

A NEW SUPERCONDUCTING LEVITATED-MASS SYSTEM

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Abstract: A new superconducting levitated-mass system is now being developed with the final target of replacing the kilogram in terms of the fundamental constants. Improving the stability of trajectory by means of introducing a superconducting linear bearing is the issue in question for the first stage of this development. The present status of the development, experimental results and further prospects are discussed.

Keywords: mass standard, replacing the kilogram, fundamental constant, superconducting, superconducting bearing

1 INTRODUCTION

With the aim of replacing the present unit of mass, the kilogram, by a definition that is based on the fundamental constants, some electro-mechanical systems, such as the levitated-mass [1] and the watt-balance [2], have been proposed, in which electric quantities, such as power or energy, measured in terms of the Josephson and quantum Hall effect are compared with mechanical quantities measured in terms of the kilogram. For monitoring and replacing the kilogram, the uncertainty of 10^{-8} is required [3]. The Levitated-mass method, in which a superconducting body is levitated in a magnetic field generated by a superconducting coil, has been studied at NRLM [4] and VNIIM [5].

Comparing to the NIST watt balance [2], which also aims to replace the kilogram by means of connecting electrical and mechanical quantities, the levitated-mass method is not widely considered as promising because of the following difficulties,

- Difficulty-1. Incompleteness of Meissner effect,
- Difficulty-2. Instability of trajectory,
- Difficulty-3. Inconvenience in using low-temperature environment.

However, this method has some definite advantages.

- Advantage-1. Absence of mechanical contact
- Advantage-2. Stability of the experimental environment
- Advantage-3. Direct use of superconductivity and cryoelectronics

We have investigated this method using a prototype system [6-9], and confirmed that the stability of trajectory must be carefully considered even for a measurement with a relative uncertainty of 10^{-6} (1 ppm).

With the aim of overcoming the instability of trajectory, Difficulty-2, we begin to develop a second system [10], which can be operated parallel with the previous system. The features of the new system are as follows.

- Feature-1. Introduction of superconducting linear bearing
- Feature-2. Precise machining
- Feature-3. Flattening of the main Meissner surface

By means of Feature-1 and Feature-2, the stability of the trajectory is expected to be considerably improved, thus making the vertical displacement determination of the center of gravity of a floating body [7] much easier. Moreover, the introduction of a weight loading/unloading mechanism [8] to the floating body will also become easy.

Because of Feature-3, the floating body can be made of a high-quality superconducting material, such as a pure niobium plate or a single-crystal niobium plate.

For the inconvenience in using low-temperature environment, Diffisulty-3, an automated liquid helium transfer system has been developed [11]. With the use of this new system, preparation for the experiment has become much easier.

2 EXPERIMENT

Fig. 1 shows the schematic of the coil frame and the floating body. The floating body is levitated by the electromagnetic force generated by the main coil, and guided by the subcoils. If the symmetry of the system is perfect, the required force generated by the subcoils must be infinitely small. The coil frame consists of one large main coil of 5000 turns, and eight small subcoils of 1000 turns each. The entire frame is made of 99.99% pure aluminum. The wire with the diameter of approximately 0.1 mm is made from pure niobium. The floating body, 170 g in mass, consists of the disk, the guide and the holder. The disk is made by drawing a niobium cylinder, 99.9% purity, by hand. The guide is a niobium cylinder, 99.9% purity, which is connected to the neck of the disk by electron beam welding. The holder houses the optics, and is also designed to accommodate a load of a ring-shaped weight.

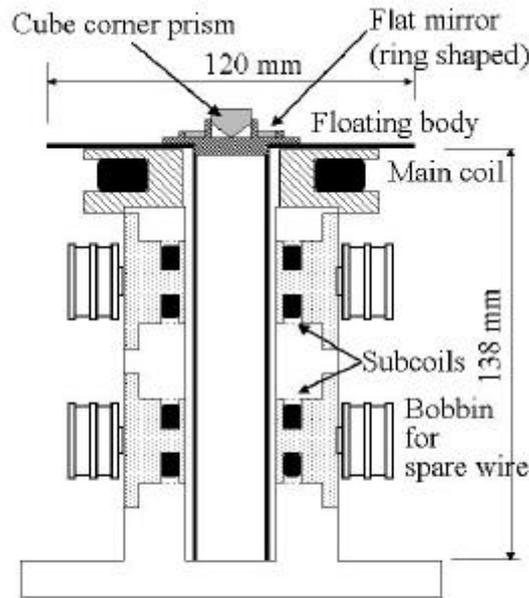


Figure 1. Schematic of the coil frame
 And the floating body

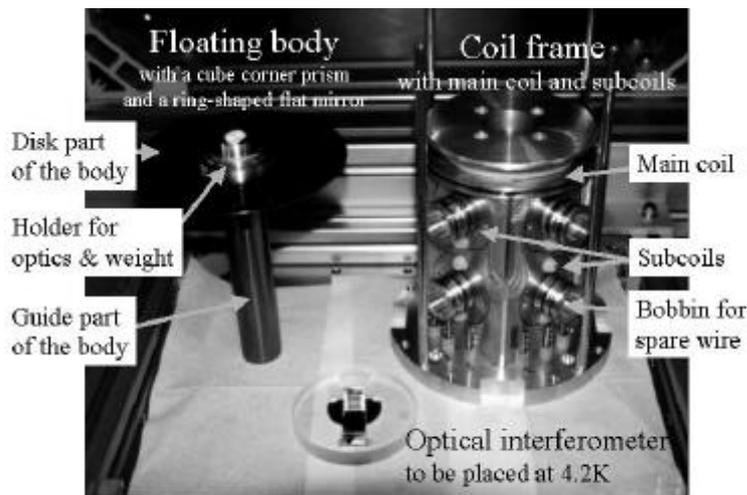


Figure 2. Photograph of the floating body, the coil frame
 and the optical interferometer

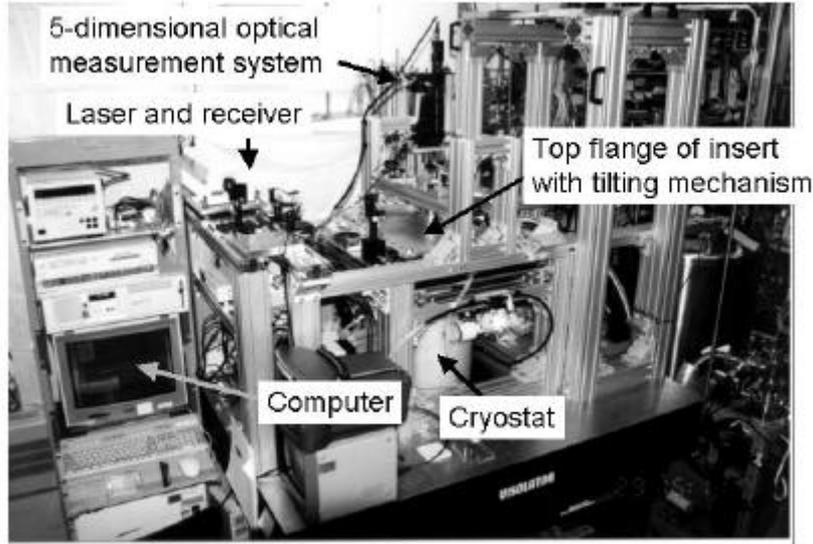


Figure 3. View of the new magnetic levitation system

Fig.2 shows a photograph of the floating body, the coil frame and the optical interferometer, which is placed just above the floating body in the cryostat. The disk of the body is distorted with a large winding of approximately 0.5 mm. This results in a requirement of a large current of the subcoils. Fig.3 shows the view of the new system. Vacuum chamber with large top flange is inserted to the cryostat made of FRP (fiber reinforced plastic) is placed on the base. The tilting angle of measurement part, which is the bottom part of the vacuum chamber, can be adjusted by adjusting that of the top flange. The measurement part, which holds the coil frame, is made of pure aluminum (99.9% in purity).

Several sets of levitation experiments are conducted in the first trial. Fig.4 shows the pattern of the targeted value of the main coil current and the subcoil current. Six sets of reciprocating motion immediately after changing the polarity of both the main coil and the subcoils are examined. The current of the main coil is changed up to 0.5 A in steps of 10 mA, and maintained at each value for about 30 seconds. The vertical displacement of the floating body during the three sets of reciprocating motion is analyzed. For each targeted value of the main coil current, the difference from the vertical displacement at the first up-motion is plotted in Fig.5. Except for the first up-motion, the vertical displacement follows a unique hysteresis loop with the width of approximately 3 μm , which corresponds to 200 ppm against the maximum displacement of approximately 15.5 mm.

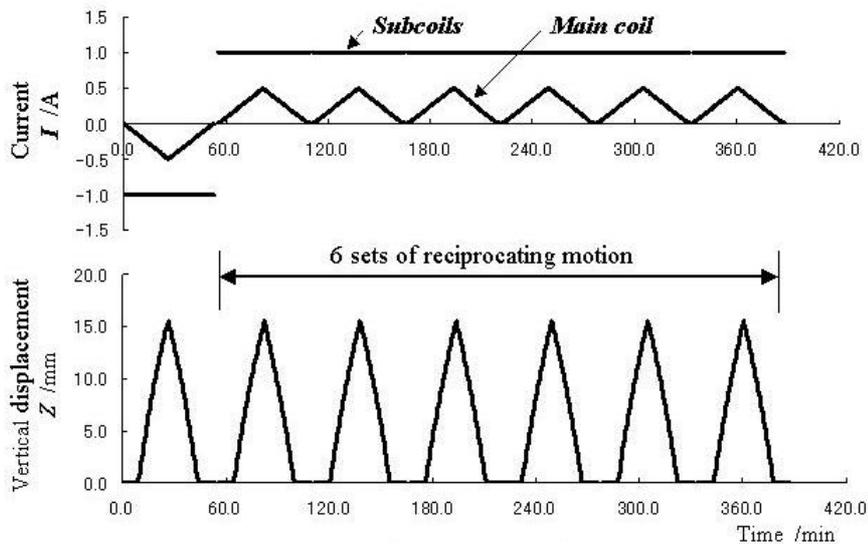


Figure 4. Pattern of the currents

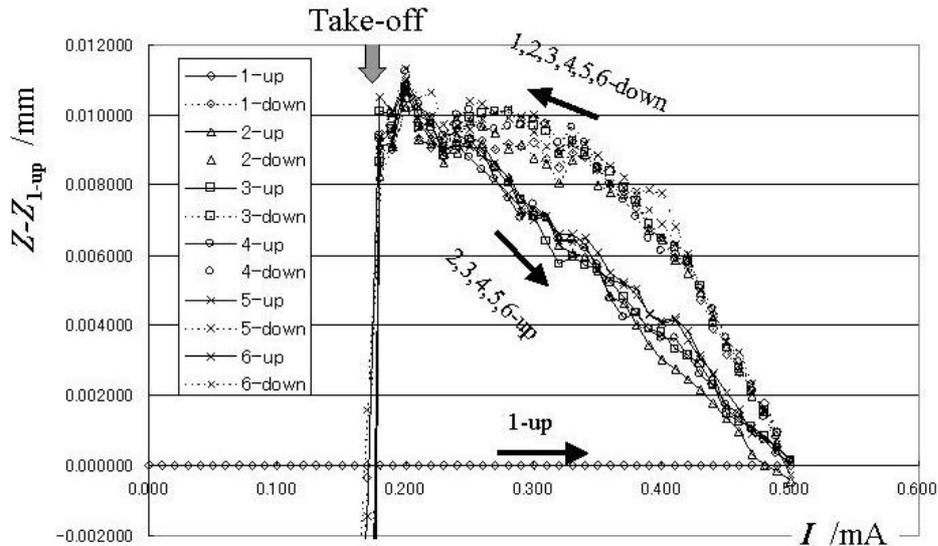


Figure 5. The difference from the vertical displacement at the first up-motion

3 DISCUSSION

In the experiment, the dimensional accuracy of the floating body is so poor, that the considerable large value of the sub-coils is required for guiding the floating body. One can only say that the superconducting linear bearing introduced to the levitated-mass system could work. For the second trial, the dimensional accuracy of the floating body will be considerably improved by simply connecting a disk cut out of a pure niobium plate (purity 99.9 %) and a pure niobium cylinder (purity 99.9 %) by electron beam welding. Simultaneously, a complete six-dimensional attitude and position measurement system, a measurement system for electrical quantities, and a weight loading/unloading mechanism are also being developed.

Floating bodies fabricated of pure aluminum, having shafts with circular and square cross sections, have been prepared. A mirror finish is obtained by polishing with a diamond bit. However, due to the difficulties of depositing niobium film (99.99 %) onto the body surface, examination of these bodies is reserved for future trials.

The first stage of the development will proceed concurrently with those of the other levitated-mass measurement methods using microgravity environment and air pressure. [12,13]

The problem of the incompleteness of the Meissner effect, Diffisulty-1, will be left for the next stage of development. The possibility of compensating for the incompleteness of the Meissner effect by means of appropriate correction methods will also be investigated.

The further improvement of the system and the further experimental data will be presented at the conference.

4 CONCLUSION

A new superconducting levitated-mass system is now being developed with the final target of replacing the kilogram in terms of the fundamental constants. Improving the stability of trajectory by means of introducing a superconducting linear bearing is the issue in question for the first stage of this development. The present status of the development, experimental results and further prospects are discussed.

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