Laser Displacement Interferometers with Subnanometre Resolution in Absolute Ballistic Gravimeters

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Introduction

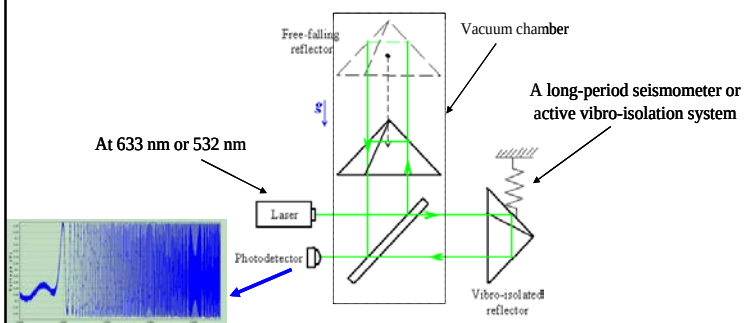
The absolute ballistic gravimeter (ABG) realizes the free motion of the test body in the gravity field and the free-fall acceleration g is obtained from the measurement of the length and time intervals using the motion equation of the falling body. Laser displacement interferometers (LDI) and precise clocks are used in such measurements.

Relative uncertainty in the free-fall acceleration g measurement is **a few part in 10^9** (a few microgals in absolute units) [1]

Required relative uncertainty:
in displacement measurement:
1×10^{-9}
in time interval measurement:
5×10^{-10}

Two types of trajectories of test body:
- rise-and-fall (symmetric)
- Free fall (non-symmetric)

PRINCIPLES OF OPERATION OF ABSOLUTE GRAVIMETERS



Motion equation of free-falling body in the gravity field:

$$z = z_0 + V_0 t + \frac{g(z_{exp})t^2}{2} + W_{zz}\left(\frac{z_0 t^2}{2} + \frac{V_0 t^3}{6}\right) + W_{zz} z_0 \frac{W_{zz}^2 t^4}{24}$$

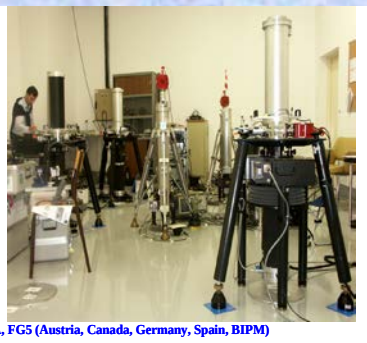
$$\tau_i = t_i - \frac{z_i - z_0}{c}$$

Corrections: instrumental and geophysical (tides, ocean loading, polar motion)

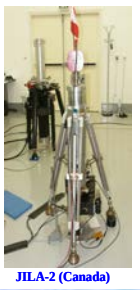
g

Various designs of absolute ballistic gravimeters


TBG (Ukraine)


JILA, FG5 (Austria, Canada, Germany, Spain, BIPM)


GABL-G (Russia)


JILA-2 (Canada)

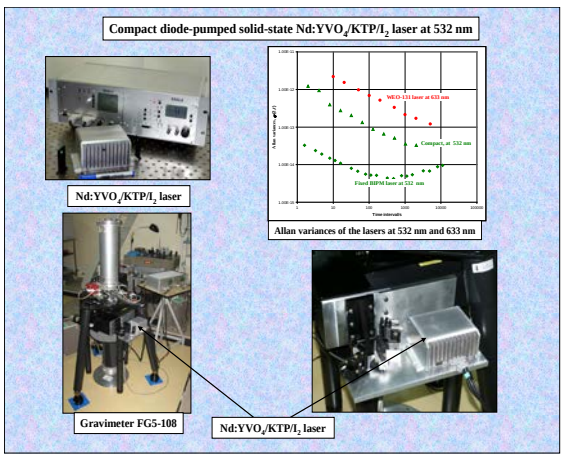

IMGC-2 (Italy)

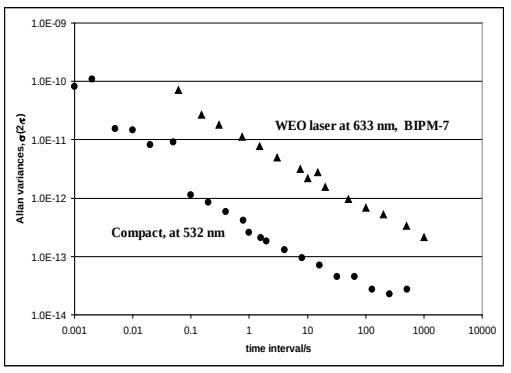

A10-008 (USA)


FGC-1 (USA)

Required uncertainties ΔL in the single drop measurement of the displacement of the test body in the ABG corresponding to the relative uncertainty $\Delta L/L = 1\times10^{-9}$.

L/m	ΔL/nm	ΔL in wavelength λ	
		λ = 633 nm	λ = 532 nm
0.5	0.5	λ/1266	λ/1064
0.2	0.2	λ/3165	λ/2660
0.025	0.025	λ/25320	λ/21280

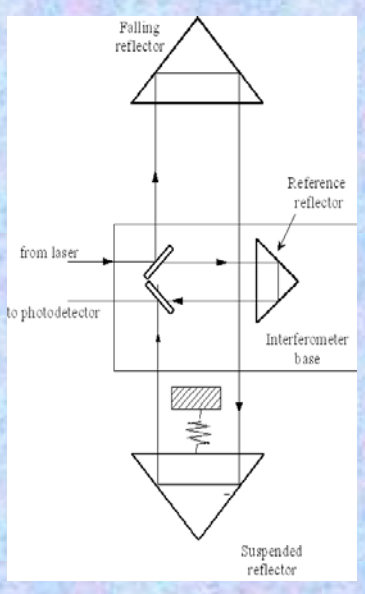




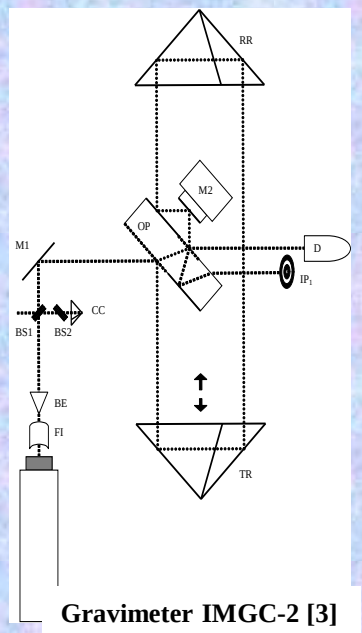
Short-term frequency stability of He-Ne/I_2 laser and Nd:YVO_4/KTP/I_2 laser at 532 nm

The use of diode-pumped solid-state iodine-stabilized laser improves the performance of absolute ballistic gravimeter [4,5]

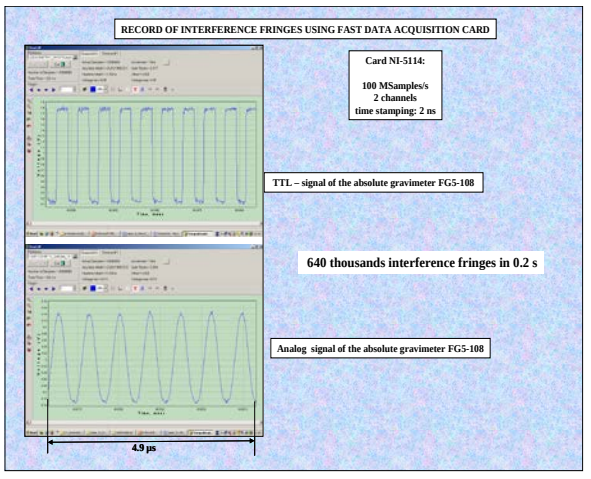
Typical optical layouts of two-beam laser interferometers of absolute gravimeters

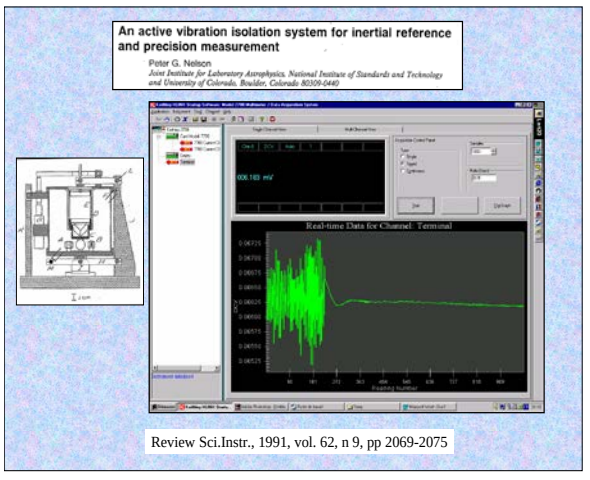


FG5-type gravimeters [2]



Gravimeter IMGC-2 [3]





Review Sci.Instr., 1991, vol. 62, n 9, pp 2069-2075

Conclusions

- **The increasing requirements for reliable, accurate and traceable measurement of the gravity field (free-fall acceleration) in geophysics, geodesy, geology and navigation determine the growing needs for transportable absolute gravimeters and necessitate further investigations of their performances and metrological characteristics, and the development of a new generation of absolute gravimeters.**
- **The core system of any absolute ballistic gravimeter is the laser interferometer for the measurement of displacement of the free-moving test body within vacuum chamber.**
- **The required uncertainty in the measurement of displacement in absolute gravimeters is less then 0.1 nm, i.e. the laser displacement interferometers of absolute gravimeters are length measuring systems with sub-nanometre resolution.**
- **R&D in laser displacement interferometry with subnanometre resolution is of common interest to the dimensional nanometrology community and to designers of absolute ballistic gravimeters. Results of such R&D obtained by both communities are complementary.**
- **The use of compact diode-pumped solid-state iodine-stabilized lasers in laser displacement interferometry is promising due to higher laser power, shorter wavelength and better short-term and long-term frequency stability with respect to the currently used He-Ne/I_2 lasers.**

References:

[1] L.Vitushkin, et al, The Seventh International Comparison of Absolute Gravimeters ICAG-2005 at the BIPM. Organization and preliminary results, *Proceedings of the 1st International Symposium of the International Gravity Field Service "Gravity Field of the Earth"*, 28 August – 1 September, 2006, Istanbul, Turkey, Ed. General Command of Mapping, June 2007. Special Issue:18, pp. 382-387.

[2] T.M.Niebauer, G.S.Sasagawa, J.E.Faller, R.Hilt, F.Klopping, A new generation of absolute gravimeters, *Metrologia*, vol. 32, pp 159-180, 1995

[3] A.Germak, S.Desogus, C.Origlia, Interferometer for the IMGC rise-and-fall absolute gravimeter, *Metrologia*, vol.39, n 5, pp 471-475, 2002

[4] L.Vitushkin, O.Orlov, V.Nalivaev, Test Measurements of Free-Fall Acceleration Using the FG5-108 Gravimeter With a Compact Diode-Pumped Solid-State Nd:YVO_4/KTP/I_2 Laser at a Wavelength of 532 nm, *Proceedings of International Symposium "Terrestrial Gravimetry. Static and Mobile Measurements. TGSMM-2007"*, 20-23 August 2007, St Petersburg, Russia, State Research Center of Russia Electropribor, 2008, pp 143-146.

[5] L.Vitushkin, O.Orlov, A compact frequency-stabilized Nd:YVO4/KTP/I2 laser at 532 nm for laser interferometry and wavelength standards, Proc. of SPIE, vol. 5856, 2005, pp 281-286