OPERATIONAL EXPERIENCE WITH DORIS II

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Summary

DORIS II is a redesigned electron-positron storage ring with a maximum energy of 5.6 GeV and mini-beta scheme. An integrated luminosity of more than 1000 $(nb)^{-1}$ per day has been achieved at 5 GeV. In addition the machine is used as a dedicated synchrotron radiation source.

Introduction

DORIS an e^+e^- storage ring started its operation in 1974 as a double ring, i.e. the beams were separated and independently guided in most parts of the accelerator. By a vertical bending they were brought to collision in two interaction points. The maximum energy was 3.5 GeV.[1]

When the Y-resonance was discovered it was decided to increase the energy to 5.1 GeV. In 1977 the machine was changed into a single bunch-single ring accelerator to save rf-power. The energy limit was given by iron saturation, especially in the bending magnets. This machine is now called DORIS I.[2] Maximum stored currents were about 20 mA in each beam, the resulting luminosity about 10^{30} cm^{-2} sec^{-1}.

An energy of 5.1 GeV is not sufficient for the higher excited states of the Y-resonance. Therefore the machine was reconstructed again. The main goals of the new design were:

a) maximum energy of 5.6 GeV and reduced power consumption
b) high luminosity ($L > 10^{31}$ cm^{-2} sec^{-1}) around 5 GeV
c) ports for synchrotron radiation users at the same positions as in DORIS I.

The new machine is called DORIS II.[3,4] As far as possible elements of DORIS I were used again. Therefore only a very short shut-down was needed for the reconstruction. DORIS I was turned off on November 1, 1981 and in June 1982 DORIS II was running for experiments again.

Maximum Energy of 5.6 GeV and Reduced Power Level

One of the main goals was to increase the energy to 5.6 GeV and to reduce the power consumption at the same time, although in DORIS I the bending magnets already ran into severe iron saturation at 5 GeV (8 %).[2] More bending magnets could not be used, because then it would have been necessary for the synchrotron radiation ports to be shifted. The way out[5] was to reduce the pole width and the gap height of the bending magnets (see Fig. 1).

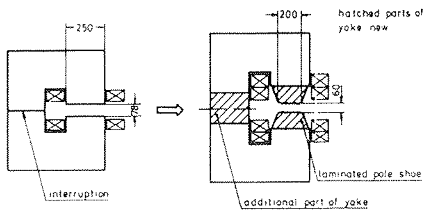

Fig. 1 Old and new bending magnets

To reduce power consumption, the number of coils per magnet was doubled, using the coils from those bending magnets of the double ring, which were no longer needed. To reduce the power consumption even more, the aperture of 40 quadrupoles (out of 68) was also reduced (from 160 mm to 110 mm), and ten 5-cell cavities were used instead of eight as in DORIS I. So altogether DORIS II needs about half the power that DORIS I needed at the same energy.

Most runs for experimental physics are performed at 5 GeV. In a short trial 5.3 GeV and a luminosity of 10^{31}cm^{-2} sec^{-1} have been achieved without any difficulty.

Mini-Beta-Scheme

The desired luminosity of $L > 10^{31}$ cm^{-2} sec^{-1} around 5 GeV can be reached by a very small waist in the two interaction regions. Vertically strong focussing quadrupoles with a focal length of about 1 m are located at a distance of 1.23 m from the interaction point. The beta-function can be reduced to $\beta_z^* = 3$ cm vertically and $\beta_x^* = 40$ cm horizontally. The limit is mainly given by the resulting chromaticity of - 25 for both planes.

Because of the small distance from the interaction points, the mini-beta quadrupoles can penetrate the particle detectors. Whereas there is no problem in the northern interaction region, where the non-magnetic CRYSTAL BALL experiment is located, the mini-beta quads practically are part of the magnetic detector ARGUS in the southern interaction region. The quadrupoles are inserted into the iron yoke, and nearly 1/3 of the magnets reach into the inner space of the set-up (see Fig. 2).

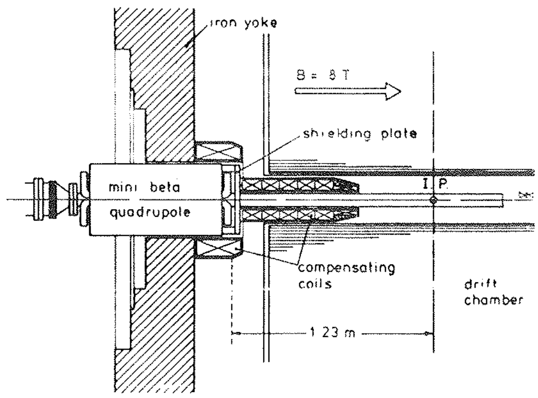

Fig. 2 Mini-beta quadrupole inserted into the magnetic detector ARGUS

The magnetic field of ARGUS must not penetrate the quadrupoles. Therefore they are surrounded by a compensating coil and shielded by a 3 cm iron plate at the front plane. Another set of coils mounted at these plates compensates the influence of the ARGUS field on the beam to 87 %. The residual detector field in the quadrupole yoke, however, would decrease the magnet strength due to iron saturation. Therefore a small power supply adds an additional current of some amperes to the mini-beta quadrupoles on the ARGUS side. This current is empirically so adjusted, that the tune of the machine is independent of the ARGUS field. Measurements of the beta-function and the luminosity show that DORIS II remains symmetric inspite of the ARGUS field under these conditions.

Vacuum System and Higher Order Mode Losses

DORSI II is equipped with a new vacuum system which consists of stainless steel chambers with copper absorbers and water cooling brazed on the chambers (see Fig. 3).

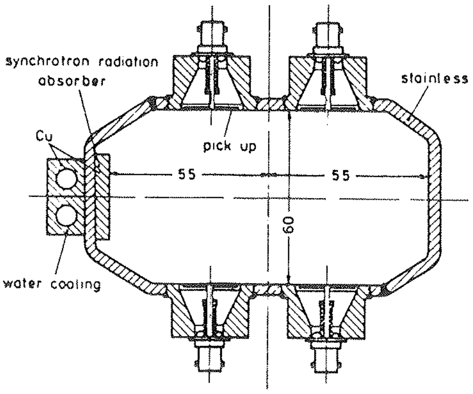

Fig. 3 Cross section of the standard vacuum chamber with position monitor

All the vacuum chambers were made as smooth as possible to avoid instabilities and higher order mode losses. But there were two exceptions: the septum magnets and some of the valves, for which existing elements were used. We soon found that these had to be replaced, however, because during longer runs with currents of $I > 2x20$ mA, a strong increase of gas desorption was observed due to heating of these elements by higher order mode losses. This reduced the beam lifetime to approximately one hour.

At present single bunch currents of $I = 2x30$ mA can be stored reproducibly at 5 GeV. The average vacuum pressure increases from $2x10^{-9}$ mbar at zero current to about $8x10^{-9}$ mbar at full current. This yields a beam lifetime of approximately 4 hours. At lower currents or during multi-bunch runs for synchrotron radiation users the lifetime is about 10 h.

Inspite of the careful design the vacuum chamber gets very hot during longer runs with average currents of 2x25 mA. This leads to movements of all the chambers. Once a horizontal movement of nearly 1 mm was observed, even at a place where the vacuum chamber is fixed to a bending magnet.

Magnet Lattice and Optics

Because the synchrotron radiation ports could not be moved from their DORIS I position, the bending magnets also had to remain at the same places. Thus only some quadrupoles could be shifted to get more room for sextupoles and separator plates. There is still a vertical bending on both sides of the interaction points to prevent the synchrotron radiation produced in the last horizontal bending magnet from illuminating them (see Fig. 4).

The beam axis is lowered by only 200 mm instead of 400 mm as in DORIS I. So less vertical dispersion is generated, and therefore the vertical emittance is much smaller than it was. The ratio of vertical to horizontal emittance is measured to be ~ 1 %.

The interaction points are easily shielded from the low intensity synchrotron radiation from the weak vertical bending magnets by some fixed and movable absorbers (see Fig. 4). Thus there is no synchrotron radiation background in the experiments.

From the optical point of view, the most difficult problems are to compensate the chromaticity and to get the horizontal beam size small enough to fit the aperture. Therefore dispersion has to be accepted all over the ring. It is about 1 m in the cavities and .4 m in

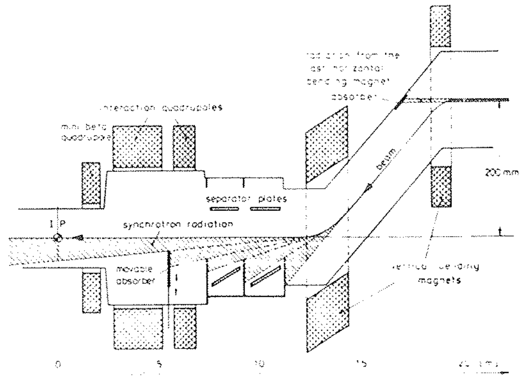

Fig. 4 Vertical bending with synchrotron radiation, absorbers, separator plates

the interaction points. By this satellite resonances may be excited.[6] But up to now they can be avoided.

The working point is $Q_x = 7.120$ and $Q_z = 5.262$. It turned out that here the machine is free from resonances in a region of $\Delta Q \simeq .005$ in both planes with colliding single bunch currents of 2x30 mA.

Due to the small beta-functions at the interaction point of $\beta^*_z = .04$ m and $\beta^*_x = .6$ m (measured $\beta^*_z = .045$ m, $\beta^*_x = .75$ m) the chromaticity is rather large: $\xi_x = -19.6$ and $\xi_z = -21.6$. It is compensated by 4 sextupole families. The optimum strength was investigated by tracking calculations. A simpler optics is used for dedicated synchrotron radiation runs.

Injection

A severe drawback of DORIS I was that the maximum injection energy was limited to about 4.7 GeV. Energy ramping with solid magnets is a difficult and tedious task, especially due to eddy currents. Therefore the whole injection system including the transport channels between the synchrotron and DORIS II has been significantly improved. The new system allows particle injection at every running energy of the machine up to 5.6 GeV. All injection elements operate reliably and stably. At constant injection energy the system requires no corrections over several days. The following data were achieved during colliding beam runs.

injection rep.-rate	f_0	= 8.33 Hz (e^+ and e^-)
max. injection rate	di/dt	= 1 - 3.5 mA (e^+ and e^-)
efficiency	η	> 90 %
filling time	t	< 1 min (2x32 mA)

There are electrostatic plates installed in DORIS II (see Fig. 4) to separate the beams at the interaction point during injection, but up to now the beam-beam limit has not been reached at 5 GeV, and therefore these plates have not been used.

Maximum Currents

The single bunch current is limited to about 15 mA at 5 Gev by a coherent transverse instability excited by the accelerating cavities. This had been observed already in DORIS I.[2] A narrowband feedback system allows more than 50 mA to be stored. This limit is not fundamental but is due to various technical difficulties.

During dedicated runs for synchrotron radiation experiments the machine is filled by many electron bunches (up to 480). Under these conditions a maximum current of 120 mA has been obtained at 3.7 GeV. It is limited by transverse multibunch instabilities due to cavity resonances. We plan to try using a narrowband feedback system to overcome this difficulty.

Luminosity

Although the magnet lattice allows a vertical amplitude function at the interaction point of β^*_z = 3 cm, a more moderate optics with β^*_z = 4 cm has been used for luminosity runs up to now. The resulting luminosity at 5 GeV per beam is shown in Fig. 5.

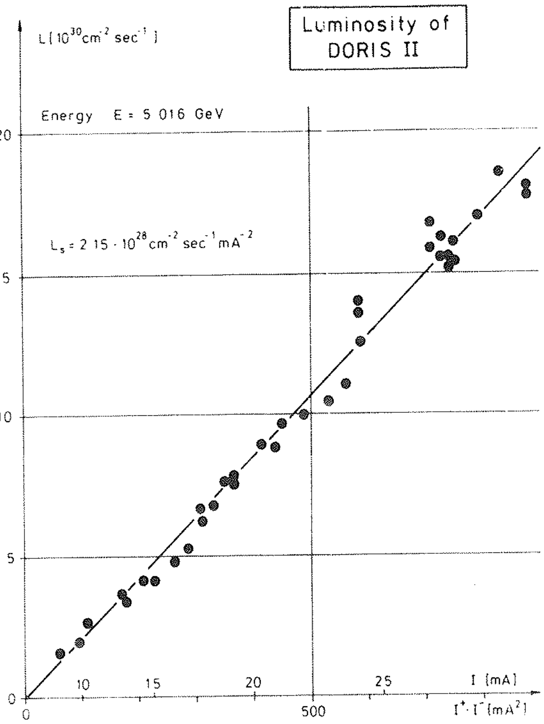

Fig. 5 Luminosity as a function of current

Most of these data were taken during normal runs for high energy physics. At present a typical run is started with currents of 2x30 mA and ended at 2x20 mA. So the machine is refilled approximately every 2 h, and the filling time is only minutes. In this way an integrated luminosity of more than 1000 $(nb)^{-1}$/day has been achieved.

The tune shift due to beam-beam interaction at 2x30 mA is ΔQ_z = .026. According to Fig. 5 this is obviously not the limit.

As Fig. 5 shows the specific luminosity is independent of the current. But this is not always true. There are runs during which the specific luminosity changes by a factor of about 1.5. The specific luminosity rather critically depends on the tune of the machine. Including this and breakdown of technical components an average integrated luminosity around 600 $(nb)^{-1}$/day has been obtained at 5 GeV.

Beam Polarization

In electron-positron storage rings the beams become polarized by the Sokolov-Ternov effect. In DORIS II during normal colliding beam runs, the degree of polarization was measured[7] to be (78±7) %. To avoid depolarization the longitudinal magnetic field of the ARGUS-detector was compensated, but only to 87 %.

By resonant excitation the polarization can be destroyed. Fig. 6 shows the very sharp depolarization curve. The resonance frequency depends on the energy of the storage ring. Therefore the beam energy for the Y'-resonance could be measured[8] very accurately and was found to be (5011.7±.3) MeV. This value is in agreement with (5016±5) MeV obtained from magnetic field measurements of the bending magnets.

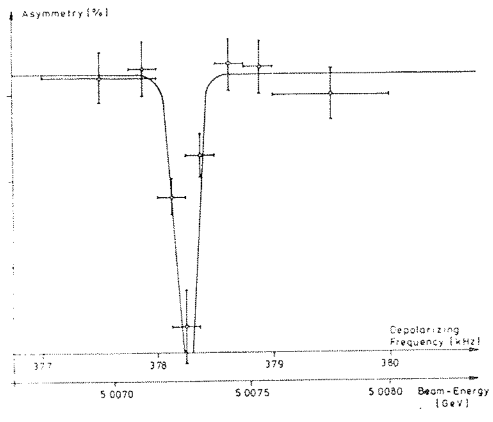

Fig. 6 Depolarizing resonance

Acknowledgement

The authors thank the members of the machine staff whose efforts and experiences made possible good and stable machine conditions as well as high luminosities. We also thank the beam polarization group for the measurements of the polarization and the energy of DORIS II. But above all they thank Prof. G.-A. Voss for his support and encouragement and for many very helpful remarks and discussions.

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