THE SURVEYING AND ALIGNMENT FOR THE PROSCAN PROJECT

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Content

1 The PROSCAN Project

PROSCAN is a new facility for medical research now being realised at PSI. The goal of this project is to build a dedicated prototype cancer therapy centre, which will consist of an accelerator (designed and built by ACCEL GmbH – our industry partner), a beam line and a gantry with spot scan technique. The design will allow installation in hospitals. Since the facility will be independent of the rest of PSI, it can be run 365 days a year, which is essential for the treatment of patients and system development.

Fig. 1 COMET (**Co**mpact **Me**dical **T**herapy Cyclotron)

Because PSI builds this facility in an existing hall and because there is an operating gantry, which will later be connected to the new accelerator, some specific problems occur. Since the therapy program with the existing gantry will continue during the installation of the new facility, we are obliged to perform many important tasks during the annual shutdown of the existing PSI accelerator facility. In order to complete our work within this limited time, we need extremely well thought out concepts.

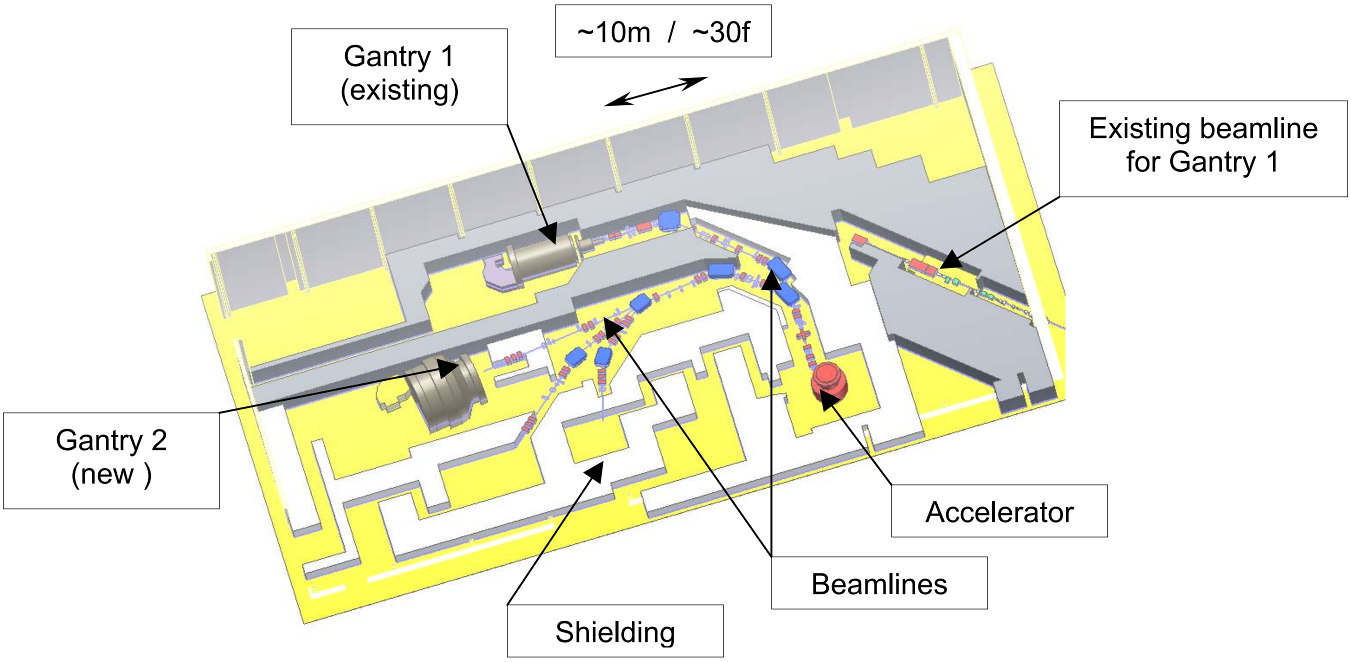


Fig. 2 PROSCAN Layout in the NA-Hall at PSI

2 The Survey Task

2.1 The Network

2.1.1 Summary

Our task is to build a network, which will allow adjustment of neighbouring components with an accuracy of one tenth of a millimetre in all directions (relative accuracy). For several reasons we have to divide the build up of the network into three parts. The first part has been measured this summer.

2.1.2 Conceptual Aspects

I. Our aim is to build the network with a minimum of points. This means that the points have to be placed at good locations, which of course are related to the layout of the whole machine complex. Furthermore it was necessary to define them in a general layout, so that other occupational groups (like cooling, electricity, construction) working on this project could easily recognise them. This avoided other installations being planned at this places and no points had to be omitted. Especially the shielding (built of standardised concrete blocks at PSI) caused some problems, because it changed with every new design of the beamline and the network points changed with it. The definite location of the points we had to measure had been fixed only a few days before we started with the network measurement. The last changes were small, so we could get a general idea of how the network would look like a few weeks before.

II. The network is built in 3 steps. This is necessary because:
- not all the beamlines are built in one step
    1. accelerator and first part of the beamline
    2. second part of the beamline and connection of Gantry 2 (new)
    3. further parts of the beamline and connection of Gantry 1 (existing)
- we had to “save” our existing points, which will be destroyed during the construction work
- the binding to the existing gantry is, from the point of view of the surveying group, more complicated because it is now separated from the rest of the hall and from the rest of the network (concrete shielding), but has to be linked with it.

The first step was completed this summer, before construction work begun. The goal of this step was to save our existing points and to ensure that there are enough points left for the next steps. Of course these new points have been placed where they can be used later. → In the beamline area, where no shielding is planned.
The next step involves the network in the accelerator bunker and in the gantry 2 area. There have to be enough points to do all alignment necessary to adjust these huge components.
The last step involves the network in the beamline area for gantry 1.

III. The shielding is movable and because of this all points are on the floor of the hall. The one exception is the accelerator bunker, where the shielding is built of “normal” concrete walls. There we will install points at various heights – planned up to 2m. They are necessary for the installation and alignment of the accelerator itself.

IV. Since the machine and the beamlines will be built oriented to gravity, the network has to follow. The Laser Tracker does not normally work oriented to gravity and therefore the measured and calculated network has to be oriented afterwards. To do so we levelled all points and transformed them.
This proceeding is show in figure below.

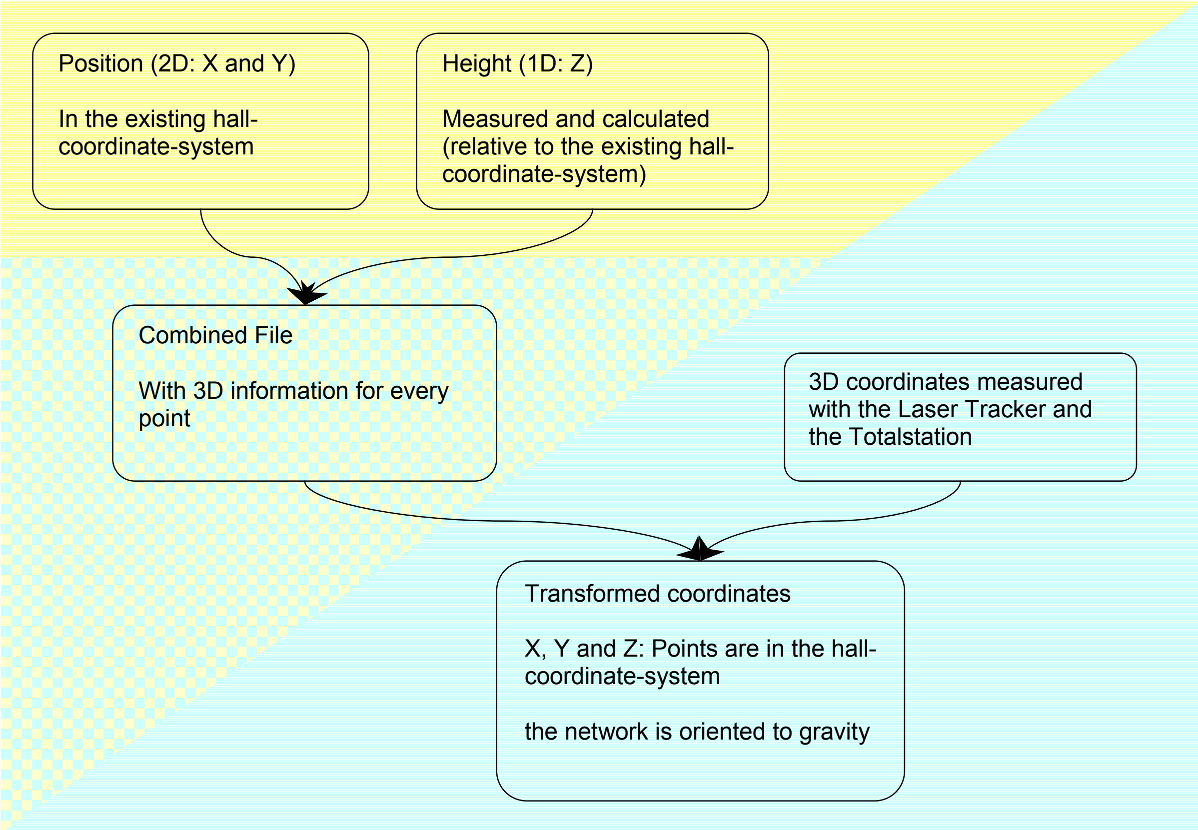


Fig. 3 Flow diagram for 3D coordinates oriented to gravity out of a 2D plus 1D initial system

Remarks:

- We had to start with this "2D+1D-coordinate-system" because, due to the shielding, the height was the only dimension that could and, because the height changes the most, that had to be checked in the old network, during the period of 10 years the hall was used for other projects and experiments.
- This procedure assumes that the X and Y positions of the existing points have not changed. If this is not the case the newly defined highly accurate levelled heights of the points become less accurate because the errors in X and Y have an affect on the heights (→ 3D transformation).

V. One of the most important prerequisites of working with the laser tracker is that there are no other actions taking place in the hall during measurements. Even a draught can make it impossible to reach the required accuracy. If the time schedule is tight it is not easy to convince those responsible that these environment conditions are necessary in order to avoid prolongation of the measurement time due to the consequent repetitions.

2.1.3 Instrumentation / Software

The following Instrumentation is used for the measurements:

Name	Accuracy (* = Value determined by us, not by manufacturer)		Picture	Remark
	Angle	Distance		
Leica Laser Tracker LTD500	0.013mgon (horizontal and vertical)	Laser Interferometer → less than 0.05mm. (→ Accuracy depending on how well the environmental conditions [temperature, pressure] can be measured)		accuracy subject to environment conditions / used for most measurements / very fast / data storage on PC.
Leica Totalstation TDA5005	0.013mgon (horizontal and vertical)	0.2mm *		easy handling / used to make the network stiff (measurements across the hall) / data storage on PC.
	Height Difference at ~15m			
Zeiss Digital Level Dini11T	0.01mm to 0.02mm *			easy handling / works with bar code staff / fast measuring / data storage with PC-Card.

The LTD500 and the TDA5005 both work with Axyz. Axyz is a group of Programs that is used for measurements (data storage) and calculations like “network orientation”, “bundle adjustment” or transformations.

2.1.4 Results of the First Part

The full lists are in the following appendix.

A: The layout of the machine with the measured points.

B: The coordinates measured with the Laser Tracker and the Totalstation.

C: Comparison between the heights measured with the Laser Tracker and the levelled heights.

D: The transformed coordinates. (Transformation described in chapter 2.1.2 point IV.)

E: Comparison between the transformed heights and the levelled heights.

2.2 The Alignment Concept for Beamline Components

At PSI most beamlines have the same structure concept: several beamline components are mounted on a girder. The components are adjustable to each other in all directions. The girders stand on the floor in the hall. They although are adjustable. Only the dipolmagnets are “standalone”. This makes sense since they are much havier then the rest of the components and like this only the supports for the dipols have to be dimensioned to carry their weight. Fig. 4 shows this very systematically:

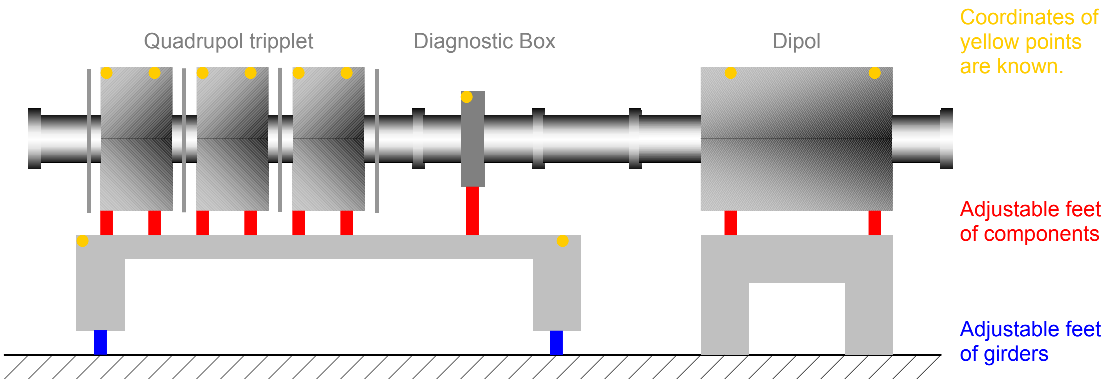


Fig. 4 Structure Concept for Beamlines at PSI

The biggest advantage of this system is, that the most alignment jobs can be done outside a beamline area. Inside, where radiation forces you to do a job within a given space of time you only have to check three points per work piece: the girder. It although helps for deformation measurements: much less points have to be measured and you know the positions of each single component.

2.2.1 Design of the girders

There is only one major difference in the concept of the beamline for the PROSCAN-Project to other beamlines at PSI. We have foreseen a plate between the grider an the components. Like this the drill holes for the lower part of the adjust devices are not in the girder itself. If the position of any component change only the plate has to modifield or has to be replaced. This is easier because the work piece is smaller and therefore faster and cheaper.

All Quadurpols “look” in the same direction. So the cooling system and the power supply always are on the right respectively on the left side. Like this the Quadrupols can be exchanged. This although helps the surveying team, because like this it is always the same situation we have to get grips with.
Most survey jobs will be done from the left side (in beamdirection). The power supply normally is the lesser of the two evils to reach the points used for the alignment.

2.2.2 The building of the Beamline (Girders)

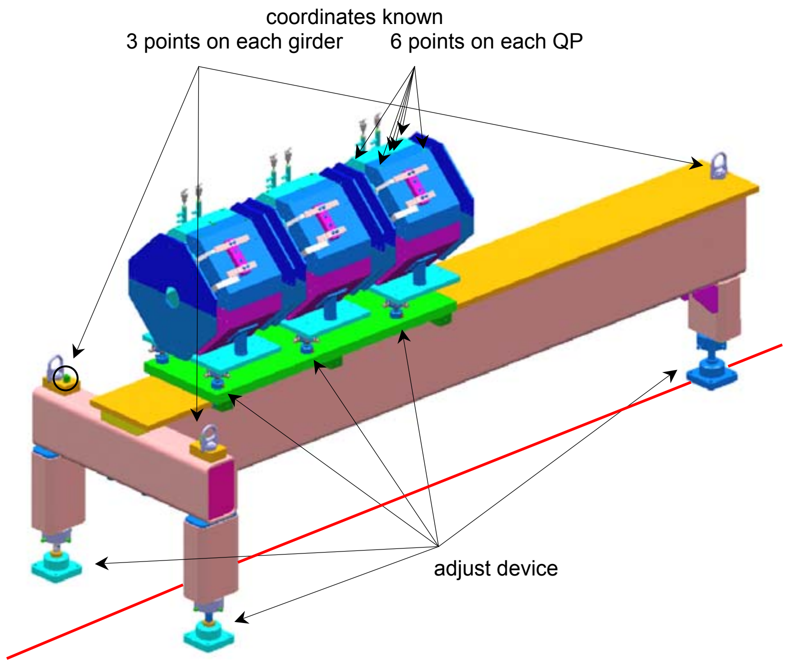


Fig. 5 Girder with quarupol triplet

The following procedure is chosen for the built of the beamline and the alignment of the components:

1. Mark the Beamline and the positions of the feet of the girders on the floor
2. Girders are placed in the hall and attched to the floor
3. Girders will be adjusted in height and in position with an accuracy of ±1mm and will be leveled. This part will be done by the surveying team
4. A packet (a quadrupol tripplet for example) is placed on a girder. This packets will be built outside the beamline area but will not be adjusted there
5. Each single beamline component will be adjusted in height an in position. Quadrupols with an accuracy of ± 0.1mm, diagnostic elements with an accuracy of ± 0.5mm
6. The three points on the girder as well as the points on the beamline components will be measured (control measurement).

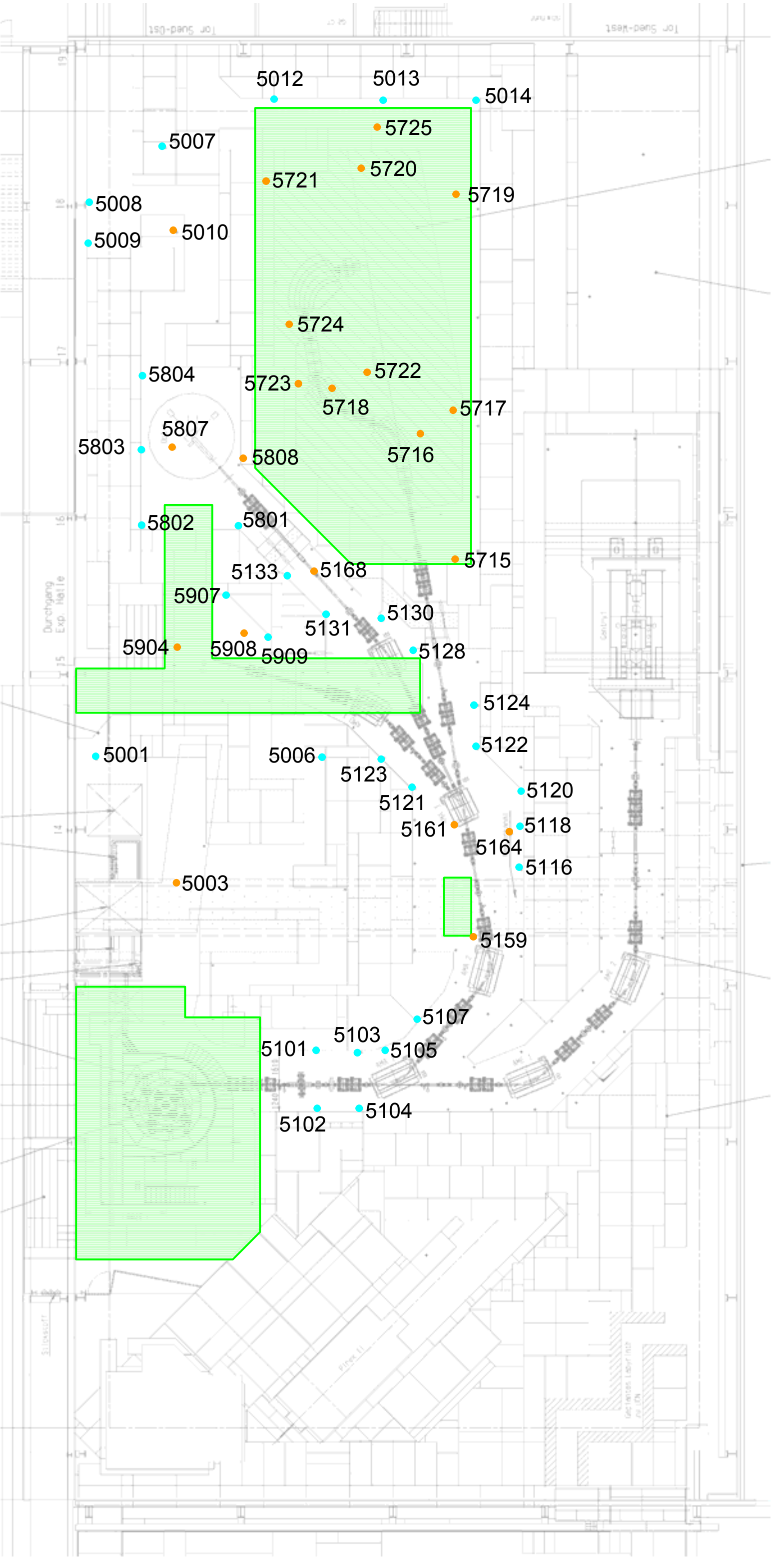
3 Conclusion

The main challenge is not the surveying or alignment itself since this is easy and fast with modern instrumentation. The problems must be resolved in the planning and concept phase of the project when the space in the narrow bunkers is allocated. There is not much room for the entire infrastructure (water, helium, electricity, etc.) and it is seldom possible to preserve visible measuring lines.
That is why the construction group draws the beamline in 3D. Especially in the cyklotron bunker this is inevitable. Each single position of the Laser Tracker and what point of the network can be measured for the orientation of the Laser Tracker is defined.

It is extremely difficult to define a network in the concept phase, because nothing is fixed or can be fixed. This leads to an iterative process, leaving only a short time between finalising the network concept and its realisation.

4 Appendix

A The layout of the machine with the measured points



Legend:

New points

Existing points

Construction work areas (loss of points)

Temporary shielding

Scale:

~10m

B Coordinates measured with the Laser Tacker and the Totalstation

Point number	X	Y	Z
NA5001	-14571.428	25947.408	-1648.267
NA5003	-10995.461	31675.378	-1649.318
NA5006	-4106.118	26006.373	-1652.260
NA5007	-11253.387	-2247.572	-1650.433
NA5008	-14759.553	235.940	-1647.426
NA5009	-14776.245	2232.913	-1647.742
NA5010	-10751.350	1647.202	-1649.282
NA5012	-6142.370	-4390.435	-1651.858
NA5013	-1143.196	-4363.216	-1653.153
NA5014	3157.674	-4340.142	-1655.917
NA5101	-4443.444	39515.115	-1655.143
NA5102	-4459.491	42046.151	-1654.968
NA5103	-2442.034	39524.311	-1655.906
NA5104	-2565.694	42054.067	-1658.667
NA5105	-1297.764	39532.654	-1660.383
NA5107	114.736	38130.538	-1659.359
NA5116	4910.241	31146.496	-1655.348
NA5118	4921.423	29161.199	-1659.363
NA5120	4922.391	27637.464	-1660.392
NA5121	86.851	27384.880	-1656.405
NA5122	2999.034	25553.010	-1660.408
NA5123	-1319.553	25966.650	-1654.817
NA5124	3009.143	23548.818	-1661.096
NA5128	63.864	21015.879	-1653.523
NA5130	-1344.198	19592.849	-1650.437
NA5131	-3867.889	19353.488	-1649.144
NA5133	-5747.008	17453.371	-1648.420
NA5159	3082.224	34317.203	-1652.400
NA5161	1992.227	29102.851	-1652.601
NA5164	4517.378	29485.911	-1656.960
NA5168	-4451.001	17250.474	-1645.322
NA5704	-7160.098	4765.821	-1646.393
NA5715	1988.853	16898.492	-1650.637
NA5716	384.925	11095.138	-1649.059
NA5717	1986.770	9892.121	-1649.812
NA5718	-3548.412	8981.001	-1644.487
NA5719	2233.273	-8.528	-1653.214
NA5720	-2102.586	-1213.080	-1649.660
NA5721	-6471.688	-739.514	-1648.681
NA5722	-2050.739	7916.458	-1648.597
NA5723	-5629.532	8822.480	-1646.586
NA5725	-1428.990	-3605.026	-1652.048
NA5801	-7903.041	15276.750	-1650.531
NA5802	-12348.065	15247.933	-1650.120
NA5803	-12328.662	11752.343	-1648.408
NA5804	-12307.477	8252.277	-1647.502
NA5807	-10911.138	11611.269	-1649.424
NA5808	-7758.342	12117.645	-1648.288
NA5904	-10956.449	21624.481	-1649.537
NA5907	-8506.743	18469.784	-1647.681
NA5908	-7734.094	20146.135	-1648.848
NA5909	-6576.404	20421.623	-1650.893

C Comparison between the heights measured with the Laser Tracker and the levelled heights

Point number	Z (levelled)	Z (Laser Tracker)	Difference	
NA5001	-1518.78	-1518.98	0.20	
NA5003	**-1520.03**	**-1520.03**	**0.00**	**matched**
NA5006	-1523.71	-1522.97	-0.74	
NA5007	-1521.43	-1521.15	-0.28	
NA5008	-1518.20	-1518.14	-0.06	
NA5009	-1518.51	-1518.45	-0.05	
NA5010	-1520.37	-1519.99	-0.38	
NA5012	-1523.23	-1522.57	-0.66	
NA5013	-1524.84	-1523.87	-0.98	
NA5014	-1527.82	-1526.63	-1.19	
NA5101	-1526.23	-1525.86	-0.38	
NA5102	-1525.99	-1525.68	-0.31	
NA5103	-1527.19	-1526.62	-0.58	
NA5104	-1529.85	-1529.38	-0.47	
NA5105	-1531.77	-1531.10	-0.68	
NA5107	-1530.90	-1530.07	-0.83	
NA5116	-1527.47	-1526.06	-1.41	
NA5118	-1531.52	-1530.08	-1.44	
NA5120	-1532.58	-1531.10	-1.47	
NA5121	-1528.17	-1527.12	-1.05	
NA5122	-1532.44	-1531.12	-1.32	
NA5123	-1526.43	-1525.53	-0.90	
NA5124	-1533.16	-1531.81	-1.35	
NA5128	-1525.36	-1524.24	-1.13	
NA5130	-1522.14	-1521.15	-0.99	
NA5131	-1520.59	-1519.86	-0.74	
NA5133	-1519.83	-1519.13	-0.70	
NA5159	-1524.30	-1523.11	-1.19	
NA5161	-1524.50	-1523.31	-1.19	
NA5164	-1529.07	-1527.67	-1.40	
NA5168	-1516.84	-1516.03	-0.81	
NA5715	-1522.68	-1521.35	-1.33	
NA5716	-1520.95	-1519.77	-1.18	
NA5717	-1521.87	-1520.52	-1.34	
NA5718	-1516.11	-1515.20	-0.91	
NA5719	-1525.19	-1523.93	-1.26	
NA5720	-1521.33	-1520.37	-0.96	
NA5721	-1520.10	-1519.39	-0.71	
NA5722	-1520.30	-1519.31	-0.99	
NA5723	-1518.06	-1517.30	-0.76	
NA5724	-1517.75	-1517.11	-0.64	
NA5725	-1523.72	-1522.76	-0.96	
NA5801	-1521.77	-1521.24	-0.53	
NA5802	-1521.05	-1520.83	-0.21	
NA5803	-1519.21	-1519.12	-0.09	
NA5804	-1518.47	-1518.21	-0.26	
NA5807	-1520.43	-1520.14	-0.30	
NA5808	-1519.53	-1519.00	-0.53	
NA5904	-1520.42	-1520.25	-0.17	
NA5907	-1518.76	-1518.39	-0.36	
NA5908	-1520.03	-1519.56	-0.47	
NA5909	-1522.11	-1521.61	-0.50	

D Transformed coordinates

Point number	X	Y	Z
NA5001	195623.253	695701.928	-1518.832
NA5003	192016.537	689993.269	-1520.138
NA5006	185157.777	695699.238	-1523.665
NA5007	192456.872	723914.342	-1521.428
NA5008	195949.632	721412.012	-1518.125
NA5009	195955.586	719414.978	-1518.428
NA5010	191933.899	720022.323	-1520.294
NA5012	187357.451	726084.657	-1523.275
NA5013	182358.203	726084.321	-1524.970
NA5014	178057.271	726084.374	-1528.079
NA5101	185422.458	682188.878	-1526.443
NA5102	185424.895	679657.792	-1526.252
NA5103	183421.028	682190.444	-1527.366
NA5104	183531.083	679660.060	-1530.103
NA5105	182276.730	682188.254	-1531.935
NA5107	180871.790	683597.945	-1531.033
NA5116	176113.909	690607.673	-1527.447
NA5118	176113.402	692593.001	-1531.473
NA5120	176120.629	694116.720	-1532.512
NA5121	180957.456	694343.298	-1528.138
NA5122	178055.166	696190.801	-1532.386
NA5123	182371.466	695753.945	-1526.446
NA5124	178055.834	698195.018	-1533.086
NA5128	181014.691	700712.083	-1525.291
NA5130	182430.384	702127.521	-1522.100
NA5131	184955.326	702353.308	-1520.606
NA5133	186844.634	704243.293	-1519.742
NA5159	177924.849	687427.182	-1524.334
NA5161	179042.869	692635.597	-1524.478
NA5164	176515.696	692266.121	-1529.037
NA5168	185549.737	704453.156	-1516.749
NA5704	188325.929	716923.061	-1517.675
NA5715	179111.870	704839.762	-1522.583
NA5716	180746.980	710634.407	-1520.910
NA5717	179151.628	711846.021	-1521.798
NA5718	184691.628	712727.363	-1516.035
NA5719	178958.367	721747.852	-1525.277
NA5720	183300.640	722929.072	-1521.382
NA5721	187667.133	722432.018	-1520.050
NA5722	183199.702	713799.944	-1520.271
NA5723	186773.571	712874.691	-1517.968
NA5725	182639.916	725324.605	-1523.838
NA5801	189012.340	706408.290	-1521.693
NA5802	193457.455	706413.204	-1520.926
NA5803	193456.849	709908.847	-1519.235
NA5804	193454.485	713408.977	-1518.351
NA5807	192040.104	710057.542	-1520.366
NA5808	188884.632	709568.126	-1519.480
NA5904	192031.571	700044.231	-1520.418
NA5907	189598.864	703212.055	-1518.777
NA5908	188817.212	701539.883	-1519.996
NA5909	187658.058	701270.624	-1522.131

E Comparison between the transformed heights and the levelled heights

Point number	Z (levelled)	Z (Laser Tracker / transformed)	Difference
NA5001	-1518.78	-1518.832	0.05
NA5003	-1520.03	-1520.138	0.11
NA5006	-1523.71	-1523.665	-0.04
NA5007	-1521.43	-1521.428	0.00
NA5008	-1518.20	-1518.125	-0.07
NA5009	-1518.51	-1518.428	-0.08
NA5010	-1520.37	-1520.294	-0.08
NA5012	-1523.23	-1523.275	0.05
NA5013	-1524.84	-1524.970	0.13
NA5014	-1527.82	-1528.079	0.26
NA5101	-1526.23	-1526.443	0.21
NA5102	-1525.99	-1526.252	0.27
NA5103	-1527.19	-1527.366	0.17
NA5104	-1529.85	-1530.103	0.25
NA5105	-1531.77	-1531.935	0.16
NA5107	-1530.90	-1531.033	0.13
NA5116	-1527.47	-1527.447	-0.03
NA5118	-1531.52	-1531.473	-0.05
NA5120	-1532.58	-1532.512	-0.06
NA5121	-1528.17	-1528.138	-0.03
NA5122	-1532.44	-1532.386	-0.05
NA5123	-1526.43	-1526.446	0.01
NA5124	-1533.16	-1533.086	-0.07
NA5128	-1525.36	-1525.291	-0.07
NA5130	-1522.14	-1522.100	-0.04
NA5131	-1520.59	-1520.606	0.01
NA5133	-1519.83	-1519.742	-0.09
NA5159	-1524.30	-1524.334	0.04
NA5161	-1524.50	-1524.478	-0.02
NA5164	-1529.07	-1529.037	-0.03
NA5168	-1516.84	-1516.749	-0.09
NA5715	-1522.68	-1522.583	-0.10
NA5716	-1520.95	-1520.910	-0.04
NA5717	-1521.87	-1521.798	-0.07
NA5718	-1516.11	-1516.035	-0.07
NA5719	-1525.19	-1525.277	0.09
NA5720	-1521.33	-1521.382	0.05
NA5721	-1520.10	-1520.050	-0.05
NA5722	-1520.30	-1520.271	-0.03
NA5723	-1518.06	-1517.968	-0.09
NA5724	-1517.75	-1517.675	-0.07
NA5725	-1523.72	-1523.838	0.12
NA5801	-1521.77	-1521.693	-0.08
NA5802	-1521.05	-1520.926	-0.12
NA5803	-1519.21	-1519.235	0.03
NA5804	-1518.47	-1518.351	-0.12
NA5807	-1520.43	-1520.366	-0.07
NA5808	-1519.53	-1519.480	-0.05
NA5904	-1520.42	-1520.418	0.00
NA5907	-1518.76	-1518.777	0.02
NA5908	-1520.03	-1519.996	-0.03
NA5909	-1522.11	-1522.131	0.02