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Bunch Lengthening in DORIS

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*The experiments were performed by the DORIS Group as part of the machine developement program.

Introduction

Two types of bunchlengthening models were investigated theoretically and experimentally:

I the single bunch potential well distortion model

II the single bunch instability model

The potential well distortion model leads to a pure lengthening without energy widening whereas the instability model describes energy widening due to unstable internal bunch motion, so that lengthening is a consequence of energy widening only. However, the mechanism of unstable bunch motion is not yet fully understood. Although the different models (1,2) allow to extract a scaling law which fits bunchlengthening as a function of current, the observed effects accompanying energy widening are not in complete agreement with the predictions of those theories. A common problem of some of these models is, that even the mechanism of instability cannot be explained.

In this context one of the most important questions concerns beam lifetime in case of energy widening in PETRA at injection energy.

In this paper measurements are described, performed at DORIS giving information about:

1. the mechanism of energy widening and accompanying effects
2. the particle distribution of the energy widened bunch

Instrumentation and check of consistency

Longitudinal line density

The visible synchrotron light is focused on a high speed photodiode (HSD50) with a redesigned housing producing reflexions of less than 6 %. The response time of the diode is 130 ps. The output of the diode is directly coupled to a sampling head (Tectronics S12/S4), which is triggered by a pulse signal derived from the

DORIS rf by digital subdevision Bunchshapes are recorded on an x-y plotter. The full width at half maximum (FWHM) is measured and corrected for reflexions and diode response on a computer.

The error is due to the uncertainty in the correction and is estimated to be less than 5 %.

Energy widening in the core region of the particle distribution

The horizontal particle distribution in the core region is measured by one of the optical systems of DORIS installed for profile measurements at a place where the horizontal dispersion is large. A second optical system installed at a place where the dispersion is small is used simultaneously to ensure that there are no superimposed changes of the horizontal betatron width.

Energy widening in the tail region of the particle distribution

In order to get information about the particle distribution in that region which defines the large time scale beam lifetime particles are removed from this region by scrapers installed at a place where the horizontal dispersion is large. The lifetime was adjusted to about 1 h.

The particle density is compared to a Gaussian distribution ρ_G with the r.m.s. σ_G having the same lifetime[3,4]. The "energy widening in the tail region" is then given in terms of σ_G/σ_V, σ_o being the low intensity r.m.s.

Check of consistency

Besides the usual optical checks (dispersion, betatron width, low intensity bunchlength as the function of rf voltage) the consistency of the instrumental equipment used was checked by the following method:

the klystron input of the DORIS rf system was phase modulated with noise extracted from current branching of a pentode.

Energy widening in the core, energy widening in the tail and total bunchlengthening is consistent with a Gaussian blow up within an accuracy of 5 %.

Analysis of longitudinal modes

The output of a wide band electrode (1 MHz... 6 GHz) is directly coupled to a wide band spectrum analyzer (AILTEC, 0.5 GHz... 6 GHz). The spectrum was observed around 3 GHz and analyzed with respect to longitudinal bunch mode frequencies.

The low frequency change of mode amplitudes was analyzed by a time display of the mode signals using a narrow band filter (10 kHz) keeping the different mode frequencies separated.

Single longitudinal bunch mode were excited modulating the phase of the klystron input. The phase modulated rf voltage was demodulated by the cavity response, using a special tuning of the cavities, to produce an amplitude modulation of the rf voltage.

Without "cures" the threshold currents for multi-turn longitudinal dipole instabilities in DORIS are near 15 mA for single bunches. In order to avoid a distortion of bunchlengthening effects an active longitudinal feedback was used for the dipole mode to compensate longitudinal multi-turn instabilities.

Experimental results

Fig. 1 shows bunchlengthening, energy widening in the core and in the tails as a function of the current at 2 GeV and at a longitudinal time of $Q_s = 0.021$.

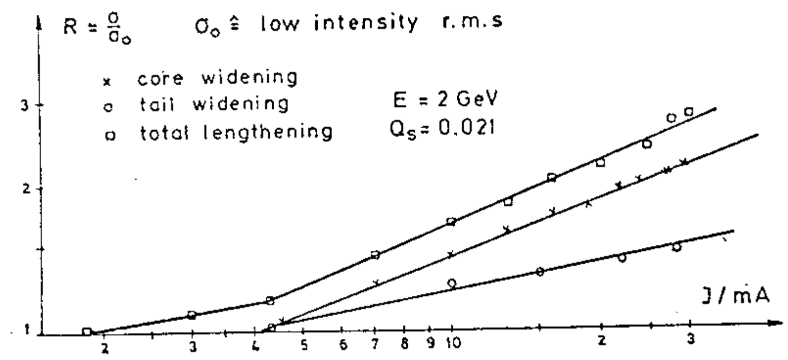


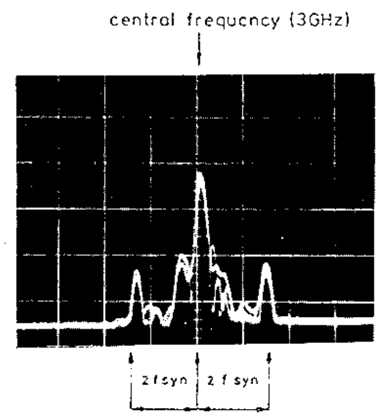
Fig. 1: Bunchlengthening, energy widening in the core, energy widening in the tails as a function of beam current.

Besides energy widening in DORIS we found a considerable amount of bunch lengthening due to potential well distrotion in agreement with earlier data[5]. This reconfirmes an inductive wall impedance. The energy widening has a typical threshold behaviour, so that the slope of the total lengthening is changed at the threshold of energy widening.

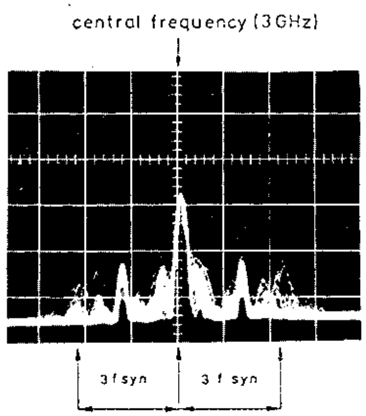
The energy widening in the tail region is considerably less than the widening in the core. This confirms preliminary data mentioned earlier[6].

This "reduction" of energy widening in the tail region is of great interest as the beam lifetime of PETRA at injection energy is concerned.

In the threshold region of fig. 1 the energy widening is clearly accompanied by single longitudinal bunch modes of Sacherer type[7].



quadrupole side bands at threshold
fig. 2
quadrupole mode



sextupole side bands at threshold
fig. 3
sextupole mode

At 2 GeV and at a longitudinal tune of $Q_s = 0.021$ the quadrupole mode occurred between 4 mA and 6 mA, the sextupole mode at 12 mA (fig. 2 and fig. 3). At the maximum current used (30 mA) the octupole - and even the decapole mode appear.

It is interesting to note, that the ovserved signals of unstable modes occur near the unperturbed low intensity frequencies of these modes.

In order to measure the time length between unstable grouth, self-stabilisation and relaxation due to radiation effects[6] the sextupole mode signal was time displayed (Fig. 4). This time length is not less than 1 msec, which is large as compared to the period of a synchrotron oscillation (at least 20 times).

Around 3 mA, far below the quadrupole- and sextupole threshold, the width of the sextupole mode was measured observing the response to an external excitation. The width increases with current but is asymmetric with respect to the low intensity frequency: modes can be excited below but not above the low intensity frequency.

This observation is interpreted as the experimental evidence for the existence of "radial submodes" described in Sacherer's mode model where an inductive wall leads to a frequency splitting of the radial modes.

As the current increases towards the threshold values of the quadrupole mode, the frequency range of the splitted sextupole submodes is extended to the low intensity quadrupole frequency.

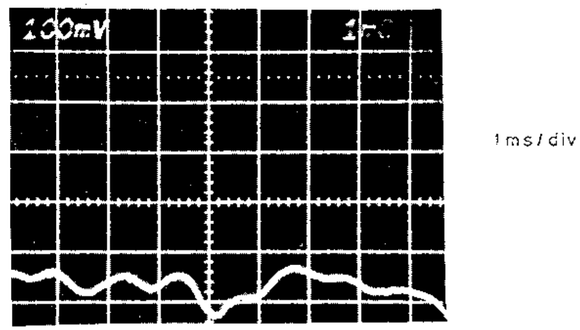


fig. 4
time display of the sextupole signal

Theoretical interpretation

According to the observations in DORIS we draw the following conclusions:

1. The coasting beam model[1] although explaining the mechanism of longitudinal single bunch instabilities is in contradiction with the observations in an electron machine since it does not describe the occurrence of single multipole modes of Sacherer type, oscillating in a time scale which is large as compared to the synchrotron period. Besides that the coasting beam model leads to a "Gaussian explosion" in case of energy widening, so that the tails are as widened as the core.

2. Although Sacherer's longitudinal multipole mode model[7] does not explain the instability mechanism it seems to be the appropriate description of the dynamics for unstable bunch motion in electron storage rings.

3. The model of large time balance[6] seems to describe the dynamics as the particle distribution in concerned.

4. Sacherer's mode coupling model[8], which modifies the original multipole mode model, describes instability for a coupling of even and odd multipole modes. This theory predicts a "merging" of the even and odd-mode frequencies, so that the signal of the unstable mode system appears between the unperturbed mode frequencies. At the first glance this seems to be in controduction with the observations.

5. However, in case of potential well distortion, present in DORIS, the mode coupling model can be modified.

   If μ denotes the azimuthal quantum number (characterizing dipole-, quadrupole modes, etc.) and m denotes the "radial" internal submode, a mode is completely described by $\langle \mu m \rangle$.

   According to potential well distortion there is a mode $\langle \mu, m_\ell \rangle$ with the largest negative frequency shift and a mode $\langle \mu, m_s \rangle$ with the smallest negative frequency shift. Then "merging" can occur between mode $\langle \mu, m_s \rangle$ and $\langle \mu+1, m_\ell \rangle$ and a modified mode coupling mechanism can produce an instability "near" the unperturbed mode frequencies.

   Since an asymmetric extension of the range of sextupole submode frequencies was observed, we conclude that the mode coupling model can be considered to be consistent with the observation in the case of potential well distortion preceeding the energy widening below threshold.

Acknowledgement

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