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BETATRON TUNE MEASUREMENT SYSTEM FOR THE HERA PROTON STORAGE RING

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Abstract:

We describe the system of pickups, kickers, and controls which have been built for betatron tune measurements in the HERA proton ring. The Schottky-type resonant pickups should provide high sensitivity over the full range of beam currents to be used in HERA.

I. INTRODUCTION

The HERA superconducting magnet storage ring will accelerate protons from 40 to 820 GeV where they will be stored and collided against 30 GeV electrons; the design fill is 200 bunches of 10^{11} protons spaced 97 nsec apart. The tune measurement system must operate well in several very different regimes; for luminosity operation the system should be sensitive to very small oscillation amplitudes, so that emittance growth resulting from excitation of the bunches will be minimized. During setup of the machine very low beam currents will be used to avoid quenches of the superconducting magnets, but modest emittance growth will be acceptable, and strong excitation may compensate for the small currents. Another special consideration comes from the large field errors caused by superconducting persistent currents at and near injection energy, which will cause significant shifts in both the betatron tunes and the chromaticities.

II. PICKUP AND ELECTRONICS

Two pick-ups (horizontal and vertical) are mounted in the West straight section of HERA; the design (Fig. 1) is based on the Schottky monitors built for the CERN SPS proton collider [1]. Two 3 m long electrodes couple capacitively to the beam and form a resonant circuit with an external coil. A secondary loop couples the signal to a 50 Ω semi-rigid cable which ends at an electronics rack in the Halle West service building. The monitors have nominal resonant frequency 8.31 MHz and a loaded Q factor of about 180.
Fig. 2 shows an equivalent circuit. The inductor is in a closed can which also contains two variable capacitors driven by external stepping motors. One is used to tune the resonant frequency; a small coil permits injection of a test signal so that the resonant frequency can be measured. The other is a small split plate capacitor which effectively adjusts the electrical center of the monitor; it is hoped that this can be used to correct for the orbit offset of the beam in the monitor. One consequence of the resonant detector circuit is that the monitor output is an average over all bunches in the machine.

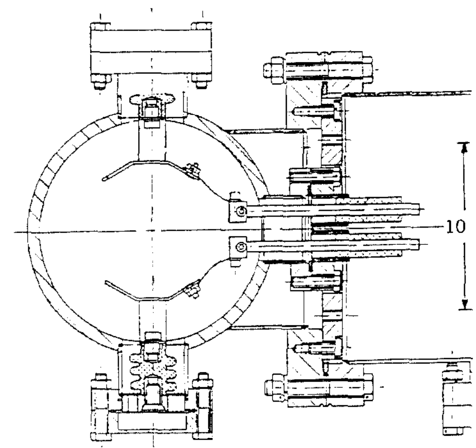

Fig. 1 Cross-section of the vertical monitor showing connection of the electrodes to feedthroughs leading to the inductor can.

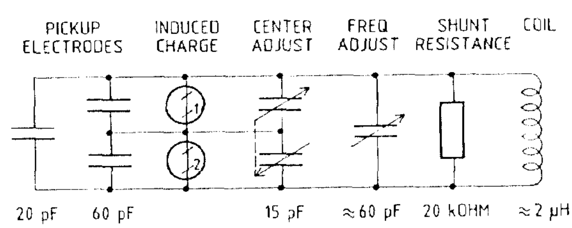

Fig. 2 Effective circuit for the monitor. The loading from the output loop is included in the shunt resistance.

Fig. 3 is a schematic of the electronics chain, which is based on a pair of 8 pole 20 kHz bandwidth elliptic quartz filters which attenuate the bunch revolution harmonic at 8.325 MHz while passing lower sidebands. The proton revolution frequency of 47.3 kHz changes by about 0.03% during acceleration, which moves the revolution harmonic by 2.3 kHz with respect to the passband.

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At 40 GeV this permits operation within 4.3 kHz of the revolution harmonic (dQ = 0.08) while giving 75 dB attenuation at 0 Hz offset and at 820 GeV 6.6 kHz (dQ = 0.14) and more than 100 dB attenuation. Because the system has no front end mixer or amplifier it is extremely insensitive to signals outside the passband. After amplification the signal is detected by mixing with an 8.33 MHz source generated from the 208 MHz HERA RF.

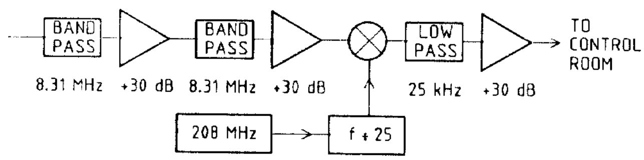

Fig. 3 Schematic of the electronics chain for the monitor

III. EXCITATION KICKER SYSTEM

The kicker system is a copy of that designed for transverse feedback on electrons in PETRA [2], and uses broadband 50 Ω ferrite magnets driven by 1 kW amplifiers to give an integrated field of 1 Gauss-m at peak power. The excitation signal is generated from a low frequency waveform which is mixed with an RF signal created from the 208 MHz HERA RF frequency, giving a single sideband output at 2.1 MHz, which is a multibunch alias of the 8.33 MHz monitor frequency. In the initial setup no time gating will be used, so that the kicker will excite all bunches in the machine; it is planned to use a sweep waveform (as for PETRA) or bandwidth-limited noise.

IV. CONTROL SYSTEM

The low frequency signals for the kicker and from the detector are connected to the HERA control room over about 500 m of RG-213 cable. Both generation of the waveform for the kicker and Fourier Transform processing of the detected signal are performed on processor cards which sit on the AT bus of the personal computer used for control and display. The computer system is very similar to that of PETRA [3], and could also be used for active control of the tunes if that becomes desirable.

V. MONITOR IMPEDANCE

A general concern for the HERA proton ring is that beam diagnostic devices may support high Q resonant modes which couple strongly to the beam, leading to instabilities or excessive heating when large beam currents are circulating, and a criterion was set that devices installed in HERA should not have any modes with longitudinal impedances larger than 100 kΩ [4]. MAFIA computer simulations were performed and laboratory measurements were made of Q and (using a bead-pull apparatus) of R/Q. The largest impedance measured was 22 kΩ for an antenna mode at 43 MHz, so the monitor satisfies the limit, but heating could be excessive if this or any of several other modes with impedances above 1 kΩ coincide with one of the multiples of the 10.3 MHz bunch spacing frequency which dominate the power spectrum for the 200 bunch filling of HERA. Since it is possible to measure these modes (and modify them by changing the coil inductance) after the monitors have been installed in HERA this should not be a severe problem.

VI. OPERATION

Boussard [5] gives a formula for sensitivity of the monitor which predicts about 7 Ω/mm (for optimal coupling of the signal). This must be compared to noise in the electronics chain; assuming 10 dB S/N degradation gives an effective input noise level at 50 Ω of 3 nv/$\sqrt{}$Hz. Thus in a 100 Hz frequency band a bunch with 10^{11} protons should yield a signal at the noise level for oscillation amplitude 8 nm, and sensitivity will increase in proportion to total beam current. If excitation at these levels is sufficient, emittance growth due to the kicker will not be an issue. The experience at the SPS collider and FERMILAB has been that when the machine is first turned on, many larger sources of excitation will be present and the monitor must be used first to diagnose and eliminate them [6].

A more relevant requirement for initial operation of HERA is that the system provide a signal 20 dB above background for a bunch with 2×10^8 protons, corresponding to amplitude 4 μm, or more if extra noise is present. This sets a scale for the excitation. The 1 Gauss-m maximum field integral of the kickers results, at 820 GeV, in an oscillation amplitude of about 1 μ at the monitors; thus a resonant excitation over 20-40 turns should easily provide an observable signal.

Because of the low fields in the superconducting magnets at injection energy, the complicated persistent current effects observed in such magnets make large contributions to the multipole field content. This results in tracking errors between the dipole and quadrupole fields during initial acceleration and in large magnet history dependent sextupole fields which must be cancelled using correction sextupole circuits. For tracking, the ability of the personal computer system to make disk recordings of the tune during the ramp should be useful. It is also planned that the PC will be able to insert small changes in the HERA RF frequency (± 400 Hz) so that measurement of the chromaticity can be automated.

A crucial point is correction of the tracking errors during acceleration; as for PETRA this must be supplied by circuits outside of the primary magnet control system. The philosophy used for the PETRA proton machine is that repeatable or predictable errors should be handled by programmed corrections rather than by feedback circuits so that successful operation of the machine does not depend on perfect operation of the tune measurement system. It is hoped that this approach will also be useful for HERA, however, the use of the personal computer should also permit a flexible mixture of programmed and feedback tune corrections if this is required.

VII. EARLY RESULTS

The first test of HERA with circulating protons has recently been concluded. Figures 4 and 5 show tune measurements taken for two different settings of a quadrupole bus, with one bunch of 10^9 protons. The beam excitation kicker is turned off, so the signals come from unknown excitation sources in the accelerator (with the exception of the low frequency noise below the 4 kHz cutoff of the filter passbands, which is pick-up of AC line harmonics). The peak amplitude of the horizontal signal at 6.9 kHz (q_x = 0.14) in Fig. 4 corresponds to an oscillation amplitude at the monitor of about 10 μm.

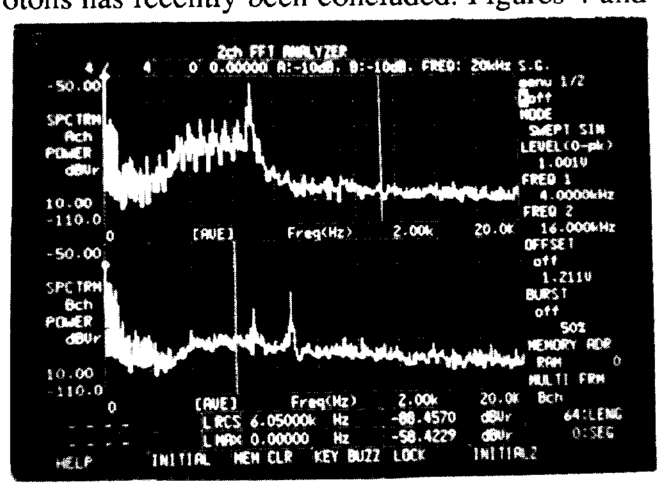

Fig. 4 Tune spectra from 0 to 20 kHz, without excitation kicker. The upper trace comes from the horizontal, and the lower from the vertical monitor. The tune values are q_x = 0.14 and q_y = 0.18.

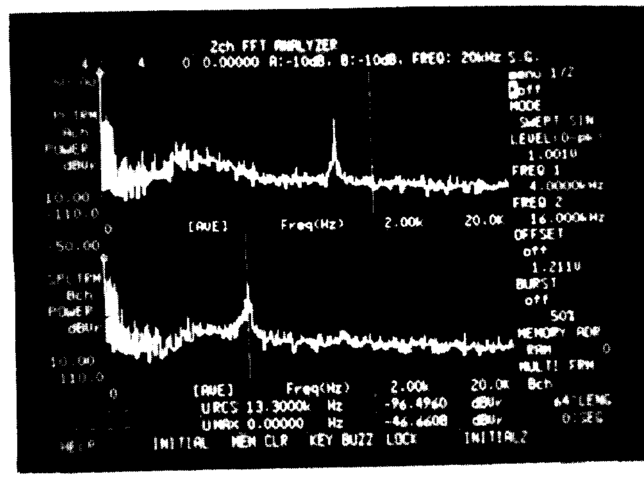

Fig. 5 Tune spectra without excitation kicker for q_x = 0.24 and q_y = 0.14.

VIII. ACKNOWLEDGEMENTS

I wish to thank D.Boussard and T.Linnecar at CERN for discussions and K.-H.Mess and D.Degele at DESY for encouragement and discussions. L.Becker contributed to the design of the electronics, and built it.

IX. REFERENCES

[1] T.Linnecar, W.Scandale, IEEE Trans.Nucl.Sci., Vol. NS-28, No.3
[2] J.Ruemmler, DESY, private communication
[3] S.Herb, submitted to this Conference
[4] T.Weiland and R.D.Kohaupt, DESY, private communication
[5] D.Boussard, CERN 87-03 (1987) 416
[6] D.Boussard, T.Linnecar, W.Scandale, IEEE Trans.Nucl.Sci., Vol. NS-32, No.5