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(Presented by M. Placidi).

Abstract

The status of the machine is described and an analysis of the behaviour with two circulating beams is discussed.

Status of the machine

The maximum luminosity measured at ADONE, after corrections for background, has been

$$L_{max} = 1.1 \times 10^{33} \text{ cm}^{-2} \text{hr}^{-1} \qquad \text{at } 1.2 \text{ GeV}.$$

Luminosity measurements at higher energies (after the installation of the second RF cavity) have not yet been performed, due to trouble with the vacuum system.

Typical values of integrated luminosity per week and per experimental section, in the energy range 1-1.2 GeV are

$$L_i/\text{crossing} = 6 \times 10^{34} \text{ cm}^{-2};$$

the maximum luminosity at energies lower than 1 GeV falls off with a γ^7 law, as will be discussed later on.

In the spring of this year the second double-gap RF cavity has been installed so that the total RF voltage available is now 160 KV and the maximum attainable energy is 1.5 GeV/beam.

Operation of the machine with four cavities has shown no appreciable modification of the single beam behaviour from the point of view of transverse instabilities; the threshold currents are the same as before and no particular trouble has been found in keeping the beam stable with the usual transverse feedback system (with an upper limit of $\sim$ 60 mA for the e^+ beam).

The situation has proved rather different with respect to the longitudinal oscillations of the bunches : the oscillations occur at lower currents and throbbing modes are more frequently observed.

The efficiency of the feedback system on the zero'th order mode of the oscillations was not affected by the change, but the setting of the frequency of the RF pilot oscillator is more critical (a typical value of the good frequency range is 0.3 KHz, the RF frequency being 8.568 MHz; the frequency that prevents longitudinal oscillations changes with temperature within a range of about 2 KHz). A positron

current of 80 mA in three bunches has been stored without any longitudinal oscillation, at low energy.

It has been checked that the operation with two beams requires a separation of the synchrotron frequencies of all the bunches present in the machine, to prevent occasional, but destructive, longitudinal oscillations.

RF feedback

The feedback system on the longitudinal instabilities presently operating on the ring, is effective in damping the zero'th order mode of oscillation (center of mass motion).

The feedback loop includes the main R. F. amplifier chains. As shown in fig. 1, a signal from the master oscillator is compared in a phase detector with that induced by the bunches in a pick-up electrode ; the output modulates the phase of the RF voltage in the two double cavities.
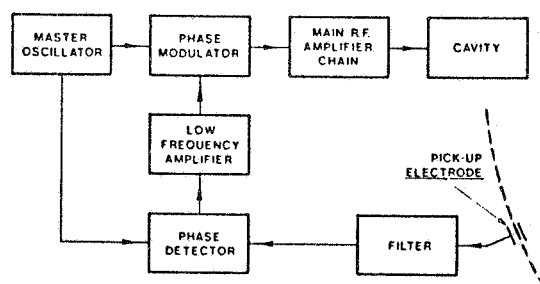

Fig. 1 - Block diagram of the feedback system for the longitudinal instabilities (center of mass motion).

It turns out that the maximum value of the damping constant the system can provide is of the order of $(3T)^{-1}$, $T = 2Q/\omega$ being the cavity time constant ($T \simeq 0.2$ msec in our case).

The bandwidth of the system, not including the cavity, is about 20 KHz, while the synchrotron frequencies are in the range of 4-8 KHz, depending on energy and RF voltage.

A feedback for the relative longitudinal oscillations is being prepared : the system is very complicated and the operation, if at all possible, will require quite a long adjustment.

Vacuum

The best value of pressure increase with current for our vacuum system (the total inner surface of the doughnut is about $150 \, m^2$ and the total pumping speed $7000 \, l/sec$) has been, before the shutdown,

$$\frac{\Delta p}{i} \simeq 0.7\text{-}1 \times 10^{-2} \, ntorr/mA \quad at \quad 1 \, GeV$$

starting from a static vacuum of $\sim 0.1\text{-}0.2$ ntorr.

The residual gas composition, with beams circulating in the ring has been the following :

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

The value of $p \cdot \langle z^2 \rangle^{1/2}$, evaluated from bremsstrahlung measurements, has been of about 10^2 ntorr at $1.2 \, GeV$ with a $12 \, mA$ circulating beam, while the value of the photon desorption efficiency, $DE_\gamma \simeq 3 \times 10^{-6}$ mol/photon, has been found in good agreement with ACO and CEA data.

Two beam behaviour

Results

The results of all measurements of luminosity have been revised correcting a sistematic error on the values of the currents and correcting the values of the luminosity for background (function of energy).

The results obtained have been analyzed to check the functional dependences on energy of the maximum luminosity L_{max}, maximum specific luminosity L/i_w (i_w being the current in the weakest beam) and maximum vertical Q-shift $(\delta Q_v)_{max}$ produced per crossing.

From the results shown in figg. 2 and 3 it can be seen that the new experimental points differ from previously presented ones[1] by no more than 20 %, while the functional dependences are unchanged and namely :

(1)
$$L_{max} \propto \gamma^7, \quad (L/i_w)_{max} \propto \gamma^{2.5},$$
$$(\delta Q_v)_{max} \propto \gamma.$$

The values of L_{max} and $(L/i_w)_{max}$ also depend on the operation point of the machine and all quantities (1) depend on whether the machine is tuned on a coupling resonance or elsewhere.

Discussion of results

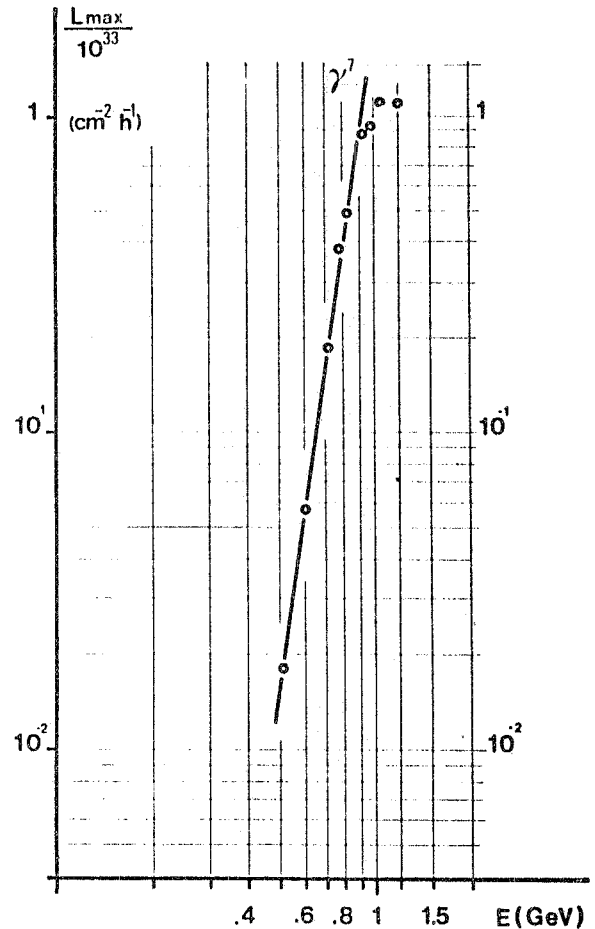The experimental behaviour of the maximum values of L, L/i_w and δQ, just described, does not

Fig. 2 - Maximum luminosity as function of energy.

agree with the usual hypothesis of the existence of a certain maximum value of δQ, independent of energy, that cannot be exceded.

This hypothesis, together with the fact that we are usually working with equal currents would lead, at the space charge limit, to the following dependences[1] :

(2)
$$L_{max} \propto \gamma^4, \quad (L/i_w)_{max} \propto \gamma, \quad i \propto \gamma^3.$$

These will be sometimes referred to, in what follows as "optical dependences" since they follow from optics only. It may be useful to stress once more the point that, in talking of $\delta Q_{r,v}$ we refer to the true small amplitude Q-shifts per crossing due to beam-beam interaction, while, in the literature, the name δQ is often applied to the parameter ζ, which measures the effect of one beam on a particle of the other, and which coincides with δQ only to a first approximation.
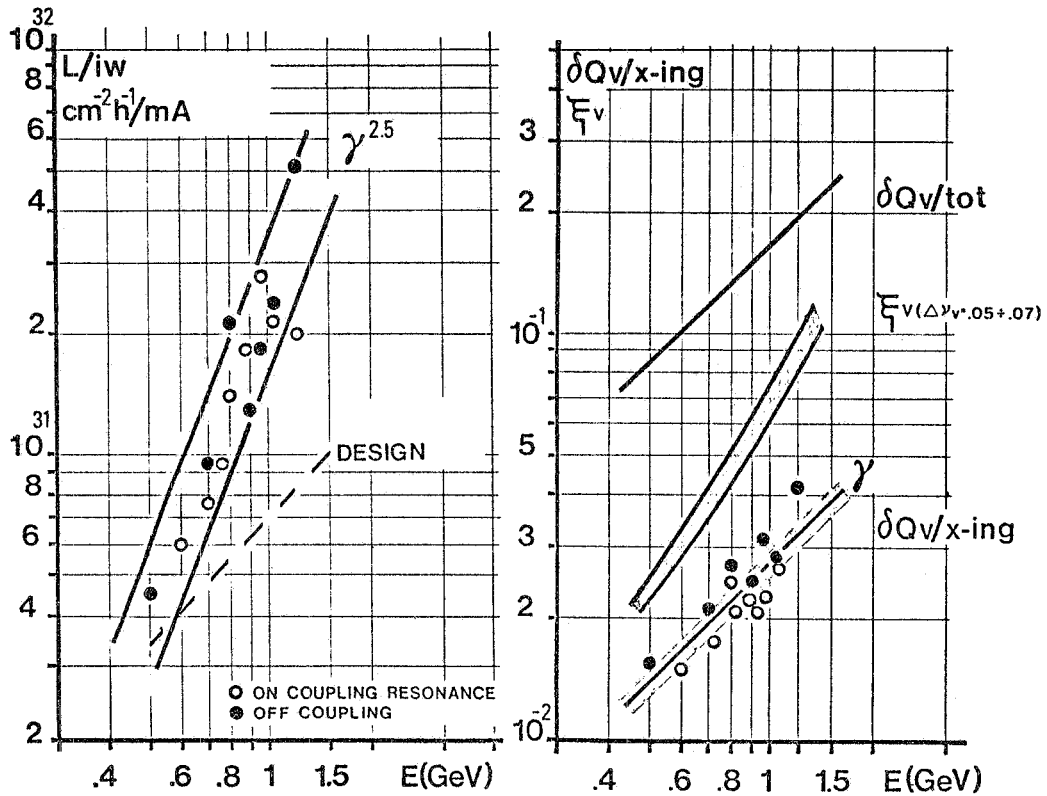
Fig. 3 - L/i_w, δQ^V and ζ_v as functions of energy.

The relation between ζ and δQ is as follows:

$$(3) \qquad \zeta = \frac{\sin(2\pi\,\delta Q)}{2\pi}\left\{1 + \cotg\,\mu \cdot \tg(\pi\,\delta Q)\right\}$$

where μ is the β-tron angle between two crossings. ζ is more directly related to the maximum obtainable luminosity, while δQ measures the true effect of the crossing on machine optics.

The first conclusion we drew[1] from the results was that the saturation of the L_{max}-vs-energy curve, above ~ 900 MeV, was due only to our inability to store enough current. No new fact has, in our opinion, arisen to contradict it.

We will therefore dismiss, for the time being, this additional complication and think of the results only in terms of the dependencies given in (1).

The question of whether, at a given energy, there exists a maximum value of $\delta Q/\text{crossing}$ or else a maximum value of the total δQ has been further investigated.

In fig. 4 the results are shown of a series of measurements performed at 0.9 GeV, under controlled conditions, and namely sitting on the ($\nu_x = \nu_z$) coupling resonance (Only vertical δQ's are considered, since radial δQ's are always lower).
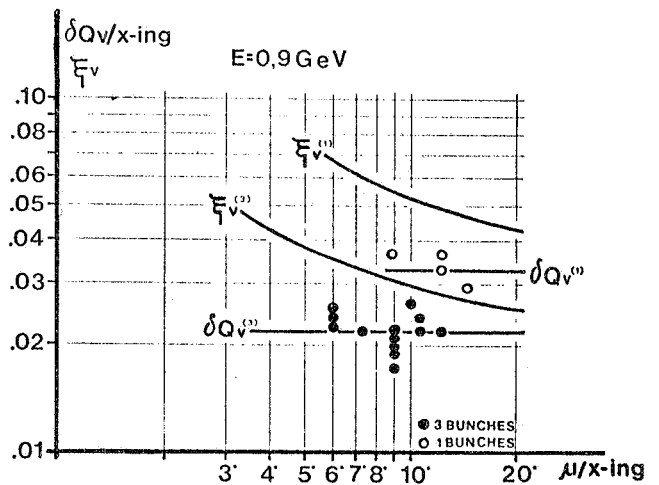

Fig. 4 - δQ^V and ζ^V as fucntion of μ, at E = 0.9 GeV.

Measurements were taken both with three bunches per beam and with one bunch per beam, and the maximum luminosity was sought.

It can be seen that:

1) δQ's obtained with three bunches are quite inde-

pendent of μ over the range explored. The values of ζ, corresponding to an average δQ, are shown in order to stress that it is convenient to work at low values of μ/crossing ($L \propto \zeta^2$). The data with one bunch are not enough to draw the same conclusion although it appears likely that the situation is the same.

2) The values of δQ for 1 bunch are consistently higher than those for three bunches. The ratio, though, is not 3 as one would expect if the total δQ were the limiting parameter but is intermediate between 3 and 1.

A quantitative explanation of this behaviour is, as of now, lacking, and it can only be said that the total δQ also appears to be part of the picture.

It is quite clear that the dependence of Q can not be explained in terms of optics only. To check on this point we have taken a few measurements where one of the beams was of negligible intensity. Under such conditions luminosity can not be measured directly. The maximum attainable density of the strong beam was defined as that at which the shape of the weak beam began to change. Measurements with three bunches were taken at 0.5 and 0.6 GeV. The calculated δQ was $\sim$ 0.03 at both energies. Although the accuracy of the absolute value of δQ could be questioned on the ground that the criterion for determining the maximum value was different from that previously used, we still think that this value and the fact that the δQ's obtained are the same at both energies are significant.

The γ dependence of the δQ's is an effect of two strong beams, while a strong and a weak beam appear to behave as predicted by the conventional theory.

Consider once more the results obtained at the space charge (s.c.) limit. From (1) it follows :

$$(3) \qquad a) \; i_{max} \propto E^{4.5} \; ; \qquad b) \; S_{lim} \propto E^2$$

where S_{lim} is the beam cross section at the interaction point and at the s.c. limit.

It can be argued that beam beam (b.b.) interaction can in principle change beam size and S_{lim} should therefore be a function, $S_{lim}(i, E)$, of current and energy. But since, because of (3b), S_{lim}/E^2 must not depend on E, it follows from (3a) that

$$(4) \qquad S_{lim}(i, E)/E^2 = h(i/E^{4.5})$$

where h is some function of $i/E^{4.5}$.

Let us call S_o^M the ratio of beam cross section at the interaction point, measured through L and i, to energy squared.

Fig. 5 shows a plot of the ratio of S_o^M to the

natural cross section, S_o^o, divided by E^2, versus the new parameter $i/E^{4.5}$.
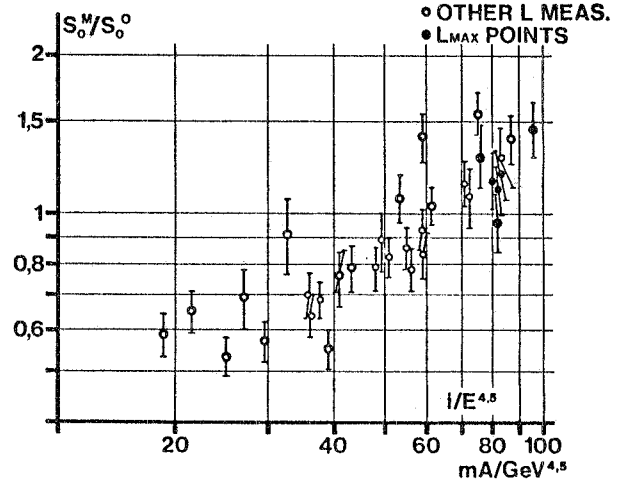

Fig. 5 - The ratio, S_o^M/S_o^o, of measured beam cross section divided by E^2, to the natural beam cross section divided by E^2, versus $i/E^{4.5}$.

All points measured belong the same tune (3.07, 3.07) on coupling, but only a few of them correspond to a maximum value of luminosity and these are clustered around the same value of $i/E^{4.5}$ ($\approx$ 80 mA/GeV$^{4.5}$) as expected from (3), (4).

It appears that there is a striking deviation of S_o^M from the natural cross section, and the parameter $i/E^{4.5}$ seems to be relevant no matter how far from the s.c. limit the points are.

It is quite natural to think that the anomalous cross sections may be due to b.b. interaction but it is, a priori, doubtful that a simple linear model, approximating the interaction by a thin lens, could account for all of the effect since optics scales as I/E^3 and not as $I/E^{4.5}$.

It is however useful to examine the predictions of a simple calculation. A linear model, in which b.b. interaction is approximated by a thin lens of intensity as would be given by a constant density beam, was constructed. An iterative computation was set up to calculate beam dimensions when interaction is present. The iterative procedure is necessary since the interaction modifies the β and ψ functions and the betatron invariant thereby changing the beam density and the strength of the equivalent lens. A self consistent solution is found for each given value of current, energy and tune.

The computation results are shown in fig. 6 where the ratio of calculated beam cross section with interaction, S_o^G, to the natural cross section, S_o^o, is shown as a function of the optical scaling parameter i/E^3 for several tunes on coupling.
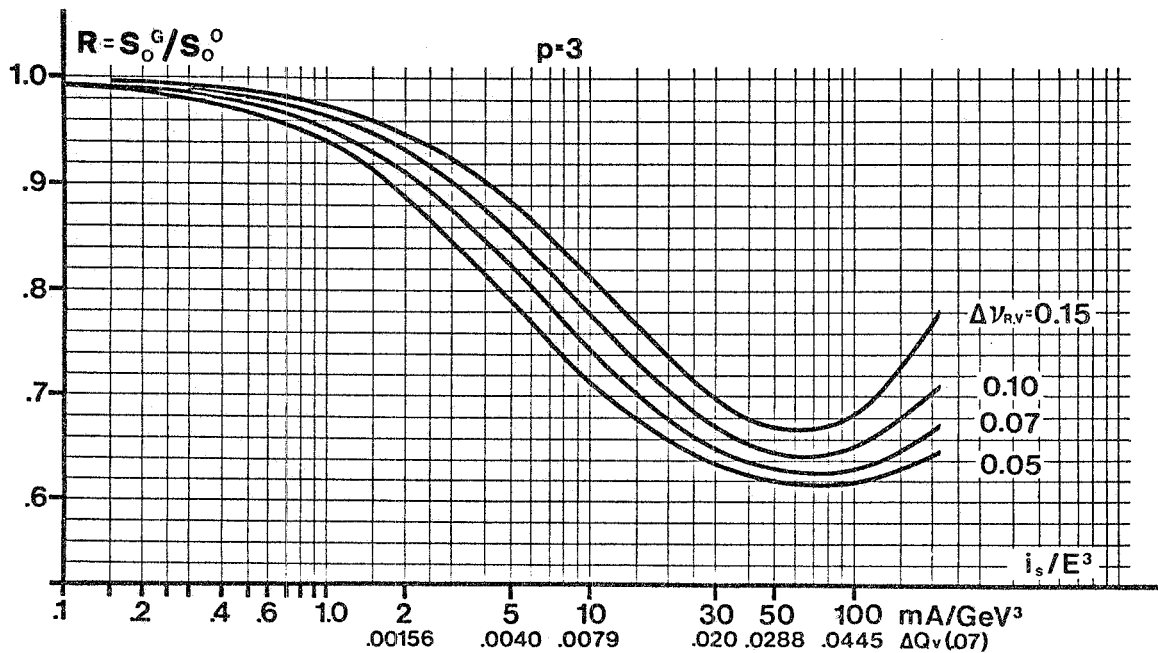
Fig. 6 - The ratio, R, of computed beam cross section at the interaction point, S_0^G to natural beam cross section, versus optical scaling parameter i/E^3. Beam beam interaction is taken into account. The computed values of δQ_V are also marked on the abscissa.

The computation was performed for tunes on the coupling resonance, since only then can it be safely assumed that the coefficient of coupling between radial and vertical motion is known.

It can be seen that the model predicts a shrinking of beam cross section. We may notice that the experimental data of fig. 5 exibit, at low values of $I/E^{4.5}$ a shrinking of much the same magnitude.

On the abscissa of fig. 6 we have marked the values of δQ_V obtained from the calculation. Given the thin lens model we argue that the computed shrinking as a function of δQ is pretty much independent of the absolute values of cross sections and currents by which the δQ is obtained. In particular actual beams of given measured δQ would produce the calculated effects even if cross sections and currents, for reasons unknown, do not correspond to the calculated ones.

We then proceed to notice that all our L measurements corresponds to δQ_V's in the range 0.01--0.04 and that, in that range, the computed ratio S_0^G/S_0^0 is almost constant to within a few percent around R $\approx$ 0.6.

This means that the thin lens part of the b.b. interaction effect should at most contribute a different normalization to the curve of fig. 5 but does not seem to be able to account for its shape.

As a last remark a word of warning should be spoken: Our results deal with maximum values of luminosity and current in an essentially unstable and not completely understood machine. The functional dependences we quote are therefore our best guesses on the results obtained up to now.

Attention should therefore be given to the raw data while the scaling laws we propose might be affected by an error that we estimate to be at most of $\pm$ 0.5 on the exponents in (1).

Studies for possible improvements

The possibility of modifying the magnetic structure of the ring by changing the excitation currents of the quadrupoles has been studied in some detail: β values of 0.2 meters in the vertical plane and 1.2 meters in the radial plane at the crossing points can be obtained and the most convenient operation procedure to follow in changing the structure of the machine from high-β configuration (which we deem to use at injection) to the low-β one, keeping the beams far from destructive resonances, is now being investigated for a possible operating point.

In the fig. 7 the functions $\beta_r(s)$, $\beta_V(s)$ and $\psi(s)$ in the low-β configuration are shown (the periodicity changes from 12 to 6 when realizing the low-β structure); it can be noticed that the β values differ considerably from the present ones, which range from 3 to 9 meters, while the ψ does not change more than 25 %.

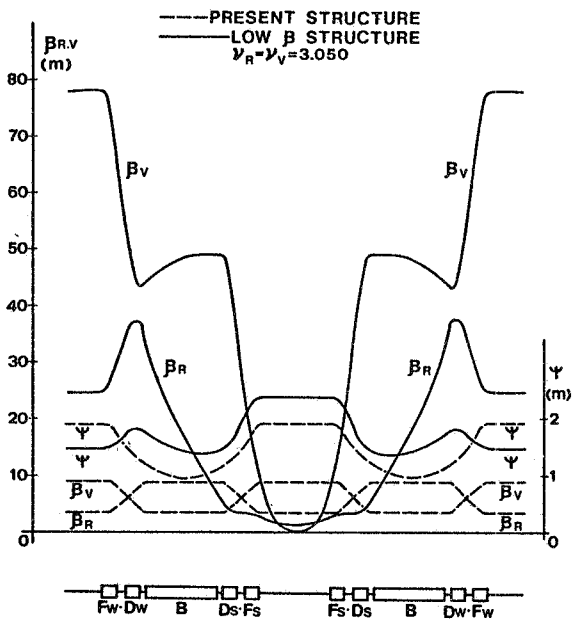During the studies a particular optical struc-

Fig. 7 - β and ψ values in the low-β structure, with comparison with the present values (dotted line).

ture has been found that, although giving β-values not very low, could prove useful in diagnostic studies on the machine, as the b. b. interaction.

The structure is of the following type :

B/2 D F 0 D F B F D 0 F D B/2.

Due to the fact that the radial and vertical structures are identical but shifted by half cell (the field index in B is 0. 5), the betatron wave numbers are equal in radial and vertical; the machine is therefore tuned on the coupling whatever the currents in the quadrupoles are.

For a fixed value of $\nu_{r,v}$ different values of β_R and β_V in the interaction region can be obtained while keeping their product constant.

References

1) ADONE Group, Status Report on the Electron-Positron Storage Ring Adone, Proc. 1971 Particle Accelerator Conference, Chicago, March 1971.