BEAM DYNAMICS ON ACO

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Summary

After a shut down of several months during which some improvements were made on ACO such as a computer control of the power supplies, and a new detector for high energy experiments was installed, an extensive beam experiment program was started. This mainly concerned the beam-beam effect with and without small beam separation at the crossing point, the cure of transverse instabilities with new sextupolar coils placed inside the quadrupoles, the check of power supplies stabilizations by means of the synchrotron frequencies, and the development of a new ACO structure with low β's.

During the same period new measurements of the neutral modes of the ϕ_c were started on ACO. Finally a beam of synchrotron light extending up to 10 Å will soon be put in operation for molecular, atomic, and solid state physics.

The typical luminosity at 510 MeV is now about $3.4.10^{32}$ cm^{-2}.h^{-1} with 35 mA in each beam, and this new improvement seems to be related to a better power supplies stabilization.

1. Beam-beam effect

More experimental data have been collected on beam beam interaction in the normal operating conditions of ACO. The main parameters of the ring with two colliding beams were :

radially $\begin{cases} \nu_x = 2.845 \\ \beta_x = 1.8 \text{ m} \end{cases}$ vertically $\begin{cases} \nu_z = 0.835 \\ \beta_z = 4 \text{ m} \end{cases}$

E = 510 MeV

$I^+ \approx I^-$ (one bunch in each beam)

$\sigma_x^+ \sim \sigma_x^- \sim \sigma_z^+ \sim \sigma_z^- \sim .5$ mm (on the coupling resonance).

For head-on collision at this energy, the maximum tolerable current in each beam is 37 mA, corresponding to a maximum luminosity $L \sim 4.10^{32}$ cm^{-2} h^{-1} and to a parameter

$$\Delta\nu_{zo} = \frac{N r_e \beta}{2\pi\gamma(\sigma_x + \sigma_z)\sigma_z} \sim .055 \pm .016 .$$

The lifetime of the beams is about 6 hours.

The effect of a small vertical separation (less than σ) of the two beams at the crossing point was also studied.

The main results obtained until now are relative to the coupled coherent oscillations of the two colliding beams, and to the range of ν_z displacement compatible with a good lifetime around this operating point.

1.1 Range of ν_z displacement.

At high energy on ACO a lifetime criterion is used to define the useful range of ν_z. For ν_x fixed, there is a small range of ν_z, around the normal operating point, inside which the beam lifetime is good (about a few hours). At the boundaries of this range a sudden and large reduction of the lifetime appears. At high current no enlargement of the beam dimensions is observed inside this range.

In head-on collisions the lower ν_z boundary seems to be due to the resonance $\nu_z = 5/6 = .833$ (Fig. 1). A strong decrease of the lifetime of the weaker beam is observed on this resonance, for currents greater than 6 mA. For smaller currents it can be crossed and only an enlargement of vertical beam dimensions is observed.

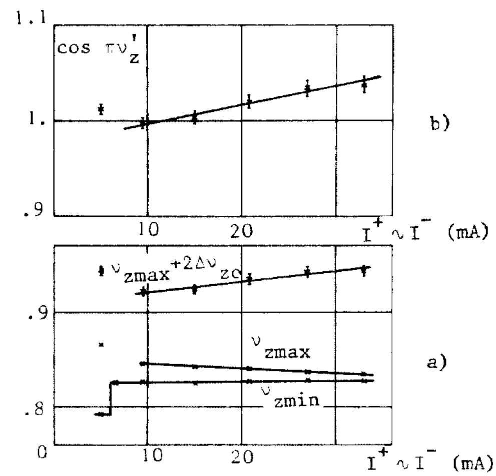

Fig. 1 : a) Range of the vertical wave number versus intensity.
b) Cosine of the linear tune shift versus intensity.
(a 30% systematic error on $\Delta\nu_{zo}$ is not shown in this plot).

The upper ν_z boundary decreases as the current increases, and reaches the lower boundary at the limit. This behaviour seems related to the increase of the dispersion due to the beam beam effect. No explanation has still been found for the upper boundary. An order of magnitude of the dispersion can be shown by plotting $\nu_z + 2\Delta\nu_{zo}$ and the linear tune shift $\cos \pi \nu' = \cos \pi \nu_z - 2\pi \Delta\nu_{zo} \sin \pi\nu_z$, versus the current of one beam.

For beams slightly separated and for currents above 20 mA one observes a large reduction of the ν_z range when the separation reaches about $\sigma/20$. Then the range decreases slowly as the separation increases, and at about $\sigma/10$ there is a new drop and the beams are lost. (Fig. 2)

As a conclusion small separations of the two beams in the interaction region are very dangerous. May this be related to difficulties encountered in the crossing at small angles ?

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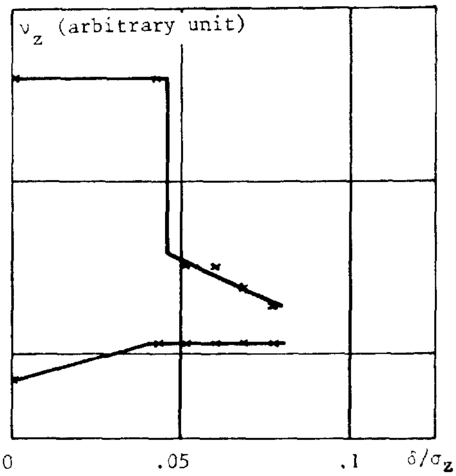

Fig. 2 : Range of the vertical wave number versus the beam separation
E = 510 MeV
I^+= 27 mA
I^-= 22 mA

1.2 Coherent oscillations of the two beams.

Coherent oscillations induced by beam-beam interaction were already reported at the Geneva Conference in 1971.[1] They have been since extensively studied. In the case of head-on collisions, coherent oscillation is frequently observed, but only with a very small amplitude ($\sim \sigma/30$).

The wave number ν_c of this coherent motion increases with the current and approaches unity as the current goes to the limit (Fig. 3). One can notice also that the coherent tune shift

$$\Delta\nu_c = \frac{\cos \pi \nu_c - \cos \pi \nu_z}{2 \pi \sin \pi \nu_z}$$

is consistent with $\Delta\nu_c \approx \Delta\nu_{zo}$.

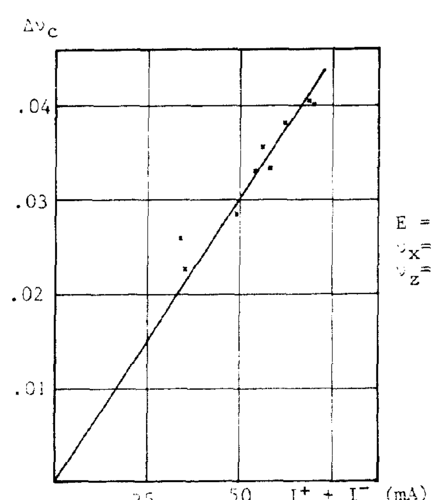

Fig. 3 : Coherent tune shift versus intensity.

No increase of amplitude is observed near the limit for a round shaped beam or below, when the tuning is changed until the beam lifetime becomes poor.

Thus we can conclude that large coherent oscillations are not observed in head-on collisions.

For beams slightly separated ($> \sigma/20$) in vertical direction and for currents in the range 10 mA to 20 mA, coherent oscillations of larger amplitude frequently appear with no decrease of the lifetime.

The wave number ν_c of these oscillations is smaller than the one observed in head on collision. Furthermore these oscillations only appear when the separation reaches a threshold which can be as small as $\sigma/20$. Nevertheless the amplitude is always limited to the order of σ and no oscillations are observed for currents near the limit. So they cannot directly explain the limit ; they only reduce the luminosity below 20 mA.

2. Experiments with sextupolar coils placed inside the quadrupoles[2]

In order to cure the "Head tail effect" by cancelling the chromaticities (natural values at the usual operating point are $\frac{\partial\nu_x}{\partial E/E} = -2.6$, $\frac{\partial\nu_z}{\partial E/E} = -3.07$), sextupolar coils with dipole compensation were placed inside the quadrupoles where the efficiency is large in the strong focussing case ; this choice was also made on account of the small available space. It does not however allow a perfect second order field component. The chromaticities were found in agreement with the predicted values within ± 12 %.

When the two natural chromaticities are cancelled the threshold for the transverse instability at the usual operating point is greater than 50 mA as compared to 4 mA with no compensation. Fig. 4 shows, for $\frac{\partial\nu_z}{\partial E/E} = 0$, the variation of the threshold of the radial instability , normalized to the radial octupolar component, as a function of the radial chromaticity.

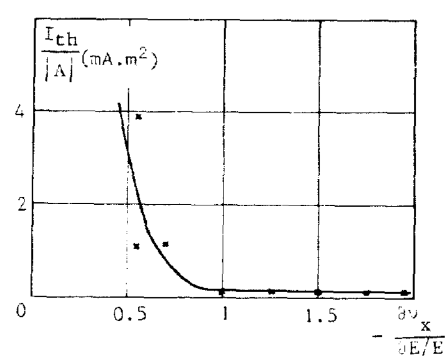

Fig. 4 : Normalized radial threshold versus the, radial chromaticity.

3. Study of the synchro betatron frequencies[3]

The response of the beam to a transverse RF excitation has a line spectrum. The central line sits on the betatron frequency and the satellite lines are separated from the central line by integer multiples of the synchrotron frequency. The width of the spectrum (i.e. the number of lines) depends on the betatron frequency spread due to the chromaticity of the machine and the momentum dispersion in the beam. Actually, when the chromaticity is cancelled, the spectrum can be reduced to one line.

The width of individual lines depends on the betatron frequency spread due to phenomena appearing at frequencies much lower than the synchrotron frequency. The frequency dispersion due to octupolar coefficients ($\Delta\nu_x = 24\ x^2$, $\Delta\nu_z = 73\ x^2$) accounts for widths one order of magnitude below the actual widths.

The observed line width has been attributed to power supply fluctuation. The stability of the guide fields, deduced from these observations is of the order of 10^{-5} for very low frequencies (< 1 Hz) and in the 10^{-4}'s for the low frequency range (> 1 Hz). When the stability is worse, the lines widen, and can even overlap.

4. Low-β structure

The possibility of modifying the magnetic structure of ACO has been studied in detail[4]. By lowering the order of symmetry of the ring, we can change the β function while keeping the wave numbers constant. Results concerning a second order symmetry structure (ACO 2) with three independant quadrupole sets has been presented at the CERN Conference in 1971. New results with a first order symmetry structure (ACO 1) are reported here.

Figure 5 shows the structure of ACO 1 with four independent parameters which allow to operate the machine at the usual point $\nu_x = 2.845$, $\nu_z = 0.845$ as in normal ACO 4 with variable β's in the experimental section. We have made a choice of equal β^* functions : the most convenient procedure to follow is then to change the gradients of the four quadrupole sets from the high-β configuration (which we use at injection) to the low-β one.

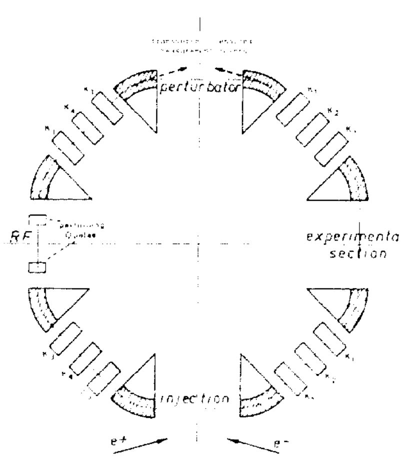

Fig. 5 : Structure of ACO 1

To check the path which leads from high-β to low-β configuration, we have made many careful measurements with one beam (electron or positron) at 250 MeV and 360 MeV. Wave numbers are measured by RFKO and β measurements are done by perturbing the tune with two small quadrupoles symmetrically located in the RF section. Figures 6, 7 show the experimental path compared to the theoretical one. The measured β being in fact the mean value over the two perturbing quadrupoles, a double determination results on β functions. Figures 8,9 show these two solutions in the (K_1, K_2) and (K_3, K_4) planes. The constant 0.25 is related to the geometrical configuration of the perturbing quadrupoles.

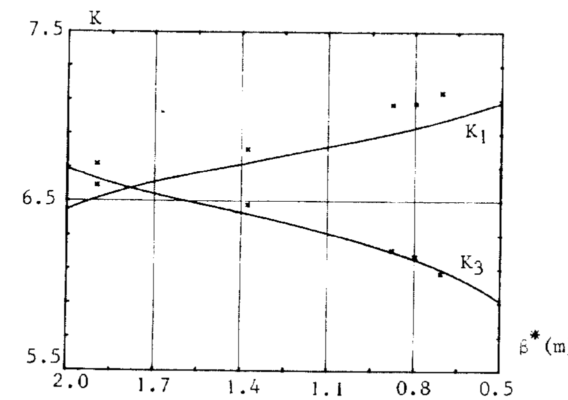

Fig. 6 : Reduced gradients of the lateral quadrupoles versus β^*

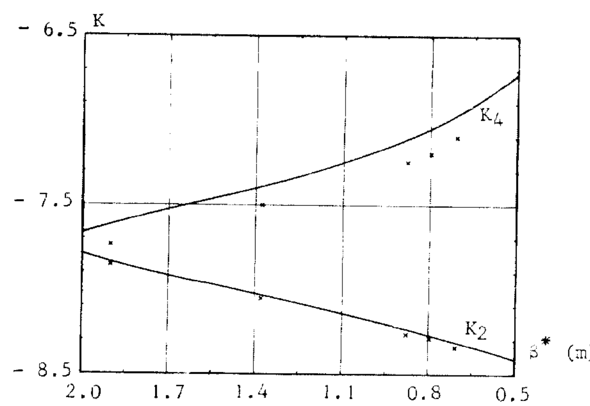

Fig. 7 : Reduced gradients of the central quadrupôles versus β^*

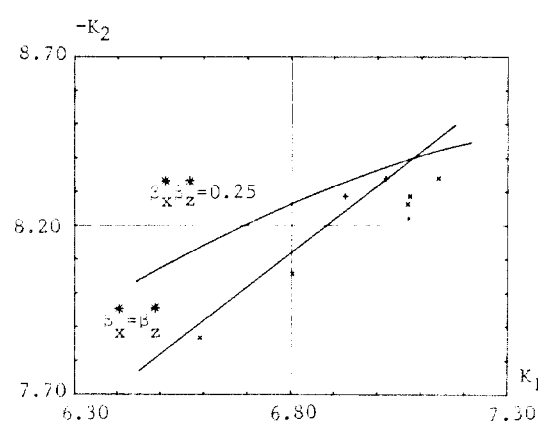

Fig. 8 : The paths ($\beta_x^* = \beta_z^*$) and ($\beta_x^*\beta_z^* = 0.25$) in the ($K_1 - K_2$) plane.

× experimental point $\beta_x^* = \beta_z^*$

+ experimental point $\beta_x^*\beta_z^* = 0.25$

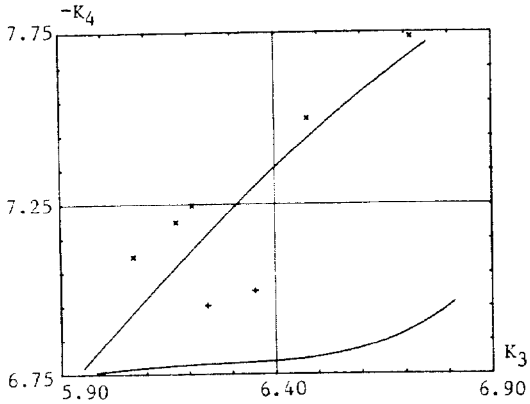

Fig. 9 :
The paths ($\beta_x^* = \beta_z^*$) and ($\beta_x^* \beta_z^* = 0.25$) in the ($K_3$-$K_4$) plane.

× exp. point $\beta_x^* = \beta_z^*$; + exp. point $\beta_x^* \beta_z^* = 0.25$

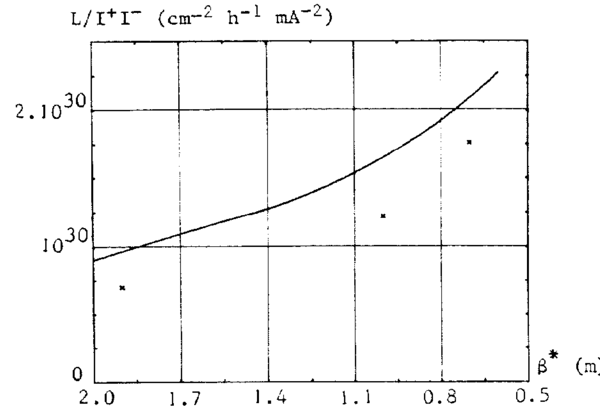

Fig. 11 : L/I^+I^- versus β^*

Theoretical value at point A $0.69 \times 10^{30} cm^{-2} h^{-1} mA^{-2}$

Experiment. value at point A $0.56\ 10^{30} cm^{-2} h^{-1} mA^{-2}$

The routine we use is a classical one on ACO. Briefly, positrons are first injected in a high-β configuration ($\beta^* \approx 2$ m) on the coupling resonance with a slight beam excitation by white noise. Electron injection follows, above the coupling resonance, with beam electrostatic separation avoiding beam-beam interaction effect.

At the end of the beam storage, the energy is increased up to 360 MeV with the help of the mini computer which drives the power supplies and the low-β path is followed towards the final operating point - then excitation noise and electrostatic separation are suppressed. Tune and orbit are manually corrected to optimize beam lifetime and to avoid beam transverse extension.

Beam dimensions, measured by scanning the synchrotron light distributions, are in agreement with theoretical predictions (fig. 10).

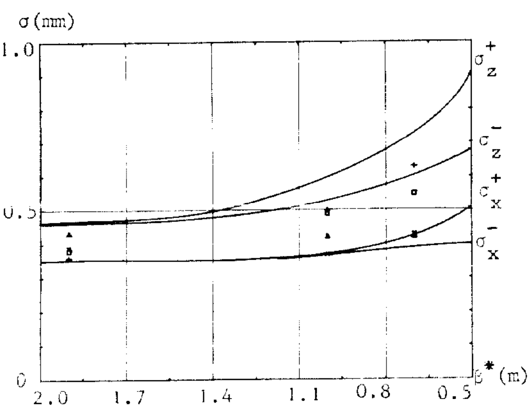

Fig. 10 : Transverse dimensions at the observation point versus β^*.

x experimental values σ_x^+ ; Δ experimental values σ_x^-

+ experimental values σ_z^+ ; ▫ experimental values σ_z^-

Luminosity has been monitored by using double photon bremsstrahlung. Figure 11 shows as a function of β^* the ratio L/I^+I^- compared to theoretical values.

The interaction cross section decreases with β^* as predicted. For instance, there is a factor 3.5 between the usual operating point A of ACO 4 and the point $\beta^* = 0.7$ m of ACO 1.

As far as the current limit is concerned, we have only preliminary results at the present moment (Feb. 11th), but it seems lower than expected, especially for $\beta^* < 1$ m, and probably the maximum luminosity is not increased in the same proportion. As in previous ACO 2 experiment, the beam beam limit is not consistent with the classical hypothesis of a constant $\Delta\nu$.

The next stage will be a systematic search for the maximum luminosity on the equal β's path and then a study of operating points slightly off this path. At the end of 1973 ACO 1 might be studied with a magnetic detector.

5. Synchrotron light facilities with ACO

(LURE Laboratory)

The synchrotron radiation for LURE is emitted by the electron beam (one or two bunches) having the following characteristics.

E = 540 MeV

I = 100 mA

Dimensions: $\Delta x = \Delta z = 10^{-3}$ m; $\Delta \ell$ = .3 m

Lifetime: 18 hours at 100 mA; 35 hours at 30 mA

The photon energy range goes from 6 Å to 10^4 Å. Considering the proximity of the synchrotron light laboratory from the ring (~ 10 meters) the useful flux is then very important as shown in the following table for I = 100 mA.

λ (Å)	6	100	500	1000	10 000
Flux	$1.6.10^{13}$	$1.3.10^{14}$	$2.4.10^{13}$	$9.7.10^{11}$	[illegible]

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