BEAM LIFETIME ON THE DARESBURY SRS

E.A. Hughes, G.I. Figura and N. Marks
Science & Engineering Research Council
Daresbury Laboratory
Daresbury, Warrington WA4 4AD, U.K.

The derivation of what is thought to be a novel expression for beam decay based on a model including gas desorption is given and its predictions compared to observed beam decays in the SRS. The model is shown to predict beam decay to within the accuracy of observation which represents a significant improvement over the simple exponential decay model. The SRS beam decay has been observed for a period of many months and statistical correlation used to separate variations in zero-beam lifetime (due to vacuum base pressure) from the faster decay due to radiation desorbed gas. Evidence is presented to show that lifetimes which do not correlate are indicative of machine malfunction such as low RF power or misaligned closed orbit. Therefore this decay analysis is an extremely useful indicator of the "health" of the storage ring. The recovery of the unbaked machine from a complete vacuum let-up has also been recorded in detail and this history is illustrated.

Introduction

As in all Storage Rings, the decay of the stored beam in the Daresbury SRS is a subject of intense interest. A model for this decay process has been developed at Daresbury which predicts beam decay to an accuracy within the limits of experimental error. The parameters associated with the model have given some fascinating insights into machine operation.

Beam Decay Model

The presumption is made that if the RF over-voltage and closed orbit are kept constant then any variation in the rate of decay of a beam is due solely to a change in vacuum pressure. The decay can then be modelled by:

$$\frac{dI_b}{dt} = -K I_b P \qquad (1)$$

where $\frac{dI_b}{dt}$ is the rate of beam decay at current I_b

P is the vacuum pressure at current I_b

K is a constant

From beam-induced gas desorption mechanisms one could speculate that

$$P = P_0 + AI_b \qquad (2)$$

when P_0 is P at $I_b = 0$

A is a constant

Then

$$\frac{dI_b}{dt} = -K I_b(P_0 + AI_b) \qquad (3)$$

which can be re-written

$$\frac{dI_b}{dt} = -I_b\left(\frac{1}{T_0} + BI_b\right) \qquad (4)$$

where

$$T_0 = \frac{1}{KP_0} = \text{exponential decay constant at } I_b=0$$

$$B = \frac{A}{T_0 P_0}$$

This may be integrated to give

$$I_b = \frac{I_0 e^{-t/T_0}}{1 + BT_0 I_0 (1-e^{-t/T_0})} \qquad (5)$$

which is the primary model for beam decay.

A typical fit of this model to an actual beam is shown in Figure 1 together with a simple exponential fit for comparison.

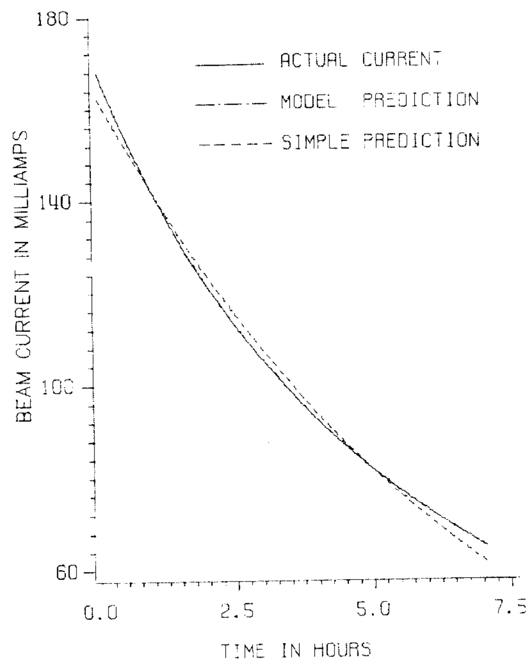

Figure 1. Actual and predicted beam current

The real and model curves are so close as to be indistinguishable in this figure size but the difference between the curves is plotted in Figure 2.

The standard deviation of the residual errors for the model is ~ 0.3% of the mean beam current compared with ~ 2% for the simple exponential curve.

Obviously this is a very good model. However it can be improved still further from examination of the dynamic behaviour of the storage ring vacuum pressure. This shows a rapid response to a change in beam conditions followed by a much slower exponential response. These presumably correspond to two different outgassing mechanisms, namely radiation desorption and thermal desorption. As a model for this process the following phase retard Laplace Transform was used.

$$P(s) = Ak\left[\frac{1 + sT_v}{k + sT_v}\right] I_b(s) \qquad (6)$$

Where:

k is the photo desorption fraction of a pressure change which must be greater than zero ?
A is the outgassing constant
T_v is the vacuum chamber time constant
s is the Laplace operator.

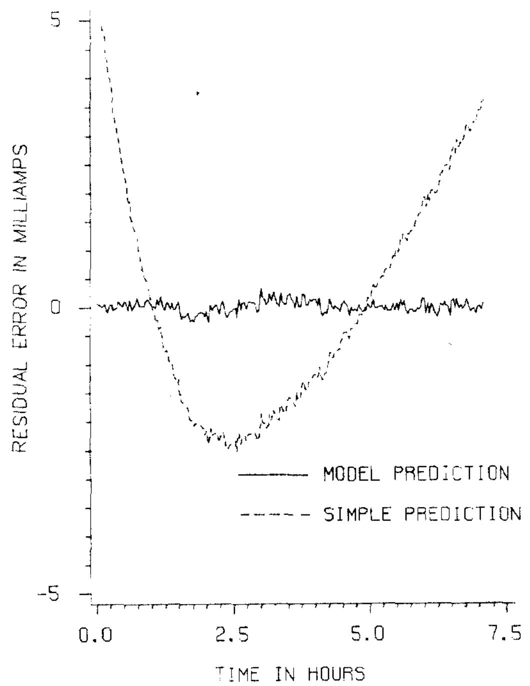

Figure 2. Difference between actual beam current and the model and simple predictions

If, for simplicity, $I_b(s)$ is written as a simple exponential decay then the following expression for the time-varying vacuum pressure P(t) is obtained:

$$P(t) = P_0 + AkI_b(t) + \frac{AT_e k(1-k)I_0}{kT_e - T_v}\left[e^{-t/T_e} - e^{-kt/T_v}\right] \quad (7)$$

Where:

T_e is the simple beam time constant
I_0 is the initial beam

Incorporating this expression into the beam decay model then gives a virtually perfect fit to beam decay. The standard deviation of the residual error is less than 0.15% which is the limit of accuracy of beam current measurements.

Storage Ring Operation

Having an accurate model, it is then possible to use it to gain some interesting insight into the operation of the Storage Ring.

Firstly it is desirable that the only significant process involved in beam decay should be gas scattering. Thus, in correct operation, other possible beam loss mechanisms such as betatron(-synchrotron) resonances, closed orbit errors or induced electromagnetic fields should only have a small effect. It should then be possible to establish a relationship between machine vacuum conditions and beam life, and any deviation from this relationship should indicate a machine malfunction. Unfortunately this has not proved to be so simple because of small long-term fluctuations in ion gauge calibration. Also the RF overvoltage has varied from time to time for operational reasons. Nonetheless, a study of machine operating statistics over a period of six months has established a limit for the deviation of zero-beam lifetime from its expected value given by zero-beam pressure. Up to the time of writing all lifetimes which were outside this limit have been traced to a machine malfunction of some sort. So it is hoped that in the future the response of the storage ring diagnostics to abnormally short beam lifetimes will be considerably improved. A graph of zero-beam lifetime versus reciprocal zero-beam pressure together with the normal limits is shown in Figure 3.

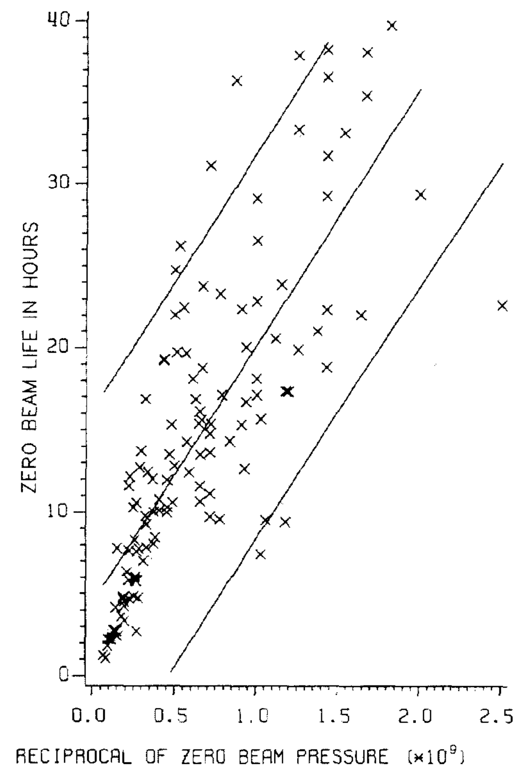

Figure 3. Zero-beam life versus reciprocal zero-beam pressure

The low lifetimes are attributed to times when the horizontal and vertical betatron frequencies were allowed to approach one another too closely or when the beam was mis-aligned. The high lifetimes occurred when excessive RF power levels were used.

The average measured lifetime-pressure gradient is 11 hours-nanotorr[1)] compared with a theoretical value of 22 hours-nanotorr predicted by gas-scattering with the average RF overvoltage we are using. The most likely explanation of this is that the average pressure which is derived from the mean of many ion gauges located exclusively in straight sections is in error by that factor.

The most useful feature of the model is perhaps that it is now possible to identify the separate contributions to machine operating pressure of base pressure and beam induced gas desorption. This is particularly useful when machine behaviour is studied over a long period of time as is described in the next section.

Recovery from a Complete Vacuum Let-up

In November 1984 the whole machine was let up to atmospheric pressure while various modifications were carried out. A deliberate decision was taken not to bake the vacuum system as was previous practice, but to run and outgas with synchrotron radiation. The history of zero-beam lifetime, zero-beam pressure and outgassing constant for the three months of machine operation at 1.8 GeV immediately following is shown in Figures 4, 5 and 6.

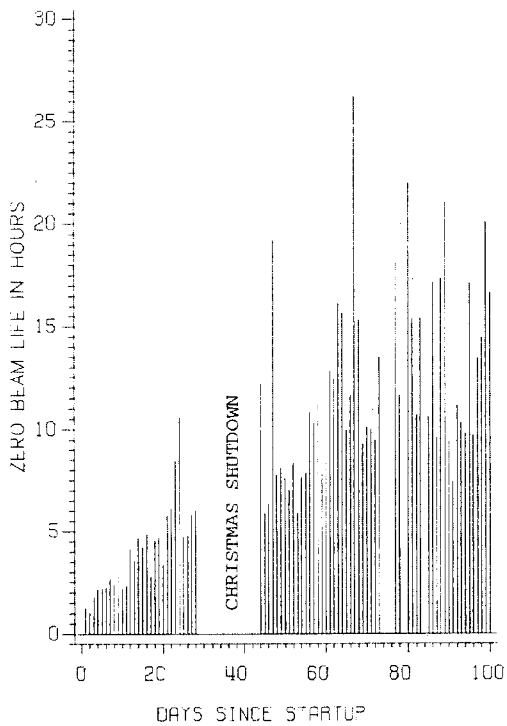

Figure 4. Zero beam life versus time

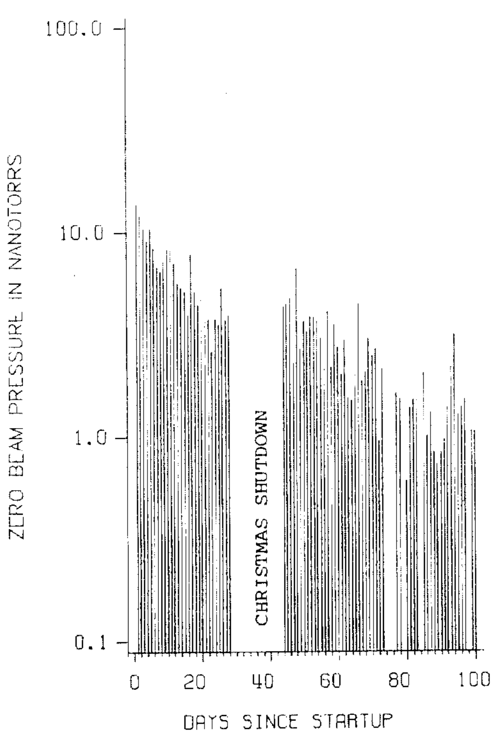

Figure 5. Zero beam pressure versus time

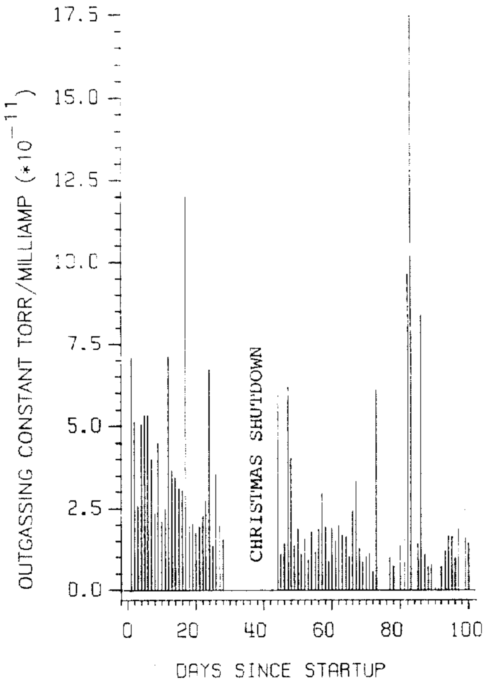

Figure 6. Outgassing constant versus time

From these graphs some immediate conclusions can be drawn. One is that the zero-beam pressure is exponentially reducing with an exponential time constant of about 130 days. However the average outgassing constant initially decayed much more rapidly with a time constant of about 32 days, but this rate slowed down considerably after the Christmas shutdown and presently the mean outgassing constant seems to be roughly steady at 25 picotorr/milliamp which gives an average lifetime of 7 hours for an injected beam of 300 mA. Any further decay appears to be very slow. Thus the high current lifetime is dominated by outgassing.

Individual values of the outgassing vary considerably from the mean. Much of this variation is attributed to the beam being steered to new positions to suit users. Other correlations have been established to shutdowns and operating energy changes.

General Conclusions

The beam decay model predictions have been compared with many actual beam decays and the correlation is at least as good as measurement error. Deviations from the model faithfully indicate machine malfunction or mis-adjustment. The operational history since the vacuum was let-up to atmospheric pressure indicates that, without a bake, the average high current beam lifetime eventually becomes dominated by beam induced outgassing which does not appear to reduce very quickly.

Reference

[1] Beam lifetime from Residual Gas Scattering, V.P. Suller, Daresbury Laboratory, SRS/MI/84/27.