A TECHNIQUE FOR THE TRANSPORT OF AN ALIGNMENT NETWORK THROUGH A SMALL HOLE

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Abstract

In the CNAO accelerator a new experimental line will be added in a dedicated existing hall. The paper describes the strategy for extend the alignment network of the main hall to the experimental hall with a mixed technique for a good connection accuracy.

INTRODUCTION

In the CNAO accelerator for adrontherapy (Pavia, Italy), a new experimental line will be added in a dedicated existing hall. The main accelerator hall and the experimental hall are separated by a 2 m thickness concrete wall. The only communication between the two hall is a 20 cm hole, normally closed by a concrete plug. The alignment network of the main hall has to be connected to a new network in the experimental hall, but using only the laser tracker through the hole would cause unacceptable errors.

In fact, the height difference between the reference points and the hole makes impossible to put directly the laser tracker in front of it, and the propagation of the unavoidable positioning errors would lead to a large unaccuracy.

Therefore a mixed technique has been applied using a Taylor Hobson telescope and a laser tracker with an inclinometer to obtain a good connection accuracy. Here the procedure for the telescope positioning by laser tracker and the alignment network expansion in the experimental hall, as well as the evaluation of the accuracy obtained, are reported.

SET UP

Data:

1. reference points in Synchrotron hall alignment network
2. XPR line positioning in the CAD solid model of the whole accelerator

Instruments:

1. Taylor Hobson micro-alignment telescope 112/537-S, with mounting sphere;
2. Two 2 1/4" optical target for telescope (standard circular e long distance);
3. Laser Tracker Leica TD 500 (LT);
4. Electronic inclinometer Leica Nivel 20;
5. two CCR 1,5";
6. two CCR 1,5" to 2 ¼" optical target adapters;
7. Three stands with micrometric stages;
8. Axyz software.

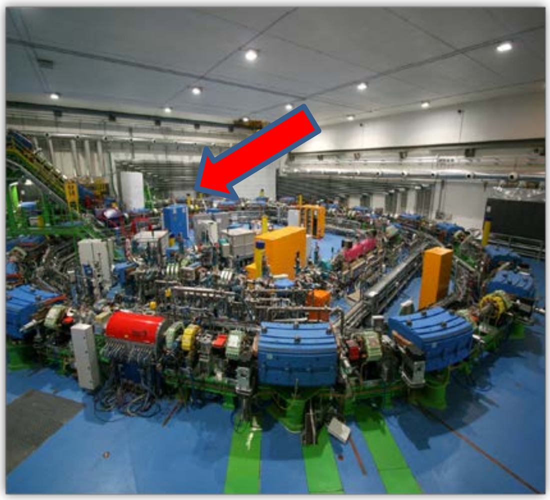
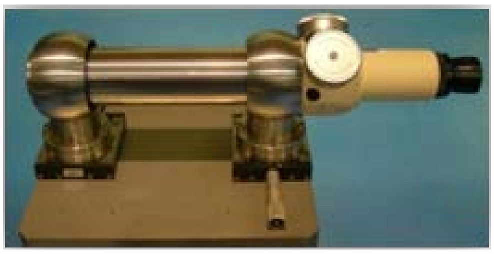


Figure 1: The Accelerator Hall and the hole towards the XPR Hall



Micrometer range:	± 1.2mm (+0.05in) with 0.02mm (0001in) graduations
Barrel diameter:	57.137-57.147mm (2.2495-2.2499in)
Optical axis:	Parallel to mechanical axis within 3 arc seconds and concentric within 6µm (0.00025in)
Field of view:	From 50mm (2in) at 2m (65ft) to 600mm (24in) at 30m (100ft)
Magnification:	X34
Image:	Erect
Accuracy:	Within 0.05mm (0.002in) at 30m (100ft) and proportionally for longer or shorter distances down to about 3m. Below this distance the errors are less than the precision to which the micrometers can be read.

Figure 1: Taylor Hobson micro-alignment telescope

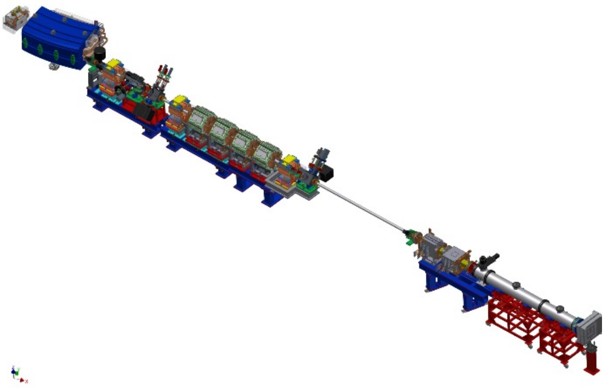
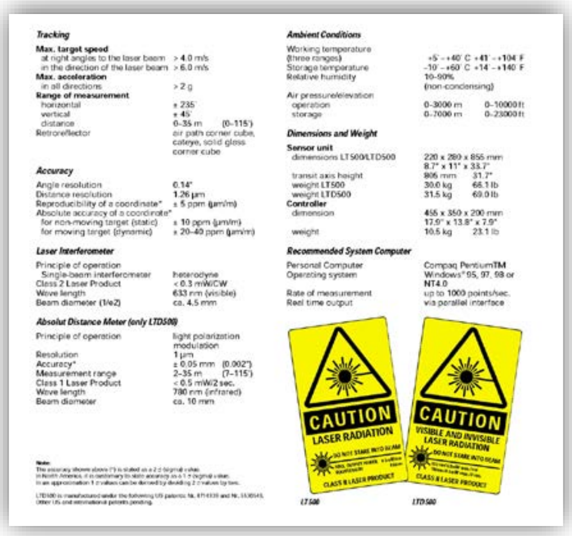


Figure 3: The new XPR line in a preliminary design (now changed). At the big dipole (left) start the line; the nude pipe in the middle crosses the wall.



Tracking	
Max. target speed	
at right angles to the laser beam	> 4.0 m/s
in the direction of the laser beam	> 6.0 m/s
Max. acceleration	
in all directions	> 2 g
Range of measurement	
horizontal	± 235°
vertical	± 45°
distance	0–35 m (0–115')
Retroreflector	air path corner cube, cateye, solid glass corner cube
Accuracy	
Angle resolution	0.14"
Distance resolution	1.26 µm
Reproducibility of a coordinate*	± 5 ppm (µm/m)
Absolute accuracy of a coordinate*	
for non-moving target (static)	± 10 ppm (µm/m)
for moving target (dynamic)	± 20–40 ppm (µm/m)
Laser Interferometer	
Principle of operation	
Single-beam interferometer	heterodyne
Class 2 Laser Product	< 0.3 mW/CW
Wave length	633 nm (visible)
Beam diameter (1/e2)	ca. 4.5 mm
Absolut Distance Meter (only LTD500)	
Principle of operation	light polarization modulation
Resolution	1 µm
Accuracy*	± 0.05 mm (0.002")
Measurement range	2–35 m (7–115')
Class 1 Laser Product	< 0.5 mW/2 sec.
Wave length	780 nm (infrared)
Beam diameter	ca. 10 mm
Ambient Conditions	
Working temperature (three ranges)	+5° – +40° C +41° – +104° F
Storage temperature	-10° – +60° C +14° – +140° F
Relative humidity	10-90% (non-condensing)
Air pressure/elevation	
operation	0–3000 m 0–10000 ft
storage	0–7000 m 0–23000 ft
Dimensions and Weight	
Sensor unit	
dimensions LT500/LTD500	220 x 280 x 855 mm 8.7" x 11" x 33.7"
transit axis height	806 mm 31.7"
weight LT500	30.0 kg 66.1 lb
weight LTD500	31.5 kg 69.0 lb
Controller	
dimension	455 x 350 x 200 mm 17.9" x 13.8" x 7.9"
weight	10.5 kg 23.1 lb
Recommended System Computer	
Personal Computer	Compaq PentiumTM
Operating system	Windows® 95, 97, 98 or NT4.0
Rate of measurement	up to 1000 points/sec.
Real time output	via parallel interface

Figure 2: Laser Tracker Leica TD 500 (LT).

PROCEDURE: PHASE 1- PREPARATION IN SYNCHROTRON HALL

STEP 1. The Laser Tracker is first positioned in the Syncrotron Hall (measurement station ST1) so to reach as reference points as possible. The LT enters in the Sincrotrone reference network, using the data available from the last Syncrotron survey.

Three 1.5" Corner Cube Reflector CCR with 2 1/4" to 1,5" adapters on three stands with micrometric 3D stages have been put approximately along the XPR line (positions named P1, P2 and P3).

By LT measurements and adjusting the micrometric screws, the positions of the CCRs are finely corrected, so to be on the nominal XPR line.

The XPR line has been defined as $y=mx+q$ in the $z=0$ plane ($m = -0.366$, $q = -11712.645$), from the 3D CAD model.

STEP 2 Now, the two CCRs in P2 and P3 and their adapters are replaced by two optical targets for the Taylor-Hobson telescope.

The CCRs and the Optical targets share the same centers P2 and P3, within their very good fabrication tolerances.

In P1, the CCR with its adapter is replaced by a 2 1/4" sphere mounting for the telescope. The telescope can rotate around P1, so to have its sight line aligned with the P2-P3 line.

COMMENT: we preferred to use a separate, independent, third stand for the telescope instead of using only two points to reduce the error in the installing the quite heavy equipment in the place of one of the other CCR.

The position of the telescope has been chosen as close as possible to the insertion flange on the synchrotron.

The P1 coordinates are not stored, and then they won't be used, because the mounting of the telescope could have altered their original, LT grade accuracy.

STEP 3. The line of sight of the telescope is now iteratively corrected by its micrometric screw until it matches P2-P3.

Note that only a target at a time is visible, so we have to remove alternatively the target in P2 and in P3.

The operation is a little time consuming, but nevertheless quite easy.

Now the line of sight of the telescope is coincident with the nominal XPR beam line, within the achievable accuracy. We are ready to transfer the geometrical information beyond the wall.

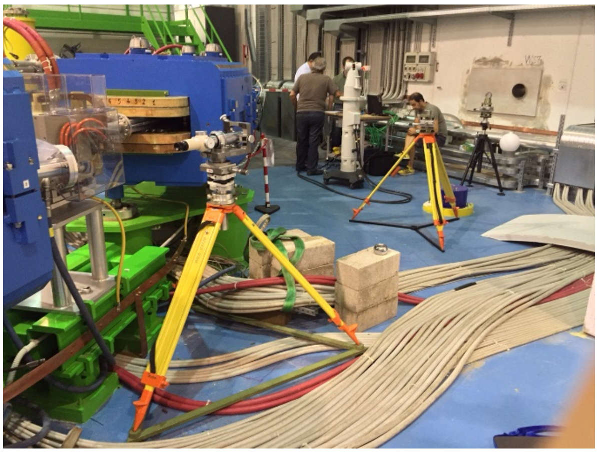


Figure 4: Step 3 (setting the telescope linesight through P2 and P3)

PHASE 2 TARGETS TRANSFER FROM SYNCHRO TO XPR HALL

STEP 4. One at a time the two stands with the optical targets in P2 and P3 are transferred in the Experimental (XPR) Hall, while tha stand with the telescope remains unchanged in P1. The first stand is placed approximately on the XPR line and then adjusted until the target is on the line of sight of the telescope. The second one is used to check again the line throught the telescope before moving in the XPR hall, then is placed a sua volta. The new positions are named P5 and P4 respectively.

During these operations the use of a long distance target is necessary for the first adjustment, due to the farther position.

STEP 5 The laser tracker stand is now shortened and put approximately on the XPR line (new station ST2), in such a way to have its line of sight through the hole. We put the CCR on P3 e su P5 and measure their distance. In addition we perform a scan of the insertion flange on the Synchrotron, to check the position of its center.

COMMENT: the second station ST2 would not have been suitable for all the operations, being the height of the hole too low for allow the laser tracker to catch the reference points of the Synchrotron network. Actually, most of them are high in the top of the big dipoles or in the top of pillars, or on the walls, but out of sight. Therefore we needed ST2 to be used just as interferometer.

Now P4 and P5 in the XPR hall are on the XPR line. We move the laser tracker in the XPR hall.

PHASE 3- SETTING THE NETWORK IN THE XPR HALL

STEP 6 In the XPR hall we set a new Laser Tracker station. The laser tracker is placed in a casual position, suitable for the acquisition of most of the wall mounted targets. The electronic inclinometer Leica Nivel 20 is switched on and initialized.

Figure 5: The xpr hall - step 6: measuring P4and P5 by laser tracker

The optical targets in P4 and P5 are replaced by 1,5" CCRs with adapters, then we acquire their position with the Laser Tracker.

With P4, P5 and the vertical direction aligned by the gravity, we set the new reference frame for the XPR hall.

Figure 4: The 2 1/4" optical target (left) and the 1,5" CCR on a 2 1/4" adapter (right)

STEP 7 Last, we measure with the laser tracker all the wall and floor mounted targets in the XPR hall, so to set a reference network for the alignment of the new experimental beam line. Thanks to the alignment of P4 and P5 to the Synchrotron hall, to the vertical (obviously) shared in both the halls and to the distance taken between P3 (in the Synchrotron hall) and P5 (in the XPR hall), we are now able to link the two networks.

ERROR BUDGET ROUGH ESTIMATION

Laser tracker typical global uncertainty $E_{lt} = \pm 0.1$ mm

Laser tracker typical distance uncertainty $E_{ltd} = \pm 0.01$ mm/m

Network entering typical uncertainty $E_{nk} = \pm 0.1$ mm

Taylor Hobson micro-alignment telescope typical uncertainty $E_T = \pm (1.67\text{e-}6 \times d)$ mm , $d>12000$ mm

$= \pm 0.02$ mm , $d<12000$ mm

Electronic nivel, typical uncertainty ± 1 arcsec = 0.005 mrad (mm/m) – therefore negligible in this budget

Transversal position uncertainty

$$E_{yz} = \sqrt{\left({E_{lt}}^2 + {E_{nk}}^2\right) \times A^2 + {E_T}^2}$$

with $A(P) = \frac{P-P2}{P3-P2}$

Longitudinal position uncertainty

$$E_x = \sqrt{{E_{ltd}}^2 + {E_{nk}}^2 + {E_T}^2}$$

Error calculations

		P4	P5
PP2	distance from P2 (mm)	8810	11747
A	amplification factor	4.195	5.594
d	distance from telescope (mm)	12000	14300
E_{yz}	transv. error (mm)	± 0.594	± 0.791
E_x	longit. error (mm)	± 0.185	± 0.201

CONCLUSIONS

The error assessment is quite satisfactory for the specific application, due to the possibility to adjust the beam in operation. Further refinement of the technique would be possible, and will be studied as soon as possible.

ACKNOWLEDGMENT

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