VACUUM SYSTEM DESIGN AND PERFORMANCE FOR THE DARESBURY HBL

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Abstract

The vacuum performance of an electron storage ring dedicated to the production of synchrotron radiation may be characterised in terms of the single parameter electron beam lifetime at the working current of the machine. The Daresbury SRS had performed satisfactorily in this respect over much of its working life, with lifetimes in excess of 10 hours at 300 mA stored current at a beam energy of 2 GeV. When the decision was taken to upgrade the performance of the machine by increasing the source brilliance, it was naturally important that this performance should continue. However, it was clear that apertures - and hence gas flow conductances - in some of the new vacuum chambers were very restricted. Thus it was by no means obvious that the requisite vacuum levels (approx. 10^{-7} Pascal) could be obtained given the engineering constraints on the possible location and physical size of suitable vacuum pumps. Extensive and detailed calculations were therefore carried out using a finite-element type of analysis to compute pressure profiles in the proposed machine, with the vacuum pumps being treated as semi-free parameters. A suitable scheme was evolved, and has proved satisfactory, with beam lifetimes of 24 hours at 200 mA stored beam at 2 GeV being regularly achieved. These lifetimes are in excess of the anticipated values, and this is discussed.

Introduction

The Daresbury Synchrotron Radiation Source (SRS) came into operation in 1980 as the world's first dedicated high energy source of synchrotron radiation, and operated successfully until 1986. Meanwhile users' requirements had changed, such that source brilliance had become a more important parameter than total flux. Hence the machine was shut down in 1986 for a major upgrade to increase the source brilliance by a factor of more than 10 for similar stored beam currents. This was to be achieved by the insertion of an extra quadrupole magnet in each of the 16 straight sections of the machine.[1]

Vacuum System Design

From the point of view of the users of facilities such as the SRS, an important parameter is the stored electron beam lifetime, which essentially determines the time between machine fills. In a well-designed storage ring, lifetimes will be determined primarily by beam scattering from residual gas molecules. In the SRS, it had become routine to achieve lifetimes in excess of 10 hours for stored beam currents of 300 mA at 2 GeV beam energy. Base pressures in the low 10^{-8} Pa region were obtained, with working pressures being typically 10^{-7} Pa. The vacuum performance of the SRS has been considered in detail by Trickett.[2]

It was considered essential that the good vacuum performance of the SRS be maintained in the upgraded machine (usually known as HBL). Suller[3] calculated that, for the new lattice, a pressure of 5×10^{-7} Pa would give an 8 hour lifetime. However, fitting sufficiently powerful quadrupole magnets into the existing, already overcrowded straight sections implied a relatively small aperture and hence restricted gas flow conductance. The SRS vacuum design utilised a single pumping stack in each straight section, comprising a 400 l/s triode ion pump and an in line Titanium Sublimation Pump (TSP), giving a net estimated pumping speed at the stack throat of 800 l/s. In addition each dipole magnet contained a distributed diode ion pump of estimated speed 240 l/s per dipole.

Preliminary calculations of pressure distributions based on a finite element model similar to that used by other workers[4,5,6] showed that the new quadrupole vessels were not the major problem, but that the concomitant rearrangement of the pumping stacks was. Because of space limitations, the stack throat would have to be longer and its cross sectional area smaller than in the SRS. The reduced effective pumping speed implied that the requisite base pressure, and hence beam lifetime, would not be achieved.

Detailed calculations of pressure distributions around the machine were therefore carried out as described elsewhere.[7] It proved possible to achieve the necessary vacuum specification by fitting two SRS-type pumping stacks at each end of most of the straight sections. The total net installed pumping speed in the beam envelope, is, however, lower than in the SRS because of the conductance limits in the stack throats. A typical result of the calculations for one straight section is shown in fig. 1. Consideration of the gauge positions indicates that the measured value for average ion gauge pressure should be about half the actual average pressure, similar to what was estimated for the SRS.[2] Table I summarises the installed pumping speeds and shows the calculated average pressures with and without beam.

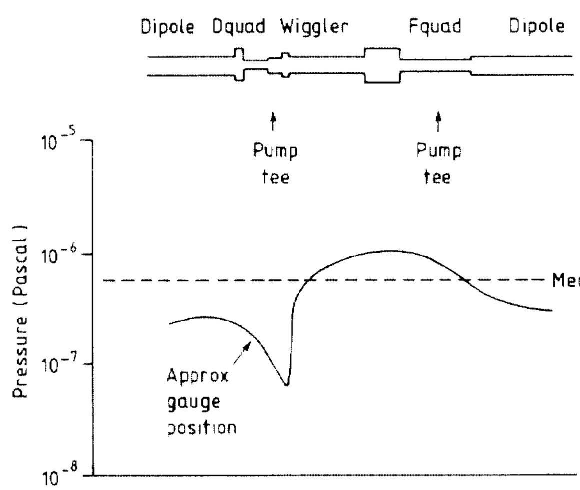

Fig. 1. Calculated pressure distribution for a typical HBL unit cell.

Table 1
Comparison of SRS and HBL installed pumping speeds

	SRS	HBL
Lumped ion pumps	6400	5900
Distributed ion pumps	3800	3800
Titanium sublimation pumps	6400	5000

HBL predicted performance

Base pressure (after bake)	5×10^{-8} Pa
Pressure with 100 mA stored beam	3×10^{-7} Pa

Measured Results

It has not as yet been possible to bake the new machine, although it is designed to be bakeable. All new components were thoroughly pre-conditioned as described previously.[8] Many machine components were re-used, and had been subject to considerable beam scrubbing in the SRS. The pump down characteristic of HBL is shown in fig. 2. Plotted here is base pressure, defined to be the pressure with no beam in the machine and the dipole magnets switched off (i.e. no distributed pumps). These pressures are usually recorded at the start of a routine shutdown and are not necessarily equilibrium pressures, so there is some scatter. Estimated beam doses are given along the base line. There is some uncertainty in initial values because of problems in measuring beam currents, but differences in cumulative doses after about day 100 are accurate.

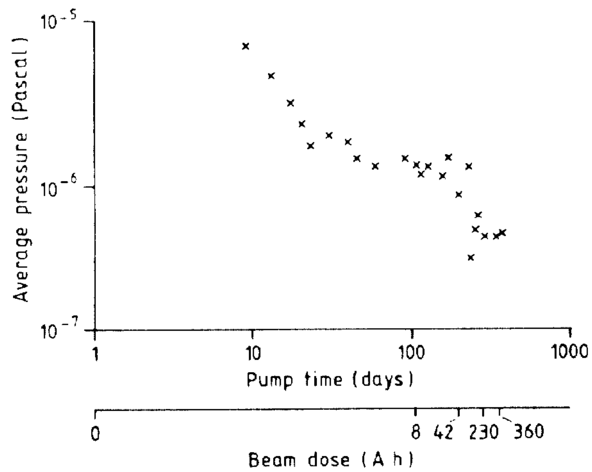

Fig. 2. HBL pumpdown as a function of time and beam dose.

Beam desorption (molecules/photon) is plotted in fig. 3 as a function of beam dose. Comparable values (after Trickett[2]) for the SRS are also plotted.

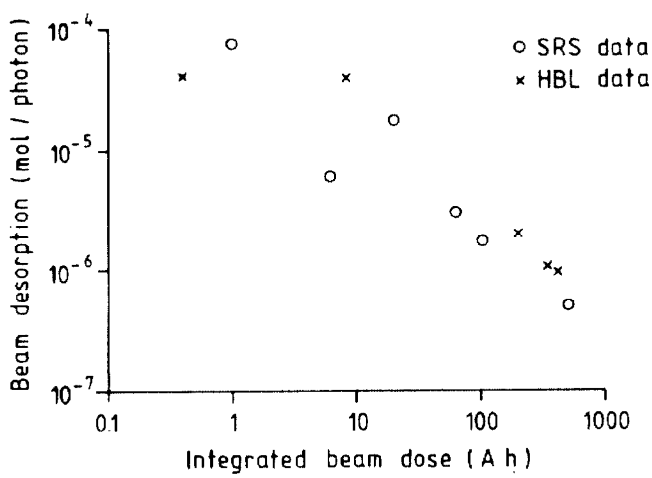

Fig. 3. Beam desorption as a function of beam dose.

Beam lifetimes, however, are somewhat longer than those anticipated. Values in excess of 24 hours are frequently attained at average pressures of about 2.5×10^{-7} Pa, permitting twelve hour fill cycles. Suller's calculations[3] from scattering theory gave a value of 3.3 microPa-hr for the HBL, compared to 3.6 microPa-hr for the SRS. It should be noted in passing that the frequently used formula of Augustin[9] incorporates machine-specific constants and may give misleading results. Figure 4 (after Corlett[10]) shows some measured values of lifetime as a function of average pressure for HBL. Although there is considerable scatter, this data indicates a lifetime figure of about 8 microPa-hr. Lifetimes for the SRS as reported by Hughes et al[11], indicated a measured lifetime of about 1.4 microPa-hr compared to the (Augustin) calculated value of 3.0 microPa-hr. This discrepancy correlates well with the estimated factor of two between the measured and actual average pressures.[2] It seems unlikely that changes in ion gauge calibration factors or residual gas composition could explain the discrepancy in the HBL figures, which are not, at present, understood.

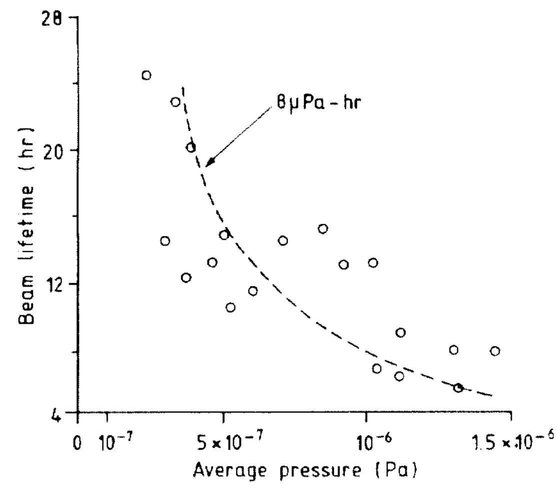

Fig. 4. Beam lifetimes as a function of average pressure. The broken curve is that for a constant lifetime of 8 microPa-hr.

Instrumentation[12]

Opportunity was taken in the rebuild to increase the number of RGA's installed on the machine to twelve, with a further four (i.e. giving one per straight section) to be installed when the opportunity arises. Their use in diagnosing problems with the vacuum system in situ, without interrupting operations unnecessarily, has proved invaluable. For instance they may be used in distinguishing betwen beam and thermal outgassing and leaks. The advantage of using Bayard Alpert gauges to measure pressure - rather than using ion pump currents - has also been amply demonstrated. At low pressures, the pump currents are noisy and are prone to misleading leakage currents, whereas the ionisation gauges have proved fairly robust. Penning gauges have proved to be unreliable, except for providing relatively uncritical interlocks. In a clean UHV system, they seem prone to develop difficulties in striking and a tendency to leakage current build up, requiring burning off with a Tesla coil from time to time.

Summary

The basic design of the HBL vacuum system has proved more than adequate for the task, meeting specification without bakeout. This indicates that the initial calculations may have been over-cautious. The discrepancy between measured and calculated lifetimes requires further investigation.

Acknowledgements

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