# Precise Alignment of Magnetic Quadrupole Axes for PETRA III

## Alignment tolerances (in lateral and height):

*50 µm* intra-girder (between magnets on the same girder)
*100 µm* inter-girder (between magnets on subsequent girders)

## Measurement principle:

1. Fiducialization of quadrupoles with a new measurement principle, i.e. direct transfer of magnetic axis to outside monuments (see poster "Precise Transfer measurement of the magnetic axis to outside monuments" by Bernward Krause)
2. Coarse alignment of magnets *with respect to* girder axis
3. Precise alignment of magnets to a common axis *not being referenced to* girder axis using two laser trackers simultaneously

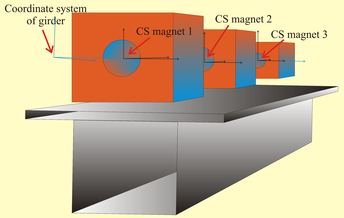


fig. 1: girder and magnets with coordinate systems

## Coarse Alignment:

A coordinate system (CS) of the girder is defined by measuring the surface and the edges of the girder. This system should represent the mechanical axes of the girder to better than 1mm. Each magnet is then shifted and rotated in three dimensions until the X-Axes (along beam) of magnet and girder system match each other and the origin of the magnet system is in the right place. After that the rotation around X of each magnet is adjusted to its nominal value (fig. 1). The position/rotation of each magnet with respect to the girder CS should be better than 300 µm / 300 µrad. However, the positions and rotations of the magnets with respect to each other are expected to be better by factor three.

## Precise Alignment:

The precise alignment is similar to the coarse alignment process, except that it is done with no further reference to the girder axes (which can not be determined with sufficient accuracy). Again, all the magnet CS are aligned to each other so that the X-Axes match each other and the rotation of all magnets are identical.
The position/rotation of each magnet with respect to each other is better than 10 µm / 10 µrad.
It should be noted that the girder itself bears *no* coordinate information at all. All the information is contained in the monuments of the magnets.

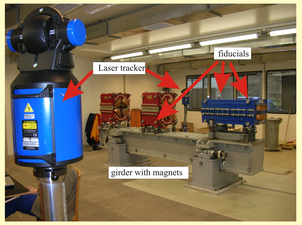


fig. 2: girder with magnets and laser trackers in air-conditioned hall

## Mechanical considerations:

1. Precise alignment of the magnets on girder has to be done in an air-conditioned environment - optical alignment in the tunnel will not be possible with an accuracy at the 50 µm level, because of refraction
2. Magnets have to be mechanically movable with a precision of 10 µm during the alignment process - this is accomplished using the DESY standard turnbuckle & ballshaped height screws system (fig. 3 and 4).
3. After the precise alignment magnets have to be fixed rigidly to the girder - this is done by gluing magnet feet to the girder with a radiation hard, non-shrinking two-component epoxy (fig. 3).

fig. 3: height screw and glued magnet foot

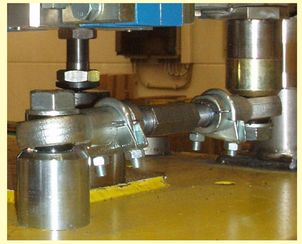

fig. 4: turnbuckle and ball shaped height screw

## Test of mechanical stability during transport

After the precise alignment the girder has to be transported by crane from the air-conditioned room to its final destination. The girder *must not* be transported by truck after the fine alignment.
It is essential that no shift of moments occurs inside the girder during transport, i.e. a traverse has to be used which attaches to the girder exactly in the same positions as the mechanical stand of the girder (fig. 5).
To prove the mechanical stability the precisely aligned girder has been treated in several ways. After each treatment the magnet positions have been checked.

fig. 5: traverse attaching to the girder in the position of the stands

fig. 6: smashing the girder into a concrete wall

Normal transport by crane and even a hard drop to the ground (also by crane) revealed no significant displacement of the magnets within the single point measurement accuracy of about = 10 µm (fig. 7). A hard lateral smash into a concrete wall however resulted in minor scattering of magnets (fig. 8).
To be on the safe side only careful transport by crane is allowed for the complete girders. Even a hard drop to the ground, which did not cause any magnet displacements in our test scenario, would result in the girder being re-checked and re-aligned if necessary.

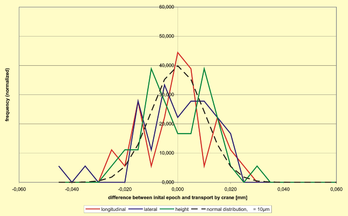


fig. 7: errors after transport with crane (no movements can be detected)

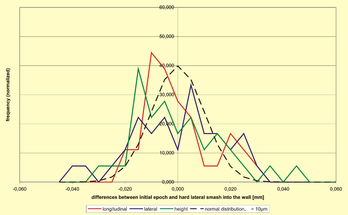


fig. 8: errors after smashing the girder into a concrete wall (minor scattering can be seen)

## Accuracy of Alignment

The alignment process consists of several steps which contribute to the overall error budget:

| | |
|---|---|
| 1. Determination of magnetic axis | = 5 µm |
| 2. Center of revolving target circle | = 5 µm |
| 3. Measurement to single monument | = 20 µm |
| 4. Accuracy of mechanical adjustment | = 10 µm |
| 5. Shift of magnets during transport | 10 µm |
| **total** | µm |

That results in:

| | |
|---|---|
| a) Fiducialization | = 21 µm |
| b) Adjustment of magnets on girder | = 22 µm |
| c) Transport | 10 µm |

The estimated accuracy is well below the required accuracy of 50 µm.

## Dynamics

As the tolerances are very tight the dynamic behaviour of the girder system (stands, girder and magnets) has to be taken into account. Figure 9 shows a transfer function between the ground and the middle magnet on the girder.

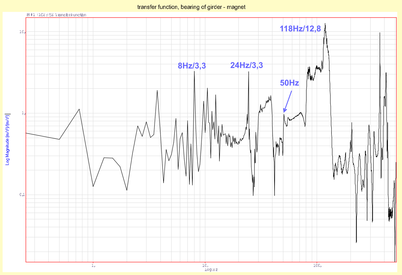


fig. 9: Transfer function between floor and magnet in a frequency range between 0.1 and 500 Hz

- The girder has only weak modes in the frequency range up to 100 Hz.
- Modes at 8.0 Hz und 24.5 Hz, which are not dominant with a magnitude of 3.3.
- The region around 50 Hz has no special modes and is neutral with a magnitude of ~1.
- There are some modes above 80 Hz with the first dominant one at 118 Hz with a magnitude of 12.8.
- The tests were done with girder including magnets. Since the mass of the whole system will increase slightly for the real girder the modes can be expected to move down for a few Hertz.

## Summary

- Critical alignments with accuracy of 50 µm have to be done outside the tunnel in an air-conditioned and quiet environment.
- One only has to deal with less critical accuracy of 100 µm in the tunnel.
- New concept of alignment and fixation is effective in terms of accuracy and nevertheless very cost efficient - no precise machining of the girder surface is required, the precise alignment of one girder takes only about 4 hours.

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