A SEARCH FOR A BEAM-BEAM EFFECT IN THE ISR

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Summary

The lifetime of an aperture limited weak proton beam at 2 GeV/c was measured in the presence and absence of a strong 26 GeV/c beam colliding with it in eight intersection points. The typical intensity was 5 mA in the weak and 12 A in the strong beam. The lifetime of the weak beam, 30 min at 5 mA, was strongly intensity dependent. No effect of the other beam was detectable at this short lifetime. The Q-shift experienced by the weak beam was calculated to be $4 \cdot 10^{-3}$ per intersection.

Introduction

In electron-positron storage rings the limits imposed by beam-beam effects are well known and a wealth of data exists [1]. The situation is different for proton storage rings, where the ISR are the only source of experimental data. But in the ISR the beam-beam effect, usually characterized by the linear tune shift per intersection, is very small, and it is unknown whether it has any effect on the beams. Certainly, it does not limit the performance. Future proton rings, however, are supposed to work at a tune shift of $5 \cdot 10^{-3}$ which is an order of magnitude higher than the tune shift experienced by the beams in the ISR. In order to explore the beam behaviour under those conditions it was proposed to collide a very low energy beam with a strong beam in the ISR [2]. To gain the biggest factor in the tune shift the minimum momentum at which our injector, the CERN proton synchrotron, will still eject conveniently was chosen for the weak beam. The strong beam was an intense stack circulating in the other ring at an ISR standard energy.

Description of the experiment

Prior to the injection of the weak beam at 2 GeV/c a large, flat beam of 11,5 A and 26,5 GeV/c was stacked in the other ring and left circulating. The vertical FWHH of this beam, the strong beam, was measured with the beam profile monitor (gas curtain) to be 3,7 ± 0,2 mm at the intersection points (β_V = 14 m). The strong beam current decreased only by 150 mA during the actual experiment; the beam height did not change.

Then single pulses at a momentum of 2,01 GeV/c were injected and their lifetime was measured. In order to have well defined conditions the weak beam was aperture limited by a vertical and a lateral scraper. The scrapers were always set to the same position one after the other right after injection. The aperture was chosen such that about 10% of the beam was lost when one of the scrapers moved into position.

In order to measure the lifetime of the weak beam at different tune shifts we varied the intensity of the strong beam by radial scraping. Thus the vertical dimension of the strong beam, which is the other parameter determining the tune shift in the case of horizontal crossing, stayed approximately constant. In a first step, the intensity was reduced from 11,5 to 4,5 A, and finally to zero. Figure 1 shows the decay of the individual pulses.

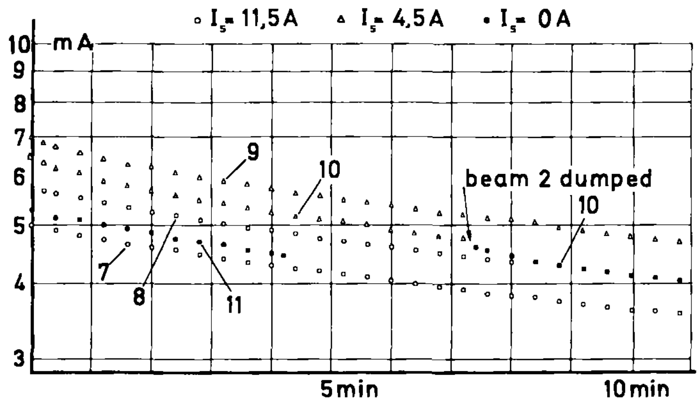

Fig. 1 – Decay of the weak beam for different strong beam intensities.

Table I gives the measured lifetime τ as a function of the calculated tune shift per intersection ΔQ and the strong beam current I_s. The lifetime τ_1 refers to a current of 5 mA in the weak beam, the lifetime τ_2 was measured 3 min after the aperture limits had been set. The accuracy of a lifetime measurement was approximately ± 10%.

Table I – Lifetime of the weak beams for different beam-beam tune shifts per intersection

ΔQ	I_s[A]	τ_1[min]	τ_2[min]	pulse No.
– 0,0043	11,5	21	30	7
– 0,0043	11,5	29	30	8
– 0,0017	4,5	34	29	9
– 0,0017	4,5	32	24	10
– 0,0	0	26	26	11

The tune shift given in the table was calculated from the following formula [3]

$$\Delta Q = -\sqrt{\frac{2}{\pi}} \frac{I_s r_o \beta_v}{e\beta c\gamma\alpha\sigma} \exp(-z_i^2/2\sigma^2)$$

The vertical beta value at the intersection β_v equals 14 m, α is the interaction angle which is 0,258 rad and β, γ are the relativistic constants. The spread σ is derived from the FWHH = 3,7 mm assuming a Gaussian distribution. One obtains σ = 1,5 mm. The exponential takes into account the vertical beam separation z_i in the intersections which is known from the measured closed orbits and shown in Table II.

Table II - Vertical beam separation in the individual intersection points

Intersection	1	2	3	4	5	6	7	8
z_i[mm]	0	0,6	0,6	1,6	5,3	3,6	2,0	1,6
$\exp(-z_i^2/2\sigma^2)$	1,0	0,9	0,9	0,6	0,0	0,1	0,4	0,6

Inspection of the table shows that the tune shift was not maximum in all intersection points. The average tune shift per intersection was 60% of the maximum one.

Discussion

It is apparent from Table I and Fig. 1 that we could not detect any dependence of lifetime on the tune shift within the precision of our measurement. The rather short lifetime of the weak beam may have masked a weak effect. Since the measured lifetimes varied between 20 to 30 min for a given tune shift, one could have discerned only effects yielding lifetimes of the same magnitude or less.

Two hypotheses can be put forward to explain the short lifetime of the weak beam in an aperture given by $A_h = 10\pi\cdot10^{-6}$ radm and $A_v = \pi\cdot10^{-6}$ radm.

The first one assumes that the beam was under the influence of isolated non-linear resonances. The working point in the presence of the strong beam was measured by inspection of the betatron frequencies after injection. We obtained for the non-integral part of the tune q_v = 0,662 and q_h = 0,725. This is quite close to a third and a sixth order resonance but only the latter is excited in a machine with a perfect median plane. Furthermore, scanning the lifetimes in the region around this working point by changing the tune of the machine with the help of the pole-face windings did not reveal any strong dependence on the tune as one would expect from non-linear resonances. Table III gives the results. The lifetime τ_1 was measured at a current level of 5,5 mA; τ_2 was obtained 4 min after the setting of the aperture limits.

When the strong beam was removed, the vertical tune increased by 0,02. Hence, the working point moved into a region where no lower than 7th and 11th order resonances were present. The lifetime, however, stayed the same even after this relatively large tune shift. This can be seen from Table I. Thus we can safely discard the first hypothesis because the lifetime did not depend on the tune of the machine.

Table III - Lifetime of the weak beam as function of external tune shifts

ΔQ_v	ΔQ_h	τ_1[min]	τ_2[min]
- 0,005	- 0,005	19	20
0	0	19	20
+ 0,01	+ 0,01	30	27
+ 0,01	0	27	26
0	0	18	19

A more likely explanation for the short lifetime is intra-beam scattering [4]. Although the theory has not yet been adapted to aperture limited beams, the strong intensity dependence of the lifetime supports this hypothesis. Table IV illustrates this point. It gives the lifetime at different current levels of an aperture limited 2 GeV/c beam, which decayed in the presence of the strong beam.

Table IV - Lifetime of an aperture limited 2 GeV/c beam as function of its current

I_w[mA]	6	5	4	3	2	1,5
τ[min]	14	20	23	29	35	39

Multiple scattering on the residual gas cannot account for the short lifetime. The N_2 equivalent gas pressure was only $2,7\cdot10^{-11}$ torr. This yields a lifetime of 280 min which is much longer than the observed one [5].

Acknowledgement

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References

1) F. Amman; Proc. 1973 Part. Acc. Conference, San Francisco, p. 858.

2) It is rumoured that B. Richter proposed it.

3) E. Keil, C. Pellegrini and A.M. Sessler; "Tune shifts for particle beams crossing at small angles in the low-β section of a storage ring", to be published in Nucl. Instr. and Meth.

4) C. Pellegrini; Frascati Report LNF 68-1 (1968).

5) W. Hardt; CERN int. report ISR-300/GS/68-11 (1968).

Henri Bruck (Saclay): Is the ingeneous idea of simulating the effect of the other beam by an external lens being pursued?

Keil (CERN): Actually, I have an abstract for a paper submitted to this Conference which I withdrew at the very last moment because the progress we have been making on that experiment was not as fast as we had expected. This idea is being pursued. There have been some very preliminary results and we hope to get better results sometime in the future.

Lee Teng (NAL): Did you say that the computed beam lifetime due to intrabeam scattering at 2 GeV agree with those experimental numbers?

Keil: I would say qualitatively yes, but we are not so sure that we have the right kind of theory to be very affirmative. They are in the right order of magnitude.

Alessandro Ruggiero (NAL): The first question is whether there was an official number for the limiting value electron-positron beam-beam tune drift?

Keil: I can not give a firm answer on that subject but the general feeling in the trade is that this number is in the vicinity of 5×10^{-2} or a little higher which means it is an order of magnitude higher than the accepted number for proton machines and two orders of magnitude higher than the actual number in the ISR, and that the electron-positron number is an experimental figure.

Ruggiero: The second question is whether the 0.05 was per intersection or not?

Andrew Sessler (LBL): Yes. We need an electron expert, someone from SPEAR presumably Ewan Paterson to respond to what the present situation is. Actually the next paper is on this subject.

Ewan Paterson (SLAC): There was some unfortunate errors in the luminosity monitors that we used to derive those calculations a year ago, so the agreement with the summation to 0.25 isn't as good as it was thought then. Concerning the number of interactions, the people you should ask to compare are from ADONE, where they have three interactions per turn compared with SPEAR's two interactions per turn. Both have very similar $\Delta\nu$ limits per crossing.

Sergio Tazzari (Frascati): We have measured small amplitude tune-shifts at ADONE with two crossings and six crossings. The ones measured with two crossings were higher than those with six crossings by a factor of about 1.5 and not by a factor of three.

Sessler (LBL): It is the $\Delta\nu$ per crossing.