The PETRA III Girder-Concept

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Since alignment tolerances of the focusing quadrupoles and the dipoles at a 3rd generation synchrotron light source like the PETRA III ring are very tight and downtime allowances for survey are low, a concept of pre-aligned magnets on girders has been developed. This presentation focuses on the development efforts of a low-cost girder system with cheap but nevertheless effective alignment mechanics. Some results of girder deformations during transportation of readily assembled and precisely aligned girders are shown. Besides that, achievements in the development of new ultrasonic hardware for the recently developed DESY-HLS are presented.

1. INTRODUCTION

After HERA had its last run on June 30, 2007, PETRA is not used as a pre-accelerator for HERA any more. Therefore it is reconstructed to a synchrotron light source, called PETRA III, from July 1, 2007 on [1]. The very ambitious planning has scheduled the start of operation in early 2009.

While the alignment tolerances especially for some components of the new 1/8th of the ring are very tight, the downtime allowance for survey tasks is low. This leads to a concept of placing magnets on girders, as it has been done already at other synchrotron light sources. This approach has two major advantages: First, the components which are to be adjusted to each other with high accuracy can be aligned outside the tunnel in an air-conditioned and quiet environment. Second, it is possible to keep some girders readily assembled in stock, to be able to change them quickly in case of a defect. This optimizes downtime requirements.

However some aspects of this girder concept need to be addressed thoroughly to avoid problems with the installation later on. First it has to be guaranteed that the alignment tolerances are still maintained, when the girder is placed in the tunnel, this means no uncontrolled permanent deformations may occur during transport. Second, the girder has to meet certain requirements concerning its dynamic behavior, which to a certain extent contradicts the requirement of mechanical stability.

This paper will address some geodetic aspects of the new girder concept at DESY and shows some of the measurements made to ensure the quality of the girder. This includes the development of a new HLS electronics for the DESY-HLS.

2. GIRDER CONCEPT

The new PETRA III Synchrotron Light Source will have eight beamlines with up to 14 experimental stations. For each of the eight beamlines one girder cell together with one or more undulators will be installed. One cell consists of four girders, making 32 girders altogether. One girder always bears three main magnets.

There are three different types of magnets on the girders, Dipoles (PD), short (PQK) and long (PQL) Quadrupoles which vary in assembly on the girder, so that one ends up with two different types of girders. The accuracy requirement for the magnet positions on one girder ("intra girder") is $\sigma = 50\mu m$ in lateral and height. The requirement for the alignment between girders ("inter girder") is somewhat relaxed with $\sigma = 100\mu m$. The longitudinal accuracy requirement for all components is $\sigma = 500\mu m$ [1].

The girder shown in Figure 1 is the second iteration of girders at DESY. It has been made more torsion resistant, which has been accomplished by inserting cross-reinforcements inside the girder at certain places. In addition it has been made more inflexible in longitudinal direction by using a larger profile.

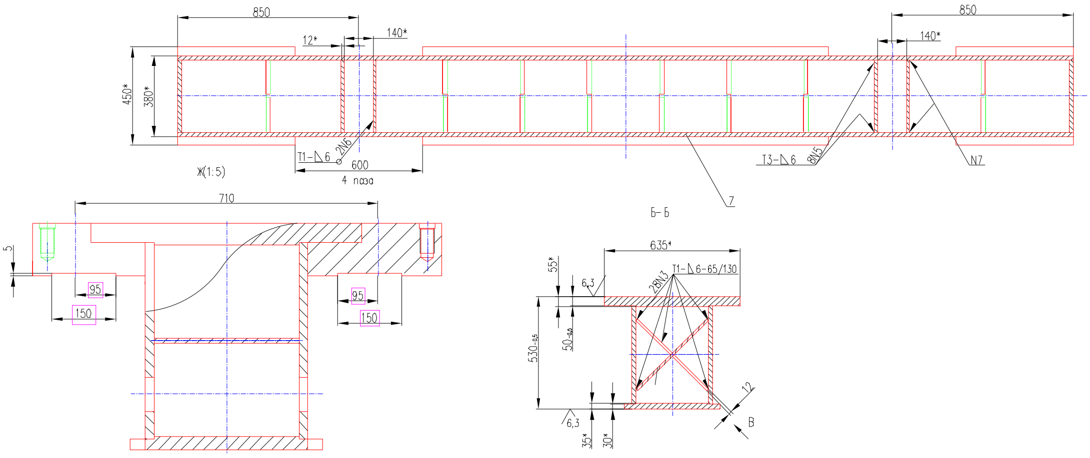

Figure 1: Diagram of girder

The stands of the girders in the tunnel will be of the same type as they are at Diamond Light Source, UK. They are therefore not described in this paper [4].

3. STATIC BEHAVIOUR

For the analysis of the static behavior it is assumed that different magnets do not change the principal result of the deformation analysis of the girder. This is a good approximation, because changing one magnet by a different type does not afflict the mass of the whole system by more than 8%.

3.1. Transfer measurement

During the transfer measurement the individual magnetic axis of each Quadrupole is transferred to a set of up to 12 target marks, which are attached to the magnet. The magnetic axis of the Quadrupole is determined while it is powered with its nominal current. A rotating coil is shifted inside the magnet in lateral and height, until the measured dipole component is zero. When this is accomplished, the coil represents the magnetic axis of the quadrupole within an accuracy of 5µm. Two SMR are then placed directly in nests on the coil and are observed by two laser trackers, while the coil is revolving slowly. This is resulting in four measured 3D circles, which are then mathematically combined to form the axis of the quad, which is also the X-axis of the local coordinate system of the magnet. The tilt of the magnet around the beam axis (roll) is determined by two mechanical points on the magnet, as well as the origin of the coordinate system along beam axis. The target marks are then measured subsequently, getting their coordinates assigned in the local magnet coordinate system (see Figure 2).

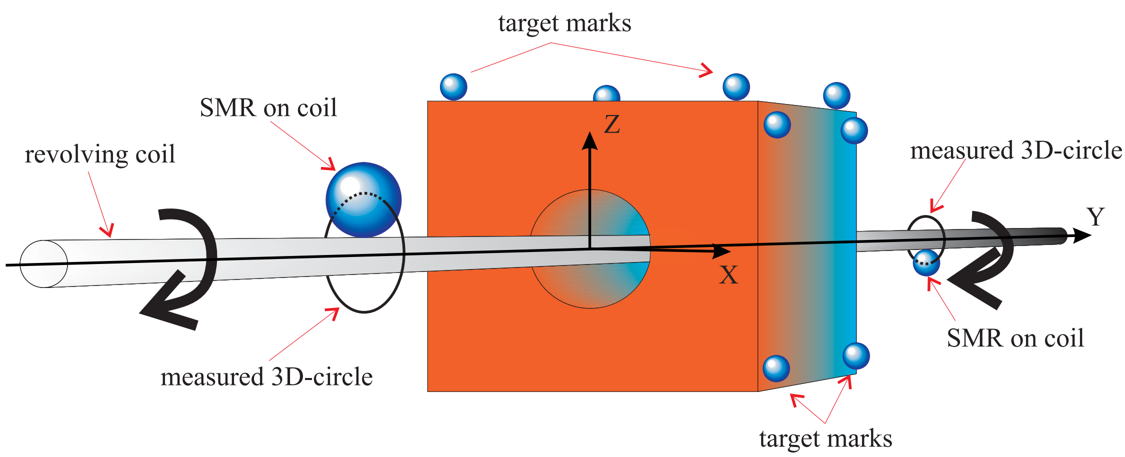

Figure 2: Transfer measurement of magnetic axis

While the mechanical axis is still determined for extra security reasons, it is not used any more during the transfer measurement and thus not adding extra amounts of uncertainty to the error budget.

3.2. Alignment of the magnets

At first, the magnets are coarse aligned on the girder with standard accuracy of 0.2 mm in all three axes. The coordinate system of the girder is then defined by its mechanical structure. The magnets and all other components are then precisely aligned in a climatized hall with respect to this coordinate system. (see Figure 3).

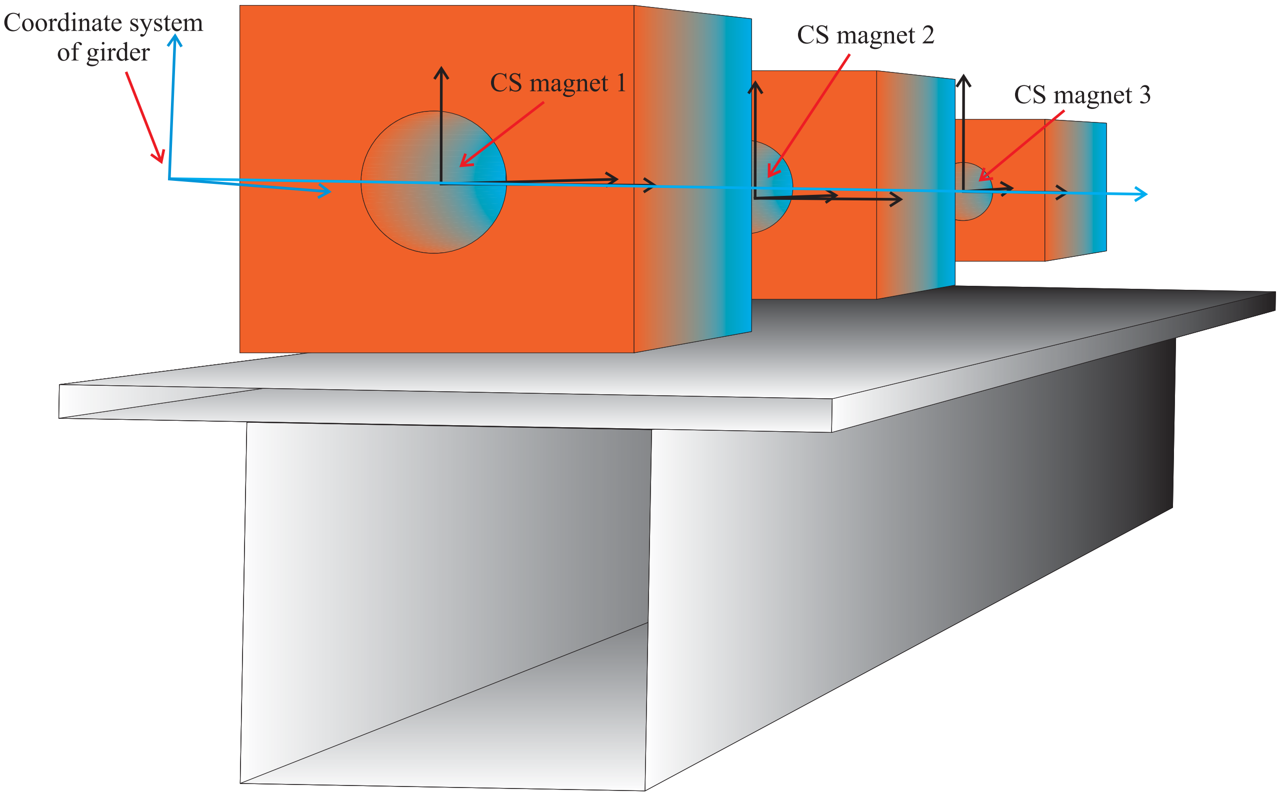

Figure 3: Alignment of the magnets on the girder (before precise alignment)

The height adjustment, as well as roll and nick are adjusted by three fine thread screws with ball shaped heads on hardened steel plates (see Figure 4). The adjustment in lateral and length, as well as the yaw are adjusted using three DESY standard turnbuckles. Experienced staff can do this mechanical adjustment with an accuracy of about 10µm within a maximum of three, but normally two iterations.

Figure 4: Magnets on Girder, screw for height adjustment, glued bolt in pot

3.3. Alignment of the girders in the tunnel

It is essential for compliance with the accuracy requirements, that the girder itself doesn't bear any coordinate information. All the coordinate information is stored in the target marks of the magnets on the girder, no accuracy is wasted by transferring coordinates to another couple of targets.

On the other hand that means, that for adjustment of the girder in the tunnel no target marks on girder are available. That makes alignment somewhat more complicated, because one doesn't have marks directly above the stands of the girder, where the shift of the stands would reproduce 1:1. This is only a minor disadvantage, which can easily be overcome by a script (e.g. with the measurement software Spatial Analyzer), which calculates the required motion values on the fly.

3.4. Transport

Of course the magnets can not be expected to maintain position during transport, when only fixated by some screws on the turnbuckles. To overcome this limitation four stiff steel bolts are incorporated into the bottom of each magnet. These bolts reach down into four pots which are welded to the girder surface. After the successful adjustment of the magnets on the girder glue is injected in the pots to install a friction-locked connection between magnet and girder (see Figure 4). The glue is a special technical glue for metallic parts, which is non-shrinking and radiation hard.

After the glue has hardened the girder can be transported with a crane from the fine-adjustment chamber to its final destination in the PETRA hall. Under no circumstances it is allowed to transport the precisely aligned girder by car, because the fine-adjustment could not be guaranteed afterwards.

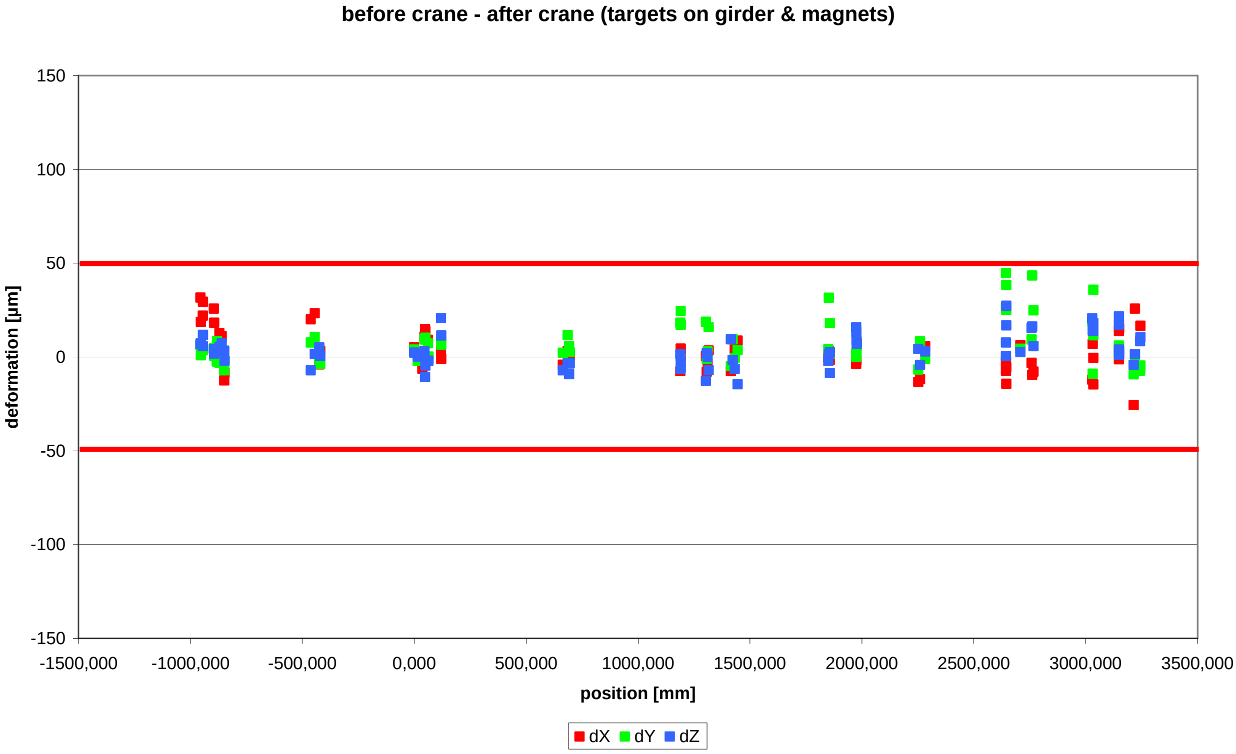

Figure 5: deformations after crane transport

Experiments have shown, that no shift of burden inside the girder could be allowed. That means, that the girder has to be mounted on the same points during alignment as it will be later in the tunnel. While this might be trivial it was also found, that even a shift of burden during transport is crucial. It has to be ensured that the crane attaches to the same points the girder stands on during adjustment and normal operation. When talking about microns steel is not behaving fully elastic under all circumstances. Rearranging the load during transport causes plastic deformations which may remain even after placing the girder on the same stands again. This can be traced back to remaining stress inside the girder, even after the girder has been thermally stress relieved.

4. DYNAMIC BEHAVIOR

As alignment tolerances are getting more and more tight the dynamic behavior of components and component stands gets into the focus of geodesists and physicists. For the PETRA III Girder it was the goal to have the lowest eigenfrequency well above 20 Hz, because lower eigenfrequencys are most crucial for machine operation. While eigenfrequencys of simple structures, like the girder itself, can easily and reliably be determined by using finite element methods during the design process, this is not true for complex structures, as the readily assembled girder, because it is difficult to model connections between components reliable enough.

The solution is to make a modal analysis of the assembled girder with measurement data. In principle this can be done measuring dynamic data on several discrete points on the structure. It is possible to describe the dynamics of a structure by three different types of measurement: displacement, velocity or acceleration. While the measurement of displacement gives the most direct information, it is difficult to measure because a sufficiently stable frame is needed as a basis for the measurement, which has to be mechanical independent of the measured structure. Instruments which measure velocity, e.g. geophones, are generally large, have a bigger mass and are thus difficult to apply. Compared to geophones, modern accelerometers are small and lightweight with a mass of only a few grams. While measurement data from accelerometers can, in principle, be transferred into velocity and displacement by integrating over time, this has of course a certain impact on accuracy. For the modal analysis the difference between the measurement principles is negligible, because the measurement data is transferred into the frequency domain anyway.

For the dynamic analysis of the girder accelerometers (see Figure 6) are used. To induct a broad frequency spectrum into the structure an impact hammer is used. This hammer is equipped with an accelerometer itself, so the calculation of transfer functions is possible.

Figure 6: Accelerometer and impact hammer used for modal analysis of girder

To be able to differentiate between the various components, three different modal analyses are made: First, the bare girder on massive concrete stands, second, the complete girder with glued magnets on concrete stands (see Figure 7), and third, the complete girder on the final, adjustable stands.

Part one and two have already been done, part three is to be finished in the near future.

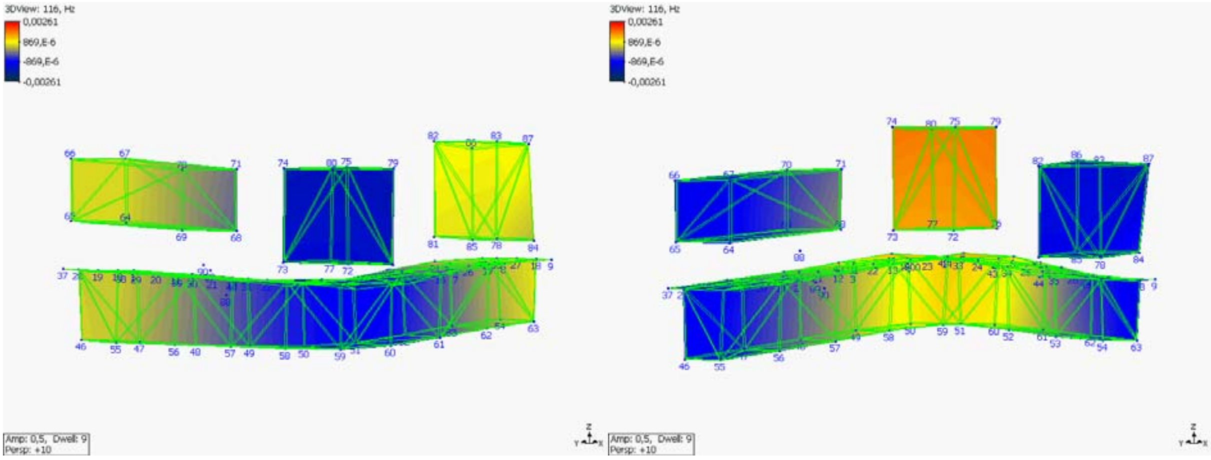

Figure 7: First vertical modal shape of girder at 116 Hz, girder on concrete stands

5. DESY-HLS

For the recently developed DESY-HLS [2, 3], which works in principle by measuring the distance to a water surface by ultrasonic ranging, a new electronics hardware which suits our needs better than the commercial ones was developed. Since negotiations with Krautkramer / GE about the prototyping of a new electronics were not successful, we decided to develop the necessary electronic components by ourself. After some brainstorming with the electronics group (FE) at DESY, the development started. The main goals were:

- be able to use up to four ultrasonic probes at one device
- communication via CAN-open
- use the already developed measurement pots with a 10 MHz Krautkramer ultrasonic probe
- automatic measurement with failure detection
- transfer the results of the measurement per default, transfer the raw data on demand
- build a cost efficient hardware
- use a standard 19” crate
- reach an accuracy of better than 2µm for the resulting height measurement

The development of hard- and firmware is still in progress, but a first prototype board (see Figure 8) and the firmware are finished and have been tested in the lab, with very promising results. The standard deviation of a single measurement is in the range of σ = 1µm, the standard deviation of moving average of 15 measurements (~7 sec) is in the range of σ_{ma} = 0.2µm (see Figure 9).

It is planned to install four measurement pots (that means one degree of redundancy) together with the new electronics for each girder in the PETRA III hall, so that they can be leveled with respect to each other during operation. A closed loop system for the steering of the girders is under discussion.

Figure 8: Ultrasonic Hardware for DESY HLS (prototype)

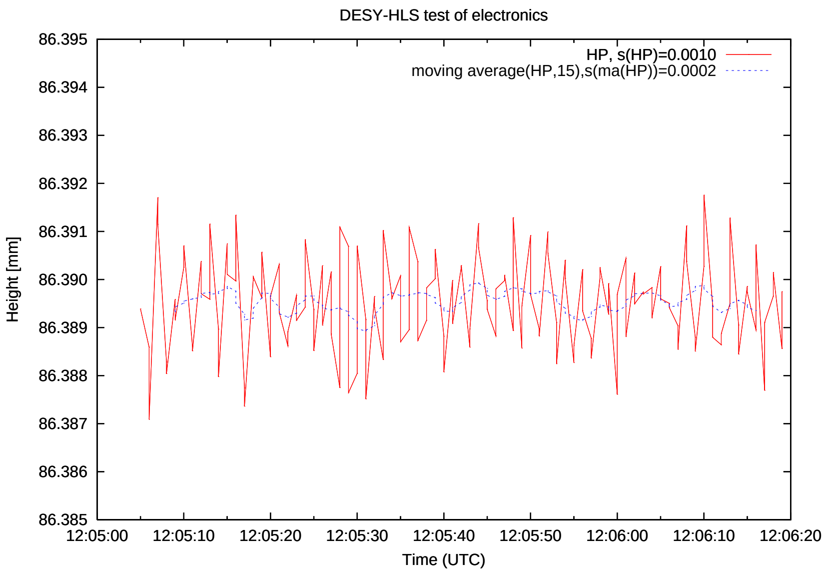

Figure 9: Measurement results of prototype

The preliminary cost estimate gives a price range from 700€/channel, when only one channel is used, down to 350€/channel, when all four channels per crate are used. This does not include the measurement pot and the ultrasonic probe, which cost about 1.2k€ per channel together.

References

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[2] Schlösser, M., Herty, A., “High precision survey and alignment of large linear colliders – vertical alignment”, Proceedings of the Seventh International Workshop on Accelerator Alignment, Spring8, Japan, November 2002

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