AN ANALYSIS OF THE OPERATIONAL PERFORMANCE OF THE AUTOMATIC GLOBAL HORIZONTAL BEAM POSITION CONTROL SYSTEM ON THE SRS AT DARESBURY

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The performance of the global feedback system for horizontal orbit position control, now in regular use at the Daresbury SRS second generation light source, is assessed in the light of operational experience. The success of the system in suppressing horizontal orbit shape changes is described, and current experimental and theoretical investigations of possible causes of residual orbit errors and approaches for their reduction are discussed.

I. INTRODUCTION

Since the advent of the high-brightness lattice [1] for the Daresbury SRS, a 2 GeV electron storage ring light source, beam position control has assumed increased importance. A range of techniques has proved successful in optimisation of electron and photon beam stability, for example the local vertical feedback system [2], now in operation on several beamlines.

A system of automatic global horizontal position control (HPC) has been used to correct the horizontal orbit during operational running. The system reads the orbit at each of 16 electron beam position monitors (BPMs) and applies corrections at 16 horizontal steering magnets (HSTRs). The correction strengths are determined by a least-squares optimisation using the steering magnet response matrix. Typically, the orbit is read and, where necessary, correction applied, every 30 seconds. The resolution of the BPM system is better than 5 µm. The hardware and software developed for the HPC system are described elsewhere [3].

II. PERFORMANCE OF THE HPC SYSTEM

Automatic global horizontal position control has been used routinely in operational running at the SRS since November 1994, and a database of around 100 user fills, each of typically 24 hours duration, has been collated. The correction software automatically records the measured beam position at each of the 16 BPMs as well as the 16 applied HSTR corrector magnet currents. Since the corrector response matrix (i.e. the effect at each of the 16 BPMs per unit current applied at each of the 16 HSTRs) is known, and indeed used by the HPC software to calculate the applied corrector strengths, the effect of the correction currents at each BPM can be back-calculated to derive the equivalent "uncorrected" beam position. Characteristics of the reconstructed data are in excellent agreement with trends typically observed in data collected during running without the HPC system in operation.

The observed electron beam position at each of 4 typical BPMs is shown in figure 1, along with the reconstructed uncorrected position, which would have been seen without HPC, for comparison. The data show a dramatic improvement in measured beam stability at the BPMs. The large and widely differing drifts of typically ~200 µm in the "uncorrected" data are reduced to a uniform drift of only about ~70 µm over the same period (about 24 hours) after correction. This residual drift is identical for all BPMs, within the resolution of the measurement system, and is known as the "offset". This is the change in measured average horizontal orbit at the BPMs. This offset could in principle be corrected at the BPM either by applying a uniform change to all HSTRs or by changing the wavelength of the radio frequency system, according to the cause of the variation in offset. Because this is not yet unambiguously determined, the correction system aims only to reduce changes at each BPM relative to the offset. Since the residual movement at each BPM, after correction, is equal (within the limits of experimental uncertainty) to the offset, the HPC system can thus be said to be functioning ideally.

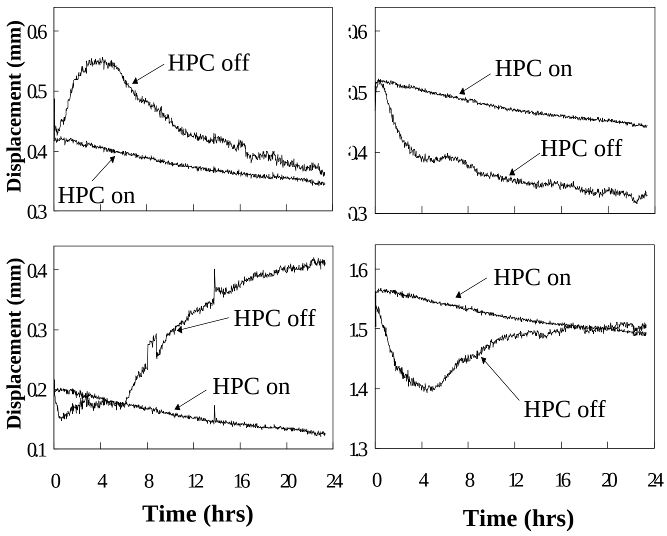

Figure 1: Typical variations of electron beam position with and without HPC

In addition to longer term drifts, sudden changes can occur. The correction of one such change is illustrated in figure 2. A step change is seen in a single BPM (fig. 2a), and the correction system responds promptly to apply an appropriate correction (fig. 2c), leaving a single-valued "spike" in the corrected BPM reading (fig. 2b). After a period of about an hour the step change is reversed, and the HSTR again adjusts. Thus a change in beam position at a BPM has been transferred into a change in applied HSTR corrector.

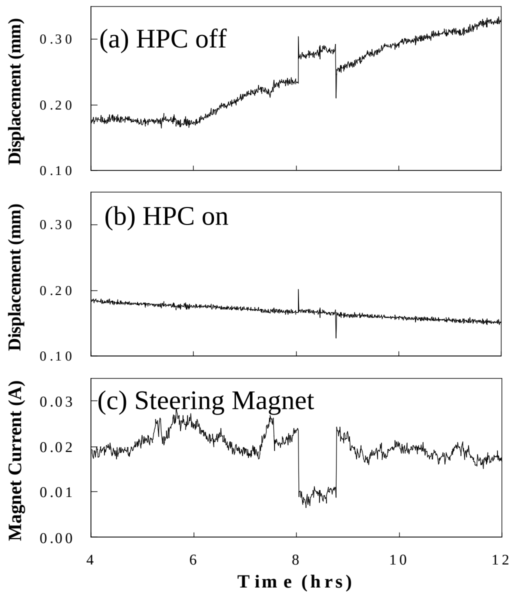

Figure 2: Correction of a step change at a single BPM

The efficacy of the HPC system in suppressing deviations from the average orbit is demonstrated in figure 3. The histograms show the rms deviation of each of the 16 BPMs from the offset (average) value over a particular fill of the storage ring. The upper part (fig. 3a) shows relatively large and widely varying deviations in the (reconstructed) uncorrected beam positions, while the lower part (fig. 3b) shows dramatically reduced rms deviations in the corrected beam position.

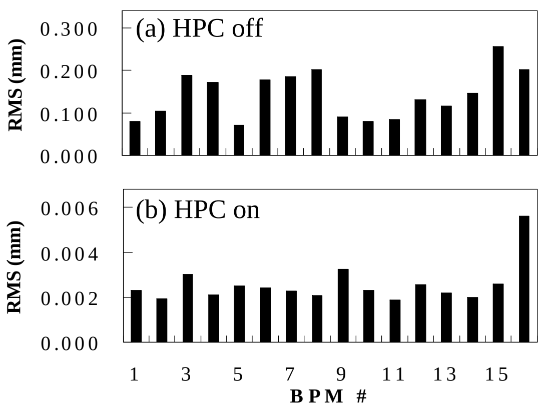

Figure 3: Typical RMS deviation from offset without (a) and with (b) HPC (Note different scales)

III. ORBIT CHANGES - CAUSES AND SOLUTIONS

It has been shown that HPC applied at the SRS is extremely effective in suppressing the build-up of orbit shape distortion or "ripple", greatly reducing beam movement at a BPM to the residual "offset". It is pertinent to seek the causes of both the evolution of orbit ripple and the observed offset drift, and, where possible, identify approaches to minimise both.

Figure 4 shows the Fourier amplitudes of components of order k=0-8 (k=0 represents offset drift) in the change in orbit at the 16 BPMs around the ring over a half-hour period, obtained for data without (fig. 4a) and with (fig. 4b) automatic position correction. The uncorrected data show that the k=6 component dominates. This is close to the horizontal tune value Q_h=6.18, and indeed further examination reveals that the relative amplitudes of the components reflect the Fourier magnification factor $Q^2/(Q^2-k^2)$ [4]. This is the result expected for so-called "random" magnet errors, whereas changes in position measurements due, for example, to movement of the BPMs themselves would not lead to selective enhancement of the components close to the horizontal tune. The corresponding Fourier amplitudes derived from data taken with automatic global correction in operation show that all components other than offset drift are effectively suppressed (to within the accuracy of the measurement system), but that the offset drift is, as expected, unchanged.

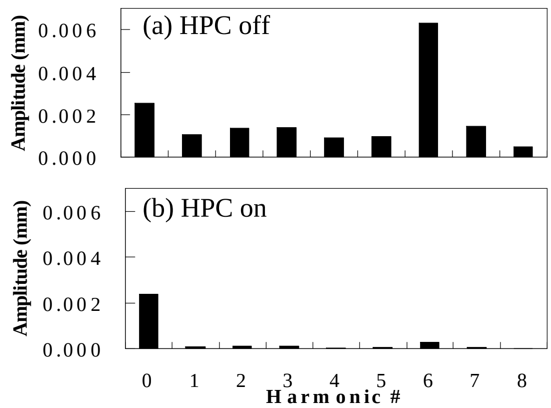

Figure 4: Relative amplitudes of Fourier harmonic components without (a) and with (b) HPC

The variation in average orbit or offset is shown in figure 5a for a typical fill. A moderately rapid increase in orbit offset is seen after injection, followed by a more gradual decline over the remainder of the fill. The plot shows the variation in offset both with position correction and after subtraction of the calculated effect of the applied corrector magnets; these are identical within the uncertainties of the measurement, giving confidence in the procedure used to reconstruct the "uncorrected" position data.

It turns out that the trends in offset as a function of time bear a resemblance to measured movements of the SRS vacuum vessel and magnets over a fill (see fig. 5b). These movements can be explained by temperature changes arising from the high magnet currents and from synchrotron radiation heating. The cycling of magnets at injection leads to increases in vessel temperature over the first few hours of each fill, while the decaying beam current leads to a slow decrease in temperature over the latter part of the fill. Measurements of movements of F-quadrupole magnets (those causing the largest beam movements due to the high horizontal β-values at FQUDs) and of the BPMs have been made for specific elements of the SRS (see for example [5]) and theoretical models used to make predictions of closed orbit changes arising from variations in magnet position. The observed variations of beam position at the BPM are consistent with predicted effects of measured vessel and magnet movements. In the light of the successful application of HPC, a more extensive programme of investigations is now in progress.

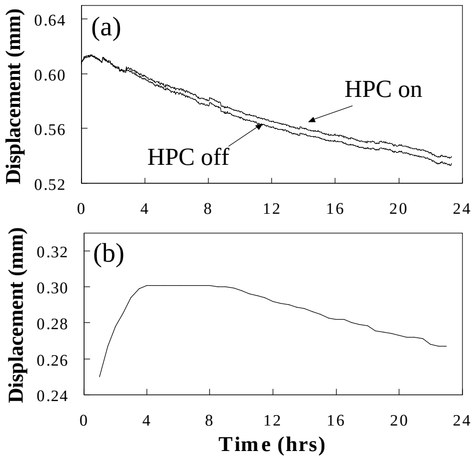

Figure 5 : Offset drift (with and without HPC) and typical vessel movement over a fill

It should be noted that the correction of apparent position changes due to BPM movements will also lead to effective magnet errors via the introduction of spurious "corrections", giving rise to orbit distortion. Thus it is critical, when operating automatic global horizontal position control, to minimise movements not only of magnets but also of the beam position monitors themselves.

First steps have already been taken to reduce movement of storage ring components, with encouraging success. In late November 1994, the "hot fill" procedure was introduced. Whenever possible, after beam dump, the magnets are maintained at the 2 GeV (full energy) currents until the moment of injection when 0.6 GeV levels are set. The magnet “down time”, during which the magnet and the vessel temperatures drop sharply, is therefore minimised and the ensuing thermal cycling of storage ring components minimised.

The measured average offset drift since the introduction of "hot fills" has shown a marked decrease (see fig. 6). It is also of interest to note that the largest offset drifts follow periods of shutdown or several hours downtime before refill. It is clear that effective temperature stabilisation is of crucial importance in achieving stable horizontal orbit conditions.

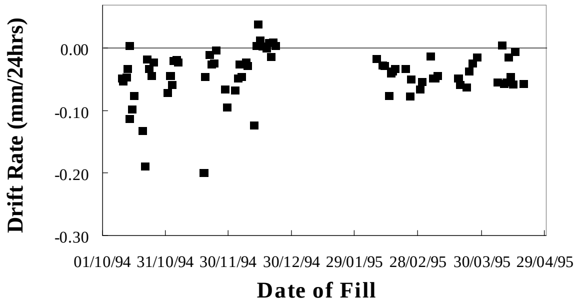

Figure 6: Average offset drift rates measured over fills

IV. CONCLUSIONS

The system of automatic global horizontal position control, used routinely at the Daresbury SRS since November 1994, has achieved a dramatic reduction in variations in the measured beam position (the orbit "ripple") at 16 beam position monitors around the ring. The comparatively small drifts in the residual "offset", or average orbit, which is determined by the RF synchronous condition, are not treated by the present approach. The dominant factor in offset drift is believed to be movement of storage ring elements caused by thermal fluctuations over the fill cycle. A programme of investigations aimed at gaining a better understanding of these effects, and of possible correction techniques, is now under way.

V. REFERENCES

[1] V.P. Suller *et al.*, "SRS-2: Performance and Achievements", Proceedings of Particle Accelerator Conference, Chicago, 1989, pp467-469

[2] J.A. Clarke *et al.*, "High Resolution Stabilisation of the Vertical Position of Photon Beams in the SRS Beam Lines", Proceedings of European Particle Accelerator Conference, London, June 1994, pp125-127

[3] B.G. Martlew, R.J. Smith, S.L. Smith, "Development of Global Feedback for Beam Position Control in the Daresbury SRS Storage Ring", Proc. European Particle Accelerator Conference, London, June 1994, pp1574-1576

[4] E.D. Courant and H.S. Snyder, "Theory of the Alternating-Gradient Synchrotron", Ann. Phys. **3**(1958)1-48

[5] P.D. Quinn and T. Ring, "Developements in Orbit Control at the SRS at Daresbury", ABI Conference Proceedings, KEK, Tsukuba, Japan, April 1991