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REPORT ON DORIS

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Summary

The double storage ring DORIS has been in operation since the beginning of 1974. Colliding beam experiments started in November of 1974. Luminosities of $10^{30}\,cm^{-2}s^{-1}$ at 2 GeV are routinely reached during experimental runs. Beam life times are 8 to 11 hours. At the present time luminosity is limited by phase instabilities.

Introduction

The DORIS-storage ring for electrons and positrons has been described in various reports. 1),2). Main feature of DORIS is the complete separation of the two stored beams in two vertically stacked storage rings. Only in the two interaction regions where beams cross at an angle of 24 mrad and in the adjacent quadrupoles are the two beams in the same vacuum pipe. (Fig.1)

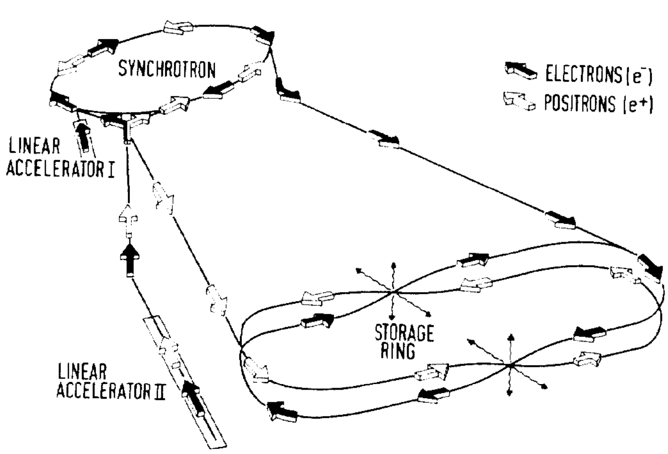

Fig.1

This arrangement allows the use of many bunches in each beam-a particular advantage at lower energies, where beam currents are limited by beam-beam space charge effects. The double ring feature also allows investigation of electron-electron and positron-positron collisions, and even collisions with protons will be possible in an experiment presently under preparation. The radio-frequency system, which compensates the radiation loss in each ring, works on the 480 th harmonic, at 500 MHz. During normal operation almost all of the 480 rf buckets are filled with particle bunches. DORIS is filled from the synchrotron DESY. Two linear accelerators at DESY inject electrons and positrons on a pulse-to-pulse basis such that both DORIS rings can be filled simultaneously. A brief summary of the main parameters is given in Fig.2.

DORIS Parameters

double storage ring with vertical crossing

crossing angle		24 mrad
no. of interaction points		2
circumference		288 m
radius of curvature in horizontal bending magnets		12 m
rf frequency		500 MHz
harmonic number		480

present operating conditions

working point	Q_x	7.24
	Q_z	5.18
max. amplitude functions	$\beta_{x\,max}$	25 m
	$\beta_{z\,max}$	60 m
amplitude functions at interaction point	β_x	0,3 m
	β_z	1,3 m
beam dimensions at interaction point at 2 GeV	$2\sigma_x$	1 mm
	$2\sigma_z$	.4 mm
rf power per ring		750 KW
no. of cavities per ring		12
shunt impedance		36 MΩ
max. rf voltage		7 MV
injection rate at 25 % efficiency	e^-	30 mA/sec
	e^+	2 mA/sec

Fig.2

First beams were stored in DORIS on Dec.20,1973. During most of 1974, machine development was going on with the aim to suppress certain types of instabilities and to increase the luminosity. This work was interrupted with the discovery of the new resonances. Since November of 1974 DORIS ran almost exclusively for experiments. The first physics results were published in Dec.74 and further results were presented at the APS meeting in Anaheim, Cal. on Jan.29,1975. Among these were measurements of the e^+e^-, $\mu^+\mu^-$ and $p\bar{p}$ decay modes of the 3.1 resonance and searches for neutral decays; upper limits on $\gamma\gamma$, $\pi^0\gamma$ and $x_0\gamma$, where x_0 decays into $\gamma\gamma$ have been obtained.

Present status

DORIS has been built for a peak energy of 3.5 GeV. During 1974 this energy was successfully reached. But most of the work on DORIS which I am going to desccribe was done at energies between 1.5 and 2 GeV.

Multicycle injection from the synchrotron DESY is done with injection effiencies up to 80%. Typical injection rates are 2 mA/s for positrons and 30 mA/s for electrons. Filling of the DORIS-rings is done in a parasitic operation, in which the main synchrotron users temporarily receive a reduced number of pulses, while the filling goes on.

The largest accumulated and stored average currents in DORIS were .9 A for electrons and .5 A for positrons. The average electron current reached in a single bunch operation, as was tried in certain machine investigations, was >10 mA. (The peak current within the bunch, of course, was much larger, about 100 A). These currents were reached after certain problems and beam instabilities had been eliminated:

Single bunch instabilities of the head-tail type were observed at average bunch currents of .25 mA. The elimination of these betatron instabilities through chromaticity compensation with sextupoles was not so easy at the beginning, because only a limited number of places for the installation of sextupoles was available. After changing the original DORIS optics, which only had dispersion in the area of the bending magnets, to one where the dispersion is carried all around the ring, and by using pole face windings in quadrupoles designed to give sextupole fields, it was possible to provide for an entirely satisfactory chromaticity compensation. This resulted in the suppression of the head-tail-type-instabilities.

Another very bothersome type of instability was produced by higher mode excitation in the rf-cavities. In particular, excitation of the lower TM-modes led to large betatron and phase instabilities. In contrast to the head-tail type instabilities, these were clearly dependent only on the average total current. Through installation of damping antennas in the cavities in locations where they do not affect the fundamental accelerating mode, it was possible to lower the Q of the strongest higher modes by factors up to 2000. Additional ferrite absorbers in the vacuum pipes outside of the cavities suppress the modes with frequencies higher than 1300 MHz. Through these measures most of the offending instabilities could be completely eliminated.The few remaining ones are only observed at large currents and can be avoided by the right tune of the cavities.

Ion accumulation in the electron ring presented some difficulties at the beginning. It caused a Q-shift of the stored electron beam and an enlargement of the vertical beam size. The ion clearing electrodes were not able to completely sweep out the ions produced by the circulating electron beam. As the vacuum gradually improved, this effect became less dominant. By not completely filling all available rf buckets, but leaving a gap of about 5% in the circumferential filling, this effect is now no longer observed.

Besides these identified and cured problems there are instabilities observed at high currents for which the cause is still not well understood. A betatron instability, which mostly occurs in the vertical plane and for which a large number of modes is grouped within a 50 MHz interval around the fundamental accelerating frequency of 500 MHz, has been called the "multi-mode instability". It occurs at beam currents larger than 20-70 mA. Its dependence on other machine parameters is not well understood. The multi-mode instability does not lead to a beam loss but to a vertical beam enlargement which in turn, of course, leads to a reduction of luminosity. This instability could be successfully eliminated up to currents of 450 mA through the use of an rf quadrupole, which produces a systematic Q-variation of 0.03 in different parts of the circumferential filling.

The present limit to which currents can be accumulated seems to be given by unidentified phase oscillations. Like the multi-mode-instability these phase instabilities do not lead to beam loss but to an increase in momentum spread and the corresponding increase in bunch length. A major part of this effect manifests itself in coherent oscillations in many modes, which so far could not be clearly associated with any particular component of the vacuum system. This bunch length increase causes a reduction in luminosity because of the crossing beam arrangement. The associated beam widening causes a reduction of beam lifetime during injection and thereby a limitation of the current which can be accumulated. An effective way to improve this situation is the decoupling of bunch motions through a second radio frequency system operating on a different harmonic number. Since DORIS has three transmitters in each ring, it is easy to operate one on the 479th harmonic (instead of the 480th). The newly discovered resonances provide - because of their narrow width - an excellent tool to study the inherent beam width of the stored beams. Fig.3 shows the first of the two resonances, which at DORIS is found to be at an energy of 3090 MeV. The measured energy width of 1.7 MeV (f.w.h.m.) corresponds closely to the theoretical number of 1.76 MeV. Without decoupling transmitter the measured cross section at the maximum may decrease by as much as a factor of 3, implying an increase in energy width by this factor.

Beam-beam interaction was observed at 1.5 GeV with bunch currents corresponding to average currents of 500 mA. The effect of the strong beam was the creation of a large number of additional resonances in the other beam. Each of these resonances was strong enough to cause very short life time. But since the relative alignment of the two beams with respect to each other at the two interaction points was not well controlled during this experiment, it is too early to say whether this is the real space charge limit in this cros-

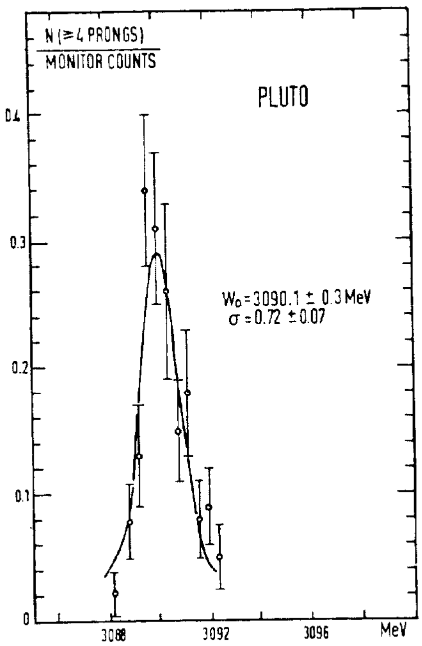

Fig.3 3090 MeV resonance, measured with the superconducting detector PLUTO .

sing beam arrangement. Beam-beam interaction has generally not been the luminosity limiting effect.

Besides these instability problems certain other difficulties had to be overcome before high energy physics runs could successfully commence. One of the difficulties with a double ring is the fact that there is no compelling reason why the two beams should meet at the interaction points:

Both rings are independent to a large degree: and the smallness of the beam cross sections at the interaction points (.8 mm wide and .2 mm high f.w.h.m.), together with the independence of the rf phases in both rings, requires a certain technique to bring those two beams to collision. The most favored method at present is the measurement of the tune shift produced by one beam on the other.

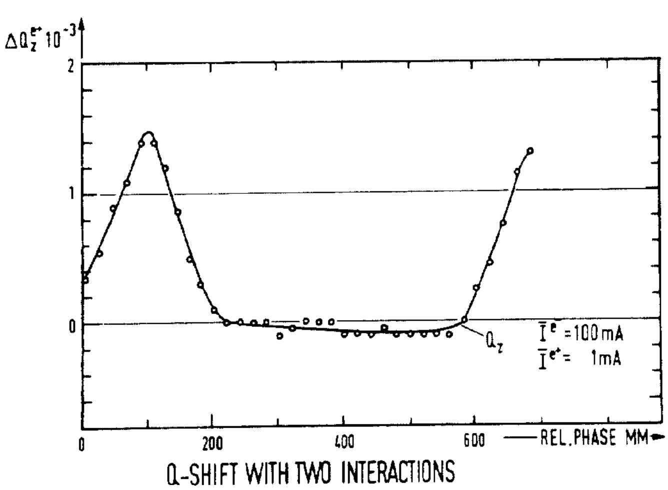

Fig.4

Fig.4 shows the measured Q-value as function of the phase position of the other beam. This method will be replaced shortly by a fast luminosity measurement based on Bhaba scattering at very small angles. At the present time DORIS runs routinely with peak luminosities of $10^{30} cm^{-2} s^{-1}$ at energies of 2 GeV. The lifetime of the beams is between 8 and 11 hours and is still improving. Average luminosities close to 35% of the peak luminosity are observed over time intervals of several days.

Three experimental set-ups have been used so far for colliding beam experimentation at DORIS, and change-over between experiments has been done within a normal maintenance period of 4 days. This is accomplished by the fact that all experiments are mounted on wheels and can be moved in and out of the interaction regions without too much trouble. One of the three experiments uses the superconducting magnet PLUTO. This magnet produces a 1.15 m long 20 kG field in the beam direction at the interaction point. This field is in its coupling effect compensated for by two shorter superconducting coils at either end of the detector, which ensure that the integral of B dl along the beam direction is zero. It may be interesting to point out that no adverse effects on the beams or on the luminosity were observed when the magnetic field was turned on.

In a 6-weeks shut down this summer the injection systems will be upgraded to allow injection up to 5 GeV. (The present system is limited to 2.1 GeV). With this change the necessity for the energy ramping of the DORIS rings will be eliminated when energies higher than 2.1 GeV are required. Energy ramping has been somewhat troublesome for the routine operation, because of the required time and some difficulties in cycling the solid core magnets in a reproducable way. Higher injection energies will have the added advantage of the much higher thresholds for the remaining beam instabilities.

At present the peak energy of DORIS is limited by the main magnet power supply, which will be replaced by a larger one during the summer of 1975. After this replacement the peak energy presumably will be limited to energies of 4.2 GeV by the available radio frequency accelerating voltage. High shunt impedance rf-cavities as they are needed for the proposed PETRA-project, might raise the energy limit to close to 5 GeV sometime during 1976.

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