Absolute gravity measurement for field applications based on quantum gravimeter

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Outline

1. Background
2. Principle
3. Instrument
4. Applications
5. Conclusions
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1. Background

Gravitational wave—containing code of the Universe
LISA, TAIJI, TIANQIN
Gravity—containing the code of the Earth
Gravimeter—The key to solve the code of the Earth
1. Background

- The earth gravity field on the earth surface changes with space and time, because the earth is not an ideal sphere, and the moon revolves around the earth.
- Accurate measurement of the earth's gravity field has very important academic value and practical application value.

Changes with space: Vertical gradient of 300 \( \mu \text{Gal/m} \)

Changes with time: Tide \( \approx 280 \, \mu \text{Gal/day} \)
1. Background

Factors Affecting the $g$

$g = 979.341 \, 114.3 \, \text{mGal}$

1 Gal = 1 cm.s$^{-2}$

- Latitude
- Altitude
- Local gravity anomaly
- Earth tide
- Atmospheric pressure
- Polar movement
- Human motion
1. Background

- Resource Exploration
- Geophysics
- Seismology
- Metrology
- Hydrology
- Volcanology
- Geodesy

Applications of the $g$
1. Background

Measurement of the $g$

**Measurement type:** relative and absolute gravity measurement

**Measurement method:** Static and dynamic gravimetry (mobile)

**Measurement carrier:** Vehicle gravity survey, marine gravity survey, airborne gravity survey and satellite gravity survey
1. Background

Absolute Gravimeters

Classical method

FG-5

Accuracy: 2µGal
Sensitivity: 15µGal/√Hz
1. Background

Advantages of quantum gravimeter: more precise, faster and can be worked in dynamic measurement method.
1. Background

Germen
Humboldt Universität
zu Berlin, GAIN

France
LNE-SYRTE
CAG-01

UK
University of
Birmingham
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2. Principle

Doppler cooling and magneto-optical trap technology

Doppler cooling  MOT  Trapped cold atom cloud
2. Principle

Cold atom interferometer based on particle wave duality

Wave particle duality of real particles
2. Principle

Atom interferometer

$^{87}\text{Rb}$ simplified atomic level scheme

$|5S_{1/2}\rangle \rightarrow |5P_{3/2}\rangle$

$|i\rangle$

$|F=2\rangle = |b\rangle$

$|F=1\rangle = |a\rangle$

780 nm

Two Photons Raman transition

Mach-Zehnder Interferometer
2. Principle

Quantum gravimeter is a new generation of ultra-high precision gravity detection device, which combines laser cooling and quantum state interference technology.
The suppression of the external acceleration, the influence of vibration phase and the compensation of vibration phase.
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3. Instrument

2006 start experiment

2011 lab setup

2016 portable Asia Pacific comparison

2017 International Comparison

2018 compact instrument

2019 Field applications
3. Instrument : Key Technology (1)

**Vacuum Chamber**

- All-glass cell
- Improved optical access
- Compact design
- No eddy currents
- Low He permeability
- Less than $10^{-7}$ Pa

The sensor head with
Single layer magnetic field shield
3. Instrument : Key Technology ( 2 )

Electronic System

- Modular design
- Low power consumption
- Few cables to plug

0.6 × 0.9 × 0.7 m³
3. Instrument : Key Technology (3)

Control System

- Parallel control
- Less time consuming
- Simplified program interface
### 3. Instrument: Integration

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4. Applications: Asia Pacific comparison

**APMP.M.G-K1 in 2016**

- **Accuracy**: 20μGal
- **Sensitivity**: 100μGal@1s
4. Applications: International comparison

The 10th International Comparison of global absolute gravimeters in Beijing in 2017, Organized by Chinese Academy of Metrology
4. Applications: Earthquake monitoring

Pakistan

Time: 2013-09-28 15:34
Earthquake magnitude: 7.2
Source: Pakistan
4. Applications: Earthquake monitoring

On May 12, 2008, at 14:28:04, Wenchuan County, Sichuan Province, with a magnitude of 8.0, many people were killed.

Variation of gravity during Wenchuan Earthquake

Time: 1976-07-28
Earthquake magnitude: 7.8
Source: Tangshan, China
Change of gravity 100µGal
4. Applications: Long term monitoring

Long-term precise monitoring of the absolute gravity data

Location: Sichuan seismic station

Duration : 14 days (November 2019)

Accuracy : 5μGal
4. Applications: Vehicular gravity survey

The field vehicle gravity survey around a reservoir was done,

The accuracy is 30 μ Gal

Field test route of atomic gravimeter
4. Applications: Shipboard mooring status

Vibration compensation

Accuracy: <1mGal
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We have developed a compact quantum gravimeter, which is suitable for field applications, and can be transported for a long distance.

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<th>Measurement method</th>
<th>Accuracy</th>
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<td>Laboratory static absolute gravity measurement[1]</td>
<td>5-10 µGal</td>
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<td>Vehicle absolute gravity measurement [2]</td>
<td>30 µGal</td>
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<td>Gravity measurement under shipboard mooring[3]</td>
<td>134 µGal</td>
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References:
A new type of compact gravimeter for long-term absolute gravity monitoring

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Abstract
Long-term absolute gravity monitoring has a wide range of applications in the field of geodesy, geophysics, seismology, meteorology, oceanography, etc. The traditional method of long-term absolute gravity monitoring is realized by the combination of absolute gravimeter and relativistic gravimeter. Here we report on a new type of compact gravimeter based on atom interferometry, used for long-term absolute gravity measurements. The long-term absolute gravity monitoring can be carried out with only a single instrument. Over the course of a month we took long-term absolute gravity measurements in a stable station. With an interrogation time of 120 ms and a repetition rate of 2 Hz, the sensitivity of a compact constant refractive index reaches 900 nGal s−1/Hz−1, without any vibration isolation system, and the gravity residual fluctuations are within 100 nGal.

Keywords: compact gravimeter, wave interferometry, long-term absolute gravity monitoring (Some figures may appear in colour only in the online journal)

1. Introduction

Gravity field variations on the Earth’s surface arise from a variety of gravitational anomalies associated with mass redistribution. The long-term high-precision measurement of time-variable gravity provides a useful tool to investigate the dynamics of Earth’s field. It is also important to the study of other subjects, such as geophysics, geodynamics, hydrology, climatology, etc. The application of long-term gravity measurement can provide crucial information in seismic, gravitational, seismological, etc. studies and can study the variation of the Earth’s tide (2.2), improvement of the gravity grid (2.3), understanding of volcanic activity (2.4), monitoring of variable gravitational variations (7, 8), and detecting of sea-level changes [9, 10]...
Many Thanks!

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