SMOOTHING OF NSLS-II SOTRAGE RING BY GIRDER SURVEY

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Abstract

A smooth storage ring orbit, generally referring to the tolerance of ± 100 micron for adjacent girders, is the goal of alignment when NSLS-II is running. With an existing initial good alignment and a stabilizing trend of slab deformation, it's unlikely to adjust girders in very large amount as there will be significant impact to beam lines. Based on this premise, the strategy of smoothing in NSLS-II is that the girders are surveyed gradually instead of a complete survey of all the girders in storage ring in one short period of time. That is, the girders, along with its surrounding monuments, are measured in a non-continuous manner. The measurement interval of adjacent girders can be several weeks depending on maintenance schedule. The relative location of girders is of interested and all the girders can be measured eventually within several years. This effectively solves the problems of limited manpower and instrument resource due to the very busy construction activities of new beam lines and very restricted access time with tight user schedule.

By best fitting the as-built location of adjacent girders with the normal, a smooth orbit can be maintained. The upstream and downstream girder centers can be hold tight so that there is minimum impact to its affiliating beam line.

Corresponding to the tight tolerance of ± 30 micron of magnets on a common girder, the girder profile are monitored as part of the girder survey. On the contrary to the traditional assumption of that girder will hold the magnets tight, it has been found that the girders themselves are deforming along with time. The smoothing technique of NSLS-II has the ability to correct girder deformation and therefore the meaning of smoothing is extended to a broad sense of maintaining the girder profile within around ± 10 micron accuracy.

INTRODUCTION

For most of the accelerators, the key alignment tolerance, usually lower than 100 micron, is the relative position of components, or girders if several components are positioned in one common girder. Comparatively, the global location is usually one order loose with the tolerance of several millimeters. The tolerances of NSLS-II are illustrated in Figure 1. What is specifically marked out is girder deformation since it's generally ignored but truly exists.

In construction stage, the usual practice is to build an accurate survey control network and then align all the components with respect to it. The alignment quality is mainly depending on the quality of network and the slab movement due to environmental changes and construction activities.

While in running stage, Periodical or long term monitoring the changes of components is a common practice. Traditional method is to measure the survey control network and components altogether and then use certain smoothing technique to improve the alignment. Wire positioning system (WPS) for horizontal direction and hydrostatic levelling system (HLS) for vertical system are used in some machines for real-time monitoring. Some machines, for example, Swiss light source [1], even have online adjustment ability which can move the location of girders by operator in control room.

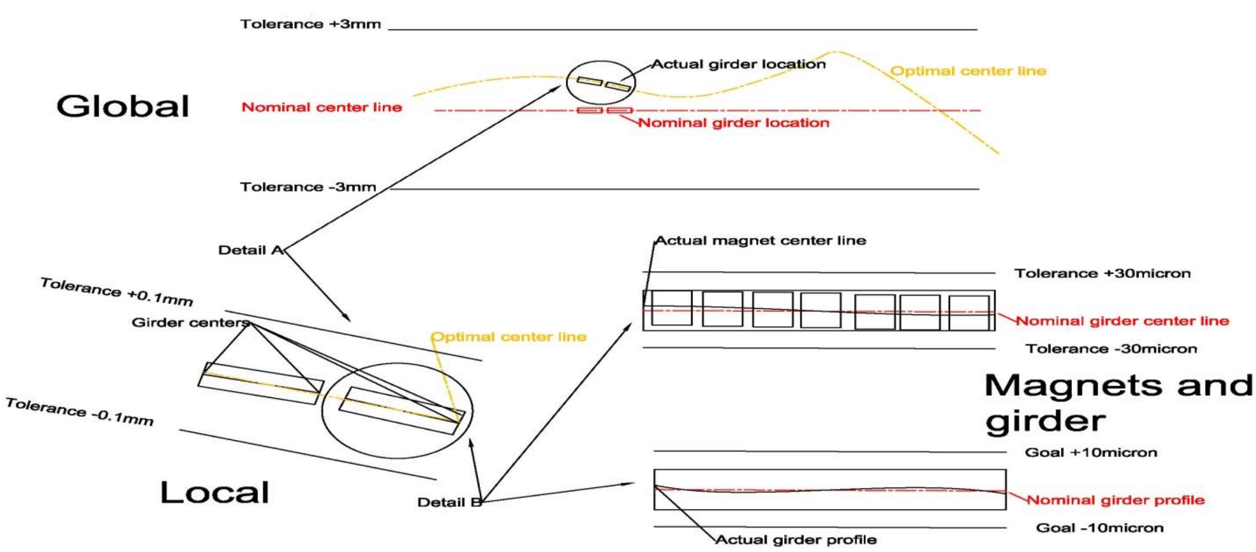

Figure 1: The illustration of tolerances and alignment errors of NSLS-II with girder deformation shown.

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However, there are limitations in all the above methods. For example, the traditional method requires a long shutdown to get all the components surveyed. It doesn't really address the core requirement of running a light source, which is to keep the down time as low as possible.

While the real time monitoring or adjusting method are costly and usually wouldn't take girder deformation into account.

As one of the solutions, the smoothing technique based on best fitting was initialized. The principle and application has been discussed during last international workshop on accelerator alignment in Beijing [2].

During the last two years, along with the maintenance work of NSLS-II, the smoothing technique, named as girder survey [3], is further developed. The main change is that non-continuous girder survey, instead of measuring the whole ring in one shutdown, is chosen to be the way of maintaining the alignment of NSLS-II. The benefits of this change are enormous as there is no need to exhaust all the resources during one long shutdown to get all the components surveyed, competing with the efforts of new installation. In contrast, every short maintenance period can be used to survey and smooth the orbit.

One major good by-product of this survey is that the beam line frame for installation and maintenance can be updated timely. This is extremely important since there is a lot of new installation for a new light source such as NSLS-II. For example, in the fiscal year of 2015, there are 9 beam lines installed.

The girder survey method used, the result will be discussed in the following section.

GIRDER SURVEY METHOD

For smoothness check, the most important information to be gathered is the relative position of adjacent girders. Therefore, each time two girders are needed to be surveyed. The monuments around the girders are also measured to ensure the relative location of the girders is accurate.

For each maintenance day which occurs every several weeks a survey crew will come in to survey 3 girders of one cell. Of course there will be connections between cells so that the relative location of girders in different cells can also be computed.

To measure girder profile deformation accurately, each girder fiducial in each setup will be measured 3 times. Figure 2 shows the observations for the 3 girders of cell 10. Girder fiducials are called out.

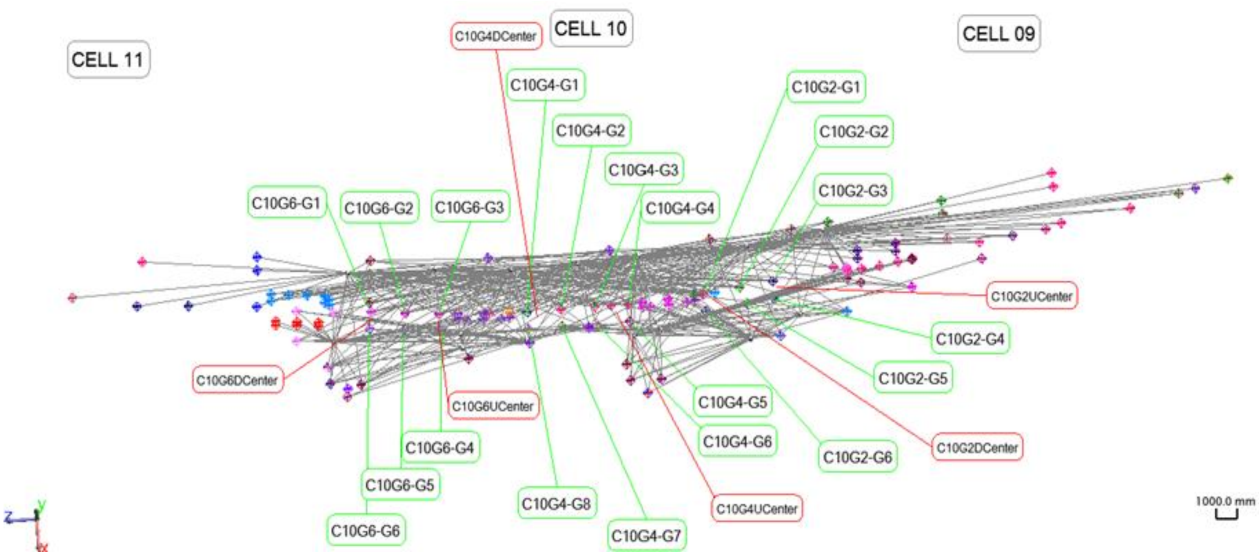

Figure 2: Example of the girder survey for the 10th cell of NSLS-II storage ring.

Local smoothness check

When the survey data has been collected, the optimal location of all the monuments, girder fiducials and instruments can be solved to generate as-built data.

Girder's reference file that was generated in environmental room after vibrating wire measurement [4] and multiple laser tracker setup survey is used as nominal data. The centers of upstream and downstream magnets will be renamed as "CxxGxUCenter" and "CxxGxDCenter" respectively to represent the girders entrance and exit points, as shown in Figure 2. The relative location of girders is defined by lattice and therefore is precise.

Table 1 the Relative Deviation of Girder C24G2 and C24G4

Point Name	X (mm)	Theta (degree)	Y (mm)
C24G4D	-0.016	0	-0.006
C24G4U	0.033	1.611	0.004
C24G2D	-0.022	3.623	0.013
C24G2U	0.006	4.944	-0.011

For adjacent girders, firstly the deviations of entrance and exit centers between the as-built and nominal data will be computed. Secondly the deviations are shown in cylindrical coordinate system so that the turning angle between girders has no impact for further analysis. Finally a best-fit transformation of the canter deviations will be performed so that the residuals of each point can be obtained.

Table 1 shows residuals of the nominal and as-built data after a best fit transformation. The 2nd and 4th columns indicate deviation in X and Y direction respectively. The residuals reflect the relative alignment deviation of girders.By processing adjacent girders set by set, the relative alignment deviation of all girders can be computed. Apparently, this method won't provide the absolute location deviation of girders, which is of little importance.

Girder deformation and magnet alignment check

Ensuring girder profile is reproduced is the key to maintain the precision of relative magnet alignment [4]. Each girder has 6 or 8 fiducials which are located above supports and hence can be adjusted to alter the girder profile, as shown in Figure 2. All girders have been adjusted with very small residuals of girder fiducials achieved when they are aligned.

Girder profile can be computed based on the residuals of girder fiducials by generating a series of virtual center line points based on girder fiducials. The number of virtual points is 3 or 4 depending on the girder type. The idea is to average the deviations of two fiducials in left and right side to generate a deviation to represent that central position of the girder.

Figure 3 shows the detail information of C10G4 which is measured in October 2015. As can be seen, the fiducials in central part are relatively higher, and the ones in both ends are lower. The profile deviation is represented by the 4 points with the name of "AVE-GxCenter". The range of girder profile change is [-0.019, 0.020] mm.

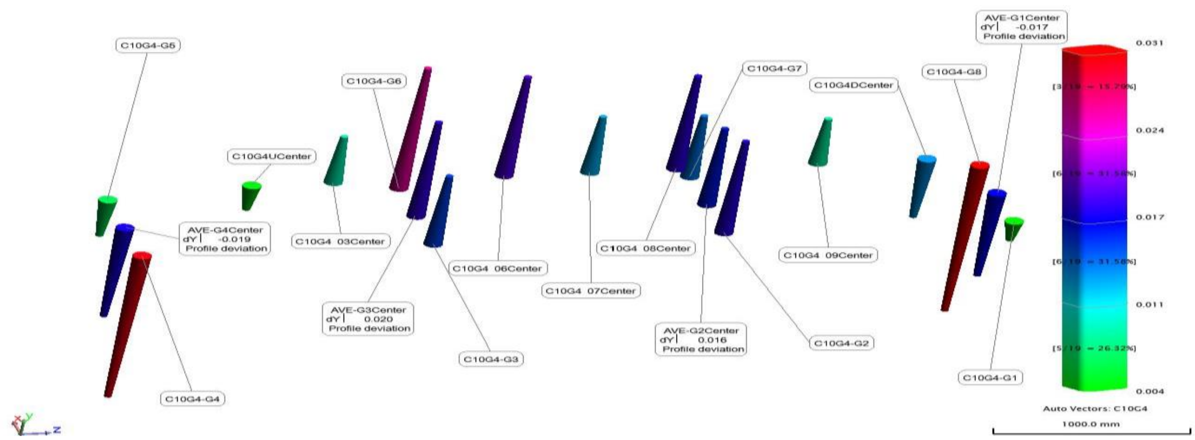

Figure 3: Girder Profile of C10G4 as of October 2015 (Unit: mm).

Table 2: Girder Profile and Magnet Center Changes (Unit: mm)

Name	Original	Current	Delta
AVE-G4Center	-395.485	-395.504	-0.019
C10G4UCenter	-0.002	-0.007	-0.005
C10G4 03Center	0.002	0.012	0.01
AVE-G3Center	-395.643	-395.623	0.02
C10G4 06Center	0.002	0.023	0.021
C10G4 07Center	-0.006	0.006	0.012
C10G4 08Center	0.003	0.023	0.02
AVE-G2Center	-395.692	-395.676	0.016
C10G4 09Center	0.005	0.014	0.009
C10G4DCenter	-0.004	-0.016	-0.012

As a further step, according to the longitudinal location of magnet centers relative to the virtual girder center points, the current magnet center deviation can be computed by interpolation. The points with the name of "C10G4UCenter", "C10G4DCenter" and "C10G4 xxCenter" are the centers of quadrupoles and sixtupoles. Table 2 lists the original and current magnets' centers due to girder profile change. As can be seen, the relative magnet alignment is significantly worsened due to girder deformation.

STATISTICS AND TRENDS

The current round of girder survey started from February 2015 and intermittently continues with the interruption caused by long shutdown, schedule pressure etc. The paper shows 27 out of a total of 30 cells that have been surveyed. The survey result will be summarized in the following.

Statistics of local smoothness

The alignment deviations of all adjacent girders are computed as shown in Figure 4. As can be seen, the relative deviations all but one girder is below the tolerance of ±0.1mm. Only 5 girder sets have relative large deviations and all others are relatively far from the tolerance. The data shows that the relative alignment of girders is still very well after about three years.

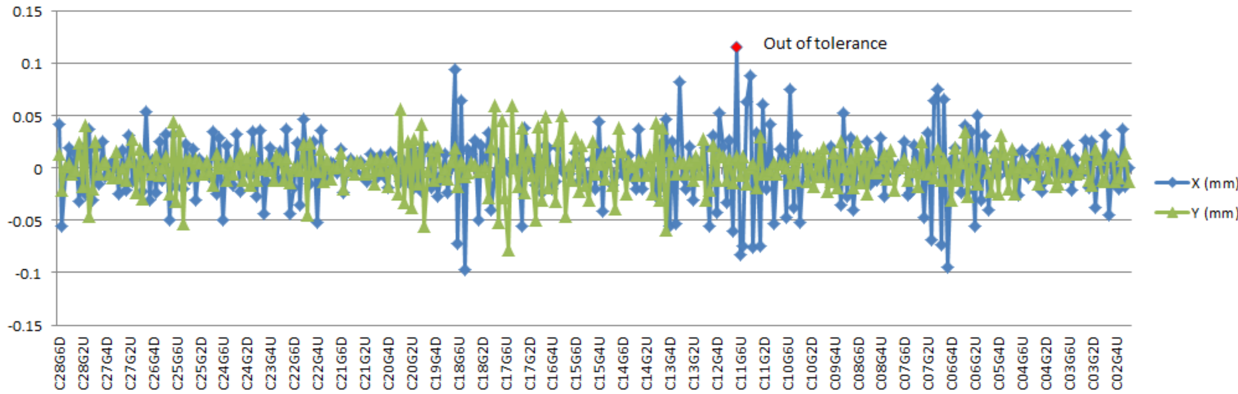

Figure 4: Relative Deviation of Adjacent Girders' Entrance and Exit Points.

Statistics of girder deformation

The girder profile change of all girders is computed as shown in Figure 5. As can be seen, the range of girder profile change is about ±0.02 mm with an RMS of 0.009 mm. Compared with the original RMS of ±0.004 mm right after the girder was precisely aligned the current girder profile is significantly deteriorated. Another phenomenon is that most of the girders show the trend of higher in middle and lower in ends.

Figure 6 shows the interpolated magnet centers with girder profile change considered. As can be seen, all the magnets are still within the alignment tolerance of ±0.03mm, although some magnets are close to the limit due to girder deformation.

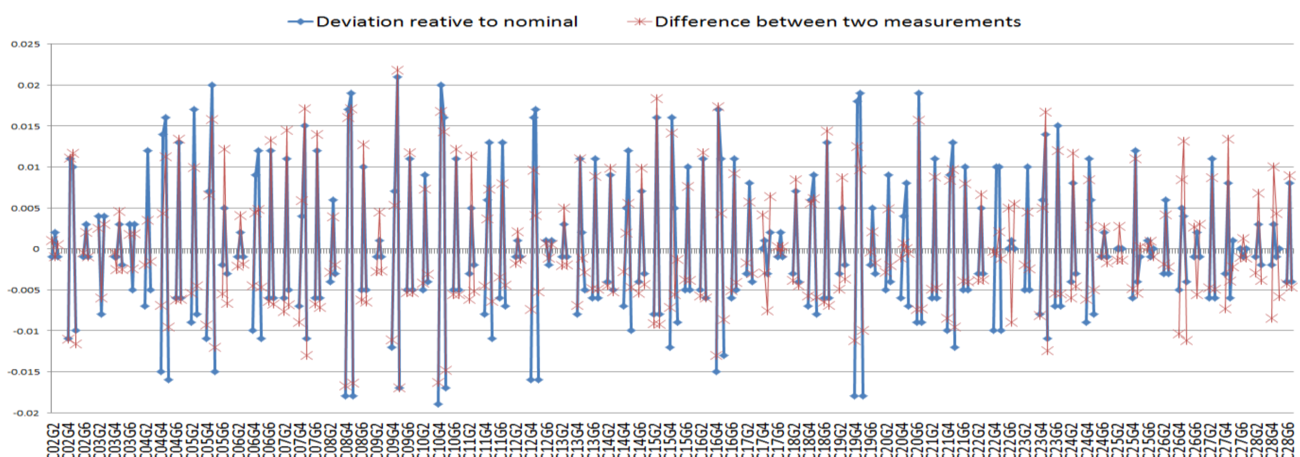

Figure 5: Girder Profile Changes (Unit: mm).

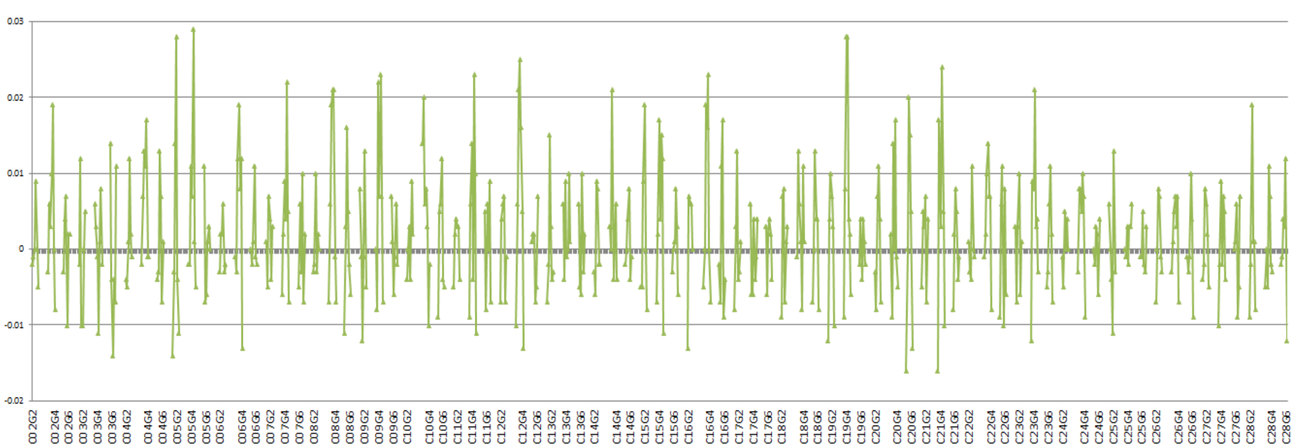

Figure 6: Interpolated Magnet Centers Considering Girder Profile Changes (Unit: mm).

Trend of girder deformation

When the girders are aligned, special consideration has been made to avoid the middle section of girder lower than both ends. However, currently the middle parts are all higher. It would be interesting to know the timing of the change.

In June 2014, several girders have been re-measured or re-adjusted based on Epoch 7 survey result. With the ongoing girder survey, girders have 2 or 3 rounds of survey depending on whether they were adjusted or not. Figure 7 shows the girder profile difference between the 1st and 2nd round survey. It should be noted that the 1st round of survey is usually accomplished right after the adjustment, either the same day or next day. Figure 8 shows the girder profile difference between the 2nd and 3rd round survey.

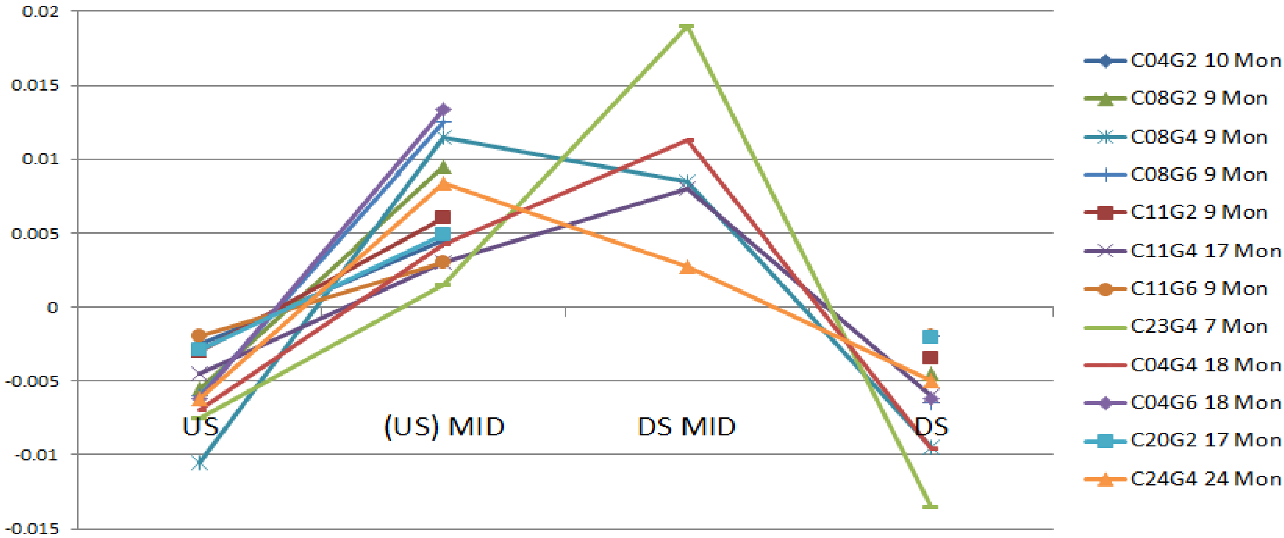

Figure 7: Girder Profile Difference between the 1st and 2nd Round Survey (Unit: mm).

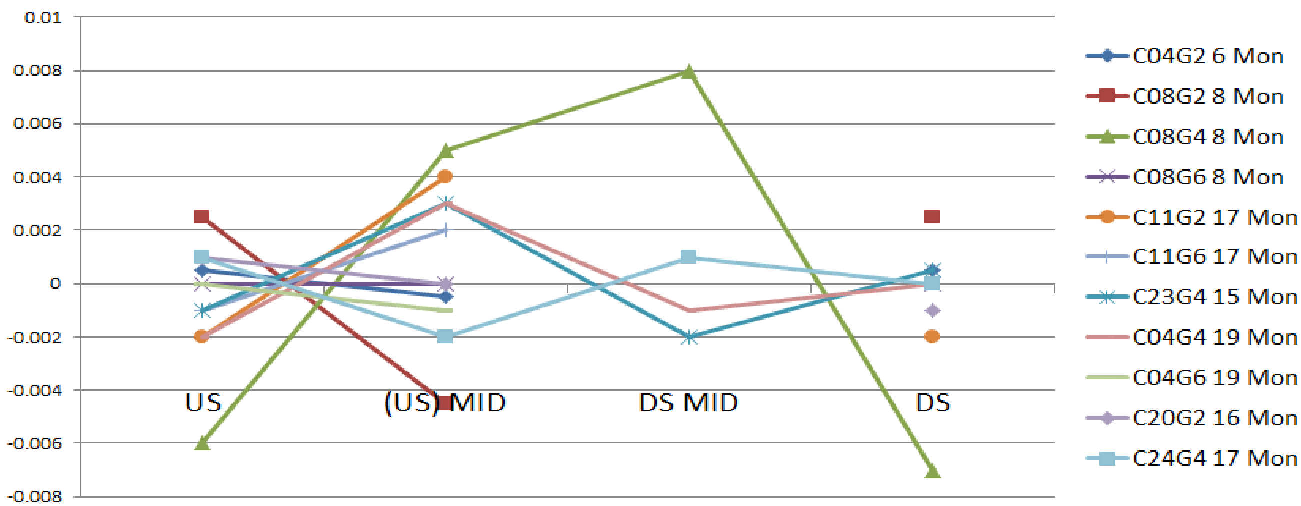

Figure 8: Girder Profile Difference between 2nd and 3rd Round Survey (Unit: mm).

As can be seen, the trend of middle section is higher and the ends are lower take place in the first period. However, there is no obvious trend in the second period as shown in Figure 8. Moreover, the amplitudes of changes in Figure 8 are all below 10 micron which is in the range of measurement error.

Therefore the conclusion is that most of the girder profile change happened in the beginning. But how soon did the change occur is not clear yet as there is no data available. As the change is slowing significantly after settling down of a couple of months it's safe to say that girder profile will maintain for a long time if no re-adjustment is made.

DISCUSSIONS

The smoothing technique, named as girder survey, effectively checked and confirmed the local smoothness and girder deformation. There are two unexpected findings based on the survey data:

- The relative alignment of NSLS-II girders holds up very well. It's against the expectation that a lot of girders might need to be adjusted at the beginning of the running due to relatively large settlement. This

- implies that the stability of the NSLS-II tunnel and mechanical system and longer interval can be scheduled for next round of girder survey.
- The girders themselves deform. It's against the common assumption of that girders are deemed as rigid body to hold the magnets above them tight. This needs to be paid more attention to in the future. Certain tests can be conducted and even the girder profiling procedure can be modified in order to resist girder profile change.

The smoothing technique employed in NSLS-II is running well so far. Its merits and shortcomings is summarized in the following.

Merits

There are several merits of smoothing technique used in NSLS-II:

- The local smoothness check of storage ring can be carried out in very limited time. Any access time shutdown can be used. There is no requirement for long scheduled shutdown time for the survey and re-alignment activities.
- The local smoothness check of storage ring can be carried out in random order. If any portion of the storage ring is suspected to have a problem, it can be checked and adjusted accordingly.
- The local smoothness check can be arranged along with the installation of front ends and beam lines so that precise beam line frames can be established.
- The upstream and downstream centers of a beam line source point can be hold tight when adjustment of girder position is necessary so that there is minimal impact to the running of a beam line if a re-alignment is necessary.

Those merits essentially solve the problem of a running light source with very tight user schedule and limited time for the alignment group which is swamped with new installation and maintenance work.

Shortcomings

The main shortcoming is that the global deviation is not well monitored. When all the cells have been surveyed, it's possible to check the global deviations comparing with previous data. But the measurement span of time is about 2 years. Accompanying with the seasonal changes of the slab, the quality of the data will not be very high. However, considering the stabilizing trend of NSLS-II tunnel and the large global tolerance, this may not be an issue at all.

Another one is that if the measurement interval for adjacent girders is too long, the accuracy will not be very high. Re-survey should be done to get a good connection with previous survey and therefore avoid poor raw measurement data.

SUMMARY

The approach and result of the current girder survey which undertakes the smoothing responsibility of NSLS-II storage ring are discussed. The goal of accelerator smoothness can be conveniently monitored and improved when necessary. It covers the traditional local smoothness of girders and extends its meaning to the extent of including monitoring and correcting girder deformation.

It improves the girder alignment with girder re-alignment at the very beginning and monitors the current girder alignment continuously.

By applying this approach, the dilemma including tight user schedule, limited survey resource for new installation and the conflict between quality alignment of storage ring and beam line can all be solved. Therefore, it can be envisioned that NSLS-II will be maintained in good alignment status for the decades to come.

However, the smoothing technique used in NSLS-II is not hard to understand and should be able to be easily applied by most of the existing and under construction storage rings and accelerators if accepted. From cost point of view, there is no need to set up an expensive online monitoring and adjustment system for orbit smoothness purpose.

One of the important findings from NSLS-II girder survey is that girders deform to the extent of about ± 20 micron at the beginning stage and then keep stable for a long time. This is against the assumption of girder as a rigid body and therefore should be noted for future accelerators if very tight tolerance is required.

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