart. There are significant betatron tune shifts during acceleration, at low energy from eddy currents in the aluminum vacuum chambers and at high energies from field saturation, especially in the bending magnets. We therefore decided to build a tune measurement system with relatively fast response to aid in understanding and correction of these effects; minimizing excitation of the proton bunches has at present second priority.

II. TUNE MEASUREMENT

A. Beam Pickup and Signal Processing

Fig. 1 shows a schematic of the measurement system. The signal source is a directional coupler pickup of the type designed for the HERA straight sections [1], mounted in the PETRA proton bypass. The electrodes are 40 cm long, which, together with the 2-3 m bunch length, results in a bipolar output pulse with signal energy concentrated between 50 and 150 MHz. The sensitivities are 50 mv pp/10^9 protons for a single electrode and 0.7 db/mm for the ratio of voltages from opposed electrodes.

Pulses from the monitor are transmitted about 100 m to a service hall, amplified in broadband chains with switchable gain, and stretched using Schottky diodes biassed to just below threshold, yielding about 30 dB dynamic range. The signals from opposing electrodes are subtracted, amplified, and subjected to 65 kHz low

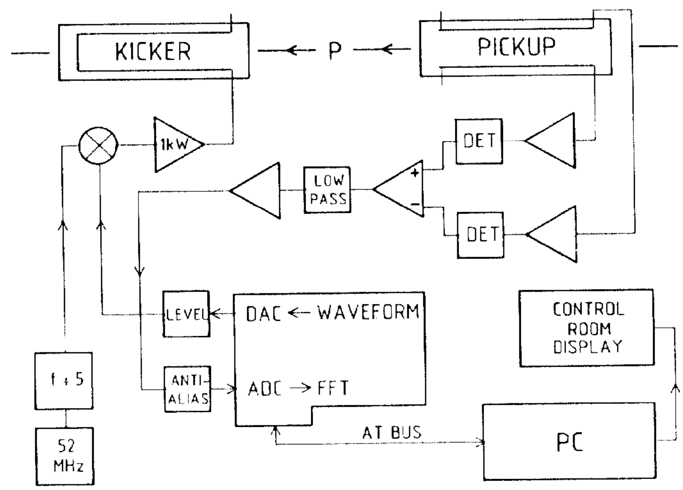

Fig. 1 Simplified schematic of one channel of the PETRA tune measurement system

pass filters (the PETRA revolution frequency is about 130 kHz). There is no time gating of the pulse train, so the low frequency signal is a sum from all bunches in the machine, with high sensitivity to modes in which the bunches are moving almost in phase (multiples of 10.3 MHz for the 97 nsec bunch spacing in PETRA). The low frequency signals are brought on 1 km long RG-213 cables to the control room, where they are fed to anti-aliasing filters with a sharp cutoff above 65 kHz, and thence to A/D converters.

A/D conversion is performed by special cards sitting on the AT bus of the personal computer used for control and display. The cards (Microstar DAP 2400/5) have also 80C186 CPU and 56001 DSP chips and are thus able to perform data processing, including fast Fourier transforms, before the data is transferred to the host PC. The 10 Hz rate is achieved with two cards (horizontal and vertical tunes) sampling at 160 kHz, performing 512 point real Fourier transforms, and transferring the 256 point power spectra to the host PC. Programming of the cards is done through high level commands which are easy to use but somewhat inflexible.

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The host is a 20 MHz 386-based passive bus PC with 12 AT bus slots in a 19" rack mount chassis. The keyboard and monitor use a commercially available extension system and are at the main PETRA console, about 30 m from the rack. The PC is used for control, display, and recording of tune spectra. It can record the spectra on disk at the full acquisition rate of 10 Hz per channel, and provides at several Hz updates of the spectra on a color monitor. In principle it could also perform intelligent peak finding; for the present the tunes are simply taken to be the highest points within settable windows. Fig. 2 shows a record of betatron tune frequency during a ramp from 7.5 to 40 GeV, with intermediate files at 30 and 35 GeV. One advantage of the PC system is

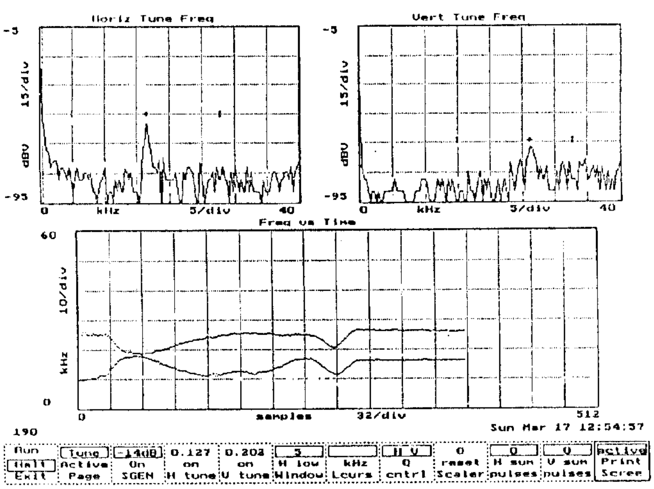

Fig. 2 Display from the tune control system. The horizontal scale is 12.8 sec per box and the vertical 10 kHz per box. Rate dependent tune shifts are compensated but various effects from non-linearities in the magnet excitation curves remain.

that it is easily reconfigured; a control menu permits, for example, switching back and forth between a program in which the data acquisition is triggered on injection, and a program in which the kicker excitation is used.

B. Beam Excitation

Beam excitation uses 50 Ω broadband ferrite loaded kickers driven by 1 kW RF amplifiers and capable of supplying about 1 G-m maximum field integral between 0.2-30 MHz. The kicker and amplifier are part of the transverse feedback system built for multibunch electron operation of PETRA [2], and are considerably stronger than necessary for excitation of tune signals. The RF waveform is created by mixing a low frequency (5-65 kHz) signal up to 10.3 MHz with a single side-band system. The 10.3 MHz comes from dividing the 52 MHz cavity RF frequency and thus tracks the RF frequency during acceleration. The low frequency signal is created by a D/A converter on the DAP card, which clocks out a pre-loaded signal as the ADC clocks in the data; the clocks are driven simultaneously by a 160 kHz pulse burst from a programmable timer card on the AT bus, with the excitation and acquisition lasting 512 samples/160 kHz or 3.2 msec. The level of the DAC cannot be quickly changed within the DAP card, so digital control lines are used to drive an external attenuator board, permitting for example control of the signal level during the accelerator cycle.

The waveform used at present is a frequency sweep moving between 5 and 45 kHz during the 3.2 msec, resulting in an excitation of the beam lasting for about 60 revolutions. Typical excitation voltage to the kicker is 2 volts, or about .01 Gauss-m maximum kick strength. As for the pickup, there is no time gating, so all bunches are excited.

Although not designed for minimum excitation, the system has several advantages in this respect. First, measurement duty factor is low (3 % for 512 pt transforms at 10 Hz), and second, the linear frequency sweep both excites and de-excites the betatron oscillation, providing that decoherence resulting from tune spread is small during the excitation. We have not yet made measurements which could indicate how well this is achieved in practice, but it is clear that at the start of acceleration eddy current induced multipoles result in tune spreads large compared to this criterion. Finally, the fact that both the excitation and the pickup work with all bunches in the machine means that as the number of bunches becomes large the excitation per bunch may be reduced.

III. TUNE CONTROL

The PETRA magnet ramp is driven by a clock with settable pulse frequency, with 512 Hz giving the design dE/dt of 0.3 GeV/sec. The ramp is performed as a series of file transfers in which all currents are stepped linearly between initial and final current values; non-linearities may be handled by increasing the number of intermediate magnet current files, but this requires stopping the ramp, reloading step sizes, and restarting, which takes several seconds and may have consequences for the beam dynamics.

During tests of PETRA with protons in mid-1990 large tune shifts were observed during acceleration. The shifts at low energy are observed to be closely proportional to the ramp rate, as expected from field errors caused by eddy currents in the vacuum chamber, with a shift of about +10 kHz in the horizontal tune frequency at 128 Hz as shown in Fig. 3. The predicted shift of 40 kHz or dQ = 0.3 at the design ramp rate is not acceptable, so some additional control of the tunes during the ramp is necessary.

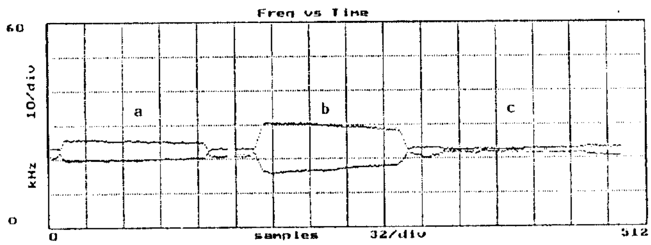

Fig. 3 Record of tune frequency vs time for three ramps from 7.5 to 9.5 GeV: a. 64 Hz magnet clock with 2.5 Hz sample rate b. 128 Hz magnet clock with 5 Hz sample rate, and c. 128 Hz magnet clock with rate dependent tune correction. The horizontal tune is initially the lower trace, and crosses above the vertical during the ramp for a. and b.

A tune control system based on a phase-locked loop already exists for PETRA electron operation; the beam is excited at fixed frequency and the loop is closed by incremental changes in the current in two specially modified quadrupole circuits [3]. For protons it was decided to build a control system not so dependent on excitation of the beam. In particular, to the extent that tune shifts are proportional to ramp rate (divided by beam energy) the quadrupole correction currents should be set proportional to the momentary ramp rate. To do this, while maintaining the possibility for other corrections, a third Microstar DAP processor on the AT bus is used, together with an input scaler receiving the clock pulses which drive the ramp. The entire correction procedure runs on the real-time multitasking operating system of the DAP, with only peripheral communication to the PC (Fig. 4).

The scaler count is read at 10 Hz by the DAP card, a smoothed second derivative is calculated, and numbers of up or down pulses proportional to the second derivative are sent to boxes which add these pulses to the clock pulse streams sent to the quadrupole current controllers.

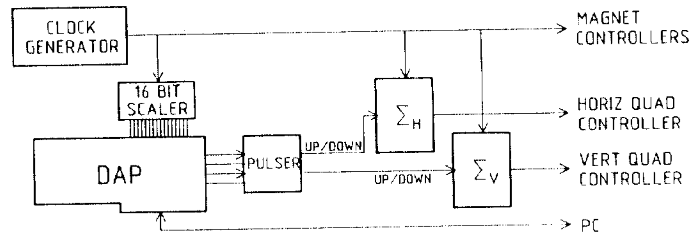

Fig. 4 Simplified schematic of the PETRA tune control system

This gives summed correction currents proportional to the clock frequency. The reaction time is limited by the maximum rate at which correction pulses can be accepted by the control system, which is about 500 Hz. At the 512 Hz clock rate 1000 correction pulses must be fed to the controller at ramp start (and again at ramp stop), so the clock frequency turn-on and turn-off times are set to 2 sec to ensure that the tunes remain constant. The correction system is effective (Fig. 3), showing that the tune shifts are indeed closely proportional to ramp rate.

It is also possible to add additional correction terms which are a function of the scaler count and could compensate magnet saturation effects. This is desirable (Fig. 2) but has not yet been tested with beam. Corrections based on the tune measurements from the PC are also possible.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

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[2] J. Ruemmler, DESY, private communications

[3] S. Paetzold, DESY, private communications