IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

PRESENT LIMITS FOR THE LUMINOSITY, THE BEAM CURRENT AND THE BEAM LIFETIME IN DORIS II

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Introduction

The e^+e^- storage ring DORIS II /1,2/ has been operating for high energy physics experiments in the region of the Υ resonances around 2x5 GeV and as a source for synchrotron radiation near 3.7 GeV. A luminosity of nearly $3\times10^{31}cm^{-2}sec^{-1}$ or more than 1500 $(nb)^{-1}$/day has been achieved. For synchrotron radiation e^--currents of about 100 mA are stored in 4 bunches (out of 480 buckets).

As long as the beam-beam interaction does not limit the luminosity the optimum performance of the ring is obtained for both modes of operation if the currents stored are large, the cross section of the beam is small and the lifetime is long. Thus we concentrate the discussion on these subjects.

Beam Cross-Section

To obtain a small cross section both the horizontal and the vertical emittance have to be small. The horizontal emittance has been minimized with the help of optics calculations aimed at making the best use of the magnet lattice whose layout is essentially determined by the old DORIS I-geometry /3/.) In agreement with experiments the emittance has been found to be

$$\varepsilon_x = 2.0 \cdot 10^{-8} \text{ radm}$$

at 1 GeV.

The weak vertical bends, which have been kept in order to prevent the synchrotron radiation of the last horizontal bending magnet from illuminating the interaction points, generate a vertical emittance ε_z which by calculation is expected to be $\varepsilon_z = 0.006\ \varepsilon_x$. By measurement of the specific luminosity and by scraper measurements an emittance ratio of

$$\varepsilon_z/\varepsilon_x = .01$$

has been found for currents up to about 30 mA/bunch. As with other storage rings /4/, ε_z increases at larger currents by beam-beam interaction, whereas ε_x remains constant and values of $\varepsilon_z/\varepsilon_x$ as large as 0.1 have been observed. Preliminary evaluation of some data taken during normal luminosity runs, indicate that the beam height increases in such a way, that the beam-beam tune shift parameter for the vertical direction

$$\xi_z = \frac{\beta_z^* r_e I}{2\pi n f_o e\gamma\sigma_z^*(\sigma_x^*+\sigma_z^*)}$$

remains constant (β_z^* vertical betatron function at the crossing point, r_e classical electron radius, I current per beam, n number of bunches, f_o revolution frequency, e charge of the electron, γ particle energy divided by its rest energy $\sigma_{x,z}^*$ horizontal (x) and vertical (z) gaussian beam size at the crossing point). Maximum values of ξ_z of about .026 have been observed.

It is possible to increase the specific luminosity, and to decrease ξ_z for a given I, by decreasing β_z^*. The disadvantage of the procedure is that with decreasing β^* the natural chromaticity of the ring and therefore also the strength of the compensating sextupoles increases. The effect of the increased nonlinearity may then impose a lower limit on β_z^*.

DORIS II has been mainly operated with the following optical parameters at the interaction point

$$\beta_x^* = .6 \text{ m} \qquad \beta_z^* = .04 \text{ m}$$
$$D_x^* = -.39 \text{ m} \qquad D_z^* = -.004 \text{ m}$$

($D_{x,z}^*$ horizontal (x) and vertical (z) dispersion at the interaction point).

These are in reasonably good agreement with the measured $\beta_x^* = .64$ m and $\beta_z^* = .05$ m. The resulting chromaticity was -20 for the horizontal and the vertical plane. A luminosity of nearly $3\times10^{31}cm^{-2}sec^{-1}$, or more than 1500 $(nb)^{-1}$/day, has been achieved, when maximum currents of about 2x45 mA were stored.

To increase the luminosity the focussing near the interaction point was modified to give (theoretically):

$$\beta_x^* = .4 \text{ m} \qquad \beta_z^* = .03 \text{ m}$$
$$D_x^* = -.30 \qquad D_z^* = .005 \text{ m}$$

The corresponding measured values were $\beta_x^* = .37$ m $\beta_z^* = .039$ m and the natural chromaticity -25 for both planes. The specific luminosity at small currents (~15 mA per bunch) behaved as expected and increased from $2.4\times10^{28}cm^{-2}sec^{-1}(mA)^{-2}$ to $3.5\times10^{+28}cm^{-2}sec^{-1}(mA)^{-2}$. But only currents of less than 2x30 mA could be stored (instead of 2x45 mA) and the background for the high energy experiments was higher. Reasons for this reduced performance are not yet known.

When DORIS II is operated as a source for synchrotron radiation, a simpler optics without waist at the interaction points is used, but the normalized horizontal emittance remains unchanged. The emittance ratio is a few percent. Up to now no attempt has been made to minimize it since it has been more important to stabilize the position of the beam. Without correction, the synchrotron radiation at a distance of about 7 m from the source would change its position by about 2 mm over a period of hours due to movements of the bending magnets. These deviations have been reduced by 2 orders of magnitude by improving the supports of the bending magnets and controlling the position of the stored beams. A wiggler magnet with 16 periods, a length of 2112 mm and a maximum field of 0.6 Tesla has been installed and as expected, at 3.7 GeV it did not change the beam parameters.

Maximum Currents

It has already been mentioned that DORIS II is operated with single bunch currents of about 2x45 mA for luminosity runs at energies lower than 5 GeV. This is possible only after careful adjustment of the rf-parameters and if a feedback system is used to damp horizontal and vertical betatron oscillations and sometimes also the synchrotron oscillations. Three effects limit this current.

1. The feedback system is not strong enough to damp the beam instabilities at higher currents.
2. The lifetime is only about two hours and gets shorter at higher currents. This will be discussed later.
3. Although the vacuum chamber is made as smooth as possible some parts of it become very hot due to higher order mode losses (HOML) and would be damaged, if more current were used. (This heating of the vacuum chamber is also the reason for the movements of the bending magnets, already mentioned).

At 5.3 GeV luminosity runs are started with maximum currents of 2.35 mA and a lifetime of only about 1.5 hr. This lifetime limitation is due to lack of rf-power.

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When DORIS II is operated as a source for synchrotron radiation - mainly at 3.7 GeV - only electrons are used. As much current as possible should be stored and the time interval between light flashes should be greater than 200 nsec to allow time resolved measurements. In practice following modes of operation have been applied

a) 1 bunch stored: The time interval between light flashes is maximum i.e. about 1 μsec. With feedback and after some adjustment of rf-parameters up to 40mA can be filled reproducibly. On one occasion, after very careful adjustment of rf- and optical parameters, 84 mA were stored - even without feedback. As a consequence, after some minutes the vacuum broke down due to overheating of a flange by higher order mode losses.

b) 4 bunches stored: This is the mode of operation most often used. 250 nsec between bunches are in general long enough for time resolved measurements and for the use of a narrowband single bunch feedback system. With this, two bunches are stabilised by the feedback system directly, and the others are stabilised by their coupling to the first two /5/. Sometimes 120 mA can be stored in this way and about 100 mA can be stored reproducibly. The limit is given by beam instabilities - usually the horizontal ones. The beam is stable just up to the limit and then a sudden beam loss occurs. The limit itself can also be influenced by rf-parameters.

c) 120 bunches or more stored (maximum 480). The time interval of 8 nsec to 2 nsec is too short for use of time resolved measurements and of a feedback system. Nevertheless sometimes 120 mA can be stored but the beam behaves very instably. There are strong oscillations in all three dimensions, horizontal, vertical and longitudinal. Again they can be influenced by rf-parameters. About 60 mA can be stored quietly and reproducibly in this mode of operation.

The influence of rf-parameters on the beam instabilities indicates that they are driven by spurious cavity resonances. Thus these cavity resonances have been sought by calculation /6/ and measurement /7/ on the 5-cell 500 MHz cavities in use. It was found that the disturbing modes are similar to those found in the 1-cell cavities that were in use earlier. At that time the currents, that could be stored, were increased by placing mode damping antennas /8/ in the cavities. It is planned /7/ to apply similar damping antennas to the 5-cell cavities too.

Beam Lifetime

The lifetime as determined by the vacuum pressure (ca.5×10^{-9}mbar) is expected to be more than 5 hours. This can be observed, for instance, if only one beam is stored.

When two beams of high intensity (more than 40 mA/bunch) are colliding, their lifetime is typically 2 h to 3 h and depends very critically on the working point of the machine. If the betatron tune is changed only by .0005 the lifetime may be reduced by a factor of 2. This applies even for the best working point found up to now. (Q_x = 7.168; Q_z = 5.235). Nearby, ($\Delta Q_{x,z}$ ∿ .01) there are several working points which also yield a lifetime of 2h to 3h. But between these points the lifetime may fall to a few minutes. Sometimes only one beam is affected.

There have not been enough measurements to enable a detailed analysis of such complex resonance structure to be carried out; but satellite resonances are presumably involved since the lifetime also depends critically on small changes of the synchrotron frequency.

Fig. 1 shows how the lifetime of a weak e^--beam (∿1 mA) and that of a moderate strong e^+-beam (∿10 mA), both single bunch, depends on Q_x. Already for rather small colliding currents the lifetime of the weaker one is obviously more severely influenced than that of the stronger one.

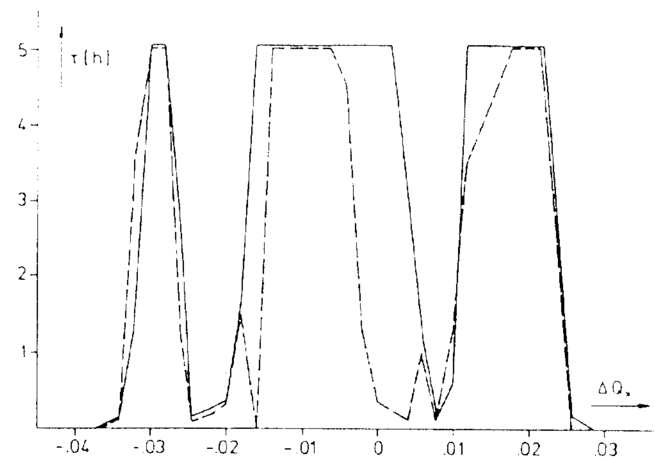

Fig.1 Lifetime τ of two colliding beams versus horizontal betatron tune Q_x

— e^+-beam of 10 mA — working point: Q_x = 7.157
--- e^--beam of 1mA — Q_z = 5.246

As already mentioned, when it is used as a synchrotron radiation source, DORIS II is filled with 1,4 or 120 or more e^--bunches. The typical lifetime of 5 h sometimes suddenly falls to ca. 30 minutes and then it cannot be improved by varying any machine parameter. Also, it may then recover just as suddenly as it deteriorated although no machine parameter were changed in between. Moreover just dumping the beam and refilling it within minutes under the same conditions usually restores the 5h- lifetime. The lifetime can also be restored by adding a surplus of positrons. If the positron current is much less than the electron current, both beams aquire a short lifetime. Measurements of the betatron tune versus the beam current show that the gradient dQ/dI is positive in periods of short lifetime, whereas it is negative in periods of long lifetime.

All these observations may be explained by the occasional presence of ions. For the single bunch case this is rather surprising as the ions should be swept out within 1μsec, the time period between successive passages of the bunch. But the observations hold for the single bunch also.

Effects of ions were never observed with single positron beams. A reversal of all magnet polarities and subsequent use of positrons for stable synchrotron radiation operation is presently under consideration.

Acknowledgements

The authors thank the members of the machine staff whose efforts and experience made possible good and stable machine conditions. They also thank Prof. G.-A. Voss for his support and for many helpful remarks and discussions.

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