Monitoring the Mass Standard: A Comparison of Mechanical to Electrical Power*

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Abstract

Except for the kilogram, all of the base units of the International System of Units (SI) are defined by invariant fundamental constants. The on-going NIST (formerly NBS) absolute watt experiment shows the promise of being able to monitor the stability of the mass standard to better than 0.05 ppm. We discuss our latest results and future possibilities.

Introduction

In the International System of Units (SI), the electrical units are defined in such a way that the unit of electrical power, the volt-ampere, is identical to the mechanical unit of power, the kilogram-meter^2/sec^3, and both are called a watt. The second is defined in terms of the frequency of a hyperfine transition in ^{133}Cs, while the meter is defined as the distance traveled by light in a certain time. Thus the units of time and length are defined by presumably invariant atomic or fundamental constants. Mass is the third quantity, with length and time, needed to define power. The unit of mass, however, is defined by an artifact, the International Kilogram. No invariant constant guarantees the stability of this artifact, and some copies of the Kilogram have shown large relative instabilities. It has been pointed out that a drift in the kilogram of 0.02 ppm per year cannot be ruled out [1].

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In the laboratory system of electrical units the volt is defined by the Josephson effect and the ohm is defined by the quantum Hall effect. These definitions tie the laboratory electrical units (in particular the unit of electrical power) to fundamental constants. Thus, the comparison of the unit of electrical power in the laboratory system of units to the unit of mechanical power in the SI offers the possibility of monitoring the stability of the mass standard. The NIST absolute watt experiment accomplishes exactly this comparison and can measure the stability of an artifact kilogram to the accuracy of the watt experiment.

Theory

When a circular current carrying coil of radius r is placed in a purely radial magnetic field B_r, a force F is developed perpendicular to the magnetic field. This force is proportional to the current I_2 in the coil and is equal to $2\pi r B_r I_2$. If the coil is open circuited and moved at some velocity v_z in the radial magnetic field, with v_z perpendicular to the field, a voltage E is developed across the open circuit and this voltage is proportional to the velocity v_z and is equal to $2\pi r B_r v_z$ (see fig. 1). It can be shown that $F_z/I_2 = E/v_z$, or $Fv_z = EI_2$. This equation expresses the equality of electrical and mechanical power and is true only if all quantities are in SI units. If I_2 and E are measured in laboratory units, we define the ratio of the units of electrical and mechanical power as $K_W = Fv_z/EI_2$. If the force is measured by comparison with the gravitational force on a mass M, we have $K_W = Mgv_z/EI_2$ where measured with adequate precision, in terms of invariant units, measurements of K_W over a period of time can be used to monitor the stability of the mass M.

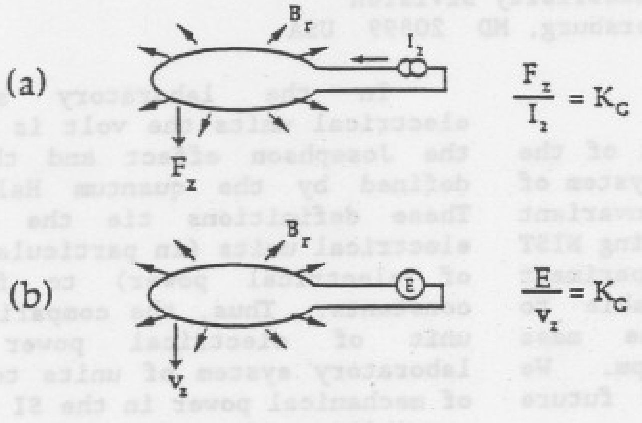

Fig. 1 Conceptual diagram of the experiment showing (a) the force measurement and (b) the voltage measurement. The geometry constant, $K_G = 2\pi r B_r$.

The Experiment

The apparatus has been explained in detail elsewhere [2], as have some preliminary (~1 ppm) results [3]. Further improvements have now been undertaken to decrease the measurement uncertainty by an expected order of magnitude, to less than 0.1 ppm for the measurement of K_W. The major improvement has been the incorporation of a liquid helium cooled superconducting magnet. This new magnet allows an increase of the radial magnetic field by two orders of magnitude. This superconducting magnet is now operational and we are measuring the performance of our system with this large increase in signal.

References

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