THE DARESBURY GLOBAL HORIZONTAL SERVO FEEDBACK SYSTEM: STATUS AND OUTLOOK

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Abstract

A system of automatic global horizontal orbit position control has now been in regular operational use at the Daresbury Synchrotron Radiation Source for more than a year. Using 16 electron beam position monitors (BPMs), the optimal combination of steering magnets, deduced from the machine response matrix, is applied to correct changes in orbit shape every 30s. The system has proved highly effective in removing orbit ripple due to magnetic field errors, principally caused by thermally induced magnet movements. At present other apparent errors, notably a slow drift in average orbit radius, are not treated; whilst these could be addressed by varying the RF frequency, this is inappropriate for contributions arising from thermally induced movements of the BPM vessels themselves. Experimental studies are currently underway to assess options for recognising such "false" orbit changes whilst correcting changes due to field errors

1 INTRODUCTION

The application of a variety of techniques has provided enhanced electron and photon beam positional control and stability on the Daresbury 2GeV electron storage ring SRS, the UK national light source. These include local vertical feedback control on user beamlines [1] and a system of global horizontal feedback continuously controlling the electron beam closed orbit.

The global horizontal servo (GHS) system commissioned at Daresbury reads the horizontal electron orbit at 16 electron beam position monitors (BPMs) and applies a global correction at 16 horizontal steering magnets (HSTRs), the strengths of which are determined by a least-squares optimisation using the steering magnet response matrix. Under operational conditions, the orbit is read and correction applied every 30 seconds. The resolution of the BPM system is better than 5µm. Further background on the system can be found in reference [2].

2 PERFORMANCE

The global servo system has now been in use on the SRS during multibunch user running for more than a year and considerable operational experience has been gained. The system is highly effective in suppressing orbit shape distortions, although the average orbit radius is not amenable to servo correction. While magnetic field errors give rise to orbit errors leading to a 'ripple' about the ideal closed orbit which are properly addressed by applying small current changes at corrector magnets, the orbit path length is fixed by the RF synchronous condition. This means that the servo system can satisfactorily ensure that all BPMs show the same reading, but cannot alter the average BPM reading. Attempts to do this are counterproductive and result in large orbit irregularities. The global horizontal servo system therefore corrects all BPMs to the average value of the 16 BPMs, known as the offset, within a precision of the order of the BPM resolution (better than 5µm). The residual offset drift is thus the same with and without servo operation. The offset shows variations of typically 70µm over a normal 24 hour user fill, in contrast to the much larger drifts of up to around 300µm at individual BPMs in the absence of global feedback. Thus only a small fraction of the movement at BPMs remains after servo correction. Furthermore, a significant part of this residual may arise from movement of the BPMs rather than true beam movement, and should therefore not be corrected. A recent account of the GHS system and its effects discusses these topics in greater detail and presents typical BPM data [2].

Datasets from 202 user fills with global horizontal feedback have been recorded and analysed. Each normal fill lasts 24 hours and the servo system records BPM readings and applied correctors at every step. Stringent software traps have been built in to ensure that the feedback system can under no circumstances apply excessively large or sudden changes and that unrealistic changes in BPM readings are ignored. Both the size of BPM or orbit change which can be corrected, and the magnet current changes which can be applied, are limited for safety. An unservoed beam is preferable to a beam with spurious or sudden servo correction.

The data show that almost 80% of user fills ran to completion (scheduled beam dump or loss due to unrelated causes) without the servo reaching a trap limit. The causes of servo shutdown on the remaining 46 fills are analysed in Table 1 below. Nine of these are due to trivial faults unrelated to servo operation. These include the large disturbance of the storage ring orbit caused by start-up of the two superconducting wigglers or by operation of the booster synchrotron; such events are rare, and the servo can if required be restarted immediately afterwards. The remaining three trips were related to hardware faults either in the VME control system or in steering magnet power supplies. A far greater number of servo trips - 18, almost half of the total number of trips - were caused by large step changes in one of two BPMs, both of which are known to exhibit intermittent noise or other faults. In these cases, because the BPMs are supplying spurious information, the servo is operating ideally by becoming inactive. A further 10 runs were interruped when one of the steering magnets reached the saturation limit. Again the correct response is for the servo to cease operation. Magnet saturation is periodically resolved by magnet moves and redistribution of steering strength, but it is inevitable that, during periods of user operation, some magnets will from time to time approach saturation. Finally, on 9 occasions (less than 5% of all servoed fills), servo operation was halted when a very large orbit change was detected.

Table 1: Total number of servoed fills and breakdown of servo trips

Total No. of servoed fills	**202**	**100%**
Fills showing no trips	156	77%
Fills showing servo trips	46	23%
Breakdown of Trips		
Coincident with wiggler startup	2	1%
Coincident with booster startup	4	2%
Controls/Power Hardware Fault	3	1.5%
Large step in one BPM only	18	9%
Large Orbit Change at many BPMs	9	4.5%
Steering magnet reaching limit	10	5%

The log files for the 9 trips attributed to large global orbit changes show characteristic features. Not only do most of the BPMs show large changes (some may fall close to nodes in the orbit change and therefore see little effect), but the pattern of the changes around the ring can be predicted. Fourier transform analysis of the changes at the 16 BPMs at the moment of a GHS trip is a useful diagnostic technique; the observed amplitudes of the Fourier components (up to order 8, the highest meaningful component given 16 sample points) are shown in Figure 1 for one example of a trip. The plot shows that component 6 is by far the largest, followed by components of order 7 and 5, reflecting the SRS horizontal betatron tune Q=6.18. In fact, for so-called "random" magnet errors, one expects selective enhancement of the Fourier component of order k in proportion to the magnification factor $Q^2/(Q^2-k^2)$. The magnification factor is also shown in Figure 1, normalised to the observed amplitude of component $k=6$ for comparison. Thus these large global orbit changes are consistent with one or more magnet errors, and the pattern observed at the BPMs merely reflects intrinsic properties of the SRS lattice. Changes caused by defective or moving BPMs do not of course show these trends. Again, the orbit changes are so large (up to several mm in amplitude) that it not desirable to allow an automatic feedback system to apply unsupervised corrections.

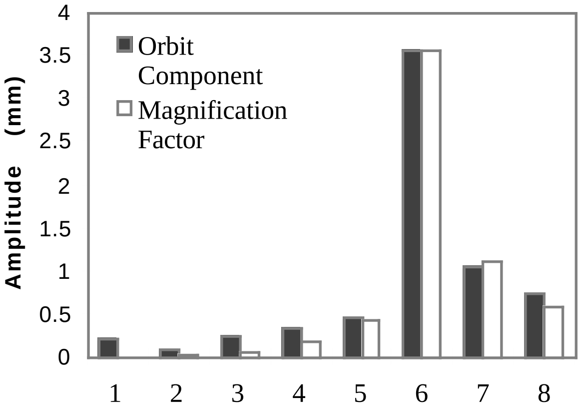

Figure 1: Amplitudes of Fourier components of order 1-8 with calculated magnification factor for comparison

3 CAUSES OF ORBIT CHANGES

The measured changes in electron orbit can be ascribed to three main sources: misreading at BPMs; movements of quadrupole magnets; and movements of the BPMs themselves. The first is a small effect, and modelling and software studies are currently seeking techniques to reject unphysical, spurious BPM read errors. The second, while a significant component of orbit errors - indeed, probably the dominant component - can at least be remedied by systems such as GHS. The last source however, movements of the BPMs, presents a more serious problem: these result in false information being fed to diagnostic and steering systems, and corrections made following BPM errors or movements are in fact unnecessarily degrading beam stability.

Several approaches are being followed in an attempt to understand and resolve these beam orbit change issues. Some steps have already been undertaken to reduce orbit drift, for example the introduction of "hot fills" [2] to reduce thermal cycling of SRS components during the fill cycle by minimising the time spent by magnets at below 2GeV settings. This has proved a highly effective technique, and underlines the significance of thermal cycling and expansion of SRS components. The positions of a variety of SRS components, including magnets and BPM vessels, have been measured to high precision (μm) during operational running and show strong linear correlations with magnet and vessel temperature. This has been quantitatively studied by modelling the measured vessel temperature after injecting a high current beam which is scraped out after several hours (see Figure 2). The data provide an estimate of the thermal time constant of the machine of around 2 hours, as well as the heating effect of a beam of known current. By relating measured component positions to their respective temperatures, a model of component movement over a fill can be constructed. The results and comparison to data during operational running show that a typical initial multibunch user beam of around 250-270mA contributes a total vessel temperature rise of around 1^{O}C. It should be noted that the high magnet currents required also contribute a large thermal effect, but since the introduction of hot fills the variation in this contribution has been kept to minimal levels. As predicted by the experimental data, drifts in SRS components and measured orbit position follow similar trends, with a rather rapid variation over the first 3-5 hours of a fill, reaching a maximum change from initial conditions, followed by a much slower drift in the opposite direction during the remainder of the fill. This is now well understood: the initial phase is the time taken to approach the equilibrium conditions for a high current beam, given the measured thermal time constant of 2 hours, and the reversal and slow drift thereafter is attributable to the slow deacy of stored beam current over a fill. This is confirmed by temperature measurements during a period of microamp beam running (Figure 3), in which the usual trends due to magnet current changes at a fill are observed, but the slow decline after the first few hours is absent: heating effects from such a low current beam are negligible, and the decaying beam current therefore is no longer observable.

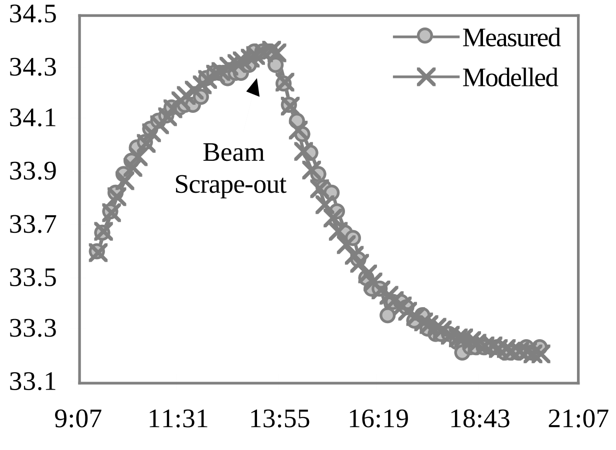

Figure 2: Measured and modelled vessel temperature (^{O}C) against time

It is clear that the largest thermally induced position changes occur at a fill when magnets are cycled. Because the thermal time constant is long compared to the duration of the fill cycle, total excursion is roughly proportional to the time taken to fill. It is therefore crucial, not only for operational efficiency but also for beam stability, to minimise this time. The effects of beam heating, though smaller, may be equally significant since they occur during the duration of use of the stored beam, rather than predominantly during the fill. These could be reduced by improving beam lifetime; at present, the effect of stabilising or varying the ambient temperature is being studied by blowing air of (roughly) constant temperature at specific components while monitoring their positions. It is also noted that the effects of seasonal and diurnal external temperature changes are observable, and it might be suggested that the fill cycle be timed so that the external and operational thermal cycles tend to counteract each other.

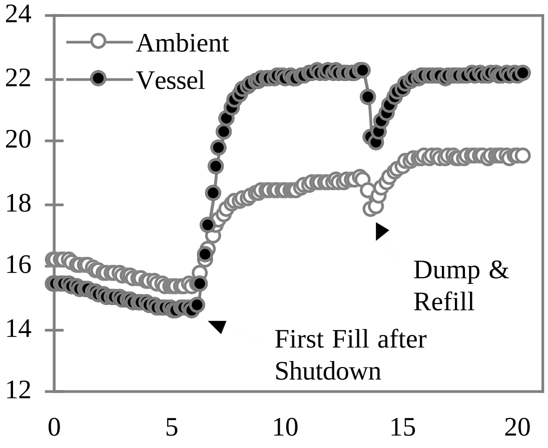

Figure 3: Ambient and vessel temperature (^{O}C) against time during microamp beam running

4 SUMMARY AND OUTLOOK

The Daresbury Global Horizontal Servo system has been demonstrably efficient at correcting electron beam orbit errors. On occasions where the servo has failed to operate until the end of the fill, there have been clearly identified reasons (including hardware failures or abnormally large orbit changes). Considerable progress has been made in understanding and modelling trends, particularly thermal cyling effects, which lead to real or spurious measured orbit changes, and work continues to minimise these effects. Further studies are attempting to devise algorithms and criteria for the automatic detection and rejection of spurious unphysical errors, such as an anomalous change at one BPM only; such errors constitute the most numerous cause of servo failure. If these effects, as well as apparent orbit changes caused by BPM movements, can be effectively eliminated, then techniques such as the control of average orbit via the RF wavelength can be considered.

REFERENCES

[1] 'Operational Performance of the Local Vertical Servo System on the Daresbury SRS', J B Fitzgerald, B G Martlew and P D Quinn, these Proceedings

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[3] 'Development of Global Feedback for Beam Position Control in the Daresbury SRS Storage Ring', Proceedings of 'European Particle Accelerator Conference', London UK, 1994, p125