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Special requirements of the design of new transfer artefacts for the calibration of mass standards

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Abstract:
The harmonised modelling of new types of transfer artefacts made of monocrystalline silicon provides the necessary basis for highly accurate calibrations of mass standards with a nominal mass of one kilogram under atmospheric conditions. The special requirements for a material-independent design are investigated. All significant physical parameters as well as the requirements for user-friendly handling are taken into account.

Keywords: Transfer artefacts, buoyancy artefacts, sorption artefact, duplex artefact, inlay artefact, silicon sphere, mass, kilogram, mass calibration

Taxometry

Transfer artefacts can be used for mass comparison measurements. The measurements in vacuum and under atmospheric conditions allow conclusions to be drawn about the surface coverage by water or hydrocarbons and systematic effects due to air buoyancy, for example. The transfer artefacts discussed refer to a 1 kg silicon sphere as a reference standard. The surface of the reference sphere represents the minimum surface. The newly created term taxometry is composed of the definition for classification into systematic categories (taxonomy) and the subject area (metrology).

The transfer artefacts are classified into three different categories: a) sorption artefacts, b) duplex artefacts, c) buoyancy artefacts. Two sorption artefacts and two buoyancy artefacts are used as a pair. All test artefacts have the same nominal mass and surface properties (especially with regard to roughness) as the reference (reference sphere). In the following, designs with cylindrical artefacts whose surfaces differ as much as possible in terms of area must be determined for sorption artefacts. This results in 2-disc, 3-disc and 8-disc artefacts.

The described sorption artefacts are uniform in mass and density, which is realised by a disc-shaped assembly. Two variants of buoyancy artefacts can be used to determine the (air) buoyancy correction. Unlike the sorption artefacts, their nominal area is the same, but their density is different. For the greatest possible volume difference between the buoyancy artefacts, a artefact with hollow space (hollow artefact) and an artefact with an enclosed core of a denser material (inlay artefact) are designed.

Another category of transfer artefacts are so-called duplex artefacts. Due to their properties, these can be used to determine both sorption effects and buoyancy effects. Nominal mass and surface properties are similar to all other artefacts, including the reference. Duplex artefacts have the same nominal volume as sorption artefacts with a multiple of the surface area of the reference.

Limitations

Uniform installation dimensions are demanded for all transfer artefacts, due to the vacuum mass comparators used. The maximum radius of a cylinder is 0.045 m due to the housing geometry. The maximum usable installation height is 0.105 m. Due to the complex handling in the comparator, however, a maximum height of 0.1 m is pursued. Due to the mounting geometry, a minimum disc height of 0.015 m is recommended. The following densities apply:

Silicon 2 328.8 kg/m³ [1], Tungsten 19 250.0 kg/m³ [2] and Air 1.2041 kg/m³ [3, 4]. The surface roughness of all artefacts should be in the range of 10^{-9} m, analogous to the reference standard. The geometry of the chamfers to be designed describes straight chamfers with an angle of 45° and a leg dimension of 0.000 5 m. The calculation accuracy is 10^{-12} kg/m³. The accuracy of the calculation is set at 10^{-12}.

A uniform basic geometry of disc artefacts is used for all transfer artefacts, which enhances the development of a uniform calculation ap-

proach and simplified manufacturing. A transfer artefact is made up of at least one disc artefact, a straight circumferential chamfer and a number of spherical spacers, so-called coupling spheres. Via the latter, a six-point bearing is obtained, which serves as a kinematic coupling [5, 6] and connects the individual disc artefacts with a defined gap height. The stability for the assembly of the individual disc artefacts, as well as the tilting stability during the placement of the comparators and during the weighing process, was determined experimentally for an angle of inclination of up to 20° [7]. The reproducible dismountability of the disc stacks enables efficient and comparable cleaning [8] to the reference. If a transfer artefact consists of more than one disc artefact, a distinction is made between top, middle and base disc(s) for the disc stack.

Special requirements

Transfer artefacts enable the correction of systematic deviations and the calculation of a measurement uncertainty contribution during the substitution calibration of mass standards of different density [9]. The objective is the determination of environmental influences. High-quality 1 kg silicon spheres are used as a reference.

The following physical properties and handling conditions must be fulfilled for all transfer artefacts:

- same nominal mass as the reference
- same material and surface quality as the reference, natural monocrystalline silicon, if possible without amorphous surfaces
- nominal surface ratios of transfer artefact to reference should ideally be designed as whole numbers (this supports the descriptive assessment of sorption effects)
- Geometrical specifications of the measuring chambers within the mass comparators, variable parameters: Number, height and radius of the transfer artefact discs
- practice-oriented placement taking into account the mounting geometry (minimum height) within the comparators, this requires a special design of the base disc
- Simple dismantling of the transfer artefact discs for efficient cleaning
- Kinematic coupling by frictional connection of the transfer artefact discs to be stacked
- High tilt stability of the transfer artefact discs for transport and assembly of the comparators.

The transfer artefacts are used both under atmospheric conditions and under vacuum in mass comparators.

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