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Background information and notes on the meeting of 7 May 1971

concerning

"Limitations on beam intensity and quality in the PSB and counter measures taken or prepared"

Present:	O. Barbalat, U. Bigliani, C. Bovet, G. Brianti, K.J. Green, I. Gumowski, W. Hardt (part time), H. Hereward, H. Koziol, G. Nassibian, K.H. Reich, F. Sacherer.
Excused:	P. Lapostolle.

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The purpose of the meeting was to review the present situation (also in the light of recent ISR and US experiences) and to set priorities for work still to be done in this field.

In the following notes, unless stated otherwise, specific information is due to particular persons as follows:

AGS: K.J. Green; CPS: O. Barbalat; ISR: H. Hereward; individual subjects: (name); instrumentation: H. Koziol.

A. TRANSVERSE PHASE SPACE

1. Single particle and coherent space charge limit at 50 MeV (C. Bovet, K.H. Reich)

a) Numbers for single particle (incoherent) Q-shifts

With[1)] $F = 1.04$, $B_f = 0.5$ and the beam and vacuum chamber dimensions given in Ref. 2 one has

$10^6\ \varepsilon_H$[rad m]	$10^6\ \varepsilon_V$[rad m]	ΔQ_i for 2.5 10^{12} p/p
130	40	0.2
65	40	0.25
30	30	0.37

b) Coherent Q-shift

With[1)] F = 0.58 and h = 52 mm [2)] one has $\Delta Q_c = 0.022$ for 2.5 10^{12}p/p.

c) Observation

- beam density distribution by means of IBS (< 100 μs resolution) and targets,
- coherent shift*) with Q measurement (observation of beam position on two successive turns at injection; standard Q-kicker system),
- incoherent Q -shift by (i) measuring smear-out time after excitation of coherent oscillations (H. Koziol), (ii) loosing beam on $Q_V = 5$ integer stop band as a function of beam intensity (K.J. Green).

d) Counter measures

- Possibility to choose at injection a working point in principle anywhere in the "quadrant" $4 < Q_{H,V} < 5$,
- Provision to shift the working point fairly rapidly by computer action (could be controlled by Q measurement),
- Compensation of certain stop bands (see point 2 below).

2. Stop band crossing (C. Bovet, G. Guignard, K.H. Reich)

The unavoidable errors in the PSB magnetic fields due to the finite dimensions of the magnetic elements and their construction tolerances give rise to fluctuations in the wanted fields, and to some unwanted terms (like skew quadrupoles) which also have systematic and statistical amplitudes. All of these may drive resonances, i.e. create stop bands. A rough list of the terms**) , their origin, their effects and counter measures proposed

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*) Koshkarov and Nikolaev of ITEP have used narrow band resonance excitation by means of a quadrupolar electrode arrangement to explore this frequency shift (and the spread).

**) Skew elements have $B_x|_{z=0} \neq 0$, i.e. a magnet pole in the horizontal plane.

is as follows*)

Term	Origin	Effects	Counter measures 3,4)
$\langle \Delta B \rangle$	R-B's, R-D's s.s. stray fields	integer stop bands	avoid
B'_{skew}	R-B's, R-Q's s.s. stray fields	H-V coupling	zeroth harmonic skew quadrupoles
$\langle \Delta B' \rangle$	R-Q's	half integer stop bands	sets of ninth harmonic correcting quadrupoles
$\langle \Delta B'_{skew} \rangle$	as for B'_{skew}	sum resonance stop band	sets of ninght harmonic skew quadrupoles
$\langle \Delta B'' \rangle$	R-B's, R-DH's	stop bands $3Q_H = p$ $Q_H+2Q_V = p$	sets of 14th harmonic sextupoles
$\langle \Delta B''_{skew} \rangle$	R-DV's	$3Q_V = p$ $2Q_H+Q_V = p$	——
$\langle \Delta B''' \rangle$	octupoles R-Q's, R-DV's	$4Q_H = p$; $2Q_H+2Q_V = p$ $4Q_V = p$	sets of 19th harmonic octupoles
$\langle \Delta B'''_{skew} \rangle$	R-B's, R-DH's	$3Q_H+Q_V = p$ $Q_H+3Q_V = p$	——

Thus, the stop bands thought to be most dangerous have been taken care of. One skew sextupole and one skew octupole (in 3 L1-1) permit one to explore the excitation of the (uncompensated) stop bands due to these field terms**). At present the computer software for "one knob stop band compensation" is being prepared5).

3. Beam equipment interaction

a) Numbers on thresholds for resistive wall (P.L. Morton)

P.L. Morton6) has studied the interaction between the PSB bunches and the wake fields due to the resistive vacuum chamber walls. His conclusions ares:

i) bunches will behave independently if $\Delta N/N > 10^{-3}$ (which is expected to be the case),

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*) In addition, the space-charge induced fourth order resonance $2Q_H - 2Q_V = U$ may be (partially) compensated by means of zeroth harmonic correction octupoles.

**) We have reserved straight section space to add in case of need the complete set for this compensation and also for compensation of the 18th harmonic.

ii) higher modes (starting from the sextupole mode $\nu \approx 3\nu_{00}$) are probably Landau damped due to the frequency spreads presumably already existing in the beam,

iii) the quadrupole mode and the sextupole mode $\nu \approx \nu_{00}$ are less likely to be damped "naturally"; some "external" damping may be possible, for instance by means of the correction octupoles,

iv) the dipole mode is stable as long as the Q value is kept in the region $4 < Q < 4.85$, provided the bunch moves as a <u>rigid unit</u> (which is debatable).

b) Thresholds for other equipment and growth rates

No numbers have been worked out yet.

c) Observation

Monopole mode : unclear in general case

Dipole mode : fast position-sensitive pick up station and spectrum analyser (not yet available)

Quadrupole mode: quadrupole PU station (in 3 L1-1)

d) Counter measures

A limited amount of extra Landau damping can be introduced by means of the octupoles (and/or the sextupoles?). If the self-stabilisation of the dipole mode would not work, active feedback damping could be the answer. This would require a wide band excitation (say 3 db point at 100 MHz) in order to ensure a linear phase relationship for the lower modes, i.e. in order to avoid excitation of others but the very lowest ones (K.J. Green). Systems of this general type have been looked at for the CPS7) and the AGS8) and are in constant successful use at the Bevatron, Nimrod9), Saturne and the ZGS10). The ISR have a similar system for correction of injection errors11).

4. <u>Head-tail effect</u> (F. Sacherer)

This is a difficult subject; no agreed theory for proton accelerators is available. In particular, the nature of the wake field appears to be a mystery. F. Sacherer (and B. Zotter) works with an analytical approach; K. Schindl continues numerical work started with P.L. Morton at the time. At the CPS, one instability tentatively attributed to this cause is stabilised by means of octupoles.

5. Beam injection (C. Bovet)

A macroparticle computer simulation study is under way by C. Bovet, D. Lamotte and R. Le Bail, to study the space charge influence on the previous results[12].

6. Filamentation (P. Lapostolle)

P. Lapostolle is progressing steadily[13]; he has now formulae ready which could be tested on the ISR once they have 10 A (or somewhat less). A (limited) application to the PSB could follow; there remains the problem of computer time.

7. Arnold-type phenomena (I. Gumowski)

New venture, which may or may not be important for the PSB.

8. Neutralisation effects and similar

No systematic work has been done on this. H. Koziol wondered whether the level of electrons trapped in the proton beam would be appreciable. H.G. Hereward felt that with 100% modulation of the 100 to 200 eV (proton) potential well electrons would be lost vertically after a certain number of cycles, which could be found from a computer simulation. In this general context K.J. Green recalled the unexplained electron currents from the hot electrode of electrostatic septa both at the AGS and the CPS.

9. Others

Nothing much specific was said about this except that the transverse emittance blow up in the CPS and the large losses at injection remain unexplained, demonstrating that we may still not yet have the correct basic picture of beam behaviour.

B. LONGITUDINAL PHASE SPACE

1. Beam dynamics and beam manipulation (U. Bigliani, G. Nassibian)

About 30% acceptance margin had been planned. With the two-frequency debuncher, the somewhat higher RF voltage reserve and suitable reduction of "parasites" 16) this is ensured.

2. Beam loading (U. Bigliani, G. Nassibian, D. Zanaschi)

Provisions have been made in a general way as regards the cavity (extra gap capacity), the RF amplifier (spare tube useable as programmed impedance), the tuning amplifier (programmed detuning) and the beam control system. Work is also in hand on reducing the response of the cavity to harmonics of the beam current.

3. Static space charge effects (U. Bigliani, I. Gumowski, K.H. Reich)

The influence of self and image forces on bucket areas and bunching factors (at injection15) and acceleration16)) and on synchrotron frequencies16) was worked out in detail for chamber walls of infinite conductivity. A low priority programme is under way to take into account finite conductivity.

4. Dynamic effects

a) Numbers on unbunched beams (D. Lamotte, K.H. Reich)

Applying the "ISR formulae" to the situation near injection, one finds that the PSB coupling impedance is about twice the critical value17). As most of this coupling impedance is due to the beam-chamber capacitance, it can be reduced in case of need by means of (programmable) inductances.

b) Bunched beams (I. Gumowski)

Expressions to determine the growth rates of the oscillation of the bunch centres (using the travelling wave and the Vlasov approach) and of bunch shape (Vlasov) up to the order of five were developed as no such expressions were available. Application to the PSB parameters showed the need to control the impedance (as a function of frequency) of resonating structures having a "Q" > 10 for frequencies up to about 500 MHz. Some further work is under way to clear up the differences resulting from the travelling wave and the Vlasov approach.

c) Observation (G. Nassibian et al.)

Bunch shape: wideband pick up station possibly with spectrum analyser.

Dipole oscillations:
- wideband station + Cappi
- self tracking filter and phase detector.

d) Counter measures

The "Working party on longitudinal high intensity effects" (chaired by G. Nassibian) has looked at the PSB hardware concerned in the light of the findings of Refs. 14, 17 and 18. A number of components have been modified as a result, in particular the RF cavity; vacuum joints, manifolds and tanks; kicker magnets etc.19). This work is still going on.

The particular instability found in the CPS after transition is now being cured by Landau damping obtained through working with tightly fitted bunches. This is also feasable in the case of the PSB.

C. CONCLUSIONS AND FURTHER WORK

1. Preparations under way concerning points:

A 1, 2, 4, 5, 6, 7, 8 and
B 1, 2, 3, 4

are considered adequate. Point A 9 will be kept under watch.

2. Highest priority is thus on point A 3, transverse instabilities.

Action

Gumowski
Reich
Sacherer

i) We need to work out actual numbers to confirm (or infirm) the tacit assumption prevalent so far that the resistive wall gives the dominant contribution. In this evaluation, both TE and TM modes should be considered (H.G. Hereward). A knowledge of growth rates would also be desirable.

Nassibian
et al.

ii) Depending on these numbers further transverse beam coupling impedances may need measurement and possibly reduction.

Nassibian
Reich

iii) Some low priority study of an active damping scheme seems justified and reservation of straight section space but no construction of actual hardware

Koziol
et al.

iv) It might be good to have in each ring a wide band position-sensitive PU station, possibly of the magnetic type (to work in "lossy" surroundings), particularly if they can be produced without interfering with the PSB construction programme. The spectrum analyser is already on our shopping list for later this year.

Action
H. Koziol
et al.

3. Just for record: the interest of preparing a sufficient variaty of tables,graphs, normograms, etc. with useful combinations of PSB parameters (for MCR and office use) was stressed.

K.H. Reich

Distribution (open)

Persons invited and informed

List MPS-SI/1

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