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EMRP
European Metrology Research Programme
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Publishable JRP Summary for Project T1 J1.1 (e-MASS) The watt balance route towards a new definition of the kilogram

The kilogram is the last unit of the international system (SI) still based on a material artefact, the international prototype of the kilogram (IPK). Past comparisons made in the last hundred years have revealed an average relative drift of about 5.10^{-8} between the IPK and a set of copies kept under similar conditions. With the present definition of the mass unit, it is impossible to assign this drift to the IPK or to the copies (or eventually to both). Moreover, variations of the mass unit directly reflect on the ampere definition and therefore on the whole set of electrical units. In this context, a new definition of the mass unit becomes a priority for the metrological community. A promising route towards a new definition based on fundamental constants is given by the watt balance experiment (WB) which links the mass unit to the Plank constant (*h*). Such a definition would not only allow to realise the unit of mass at different places at the same time but also improve the consistency of the SI and drastically reduce the uncertainties on a large number of other constants through a statistical adjustment procedure. All units depending on the kilogram such as the ampere, the mole or the candela will no longer depend on the behaviour of a material artefact.

Even though the decision to change the definition of the mass unit can only be taken by the CGPM, a set of coherent values obtained by independent experiments is a mandatory condition. Each published value of *h* obtained with a watt balance will directly contribute to the new definition and therefore have a strong worldwide impact.

The e-MASS project supports the effort of the two European experiments of EJPD and LNE and creates synergy between the teams to share their expertise in order to develop new tools, techniques and methods in several fields of application.

The first topic of the e-MASS project is mainly experimental and is intended to show the feasibility and to provide solutions adaptable to both watt balances. Three main issues relative to the WB experimental set-up have been selected. The first one is dedicated to the difficult problem of alignment of the experimental set-up in order for the apparatus to work according to theory. The second deals with magnetic field behaviour, while the third concerns noise reduction.

The second topic deals with gravimetry and the capability to transfer the free-fall acceleration from the position of the gravimeter to the position of the test mass itself, with a relative uncertainty of a few parts in 10^9. To succeed, two tasks have to be accomplished: i) determine the free-fall acceleration with absolute gravimeters and ii) transfer the absolute value to the reference position in the watt balance.

Finally the e-MASS project is a unique opportunity to merge the expertise from the different laboratories and gather the experience of each one, in order to

provide advices to laboratories planning to develop a watt balance for the “mise en pratique” of the future definition of the kilogram. A critical analysis of the different existing devices will be done to select the methods, techniques and design of individual components best suited for the realisation of an optimised watt balance.

The main goal of the e-MASS project is to bring the European laboratories presently developing watt balances at a level sufficient to allow future determinations contributing significantly to a new definition of the mass unit. During three years, the project will contribute to the characterisation of parameters having a critical influence on the uncertainty budget of the two remaining watt balances in Europe.

Key project achievements

Since the beginning of the project, a special attention has been paid to define the consequences of perturbing effects on the watt balance through uncertainty calculation. In particular, the influence of misalignments has been estimated and the possibility to bring corrections to final results from their measurement has been shown. This approach leads to define or design detectors, alignment methods and parts of the watt balance in such a way to minimise the final uncertainty.

To this end, several devices have been made or are under fabrication to adjust the vertical linear displacement of moving parts of watt balances (including their moving coil) or to measure their unwanted displacements.

On the mechanical side, the problem of the vertical alignment of the trajectory of the watt balance guiding stage is solved by using a method based on a reference inclinometer and the determination of the trajectory of a reference body linked to the guiding stage, with the help of capacitive sensors. The measuring device has been used on the LNE watt balance for which an alignment on the vertical at about 5 µ radians has been achieved. The same device has been used to align the magnetic induction field in the horizontal plane with an uncertainty of 10 µradians

Several high resolution optical tuneable position sensors based on propagation properties of gaussian beams and intended to determine unwanted displacements of the watt balance moving coil have been developed. These detectors, as well as interferometers are associated to optical elements used for their alignment along the vertical. For this purpose, specific collimation tools have been developed and a set-up based on long focal length telescope associated to a CCD camera and image processing has been developed. The LNE device, equipped to be easily positionable around the watt balance is fully automated and is used to compare the orientation of laser beams with an uncertainty better than 10 µradians

It has also been demonstrated that the number of degrees of freedom of a watt balance suspension may be adjusted in such a way that the use of the above mentioned interferometers and position detectors allow to distinguish forces and torques on the coil in the static phase. The uncertainty calculation on these terms , based on Monte-Carlo method, allowed to establish a number of constraints to be satisfied by the suspension and detectors. Consequently, the coil’s suspension of the LNE watt balance has been machined and assembled.

Noise reduction will be reached by developing totally fibered Doppler interferometers to control the watt balance moving coil velocity. A new frequency doubled Nd-YAG laser source stabilised on iodine has been mounted and three totally fibered Doppler interferometers have been constructed. They will be used in close loop operation with three piezoelectric actuators situated in the suspension of the moving coil. The study of the necessary electronics is now under way.

The second main topic is gravimetry for which three gravimeters of different principles (two falling corner cube gravimeters and a cold atom gravimeter) are in use or in development to determine the absolute value of *g* in watt balance laboratories. The knowledge and the performances of these gravimeters have been improved and they all took part in the International Comparison of Absolute Gravimeters (ICAG 2009) at BIPM. The CNRS cold atom gravimeter has then been transferred to the LNE watt balance laboratory. Type B uncertainties of the three gravimeters have been studied and compared to each other at the LNE watt balance site

These actions are completed by *g* transfer study from the gravimeter to the watt balance for which gravimetric mapping has been made in LNE and METAS laboratories. Modelling of surrounding masses by FEM has been made by INRIM, as well as the self-gravity effect of the cold atom gravimeter. Modelling of the LNE watt balance self-gravity effect is presently underway.

EJPD determined a value of the Planck constant with a relative uncertainty of 4×10^{-7} with its present watt balance. New solutions for the realisation of magnetic circuit, guiding stage, weighing cell are presently under investigation in view of the realisation of a second generation watt balance. The knowledge gained through this analysis will be made available through a report to those organism intending to develop a watt balance experiment

The interest of such researches has been emphasised during the Watt Balance Technical Meeting held at LNE in March 2009 where the above mentioned state of development of the e-MASS project has been presented to the watt balance community.

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