IMPROVEMENTS IN THE NIST WATT MEASUREMENT: MONITORING THE MASS STABILITY OF THE KILOGRAM*

P. T. Olsen, *Member, IEEE*, W. L. Tew, *Member, IEEE*, and E. R. Williams, *Member, IEEE*
National Institute of Standards and Technology
Electricity Division
Gaithersburg, MD 20899 USA

Abstract

Considerable progress has been made toward the two orders of magnitude decrease of the experimental uncertainty of the NIST watt measurement from that previously reported. The rebuilding of the apparatus and electronics provides the automated measurement capability to obtain the statistical resolution required to study the system's behavior and the numerous possible sources of error.

Introduction

By International agreement, the Josephson frequency to voltage quotient or Josephson constant and the quantum Hall resistance or von Klitzing constant are fixed in value [1]. These two stable sources provide highly reproducible laboratory units of voltage and resistance which can be converted into a highly reproducible unit of electrical power. Through the use of a watt balance, the stability of the mass of the kilogram can be evaluated 'to the accuracy of the watt determinations. The previously reported NIST electrical watt as measured in terms of the SI watt had a measurement uncertainty of 1.33 ppm (parts per million). It has been reported that the mass of the kilogram is thought to be stable to at least 0.01 ppm/year. Thus the measurement uncertainty of a watt balance experiment would have to be of the order of 0.01 ppm to be of significance in the monitoring of the stability of the international standard of mass, the SI kilogram.

Experiment The theory [2] and apparatus of the NIST watt balance have been fully discussed elsewhere [3,4]. Simply put, one can consider the heart of the apparatus as being a linear motor-generator, a coil in a radial magnetic field whose axes are coincident and parallel with respect to the local vertical. The required measurements are:

1. the ratio of voltage V induced in the coil when that coil moves at some velocity v parallel to the axis of the radial magnetic field (V/v); and
2. the ratio of static force F that the coil will exert parallel to the axis of the radial magnetic field to a dc current I in that coil (F/I).

Measurement 1 requires the simultaneous measurement of induced voltage V, the coil position z along the vertical path traced out by the moving coil, and the time t at position z. Because of unwanted induced voltages caused by nearby power lines, the voltage measurement is integrated over ten power line cycles. The vertical position and time at the start and end of the voltage measurement is monitored by a laser interferometer and recorded by a commercially available "frequency and time interval analyzer". The voltages, positions, and times are recorded over a path length of approximately ten centimeters. An alternating series of upward and downward measurements are recorded. Progress on increasing the overall measurement sensitivity is monitored with a regular series of data taking. Such a series was made in November 1991. The results of the individual measurements are shown in figures 1 and 2 (The standard deviation (S. D.) and standard deviation of the mean [S. D. (mean)] are given in each figure). The recorded average value for the voltage to velocity is approximately 481 V s/m.

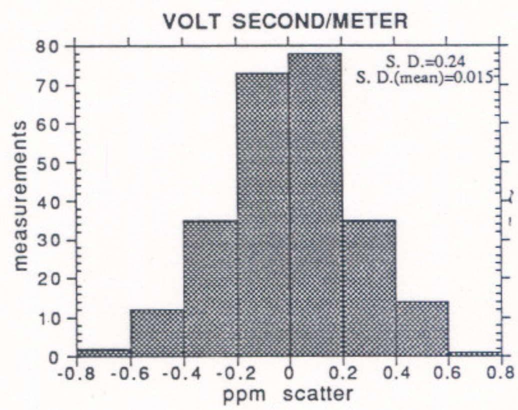

Fig. 1 Typical scatter of a series of voltage to velocity measurements as of November 1991.

The system is then switched over to begin measurement 2. In the force measurement the coil is servo controlled to some vertical position as measured by the laser interferometer and magnetically held in place. A gravitational force equivalent to a one kilogram mass in the earth's gravitational field is applied to the coil. The servo responds by exerting a magnetic force via a 10 mA current in the coil to just counter balance the force applied by the kilogram mass. The value of the current is recorded when the resultant kilogram force is applied and when it has been removed. A bias force equivalent to one half the kilogram mass is continuously present in the upward direction. Thus there is a 10 mA current in the coil during all the force measurements which reverses when the principal force of the one kilogram mass is applied. The value obtained for the November 1991 measurement series is approximately 481 N/A. The force per current is measured over the entire path length evaluated in the voltage to velocity measurement.

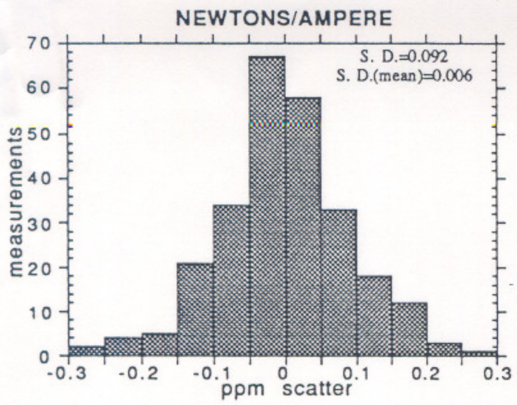

Fig. 2 Typical scatter of a series of force to current measurements as of November 1991.

The ratio of the electrical watt to the SI watt is the result of measurement 2 divided by the result of measurement 1. The overall uncertainty in monitoring the stability of the kilogram mass rests in how well one can do measurements 1 and 2. For completeness, the results of the watt measurements are shown in figure 3. A small linear drift in the data has been removed. The linear drift is assumed to be the result of incomplete monitoring of environmental conditions.

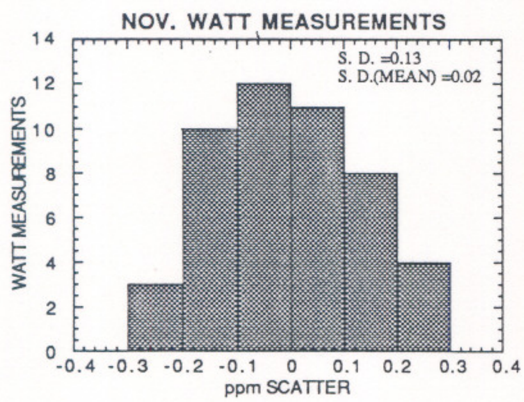

Fig. 3 The resulting watt measurement scatter. A linear drift has been removed from the data.

Conclusion

As of November 1991, preliminary data (standard deviation = 0.13 ppm for 48 measurements; standard deviation of the mean = 0.02 ppm) indicates that the required resolution or precision for monitoring the kilogram mass stability may soon be realized. Still to be accomplished though for the required accuracy (overall experimental uncertainty 0.01 ppm) are: the real time measure of the air index of refraction (approx. 270 ppm) and the real time measure of the air buoyancy correction (approx. 70 ppm). Various sources of systematic error also must be more fully evaluated, such as the balance knife edge hysteresis, coil alignment in the magnetic field [5], and non vertical motion of the coil. To date, though, no limiting factor has been discovered which would preclude a monitoring of the mass stability of the kilogram at the 0.01 ppm level.

References

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