BEAM STABILITY IN A 6 GeV SYNCHROTRON LIGHT SOURCE*

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Summary

Future synchrotron radiation sources designed to produce low emittance electron beams for wigglers and undulators will present beam position control problems essentially similar to those encountered by users of existing accelerators,[1,2] however tolerances will be tighter due to: 1) the small emittance (7×10^{-9} mrad) proposed for the electron beam and the correspondingly small emittances (sizes) of secondary photon beams, 2) the sensitivity of the electron beam closed orbit to quadrupole motion and dipole roll, 3) the high power levels associated with undulator and wiggler beams which will permit (and probably require) high precision and stability of the photon beam position measurements, in addition, 4) the large number of users on the roughly sixty beam lines will demand beams capable of producing the best experimental results. For the present paper, we assume the accelerator control function, which would initially involve making and coordinating all changes, would eventually evolve to setting and verifying the limits of user control: within these limits the beam position would be controlled by users.

This paper describes the effects of motion of beam components (quads, rf cavities and dipoles) on the beam and considers the properties of a compensation system from the perspective of users. The system departs from standard practice in considering active perturbation of the electron beam to verify beam corrections. The effects of local closed orbit perturbations to direct undulator beams at different experimental setups are also considered.

Photon Beam Stability

The properties of undulator radiation depend strongly on the angle of photon emission, since the wavelengths produced[3]

$$\lambda_i = \frac{\lambda_o}{i2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right) \quad i = 1,2,3 \ldots$$

depend explicitly on the emission angle θ and K, the product of $\gamma\alpha$. Here λ_o is the wavelength of the wiggler, γ is the electron energy divided by its rest mass, and α is the maximum angular deflection of the electron beam in the undulator. Calculations[4] have shown undulator spectra from zero divergence electron beams have widths $\theta\gamma \cong 0.1$. Adding finite electron beam divergence gives

$$\sigma' \approx \sqrt{\varepsilon/\beta + (0.1/\gamma)^2} \approx 18 \times 10^{-6} \text{ rad}$$

assuming $\varepsilon = 7 \times 10^{-9}$ mrad, $\gamma = 12000$, and $\beta = 25$ m. Individual beams would operate at high powers and power densities (1 kW, 500W/sq mm) permitting high sensitivity to alignment errors.

We have attempted to calculate the amplitude of fluctuations in the beam position due to motion of accelerator components by assuming misaligned quadrupoles would steer individual bunches by an amount $\phi = \langle d\rangle\, \ell B'/B\rho$. Where B' is the quad gradient, ℓ, its length, $B\rho$ the electron rigidity and $\langle d\rangle$ the error in quadrupole position. Each kick displaces bunches from a stable orbit, and produces a subsequent oscillation around the stable orbit with an emittance $\delta\varepsilon_k = \beta\phi^2$. Summing up these contributions around the lattice gives an emittance growth of

$$\Delta\varepsilon_k = \langle d\rangle^2 \sqrt{\Sigma\beta_i^2\, (B'\ell/B\rho)_i^4}$$

per turn, where i refers to individual elements. Note that though the emittance of individual bunches would not change, the envelope within which they move would increase. The frequency dependence can be studied by assuming motion at a single frequency d = d(A Sin $(\omega t))/dt^*\tau$, assuming amplitude A and rotation period τ, vibrational frequencies are assumed to be much less than rotational frequencies.

Setting the emittance growth/turn equal to the synchrotron damping gives an equilibrium emittance due to kicks, ε_K, applicable to the envelope of noise induced fluctuations, which are a function of the frequency and amplitude of the vibration. In the vertical plane,

$$\varepsilon_K = \frac{-E_o}{U_o}\,\Delta\varepsilon_K$$

where E_o and U_o are the electron energy and radiated energy per turn. For the Argonne lattice design,[5] random fluctuations produce significant emittance growth when $A\omega/2\pi > 1000$ Hz µm.

Vibration can be transmitted to the beam by means of electric and magnetic fields, due to quadrupole motion, dipole roll and vibration of accelerating cavities. (The skin effect of a vacuum chamber can damp high frequencies if the chamber itself is not moving.) Electrons damp by means of synchrotron radiation damping and re-acceleration to the direction of the accelerating field, as averaged by betatron motion. Damping could be altered if the accelerating field changes direction within one damping time, due to vibration. For low frequency oscillations, the orbit will move adiabatically with amplification factors (orbit motion/quad motion) of 100-300.[6]

Experimental data[1,7] have shown that photon beams at SSRL and Aladdin both vibrate at 60 Hz, harmonics of 60 Hz, and other lower frequencies. Measurements of components of the Intense Pulsed Neutron Source accelerator[8] showed motion at 60 Hz, harmonics of this frequency, and 344 Hz, the latter caused by a turbopump mounted on the vacuum pipe.

Beam Control System

The beam position and direction can be maintained with respect to experimental apparatus using systems similar to that shown in Fig 1. Photon beam diagnostics at two collimators (or fixed points) detect misalignments and these signals are used to calculate currents to correction magnets up and downstream. (Simple diagnostics might use photoelectron currents generated from cylindrical collimator jaws, which minimize local heat loading.) Ideally one pair of correction magnets are located $\lambda_\beta/4$ up and downstream of the source point, and one pair are as close to the source point as possible in each plane, with λ_β being the betatron wavelength. Corrections provided for one insertion region should, in principle, not affect the others, however, insuring

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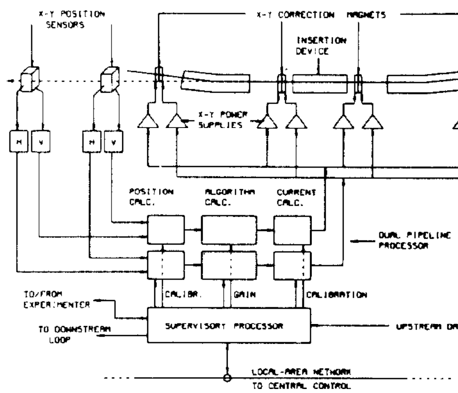

Fig. 1. Diagnostics and control system for photon beam line position control system.

the orthogonality of these corrections with high precision could be a significant control problem.

The bandwidth of such a system depends on the skin time for the vacuum pipe (since the correction magnets must be outside the vacuum chamber), the anticipated spectrum of noise and the alignment precision required by experiments. We have assumed that 1 kHz oscillations could be corrected by the proposed system, which would make these corrections at roughly 10 kHz. Skin times for an aluminum chamber would be on the order of 1 ms, with a stainless chamber perhaps a factor of ten less. Copper heat sinks to distribute synchrotron power could interfere with high frequency corrections.

In order to evaluate the control requirements we have examined one possible computer architecture capable of handling the high data rates. Present day technology would suggest the use of a bit slice processer much like those used in array processors. A separate, fixed point, add/subtract and multiplier/divider along with several dedicated registers should be capable of handling the comparatively simple matrix operations required. The entire process would be controlled and monitored using a commercial microprocessor system which would insert gain, sensor and magnet calibration constants, in addition to verifying that the system was operating within preselected limits minimizing interactions between users. During the development phase, this processor would act as a link between the central control system and the beam control elements. As the system began to function at higher speed only supervisory and gain control functions should be required.

We have considered techniques to verify the simultaneous orthogonality of the many beam correction systems required by the sixty odd beam lines in order to insure that alignment on one line is not affected by all other corrections made by users. The primary method of insuring this would be by setting limits on the amplitude of corrections that can be applied on any one line and verifying that corrections within this amplitude are undetectable elsewhere. High precision measurements of alignment error could be made quickly using high frequency, narrow band systems, by exciting betatron oscillations in the electron beam at two points $\lambda_\beta/4$ apart and measuring the subsequent motion around the the equilibrium position (Fig. 2). The amplitude of these oscillations would be small, perhaps 0.01 σ'. All photon beams could be measured simultaneously before coherent oscillations damped out, and emittances would damp back to original values in 5-10 msec. This process should be undetectable to most users, and those others could be gated off.

Multiple Use of Undulators

In order to more fully utilize insertion facilities, we have looked briefly at the possibility of introducing fixed local closed orbit deflections in the electron beams which would enable a single undulator to serve multiple experimental facilities on a time shared basis. This could be done if beams could be moved from one mirror to another as shown in Fig 3. Since the mirrors will probably be grazing incidence, deflections on the order of a few σ' might be sufficient to accomplish this. These small deflections would be roughly equivalent to asymmetric boundaries of the physical aperture assuming a linear optical system. [The presence of higher order correction elements and error fields complicates things somewhat, however, the simplest solution may be to assume that the undulations and correction elements (sextupoles etc.) move with the closed orbit.] This technique could reduce the required number of straight section/insertion devices required for a given number of experiments (reducing the size of the storage ring) and improve the utilization of special facilities such as two undulator systems for two-photon experiments.

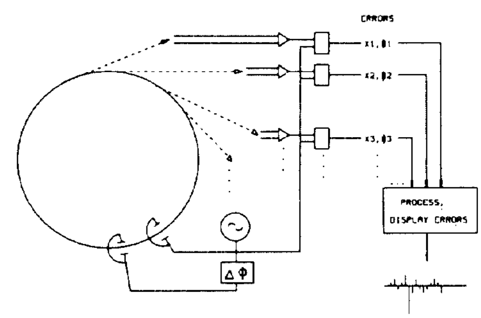

Fig. 2. Simultaneous measurement system for photon beams.

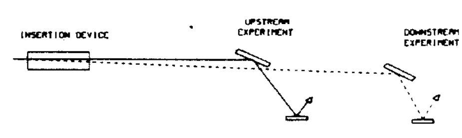

Fig. 3. Multiple beam lines from a single undulator.

Conclusions

Existing technology should be able to control the positions of electron and photon beams with the required accuracy for undulator and wiggler users. The development of techniques to minimize the mutual interactions of many users, and to optimize the access to undulators might be desirable.

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