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R. D. Kohaupt

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R. D. Kohaupt

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SYSTEM IN PETRA

R.D. Kohaupt
Deutsches Elektronen-Synchrotron, DESY
Hamburg, FRG

Summary

At the natural bunchlength the single bunch currents in PETRA are limited by satellite resonances and a new vertical instability[1], which causes a vertical blow-up of a particle bunch if the single bunch current reaches the threshold value of that instability. The "PETRA instability" was explained in terms of head-tail mode coupling[2] and according to this model the vertical blow-up was cured by bunchlengthening changing the longitudinal damping partition. The disadvantage of this kind of bunchlengthening is the increase of energy spread leading to a reduction of quantum life time during energy ramping. The satellite resonances are avoided by a careful steering of the longitudinal and transverse tunes. A more effective method of bunch lengthening is the use of a higher harmonic rf system. Such a system was installed in PETRA. With the higher harmonic rf system the threshold current of the vertical "PETRA instability" could be increased from 3 mA (natural bunchlength) to 15 mA (with higher harmonic rf system). Besides bunchlengthening the higher harmonic system leads to a considerable reduction of satellite effects in the range of normal PETRA tunes.

Basic considerations

The dynamics of a double rf system is described in great detail in ref. 3. Following this analysis we present the determination of the relevant parameters for PETRA.
The higher harmonic rf system of PETRA was installed in the west of the ring, where 8 seven-cell 1 GHz cavities provided a peak voltage of 5 MV on the second harmonic with respect to the fundamental 500 rf system. The available rf power input was about 200 kW.
Figure 1 shows the voltage of the fundamental rf system $\mathcal{U}_{500}$ as a function of the phase angle φ of the passing bunch; $\mathcal{U}_T$ is the "particle voltage" defined by the synchrotron radiation loss and the higher order mode losses; φ_s denotes the equilibrium phase angle.

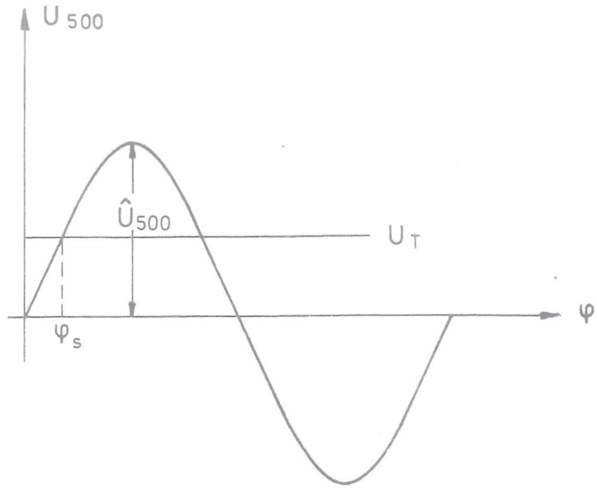


Fig. 1

phase focussing by the fundamental rf system

The synchrotron motion governed by the fundamental rf system is described by a differential equation for : φ

$$\ddot{\varphi} + \frac{\hat{\mathcal{U}}_{500}\,\alpha\,\omega_0^2\,h}{2\pi\,E/e}\left[\sin\varphi - \frac{\mathcal{U}_T}{\hat{\mathcal{U}}_{500}}\right] = 0 \qquad (1)$$

where we defined

$\hat{\mathcal{U}}_{500} \hat{=}$ peak voltage of the 500-MHz system
$\alpha \hat{=}$ momentum compaction factor
$\omega_0 \hat{=}$ circular revolution frequency
$h \hat{=}$ harmonic number
$E \hat{=}$ equilibrium particle energy

The small-amplitude synchrotron frequency of (1) is

$$\Omega_s^2 = \frac{\hat{\mathcal{U}}_{500}\,\alpha\,\omega_0^2\,h}{2\pi\,E/e}\cos\varphi_s \qquad (2)$$

The Hamilton function of equ. (1) reads:

$$H = \frac{1}{2}\dot{\varphi}^2 + V(\varphi)$$

with

$$V(\varphi) = \frac{\hat{\mathcal{U}}_{500}\,\alpha\,\omega_0^2\,h}{2\pi\,E/e}\left[-\cos\varphi - v\varphi\right] \qquad (3a)$$

and

$$v = \mathcal{U}_T/\hat{\mathcal{U}}_{500} \qquad (3b)$$

It is convenient to introduce

$$\eta^2 = \dot{\varphi}^2 \Big/ \frac{\hat{\mathcal{U}}_{500}\,\alpha\,\omega_0^2\,h}{2\pi\,E/e}\,, \quad \mathcal{H} = H \Big/ \frac{\hat{\mathcal{U}}_{500}\,\alpha\,\omega_0^2\,h}{2\pi\,E/e} \qquad (4)$$

so that we can write

$$\mathcal{H} = \frac{1}{2}\eta^2 + \mathcal{U}(\varphi) \qquad (5a)$$

with the "potential"

$$\mathcal{U}(\varphi) = -\cos\varphi - v\varphi \qquad (5b)$$

and the "force"

$$F(\varphi) = \sin\varphi - v \qquad (5c)$$

The maximum value of $\mathcal{H}$ is defined by the maximum value of the energy spread, i.e. by the maximum value of η, which we call $\hat{\eta}$

The higher harmonic rf system

The higher harmonic rf system can now be simply introduced by modifying the force F:

$$F(\varphi) = \sin\varphi - v - \underline{k \sin(n\varphi + \varphi_0)} \qquad (6)$$

with the corresponding potential

$$\mathcal{U}(\varphi) = -\cos\varphi - v\varphi + \frac{k}{n}\cos(n\varphi + \varphi_0) \qquad (7)$$

Here n denotes the harmonic member with respect to the fundamental system.
For PETRA we have: n = 2.
The factor k is the ratio of the peak voltages of the two rf systems:

$$k = \hat{\mathcal{U}}_n / \hat{\mathcal{U}}_{500} \qquad (8)$$

peak voltage of the h.h. rf system.

The angle denotes the phase angle between the rf systems, which has to be properly adjusted.

Determination of parameters

The parameters are determined by the condition, that the bunchlength in the presence of the h.h. rf system becomes a maximum.
The conditions are:

i equilibrium $\quad : \mathcal{U}'(\varphi_s) = 0 \qquad (9a)$

ii compensation of the voltage gradient at the aquilibrium point $\quad : \mathcal{U}''(\varphi_s) = 0 \qquad (9b)$

iii symmetry of the distribution $\quad : \mathcal{U}'''(\varphi_s) = 0 \qquad (9c)$

The solution of the equations (9) leads to the following parameters

$$\sin\varphi_s = \frac{v}{1 - 1/n} \qquad (10a)$$

$$k^2 = \frac{1}{n^2}\cos^2\varphi_s + \frac{1}{n^4}\sin^2\varphi_s \qquad (10b)$$

$$\varphi_0 = \arctan\left(\frac{1}{n}\tan\varphi_s\right) - 2\varphi_s \qquad (10c)$$

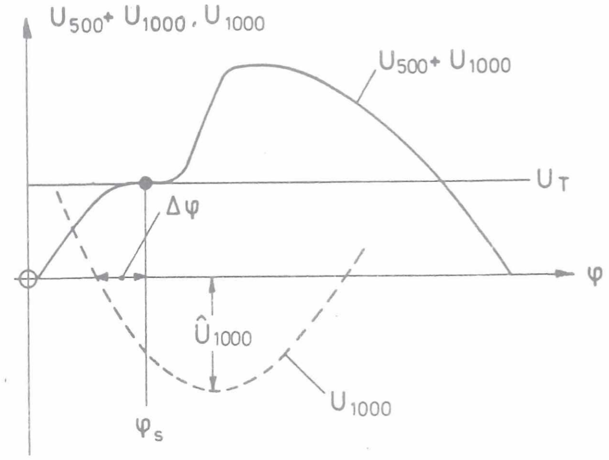
According to (10) we find for PETRA

$$\sin\varphi_s = \frac{4}{3}v \qquad (11a)$$

$$k = \sqrt{\frac{\cos^2\varphi_s}{4} + \frac{\sin^2\varphi_s}{16}} \approx \frac{1}{2}\cos\varphi_s \qquad (11b)$$

$$\varphi_0 = \arctan\left(\frac{1}{2}\tan\varphi_s\right) - 2\varphi_s \qquad (11c)$$

In order to keep the maximum bunchlength during current accumulation and energy ramping, the parameters have to be controlled accordng to (11 b) and (11 c).
Fig. 2 shows the superposition of the 500 MHz and the 1 GHz system



$$\Delta\varphi = 2\varphi_s + \varphi_0$$

Fig. 2
superposition of the 500 MHz voltage and the 1 GHz voltage

It turns out, that the conditions for gradient compensation and for symmetry lead to a φ_0, which differs from $-2\varphi_s$, so that the voltage $\mathcal{U}_{1000}$ does not pass through zero at the bunch center positon. The deviation, however, is rather small at least at the injection energy, where the phase angle φ_s is small.
Fig. 3 shows the calculation of the potential for typical PETRA parameters at injection without (dashed line) and with the property adjusted h.h.r system (solid line)

PETRA Parameters:		
E	=	7 GeV
$\hat{\mathcal{U}}_{500}$	=	10 MV
$\hat{\mathcal{U}}_{1000}$	=	5 MV
energy spread	=	$4.3 \cdot 10^{-4}$
v	=	0.1
φ_s	=	7.6°
φ_0	=	−11.5°