Do It Yourself: a Simple Model of the Kibble Balance

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Abstract. The Kibble balance is an instrument used for determining mass in the new definition of the SI system. The fact that this is a rather complex device may complicate students' understanding of how the unit of mass is now defined. A simple model (showing just the "electromagnetic part" of the Kibble balance, not the relation of a kilogram to Planck's constant) can help understand the principle of this device. The paper will present the construction of such a simple model, show how to use it in both velocity and force modes, and discuss the results of measurements.

Introduction

In the "old days", the definition of a kilogram was simple and understandable even to young pupils: kilogram was simply "that what is in Sèvres under a glass bell". After a new definition of SI units was adopted in 2019, the definition of a kilogram is much less comprehensible for non-experts. Also, the device used for determining (the unit of) mass is now more complicated than simple balance. Even if we left aside sophisticated quantum issues concerning the precise measurement of voltage and current used in professional Kibble balance, the electromagnetic part of its function using force and velocity modes seems not easy to grasp for students and for physics teachers too, at least at first glance. Some simple model, not costing millions of dollars as a professional Kibble balance, can help to understand the principle of this instrument.

A "LEGO model" of the Kibble balance was built by physicists in NIST [1] just for this purpose. Nevertheless, it is still quite sophisticated. (For example, the position of a 3000-turns coil is measured here to an accuracy of 50 μm.) This was a motivation for trying to build a much simpler device that could be built by teachers themselves and could still demonstrate the principle of the Kibble balance. The first wish was very modest, to make a device that would demonstrate measuring a small mass to an accuracy of just an order of magnitude.

Model of the Kibble balance

Figure 1 shows the simple model of the Kibble balance in velocity mode measurement: the beam from the wooden batten can oscillate, forced by a spring; the voltage induced in the 330-turns coil is measured by a Vernier Labquest voltage sensor. (A neodymium magnet pole is inside the coil.) A laser pointer is attached to the beam, the spot of its light on the wall is used to measure the amplitude of oscillations of the beam.

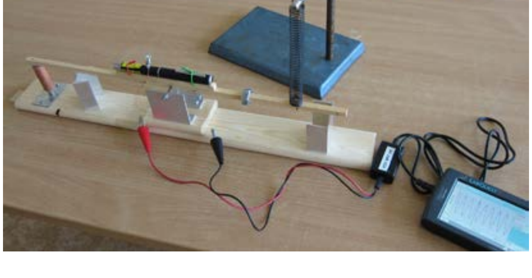

Fig. 1. A simple model of the Kibble balance: measuring in velocity mode.

In force mode (not shown here) the weight of the 0,1 kg is balanced by a magnetic field force acting on the coil. The current through the coil is measured by a common multimeter.

Results of measurements

In our case, the amplitude of the induced voltage in velocity mode was almost 0.15 V. The maximum velocity υ of the coil was calculated from the amplitude and period of its oscillations and put into the formula $F = U{\cdot}I/\upsilon$ determining the force acting on the coil in the force mode. This agreed with the weight of the mass hanged at the other end of the beam to an accuracy of about 4 % or slightly better. (This can be compared with the accuracy of NIST "LEGO balance" which, according to [1] was about 1 %.)

Conclusions

The above-mentioned simple model of the Kibble balance was presented at the national conference of Czech physics teachers in 2020 and described in the conference paper [2]. As it has attracted teachers' interest, it could hopefully be of some interest also to the international community of physics teachers and educators. The conference paper will describe details of the construction of the model as well as high school level derivation of the principle of its function and the formula for the force. Also, measurement with this device, its results, and possibilities for further improvements will be discussed.

References

[1] L. S. Chao et. al.: A LEGO Watt balance: An apparatus to determine a mass based on the new SI. *Amer. J. Phys.* **83** (2015) 913-922.

[2] L. Dvořák, Jak vážit pomocí ampérmetru a voltmetru aneb vyrobte si (skoro) Kibblovy váhy, In: *Veletrh nápadů učitelů fyziky 25. Sborník z konference*. MatfyzPress, Prague (2020) 47-56. (In Czech) Available online: https://vnuf.cz/2020/sbornik_VNUF_2020.pdf.