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STATUS REPORT ON D.C.I.†

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Abstract

A brief summary of DCI operation with a single ring is given. Experimental results on space charge compensation with the two rings are presented which include studies with three beams (strong-weak interaction) and four beams (strong-strong interaction). These studies were carried out at the energy of .8 GeV.

Machine Performances for Users

Until now, only one of the two rings of DCI has been used for high energy physics experiments as well as source of synchrotron radiation.

Electron-positron annihilation has been studied in the range of .68 to 1.08 GeV per beam. Positron-positron collisions have also been achieved at the energy of 1.2 GeV per beam for $\gamma\gamma$ experiments. The optimization of the machine in e^+e^- led to a typical luminosity of 7.10^{29} cm^{-2} s^{-1} at the energy of 1.2 GeV, on the coupling resonance, with $Q_x = 3.71$, $Q_z = 1.71$. The space charge strength ξ saturates very rapidly with current reaching a maximum value of about .03. Further increase in current leads to transverse cross-section enlargement of both beams which practically fill the vertical acceptance and to a linear dependance of the luminosity versus current. In the energy range .8 to 1.2 GeV per beam, with the magnetic detector DM1 at full field, the maximum current scales roughly like $E^{1.25}$ and the maximum luminosity like $E^{2.5}$ (fig. 1) corresponding to a computed maximum ξ value which scales like $E^{0.25}$ assuming the cross section is still gaussian shaped when enlarged.

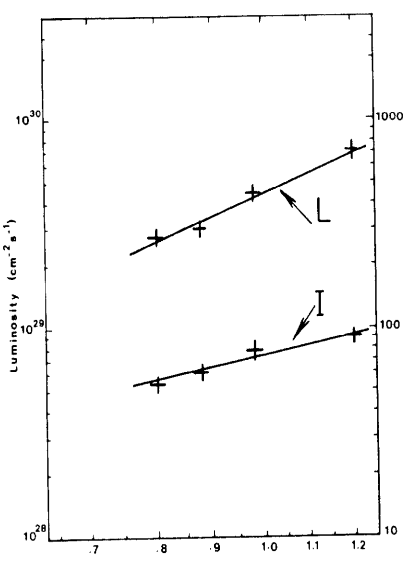

Fig. 1 : Lower Ring e^+e^- Operation

At a typical energy of 1 GeV, owing to the beam lifetime (20 hours) and to the decrease of the beam cross-section with current, the luminosity drops by 40 % only, over 10 hours. An integrated luminosity of 10^3 nb^{-1} has been delivered to the experiment DM1 over a working period of 7 months.

Typical performances for synchrotron radiation use are

Energy	Stored Current	Cavity Losses	Radiated Power	Lifetime
1.72 GeV	236 mA	40 kW	58 kW	10 hrs
1.80 GeV	192 mA	40 kW	56 kW	10 hrs

Present limitations are due to the maximum transmitter power available (100 kW).

The time devoted to machine studies and development is 30 % of the total available time. Single beam problems connected with head-tail, phase oscillations, synchrobetatron instabilities have been solved. Since May 1978, most of the time has been spent on the study of space charge compensation.

Experimental Conditions Relevant to Space Charge Compensation Experiments

All the experiments were carried out at a beam energy of 800 MeV and most of them on the coupling resonance $Q_x - Q_z = 2$ (in that case the beam at interaction point is round shaped : $\sigma_x \simeq \sigma_z = .55$ mm).

Three conditions were ensured whenever desired :

- equality of the companion beam intensities to within better than .7 mA (5 %).
- adjustment of the orbits of the two rings at both interaction points, with the help of two pairs of pick-up stations : the center of gravity distance of the two-orbits was adjusted in X and Z to better than .1 mm and the crossing angle to less than .05 mrd.
- adjustment of the companion beam phase to better than 100 ps (σ_1 = 230 ps).

These last two settings are affected by other phenomena :

- residual fluctuations of the currents in horizontal and vertical magnets which lead to a maximum vertical separation of the two orbits of 50 μ at frequencies of a few Hz (n_z^* being of opposite sign for the two rings). Position feedback tested with a single beam has brought this figure down to a few μ[1].
- Residual phase instabilities. The 25 ps residual fluctuations amount again to a 50 μ vertical orbit separation at 8 kHz. Phase feedback has brought this figure down to 5 ps in the lower ring, but it is only used for single beam operation at present time.

Horizontal and vertical decoupled orbit bumps were used in each interacting region to investigate the effect of beam separation. Displacements as small as 1 μ and change of angle of 10^{-3} mrd can be made. Furthermore, change in tune of both rings or each ring separately was available to study the size of the

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stability region. Two sets of correcting coils in the quadrupoles provided for change in tune either parallel or perpendicular to the coupling resonance, or alternatively along Q_x or Q_z.

Finally, the luminosity (small angle scattering luminometer in the experimental section) together with the value of the stored currents gave the specific luminosity and therefore the common cross-section of interaction of the beams, S^*.

In the 3-beam case, the specific luminosity was defined as

$$L_s = \frac{L}{(\Sigma I_{companion}) \times I_{single}}$$

and in the 4-beam case as

$$L_s = \frac{L}{(\Sigma I_{companion}) \times (\Sigma I_{companion})}$$

The limit of the stability region was defined either by bad lifetime < 1/3 gas lifetime for at least one beam or by unstable cross-sections as seen on TV cameras.

Three-Beam Behaviour

The compensation of the incoherent effect of space charge can be tested in the case of two strong companion beams against a weak beam used as a probe. The interaction cross-section of the beams is plotted versus the intensity of the strong beams on fig. 2 which shows for comparison the e^+e^- and e^+e^+ behaviour of both rings. One observes that the three-beam cross-section S^* stays approximately constant and equal to the natural cross-section S_0^* of a single beam in the range up to 55 mA, whereas the e^+e^- cross-section rises by a factor 2.5 at 25 mA. In the last case the ξ value is 0.018. In the three-beam case, ξ can be similarly defined from the intensity and the cross-section of the strong companion beams. Its maximum value is 0.1. We can therefore say that a compensation factor of 5.5 has been reached. It is however important to mention that these results were obtained with a small unbalance of the two companion beam intensities of sign opposite to the polarity of the weak beam (e^+e^- overall interaction). In the other case (e^+e^+ overall interaction) the beams are stable only for lower companion beam intensities (< 20 mA).

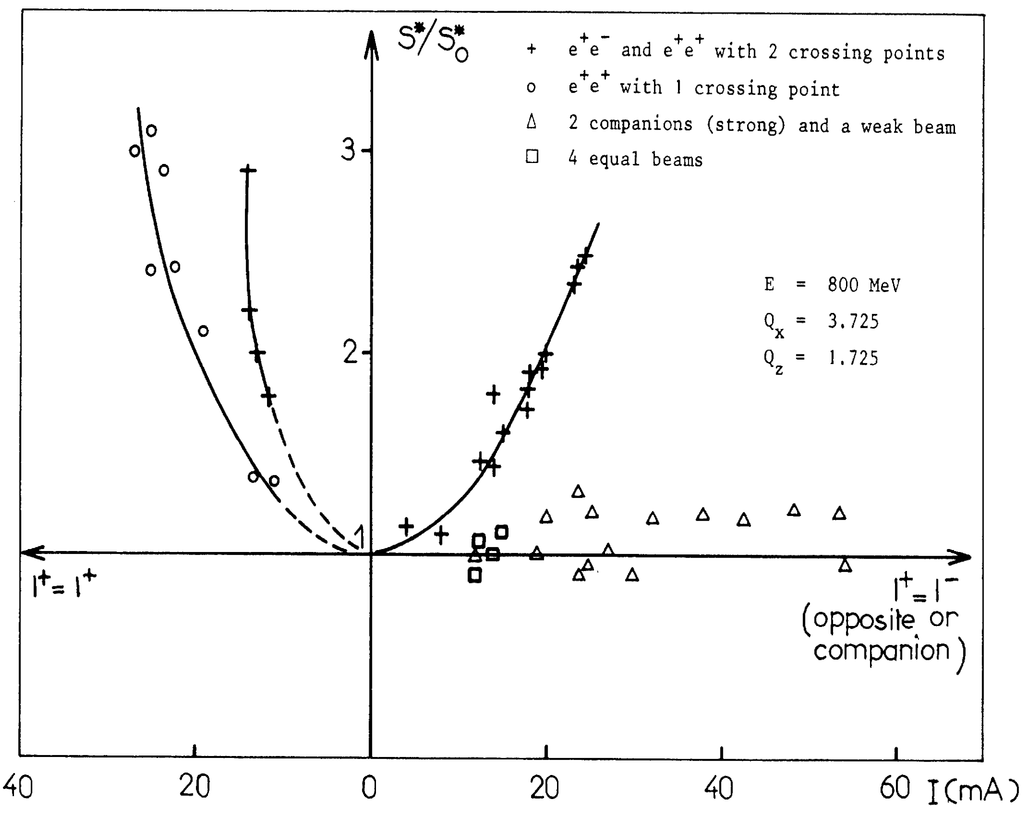

Fig. 2

This peculiar behaviour is schematically shown on fig. 3 :

upper ring		← I_1	$I_2 > I_1$	stable
lower ring	→ i	← I_2	$I_2 \leq I_1$	unstable
upper ring	→ i	← I_1	$I_1 > I_2$	stable
lower ring		← I_2	$I_1 \leq I_2$	unstable

No model is presently available to describe it.

In all the three-beam experiments the probe beam was kept at a level of 2 to 5 mA, high enough to permit luminosity measurements and low enough to avoid disturbance of the companion beams.

The e^+e^+ interaction cross-section versus current is plotted on the left hand part of fig. 2 for 1 and 2 crossing points. A sharp limit is observed at 14 × 14 mA in the second case, which does not seem to be correlated to special requirement on beam orbit adjustment of the two rings.

Four-Beam Behaviour

Most of the four-beam experiments were carried out with four equal beams at the energy of 800 MeV. Rapidly a limit in current was found at 15 mA per beam. Up to this value no increase in cross section was observed but the limit is very sharp in terms of optics parameters, mainly the tune, which in fact leads to a poor reproducibility.

Recent investigations in the Q_x, Q_z diagram ($3.7 < Q_x < 3.9$; $1.7 < Q_z < 1.9$) along the coupling resonance ($Q_x - Q_z = 2$) have shown that non-linear resonances are still present with four beams, which reduce the stability domain to small discrete areas as shown on fig. 4. For the same current per bunch these

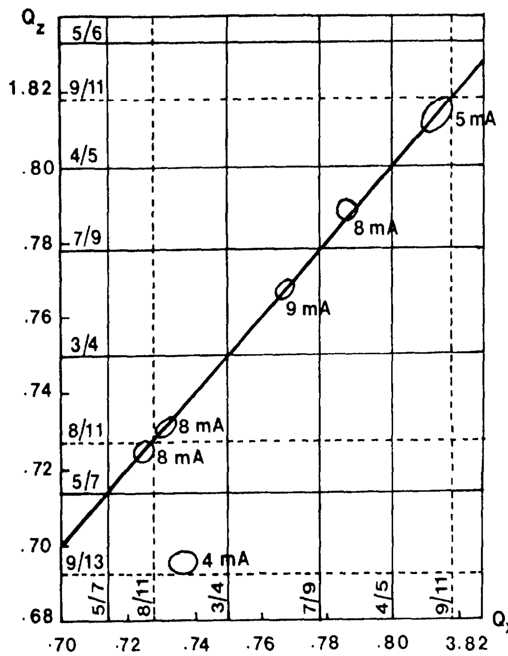

Fig. 4 : Stability Diagram with 4 Equal Beams (2 Crossing Points)

stable areas are much smaller than in the e^+e^- case, but of the same order of magnitude as for the e^+e^+ case. An experiment with flat beams is also presented on the same plot. In both cases, round beams and flat beams, no real differences were observed between two and only one crossing per turn.

The four-beam behaviour in DCI seems in qualitative agreement with theoretical predictions[2)3)]. Y.Derbenev showed that collective instabilities of compensated colliding beams should be strongly dependent on the operating point in the Q diagram. Following this model, a more accurate calculation was worked out for DCI by Nguyen Ngoc Chau and D. Potaux assuming single non-linear resonances up to the 10^{th} order and neglecting machine resonances. Their results can be summarized as follows :

case	Q between two crossing points	ξ_{max}
1	.87	.075
2	.73	.15
3	.39	.22

Cases 1 and 2 correspond respectively to the present operating conditions with two and one crossing point. The present experimental limitations correspond roughly to $\xi_{max} \simeq 0.018$ in both cases with round or flat beams. This might be an indication that non-linear resonances of orders higher than 10 play a role. The third case corresponds to one of the design operating points of DCI ($Q_x = 4.8$; $Q_z = 2.8$) for which no good injection with sextupoles could be achieved at the time the first ring was commissioned.

One must emphasize that with four beams colliding, coherent signal with frequencies above and below the operating point have been observed, which point out also in favour of collective coherent instabilities.

Conclusion

The present status of the space charge compensation does not permit a gain in luminosity with double ring operation, apart from a factor 2 that could be achieved with two independent rings, as soon as the upper ring will be better conditioned from the vacuum point of view.

A better understanding of the four-beam behaviour may come from new operating conditions such as $Q_x = 4.8$ $Q_z = 2.8$. These require either an operational betatron feedback with two beams in each ring, or the use of a constant tune path from a good injection point to the operating conditions.

Standard cure for coherent instabilities can also be tested such as tune split of the four beams and feedback. However coherent and incoherent effects are difficult to disentangle in 4-beam interaction.

Alternatively, efforts will be made to increase the performances of each ring.

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References

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