FEEDBACK SYSTEMS AT DESY

R.-D. Kohaupt, DESY, Hamburg, Germany

Abstract

The theory of longitudinal and transverse feedback systems is presented including the fact that the components of the systems are localized.
The development of the systems using digital methods of data processing is described.
The behaviour of all feedback systems at DESY is discussed.

1 THEORY OF MULTI BUNCH FEEDBACK SYSTEMS

The multi bunch systems can be described by a set of N differential equations, N being the bunch number

$$\left(\frac{d^2}{dt^2} + \Omega^2\right) x_\mu = \sum_{\upsilon=0}^{N-1} V_\mu(x_0,\ldots,x_{N-1}) + \sum_{\upsilon=0}^{N-1} F_\mu(x_0,\ldots,x_{N-1}) + D_\mu(t) \qquad \mu = 0,\ldots,N-1 \qquad (1)$$

In this equation, t and Ω are the time and the synchrotron frequency in the longitudinal, the quasi-time and the betatron frequency in the transverse direction. The forces in the ring are described by V, which is a linear function of the dipole displacements x_μ of the bunches. The forces account for all instabilities. The forces F_μ are added to take care of an active damper system, which will be discussed later. Finally $D_\mu(t)$ is an external force added in order to test the system by external excitation. Passing to the domain of complex frequency ω equation (1) becomes:

$$\hat{Q}(\omega)\,\hat{x}_\mu(\omega) = \sum_{\upsilon=0}^{N-1} (\hat{V}_{\mu\upsilon}(\omega) + \hat{F}_{\mu\upsilon}(\omega))x_\upsilon + \hat{D}_\mu(\omega) \quad (2)$$

with

$$1/\hat{Q}(\omega) = \sum_{l=-\infty}^{+\infty} \frac{1}{\Omega^2 - (l\omega_0 + \omega^2)} \qquad (3)$$

ω_0 being the revolution frequency. The Fourier transforms $\hat{x}_\mu(\omega)$ are closely related to the z-transform of sampled data due to the fact that all exciting objects are localised. This guarantees that no „unphysical Q-values exist.

The equation (2) can be diagonalized in terms of the „normal mode“ vectors, leading to the complex eigenfrequencies of the systems. In order to solve the instability problem, the forces F_μ have to be chosen in such way that all modes are stable.

As we know from the instability theory, any resistive impedance around the revolution line causes opposite instability behaviour of the „upper“ and the „lower“ mode, therefore in order to damp all the modes we need a sort of „notch“ filter giving opposite phases below and above the revolution line. This notch filter is the essential part of the forces F_μ.

2 REALISATION OF THE FEEDBACK

Within the bandwidth of the feedback system the transfer function has to be very flat:

$$1.\ \tilde{F}(\omega) \approx F(\omega'), \qquad (4)$$

(ω, ω' are different frequencies in the frequency range of the feedback systems.) The transfer function has to change sign at the revolution frequency.

$$2.\ \mathrm{Im}\ \tilde{F}(\omega) \text{ changes sign at } l\omega_0 \qquad (5)$$

After the beam oscillations have been picked up, the signal passes the detector. At the output the analog data will be converted to digital information. The „notch filter“ properties of the transfer function are prepared by a digital filter unit. Going back to analog data, the signals are transferred to a chain of amplifiers. At the end of the chain a power amplifier drives the active device which influences the beam. An example for an „adjustable notch filter“ is given by

$$\tilde{F}_{NF}(\omega) = e^{-i\omega T}(\cos\varphi + \frac{4}{\Pi} i \sin\omega T \sin\varphi) \qquad (6)$$

where φ can be adjusted such that the total transfer function of the feedback system corresponds to optimum damping. The function (6) can be realised by digital FIR-Filters:

$$G(\upsilon T_B) = \sum_{l=0}^{2} T_l x(\upsilon T_B - lT) \qquad (7)$$

In this relation x and g are the input and output data respectively, T_B denotes the time between adjacent bunches and T is the revolution time. Finally, the T_l represents the filter coefficients. In order to realise (6) one finds:

$$T_0 = \frac{2}{\Pi}\sin\varphi, T_1 = \cos\varphi, T_2 = -\frac{2}{\Pi}\sin\varphi \qquad (8)$$

3 OBSERVATIONS

In order to get information about the stability of all the modes it is possible to excite the beam on the different mode frequencies. The experiments were done for PETRA, HERA and DORIS.

Without the feedback loop the damping times were 10 msec for PETRA, HERA and 1 msec for DORIS. When the feedback system was closed, the damping times were 100 µsec, 0.5 msec and 100 µsec respectively.

4 THE DESY III FEEDBACK SYSTEM

In order to damp the longitudinal instability in DESY III, we developed a completely new feedback system.

We detected the phase displacement of the eleven proton bunches for each single bunch. This detection signal is the input of a multiplexer, which arranges the displacements according to the adjacent bunches. This information is led to four transfer kickers at places where the dispersion is different from zero.

The closed orbit then follows adiabatically the motion of the phase displacement, giving a damping without an additional 90°-phase shift. The damping system allows the transfer of 180 mA protons from DESY III to PETRA.

5 STRONG STABILITY

As far as damping rates and growth rates are concerned, one would naively conclude that the relation,

$$\delta_D \succ \delta_g \qquad (9)$$

where δ_D and δ_g are damping and growth rates respectively, leads to a stable beam. However, even when the beam is „stable“ there is still a strong coupling between the bunches. As a consequence, there is an energy transfer between the bunches. If a single bunch is excited, its energy is coupled to all the other bunches during the time the whole system is damped. If nearly all the bunches are excited with a tolerable amplitude, the energy can be transferred to a small number of bunches, so that their oscillation amplitude exceeds the tolerable limit. This internal „impact“ is based on the real frequency shifts which are in general different for all modes and which are not compensated by the damper system. This „overshoot“ effect increases if the number of bunches increases. The remaining damping rate at high currents has to be sufficiently large in order to keep the overshoot effect small. Since the real frequency shifts are of the same order as the growth rates (roughly) and since these phase shifts can be positive and negative, we demand:

$$\delta_D - \delta_g \succ 2\delta_g \qquad (10)$$

so we obtain

$$\delta_D \succ 3\delta_g \qquad (11)$$

instead of (9). The overshoot phenomena are still under theoretical investigation. For PETRA and HERA the feedback systems satisfy (11).

REFERENCES

[1] R.-D. Kohaupt, DESY 91-071
[2] M. Ebert et al. DESY 91-036