DEVELOPMENT OF A NEW ORBIT MEASUREMENT SYSTEM

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Abstract

Since DORIS III became a dedicated source for synchrotron radiation in 1993, the demands of the synchrotron-light-users concerning the beam position stability have permanently increased. In order to improve this stability, different measures have been adopted, all with success. The vacuum chambers have been renewed, since they were the source of quadrupole movement, which caused strong horizontal orbit distortion. In 2003 a new orbit position control was implemented, based on the "Singular Value Decomposition" [1] method. The position information comes from synchrotron light monitors, installed in the beam-lines, and from the orbit measurement system, which operates with a maximal measurement rate of 5Hz and a spatial resolution not less than 20µm. To satisfy the requirements for beam-position stability, the orbit measurement system has been further developed. The test stage is nearly finished and the new system will be installed soon. The orbit measurement rate will exceed 250Hz und the spatial resolution will be less than 2µm. In addition beam oscillations of up to 20Hz can be damped.

ACTUAL ORBIT MEASUREMENT SYSTEM

The charges of the circulating bunches generate very short voltage signals at the four electrodes of each beam-position-monitor. These signals are fed into one cable per monitor by means of a special delay-line and additional hybrids, so that the four signals are 20ns apart. In 6 gauging stations, which are distributed symmetrically around the DORIS storage ring and are designed for up to eight monitors, these signals are converted by an 8bit **ADC** (**A**nalog to **D**igital **C**onverter) for each monitor. The advantage of the serialisation of the measurement signals of one monitor is, that only a single ADC carries out the analog to digital conversion. Therefore the characteristics of different converters and / or amplifiers can have an effect on the result only in the second order.

Because of the monitor geometry and the ADC's used, a spatial resolution of about 100µm is achievable. In order to improve this resolution up to 64 consecutive measurements are added in the actual system (Signal Averaging) at an orbit measurement frequency of 5Hz. For the First Turn measurement just the raw 8bit data are analysed. The numerical values are transferred via a serial data-bus (SEDAC [3]) to a computer of the DORIS control-system (see Fig. 1).

This computer has to accomplish several tasks. At first the orbit values of the existing 40 monitors are calculated using the raw data and then are fed into the DORIS network by means of an Ethernet connection. After that it is checked, if the measured orbit values exceed some given limits. In such a case the computer transmits a signal to the control-system, which causes a dump of the storage-ring. Thereupon the excitation of the two 500MHz transmitters, which compensate the energy loss of the circulating positrons, will be interrupted. At the storage-ring energy of 4.5GeV and an energy acceptance of 1% the stored particles are lost after at least 100µs. Because of the orbit measurement repetition rate of 5Hz the dump will be triggered after approximately 200ms. This is fast enough to protect the components of the vacuum-chamber.

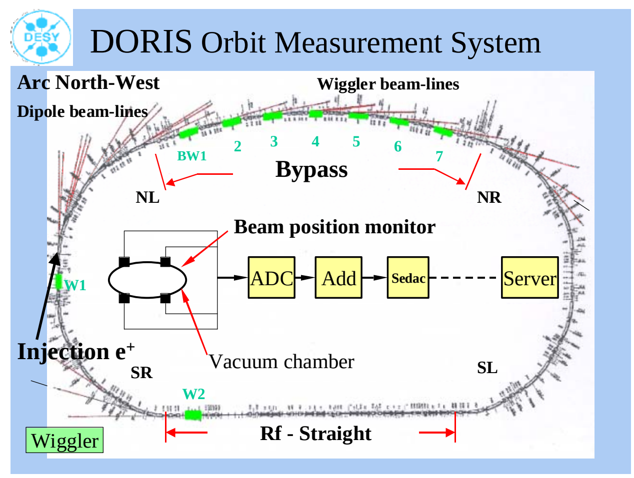

Figure 1: Overview of DORIS. Scheme of Orbit Measurement System

The orbit data, which has been transferred to the DORIS control-system, is used to carry out necessary orbit corrections and to serve as input for the global position control besides being the values of the photoemission monitors. The measurement rate of 5Hz is large enough to provide the position control with data, because the control loop just amounts to 2sec.

The global position control, which works according to the **SVD** (**S**ingular **V**alue **D**ecomposition**)** [1] method, was implemented successfully at the end of the year 2003 and replaced the previous local controls, from which up to nine have been working simultaneously. The disadvantage of these local controls was a cross-talk between the different control loops, because of the inaccurately closed beam bumps. This may result in uncontrolled orbit oscillations. It appeared, that the temporary fluctuations (noise) of the orbit measurement were so large, that the vertical beam positions in the bending magnet beam-lines were unacceptably disturbed. Therefore the orbit values of this storage-ring section were removed from the global position control.

However there are irregular vertical and horizontal orbit oscillations, which are caused mainly by mechanical movements of the storage-ring quadrupoles and dipoles. They cannot be damped, because they are positioned in the frequency range of 4 to 15Hz, which is far beyond the working area of the actual orbit measurement and position control.

DEVELOPMENT OF A NEW ORBIT MEASUREMENT ELECTRONICS

To fulfill the increased requirements concerning the precision und measurement frequency rate new electronics were developed, which is an advance of the old system. As before the monitor signals are converted by means of 8bit ADC's. To achieve a larger accuracy the signals are averaged using the ‚Signal Averaging Method' with 2048 additions. With the newly developed electronics a measurement takes place each time a bunch passes. Therefore a value can be measured and averaged every 400µs (the standard filling mode of DORIS is a five bunch filling). These values are transferred via a SEDAC connection to the Server-PC (Fig. 2).

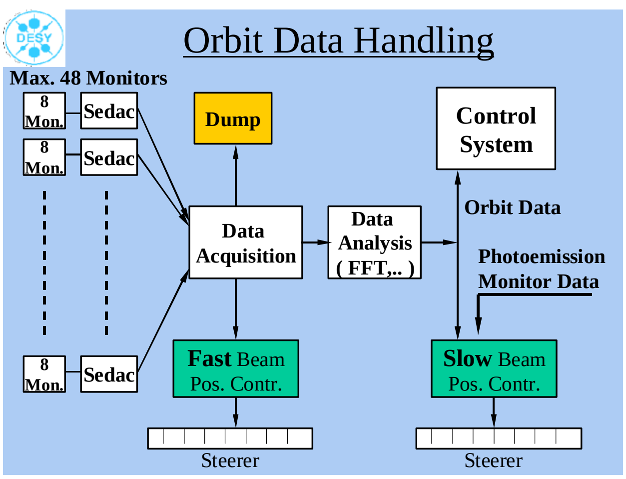

Figure 2: Block diagram of the new fast DORIS orbit measurement

To allow for the desired maximal measurement rate of 500Hz, the SEDAC telegram period was shortened from 250µs to 90µs as well as the length of the telegram increased from 16 to 32bit. With the previous SEDAC system the data are exchanged using the parallel port (Line-Printer), while for the new system a PCI-Bus card was developed, which permits faster data throughput [4].

Because the improvement of the signal-to-noise ratio is proportional to the square root of the addition factor, a short-time precision of 2µm with the orbit measurement is achievable.

Signal Averaging:

With n as the number of additions, the signal-to-noise ratio (S/N-Ratio) will be improved with respect to the following relation:

$$U_{signal}\ (N) = n * U_{signal}$$

$$U_{noise}\ (N) = \sqrt{n} * U_{noise}$$

$$S/N\text{-Ratio} = \sqrt{n} * U_{signal} / U_{noise}$$

The background noise, due to the quantisation of the analog to digital conversion, amounts to approximately 100µm. With the previous addition factor of 64 the achievable accuracy is decreased by a factor of 5. Even the slow beam position control will benefit from that, as the orbit in the critical sections of the storage-ring can be stabilised too, without degrading the beam position stability in these beam-lines. (see Fig. 3)

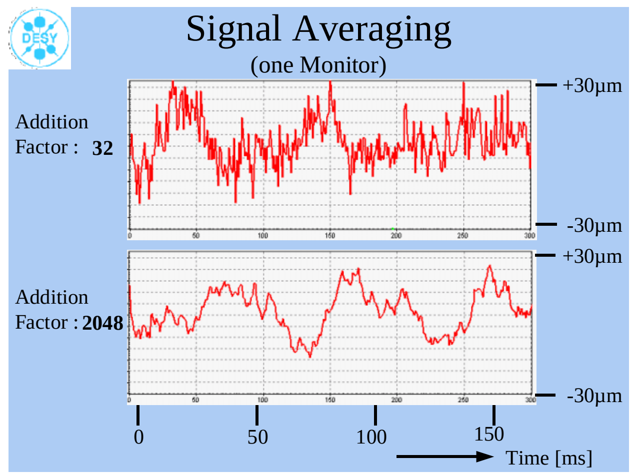

Figure 3: Signal Averaging of the horizontal component of one monitor

FAST BEAM POSITION CONTROL

The measurement rate of 500Hz, which has been increased by a factor of 100, is necessary to design a fast beam position control, which is able to damp the above mentioned orbit perturbations.

To avoid a conflict with the slow working global control, the new control has to react only on fast relative changes of the orbit. For this a high pass filter was realised, using the moving average technique with a lower frequency limit of 2Hz.

The new average $X_1(av)$ will be calculated from the last average $X_0(av)$ and the actual measurement value X_{life} using the following formula.

$$X_1(av) = X_0(av) * (1 - Fak) + X_{life} * Fak$$

$$X_0(av) = X_1(av)$$

The value of Fak adjusts the lower frequency limit.

By means of the well-established SVD algorithm the kicking power of some additionally installed small steering coils are computed. These values are transferred via a SEDAC connection to digitally controlled amplifiers, which are able to deliver a maximal current of +/-200mA. Measurements have demonstrated that the magnetic field in the copper vacuum-chamber will be attenuated by 40% and delayed by 1.6ms at a frequency of 50Hz. This corresponds to a phase failure of 11degrees at a frequency of 20Hz, therefore a damping of oscillations up to this frequency should be no problem. In principle one has to state, that the phase difference between measurement and correction time has to stay below 60degrees for each frequency, otherwise the stored beam will be stimulated. At 20Hz this corresponds to a maximal delay of 8ms. With the orbit measurement rate of 500Hz this limit is clearly under-run, according to the measurement repetition rate of 2ms.

Correction of Orbit Pertubations.

If orbit perturbations occur with frequencies larger than 20Hz, the delay of the corrections used is so large, that an undesired stimulation occurs instead of damping. In order to avoid this, one has to prevent these corrections. Therefore the orbit measurement values have to undergo a low pass filtering. The only filtering methods considered are the so-called causal filter, which generate a corrected actual orbit measurement value using the actual value and a fixed number of past values. The Savitzky-Golay Filter [2] is of this type. With a n th order polynomial fit the desired smoothing will be accomplished.

A parabolic fit (n=2) with 22 measurement values is a suitable solution. On the one hand the desired low pass filtering will be achieved and on the other hand the unavoidable delay remains sufficiently small.

With an additional stable fraction of harmonic power-line disturbance of 50Hz in the measured signal, one can calculate phase and amplitude of this fraction by means of a Fourier analysis. The last 32 measurement values of each monitor are taken as input for a FFT (Fast Fourier Transformation). After this, these values are corrected by subtracting the 50Hz fraction. In a last step the Savitzky-Golay filter smooths the remaining orbit. (Figure 4)

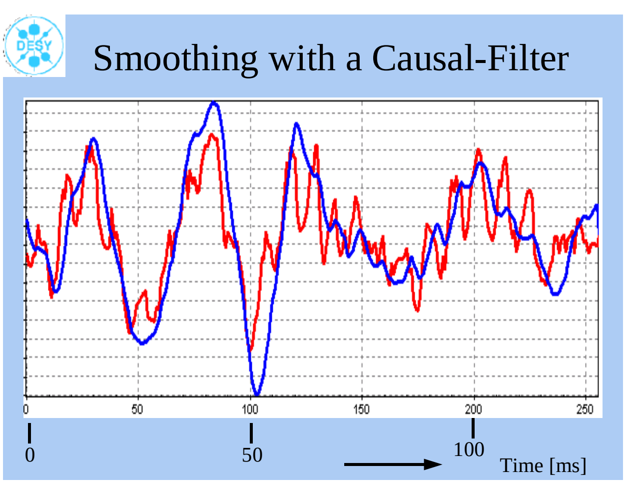

Figure 4: Coordinate of a single monitor before (red), after (blue) smoothing

But it is quite obvious that it is more efficient, to antagonise these stable power-line perturbations by means of a ‘Feed Forward’ method, provided that one cannot detect the source of these troubles and therefore cannot eliminate them. With the new orbit measurement system the phase as well as the amplitude of the power-line admixture can be acquired. These values serve as input for digitally controlled amplifiers, which feed separate steering coils with the necessary currents. For this reason the power-line perturbation will be mostly compensated. These special amplifiers are in the design phase. Furthermore only eight monitors are equipped with the new electronics, so that a final conclusion concerning the damping behaviour of the new fast position control can only be given after the planned shutdown next summer. Then the system will be complete.

When all these measures are adopted, the damping of oscillations up to 20Hz should be achieved successfully.

REFERENCES

[1] W.H. Press et al., “Numerical Recipes”, Cambridge Press, (1992)

[2] Savitzky A., and Golay, M.J.E. 1964, Analytical Chemistry, vol. 36, pp. 1627-1639

[3] **SEDAC**, **SE**rial **D**ata **AC**quisition, development at DESY in 1976

[4] SedIp , Stadtmueller, DESY