# IMPROVEMENTS OF THE ORBIT STABILITY OF DORIS III

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*Abstract*

Running since 1974, the storage ring DORIS experienced a major modification in 1991 to run as a dedicated synchrotron radiation source. Since then the increasing requirements of the users on beam stability lead to a series of technical and operational measures to improve the beam conditions. The beam pipe has been mechanically isolated from the magnets, the cooling has been improved and this year a new orbit feedback came to operation which uses positron beam position monitors as well as photon monitors in the beam lines to stabilize the different photon beams. The different measures taken are presented.

## INTRODUCTION

The storage ring DORIS was build in 1974 as an electron-positron collider for high energy physics and from start on the synchrotron radiation (SR) was used at two detectors. In the year 1981 the synchrotron radiation laboratory HASYLAB came into operation, using the bending magnet beamlines. The racetrack form of the ring with two 180 degree arcs and two long straight sections for the particle detectors had not allowed the insertion of a larger number of wigglers or undulators. In 1991 one of the long straights was changed into one weakly bend arc, in which seven insertion devices found their place [bre2]. In the second straight the very successful ARGUS detector was operating until 1993 for high energy physics. Due to its design and magnet structure with 30 degree bendings DORIS is a high emittance machine with $\varepsilon_x$=432 nm rad at 4.45 GeV particle energy. Nevertheless the experiments suffered from the drifting beam orbit. One of the major problems is the power of the synchrotron radiation itself. In DORIS the stored positron current was increased from about 40 mA (1982) to 150 mA now. With this current the power of the emitted SR reaches 430 kW or 5.6 kW/m in the bending magnets. In DORIS this power is absorbed on the outside of the vacuum vessels. These are build from copper and have a cooling tube on the outside. With this configuration it is unavoidable that there is a radial temperature gradient over the vessel which results in a bending depending on the total current filled. Since DORIS is not running in a "top up" mode, the filled current changes permanently.

## MECHANICAL STABILIZATION

In the design of DORIS II the beam position monitors (BPM) were positioned close to the quadrupole magnets and fixed to the pole faces. In this design one measures with high accuracy the beam position w.r.t. the magnetic axis of the quadrupoles. The drawback of this solution which became more and more important in the last years is that the chambers which are deformed under the power of the SR are shifting the quadrupoles and by that also the beam orbit. The observed quadrupole shifts were about 0.4 mm during a typical fill with currents from 150 mA to 90 mA resulting in difference orbits with typ. 1 mm rms deviations [nes2]. To avoid this problem, new vacuum vessels for all quadrupole triplets have been build, which have a free space to the pole faces. The BPMs now have their own adjustable support and a holder for Taylor-Hobson balls used for alignment. This modification was done in oct/nov. 2000 beside the sections including the injection kickers, which have been replaced in 2003. The success of this effort was a reduction of the orbit drifts over one run from typ. 2 mm to 0.4 mm amplitude.

Another source of orbit distortions are mechanical vibrations of the dipoles with their eigenfrequencies at 5-6 Hz. These oscillations have been reduced by additional supports in the middle of the 3.19 m long magnets. These consist of girders pressed with screws against the lower edges of the magnets to stiffen the construction.

## INFLUENCE OF COOLING WATER TEMPERATURE

Another important factor influencing the orbit stability is the temperature of the cooling water. The influence has been reduced by the decoupling of the vacuum chamber from the magnets but there is still a significant influence seen. There are changes in the position of the photon beams of up to 10 μm/°C.

To minimize these effects the cooling water temperature has been stabilized to ±1.5 degree in 1994 and to ±0.2 degree in the year 2000.

## ACTIVE STABILIZATION

Beside of these passive measures to reduce the sources of orbit distortions we began already in late 80$^{th}$ with an active beam position control [bre1]. This fight not only against the residual thermal drifts but also against the other sources of orbit distortions like changes of the wiggler gaps or the influence of the energy of the PETRA storage ring.

The BPM system up to now has a resolution of about 30 μm, which is not precise enough to stabilize the photon beam at the end of the up to 40 m long beam line. Therefore monitors based on the photoemission of the SR where developed, which are measuring the position of the photon beam itself with an accuracy of 2 μm. These monitors are placed in all beamlines now and are available as input to a feedback system. Up to 2003 a system was used, which uses local bumps to steer the beam at dedicated beamlines. With 2 correctors before the source point the offset and angle are kept constant and with 2 correctors behind the source the bump was closed. [wilg] This setup improved the situation dramatically.

The controlled beamlines were stable to within ±2 μm vertical and ±5 μm horizontal. There were 6 vertical and 3 horizontal independent bumps for the 42 beamlines installed at DORIS. The problem is that the phase advance between the different source points is too small to install one bump for each beamline. The strategy was to have some beam lines stabilized to high precision whereas the others just benefit from their stable neighborhood. One basis for the success of the feedback was the replacement of the corrector power supplies. In 1999 the new power supplies, developed at DESY, with a 16bit regulation and a minimal step of 0.5 mA corresponding to a kick of 0.01 to 0.1 μrad, depending on the magnet used, were installed.

The beamlines not controlled observed orbit drifts which were larger than necessary due to several facts :

- There were still correction coils which could in principle be used for corrections but did not fit into the system of independent local bumps
- The system was not flexible in that the feedback for the beamline had to stop if one of the photo monitors or one of the correctors was not available
- Small failures in the bumps or other sources of distortions resulted in build up of orbit deviations in the uncontrolled regions of the machine

In 2003 we installed therefore a system with a different approach. The data from all available monitors are collected in one vector **x**. All correctors are then used to minimize the weighted sum of squared deviations from the target values (Δy = y – reference value):

$$S = \sum_{m=1}^{M} \frac{\Delta y_m}{\sigma_m} + \sum_{n=1}^{N} \frac{\Delta y_n}{\sigma_n} + \sum_{k=1}^{K} \frac{\Delta I_k}{\sigma_k} \qquad (1)$$

The summation runs over M BPM values, N photo monitor readings and in addition over K corrector currents – the last point will be discussed below.

Of special importance are the $\sigma_i$ – in a typical data fitting routine these are the probable errors of the individual measurements. Here this is half of the truth: to start the σ of the BPMs are set to 30 μm and those of the photo monitors to 5 μm. In a second step the σ-values are reduced for such beamlines, which have special requirements on beam stability whereas higher values are allowed in parts of the ring without SR source points. This setup together with the correctors used is described in a script language which allows a simple modification of the feedback if the requirements are changing. A computer code then calculates the response matrix **R** for this setup, where each element is calculated as the effect of a corrector setting k on a Monitor value y:

$$R_{i,j} = \frac{\partial y_i}{\partial k_j} \qquad (2)$$

This matrix is often singular or nearly singular, so that the solution of the minimization problem gives unwanted large corrector values. To overcome this problem it is common practice to use the singular value decomposition (svd) to find the best solution with limited corrector changes [num]. Here the pseudo inverse matrix **P** is calculated and send to a client program, which multiplies **P** with the vectors **Δy** of the monitor values for ongoing corrections.

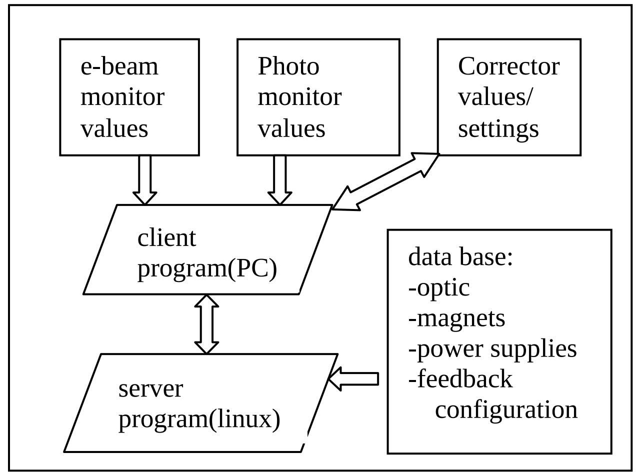


Figure 1: Overview of the components of the DORIS orbit feedback system. The client sends information about valid correctors and monitors to the server which then sends back the pseudo inverse matrix. The calculation of new corrector settings are then done by the client itself until a new matrix is needed.

A potential problem one has to handle is the limitation of the corrector currents. This is the reason for the third term in (1). The corrector values in the vector **Δy** are set according to:

$$\Delta I = 0 \qquad ; I < I_{\lim}$$

$$\Delta I = I - I_{\lim} \qquad ; I > I_{\lim}$$

where $I_{\lim}$ is about 70% of the maximal possible current. As long as the current is far from its maximum values, the only effect is, that the algorithm does not change the current by values large compared to its σ – which is chosen fairly large. But if the current exceeds its threshold then the algorithm tries not to increase this current any further and even to reduce it again if possible. So we created a bathtub shaped potential which avoided efficiently running coils to their limits without adding hard limits.

The global feedback described here has proven to work reliable without serious problems. By adjusting the σ-values for each monitor the requirements from the users which are sensitive to smallest orbit fluctuations are taken into account, by fixing the orbit at other beamlines as good as possible. During injection for instance when most of the beam shutters are closed and the photo monitors do not deliver a signal the BPM-values keep the orbit constant. In case of a corrector failure the client program asks the server for a new pseudo inverse matrix without this coil and continues its work.

One critical point could not be solved up to now. The fact that part of the horizontal correctors are backleg windings on the main dipole magnets limits the speed of the corrections to about 0.2 Hz. It takes about 4 to 5 seconds until the magnetic field reaches its end values after changing the magnet current. Fortunately the orbit oscillations with 6, 12.5 and 50 Hz to mention the most important lines in the spectrum do not disturb the users up to now. Nevertheless we will try to damp these oscillations after having added faster BPMs and corrector magnets [kaul].

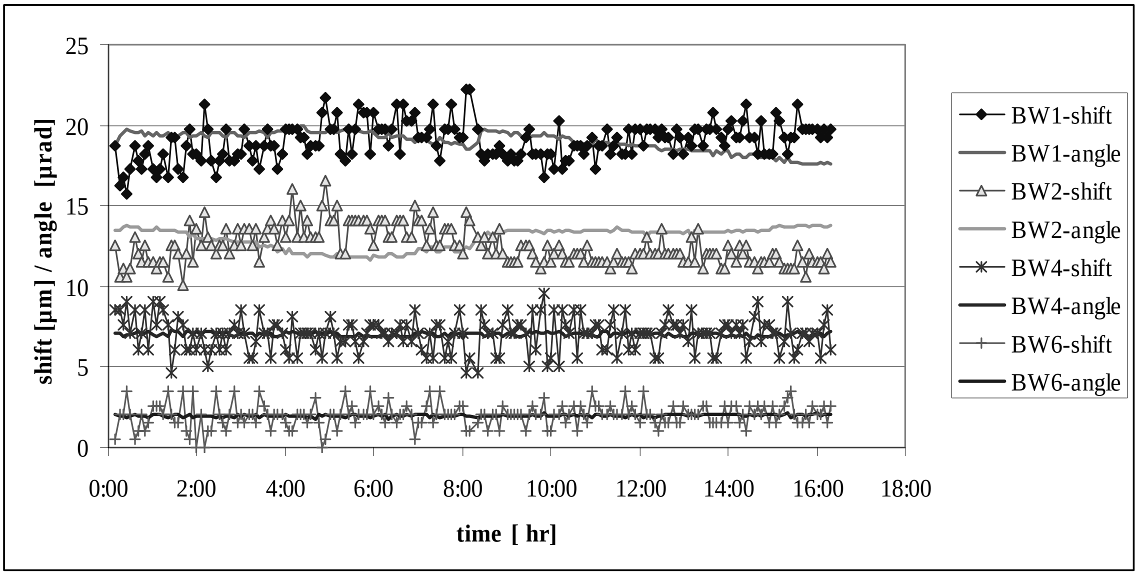


Figure 2: Vertical position and angle of the photon beam in 4 of 8 wiggler beam lines measured with the two photocurrent position monitors in each beamline. The precision of the beam shift measurement is about 1.5 µm and that of the angle 0.4 µrad. The plot shows the development over 2 runs with a new injection at 8:00. The beamlines BW4 and BW6 are stabilized with high priority.

| | horizontal | | | | | | vertical | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Beam drifts | | | | Beam size | | Beam drifts | | | | Beam size | |
| | Shift | | Angle | | σx | σx’ | Shift | | Angle | | σz | σz’ |
| | µm | % of size | µrad | % of size | µm | µrad | mm | % of size | µrad | % of size | µm | µrad |
| BW1 | 6.2 | 0.23 | 0.52 | 0.17 | 2690 | 542 | 1.2 | 0.59 | 0.62 | 0.47 | 197 | 132 |
| BW2 | 5.3 | 0.23 | 1.2 | 0.51 | 2280 | 230 | 1.12 | 0.20 | 0.65 | 0.56 | 569 | 117 |
| BW4 | 38 | 3.3 | 7.5 | 1.21 | 1160 | 620 | 1.03 | 0.33 | 0.10 | 0.09 | 316 | 122 |
| BW6 | 3.0 | 0.13 | 0.53 | 0.23 | 2290 | 230 | 0.71 | 0.14 | 0.07 | 0.06 | 122 | 500 |
| BW7 | 11.8 | 0.44 | 6.7 | 2.23 | 2690 | 300 | 2.4 | 1.13 | 2.5 | 1.9 | 213 | 131 |

Table 1 : Comparison of rms values for beam drifts and angle changes of photon beams compared to the beam sizes of the positron beam and the opening angles of the photon beam calculated at the source points. The rather large values for the horizontal drifts at BW4 are probable due to problems with the second photo monitor in this beam line which are not yet understood

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