COMPARISON OF TWO MODELS OF TABLE TOP WATT BALANCES

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Abstract: The watt balance[†] is an experiment that has been used for the upcoming redefinition of kilogram in terms of the Planck, constant, h. The watt balances at several national metrology institutes perform at a 1 kg level and the best ones have achieved relative standard uncertainties of a few parts in 10^8. This presentation shows the design and improvements of two table top watt balance prototypes developed at NIST, intended to measure up to 10 g with a relative standard uncertainty of 10^{-6}.

1. INTRODUCTION

In 2018, the unit of mass, the kilogram, will be redefined in terms of an invariant of the nature [1], the Planck constant, h. Two main projects are being undertaken for this purpose: The Avogadro project which relates the kilogram to the Avogadro constant N_A by determining the atoms contained in a 1 kg mono-crystalline silicon sphere and, the watt balance that would link the kilogram to h, by virtually equating mechanical power to electromagnetic power. The product of the Avogadro constant and the Planck constant is very well known, via measurements of the Rydberg constant. This means both methods can ultimately be traced back to the Planck constant.

NIST, has built two prototypes of table top watt balances and, in collaboration with CENAM, have been tested and improved with the aim to achieve a relative standard uncertainty of some parts in 10^6 at a maximum load of 10 g. The target uncertainty was based on the uncertainty required for calibration of OIML weights [2]. For a 10 g Class E_2 weight, the standard uncertainty should be less or equal to 10 µg, i.e., $u(m) / m = 1\times10^{-6}$.

2. WATT BALANCE BASICS

The watt balance is a self-calibrating instrument proposed by Kibble in 1976 [3]. This instrument uses two measurement modes: the weighing mode (or force mode) and the velocity mode. In the weighing mode, the weight w (gravitational force) of a mass m is counteracted by an upward electromagnetic force produced by an electrical current I circulating in a coil with wire length L immersed in a magnetic field with flux density B perpendicular to the direction of the current. The electrical current can easily be measured to high precision by passing it through a well-known resistor R and by measuring the voltage drop U_w across it. The measurement model is:

$$w = mg = BLI = BL\frac{U_w}{R} \tag{1}$$

In order to avoid the complexity of measuring to high accuracy the length of the wire L, the second measurement mode, i.e., velocity mode, is performed. The geometric factor BL in equation (1) can be obtained by measuring the voltage U_v induced in the same coil as it is moved in the magnetic field along its vertical axis at a constant velocity v. The symmetry in Maxwell's equations is such that the quotient of the induced voltage to velocity is equal to the geometric factor, so:

$$BL = \frac{U_v}{v} \tag{2}$$

By combining equations (1) and (2) the watt balance equation is obtained:

$$mgv = U_v I \tag{3}$$

The mechanical power to move the mass vertically in a gravitational field at a given velocity is equal to the electrical power. The unit of power in the SI is the watt, hence the name of this experiment.

[†] Recently, the International Committee for Units (CCU) has renamed the watt balance for the Kibble balance, in honor of his inventor, Dr. Brian Kibble (1938 – 2016).

3. TABLE TOP WATT BALANCE MODELS

Two prototypes of table top watt balances (TTWB) were developed with different mechanical designs but capable to perform the two measurement modes described above.

3.1. Seismometer TTWB

The seismometer watt balance was inspired by [4]. The CAD drawing of this model is shown in Figure 1. The significant difference of this balance is that the permanent magnet is moved instead of the coil.

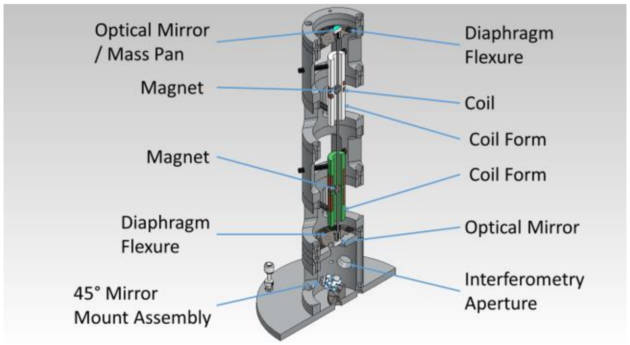

Fig. 1. *CAD drawing of the seismometer TTWB.*

3.2. Beam Balance TTWB

Figure 2 illustrates the CAD drawing of the Beam balance TTWB model.

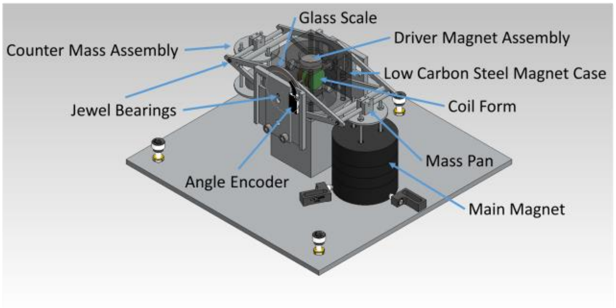

Fig. 2. *CAD drawing of the beam balance TTWB.*

4. DISCUSSION

Both balances were built at NIST and we collected some experience using the balance to weigh masses. The following table shows the pros and cons of both TTWB models:

Feature	Seismometer TTWB	Beam Balance TTWB
Large BL	NO	YES
High speed	YES	NO
Long travel range	NO	YES
High mechanical hysteresis	NO	YES
High sensitivity	YES	YES
Eccentric load error	YES	NO
Compact design	YES	NO
Easy assembly	YES	NO
Innovative idea	YES	NO

Table 1. Comparison chart of the two TTWB models

5. CONCLUSIONS AND FUTURE WORK

All the test and improvements so far of both TTWB models were focused on minimizing type A uncertainty. Type B uncertainty should be study in the future. This instrument could be used in mass measurements for industrial application with direct traceability to h.

REFERENCES

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