The Measurement of the Local Acceleration of Gravity for the NIST-4 Watt Balance

D. B. Newell[1], J. O. Liard[2], L.S. Chao[1], A. Cao[3], F. Seifert[3], D. Haddad[3], J.R. Pratt[1], and S. Schlamminger[1]

[1]National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899 USA
Email: david.newell@nist.gov

[2]National Research Council, Ottawa, ON, K1A 0R6 Canada

[3]Joint Quantum Institute/NIST, College Park, MD 20742 USA

***Abstract* — A new watt balance is being constructed at National Institute of Standards and Technology (NIST) in preparation for the redefinition of the International System of Units and the realization of mass through an exact value of the Planck constant. We describe the procedures used and give results for the measurements of the local acceleration of gravity in the new watt balance facility.**

***Index Terms* — fundamental constants, Planck constant, gravity, international system of units, watt balance.**

I. Introduction

Resolution 1 of the 24th Meeting of the General Conference on Weights and Measures (CGPM) outlines a revised International System of Units (SI) based upon fixed numerical values of invariants of nature [1]. A consequence is that the unit of mass will be realized through an assigned value of the Planck constant, h. A method for realizing mass from the Planck constant utilizes a watt balance that requires the determination of the local acceleration of gravity, g, with parts in 10^9 accuracy. Significant progress has been made with the existing NIST watt balance (NIST-3 WB) towards providing the necessary experimental results [2] for the possible SI redefinition to occur at the 26th meeting of the CGPM. In preparation for disseminating mass in the revised SI, a new robust NIST watt balance, NIST-4 WB, is being constructed [3]. We report on the initial measurements to evaluate g within the new NIST-4 WB laboratory and the plans for monitoring g for the future dissemination of mass.

II. Watt Balances and the Local Acceleration of Gravity

To summarize the operational principle of a watt balance, the measurements involved relate the Planck constant to mass, length, and time through

$$m = hC/gv \qquad (1)$$

where m is the mass of an artifact mass standard, g is the local acceleration of gravity, v is a velocity, and C is a combination of frequencies and scalar constants. With a total uncertainty goal for the watt balance on the order of a few parts in 10^8, equation (1) highlights the importance of determining g at the location of the mass standard used in a watt balance to an accuracy of a few parts in 10^9 such that its uncertainty does not significantly contribute to the final watt balance result.

A challenge in the evaluation of g for the recent NIST-3 WB result [4] was that the apparatus was physically in the way. Moreover the measurements of the absolute value of g were performed intermittently, with corrections being applied for tidal, polar motion, and atmospheric effects during the operation of the watt balance. For the NIST-4 WB local gravity and gravity gradients are being measured, mapped, and modeled before and during the construction phase of the laboratory to establish a tie between the mass standard position and a stable gravity observation station nearby where a superconducting (SC) relative gravimeter will reside. The SC gravimeter will have a continuous data stream of relative changes in local acceleration at a location close to the watt balance, allowing the monitoring of difficult to model effects, such as the ground water table.

III. Gravity at the NIST-4 WB Facility

The new NIST-4 WB facility, building 218 room E024 (218/E024), is in a subterranean laboratory at a depth of 12 m from the surface and five meters from the southern wall of the subterranean laboratory. The NIST-4 WB will be placed on a 60 ton concrete pier, 4 m x 4 m x 1.7 m high, that was constructed to accommodate eight pneumatic air springs for vibration isolation and a 1 m diameter hole for the possible use of a superconducting solenoid. While the NIST-4 WB does not plan to use a superconducting solenoid [5], the location of 218/E024 and the mass distribution of the pier creates significant non uniform gravity gradients.

Initial absolute g determinations were made in the southwest (SW), southeast (SE), and northwest (NW) corners of the pier and are listed in Table 1. A Micro-g LaCoste free-fall gravimeter [6], model FG5-204,* was used for the absolute determinations. The runs consisted of between 85 to 96 sets with a set interval of 15 min, 25 drops a set, and a drop interval of 20 s. The runs were sequential with the SW

*Any commercial equipment, instruments, or materials identified in this paper are to foster understanding. Such identification does not imply recommendation or endorsement, nor does it imply that the material or equipment are necessarily the best available

position measured twice for closure. The results show a significant north-south difference in gravity.

Date	NIST-4 Site	position (meters)	Value @ 130 cm (μGals)
2013-July-04	SW	(0.5,0.5)	980103105.3±2.0
2013-July-05	SE	(3.5,0.5)	980103108.6±1.9
2013-July-06	NW	(0.5,3.5)	980103131.5±1.8
2013-July-07	SW	(0.5,0.5)	980103105.2±1.6

Table 1. Gravity measurements of the NIST-4 WB Pier. Positions are with respect to the southwest corner of the 4 m x 4 m pier. The stated uncertainties are set standard deviations only.

The vertical gravity gradient (VGG) was determined in the SW, SE, and NW corners of the pier and are listed in Table 2. A Scintrex CG5 Autograv gravity meter [7]* s/n 051200158 was used for the VGG measurements with the sensor mass vertical positions of h_1 = 23.8 cm, h_2 = 76.8 cm, and h_3 = 130.0 cm. The lower position was chosen to coincide with the vertical height of the superconducting relative gravimeter sensor mass. The upper position was chosen to coincide with the nominal height of the stated results of the FG5 and the nominal FG5 drop start position. The positions were measured in a h_1, h_2, h_3, h_1 . . . pattern for 7 cycles with a final measurement at h_1 for closure and a linear fit to the gradient was applied. Due to the subterranean laboratory, the VGG measurements show a significantly smaller value with respect to the value -π μGal/cm derived from the definition of the meter being 10^{-7} of ¼ of the circumference of a spherical earth.

NIST-4 Site	(*x*,*y*) position (meters)	VGG @ 130 cm (μGal/cm)
SW	(0.5,0.5)	-2.437±0.019
SE	(3.5,0.5)	-2.487±0.019
NW	(0.5,3.5)	-2.560±0.020

Table 2. Vertical gravity gradients of the NIST-4 WB Pier. Positions are with respect to the southwest corner of the 4 m x 4 m pier. The stated uncertainties are statistical only.

Using the CG5, the change in gravity, Δg, as a function of horizontal position was mapped across the pier by measuring a 7 by 7 grid with a 0.5 meter spacing (Fig. 1). Seven north-south and seven east-west lines were measured and to take out drift, each line had a position pattern of 1, 2, 3, 4, 1, 5, 6, 7, 1. The lack of mass at the center of the pier is clearly visible and is being addressed prior to the installation of the NIST-4 WB.

IV. Summary

Preliminary measurements of the local acceleration of gravity, vertical gravity gradients, and mapping of gravity as a function of horizontal position of the NIST laboratory 218/E024 have been made prior to the installation of the NIST-4 WB. Installation of NIST-4 WB into 218/E024 has commenced and we will present a completed set of gravity measurements during installation and construction.

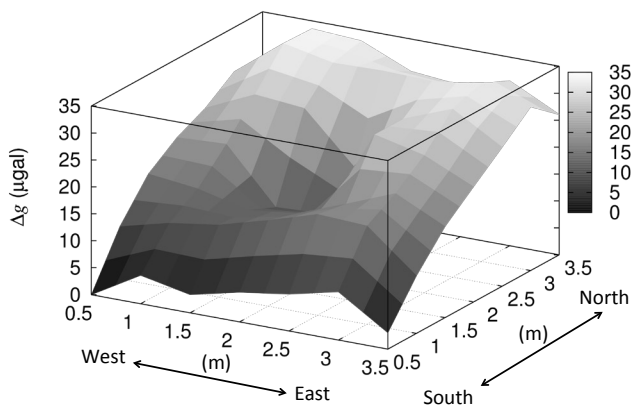

Fig. 1. Change in gravity, Δg, as a function of horizontal position across the NIST-4 WB Pier. The vertical position of the CG5 sensor with respect to the pier was constant at 25.9 cm.

References

[1] Resolution 1 of the 24th Meeting of the Governing Committee on Weights and Measures (CGPM): On the possible future revision of the International System of Units, Bureau International des Poids et Mesures, Paris, 2011

[2] S. Schlamminger, D. Haddad, F. Seifert, L.S. Chao, D.B. Newell, R. Liu, R.L. Steiner, J.R. Pratt, "Determination of the Planck constant at the National Institute of Standards and Technology," this conference

[3] D. Haddad, L.S. Chao, F. Seifert, D.B. Newell, J.R. Pratt, S. Schlamminger, "Construction of a watt balance with the aim to realize the kilogram at the National Institute of Standards and Technology," this conference

[4] D. B. Newell, J. O. Liard, A. D. Inglis, M. C. Eckl, D. Winester, R. J. Silliker, and C. G. L. Gagnon, "The possible contribution of gravity measurements to the difference between the NIST and NRC watt balance results," *Metrologia* **50**(4), 337-344 (2013) E **50**(5), 557-558 p. (2013)

[5] L.S. Chao, S. Schlamminger, F. Seifert, A. Cao, D. Haddad, D.B. Newell, and J.R. Pratt, "Design of a New Watt Balance," this conference.

[6] Micro-g LaCoste, 1401 Horizon Ave., Lafayette, CO 80026

[7] Scintrex Limited, 222 Snidercroft Road, Concord, L4K 2K1 Ontario, Canada