CHARACTERISATION OF A LOCALISED BROAD-BAND IMPEDANCE PHENOMENON ON THE SRS

S.F. Hill, Daresbury Laboratory, Warrington, WA4 4AD, UK

A major perturbation to the SRS vacuum envelope was required to install a second superconducting wiggler in 1992. As part of this, all of the new wiggler straight (straight 16) vacuum vessels were re-designed to give a good match to the small elliptical chamber of the wiggler, including the sector vacuum isolation valve. Because of engineering problems this valve was not fitted and a standard circular aperture valve of much larger diameter had to be installed. This caused a localised impedance, which manifested itself by gross overheating due to the energy dissipated in it from the beam. A study of the effect of this valve has been conducted and is summarised. All data from the period of installation in the ring is collated, including beam heating and instability data. On removal from the ring a bench measurement of the effective broad-band impedance has been made, using time-domain measurement techniques.

I. INTRODUCTION

The installation of a second superconducting wiggler in the SRS in 1992 [1] was the second major upgrade to the light source, the first having been a lattice upgrade to achieve higher brightness in 1986/87. The insertion of the 1 m wiggler vessel into straight 16 had a large impact on the rest of the ring, including the rearrangement of the 4 D-sextupole magnets; the design of 3 new ultra-short kickers and a new septum; as well as the relocation of components such as the dump collimator and the betatron tune driver vessel. The vacuum system of the ring is divided into 4 main sectors, isolatable by sector vacuum valves. These could not be rearranged in the ring, so a special valve was specified for the wiggler straight, with an elliptic section to match the wiggler beam tube shape. The upstream (D-Quadrupole) and downstream (F-Quadrupole) straight assemblies were already being modified with elliptic flare sections to match to the wiggler tube.

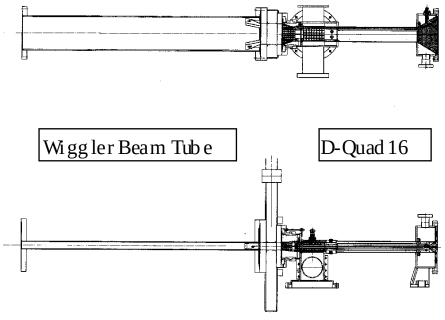

Figure 1. Upstream Straight 16 Layout

Figure 1 shows the planned layout of the chambers in the vicinity of the valve. Unfortunately this valve failed during the installation shutdown so was replaced by a standard sector valve with a circular aperture. Figure 2 illustrates the cross-section differences.

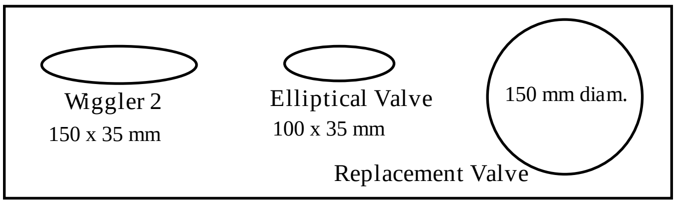

Figure 2. Cross Sections of Relevant Vessels

II. EXPERIENCE WITH BEAM

The first evidence of a large energy dissipation occurred in January 1993, some 4 months after first beam in the wiggler 2 lattice. Whilst experimenting with different fill structures (to remove a vertical beam blow-up due to ion trapping) a 300 mA beam in ~ 30 bunches (out of 160) caused a vacuum seal on the sector valve to fail due to excessive heating of the valve.

Some time was then spent on characterising this phenomenon in subsequent beam studies and operations periods [2], where valve temperatures in excess of 150 °C were seen. A measurement with a probe immediately after a beam dump indicated a localised hot spot on the upstream flange of the valve.

A temperature-time model for the effect was suggested:-

$$\frac{d\mathrm{T}}{dt} = -a(\mathrm{T} - \mathrm{T}_a) + b\mathrm{I}_b \qquad (1)$$

where T = temperature at time t
T_a = ambient temperature
and a, b are coefficients of cooling and heating respectively.

This model gave some limited success in assessing the nature of the heating effects. Some data was taken to assess the cooling rate as a function of average temperature, yielding a value of (0.016 °C/minute) per °C above ambient temperature (estimated @ 26 °C in beam studies and slightly higher during operations time). Measurements of heating rates were made with single bunch, multibunch and partial fill beams at low and high currents at injection energy (600 MeV), summarised in Table 1. This shows that full multi-bunch (160 bunches) gave small heating rates, essentially of small variation over a wide current range. The ~30 bunch fill gave increased heating rates and single bunch gave the greatest heating, with a strong non-linear dependence on bunch current.

Temp. (°C)	Current (mA)	Fill Structure	Rate ($x10^{-3}$ °C/mA/minute)
32	65	Multi-	0.6
29-34	100-300	Multi-	~1.0
44.3	283	~30 bunches	2.2
37.5	264	~30 bunches	2.5
29.3	2	Single	2.4
33.8	51.1	Single	11

Table 1. Heating Rates at 600 MeV

The ~30 bunch fill results were surprising, since its power spectrum is not very different to the full multi-bunch case. A second investigation looked at the variation with energy, at 0.6, 1.125 and 2 GeV. Despite the change in synchrotron radiation emission at these energies, the available data still suggests that a modest single bunch current gives greater heating than a higher current multi-bunch beam.

III. BENCH TEST OF VACUUM VALVE

Impedance measurements at Daresbury are performed in the time domain, using a Tektronix 7854 sampling oscilloscope fitted with a 7S12 Time Domain Reflectrometry (T.D.R.) insert. This is configured with an S52 step pulse generator ($t_r \le 25$ ps) and an S6 sampling head ($t_r \le 30$ ps). Loss parameter measurements are made using an Impulse Forming Network (I.F.N.) which produces a near gaussian output pulse by differentiating a fast step input pulse. This allows a simulated beam measurement to be made at σ ~20ps. The full system and planned upgrades is described elsewhere [3] as is the theory used to calculate the loss parameter [4], summarised below:-

The loss parameter $k(\sigma)$ is calculated from :-

$$k(\sigma) = \frac{2Z_o}{Q^2}\int_{-2\sigma}^{+2\sigma} I_o(I_o - I_s)\,dt \qquad (2)$$

where I_o = Current pulse launched through an ideal vacuum vessel (the reference vessel)

I_s = Current pulse launched through the vessel under test

Z_o = Characteristic impedance of the coaxial line section (the reference vessel)

and $$Q = \int_{-2\sigma}^{+2\sigma} I_o\,dt = \text{charge in the reference vessel pulse}$$

with a broad-band impedance contribution estimated using a resonator model with an appropriate Q centred at the cut-off frequency of the beam pipe under test.

The system chosen for the test and reference vessel assemblies was the upstream straight 16 assembly: the D-quadrupole and wiggler tube located either side of the vacuum valve under test. The reference system used an aluminium block with the elliptic aperture cut into it, whilst the test assembly used the circular aperture vacuum valve. Impedance matching to this system was done using thin steel cones supported within rigid copper cones which bolt to the vessel flanges. The present SRS D-Quadrupole cone was the only one available for upstream matching and a new elliptic cone to match to a the wiggler tube ellipse was constructed. The measurement system is shown in Figure 3.

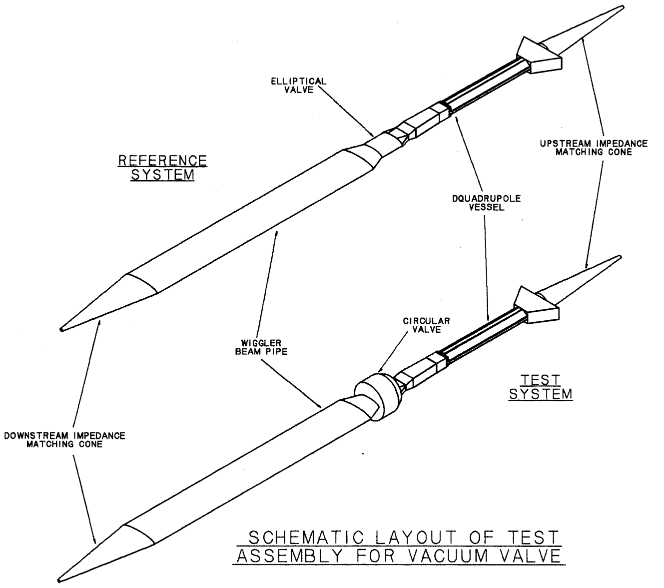

Figure 3. Measurement System Layout

The D-Quadrupole vessel was first fitted with all internal components, vacuum cleaned and tested, then impedance tested to check that no undue contribution would arise from it.

The loss parameter $k(\sigma)$ measured was within a few percent of that measured at wiggler installation time (March 1992). The vessel system was then assembled with a central conductor of 1.22 mm diameter copper wire (the 5 mm rod normally used for vessel measurements could not be easily supported in the 3 m long assembly) and T.D.R. data taken. Figure 4 shows the reference vessel assembly (elliptical valve) measured from the downstream (wiggler) end.

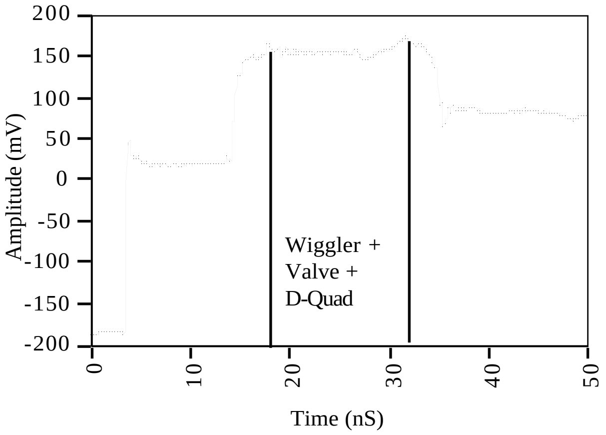

Figure 4. Full Downstream T.D.R. of Reference System

This shows that the impedance matching to the system is poor, with large reflections. However inspection of the aligned T.D.R. waveforms from the reference and test systems shows clearly the effect of the circular vacuum valve (Figure 5).

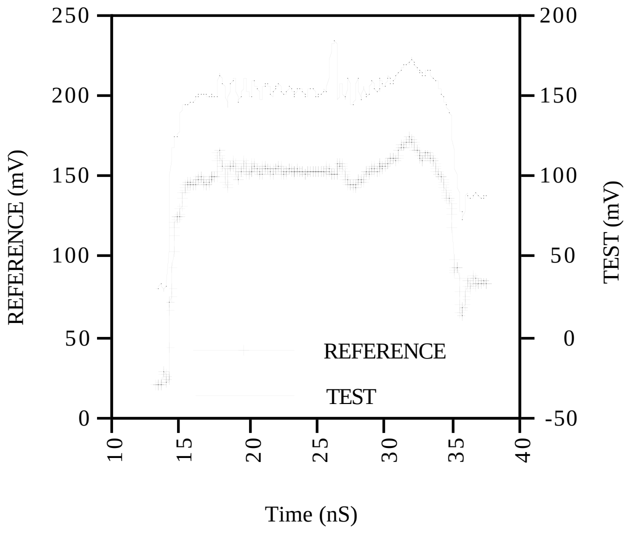

Figure 5. Comparison of Aligned T.D.R. Data

The 7854 scope T.D.R. system was then reconfigured to launch gaussian pulses through the two systems.

Applying (2) with Z_o = (213 ± 11) Ω (average value calculated from the T.D.R. data) gave a loss parameter result $k(\sigma) = (0.93 \pm 0.05)$ VpC^{-1}, for $\sigma = 20$ ps. Using an assumed vessel cut-off frequency f_c = 2 GHz this gives an estimated broad-band impedance contribution of $Z/n = (0.12 \pm 0.01)\ \Omega$.

IV. SUMMARY AND CONCLUSIONS

The installation of a standard circular sector valve in the wiggler 2 straight in the SRS gave rise to a large energy dissipation and overheating of the vessel. Beam measurements at different energies indicates that synchrotron radiation was not the probable cause, whilst the enhanced heating rates seen with partial fills as well as single bunch cannot be explained easily with a simple broad-band impedance model. Bench measurements of the valve were carried out, which whilst showing that the vessels were not well matched to the 50 Ω measurement system, gave T.D.R. data clearly indicating the effect of the valve. Loss parameter data acquired with this system allowed an estimate of the broad-band impedance (Z/n) contribution to be made, suggesting that any change to the ring impedance to be small (< 5 % of the most recent estimate [5]). Inspection of beam data leads to the suggestion that the effects were (partially) due to an interaction with a resonant structure with Q >> 1 which is plausible when the valve and its connecting vessel sections are examined. Further work will involve an assessment of the resonance behaviour of the valve system.

V. ACKNOWLEDGEMENT

I would like to thank D.M. Dykes and S.L. Smith for their help and support in this work.

VI. REFERENCES

[1] M.W. Poole et al. Commissioning a Second Superconducting Wiggler in the Daresbury SRS. Proc. IEEE Particle Accelerator Conference, Washington 1993, p1638-1640.

[2] S.L. Smith, Investigation of Valve Flange Heating. Daresbury Internal Note SRS/APES/93/09.

[3] S.F. Hill and M.J. Pugh, Improvements in Vessel Impedance Measurements at Daresbury. Proc. European Particle Accelerator Conference, London 1994, p1339-1341.

[4] M. Sands and J. Rees, SLAC-Report PEP-95, August 1974.

[5] J.A. Clarke, Bunch Lengthening Thresholds on the Daresbury SRS, these proceedings.