STATUS REPORT ON THE ELECTRON-POSITRON STORAGE RING ADONE

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Summary

Data on the first year of operation and on recent bunch length and luminosity measurements at the electron-positron 1.5 GeV/beam storage ring Adone are presented.

ADONE operation for experiments

ADONE operation for experiments started in December 1969. The normal mode of operation has been, up to now, two beam head-on collision with energy ranging between 0.7 and 1.2 GeV/beam. The energy limitation is due to available RF power: only one of the two RF cavities is installed. The second cavity will be installed in March, extending the energy range to 1.5 GeV/beam.

Four experimental sections are used, at one time, by high energy physics experiments. Recently the injector Linac has started running for nuclear physics experiments, in between injections, since, on average, only 2-3 injections in 24 hours are made.

The effective machine time for experiments during 1970, defined as the time during which experiments have taken data, has been as follows:

Two beams effective time	2360 hours
One beam effective time (background meas.)	240 hours
Available machine time	5000 hours
Machine studies assigned time	500 hours.

At energies higher than 850 MeV/beam the design values of luminosity have been attained or exceeded.

Fig. 1 shows the average luminosity per crossing as a function of energy. Fig. 2 shows the integrated luminosity per crossing (all energies) as a function of time. It should be borne in mind that its slope also depends on the average working energy during each period. It can be seen that the total integrated luminosity/crossing at the end of December 1970 was

$$L^{tot}_{i/crossing} = 6.7 \times 10^{35} \ cm^{-2} .$$

Since four crossing are producing luminosity at the same time the total integrated luminosity produced by Adone was

$$L^{tot}_{i} = 2.7 \times 10^{36} \ cm^{-2} .$$

The luminosity averaged over all energies and over the first year of operation has been: $3 \times 10^{32} cm^{-2} h^{-1}$.

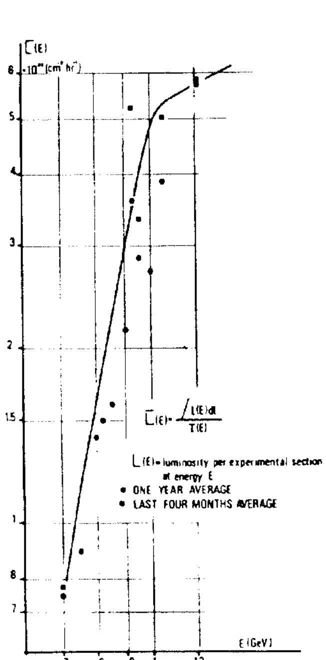

Fig. 1

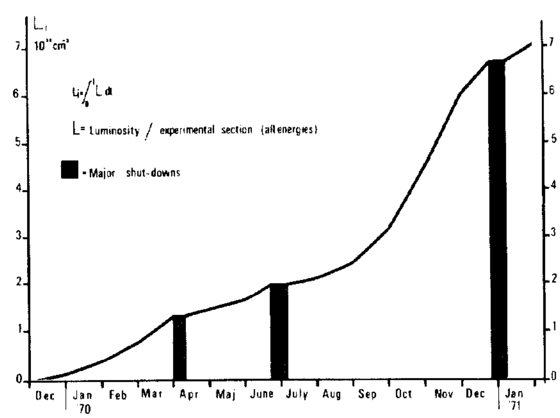

Fig. 2

Vacuum

About 200 Kcoulomb have been circulated through the chamber since the last opening. The static vacuum is around 2×10^{-10} torr over most of the machine (the chamber total surface is $\sim 150 \ m^2$ and the pumping speed 7000 l/s). The gas composition, with beam on, is as follows :

H_2, H	45 %
H_2O	8 %
CO	31 %
CO_2, C, CH_4, OH, ..	16 %.

The best value of pressure increase with current is $\Delta p/i = 1 \times 10^{-11}$ torr/mA at 1 GeV and its dependence on energy is in agreement with the Bernardini-Malter[1] assumptions. The value of $p \langle Z^2 \rangle^{1/2}$ with beam, as given by bremsstrahlung measurements, is ~ 100 ntorr at 1200 MeV and with a circulating current of 12 mA. The photon desorption efficiency DE_γ is found to be

$$DE_\gamma \cong 3 \times 10^{-6} \text{ mol. /photon}$$

in good agreement with ACO and CEA data.

An appendix to the vacuum chamber, in which it will be possible to carry out tests on desorption efficiency and surface treatments, under actual working conditions, is being installed.

One beam behaviour

Instabilities : Transverse instabilities of the head-tail type in the zeroth order mode are present and are controlled by means of fast radial and vertical feedbacks. An upper limit of $\sim$ 60 mA per beam exists above which, at energies lower than $\sim$ 800 MeV, the feedback is not capable of stabilizing spatially separated beams. Crossing beams are stable up to higher currents due to tha additional nonlinearities introduced by beam-beam interaction. A better performance of the feedback is desirable, and is being worked on, since these instabilities limit our luminosity, above 900 MeV.

Phase instabilities are also present and have been cured by separating the synchrotron frequencies of the three bunches and by introducing a longitudinal feedback to stabilize the zeroth order (c.m.) mode. As a substitute for the frequency separation additional feedbacks on the other modes are being worked on.

Bunch length : Measurements performed at ACO[2], Kharkov and Adone have shown that the ratio of measured to natural bunch length increases with current, and the lengthening is a function of energy and RF voltage.

We have recently repeated some measurements of the effect and the results can be summarized in the following formula :

$$\left(\frac{L}{L_r}\right)_{fwhm} = 1 + (2 \pm 0.2) \times 10^{-2} V_{KV}^{0.3 \pm 0.05} \times \frac{I_{mA}^{1.05 \pm 0.05}}{E_{GeV}^{4 \pm 0.2} L_{nS}} \qquad (1)$$

where L_r is the length due to radiation only. The formula is the result of a four parameter best fit of $\sim$ 140 points that are accurate to the order of 10%, and is similar to that given in the Nov. 1969 ACO[2] report except for the presence of $V^{0.3}$. The Kharkov formula as reported on the same ACO paper, is similar to ours but the energy dependence has not been measured. Fig. 3 shows our L/L_r data and the fit by formula (1).

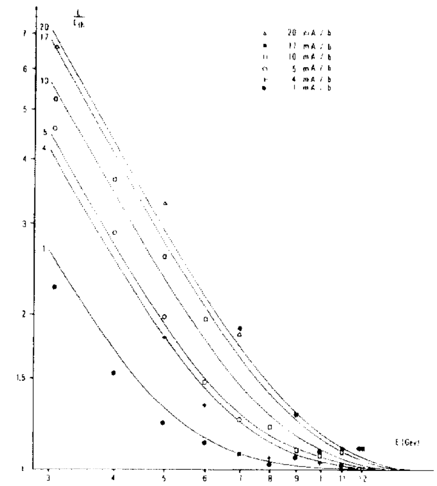

Fig. 3. Ratio between experimental and theoretical bunch length as function of energy and current per bunch.

The following features of the effect are also in agreement with the ACO results :

1) The lengthening is a function of current per bunch and not of total current.
2) It does not appear to depend on transverse density. On this point we have scant data since only a few checks were made by enlarging the beam with a sweeping oscillator.

Most remarkably we found a strong correlation between length and width of beam. Fig. 4 shows $(R/R_r)^2$ against $(L/L_r)^2$, R_r being the width due to radiation only, and R the measured width.

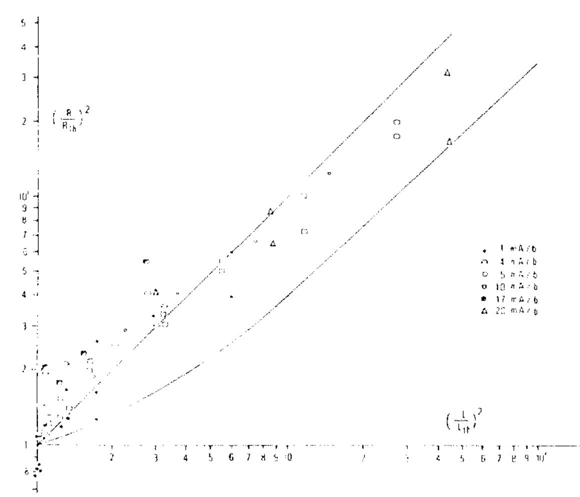

Fig. 4. Correlation between bunch width and bunch length.

Our transverse dimension measurements are affected by systematic errors on calibration and resolution, whose magnitude we can estimate to be of the order of 30% and that could vary in a quasi-random way from one series of measurements to the next. We therefore chose to plot our points without error bars intending only to evidence the correlation.

We have considered the possibilities that the anomalous width be due to the feedback when e^+'s are studied and to the ions for the e^- case but, to decide on these points, we need more accurate measurements and these are difficult to perform with our present dimension monitor. A new monitor is being built.

Several theories[3,4] have been proposed to account for this effect. The correlation between R and L rules out all theories that propose only a modification of the potential well, and no theory known to us can explain both the correlation and the functional dependences.

Luminosity measurements

Having gained a sufficient knowledge of the behaviour of the ring we have performed a series of measurements of maximum luminosity, L_{max}, maximum L/i_w and maximum $\delta Q_{R,V}$, as functions of energy. i_w is the weakest of the two circulating currents, while δQ_R and δQ_V are the radial and vertical small amplitude Q shifts produced by one crossing.

The new results differ somewhat from the preliminary ones previously reported, since measurements of maximum values are now more reliable and accurate. In fact maximum or near maximum values of L, L/i_w, and δQ can be now routinely obtained.

It can be seen from Figg. 5 and 6 that L_{max} is proportional to γ^7, $(L/i_w)_{max}$ to $\gamma^{5/2}$, and $(\delta Q_{R,V})_{max}$ to $\sim \gamma$. The values of L_{max} and $(L/i_w)_{max}$ also depend on the Q values of the unperturbed machine. It can also be seen that $(L/i_w)_{max}$ and $(\delta Q_{R,V})_{max}$ follow their power laws right up to

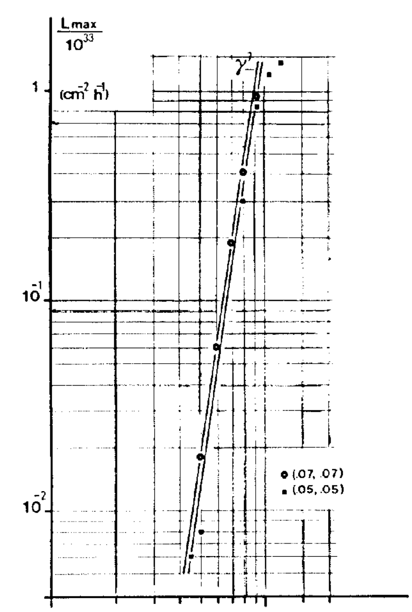

Fig. 5. Maximum luminosity as function of energy.

1200 MeV while L_{max} starts to saturate above $\sim$ 900 MeV. The values of L_{max} below $\sim$900 MeV are obtained by tuning the machine on a coupling resonance (usually (.05, .05) to (.07, .07)) and it is an experi-

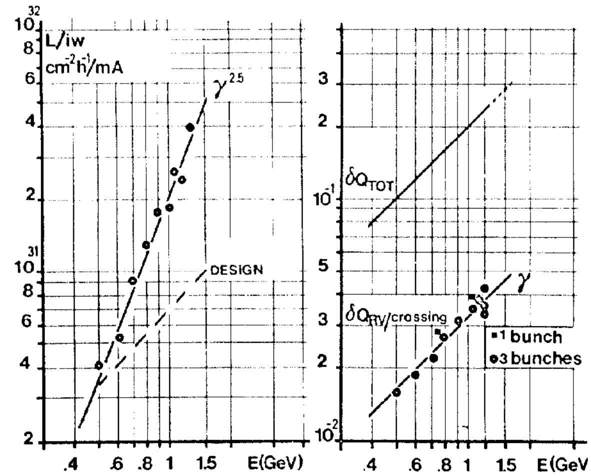

Fig. 6. L/i_w, $\delta Q_{R,V}$ per crossing and Q_{TOT} as functions of energy.

mental fact that, when a maximum value of luminosity is obtained, even a small displacement from the coupling, say a separation in the Q's of .005, results in beam loss or in sudden changes in beam shapes - with a sharp drop of luminosity.

Discussion of results : In order to discuss these results we recall that :

$$\text{a)}\ \frac{L}{i_w} \propto \frac{i}{S} \qquad \text{b)}\ L \propto \frac{i^2}{S} = i\left(\frac{L}{i_w}\right) \tag{2}$$

where S is the beam cross section.

We also recall that $\delta Q_{R,V}$ are given by the following formulas :

$$\delta Q_V\left(1 + \frac{p\,\delta Q_V}{2\Delta\nu_V}\right) \simeq \xi_V = \frac{\beta_V}{\gamma}\frac{L}{i_w}\, f(\eta)$$
$$\delta Q_R\left(1 + \frac{p\,\delta Q_R}{2\Delta\nu_R}\right) \simeq \xi_R = \xi_V \frac{\beta_R}{\beta_V}\,\eta \tag{3}$$

if $\frac{2\pi\Delta\nu}{p} \ll 1$ and $2\pi\,\delta Q \ll 1$

where : $\Delta\nu = Q - \mathrm{INT}(Q)$; $\eta = \sigma_z/\sigma_x$; $f(\eta) = \frac{2\,e\,r_0}{(1+\eta)}$

p is the number of crossings around the ring, $\beta_{R,V}$ are the usual betatron wavelengths and $\sigma_{x,z}$ the standard radial and vertical beam widths. In our machine $p\,\Delta Q_{R,V}/2\Delta\nu \approx 1$ so that the usual approximation of neglecting it with respect to 1 is not appropriate.

It is usually believed that the maximum obtainable luminosity is limited by the existence of a value of $\delta Q_{R,V}$ (or of $\xi_{R,V}$) that can not be exceeded. If the maximum value of $\delta Q_{R,V}$ for a given $\Delta\nu$, is independent of energy, it can be seen from (3) that $(L/i_w)_{max}$ must be a linear function of γ. It follows from (2b) that L_{max} should be proportional to $\gamma \cdot i$, and from (2a) that, since if one works on a coupling resonance S is proportional to γ^2, i can be increased like γ^3. It follows eventually that L_{max} should increase with energy like γ^4. It also follows from what said that, leaving for the moment artificial methods to increase the beam incoherent cross-section aside, the maximum value of L should be obtained on the coupling resonance since S (and therefore i) reaches a maximum there.

Our results are not fitted by this simple explanation although they are consistent with the natural assumption that S increases with γ^2.

From the results on L/i_w and δQ it can be concluded that the saturation of L_{max} above 900 MeV is not due to space charge interaction but to the "trivial" fact that transverse instabilities prevent us from storing enough current. Higher luminosities would therefore be attainable if this problem could be fixed.

It is noteworthy that a δQ per crossing of .042, and therefore a total Q shift (6 crossings) of .27 has been attained.

The question remains as to what is causing the extra limitation of luminosity towards lower energies.

We may recall that one of us has proposed a possible instability mechanism(5). He has found that head-tail wake fields can give rise to instabilities through the feedback path provided by beam-beam interaction. A threshold current of the right order of magnitude is found and, if the ratio between bunch length and field decay length were of the order of 1, a dependence of $i_{threshold}$ on $\gamma^{4.5}$, consistent with our exponents, might be found.

We are now in a position to rule out the possibility that this effect be the one that limits our luminosity. The results on δQ and the fact that being exactly on resonance is quite critical, can not be explained by a current threshold depending only weakly on beam shape and that should be higher for a flat beam than for a round one. Moreover, if the high power of the i_{max} dependence on γ is to be explained, according to this theory, one should also observe an increase in threshold current with increasing bunch length while measurements of L_{max} as a function of V_{RF} show quite clearly a contrary behaviour.

Our evidence rather points to the existence of a dependence on energy of the maximum allowed δQ.

It should be also noticed that δQ's obtained with one bunch per beam (2 crossing) are slightly higher than those obtained with three bunches. This seems to indicate that the total Q shift plays a role in determining the limit. We are planning to take more data on this point.

Several attempts were made to investigate the effects of beam-beam interaction by means of an electric quadrupole (E.Q.). The quadrupole separates the betatron frequencies of the two beams and should therefore reduce beam-beam couplings but it can be shown that, in order to be effective, the E.Q. should produce a frequency separation of the same order or larger than the frequency spread due to the crossings.

In practice, though, the E.Q. has not proven useful as a diagnostic tool and no result has been obtained. In fact, since the crossings, at our machine, produce large Q shifts, the E.Q. should produce a large frequency separation, but in this case large changes in β are also produced, altering the physical situation altogether. The conclusion is that a localized focusing element, that varies several parameters at once is unsuitable for investigating an effect as complicated as beam-beam interaction.

At energies around 600 MeV we have also tried to control beam size by means of swept oscillators, and thus obtain a higher luminosity at the same δQ (This kind of procedure does not work without E.Q., since coherent oscillations of the two beams are excited). Trials of this kind have shown, we think beyond any doubt, that incoherent beam enlargement is possible with E.Q., but, up to now, we have not been able to actually increase the luminosity.

Possible improvements

It should be possible to improve our control system in such a way as to be able to store two beams of $\sim$150 mA. Luminosity should than follow the γ^7 law up to 1200 MeV.

We are also considering the possibility of lowering the β values at the crossing points by changing the currents in one half of the ring quadrupoles. In fact by supplying stronger currents to the quadrupole doublets nearer to the crossing regions, the beam dimensions are modulated with periodicity 6 rather than 12, and β values one order of magnitude lower than the present ones can be obtained. Hopefully higher current densities and therefore a higher luminosity should be allowed. A few tests of the behaviour of the ring under "disturbed" conditions were carried out by placing an extra quadrupole in one of the straight sections. The results were encouraging in the sense that no unexpected effect arose. The power supply modifications necessary to obtain the low β's are being worked on.

References

(1) - M. Bernardini and L. Malter, Frascati Report LNF-64/19 (1964).
(2) - ACO Report n. 34/69 (1969).
(3) - C. Pellegrini and A. M. Sessler, Report UCRL-19895 (1970).
(4) - A. N. Lebedev, Frascati Report LNF-69/52 (1969).
(5) - A. Renieri, Frascati Report LNF-70/8 (1970).