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SINGLE BEAM INSTABILITIES IN PETRA

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Summary

One of the most important questions during the study and the construction period of PETRA was connected with the high particle intensity effects. Therefore the first high current experiments at PETRA were performed to study average current limitations, higher order mode losses, bunchlengthening, single bunch instabilities and single bunch current limitations.

The first results show, that the strength of the observed effects remain within estimated limits, so that the currents are not limited below the design values.

Damping Times in PETRA

The basic parameters for studying the strength of instabilities are the damping times. At 6.5 GeV the radiation damping times in PETRA are

$$\tau_{long} \approx 70 \text{ ms}, \quad \tau_{trans} \approx 150 \text{ ms}.$$

The Landau-damping was observed by exciting the longitudinal and transverse dipole modes

$$\tau_{L\ long} \approx 40 \text{ ms}$$

and

$$\tau_{trans} \approx 4 \text{ ms} \ldots 20 \text{ ms}$$

depending sensitively on the closed orbit adjustment. When the longitudinal and transverse feed back system (F.B.) is operated, the dipole damping times become (1)

$$\tau_{F.B.\ long} \approx \tau_{F.B.\ trans} \approx 0.5 \text{ ms}.$$

Average Current Effects

Longitudinal and transverse dipole instabilities driven by parasitic modes of the rf cavities were observed when some of these cavities were detuned off the working point. The threshold currents were found to be around 5 ms when the Landau-damping was 40 ms in the longitudinal and 20 ms in the transverse direction. When the F.B. was switched on, these effects could be cured completely.

Higher Order Mode Losses

The higher order mode losses (HOML) were measured by a special method (2): ahead of the high current main bunch a low current prebunch was filled into the preceeding bucket. Since the prebunch does not affect the main bunch and the main bunch does not affect the main bunch after one revolution, the prebunch is used as a time reference. Such a time reference is necessary in order to eliminate the phase shift of the rf voltage due to the phase control of the rf system in the case of pulsed beam loading. The time elapsing between the prebunch and the main bunch (Fig.1) and the synchrotron frequencies of the two bunches were measured. As a result the total loss parameter for PETRA (4 rf cavities) was calculated

$$k = 12 \text{ V/pC}$$

at a bunch length $2\sigma_s = 2 \times 3.7$ cm.

The loss parameter of PETRA per meter becomes

$$\bar{k} = 5.2 \text{ mV/mpC}.$$

This means that the loss parameter of the PETRA chamber has been reduced by a factor 15 with respect to the DORIS chamber (3).

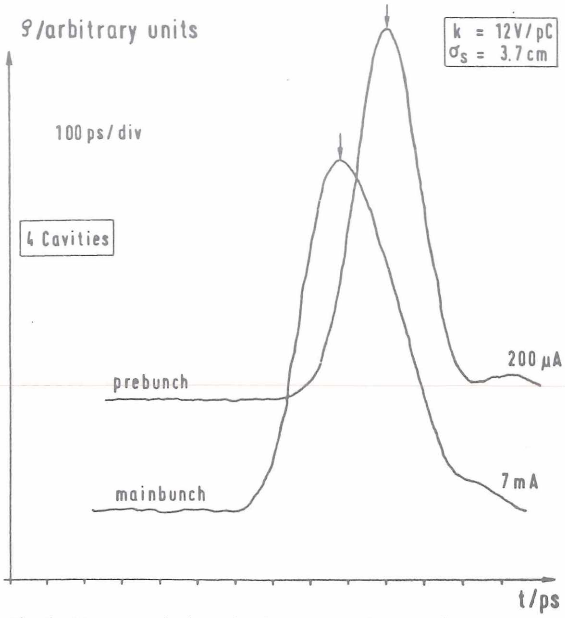

Fig.1 Measured bunch shapes and positions

Bunch Lengthening

At 6.5 GeV the bunchlength was measured as a function of the single bunch current. The apparatus employing a fast photodiode is similar to the apparatus used at DORIS (4). The result of the measurements is plotted in Fig.2. The dashed line shows the interpolation of the experimental data, whereas the solid line shows the expected bunchlength following the Chao-Gareyte scaling (5) using the observed value of the PETRA loss parameter. No change of the slope of the measured curve could be observed around the expected threshold currents of turbulent motion. The rf signals picked up from a loop in the ring were investigated between 1 GHz and 6 GHz. No higher longitudinal modes could be detected

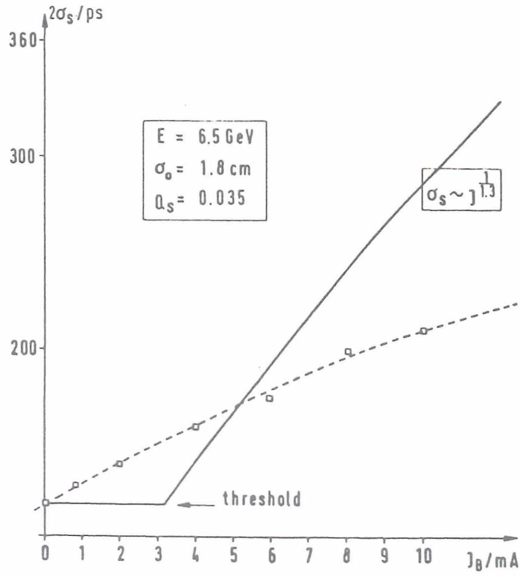

fig.2 Bunchlength vs current in a single bunch

When the dipole and quadrupole modes were excited externally with an amplitude much smaller than the amplitude corresponding to the observed lengthening, these modes were clearly detected.

The observations at PETRA are completely different from the observations at DORIS and they seem to indicate that the mechanism for bunchlengthening at PETRA is based mainly on potential well effects rather than on effects described by the different models of turbulent energy blow up (6,7).

Head Tail Effect

The horizontal and vertical head tail effect was observed in PETRA leading to an additional damping of the horizontal and vertical dipole modes when the chromaticities were positive. When the Landau damping in the transverse direction was 20 ms the head tail effect leads to a dipole damping time

$$\tau_{HT} = 4 \text{ ms}$$

at 5 mA/bunch and a chromaticity $\xi = + 3$.

Vertical Single Bunch Instability and Current Limitation

The maximum single bunch current in PETRA is limited by a vertical instability which has not yet been understood. This instability leads to a sudden vertical blow up of the beam if the current reaches the threshold current of this instability. The threshold current depends strongly on the optics. For the optics with the smallest vertical β-value at the interaction point (β_{zo} = 15 cm) the threshold was found at 7 mA. When the optics were changed to β-values of β_{zo} = 100 cm, the threshold current increased to 15 mA. Since the low β-values at the interaction points are connected with high vertical β-values in the adjacent sections the instability mechanism seems to be based on the β-values in these sections.

The threshold current for the vertical instability of a single bunch was independent of the number of bunches even in the case where adjacent buckets were filled, so that the blow up is due to a single bunch (bucket) instability.

Near the threshold current the rf signals picked up from the loop were investigated with respect to coherent signals. No such signals could be detected and the F.B. has no essential influence on the instability.

The chromaticities were changed over a wide range including negative values with help of the F.B. curing the head-tail dipole mode. No fundamental influence on the instability could be observed. However, for positive chromaticities close to zero the threshold currents increased by about 25 %.

After the beam has blown up above threshold, the vertical aperture limit is reached and the injection stops. This means that the maximum current in a single bunch is nearly identical with the threshold current.

Changing the optics to β_{zo} = 100 cm and keeping the chromaticities near zero a maximum current of 18 mA was reached in a single bunch at 6.5 GeV.

When the bunchlength is increased by a pulsed excitation of the longitudinal quadrupole mode the blow up at threshold can be removed. When the bunchlength is increased by a change of the longitudinal damping time due to a change of the radio frequency the same effect is observed. The bunch length was increased by a factor 3 in that case. However, it was not possible to increase the maximum current significantly by these methods.

Below threshold the vertical betatron frequency of the dipole mode changes with current (Fig.3), but the maximum tune shift is small as compared to the dimensions of the $Q_x - Q_z$ area which is free of optical resonances limiting injection or lifetime. Since this area remains nearly unchanged when the current increases, there is no incoherent tune shift much greater than the dipole tune shift.

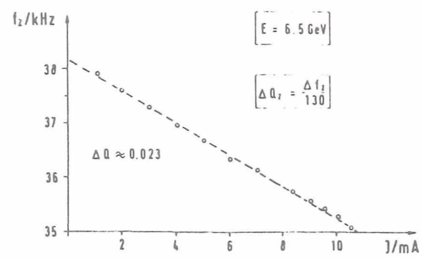

fig.3 Vertical dipole tuneshift vs current in a single bunch.

References

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