POSITIONING OF THE ELECTRODE MODULES OF THE KATRIN EXPERIMENT BY USING A LASER TRACKER

Manfred Juretzko
Geodätisches Institut
Universität Karlsruhe
Email: juretzko@gik.uni-karlsruhe.de

Abstract: To verify the mass of the neutrino, the experiment KATRIN was developed at the Karlsruhe Institute of Technology (KIT). The surveying task was to determine the position and orientation of 380 mounting bolts inside the world largest ultra high vacuum container. In a pilot study the measurement of this unusual device under test was thoroughly prepared. So the local measurement work could be accomplished well despite problematic environmental conditions such as cleanroom requirements, obstructions of vision and difficult accessibility of the measuring points without any problems. A main focus was the development and examination of suitable measuring tools and of appropriate measurement strategies. Altogether the required accuracy was clearly kept by 0.5 mm for the bolt positions.

1. Introduction

In search for the mass of the smallest elementary particle, the neutrino, the experiment KATRIN (**KA**rlsruhe **TRI**tium **N**eutrino experiment) was developed by an international collaboration under participation of the institute for nuclear physics of the "Forschungszentrum Karlsruhe" (FZK), belonging to the KIT (Karlsruhe Institute of Technology). The central equipment of KATRIN is an electrostatic spectrometer tank (fig. 1). With a volume of 1250 cubic meters it is the largest ultra high vacuum container world-wide [1].

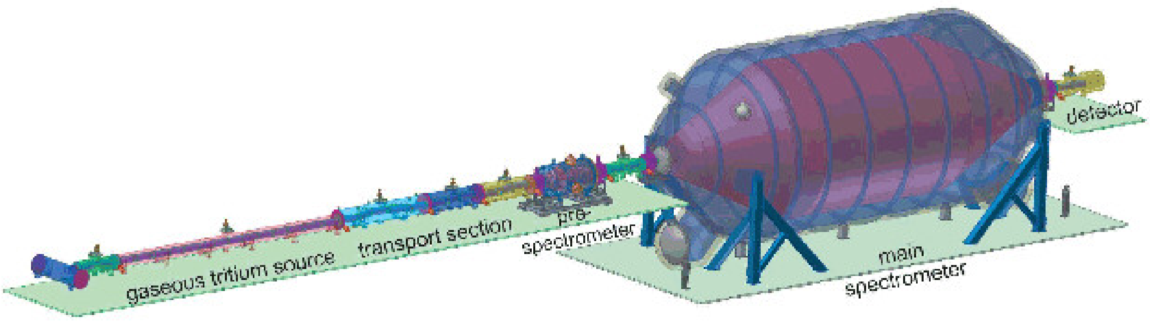


Figure 1: KATRIN (Pic.: FZK)

Into this tank 248 prefabricated electrode modules are to be mounted to approximately 380 welded bolts (fig. 2/3). The surveying task consisted of determining the position and the spatial orientation of these bolts. The measurement uncertainty of a coordinate should not exceed 0.5 mm. The direction in space is of crucial importance for the adjustment of the electrode modules.

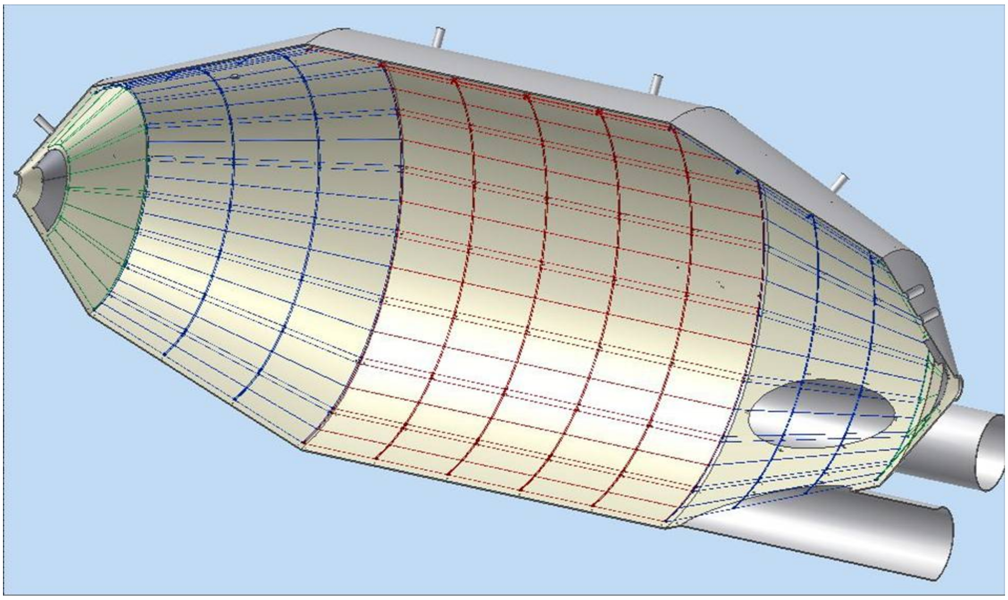
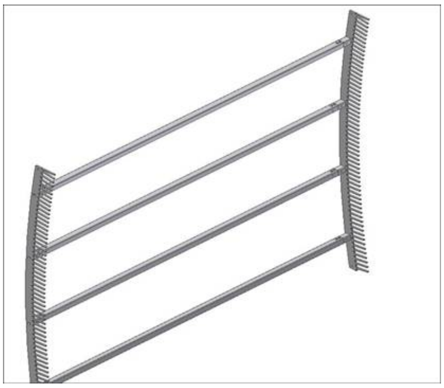


Figure 2: Distribution of the electrode modules (Pic.: FZK)



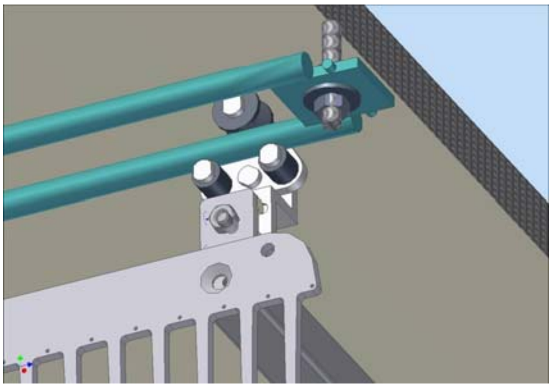


Figure 3: Electrode modules and mounting rail (Pic.: FZK)

Due to the object dimensions and the precision demands a laser tracker was selected as the adequate measurement instrument. In the following pilot study the measuring concept, the development and check-up of several measuring tools are presented as well as some of the results of the measurement.

The special challenges to the measurement are the high accuracy requirements as well as the large number of measuring points in connection with the size of the object and the cleanroom conditions which must be kept inside the tank. The size of the object (23.4 m length, 10 m diameter) requires that inside the tank a specially developed mobile rack system must be used, even for the later assembly of the modules (fig. 4). Thus the measurement can be accomplished only in several stages – with and without rack system – because due to the installation of the system the near-bottom bolts are hidden by the rack. The cleanroom conditions interdict stationing the laser tracker inside the tank. There it is however the possibility of fastening the laser tracker to both main ports of the tank and aim into the tank through the ports of 500 mm. An artificially produced overpressure inside of the tank prevents that dust can intrude through the ports (fig. 6).

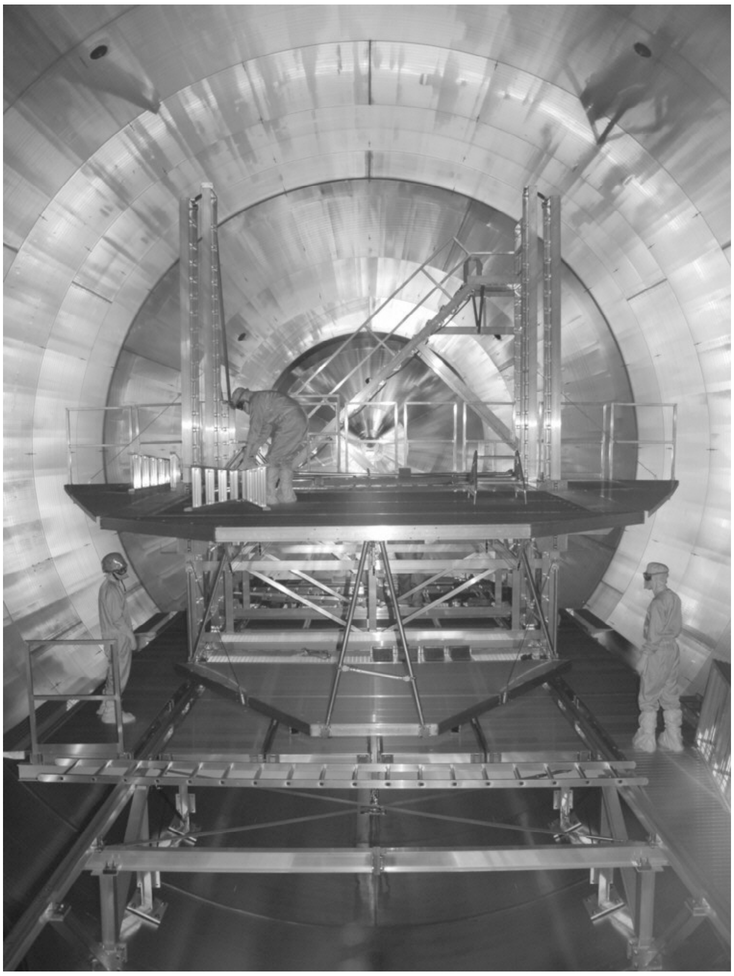


Figure 4: Rack system

2. Pilot study

In a pilot study the measuring task was analyzed in detail and a measuring concept was developed and examined. It could be proved that the laser tracker is the suitable measuring instrument. A measurement net was simulated and evaluated, which corresponds to the conditions during the tank measurement. However, the development and examination of suitable measuring tools for the survey of the bolts was the most important task.

2.1. Laser tracker

As surveying instrument a Leica LTD500 was used. The manufacturer's data for the absolute accuracy of a coordinate are ± 10 ppm for fixed targets and ± to 20 - 40 ppm for moved targets (in each case 2σ) [2]. These values are supported by appropriate studies [3], [4] and prove the instrument as in principle suitable for the measurement desired.

For the application of the used type of laser tracker it is to be noted that its vertical measuring range is limited to ± 45°. For some bolts it is necessary to station the laser tracker in a horizontal position. The manufacturer states that such an application is possible in principle, but the specifications were not guaranteed generally. Investigations in the context of the pilot study showed that the angle uncertainty is worse about factor three compared to horizontal operation.

2.2. Design and inspection of measuring tools

Laser trackers use so-called „Corner Cube Reflectors, (CCRs)“, i.e. laser tracker raw data primarily refers to the position of the sphere centre of the CCR. The determination of discrete points or the adjustment of a construction unit requires the application of certain measuring procedures and/or certain adapters to transfer the measuring point to the object. For the determination of a defined object point and the spatial orientation of the bolts in respect to the tank-coordinate system a so-called „Vector-Bar” is used, which is adjusted by adapters to the bolts. These adapters were especially developed for this surveying task (fig. 5). The two reflectors were sighted and the point of definition (point #3) was calculated.

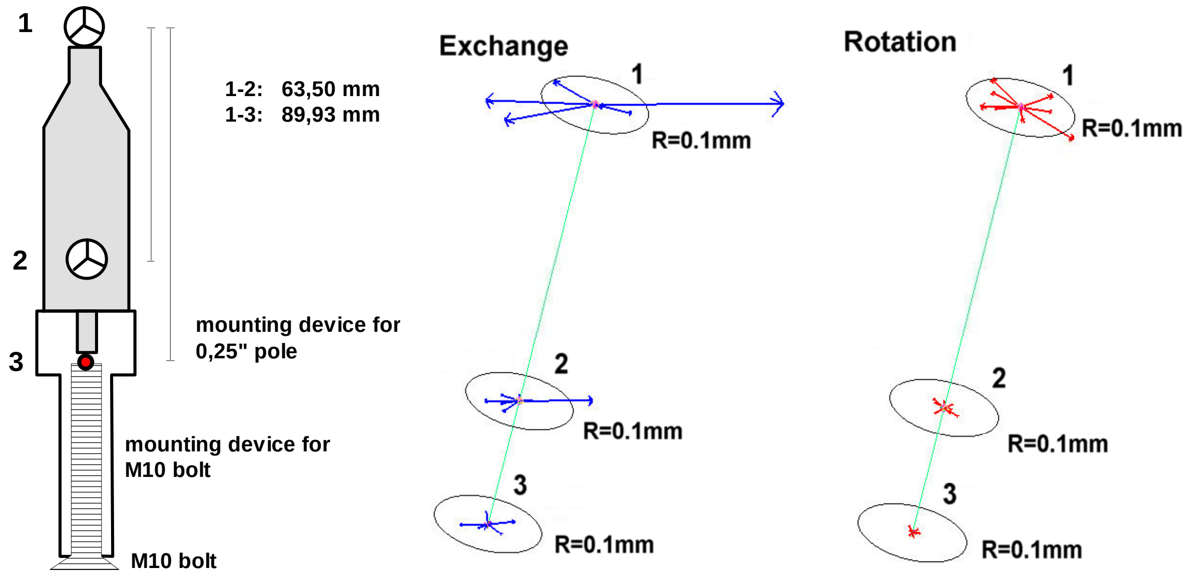


Figure 5: Vector-Bar mounted to a bolt

For the examination on exchangeability seven identically constructed adapters were fastened successively on a bolt sample. By determining the standard deviation of the bolt´s coordinates (point #3) basing on these repeated measurements, manufacturing tolerances of the adapter could be evaluated. The maximum deviation of a position from the average for this point was 0.06 mm, the standard deviation of a position was 0.04 mm.

A further experiment was set up for examining, how adapter rotation around the bolt affects the position of the reflectors and the computed point #3. With this experiment any eccentricities or tumbling motions could have been detected. The maximum deviation of a position from the average for the computed point amounted to 0.02 mm, the standard deviation of a position amounted to 0.01 mm. Thus it was proven that the individual adapters are exchangeable against each other and the adjustment does not have a significant influence on the position of the computed point.

3. On-site survey

Based on the realizations and experiences of the pilot study the measurement of the bolts was accomplished in two phases: In the first phase in April 2008 the bolts within the bottom part of the tank (cylinder part) were measured. These could be achieved by using a ladder. In this phase also the measurements were accomplished for the definition of the object coordinate system. In the second phase in June 2008, after the installation of the rack system, the measurement of the bolts within the upper range and in the cones followed. The capture and the analysis of the data were accomplished with the help of the program “Spatial Analyzer” by “New River Kinematics”.

3.1. Mounting of the laser tracker

For the mounting of the laser tracker at the spectrometer tank a fastening element was designed, which permits both the vertical and the horizontal use of the laser tracker. This adapter was mounted to the port of the spectrometer tank.

Figure 6: Vertical and horizontal mounting to the spectrometer tank

Static computation by the institute for nuclear physics prognosticated that a movement of persons or the rack system inside of the tank will not have a considerable effect on the form of the tank. This statement was verified as follows: Selected points were observed with a frequency of 10 Hz during a period of 25 seconds. A first measurement without movements in the tank shows thus „the background noise“of the measurement. During the second measurement the rack system was moved. It was to be recognized that the movement does not have significant influence on the coordinates of one point.

The influence of changes of temperature on the object and/or the atmosphere could be neglected by the complete air conditioning both the workshop and the tank covering.

3.2. Survey of the bolts

The determination of the position and adjustment of the individual bolts were accomplished as follows (fig. 7): After the adapter with the vector bar was mounted at the bolt, the two reflectors were aimed in each case in two faces. The measurements to the two reflectors of the vector bar can be coded in such a way that the bolt point is computed automatically. The coordinates of the two reflectors were stored additionally and permit a computation of the spatial orientation of the bolt.

Apart from the position of the bolt point and the spatial orientation, furthermore, the surface was measured around its fixing point at the tank wall. For that purpose one of the reflectors was routed around the fixing point of the bolt. The laser tracker was set to the kinematic measuring mode, and a point was acquired every 2 mm.

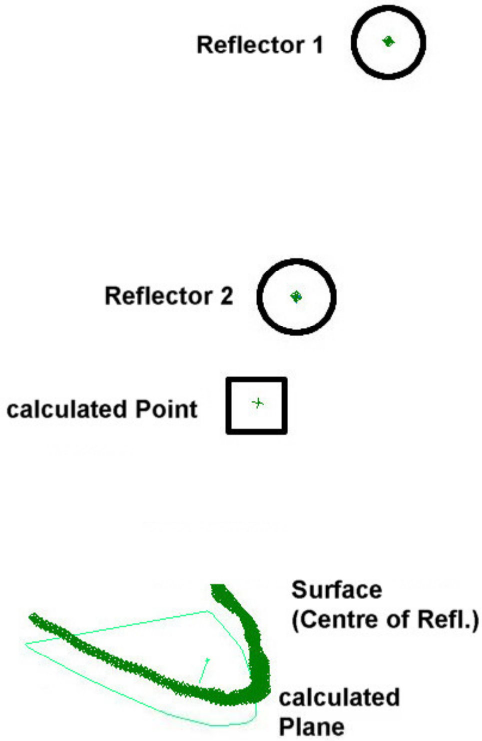


Figure 7: Survey of the bolts

In first approximation the scanned cylinder and/or cone surface can be regarded as plane. Thus a measuring point, which is distant for 30 mm from the base point of the bolt, deviates with a cylinder radius from 5 m only 0.09 mm from a plane through the base point of the bolt. After the computation of each base point a plane could be computed from the points of the surrounding area. The deviations of the individual points of the surrounding area from the plane were indicated immediately. Individual faulty measurements – e.g. by taking off the reflector of the surface – were eliminated immediately.

Each bolt was measured at least two times with different orientation of the laser tracker. By analyzing the deviations of the coordinates it could be judged immediately whether the measuring accuracy was kept or whether an additional measurement would be necessary.

4. Results

The measuring data were processed in such a way that for all bolts coordinates are present, both for the computed bolt points and for the measured reflector positions. These data serve as basis for the adjustment of the electrode modules. But also without complex subsequent treatment of the data well-founded statements can be made about the measuring uncertainty and the production accuracy of the tank:

After network adjustment the repeated measurements available for the bolts were analyzed. Thus the standard deviations for the majority of the computed points, derived from repeated measurements, were below 0.1 mm. For almost all points it was below 0.3 mm.

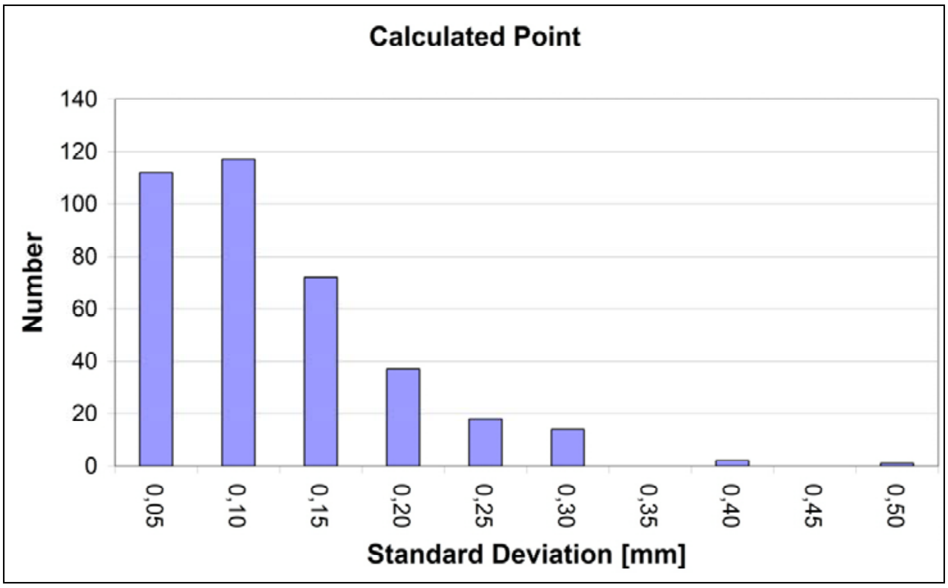


Figure 8: Distribution of uncertainty

Furthermore, the actual laser tracker accuracy results from the network adjustment. The comparison of vertical and horizontal application of the laser tracker showed almost identical accuracies for the distance (0.05 mm) and for the vertical angles (1.5“). For the horizontal angle the horizontal positioned laser tracker with 6.7” was clearly less accurate than the vertically positioned with 1.1 “. However it is to be noted that even an uncertainty of 10” still fulfils the requirement due to the short distances: in the horizontal application in a range of less than 3 m this corresponds to a coordinate uncertainty of less than 0.15 mm.

The deviations of the bolt points from their required (designed) position amounted to up to 20 mm (fig. 9).

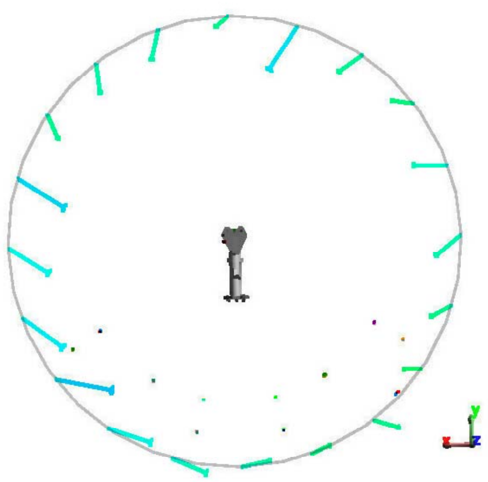


Figure 9: Deviations

5. Future activities

In near future, the rail system will be installed and its position shall be checked for the mounting of the electrode modules. A number of electrode modules (generaly 20 per ring) are built up to one „module polygon“[5]. This compound polygon should not exceed 0.5 mm in its overall length compared to the design length. The overall length of the polygon is determined primarily by the radial positions of the attaching bolts.

6. Conclusions

The measurement of approximately 380 attaching bolts inside the world largest ultra high vacuum container required a position uncertainty of at least 0.5 mm per coordinate. The dimensions of the object, the demanded measuring accuracy as well as the cleanroom conditions were unusual requirements. Especially, the net configuration had to deal with restrictions because the tank could only be visually accessed through small windows at its face sides. An effective operational sequence of the measurement could be realized and the demanded accuracies could be kept by the intensive preparation by performing a pilot study. The development of suitable measuring adapters and the proof that also with horizontal application of the laser tracker very high accuracies can be obtained were thereby of crucial importance. Also during the planned measurement of the mounting rails special value is to be put on the development of appropriate measuring tools and their inspection.

References:

[1] „KATRIN - das Karlsruhe Tritium Neutrino Experiment“, Info-Flyer, Forschungszentrum Karlsruhe GmbH (2008)

[2] LEICA (2001): Axyz Trainingshandbuch für Tracker, Ausgabedatum Dezember 2001. Leica Geosystems AG, Unterentfelden

[3] DEPENTHAL, C., BARTH, M. (2007): „Zur Leistungsfähigkeit eines zeitreferenzierten Dreharms als Prüfmittel für 4D-Messsysteme in Hochgeschwindigkeitsanwendungen“, AVN, Heft 7/2007 S. 244-249

[4] JURETZKO, M. (2007): „Untersuchungen zur Wiederholgenauigkeit eines geregelten Winkelmesssystems am Beispiel eines Lasertrackers LTD 500“, Beitrag zum 15. Internationalen Ingenieurvermessungskurs, Graz, 17.-20.4.2007, in: Brunner, F. K. (Hrsg.), Ingenieurvermessung 07, Herbert Wichmann Verlag, Heidelberg, S. 181-186

[5] Juretzko, M. (2009): „Positionsbestimmung der Elektrodenmodule des KATRIN-Experiments mit Hilfe eines Lasertrackers“, AVN, in print