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DORIS AT 2 × 5 GeV

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Abstract

During the last year the e^-e^+-storage ring DORIS was changed from a 2 × 3,5 GeV double ring with 2 × 480 bunches circulating to a single ring single bunch machine with a maximum energy of 2 × 5.1 GeV. The modifications in the magnet structure and of the rf system are described. The main problems at higher energies were due to magnet saturation and insufficient sextupole strength. To overcome transverse instabilities, a feedback system had to be used. Experimental data in the c.m. energy range of 9.5 to 10.1 GeV were taken successfully with luminosities up to 25 nb^{-1} per day.

Introduction

Recently a broad structure in the invariant mass distribution of muon pairs produced in proton interactions has been observed (1). One possibility was to interpret this structure as a new quark-antiquark bound state, called Υ-particle, and its excited state. The best way to test the correctness of this interpretation and to study the properties of this structure was to produce it in e^+e^- annihilation. Immediately after the discovery of the new structure the DORIS group started preparations to increase the particle center of mass energy of the storage ring DORIS up to the Υ-region. Plans for this had existed since 1973.(2)

The electron-positron storage ring DORIS was originally designed as a double ring with vertical crossing for energies up to 2 × 3.5 GeV.(3)...(5)

The limitation of the energy had three reasons:

i. Saturation of magnets
ii. Insufficient rf voltage
iii. Increasing background from synchrotron radiation above 2 × 3.2 GeV.

Another technical limitation was given by the lack of power supplies for magnet excitation.

Most of these problems could be solved by changing the double ring-multibunch machine to a single ring single bunch machine with head on collisions. (6)

The new vertical bending section

The two high energy detectors DASP and PLUTO have a fixed position and it was therefore necessary to maintain the vertical bending on both sides of the interaction regions. Fig. 1 shows a comparison of the vertical bending in the double ring and in the single ring.

In the single ring the beams pass the interaction quadrupoles on axis, i.e. without vertical bending. The beam then passes through a weak dipole magnet with a large vertical bending radius. This slight bending around the interaction region leads to a considerable reduction in the synchrotron radiation background if compared with the double ring.

In the old arrangement quadrupoles would be seriously saturated when operating at 5 GeV. Hence, the quadrupole strength had to be reduced or in other words the focus length had to be increased. This was affected by the 0.8 m position shift as shown in fig. 1. As a consequence the saturation was reduced to 3.6 % at 5 GeV.

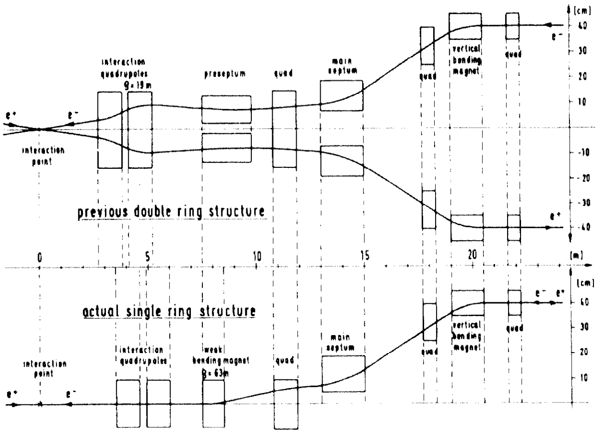

Fig.1 Comparison of the vertical bending in the double and the single ring structure

To reduce the saturation effect in normal cells a new optic was developed. Fig. 2 demonstrates the advantage of this optic at 5 GeV over the old double ring optic.

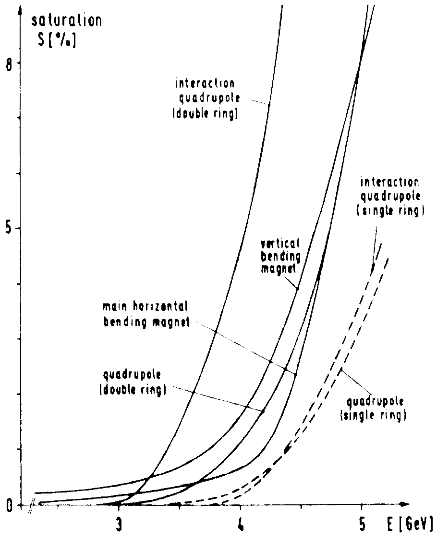

Fig.2 Saturation of the most excited magnets in the double and the single ring structure

The correction of the remaining saturation effects is done by the DORIS-computer. The excitation curves are stored in the computer in the form of measured values. If the energy is increased the current of the magnets is altered nonlinearly.

Chromaticity correction

In order to stabilize the beam against the head tail effect, the chromaticity in DORIS is compensated by sextupoles. To avoid strong nonlinearity in the particle motion caused by high sextupole strengths, sextupole windings in quadrupoles were used in addition to strong sextupole magnets. This resulted in a more even distribution of the nonlinear fields.

These additional sextupoles in the quadrupoles were limited in their sextupole strength at a rather low level. At high energy only the strong sextupoles were effective.

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Therefore the arrangement of sextupoles for minimum higher order perturbation of the linear motion and for maximum stable particle emittances had to be carefully optimized with a tracking program.

From this program the expected acceptance of the machine (∿ 40πmmmrad) is only slightly larger than the beam emittance at 5 GeV for 6.5 standard deviations (25πmmmrad). A good orbit correction was therefore necessary to achieve stable operating conditions.

RF-system for single ring operation of DORIS

To increase the energy of DORIS it was necessary to modify the rf-system. The original 12 single cell DORIS cavities were replaced by 8 inductively coupled five cell PETRA cavities (7) with a shunt impedance of 18 MΩ per cavity. Each is driven by 125 kW rf-power. This increases the accelerating peak voltage up to 16MV. With this it was possible to achieve a maximum beam energy of 5.1 GeV.

Table: Main rf-parameters for the single ring operation of DORIS at high energies

Particle energy	E(GeV)	5.1
No. of PETRA cavities		8
Radiation loss per turn	U_r(MeV)	4.77
Synchronous phase angle	ϕ_s(deg)	27.5
Peak acc. voltage	$\hat{U}_c$(MV)	11.9
Total rf-power	P_{HF}(kW)	1000
Dissipated power in cavities	P_c(kW)	490
Beam power	P_b(kW)	410
Power loss due to parasitic modes	P_{PM}(kW)	60
Additional rf-power (waveguide loss, mismatch etc.)	P_L(kW)	100
Total rf-limited beam current	2 × I_b(mA)	73.5

Vacuum system

Extensive modifications in the vacuum system were needed to permit the single-ring operation. The upper half-rings had to be modified to take care of the additional beam now circulating in reverse direction in a common vacuum chamber.

The main task was to protect all components and vacuum chambers with watercooled synchrotron radiation absorbers.

All new absorbers were designed to provide adequate cooling for a synchrotron radiation thermal load of 180 kW from each circulating beam (2 × 40 mA at 5 GeV).

Power supply and cooling

Instead of the original DORIS power supply for the bending magnets, a new power supply was used. With this power supply the currents could be increased by a factor of 1.55 as compared with the original value.

For an operation at 5 GeV the water quantities had to be adapted to the needs of the new system by increasing the pressure from 6 to 12 bar. But even with this high pressure the operation temperature of the magnets had to be increased up to 75°C and the threshold for the thermal interlock from 75 to 90°C.

Instabilities

Coherent transverse instabilities limit the maximum average current of the two bunches in the single ring structure. The instability limit depends on the sum of both beam currents and is almost independent of the ratio of the two bunch currents. The instability threshold is between 15 and 25 mA and depends mainly on the tuning of the cavities and the working point of the machine.

In order to damp these coherent transverse beam oscillations and to achieve higher currents a narrow-band bunch-by-bunch feedback system was installed.(8)

The damping effect of the feedback system is shown in fig. 3.

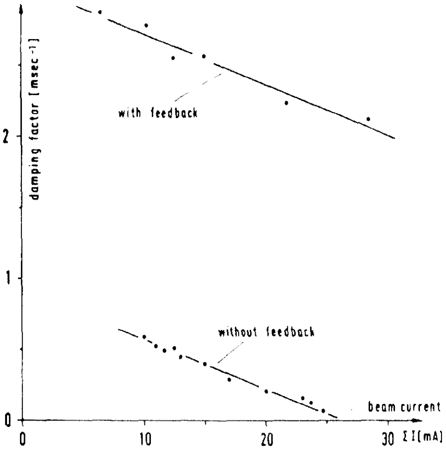

Fig.3 Damping factor of horizontal coherent beam oscillations measured at DORIS at an energy of 4.6 GeV.

Using a high speed photodiode (9) the bunch length was measured as a function of bunch current (fig. 4) at 3.5 GeV and an rf voltage of 2.8 MV. This measurement shows that the lengthening factor R remains below 2 at currents of 25 mA/bunch. At 4.5 GeV the bunch lengthening was measured during the luminosity runs. No significant lengthening was detected between 10 mA and 23 mA/bunch.

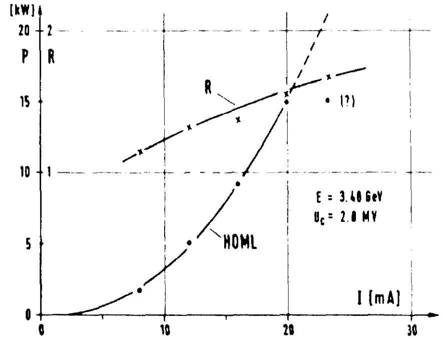

Fig.4 Higher order mode losses (HOML) and bunchlengthening factor R as a function of bunch current.

The higher order mode losses were measured by observing the phase shift of the center of bunch charge with respect to the phase of the master oscillator of the rf-system as a function of current (fig. 4).

This measurement was performed at 3.5 GeV with 8 DORIS cavities and 2 PETRA cavities.

From these data and the theory of cavity losses (10) it could be concluded that the power dissipated in the vacuum chamber was less than 12 kW for a current of 25 mA in one bunch.

Beam-Beam Interaction

The tune shift can be measured directly. The betatron frequency is excited weakly and the coherent signal is measured with a loop. Fig. 5 shows the two eigenfrequencies of the two bunches which are coupled by the space charge forces. The difference in the frequencies is the coherent tune shift per ring (11).

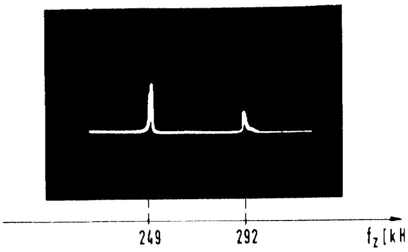

Fig.5 Splitting of the vertical betatron frequency due to the beam-beam interaction (energy $E = 4.6$ GeV $f_0 = 1041$ kHz)

Fig. 6 shows the dependence of the horizontal and vertical coherent tune shifts per ring on the bunch currents.

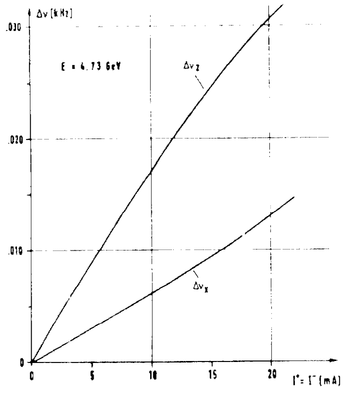

Fig.6 Dependence of the coherent tune shifts on the bunch current with two interaction regions

Operating experience

The first run period at center of mass energies of between 9.35 GeV and 9.47 GeV lasted about four weeks and the second run at center of mass energies of 9.8 GeV and 10.14 GeV another four weeks.

In both runs the injection energy was 4.6 GeV per beam. Single bunch injection rates of 6 mA/min for positrons and about 10 mA/min for electrons were achieved. The total injection time (magnet training program and filling time) was normally less than 30 minutes. The time interval between two filling procedures was about 2 to 3 hours.

Currents of about 20 mA per bunch were usually stored. At higher currents the gas pressure increases rapidly. As a consequence, the beam lifetime became less than 2 hours and the background in the experimental areas increases to a very high value. This practical beam limit is lower than the well known beam-beam limit. It is therefore not necessary to separate the two beams by separation plates during injection. The initial value of the luminosity at the maximum beam currents was about $L = 1 \times 10^{30} \mathrm{cm}^{-2}\mathrm{sec}^{-1}$ and at the end of a run normally about $L \approx 3 \times 10^{29}$ $\mathrm{cm}^{-2}\mathrm{sec}^{-1}$.

The measured luminosities agree within 20 % with the calculated values wherein the horizontal and vertical dispersions at the interaction point are taken into account.

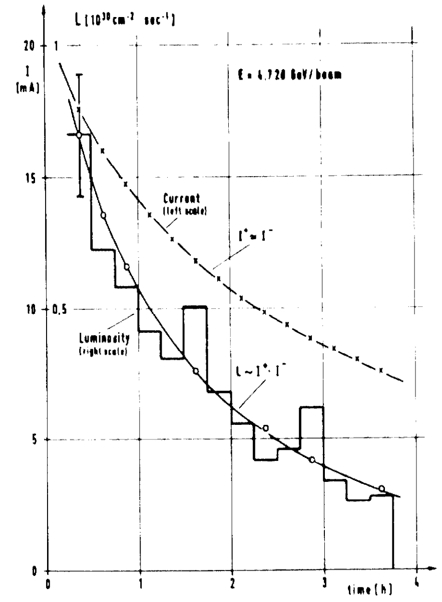

Fig.7 Luminosity at interaction point 2 and beam currents VS. time (error flag contains only statistics)

$\left[\int_{run} L\,dt = 4.7\ \mathrm{nb}^{-1} \ \hat{=}\ \text{ca } 45\ \Upsilon\text{- events}\right]$

The behaviour of luminosity and currents during a special filling of about 4 hours duration is shown in fig. 7. The slope of the curve is in good agreement with a $L \sim i^+ \times i^-$ dependence. Both bunches had nearly the same current over the whole period.

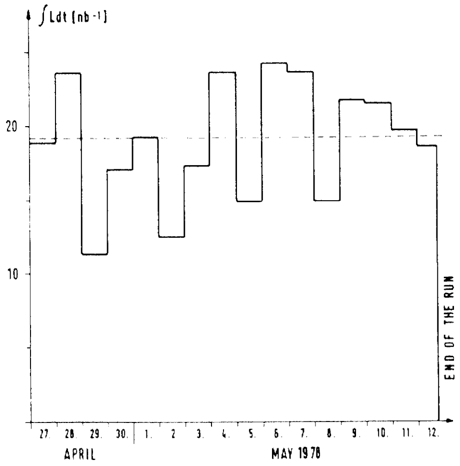

Fig.8 Integrated Luminosity per interaction point averaged over one day

The integrated luminosity per interaction point for a certain run period is shown in fig. 8. The values have been averaged over one day.

References

1) S.W. Herb et al.: Phys.Rev.Lett. 39(1977) 252
2) G.Mülhaupt,H.Wiedemann: DESY H5-74/1 (1974)
3) DESY Storage Ring Group: Stanford, p.43, 1974
4) G.Mülhaupt: Proc.Accel.Conf. Moskau,p.345,1974
5) DESY Storage Ring Group: Serpukhov,V.I,p.458, 1977
6) DORIS Group: DESY 79/08
7) H. Gerke et al.: DESY PET-77/08 (1977)
8) K. Wille: These proceedings
9) R.D. Kohaupt: DESY 77/66 (1977)
10) A.W. Chao: PEP-118 (April 1975)
11) A. Piwinski: DESY H2-75/3 (1975)