THE NEXT GENERATION OF THE NIST WATT BALANCE

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Abstract

Reduction in the total uncertainty of the NIST watt balance is limited by the present configuration of the experiment. Most of the major uncertainty components arise from the fact that the experiment is performed in air. To reduce the contribution of these components, a vacuum system for the NIST watt balance has been constructed. The vacuum system and other future modifications to the NIST watt balance are discussed.

Introduction

The last remaining base unit defined by an artifact is the kilogram. The NIST watt balance [1] has been designed to measure the ratio of mechanical to electrical work, linking the artifact kilogram, the meter, and the second to the practical realizations of the ohm and the volt derived from the quantum Hall effect and the Josephson effect. The goal is to monitor the drift of the artifact kilogram and ultimately provide an alternate mass standard definition in terms of electrical units.

The present generation of the NIST watt balance has reached a combined standard uncertainty of 145 nW/W [2]. At this stage, major modifications need to be made to further reduce the total uncertainty. Since the experiment is performed in air, large corrections for the refractive index (260 μW/W) and the buoyancy force on the mass (60 μW/W) need to be applied. The corrections are calculated using environmental sensors, but they do not take into consideration deviations from standard air composition such as helium contamination. A novel refractometer [3] has been used to directly measure the refractive index near the main interferometers, however the optical path length may vary between locations due to temperature and pressure gradients. Air currents also apply spurious forces on the mass and coil, increasing the noise during the mode of the experiment where a force on a 1 Kg mass in local gravity is measured. Construction plans have been made to modify the existing experimental building to accommodate a vacuum system for the watt balance. The vacuum system has been designed, built, and tested and is ready for installation. The conversion to a vacuum will provide an opportunity to reduce other noise sources and test other possible improvements to the watt balance.

Next Generation

The new vacuum system consists of an upper and lower chamber connected together by three tubes as shown in Fig. 1. The whole vacuum system is constructed of fiberglass and nonmagnetic, nonconducting materials to eliminate systematic errors from a change in the external field upon current reversal in the induction coils. The upper chamber contains the balance which sits on a three inch thick base plate with vacuum on both sides to reduce alignment changes with changing vacuum level. The lower chamber, which contains the induction coils and interferometers, is in the shape of a donut so that it can fit around the dewar containing the superconducting coils. There is four inch thermal insulation wrapped around both chambers with twisted pair heater wires between the vacuum chambers and insulation. This will give us another layer of temperature control, bringing the total to three. An electrostatic shield is on the inside wall of the vacuum chambers to prevent static charge buildup.

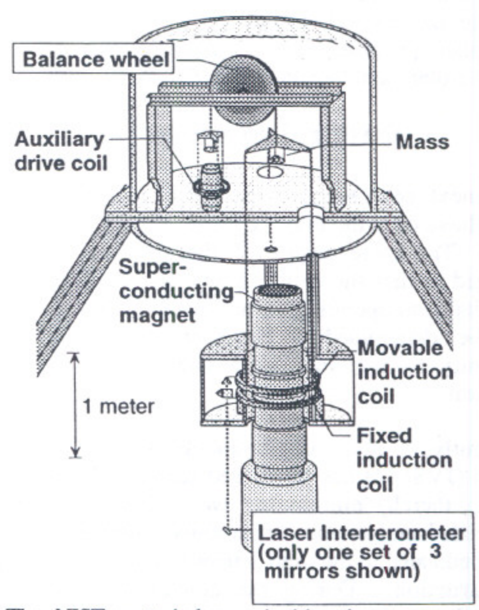

Fig. 1. The NIST watt balance inside the new vacuum chamber.

The vacuum chamber has been tested and can maintain a vacuum level of 3 Pa with a continuous pumping rate of 20 liters/s. At this level, both the index and buoyancy corrections are reduced by a factor of 2.5 x 10^{-5} with the index correction at 8 nW/W. Since the thermal

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conductivity of air drastically decreases below 20 Pa and 10 mW is dissipated in the main measurement coils, it may be necessary to operate at a slightly raised pressure. Without pumping, the vacuum level quickly increases to 70 Pa due to the outgasing of the fiberglass. An alternate approach would be to have a controlled environment of helium or nitrogen. Both approaches would still require the use of the refractometer to account for the index correction, but deviations in the refractive index due to temperature and pressure gradients will be greatly reduced. The optimum operating conditions will have to be determined experimentally.

The experimental building will be modified to reduce vibrational noise and to accommodate the new vacuum system. The inner room which houses the vacuum system will be reconstructed on a separate concrete slab and holes will be cut in the second and third floors of the main building so that there is no physical contact between the inner room and the external building. A second electrostatic shield will be on the inside walls of the inner room. Temperature control of the inner room can either be by forced air or by electric heaters as is now done. Inside the inner room, the upper vacuum chamber is supported by a fiberglass tripod. This design provides high frequency, highly damped structural modes with a low sensitivity to drift caused by temperature or humidity changes. Recently it has been determined that the building's air conditioning introduces vibrational noise, increasing the overall scatter in the data. The tripod design also provides convenient locations for active vibration isolators to be added if required.

Further Improvements

The next generation of the NIST watt balance will initially have only the major change of going to a vacuum system. The basic design of the balance will remain unchanged so that the cause of any discrepancies between the results from operating in air and in vacuum can more easily be determined. However there will be an opportunity to try new ideas and designs during the conversion.

Recently, a new programmable Josephson Voltage Standard (JVS) [4] has been used successfully as a direct reference, thereby eliminating two voltage transfers and their related noise and uncertainty contributions. A system dedicated to the watt balance is in the final stages of construction. During the conversion to a vacuum system, there will also be an opportunity to test a new dual flexure balance. Instead of a single knife edge, the design uses two flexures, one for the force measurement and one for the velocity measurement. Since the balance doesn't move during the force measurement, the drift due to knife edge or flexure hysteresis is reduced. Finally, we'll be collaborating closely with the NIST Mass group to study the effect of an artifact mass stored in a vacuum and the transfer of a mass from vacuum to vacuum. With the above improvements to the NIST watt balance, we hope to achieve the sensitivity necessary to measure the drift of an artifact mass.

References

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