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Title :

Installation of the Wall Brackets and the Brass Nails
SESAME-SOLEIL Mission October 2009

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Introduction:

The Survey and Alignment work in SESAME is one of the **Mechanical Engineering Group** tasks, the group consists of three Mechanical Engineers; **one** is dedicated for the Survey and Alignment.

Developing Alignment Strategy, designing the Alignment Network and Optimising the Network need dedicated efforts and knowledge. To perform these in a right and accurate way; the group has strong collaboration with **Soleil** Synchrotron (A. Lestrade).

Two persons from Soleil participated to complete the SESAME-SOLEIL mission in October 2009. Alain Lestrade and Murad Sebdaoui joined SESAME for 12 days; and the mission was finished in the right way as proposed in the plan.

Industrial Total Station Calibration:

What is Industrial Total Station?

The Industrial Total Station is the standard instrument of choice for large-scale assembly and inspection processes. By incorporating a precision distance meter and motorization features, the Industrial Total Station has spread into every industry as a truly large-scale solution for tooling, inspection and assembly.

The Industrial Total Station we use in SESAME is Leica TDA5005 (*figure 1*); its ability to locate and track a target makes the Leica TDA5005 Industrial Laser Station perform much like a standard laser tracker. Additional tracker-like capabilities make it an ideal tool for extremely large-part inspection and assembly.

The built-in precision distance meter and its ability to locate and track a target make the Leica TDA5005 Industrial Laser Station perform much like a standard laser tracker. Additional tracker-like capabilities, such as fast and flexible one-man operation, along with a measurement volume far above 500 m (1,640 ft), make it an ideal tool for parts inspection and assembly.

Figure 1: Leica TDA5005

The Calibration of the TDA was done in two steps:

1- Calibration at ESRF (Grenoble):
   The TDA5005 is given with a precision of 0.5 mm, and we need 0.01 mm; so it is calibrated at ESRF where the instruments to reach such precision exist.

2- Calibration at SESAME experimental hall:
   It is a general calibration for mechanical errors which are:
   a. **Index error from the 2-axis compensator:** the determination of the index error for the longitudinal and transverse axes of the compensator corresponds to the determination of the centre of the bubble used in the level, the index error for the longitudinal and transverse axes is determined at the factory and adjusted to zero before delivery.
   b. **Index error from the vertical encoding circle:** the V-index error is the zero-point error of the vertical encoding circle in relation to the vertical axis of the instrument, the V-index error is set to "0.00" before delivery, and all vertical angles are corrected with the V-index error.
   c. **Line-of-sight error:** the line-of-sight error is the divergence of the line of sight from a line perpendicular to the tilting axis; the line-of-sight error is adjusted and reduced to "0.00" before delivery from the factory.
   d. **Tilting-axis error:** the tilting-axis error is the deviation of the tilting axis from a line perpendicular to the vertical axis; the tilting-axis error is adjusted to "0.00" before delivery.
   e. **Collimation of the target recognition axis:** the ATR1 collimation error is the combined horizontal and vertical angular divergence of the line of sight from the axis of the CCD camera. The collimation procedure includes, optionally, the determination of the line-of-sight error and the vertical-index error.

These errors change over time and with temperature; therefore a calibration for the instrument should be done in the following cases:

1- Before the first use.
2- Before each precision survey.
3- After long periods of transport.
4- After long periods of work.
5- After long storage or shipment.
6- If the temperature alters by more than 20°C.

The method of the determination and the calibration of the instrument errors are illustrated in details in the User Manual of the instrument start from page 175 under the title of (Checking and Adjusting). [1]

Installation of Wall Brackets:

Wall Brackets are Steel Wall Brackets, used as references with accurate positions; they are used to hold the TDA5005 and its ATR (automatic target recognition) Reflector; they act as absolute and accurate mechanical references. 16 wall brackets will be enough to cover all the Experimental Hall; details are illustrated next.

First of all for installing the wall brackets, we have to mark their locations on the columns. The top surface of the wall brackets should be at the level of the top surface of the Storage Ring Qpole which is 1660 mm in order to use the Quads for Alignment to link the tunnel with the Primary Network.

To install the wall brackets we need two heights (h_4 and h_5) as shown in (*figure 2*):

- Start by defining h_1=top face of SR Qpole. *($h_1=1660mm$)*
- Find the h_2 height on the assembly drawing of the wall brackets. *($h_2=2.5mm$)*
- Find the h_3 height on the drawing of the wall plate. *($h_3=75mm$)*
- $h_4=h_1+h_2-h_3$ is the height of the drills to be realized; use a wall plate as a template when drilling, you will get the right axis length between both holes. *($h_4=1587.5mm$)*
- $h_5= h_1+h_2$ is the height of the top of the wall plate; This one must be horizontal by means of a level laid on it, it has been machined for that use. *($h_5=1662.5mm$)*

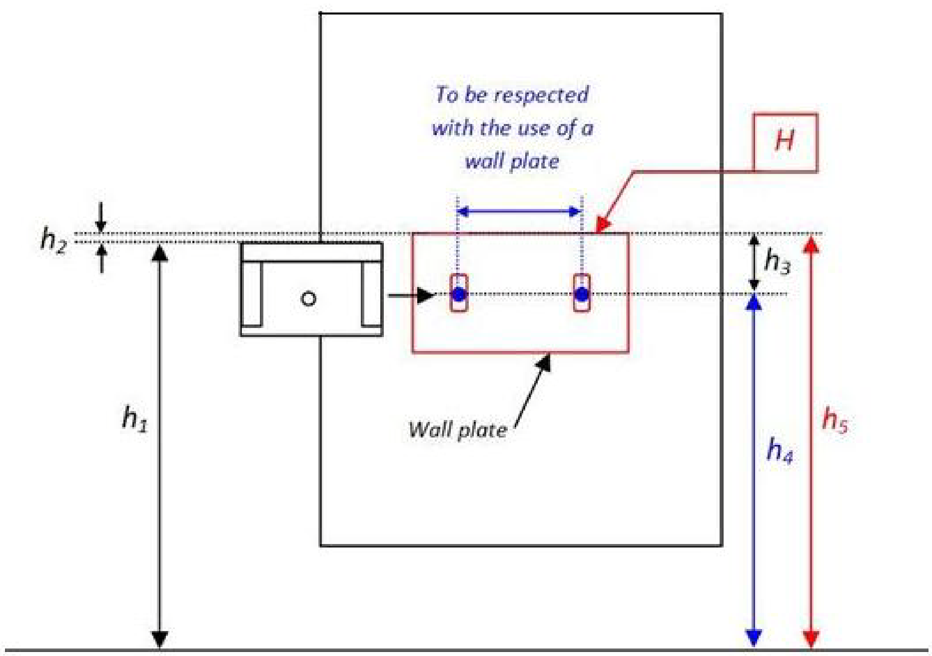


Figure 2: Wall Brackets Installation

Since the floor of the experimental hall does not have the same level everywhere; a point approximately in the centre of the hall is chosen to specify the same height for all the wall brackets according to this reference point. This is done using Rugby instrument and Leica Leveling Staff as shown in (*figures 3, 4, and 5*):

Figure 3: Rugby

Figure 4: Leica Staff

Figure 5

Using the accurate graduated Leica leveling staff, the height of the Rugby is adjusted to give a horizontal Laser trajectory on the level we want (which is here h_4*=1587.5mm* and h_5*=1662.5mm*), and we mark these levels on the columns as shown in (*figure 6*):

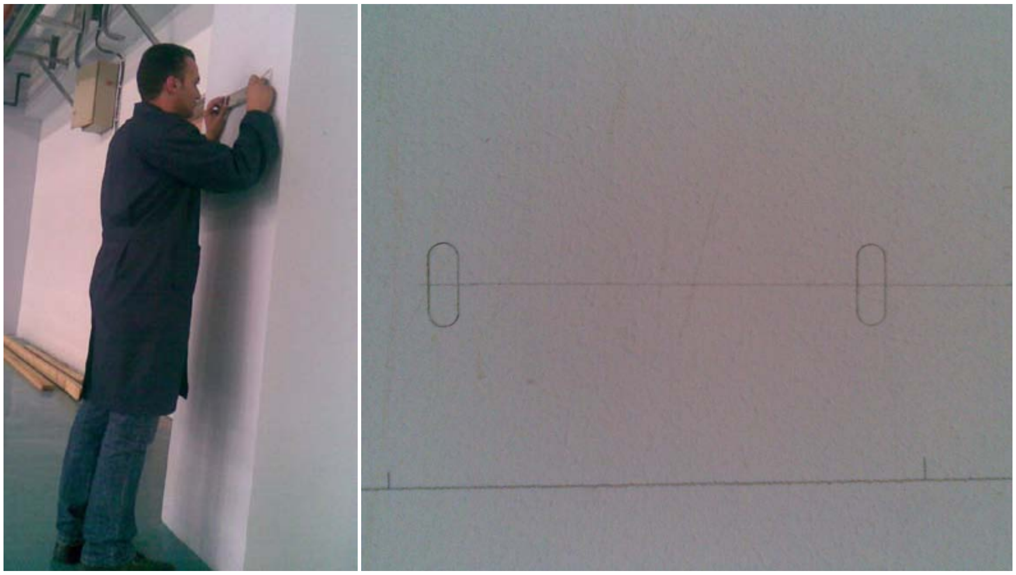


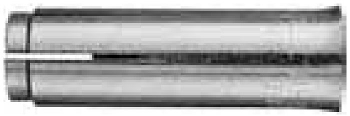
Figure 6

Now, as we have the two levels needed for installing the wall brackets, we specify the two drilling points using: meter tape, water level, and Leica Disto for checking.

Finally, we are ready for drilling. The drilling process comes in two steps, the first one is drilling with small drill and small diameter, and the second step is drilling with HILTI hammering drill and the big desired diameter. This is done to ensure accurate drilling in one vertical direction in the exact drilling point. The photo (*figure 7*) below shows holes ready for installing the wall bracket:

Figure 7

A problem was raised during the work that was the Anchoring system proposed by Alain is small and short with respect to the wall plate thickness and according to the concrete columns. So, another Anchoring system was chosen as shown below:



Old Anchoring System

New Anchoring System

The wall plate is installed first, and then the wall bracket is fastened to it as shown in the photos in (*figure 8*) below:

Figure 8: the Installation of the Wall Bracket

Finally; vertical, horizontal and tilt adjustment is needed for all wall brackets. This was done using accurate bubble (*figure 9*) from Soleil.

Figure 9: Accurate Bubble

And now, as the Wall Brackets are installed; we are ready for Network Measurements.

Primary Geodesic Network Measurements:

The primary geodesic network is made of 16 wall brackets installed on the concrete columns surrounding the hall, two of them cannot be installed before the network measurement and the end of the theoretical co-ordinate calculation; these two wall brackets are the ones for the line of sight. Therefore, the set of network measurement included only 14 of them.

These wall brackets will allow tracings and adjustments of any part of the project since they act as absolute and accurate mechanical references.

The measurements have been carried out with Leica total station TDA5005. All the available distances and angles between one wall bracket and the others were measured. The distances were corrected through the calibration formula defined by ESRF (European Synchrotron Radiation Facility, Grenoble, France). The meteorological correction has been applied to the distance measurements (1018hPa, 27°C). The centering system designed by SOLEIL for SESAME has been used for both, instrument and retro-reflector.

The calculations of the final wall bracket planimetric co-ordinates were obtained by a least square bundle adjustment performed by SOLEIL's software called *reseau.m* and developed with MatLab®.

The general results are as follows; where the σ error is given:

Angle measurements : $1\sigma = 0.00045$ deg

Distance measurements : $1\sigma = 0.15$mm

A short checking of the network was held on 30th October 2009; 4 wall brackets were measured again in order to compare with the initial survey. The corresponding meteorological correction has been applied to the distance measurements. A linear tendency appears in the distances comparison of about 10^{-5}. That error may come from meteorological uncertainty. However, the control of the network size is enough at this level of precision.

The two additional wall brackets for the line of sight have been fixed on the exact diameter of the SR and adjusted at the end of the work.

In the below layout (*figure 10*), it is clear that some wall brackets cannot be measured from other ones, and that was because of the obstacles in the Microtron area (green area).

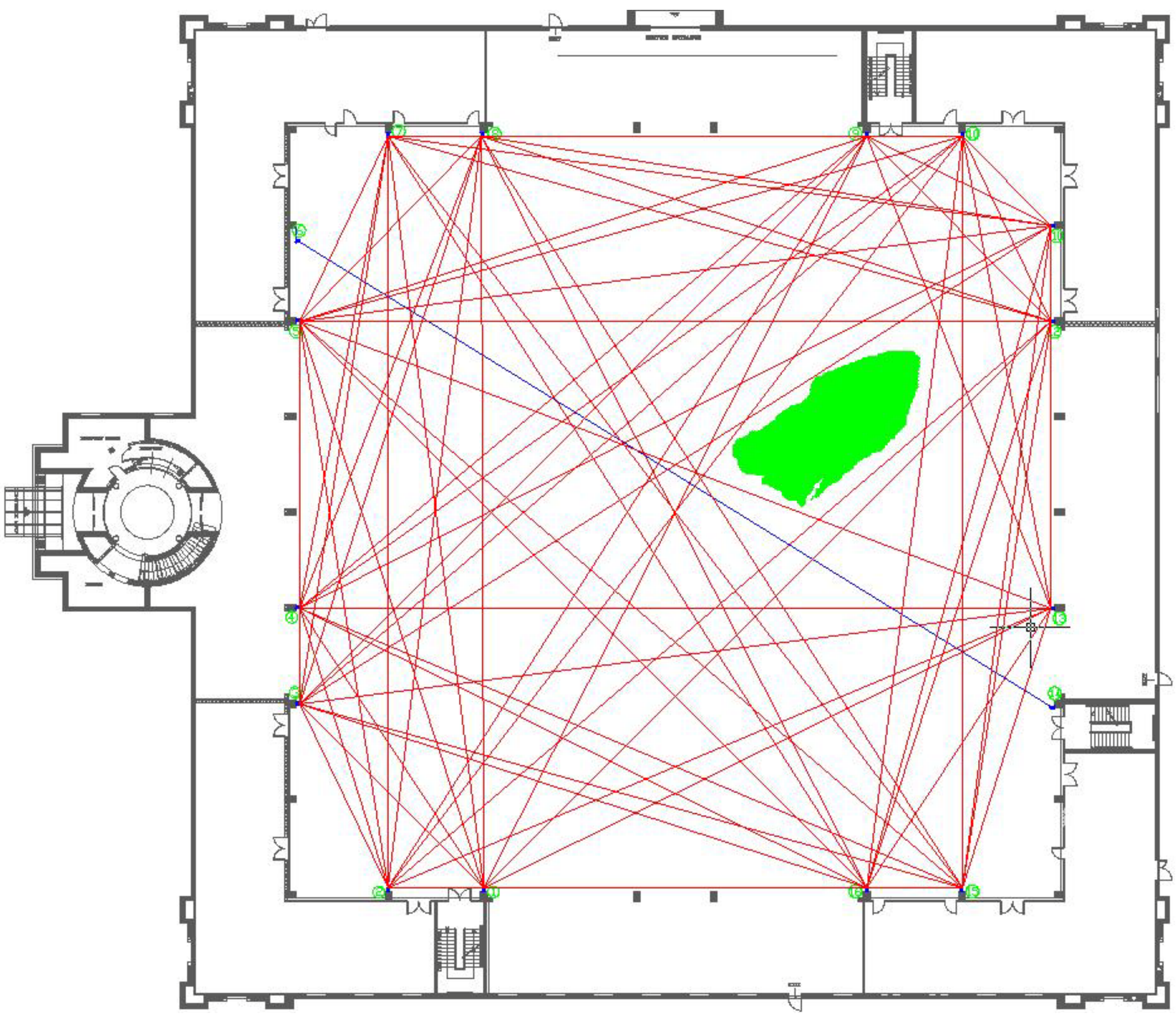


Figure 10

Theoretical Co-ordinates of the Project Axes (Beam):

The theoretical definition of the projected axes (beam path) is given by the machine physicists through synoptic which are tables containing angles and lengths between components. These synoptic allow the co-ordinates computation of each component in order to locate each of them accurately by means of survey instrumentation as Leica TDA5005. The co-ordinates computed from the synoptic must fit exactly the layout drawing of the project.

At the beginning of the work, several points were not in coincidence between synoptic and layout:

- The layout showed the distance 24.89mm between the Transfer Line 1 (TL1) and the Booster beams instead of 25mm.
- The exit of extraction septum with respect to the Booster axis differs depending on the source: 114.25mm for the Transfer Line 2 (TL2) synoptic, and 116mm for BESSY drawings.

At that occasion, an offset in the transverse direction between TL2 components was found, creating a small angle error on the layout drawing. It has been decided to use all the synoptic information to define the beam orbits. The point used as the origin of the co-ordinate system is the middle of the injection straight section of the Storage Ring. The orientation of the co-ordinates system is the one of the straight section picked up on the layout drawing. All the co-ordinates of the project have been computed from that origin, including the accelerator parts and the beamlines axes.

Tracing the Project Axes (Beam Path):

- The points to be traced were chosen as follows:

1. Transfer Line 1 (TL1): two points define the TL1 axis; Septum Entrance (TL1-SE-E) and another one 2m away upstream from the septum (TL1-1).

2. Booster: All the Qpoles have been staked out (18 nails); the Qpoles at both ends of the girders (B-C_i-QF_k, with i=1→6: cell n^r and k=1→2: Qpole n^r) define the straight sections of the Booster and are close to the feet of the girder; thus they will be available for the use of templates or tracing the drilling necessary to fix the girders.

   The Qpoles in the middle of the girders (B-C_i-QD) have been added in order to help the tracing of the shielding.

3. Transfer Line 2 (TL2): In absence of details concerning the TL2 magnet supports, it has been decided to stake out the normal and vertical Qpoles of TL2 and some points on the septa (10 nails):

   a. TL2-SE-EXTR-S

   b. TL2-Q_k, *k*=1→6, except *4*

   c. TL2-QV_k, *k=1→2*

   d. TL2-SE-THICK-C (vertex of septum angle)

   e. TL2-SE-INJ-C (vertex of septum angle)

4. Storage Ring (SR): The nails tracing which have been carried out define the straight sections of the SR (32+1 nails); they have been calculated at 550mm away from the centres of the sextupoles located at both ends of the girders:

   a. S-C_i-N_k, with *i=1*→8: cell n^r and *k=1*→4: nail n^r

   b. In addition, the centre of the SR has been staked out (SR-C).

5. Beamlines (BL): Two points define the Front-End (FE) axis of the Beamline, i.e. the part located in the Storage Ring tunnel and two additional nails define the BL part in the hall (100 nails). There are two kinds of BL:

   a. Insertion Device (ID) oriented on zero degree from the corresponding straight section.

b. Bending Magnet (BM) oriented on 6.5 degrees from the upstream straight section.

Each cell includes two pairs of ID & BM beamlines.

ID_n-C_i-N_k with $n=1\rightarrow2$: pair n^r, $i=1\rightarrow8$: cell n^r and $k=11\rightarrow14$: nail n^r.

The following beamlines do not exist:

i. The four beamlines in C1

ii. ID1-C2

iii. ID2-C8 & BM2-C8

The nails location along the BL axes have been chosen for practical reasons 500mm away from the SR external shielding wall and from the end of the BL. The first nail is calculated in order to avoid the dipole:

i. 2646.10mm from the closest sextupole for ID beamlines.

ii. 3338.35mm from the source point for BM beamlines.

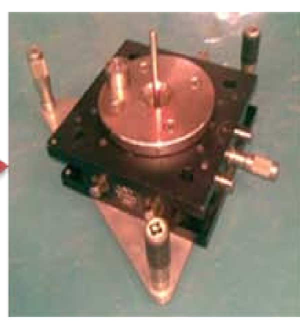
The BM2-C2 beamline is a special case since the C2 external wall is different from the other cells.

- Raw Location (163 points):

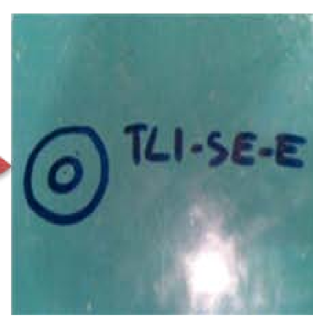
The approximate tracing of the nails has been staked out from two wall brackets with the Leica TDA5005. The SOLEIL 2D translation stage has been used with a needle to mark the point on the floor. A problem occurred at the very beginning of the mission; the new needles from SOLEIL could not run properly with the stage, forcing to a machining correction achieved by a mechanical supplier at Amman.

After the tracing of the points, a checking is done with another tool from SOLEIL.

Translation Stage with Reflector



Translation Stage with Needle

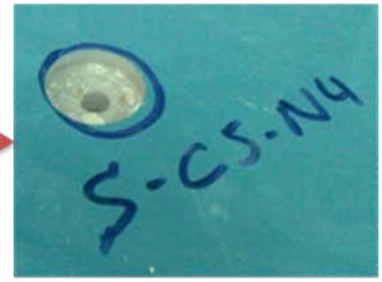


Accurate Drilling Point

Stage for Checking

From these marks, the hole for the nails sealing have been drilled in two parts; ø8mm depth 40mm with a standard drill and ø40mm depth 20mm with a special drill.


Special Drilling Tool


Hole Ready for Brass Nail

The nails sealing has been realized by means of the epoxy resin HILTI RE100.


Epoxy Resin Injection


Installing the Brass Nail


Brass Nail ready

- Accurate Definitions (163 points):

The TDA5005 has been set up closed to the centre of the SR in order to make use of the accuracy of its Electronic Distance Meter (EDM); the radial position of the points traced accurately on the sealed nails depends on the EDM accuracy. The priori EDM dispersion is ±0.15mm which is interesting for tracing the SR axis on the floor through the nails. The exact co-ordinates were defined by the free station method using the wall brackets as targets in angles and distances. The results of the TDA5005 station co-ordinates differed from less than 0.08mm during four days of work. No meteorological correction was applied to the distance measurements.

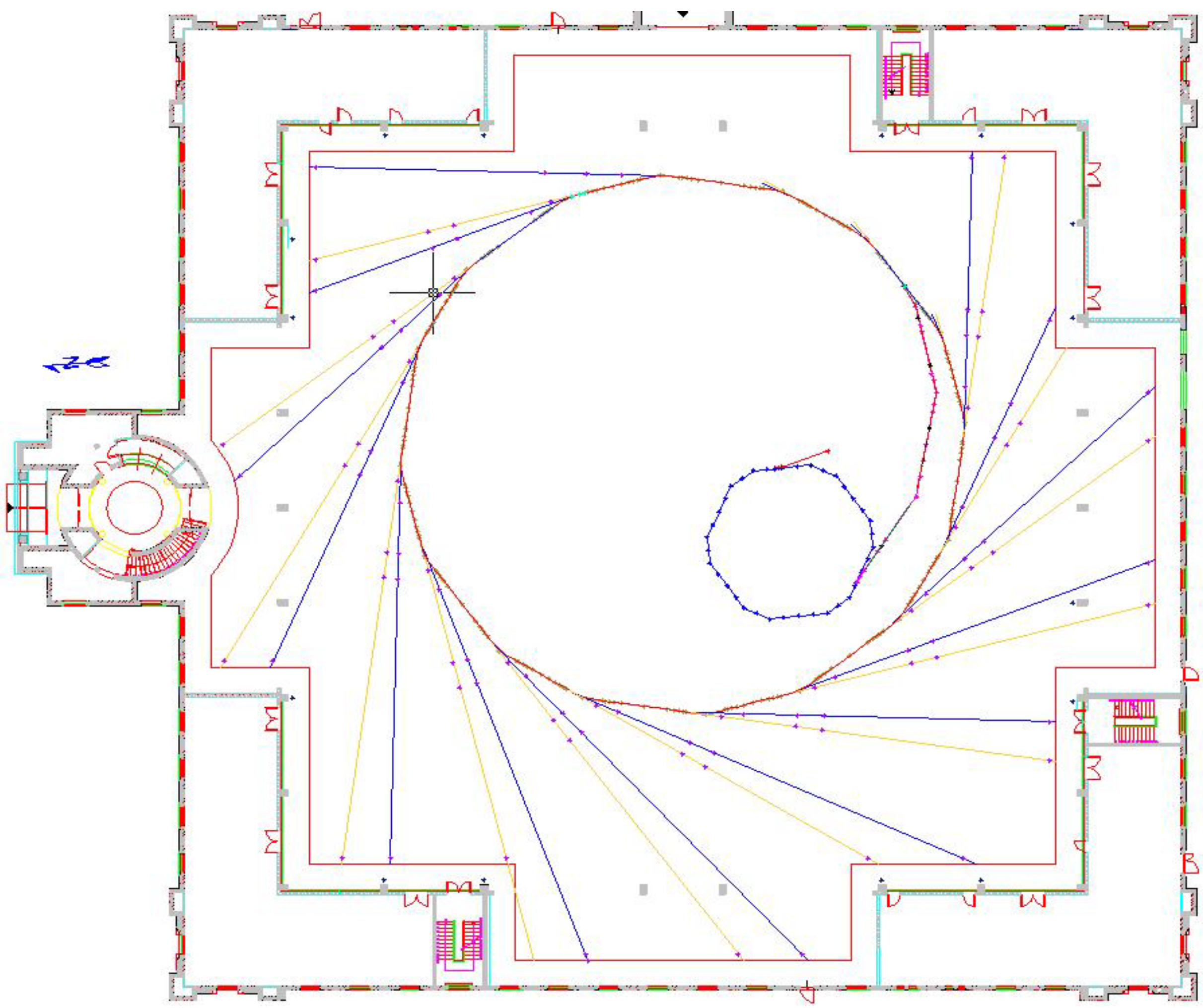


Figure 11: Brass Nails on Beam Path (Projected Axis)

Leveling Machine NA2 Calibration:

The Leica levelling machine NA2 has been verified and calibrated.

NA2 Automatic Level

Calibration of NA2 Level

Softwares from Soleil:

During this work; three softwares dedicated to the Alignment have been used, and should be transferred from SOLEIL to SESAME later on. These are in-house software to manage network adjustment computation by means of least square principle (*reseau.m*), Alignment operations (*OFFSET-REGLAGE.xls*) and TDA 5005 (*Pilot-TDA.exe*).

Unfortunately, only *reseau.m* is fully compatible with SESAME computers since it is developed with MATLAB® which is already installed on some of SESAME computers.

OFFSET-REGLAGE.xls and *Pilot-TDA.exe* need a Visual Basic basis and some other softwares which are missing on SESAME computers. Several tests of installation have been carried out, a problem has been solved; the change of OFFSET-*REGLAGE.xls* version (EXCEL language) from French to English.

The required software environment will be defined by SOLEIL later on. In any case, SOLEIL could not assure the full compatibility of its software since the Windows basis is not exactly the same but will try its best to achieve it.

Booster Alignment:

- Girders Alignment:

  The range of adjustment of magnets on their girder is only ±5mm; it means that a vertical profile of the concrete slab at its location is necessary. The best way should be to trace the location of every foot before a vertical measurement by means of the Leica levelling machine NA2. That profile would help to define the zero of the altimetry (vertical direction) of the whole project and would allow the manufacturing of shims for aligning all the girder's feet at the same level.

- Qpole Alignment:

  A gauge could be used for the alignment of the Qpoles. That gauge should be in contact with the lamina which defines the poles at a supposed accuracy within 0.05mm. It is better to start from the poles area but more complicated and without any checking after having mounted the Booster than when using the external sides of the yokes. Note that the BESSY method was also based on the use of the yokes. The gauge could be equipped with three contact points and a pair of small fiducials (ø24mm) and used in two reversed positions to define the Qpole axes.

- Dipole Alignment:

  The method for aligning the dipoles is less clear than for the Qpoles. Two documents exist from BESSY and the information on the topic does not correspond. Either fiducials (survey monuments) are mentioned or a gauge to be applied on the yokes as for the Qpoles. Both methods are relevant: In the first case; the monuments location with respect to the magnetic definition of the dipole has to be checked, i.e. measured by means of a bench or of a procedure for mechanical measurements (finding the magnetic "axes" of the dipole is not necessary). The gauge method requires a tool whose size is not too big for practical reasons.

Next Steps …

- Finishing of the Tracing operation:

1. Purchasing Electrical Engraver Pen.
2. Marking the names of the points on the Brass Nails using the electrical engraver.
3. Protection of the Brass nails.
4. Designing Tracing Tools (as Soleil translation stages).
5. Purchasing a special Laptop dedicated for Alignment only, and should be compatible with all Alignment softwares.

- Primary Levelling:

1. Purchasing Target Sphere hubs machine (T1.5S-.010”) for the leveling purposes.
2. Sealing the RN (levelling benchmarks; Steel Nails): 3 in Booster, 8 in SR.
3. Tracing the approximate location of the girders feet of the Booster.
4. Levelling measurement of the slab at the location of the project axes, from the Microtron to the beamlines axes through Booster girder feet, TL2 and SR, including levelling benchmarks.
5. Calculation of the concrete vertical (Z) profile and of the benchmarks Z.
6. Choosing the Z = -1400mm, most probably the floor Z average. Calculation of the definitive Z for benchmarks.
7. Calculation of the shims for girders of Booster.

- Design of Booster Alignment:

1. Design of Qpoles fiducialisation (gauge?).
2. Design of Dipoles fiducialisation (gauge? survey monuments?).
3. Measurements of survey monument if required.
4. Design of the planimetric network of the Booster.

- Booster Wall Brackets Network:
  1. WB installation.
  2. Survey of the set WB-brass nails.
  3. Calculation of the WB co-ordinates with respect to the brass nails.

- Booster Alignment:
  1. Realization of the girder shims.
  2. Girders installation with their shim.
  3. Checking of Z girders before installing the magnets.
  4. Mounting the magnet on girders.
  5. Middle range adjustment as a primary alignment.
  6. Adjustment of the tilt of the magnets.
  7. Iteration loop is as follows:
     i. Magnet survey (tilt, Z, planimetry) including the WB.
     ii. Survey calculation with *reseau.m*
     iii. Displacement calculation for each magnet.
     iv. Displacement of the magnets.

Conclusion:

The following objectives planned for the mission were reached: tracing the whole axes of the project, skill transfer of the SOLEIL experience.

Nevertheless, the software transfer was not possible due to compatibility problems (VB environment missing in SESAME PC). SOLEIL will continue for the coming months working on a Laptop configuration, A. Nadji’s PC; in waiting for a laptop dedicated to Alignment.

References:

[1] ; *TPS1000 System User Manual*.