LEICA ABSOLUTE LASER TRACKER OPERATION IN MAGNETIC FIELD ENVIRONMENT

A. Lippitsch, M. Saure, M. Esser, H.-U. Minder, R. Loser, Hexagon Manufacturing Intelligence, Unterentfelden, Switzerland

Abstract

Leica Laser Trackers provided by Hexagon have a long-lasting history in alignment survey work at particle accelerator facilities.

In recent years customers requested the possibilities and limitations of operating laser trackers in special environments, exposing the instruments to magnetic fields. At Hexagon we have followed up this new interest and investigated in a dedicated experiment the effect of magnetic fields of up to 400 Gauss on two of our instruments, Leica Absolute Tracker AT403 and Leica Absolute Tracker AT960.

In this paper we would like to give an overview of our findings and give some guidance to customers on the operation of our instruments exposed to this environment.

MOTIVATION

Laser Trackers are widely used in accelerator alignment and general surveying tasks at accelerator laboratories. These applications demand for highest accuracy and often must be made in special environments. One of these cases comprise measurements in magnetic fields.

Several users of the accelerator community raised the question if laser trackers can operate in magnetic fields and what limitations apply. Hexagon as the supplier of Leica Laser Trackers had been addressed to answer this question. As no dedicated study had been done on this topic before, the answer could not directly be given.

Previously, investigations such as [1] have been carried out. In this publication the authors describe that for the task of magnetic field mapping it was difficult to find an instrument which would fulfil the requirements for highly accurate positioning and operation in magnetic fields in the range of up to 200 Gauss. Recently this and similar applications appear more often in high energy experiments. The study [1] showed that only a few models of the then available laser trackers could operate in the demanding environment. Some questions remained open and to be answered by the laser tracker manufacturers.

SCOPE

Leica Laser Trackers are developed and manufactured by Hexagon Manufacturing Intelligence in Switzerland. The R&D department was addressed with the task to set up a small, dedicated experiment to investigate the behaviour of the main two Leica Absolute Laser Tracker families, namely AT930/AT960 and AT403 in magnetic fields. The focus was on 3D measurements to a 1.5” corner cube reflector (CCR).

The goal of the experiment was to give some guidance to customers, on how to safely use Leica Laser Trackers in magnetic field environments and what limitations apply. No changes or alterations to the systems’ hardware nor software were ever intended.

Leica Absolute Laser Tracker

For the investigation under discussion here, Leica laser tracker systems differ in one significant aspect:

- AT930/AT960 uses interferometric technology in combination with ADM (Absolute Distance Meter) technology, thus can provide highly dynamic positional information with a data rate of up to 1 kHz. The interferometer (IFM) laser source is a He-Ne (ionized gas) laser tube.
- AT403 distance measurement does not work on the interferometric principle and only uses the quasi-dynamic (ADM) distance measurement technology, resulting in a lower data rate of 5 Hz.

Figure 1: Leica AT960 Figure 2: Leica AT403

For details on Leica Laser Trackers, refer to [2].

SETUP

Magnetic Field Realisation

To realise a magnetic field environment, a very simple setup had been chosen. A small sized copper coil had been commissioned, the details are given in Table 1.

The coil is fed by a standard power supply to create a static magnetic field in the coil’s core. The theoretical relation between magnetic field strength and current applied to the coil, proved to be correct, as can be seen in Figure 3.

Table 1: Copper Coil Details

Windings	160
Diameter of coil	0.482 m
Height of coil	0.1 m
Copper Cable diameter	5 mm
Resistance R_{DC} (@22°C)	0.21 Ω
Inductance L (measured 100Hz @22°C)	16.7 mH
Magnetic flux density B	4.2 Gauss / A

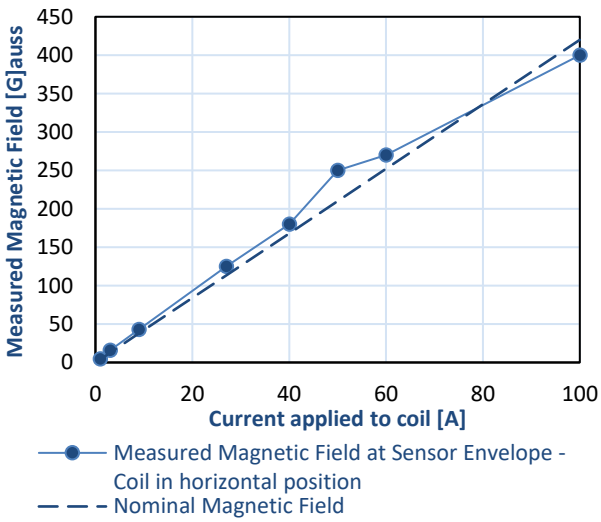


Figure 3: Relationship Magnetic field vs Current

The magnetic field strength was verified in a simple calibration measurement with a Hall sensor probe, see Figure 4. For this measurement no laser tracker instrument had been placed inside the coil. A nominal current of 1 A was applied to the coil.

Figure 4: Hall sensor probe

The resulting map of the magnetic field can be seen in Figure 5: The field is not very homogenous due to the relatively small dimensions of the coil. But the measured magnetic field in the centre of the coil where the main components of the laser tracker sensor were to be placed corresponded well to the theoretical design value.
First tests showed that if current is applied to the coil for extended periods of time, the coil heats up substantially and affects laser tracker measurements in terms of atmospheric disturbances (convection of hot air). To reduce this effect, it was decided to gate the magnetic field to only a few seconds each time and if necessary repeat certain measurements several times. The current was changed in steps.

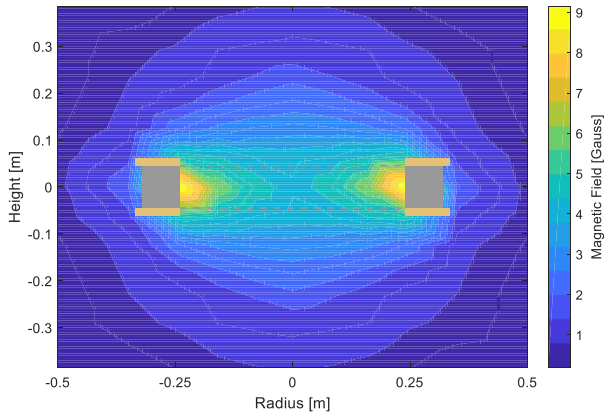


Figure 5: Magnetic Field Map for 1A ^= 4.2 Gauss

Measurement Setup

For the magnetic field experiment, the laser tracker systems were either positioned inside the coil's core (if the coil is in horizontal position, see Figure 6) or very close to its' centre (if the coil is in vertical position, see Figure 7).

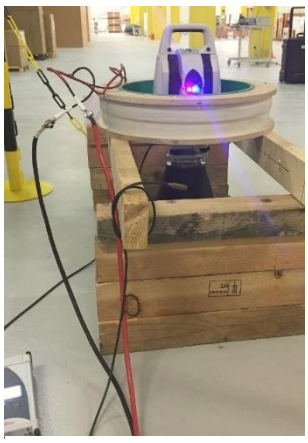


Figure 6: AT403 inside coil in horizontal position

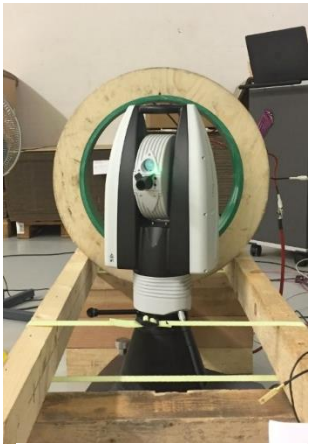


Figure 7: AT960 next to coil in vertical position

The laser tracker sensors were set up on a stable stand. Measurements to a 1.5" CCR at distances of 3m and 10m were carried out. Continuous data was recorded and evaluated. Laser tracker accuracy was verified before and after the experiment by standard procedures. System components other than the sensor e.g. controller, power supply, external temperature sensor, etc. were placed outside the maximum magnetic field.

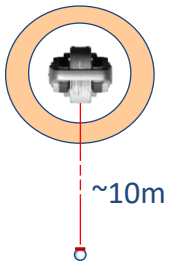
To detect any effects caused by (short time) magnetic fields, continuous observations were done and recorded.

EXPERIMENTS & RESULTS

AT403 in Magnetic Field Environment

Data for one specific instrument (AT403 SN393203) are presented here. The experiment was repeated with another sample instrument, giving very similar results.

AT403 - Coil in Horizontal Position

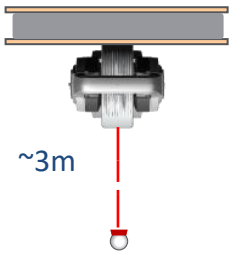


The Laser Tracker was placed inside the coil, so that the measurement beam was just passing the coil, pointing towards the target at 10m distance, roughly at the same height as the sensor's tilting axis.
Figure 8 shows the time series of changes in horizontal (H) and vertical (V) angle and distance over time.

No effects on system's behaviour or performance could be seen up to 400 Gauss, when the ADM dropped out and no measurements were obtained any longer.

The system quickly recovered autonomously once the field had been removed. The limit when the system stops to measure reproduces well in several repeat measurements. The system's accuracy performance remains well within the specified tolerances.

AT403 - Coil in Vertical Position



When the coil was in vertical position, four (main) orientations of laser tracker with respect to coil position were investigated. The 1.5" CCR target was positioned at 3m from the sensor and roughly at the sensors' tilting axis height. Again, the sensor was exposed to several short time period magnetic fields in increasing field intensity steps.

The maximum effect on the sensor could be seen in Orientation #1, when the laser tracker measured away from the coil, thus when the backside of the telescope was exposed to the maximum magnetic field.

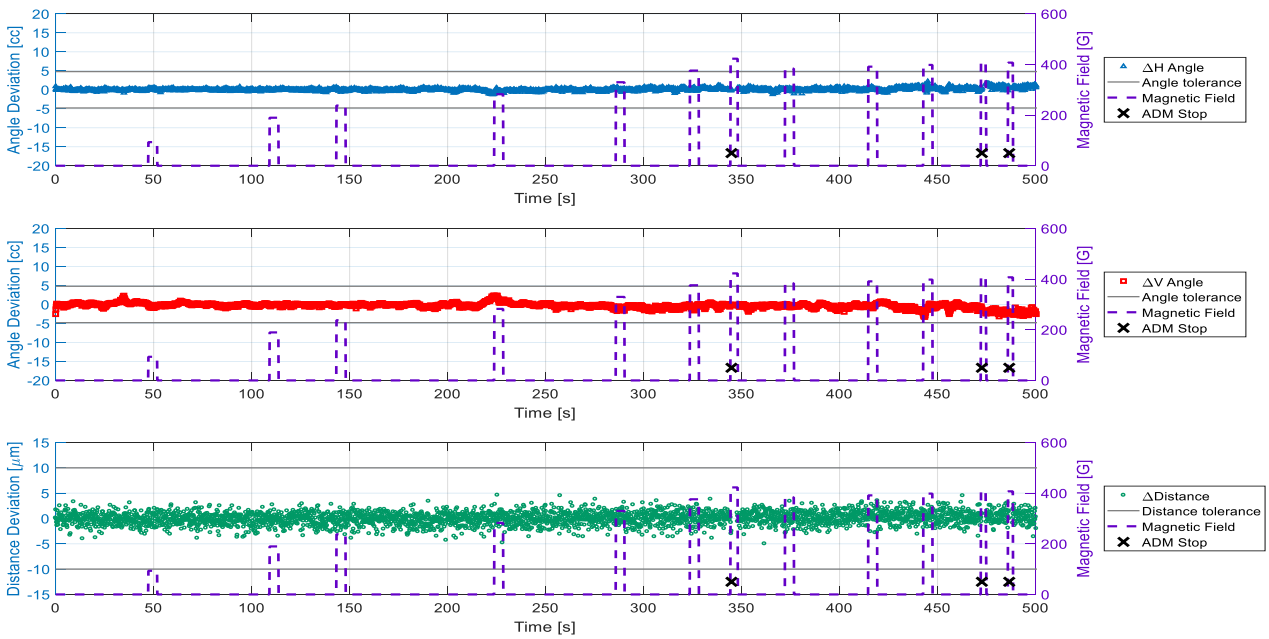


Figure 8: AT403 continuous measurements in magnetic fields of horizontal coil

In Figure 9 it can be seen that the system reacts significantly to large changes in magnetic field (induction), the effect showing in angles and distance. Especially V angle differences peak at times when the field is applied and removed but returns to neutral when the field is constant. Horizontal angle and distance change systematically in the presence of a magnetic field. It is assumed that in user applications of measuring in magnetic fields, the magnetic field would be constant over a longer period of time, thus the effect on V angles as seen here could be neglected.

At one instance the ADM stopped at approx. 190 Gauss, Figure 9 (time 40s), which could not be reproduced later. It is assumed that in this case the magnetic field change was too fast. Subsequently, ADM did not stop up to magnetic fields of 500 Gauss.

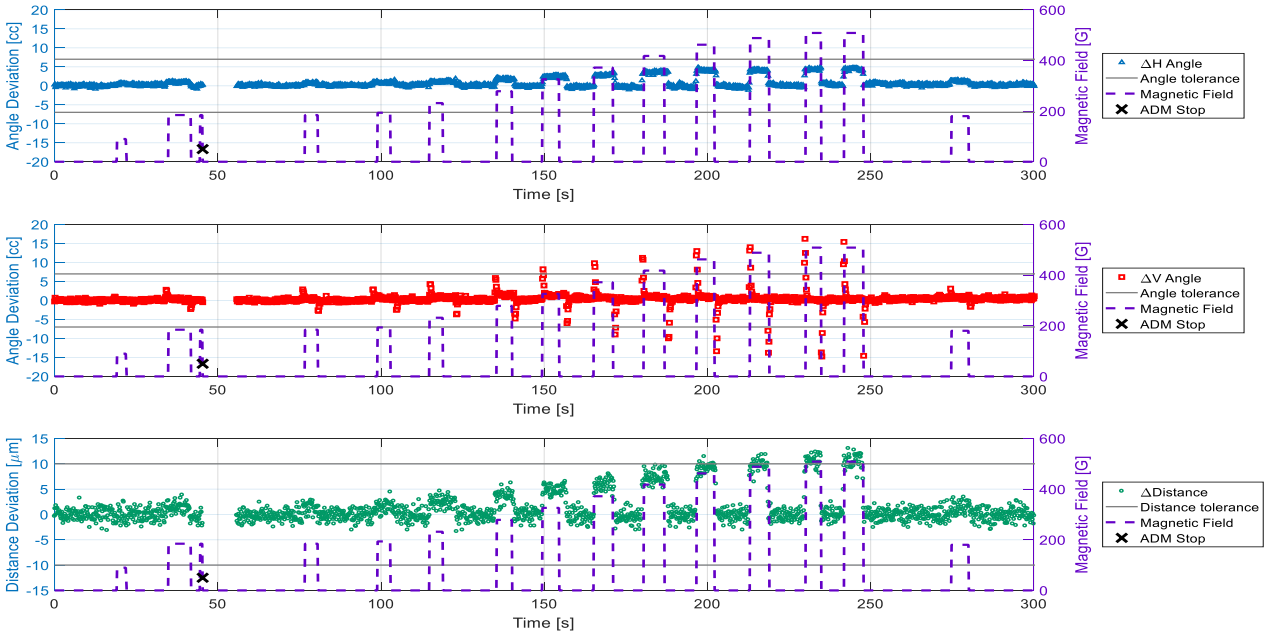


Figure 9:AT403 continuous measurements in magnetic fields of vertical coil – Orientation #1

The measurement was repeated for one single magnetic field of 360 Gauss, see Figure 10. The systematic effects when the magnetic field is applied / removed reproduced well, again H angles and distances are systematically offset from the original values, differences just at the level of accuracy specifications. V angles deviate when the magnetic field changes, the differences exceeding tolerances by ~50%.

Results for the three other laser tracker orientations (at 90° /180° / 270° with respect to orientation #1), exposing the instrument to magnetic fields up to 350 Gauss, showed less significant effects and are not presented in detail here. In Orientation #3, mirroring the situation in orientation #1, the results are very similar but with half the magnitude of the effects. Orientations #2 and #4 showed no significant effects at all. No more ADM drop outs had been observed.

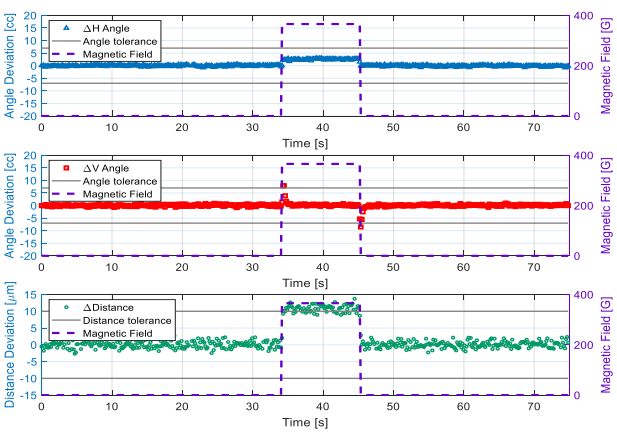


Figure 10: AT403 continuous measurements in single magnetic field of vertical coil – Orientation #1

Additional Experiment: Laser Tracker Initialisation AT403 - Coil in Horizontal Position

In [1], it was reported that AT403 occasionally could not successfully complete its initialisation procedure when exposed to magnetic fields. To verify this, an additional experiment was carried out: AT403 takes roughly 70 seconds to complete its initialisation process. The magnetic field had to remain constant throughout this time. Magnetic fields from 50 – 370 Gauss were applied, and the ADM stopped to measure at 370 Gauss.

Only a few repeats of this process were possible until stability checks unvalidated angle measurements showing too large variations due to thermal effects, as the coil started to heat up significantly. Up to the level of 370 Gauss reached, when thermal effects were still small, no performance effects in accuracy could be observed.

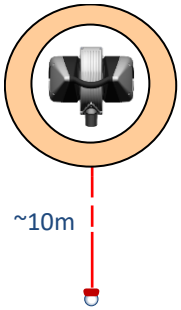
AT960 in Magnetic Field Environment

From previous experience it had been expected that already low magnetic fields would interfere with laser stabilization of AT930/ AT960. Component tests of individual laser tubes had shown large variations in laser tube performance with respect to magnetic field exposure.

Similarly, we found here different behaviour in terms of magnetic field limitations when repeating the experiment with a second sensor. The overall behaviour was similar for both sensors. Nevertheless, if large variations are known in a set, a sample of two does not give a reasonably good representation, so the limits of operation in magnetic fields found here might not be true for any system AT930/ AT960.

The most significant results for AT960 SN750160 will be presented in the following.

AT960 - Coil in Horizontal Position



In this geometry the magnetic field lines of the coil are roughly aligned to the laser tube in the laser tracker sensor. A stable 1.5” CCR target at 10m and laser tracker tilting axis height was observed in continuous measurement mode.

As can be seen in Figure 11 the laser stabilization became interfered at 70 G. In this case the laser needed to re-stabilise, which normally takes several minutes. No data is available in this period.

No effect on angle measurements could be observed whereas a small degradation of distance measurements could be seen when laser stabilization became interfered.

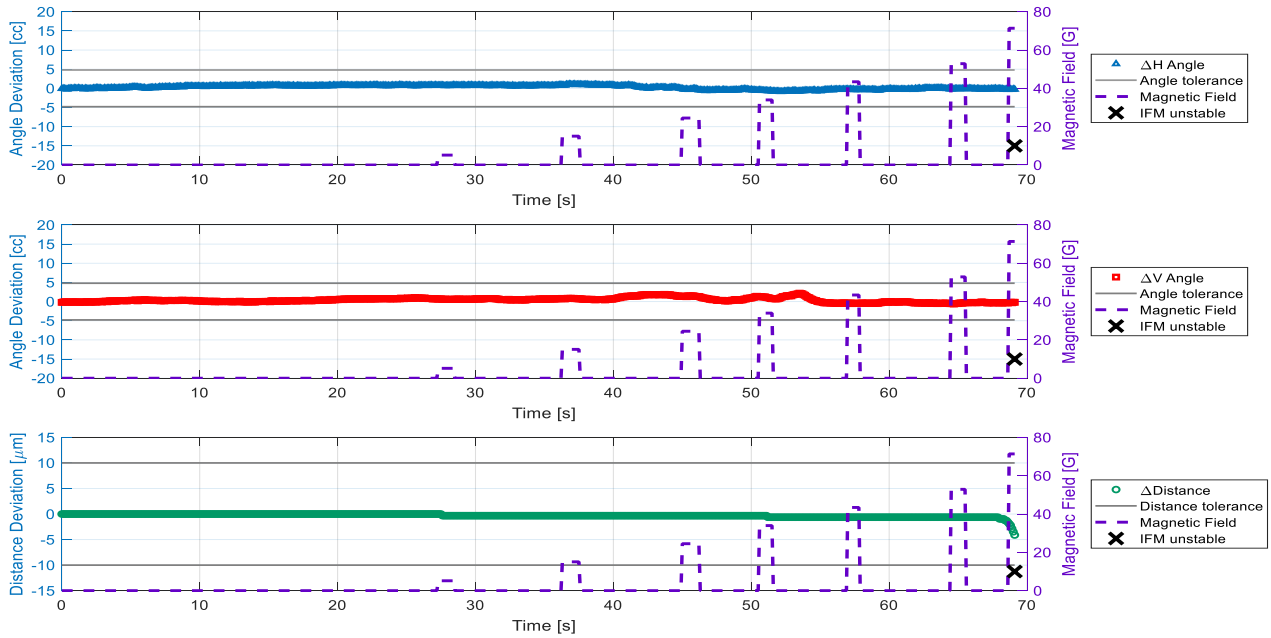
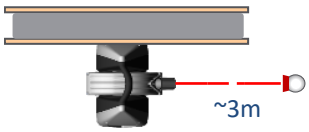


Figure 11: AT960 continuous measurements in magnetic field of horizontal coil

AT960 - Coil in Vertical Position

With the 1.5” CCR target at 3m at laser tracker tilting axis height, continuous measurements were made. The results for the laser tracker in orientation #4 are presented in Figure 12, This orientation was expected to be most affected by magnetic fields.

The laser stabilization became interfered at the 150 G level. After such an incident the laser needs to re-stabilise, which takes several minutes. No data is available in this period.



For this measurement no effect on angle and distance measurements could be observed before the incident. Any small differences in measurements are caused by normal atmospheric disturbances.

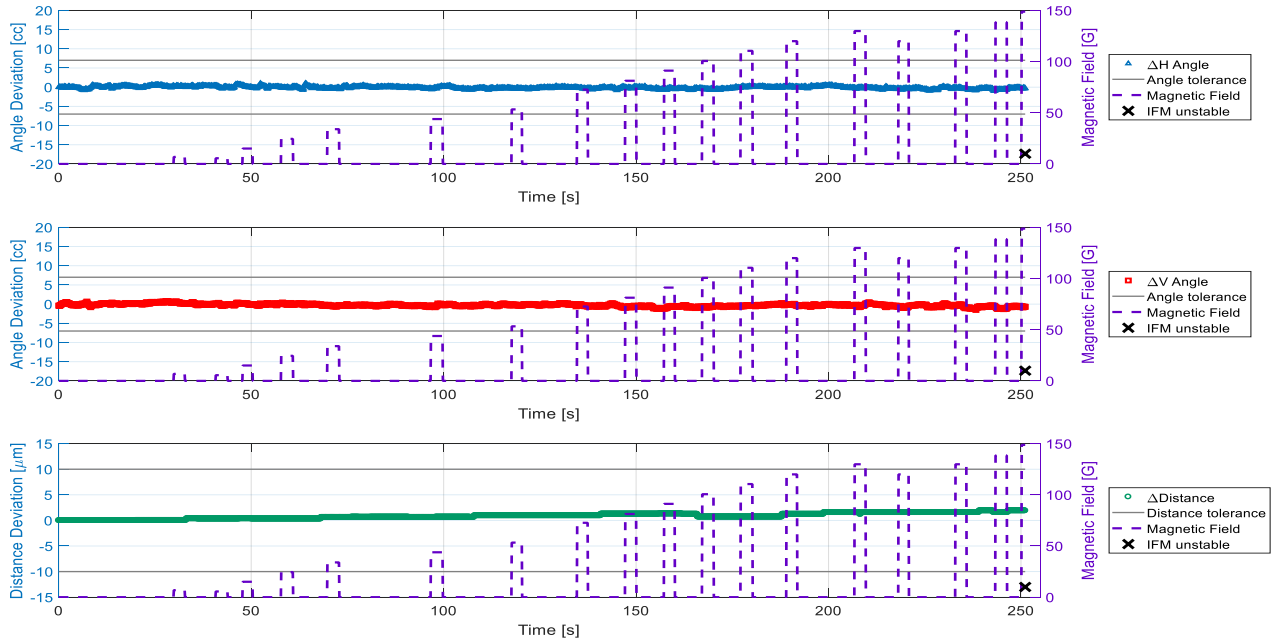


Figure 12: AT960 continuous measurements in magnetic field of vertical coil – Orientation #4

CONCLUSIONS

With a small experiment we have shown that Leica Laser Trackers can be used in magnetic field environments up to certain levels. The following recommendations can be given to Leica Laser Tracker users:

- In the analysed setup AT403 laser tracker operates up to 200 Gauss without showing any significant effects on system's performance. At higher fields accuracy starts to degrade, especially if laser tracker orientation (standing axis) is orthogonal to magnetic field lines.

Table 2: AT403 in magnetic field environment

Magnetic field	
≤ 200 Gauss	Full functionality
	Full accuracy
	No damage expected
200 – 300 Gauss	Full functionality
	Accuracy begins to decrease
	Probably no damage
≥ 300 Gauss	ADM stops measuring at some point
	System recovers quickly if field is stopped
No tests for AT401 / AT402 or B-Probe	
No tests for long term exposure to magnetic field	

- The operation of AT930 / AT960 in magnetic fields is limited due to the laser tube principle and variation in individual tubes' sensitivity. Operation in up to 50 Gauss should be possible without seeing any systematic effects. It has been shown that the system's 3D accuracy is unaffected by magnetic fields. The data stream stops when laser stabilization becomes interfered. AT930 / AT960 in upright position demonstrates larger sensitivity (up to factor 2) to magnetic fields with lines in similar orientation. It should be noted that AT930 / AT960 can be setup in any orientation. Thus, an experiment's measurement setup could be adapted to make use of this significant property.

Table 3: AT930 / AT960 in magnetic field environment

Magnetic field	
≤ 50 Gauss	Full functionality
	Full accuracy
	No damage expected
> 50 Gauss	Laser stabilization interfered
	Need for laser to re-stabilise if field is stopped
No tests for 6DoF/ T-Products	
No tests for long term exposure to magnetic field	

REFERENCES

[1] H. Friedsam, "Alignment Aspects of the Mu2e Magnetic Field Mapping System," in *IWAA 2016*, Grenoble, 2016.

[2] "Leica Absolute Laser Tracker," Hexagon Manufacturing Intelligence, 2018. [Online]. Available: www.hexagonmi.com/products/laser-tracker-systems.