A review of the Kibble balance technique for relating mass, force and torque to the Planck constant.

Ian A. Robinson

National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 OLW, U.K.
email: ian.robinson@npl.co.uk

The 2019 revision of the SI fixed the numerical value of the Planck constant to define mass within the SI. Thus any technique, at any scale, which, previously, was able to measure the Planck constant in terms of mass, can now be used to measure mass in the SI without reference to a macroscopic artefact standard.

The Kibble balance technique, which relates virtual electrical and mechanical power, was first conceived at NPL in 1975 by Bryan Kibble. The world's first Kibble balance (originally called the moving-coil watt balance) : the NPL Mk I, was used to help unify the world's voltage measurement systems. By combining the Josephson and Quantum Hall effects it is possible to relate virtual electrical power to the Planck constant and time. This allowed the Kibble technique to measure the Planck constant and now, after the revision of the SI, allows the technique to measure SI mass, force and torque.

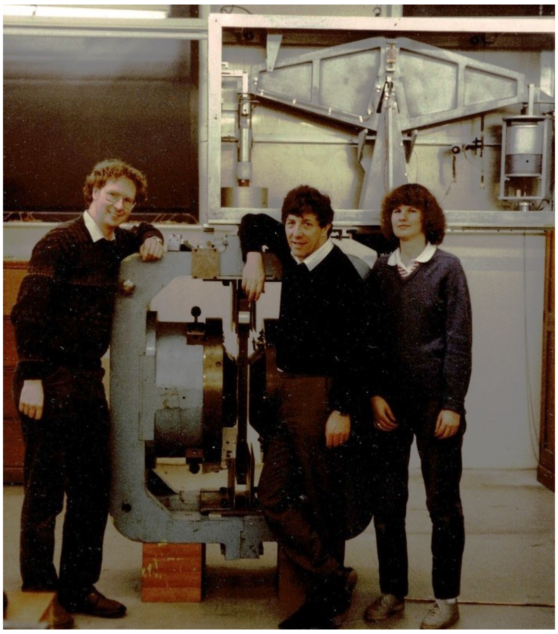

Figure 1: Ian Robinson, Bryan Kibble and Janet Belliss with the NPL Mk I Kibble balance.

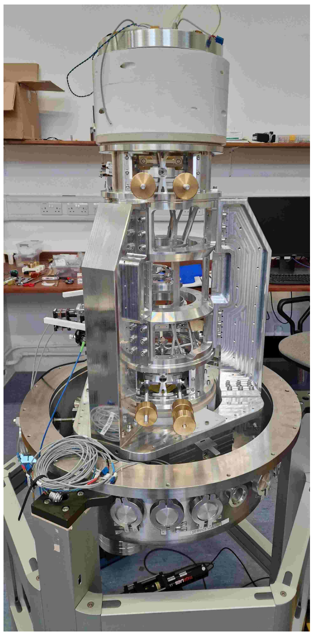

Figure 2: A "proof of concept" prototype of the NPL Next Generation Kibble balance.

Before the redefinition many National Measurement Institutes built Kibble balances for measuring the Planck constant and, after redefinition, these balances have been repurposed for realising the mass unit in the revised SI. Kibble balances with this aim are very expensive (costing many millions of Euros) but, for masses in the mg to μg range, large conventional measurement uncertainties arise from successive subdivision of the kg reference. In this case carefully designed Kibble balances, using conventional electrical standards can be used to make these measurements with improved accuracy and convenience. The technique can also measure force and torque, both statically and dynamically, and some laboratories have been developing instruments to work in these areas.

The technique has not stood still since it was conceived. BIPM proposed a new operating method and NPL has produced an extended theory which simplifies the operation of the balance under specific circumstances. Many laboratories have worked on novel forms of balance ensuring that the technique does not stagnate.

Future aims include making it easier for laboratories to make independent measurements at the highest level and also to make full use of the technique for smaller masses, forces and torques to support novel industrial applications.