SURVEY AND ALIGNMENT OF THE SSRF COMPLEX

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF) is a 3.5GeV third-generation synchrotron radiation light source. Up to the end of 2007, the installation and alignment of accelerators and 7 front-ends were completed. In the linac, booster and storage ring installation, laser trackers are the main tools for survey and alignment, which ensure accuracy and efficiency and speed up the progress ahead of almost half a year. Main alignment activities such as control network, girder assembly and alignment in tunnel are introduced in this paper.

INTRODUCTION

Construction of the SSRF (see Fig.1) commenced on 25th December 2004 with the first piling. And the first synchrotron radiation light was gotten on 24th December 2007 after a 3 years' span.

Figure 1: The SSRF Site, July 2007

The linac installation and realignment were completed on 6th May 2007 and the commissioning started on 13th May with first beam at the end profile of linac a day later. All of the design parameters were achieved in August.

The SSRF booster installation and re-measurement were completed on 22nd September 2007 and the commissioning started on 30th September. The beam arrived at the entrance of the booster 1.5 hours later and was successfully circulated several times without using any correctors, on the night of 1st October. On 5th October, beam was ramped to 3.5GeV and on 29th October, beam of 3.5GeV was extract out from the booster and sent to high energy transfer line.

The storage ring installation and re-measurement completed on 13th December 2007 and commissioning started at 18:20 21st December. First turn beam was gotten at 21:08, and many turns at 21:18. On 24th December, beam was stored at 3GeV and first synchrotron radiation light was seen at the light diagnostic beam line and 16B's front-end.

GLOBAL CONTROL NETWORK

control network

The SSRF global network takes two key tasks: first, make sure the relative position of linac, low energy transfer line, booster, high energy transfer line, storage ring and beamlines. Second, keep the circumference of booster and storage ring right [1].

The global network has been surveyed 4 times since September 2006 by total station with change in observations each time. The first time survey took place in September 2006 and the result was reported in the last workshop [2]. In November 2006, after reinforcing the instrument pillars, we took a second time measurement and got a network with smaller than 0.5mm absolute and relative point error which serves as the formal control for survey and alignment.

At the end of January, 2007, a third time measurement was carried out by the IHEP survey and alignment group and served as a double check. For convenience, the monument number of experimental hall increased from 6 to 8. And the final network shape can be seen in Fig.2. With better environment and better preparation, better quality was achieved with 0.3mm absolute and relative point error. Compared with last survey, an obvious constriction factor can be deduced which is 9.2×10^{-5} .

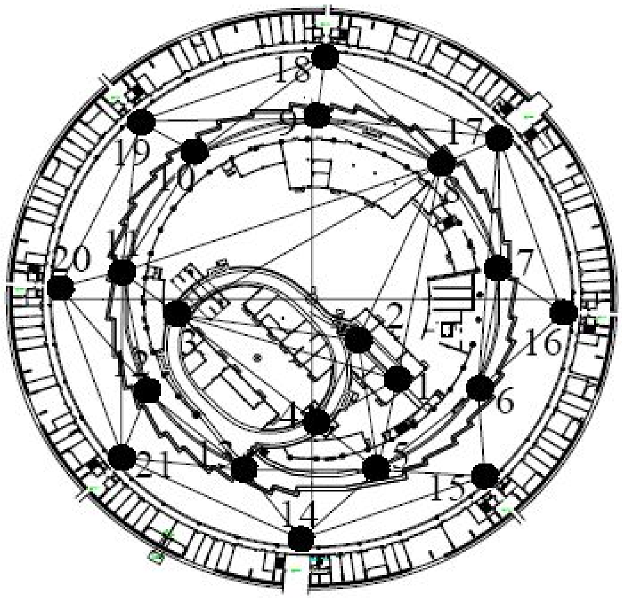

Figure.2: Actual SSRF global control network

The last time measurement was carried out in November 2007 with the intent of confirming storage ring's circumference by only point 5, 8 and 11 being measured. The result showed good coincidence with the formal data.

Several times of survey indicate that the floor slab can expand or shrink with season which may be a result of heavy utilizing steel and concrete in slab. As a result, it roused difficulty to control the circumference of booster and storage ring.

Vertical control network

Most of the floor monuments take the role of height transfer and slab deformation monitoring. The first leveling run was carried out in November 2006 and subsequently repeated every 3~4 months. Fig.3 chooses 16 points and gives the deviation relative to the first time measurement. The figure shows that absolute vertical movement of slabs is bigger than relative one.

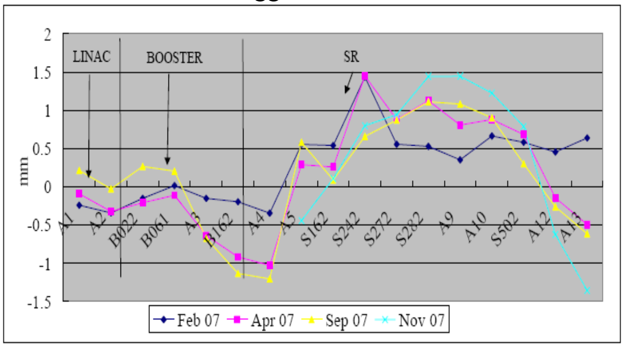

Figure.3: The 5 times slab deformation monitoring

LOCAL CONTROL NETWORK

With the constraint of global control network, local control network can be established. Because of the partition wall among tunnels, local control network are classified as linac, booster and storage ring ones which have been presented in last two workshops. The method of measurement and adjustment is very similar for the 3 local networks. The storage ring local network is detailed as an example in the following. The storage ring control network has been surveyed for four times.

First survey

The first survey was done in December 2006 when the storage ring tunnel and slab had not been fully cast and the cell 8-area is still free for providing access to the central courtyard. Besides, the first survey was going on with huge building construction. This caused the quality of this survey was not so good and only served as coarse setting out for girder concrete.

Second and third surveys

In June 2007, just before first pre-aligned girder was craned into the storage ring tunnel, the second survey was carried out. The instrument, Faro Xi 4500 with software Insight was used, and it took about one and a half weeks to obtain raw observations with 73 stations.

After all the observations were collected, the data was divided into horizontal and vertical parts for different data processing. For horizontal part, software "Survey" was adopted for adjustment to get optimized 2D coordinates. The reports showed that absolute point errors were smaller than 0.5mm and average adjacent point errors were smaller than 0.1mm.

As for the vertical part, the software "NASEW95" was adopted for adjustment to get optimized height coordinates.

Then horizontal 2D coordinates and vertical ones were put together to shape a group of points with 3D coordinates and they were the formal control network data to direct all of the installation and alignment in tunnel.

The third survey serves as a recheck for the formal data and was carried out in July 2007 by the IHEP survey and alignment group. The result showed that there was no problem. The overview of storage ring local control network can be seen in Fig.4.

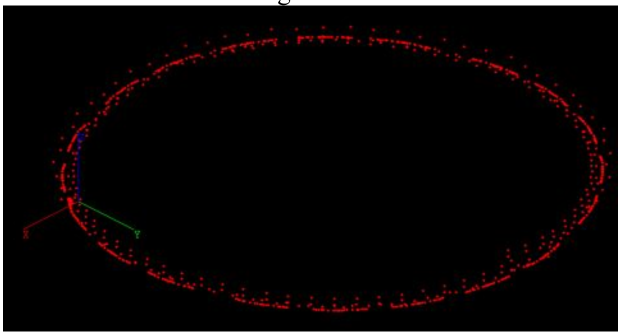

Figure.4: Local control network of storage ring

Fourth survey (before commissioning)

Before commissioning, most of the nests on walls, monuments in floor and nests of all the quadruples and dipoles were served as observation points and a complicated measurement was carried out. The method of calculation and adjustment was similar as the second measurement. The maximum difference in beam radial directions was smaller than 1.5mm and in vertical directions was smaller than 0.5mm (see Fig.5).

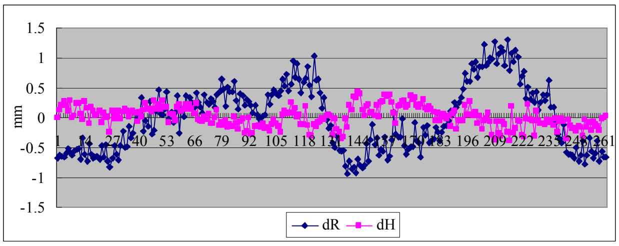

Figure.5: The difference between fourth and second time of storage ring control network

FIDUCIALIZATION

Fiducialization is another key technique for the SSRF survey and alignment. Almost 95% of the components' fiducializaiton was done by the SSRF survey and alignment group, and the main instruments used for fiducialization are laser trackers and articulated arm.

A 2.4m platinum arm from FARO (see Fig.6) was equipped in October 2006 and used for taking 80% fiducialization tasks such as coils, magnets of the linac, and quadruples, sextupoles, dipoles and correctors of booster, and sextupoles, correctors, vacuum chambers and absorbers of the storage ring. Because of the procedures is same for all type of accelerator components, an automatic program including operator indication, calculation and analysis is very convenient, so it can avoid blunder and enhance efficiency. Software”CAM2” provides such an platform for us to operation and most of the requirement can be fulfilled.

Figure.6: Sextupoles fiducialization of storage ring

Quadruples and dipoles of the storage ring are fiducialized by laser tracker. The IHEP survey and alignment group take the responsibility to fiducialize these two types of magnets. For quadruples of storage ring, it designed to trace the origin to magnet centre through magnet field measurement coil, but some mistakes caused this some difficulty and as a result mechanical centre substituted the field centre.

Quadruples were fiducialized again as an accept test initially, but an about 10~20°C temperature difference between IHEP site and SSRF pre-alignment site challenged our tolerance. Although after scale compensation, the difference of magnets’ fiducials were small (Cell 02 for example, see Fig.7). For confirmation, all the quadruples were fiducialized again.

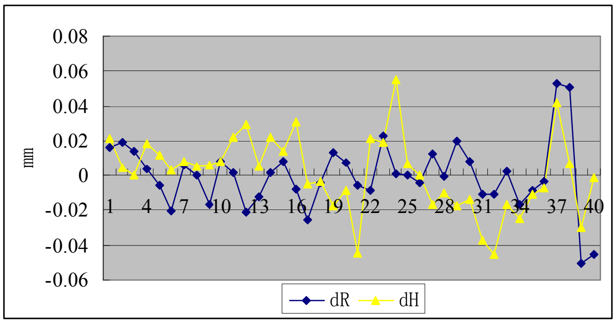

Figure.7 Contrast of Quadruples fiducialization

PRE-ALIGNMENT

Pre-alignment was done for the standard cells’ girder of the booster and the storage ring. Alignment could be done after the fiducialization had been done and relative coordinates had been calculated according to the survey parameters set from accelerator physics. The number of girders to be pre-aligned for the booster and the storage ring was 56 and 60 respectively.

Figure.8: Pre-alignment of booster

For the booster, a standard cell’s girder includes a dipole, a quadruple, a sextupole, a corrector and a vacuum chamber with BPM (Fig.8). For having the reasonable volume and weight, dipole was set to be fixed and the other components were adjusted according to the deviation measured relative to dipole. Firstly, quadruple and sextupole were adjusted within the tolerance of 0.05mm in radial and vertical direction; secondly, the upper parts of the three magnets were dismantled for vacuum chamber to be installed; thirdly, the vacuum chamber was aligned and the position of BPM was aligned with in the tolerance of 0.05mm in radial and vertical direction; finally, the upper parts of magnets were mantled again and a repeatability check was done to confirm the pre-alignment quality.

Figure.9: Pre-alignment of storage ring

For the storage ring, a standard cell’s girder includes several quadruples, sextupoles, correctors and a vacuum chamber with BPM (Fig.9). There was a remarkable difference of the adjusting mechanism compared with that of the booster. Due to the stringent requirement of beam dynamics, the vertical adjustment was done by using shims of 0.03mm, 0.05mm, 0.1mm, 0.5mm. In order to make the shimming, a highest position needs be found first and be set as a relative zero. By the way, in order to avoid the effect of locking, the relative zero was gotten at the status of all magnets had been locked.

Because of the mechanical structure and assembly, the SSRF sextupoles always need a bigger rotation which may cause the change of relative zero, so sextupoles were the first shimmed magnets for making a procedure. After shimming was finished, horizontal magnet adjustment was carried out, and magnets are aligned to the tolerance of 0.05mm in both radial and vertical direction. Fig.10 details an example of A3 girder pre-alignment result of Cell 02.

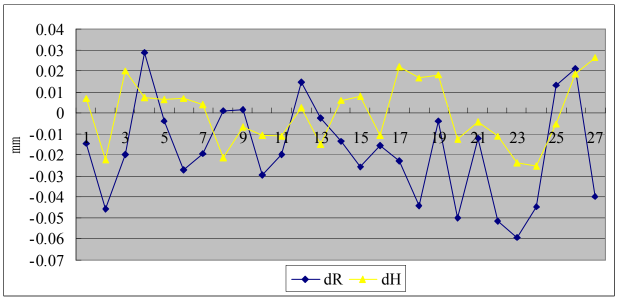

Figure.10: A3 girder pre-alignment result of Cell 02

When all the magnets were aligned within the required tolerance the actual coordinates would be recorded. Then poles' check was performed by laser tracker and special fixtures. The initial purpose was to confirm fiducialization and pre-alignment quality by alignment telescope and fixture through direct poles' measurement. When doing this, for operator's convenience, the instrument was substituted by laser tracker, and central target of fixture was replaced by a 1.5" corner cube reflector of laser tracker, and the poles of magnets are served as main check targets. The head of laser tracker was set as high as the centre of magnets. As the reflector moved the poles of each co-girder magnet can be measured subsequently and the relative deviation can be determined. Most of the poles' check was coinciding with the alignment result exactly, three of total 60 girders show a little bigger deviation which may be caused by unqualified fiducialization or pre-alignment, and they were corrected correspondingly. Fig.11 details an example of A3 girder's pole check result of Cell 02.

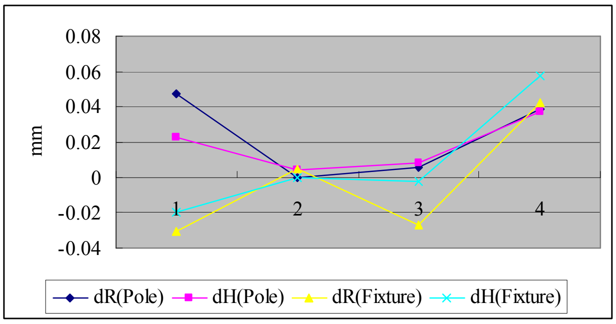

Figure.11: A3 girder's pole check result of Cell 02

INSTALLATION IN TUNNEL

After pre-alignment, girders were craned to tunnel and installed on site. Besides, installation in tunnel includes pouring the support and aligned the non-standard girders, injection components and most components of the two beam transport line etc. For storage ring, dipoles and ID-BPM were installation on site (see Fig.12 and Fig.13).

This procedure was done by laser tracker under the control of local survey network. Through more than 10 adjacent nests' measurement, a best fit can be done and the instruments' local frame could be transformed to global frame and the adjustment and alignment could be started. In order to reduce the influence of longitudinal direction to radial direction, a local frame with two coordinate axes were coincide with beam longitudinal and vertical direction respectively was widely adopted.

Figure.12: Tunnel installion of linac

Figure.13: Tunnel installation of storage ring

For the storage ring, in order to validate the roll of quadruples and dipoles an electronic inclinometer, nivel20, was used. When a girder has been aligned and re-checked by laser tracker, the nivel20 was put on the top of quadruples via an precisely-machined marble （see Fig.14）. For all of the quadruples, the roll readings were no bigger than 0.2mrad which validated the quality of control network and alignment.

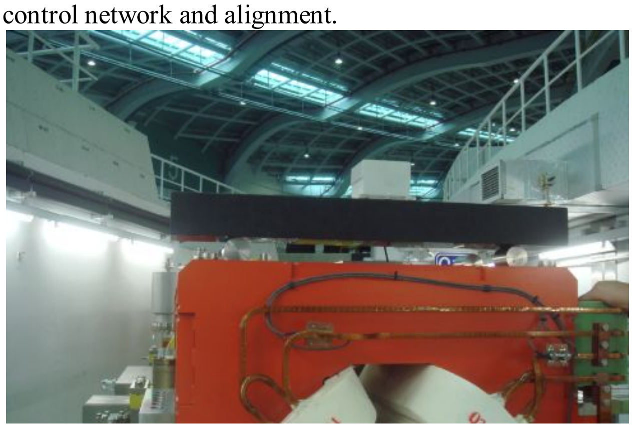

Figure.14 Inclinometer check of storage ring

SMOOTHING

For all the three accelerators, before commissioning, a final survey including control network and magnets' fiducials had been performed. The purpose was to find the oblivious or wrong-aligned components and change some components' position to keep the beam track smoothing.

For the linac, the final adjustment including some magnets and accelerating sections were done. For the booster and the storage ring, we provided a list to be adjusted according to the smoothing result, the result was considered rather good and then remained the alignment unchanged. The SSRF commissioning was unbelievable smoothing which may give a judge to the quality of alignment with a half year for booster and storage ring each.

As for smoothing, the magnets' centres were deduced according to the fiducials measured. Then a local fitting was done to determine whether the local beam track were smoothing or not. Fig.15 showed the biggest deviation, the x-axis showed the sequence of dipoles, quadruples and sextupoles in one cell.

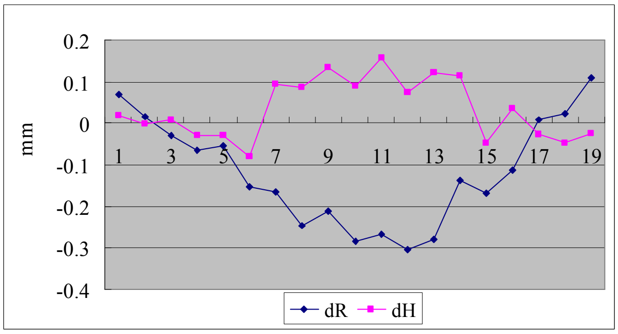

Figure.15 The biggest deviation of storage ring

FRONT-END

The survey and alignment status of front-end will be shown by Ms. Ke in this workshop, so this paper omits.

INSTRUMENTATION

Most of the instruments have been introduced above. A list can be found here:

- Total station (TDM5005)+plummet (NL)
- Level (NA2, NA3003, substituted by DNA03)
- Laser tracker (LTD500, 2 LTD640)
- Articulated arm (FARO platinum 2.4m)
- Inclinometer (Nivel20)

The key instruments are laser trackers and articulated arm. Articulated arm keeps doing fiducialization such as magnets, RF cavity, light absorber etc. Laser trackers do almost everything else which causes works are queued for laser tracker frequently. There are 3 laser trackers always at the SSRF site and in rush hour two others are borrowed to relief the pressure of requirement which last about 2 months.

So many software used in laser trackers and articulated arm make us a hard time. The software have been used includes “MeasurePro” from API, “CAM2” and “Insight” from FARO, “Spatial Analyzer” from New River Kinematics, “Axyz” from Leica and “Metrology” from Metrology group, besides, the version of “Metrology” used at the same time includes 5.0, 6.0 and 7.0. By the way, the operators' training is another standing problem we faced. As mentioned above, diversity of instruments and software causes that the operators need be trained. And operators are not very fixed, so training is frequently being done. Fortunately, after early days' difficulty, all the software is used smoothly.

CONCLUSION

The global and local control network of SSRF can be surveyed periodically and accurately. The geodesy method of utilizing total station showed wonderful precision in the range of about 130m, while laser tracker gave the network a very smooth characteristic. The surveys have been done and recheck from IHEP confirmed the accuracy.

Fiducialization was a huge job we have done. Thanks to articulated arm, small and complicated components can be performed accurately and rapidly. As for big components, laser tracker might be more robust.

Pre-alignment was done in more capacious place which reduced the work in confined tunnel. Batch and pipelining operation can ensure quality and can be very effective.

Installation in tunnel depended on control network greatly. But many factors can affect the reading of laser tracker, so the accuracy of this procedure may be the hardest to control.

Too many software do cause difficulty at the beginning, but each has its merits which can be very useful in special occasions.

Several crucial procedures such as fiducializaition and pre-alignment have been controlled to make sure the quality of alignment which was validated by the successful beam commissioning.

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