1. Introduction

Since the last report on work done with CESAR (International Symposium on Electron and Positron Storage Rings, Saclay, September 1966) most of the time has been devoted to the following three topics:

Unstable coherent transverse oscillations of coasting beams were studied. Their spectra, thresholds and growth times were investigated as a function of beam intensity and the external impedance connected to the clearing field electrodes.

An experiment interesting for multturn injection was the splitting up of a beam by means of a third order resonance.

Electrons were stacked with an r.f. voltage shaped such that one of the two accelerating buckets was suppressed. The stacking efficiency was found to be the same as with normal r.f. voltage.

These three subjects are dealt with in more detail in the following chapters. Two further experiments should also be mentioned:

A phase-lock system was used successfully to show that with such a device the influence of r.f. noise (which for this purpose was deliberately put on the frequency program) on the stacking process can be reduced significantly.

If for reasons of momentum definition the Δp occupied by the particles in a storage ring should not exceed a certain value, it is better not to make a stack which just extends over the available range, but to make a wider stack, so that the high density part of it is contained in this Δp and to avoid using the average density tail. By such a procedure* the available Δp can be filled with a higher average density. The cutting away of the tail of a stack was realized with CESAR in the following way (see Fig. 1):

After establishing a stack (see Ref. 1 for details of stacking and scanning procedure) a series of empty buckets was run through it in direction from low to high density. At the value of momentum where one wished to cut off the tail, the r.f. voltage was reduced to zero. By phase-displacement that part of the stack, which had been traversed by the buckets was displaced onto a target.

At the beginning of this year new combinations of sputter-ion and sublimation pumps were installed and the average pressure subsequently reduced by a factor of three to 1 × 10^-10 torr.

* suggested by A.K. Sessler.

2. Coherent transverse oscillations

A single turn was injected and brought to central orbit by betatron acceleration. Signals from an electrode sensitive to the vertical oscillations of the coasting beam were analyzed (Ref. 2). We tried to influence these oscillations by terminating the clearing field electrodes with different inductances L_t in order to make the latter resonant at certain frequencies.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>L_t (µH)</th>
<th>f_res (MHz)</th>
<th>Prevailing mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.1</td>
<td>37.8</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>44</td>
<td>1.8</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2650</td>
<td>0.25</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>undefined</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>

The 22 electrodes, each 7 cm wide and 50 cm long, were placed at the bottom of the elliptic (8 cm × 4 cm) vacuum chamber. The capacity C_v to the vacuum chamber was 140 pF and the connections were made at 1/3 of their length.

Further relevant data:

Q_v = 1.8
f_rev = 12.2 MHz
length of closed orbit = 24 m
γ = 4.6

Scanning the signals with a frequency analyzer we found certain prevailing modes. The mode numbers are given in the table above. Case Nr. 5 refers to the situation where the clearing electrodes were connected to their power supplies.

Figure 2 shows the growth of oscillations of mode n = 2. Notice the subsequent damping. No beam loss was discernible.

The normalized growth times of mode n = 2 are shown in Fig. 3.

The maximum amplitudes of all the other modes (including n < 2) were generally smaller by more than 5 db than the prevailing ones. The latter were generally those corresponding to f_res = |n-Q| · f_rev.

Theoretically (Ref. 3) the modes n < 2 should be damped, however they appeared to be excited during the damping time (compare Fig. 2) of the prevailing modes. This would seem to imply some sort of energy exchange between the prevailing and the theoretically damped modes. The possibility that the modes with n < 2 were excited by beam loss was excluded.

The threshold currents I_th were influenced appreciably by the external impedances, for example with mode n = 2:

<table>
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<th>L_t (µH)</th>
<th>I_th (mA)</th>
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</tr>
<tr>
<td>2650</td>
<td>1.5</td>
</tr>
</tbody>
</table>

3. Beam splitting by a third order resonance

The experiment was to split a beam in transverse phase space into three parts by means of subresonance excitation using sextupole fields together with some extra "stabilizing" non-linearity, in our case an octupole field.

The trajectories in betatron phase space obtained with such considerations are given in Fig. 4 (Ref. 4). Examination of these trajectories indicates that under certain conditions in the vicinity of a sub-resonance of third order, there would be three stable regions outside the origin of the phase space coordinates. Thus if one is able to look at the beam at a particular azimuth of the machine, the projections of the stable regions onto the transverse axis should be apparent.
In the experiment we used vertically mounted sapphire rods inside the vacuum chamber viewed by a television camera through a window.

The vertical q-value was arranged such that it decreased with increasing orbit radius r until it came to be 1/2 at a position near the sapphire target. The beam was then moved through the resonance by betatron acceleration onto the sapphire target, the light spot showing its vertical positions.

We tried to produce the three "island" situation where the projections of two of them were superimposed so that the upper beam was 2 times the distance away from the median plane as the two bottom ones. Fig. 5 shows what is believed to be near such a situation. The central spot is the beam on median plane. The vertical q value of this central beam was believed to be 1.611, that of the island beams 1.666. The difference and the fact that dq/dr was negative are in agreement with theory.

4. Stacking with "missing" buckets

The intersecting storage rings (ISR), at present under construction at CERN, will have a circumference 1.5 times larger than that of the PS. When a pulse of protons is transferred from the PS to be stacked in one of the rings of the ISR then 10 of the 30 ISR buckets will remain empty. They will cause phase displacement and increase the width of the stack without contributing particles. Several propositions to avoid this loss in particle density have been made. A. Schoch suggested to gate the r.f. voltage in such a way that the normally empty buckets would not exist at all. This scheme has been studied and worked out in detail for the ISR by W. Schnell and is reported in this conference (ref. 5).

In order to verify the obvious expectation that the suppression of empty buckets will yield the same stacking efficiency as obtained with only full ones (for the same total number of buckets of which the stack is built up) an experiment has been carried out with CESAR.

The conditions for the r.f. system were rather stringent as with h - 2 every other period of the r.f. voltage had to be suppressed. The wave form obtained in practice is shown in Fig. 6a. For high values of r the influence on the remaining bucket of such imperfections in the wave form may be neglected (ref. 8).

The electrons were always accelerated to the same energy E, displacing the previously stacked ones to lower energies ("stacking on the top"). After completion of the stack empty buckets were run through it, the signal produced by them on a pick-up electrode showing the density of the stacked electrons as a function of energy (fig. 7) (ref. 1).

Stacking efficiency as defined in ref. 1, 6 and 7 is given by the ratio

$$\eta = \frac{N_{lim}}{N_{tot}}$$

where N_{tot} is the total number of particles in the stack and N_{lim} is the number of particles contained in the width

$$\Delta E = n \cdot \frac{\Delta \epsilon}{2\pi}$$

where n is the number of acceleration cycles and \(\Delta \epsilon\) is the area of (h - n) buckets (h = harmonic number, s = number of suppressed buckets).

N_{lim} and N_{tot} are both proportional to the corresponding areas under the envelope of the scanning signal, so that \(\eta\) follows from these measurements of area. Fig. 6 shows the values obtained for \(\eta\) with one of the two buckets suppressed (r = 0.74). For comparison the values measured earlier for normal stacking (ref. 1, r = 0.7) are also given, as well as a theoretical curve (ref. 7, r = 0.7). To compare \(\eta\) for the same total number of buckets stacked, the n-scale has of course to be changed.

Within the limits of error stacking with missing buckets yielded the same stacking efficiency as normal stacking.

REFERENCES


DISCUSSION (condensed and reworded)

K. Johnson (CERN): I would like to make a comment on the first experiment to stress the importance of this for the ISR. If one were interested in a momentum spread of less than 10^{-3} (which is very likely), the vacuum chamber space occupied by the momentum spread would be considerably smaller than is required for the betatron oscillation. In this case, it is impossible to strip the beam by any other method. This experiment was very conclusive.

H. Kocio (CERN): If we had done this experiment only for application to CESAR, it could have been done much more simply. The width of the beam in CESAR is determined by the momentum spread rather than by the betatron oscillation amplitude. Therefore the experiment could be done simply by bumping the beam in and out. But this experiment was done with the ISR in mind, in which case we might have a very small momentum spread.
Fig. 1. Stack shaping. $p$ = momentum, $q$ = density of particles, $V$ = r.f. voltage of displacing buckets.

Fig. 2. Signal induced by vertical coherent oscillations of a 2.2 mA beam on a pick-up electrode. Filter adjusted to mode $n = 2$. $L_{ext} = 2.65 \text{ mH}$. Hor. scale: 1 ms/Div, vert. scale: $5 \times 10^{-5}$ A/cm/Div.

Fig. 3. Normalized growth time constants of mode $n = 2$. $\tau = \text{e-folding time in sec}$, $I = \text{circulating current in A}$.
- clearing field electrodes connected to power supply
- externally connected inductance: $2.65 \text{ mH}$
- $44 \mu\text{H}$

Fig. 4. Betatron phase space trajectories for a third order resonance (from A. Schoch, ref. 4).
Fig. 5. Photograph of a sapphire target illustrating the splitting up of a beam into three "islands".

Ratio of detuning ($\Delta Q$) to frequency shift at reference amplitude due to non-linearity ($2A_{220}$):

$$\frac{\xi}{\chi} = (-0.24 \pm 0.11) a_0^{-2}$$

where

$$\Delta Q = 1.611 - 1.666 = -0.055$$

octupole non-linearity:

$$b_{220} = (0.14 \pm 0.07) \text{ cm}^{-2}$$

$$a_0 = \frac{Q}{\chi^{2/2}}$$

where $a_0$ is the real betatron reference amplitude in cm.

Fig. 6. a. R.f. voltage required for a missing bucket with $h = 2$

b. Voltage obtained in practice at CESAR (24.6 MHz).

Fig. 7. Scanning signal of a stack. $E_{\text{stop}}$ indicates the point to which the particles are brought by the stacking buckets. $n_{1/2}$ gives the width which an ideal stack would occupy.

Fig. 8. Stacking efficiencies as a function of the number of acceleration cycles.

- with one missing bucket
- with two full buckets

Full line: theoretical curve (ref. 7).