

Background

Kibble balances are highly accurate instruments for the realization of the SI unit of mass, commonly at the level of 1 kg or sometimes 500 g [1]. However, its application is not limited to those mass values, but can be extended to mass values such small as milligram and below. Compared to conventional balances, there is no need for a calibration via mass standards. Its traceability is performed via voltage, resistance, length and time measurements. PTB's Kibble balance for such purposes is called Planck-Balance [2].

Applications

Its main application lies in the determination of small mass values, as its potential is high to reach lower uncertainties than by means of conventional mass calibration, i.e. by mass comparison. Moreover, Kibble balances can weigh "odd" mass values, such as, e.g. 2.76 g, and thus allow weighings of substances directly. The traceability is realized via electrical (voltage and resistance), length, and time measurements, which can be calibrated from remote. This allows its use in areas with biological, chemical or radioactive hazardous substances.



Calibration of mass standards



Calibration in hazardous areas



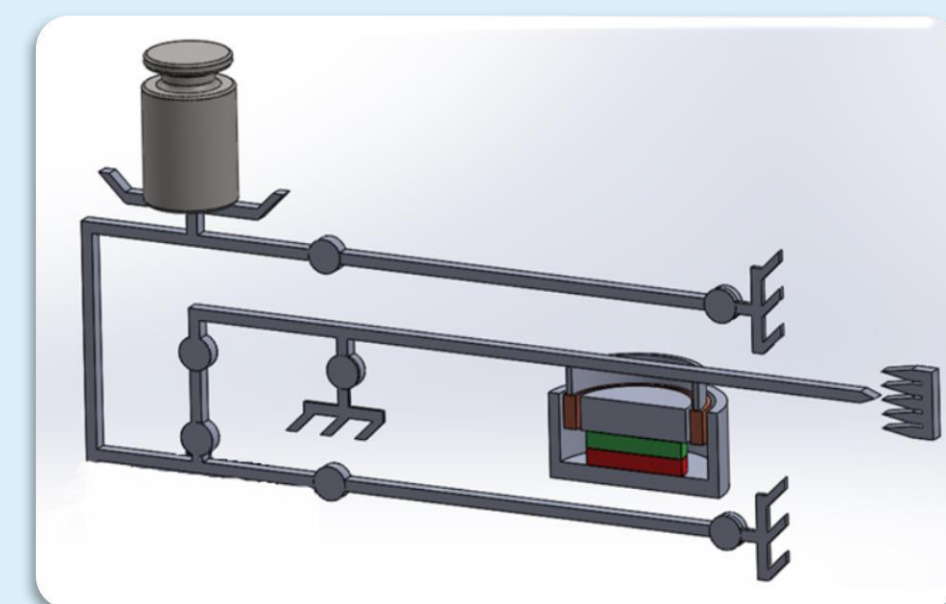
Weighing of substances

Principle of Planck-Balance

Principle of an EMFC* load cell

$$m = \frac{Bl}{g} \cdot I = \frac{Bl}{g} \cdot \frac{U_f}{R_f}$$

$$F = m \cdot g$$



Compensation of weight by electromagnetic force from magnet-coil system

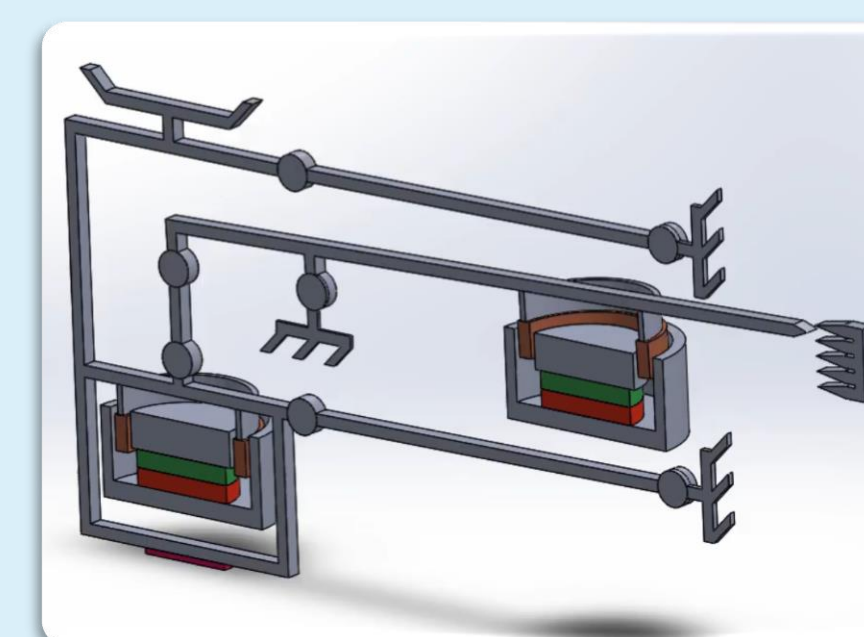
$$F = Bl \cdot I$$

"geometric factor":
property of magnet-coil system

+

Application of „Kibble's principle“: Determination of geometric factor

$$Bl = \frac{U_v(t)}{v(t)}$$



Determination of Bl via Faraday's induction law.

$$m = \frac{U_v(t) \cdot U_f}{v(t) \cdot g \cdot R_f}$$

Applied also in conventional analytical laboratory balances



Nomenclature:
 B : magnetic flux density
 l : coil wire length
 m : mass
 g : local gravity
 I : electrical current
 U_f : voltage in force mode
 R_f : electrical resistance
 U_v : voltage in velocity mode
 v : velocity
 t : time



The Planck-Balance is PTB's compact Kibble balance, designed to operate in air. The mechanical setup fits onto a standard weighing table and has a height of less than 0.5 m. In the image, protective covers have been removed to expose internal components.

Results

The Planck-Balance is capable of determining masses from 1 mg to 5 g with standard uncertainties that are lower than what is needed to calibrate E1 mass standards [3]. No subdivision of masses starting from 1 kg is necessary. The results presented in this figure represent measurements over 12 h for each mass, but even with 1 h measurements the uncertainty lies below the requirement for accuracy class E1 calibration.

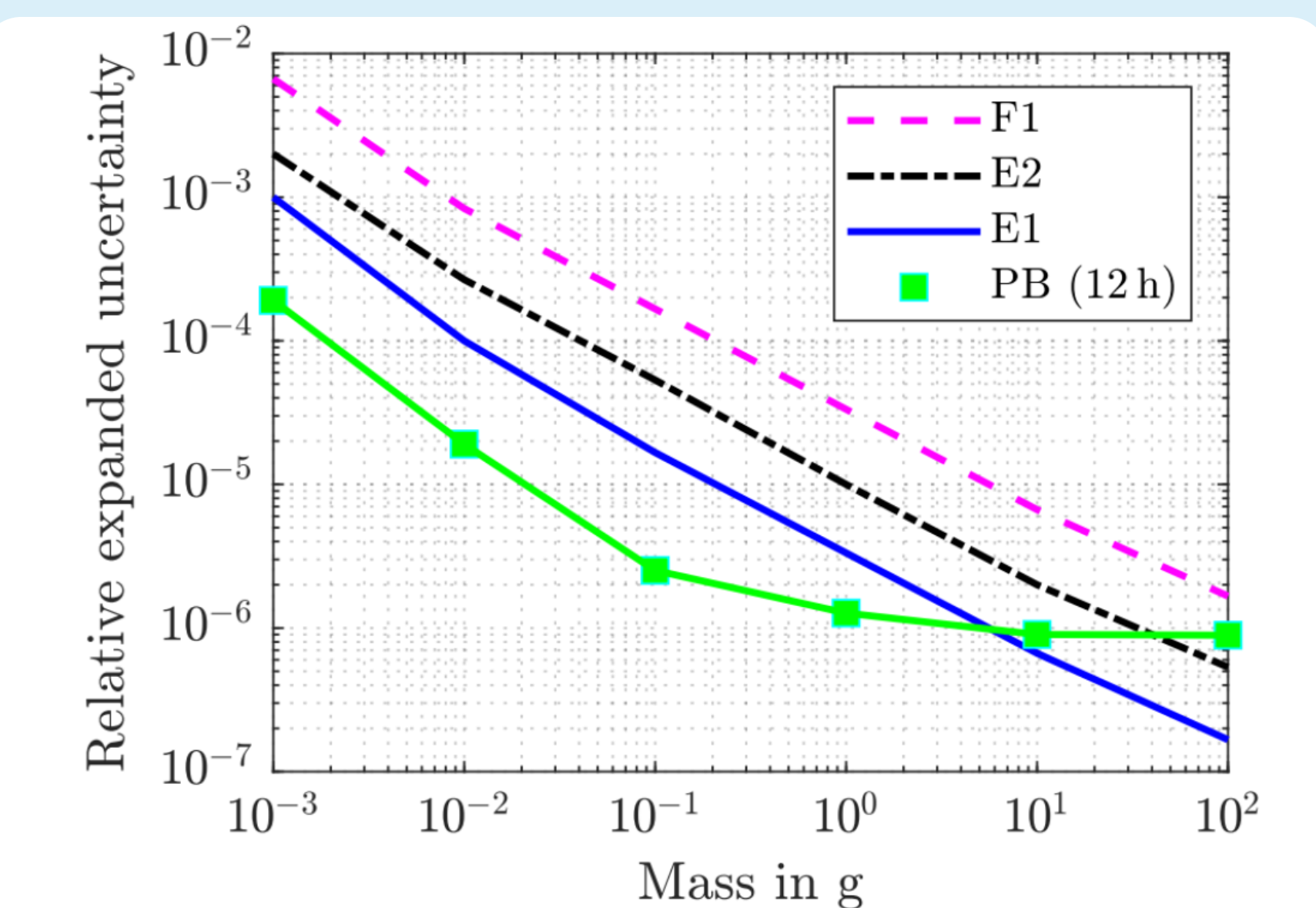


Figure: Relative uncertainties of mass standards of accuracy classes E1, E2 or F1. Green: uncertainties reached with the Planck-Balance.

Outlook and future tasks

- Development of a more compact setup.
- Improvement of weighing repeatability to below 0.5 μ g.
- Identification of cost reduction opportunities.

References

- [1] Robinson, I. A., & Schlamminger, S. (2016). The watt or Kibble balance: a technique for implementing the new SI definition of the unit of mass. *Metrologia*, 53(5), A46.
- [2] Rothleitner, C., et al. (2018). The Planck-Balance—using a fixed value of the Planck constant to calibrate E1/E2-weights. *Measurement Science and Technology*, 29(7), 074003.
- [3] Konrad J. et al. (2025). Small mass value realization equivalent to accuracy class E1 using the Planck-Balance at PTB. submitted for publication

* EMFC – electro-magnetic force compensation