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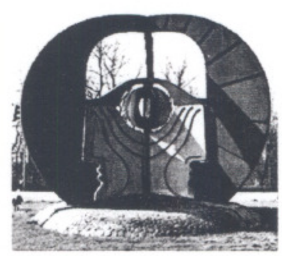

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THE NIST WATT BALANCE: PROGRESS TOWARD MONITORING THE KILOGRAM

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Abstract

Random uncertainty of 0.08 µW/W in the NIST watt balance has been achieved by improvements in a velocity measurement using three laser interferometers and by the reduction of filter delays and electrical noise. The latest results of this experiment are presented.

Introduction

The NIST watt balance [1] has been developed to compare the electrical values of the ohm and the volt to the mechanical and time values of the meter, kilogram, and second by measuring the watt in both electrical and mechanical units. Specifically, the force on a current through an induction loop in a magnetic field is measured, as is the voltage induced around that same loop when it moves at some velocity through that same magnetic field. By comparing the force times the velocity to the voltage times the current, the same quantity of power is measured in both electrical and mechanical units.

The accurate determination of this force, current, voltage, and velocity is limited by interactions in the physical, optical, and electrical characteristics of the entire system. Analyzing and reducing these error sources have been continuing activities on this project. Within the last year, significant changes in the basic design of the system, both physical and procedural, have reduced these errors.

The most important improvements have been in: 1) using three laser interferometers with precise alignment for the velocity measurement, 2) the reduction of filter time-delays and electrical noise in the voltage measurements, 3) procedures for reproducibly aligning magnetic, gravimetric, and geometric centers of the superconducting solenoid and gravitational fields with the inductive pickup coil, and, 4) the use of a refractometer for air index of refraction measurements. Some details of items 1) and 2) will be discussed here, but 3) and 4) are discussed in greater detail in companion papers [2, 3].

System Improvements

Volt - Velocity Parameter The velocity of the electromagnetic center of the coil as it travels through a magnetic field is the required value, but since the coil surrounds a superconducting solenoid inside a liquid helium cryostat, only a measure of its position vs. time at the coil edges is available. To allow an accurate measurement of velocity and voltage the experiment has been devised as a differential measurement. Two coils with equal turns and nearly equal voltage/velocity ratios are used. The voltage difference and the velocity difference between the moving coil and the fixed coil are measured. This arrangement insures that unwanted motions of the superconductor with respect to the two coils is canceled in the voltage/velocity ratio. The position of the coil's edge is measured with three laser interferometers mounted at equally spaced points on the coil (Figure 1). Three position and time signals are measured via three time interval analyzers. The lasers are aligned with gravity to better than 0.2 mrad. The three signals are

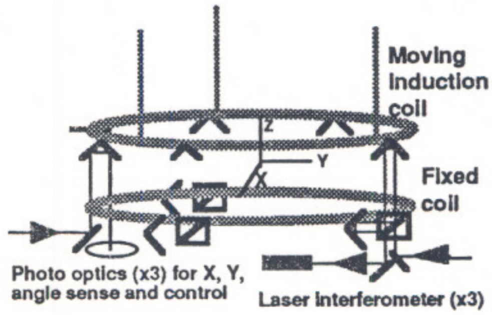

Figure 1. Coil schematic showing interferometer and alignment optics.

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mathematically combined in a way that minimizes the Abbe offset as detected by deliberately swinging the coils. Coil rotation is actively damped, using a separate set of optics, during all measurements to further limit offset errors caused by a coupling to motions other than along the vertical. This three laser arrangement provides a more exact record of the coil motion over previous designs which used a single interferometer which was axially central but displaced vertically above the cryostat. In the earlier arrangement, vibrations in the support rods contributed significant noise between the coil position and its induced voltage.

Calculated corrections to the length measurements for the air index of refraction are applied from measurements of temperature, humidity and pressure. A refractometer was built [3] to check the uncertainty of the corrections to be less than $1 \cdot 10^{-8}$.

The position measurements coincide in time with voltage measurements recorded on three digital voltmeters, each acting consecutively to minimize measurement dead time to a few microseconds of the 50 s signal duration. The wide dynamic range of the voltmeters also permitted averaging of large amplitude, high frequency signals without the use of low pass filters which produce unwanted time delays in the voltage measurements. Leakage resistance and ground loop interference in the electrical path were also reduced.

The uncertainty of voltage-to-velocity ratio values is presently about $5 \cdot 10^{-8}$ V·s/m. Greater reductions in this ratio appear to be limited by voltage noise generated by vibrations and environmental EMI coupling to the superconducting solenoid.

Force - Current Ratio The coil alignment procedures mentioned previously also helped to reduce the uncertainty in the force measurements. After reducing the alignment errors, the most severe limitation is in the hysteresis of the knife edge balance point. Due to the present limits of the positioning servo-system, adding or subtracting a 1-kg mass rotates the balance, causing unavoidable distortions of the knife edge. This rotation has been reduced to only about 200 mrad. A series of controlled oscillations was used to try to erase the hysteresis memory in the knife edge, but a component due to the previous rest position of the balance seems to have a decay constant of several hours. Also, the temperature measurements recorded on opposite sides of the balance wheel indicate that variations of several 10's of mK may be present and thus can contribute to the fluctuations in the weighings.

Moving the mass, restoring the position servo control, and oscillating the position take considerably more time than is spent in averaging the current readings. A set of six pairs of mass on/off weighings takes about 1.5 hours. Drifts during this interval are a major source of noise. An improvement in the weighing is expected when we reduce this time and reduce the fluctuations in the room environmental factors. Random uncertainty of the force-to-current ratio is now about $6 \cdot 10^{-8}$ N/A.

The Watt: Present and Future The combined random uncertainty has been maintained low enough, so that applied tidal corrections consistently improve uncertainty of K_{W90} determinations to the 0.08 μW/W level.

Improved design of the entire experiment will be necessary to reach our goal of monitoring the Kilogram to better than 10 μg/kg. Our designs for a new vacuum system, use of a gravimeter, and other improvements will be described.

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