Estimating the gravity field impact on a 10 meter atom interferometer

G43B-1061

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Abstract

A large variety of scientific experiments as well as common applications require more and more precise knowledge of gravity g, its derived quantities, and their change in time. For several phenomena the effect on g can be modelled for any given location, e.g., Earth tides and the redistribution of mass in the ocean and the atmosphere. Considering the desired sensitivity of future instruments, these models have to be evaluated for their suitability. The gravitational effect of the instrument itself is typically either neglected or determined once and assumed to be stable. Local changes in gravity, e.g., changes in the groundwater table, are often neglected. The vertical gradient in gravity is assumed to be linear and stable in time and, depending on the size of the experiment, this often is a valid assumption. In case of the Very Long Baseline Atom Interferometer (VLBAI), a 10 m vertical atom interferometer currently being installed at Leibniz Universität Hannover, HI Tec with the scope of precise gravity, gravity gradient measurements and tests of the universality of free fall, higher order corrections have to be estimated. This is especially relevant, since the instruments extends over three floors, experiencing non-linear gravity variations when passing the concrete floor of the building. Additionally, the impact of the instrument itself and its supporting structure has to be evaluated. Since the VLBAI has the potential to serve as a reference providing a very high accuracy, the vertical gradient in gravity has to be investigated for their suitability. This is especially relevant, since the instruments extends over three floors, experiencing non-linear gravity variations when passing the concrete floor of the building.

Very Long Baseline Atom Interferometer (VLBAI) see G43B-1060

The VLBAI extends the baseline of current atom interferometers, e.g., transportable gravimeters or experiments designed for micro-gravity, from some cm or dm to 10 m. In its initial phase of operation the atoms of two atomic species are dropped from the top of the instrument. In a later phase atoms will also be launched from the bottom, increasing the time in free fall. The main applications and research goals are in geodesy and fundamental physics [1]:

- absolute gravimetry with 1 × 10⁻⁷ m s⁻² accuracy
- gradientimetry with better than 5 × 10⁻¹⁰ m s⁻² accuracy
- quantum test of the universality of free fall (UFF) / Eötvös ratio at 7 × 10⁻²⁵ level

In the gravimeter and the UFF test, gravity gradients have to be modelled at a level of 3 × 10⁻⁷ m s⁻².

HI Tec - Hannover Institute of Technology

The Hannover Institute of Technology (HI Tec) is a research building, currently under construction at Leibniz Universität Hannover. It is focused on basic and applied research in the fields of quantum physics and geodesy. The VLBAI atomic fountain is one of three major large-scale facilities. The Einstein Elevator for experiments in micro-gravity and a fibre drawing system for space qualified applications are the other two.

Simplified model of HITec and VLBAI

Gravitational Attraction

Gradients

Figure 3 shows the horizontal gradients in X direction in the opening of the first floor. The centre of the plot is the VLBAI main axis. The vertical and horizontal gradients on the VLBAI main axis are shown in the centre. The blue and the dashed blue lines are the vertical gradients. The dashed line is the gradient without the VLBAI itself. The light blue and the red line are the horizontal gradients. The largest gradients, positive and negative, are calculated for the parts of the main axis, when the first and second floor is passed. In the right plot the influence of groundwater level changes on the vertical gradient is shown. The blue/red line corresponds to the average maximum amplitude of groundwater level changes during one year.

Gravitometric Methods

As shown in the centre plot of figure 3, the vertical gradients reaches up to 150 m s⁻². This is the effect of the model only and it cannot be separated from the overall gradient, which is easily measured using relative gravimeters [4]. Figure 2 shows the attraction along the main axis and in 3 m away, the closest a relative gradient can be deployed. They are almost identical. This suggests the gradient can be monitored next to the VLBAI and compared to VLBAI measurements once it is operational.

Conclusions

- Local gravity affects experiments in the VLBAI
- A first model of HI Tec and the VLBAI for attraction and gradients is demonstrated.
- The modelled effects are in an order of magnitude that can be verified with gravimetry.
- The combination of modelling and gravimetry should be used for testing and experiments in the VLBAI.
- Next steps (depending on construction progress)
  - Implement local gravity network with connection to existing absolute measurements

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References


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