

Design and Test of a Superconducting Levitation System for Gravity Measurement

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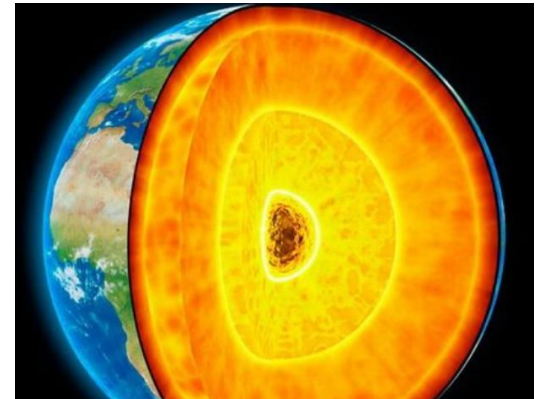
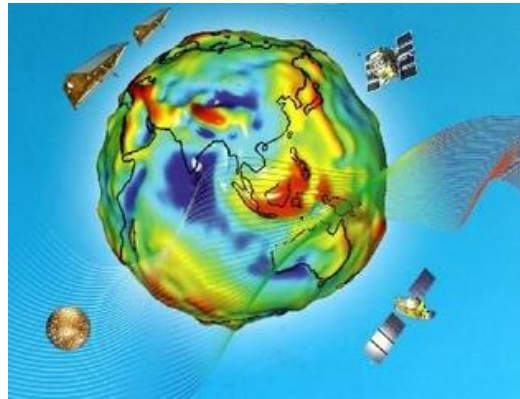


Outline

- 1 Introduction
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- 3 Construction and manufacture of the levitation system
- 4 Test and results
- 5 Conclusion

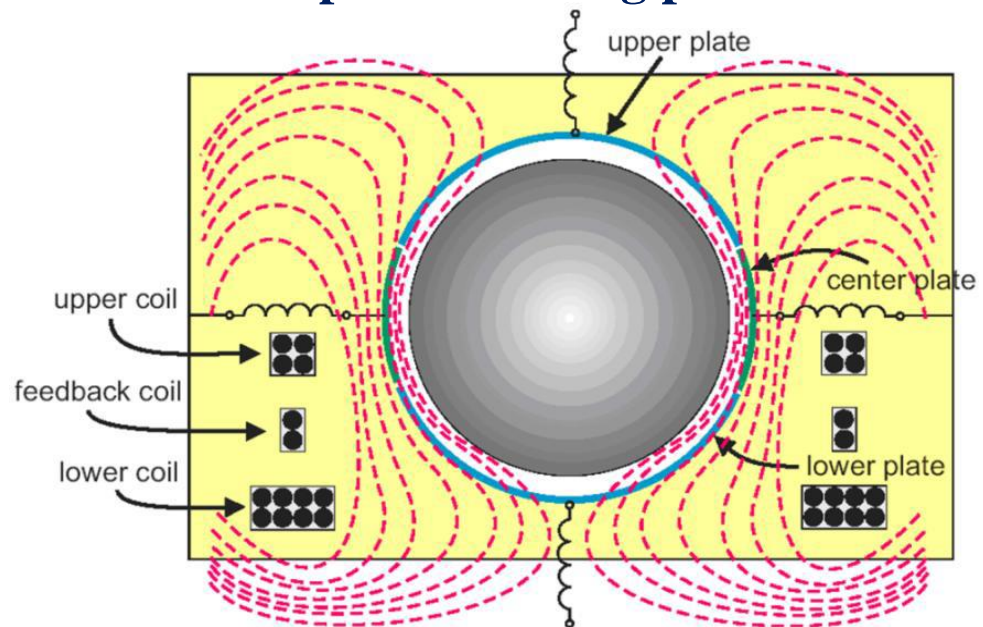
Introduction

- ❑ Superconducting magnetic levitation system with the advantages of high precision and low noise has been widely applied in some precision instrument, such as gravimeter, accelerometer, etc.
- ❑ Geodesy and Geophysics
- ❑ Space geodetic research
- ❑ Tidal gravity measurement
- ❑ Seismic survey

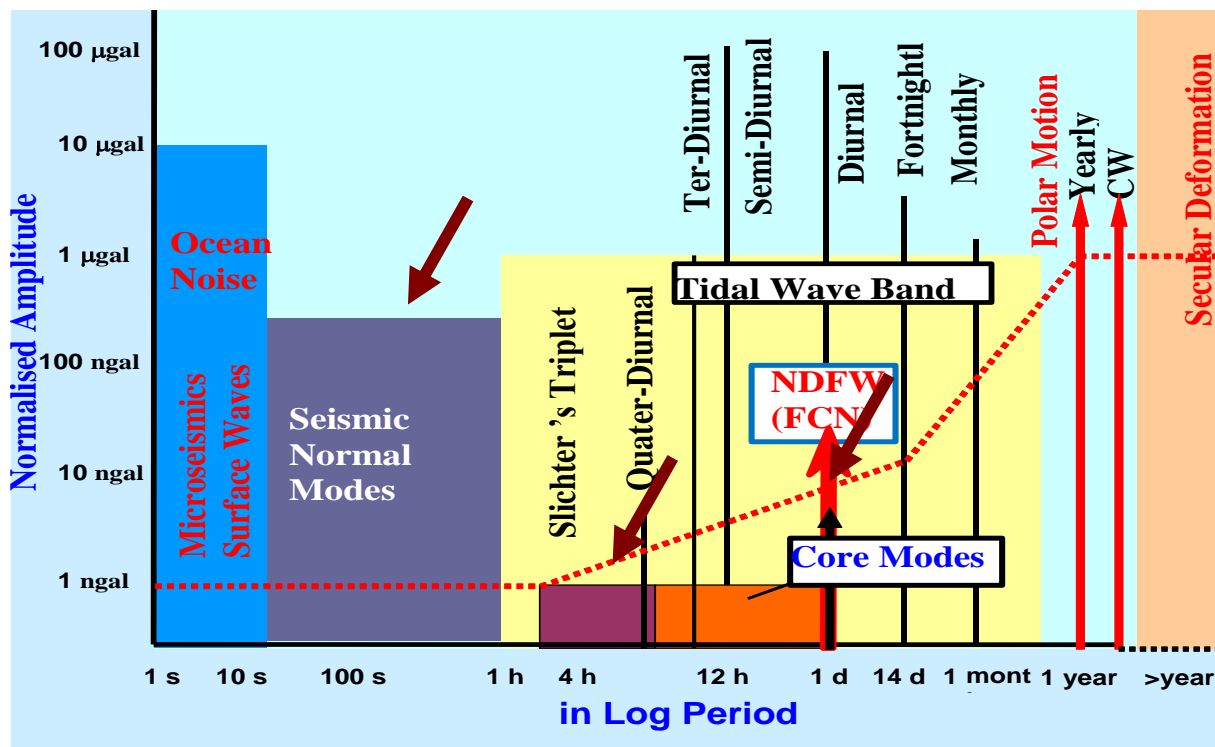


- Superconductivity has the advantages of zero resistance and Meissner effect.
- To utilize the perfect stability of supercurrent to create a perfectly stable spring.
- The superconducting device is a spring type gravimeter in which the mechanical spring is replaced by a magnetic levitation of a superconducting sphere in the field of superconducting persistent current coils.

$$\text{grad}f(z) = \frac{m \cdot \Delta g}{\Delta d}$$

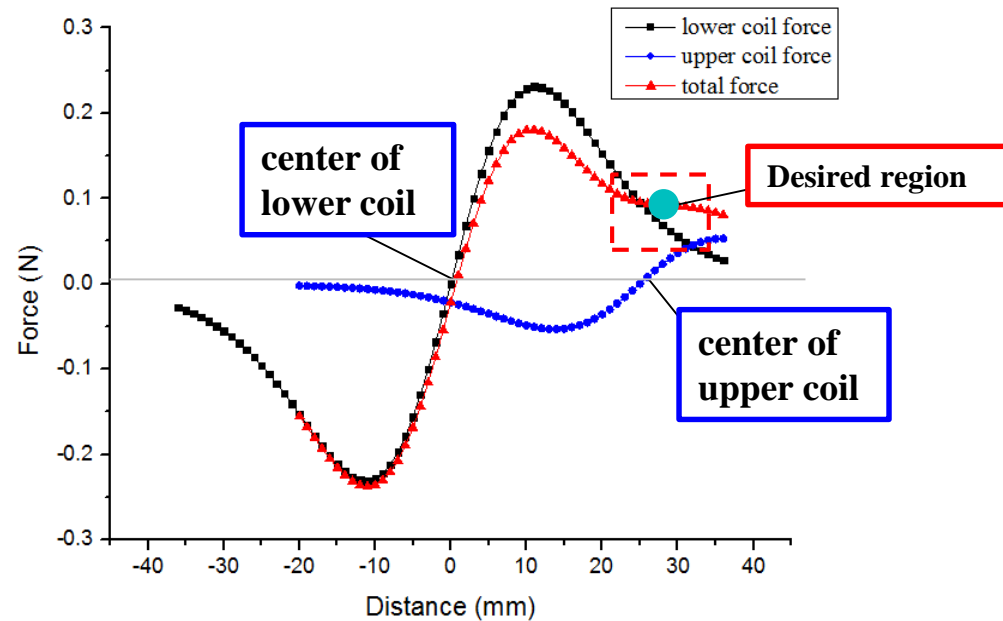
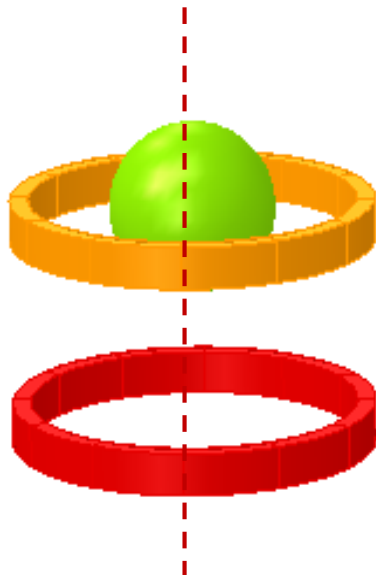


Introduction



- Need a wide range of signal strength from a nanoGal to a few 100 µGal.
- Superconducting gravimeter sets the highest standard possible for measuring the whole spectrum of geophysical phenomena that occur in the Earth, ocean and atmosphere.

Electromagnetic characters of a superconducting levitation system



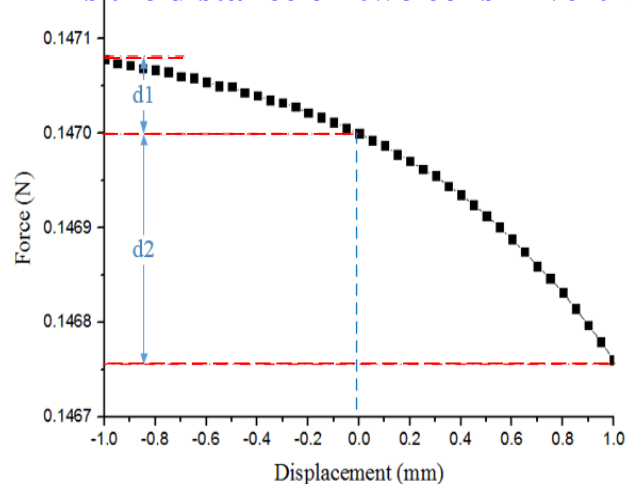
- The force gradient value is negative and the total force is positive to provide the levitation stability of the sphere,
- The desired levitation range is near to the plane of upper coil.
- This region can provide that the vertical force gradient is small and the levitation force is equal to the gravity on the sphere.

Optimize the relative location of two support coils

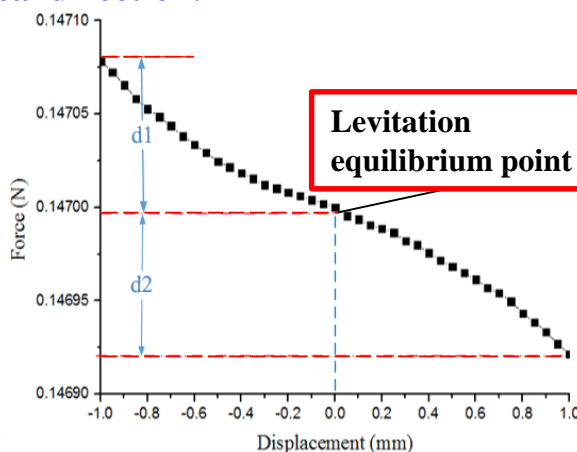
Diameter of two coils is 50 mm.

Mass of sphere is 15 g.

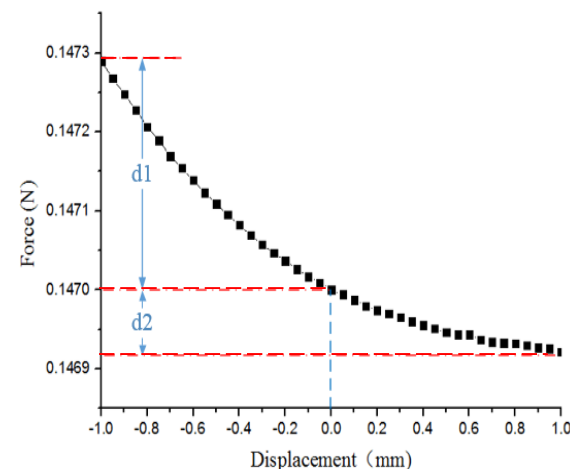
L is the distance of two coils in vertical direction.



(c) $L=10\text{mm}$



(a) $L=25\text{mm}$



(b) $L=30\text{mm}$

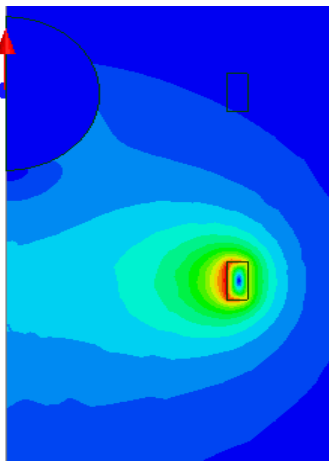
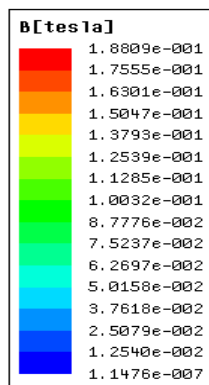
- When $d=25\text{mm}$, we can find the levitation equilibrium position where force gradient is near to zero.
- Upper coil and bottom coil are approximately regard as a Helmholtz coils.

Simulation of superconducting sphere levitation

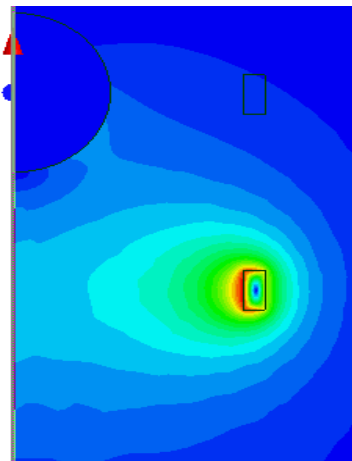
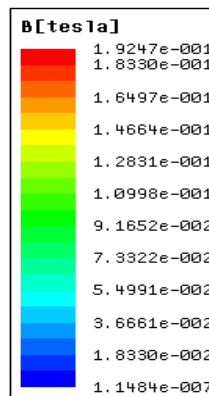
Mass of sphere is 13.09g,

Diameter of coil is 60mm, number of turns is 612

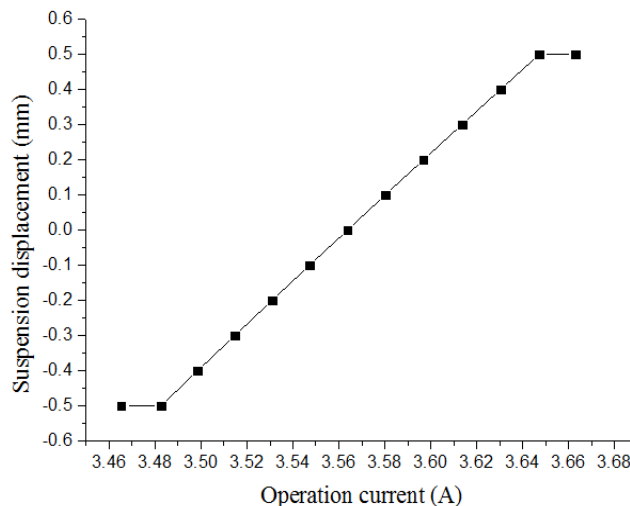
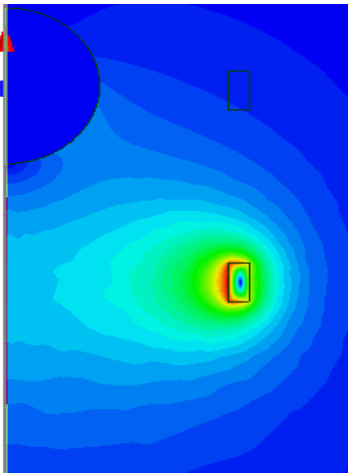
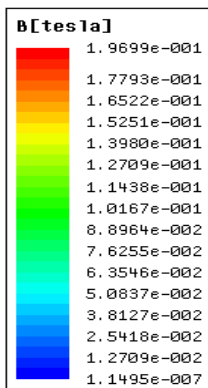
bottom



Center



top



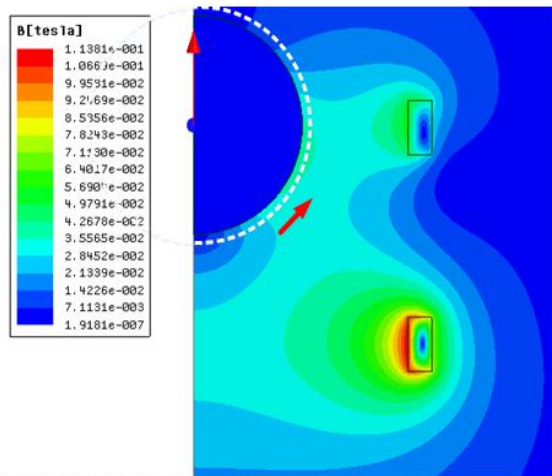
Lower coil current
VS
Levitation displacement



Analysis of field characters

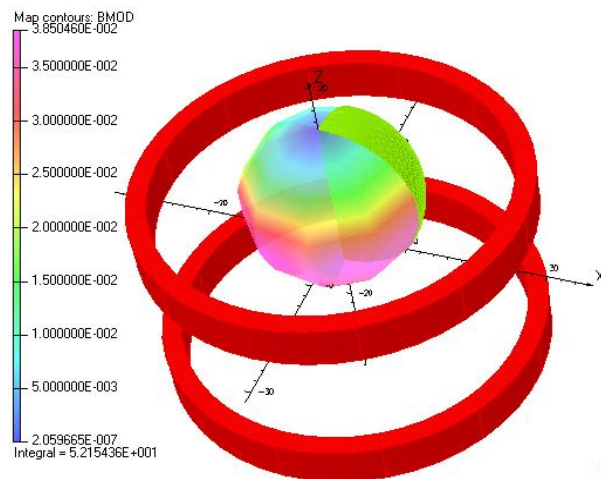
$$I_{up}=0.656A, I_{low}=1.545A$$

2D

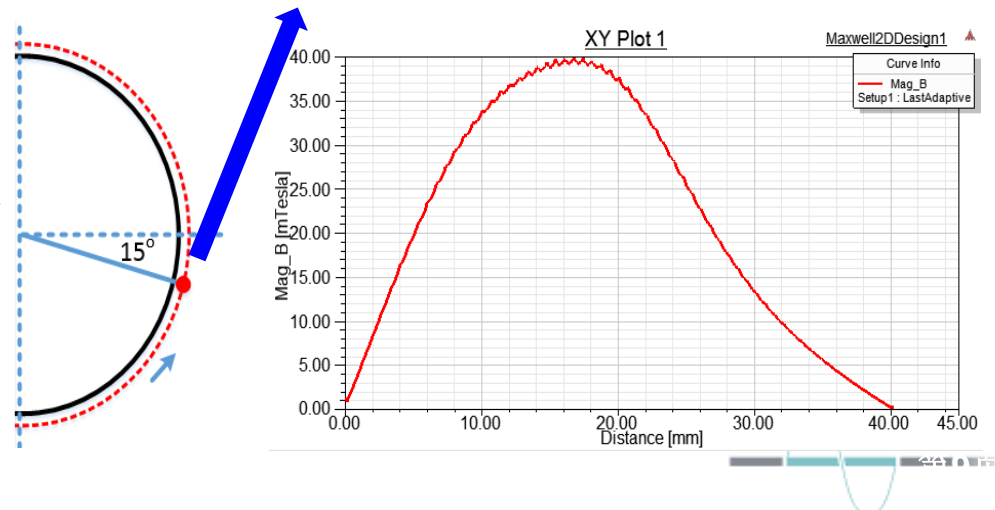


Maximum field on sphere is 398.33G

3D



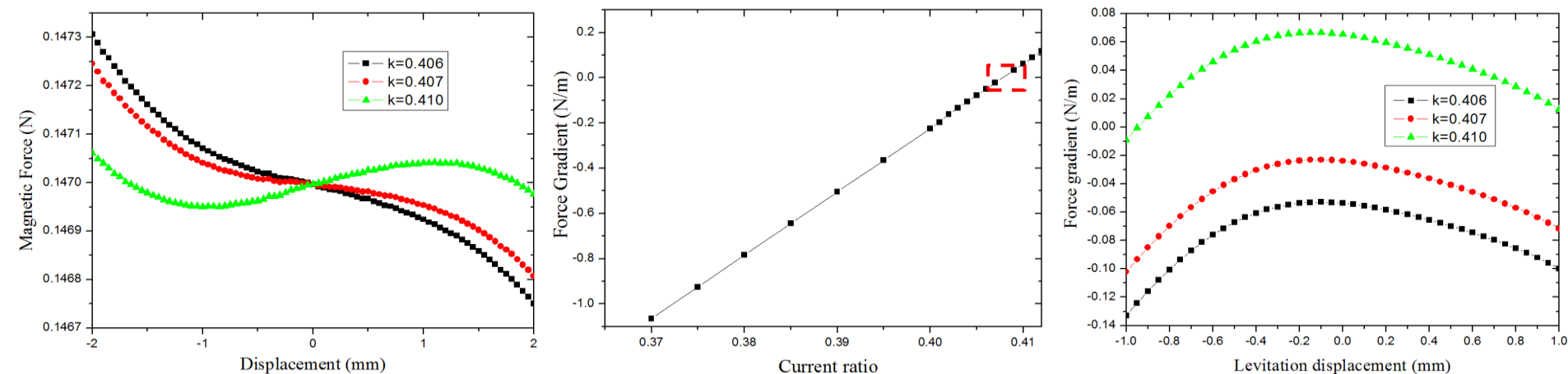
Maximum field is 385G



Adjusting desired force gradient

Diameter of coils is 60 mm.

L=31.2 mm.



- Current ratios(k) are 0.406, 0.407, 0.410 and the corresponding average force gradient are -5.365×10^{-2} N/m, -2.386×10^{-2} N/m, 6.541×10^{-2} N/m respectively.
- If we need a smaller gradient to near zero, the current ratio could be adjusted between 0.407 and 0.408.
- As the gradient is changed very small when the sphere is near center position, it can decrease levitation range to increase the stability of the gradient.

Calculation of the sensitivity of the system

The sensitivity of the levitation system for gravity measurement is defined as:

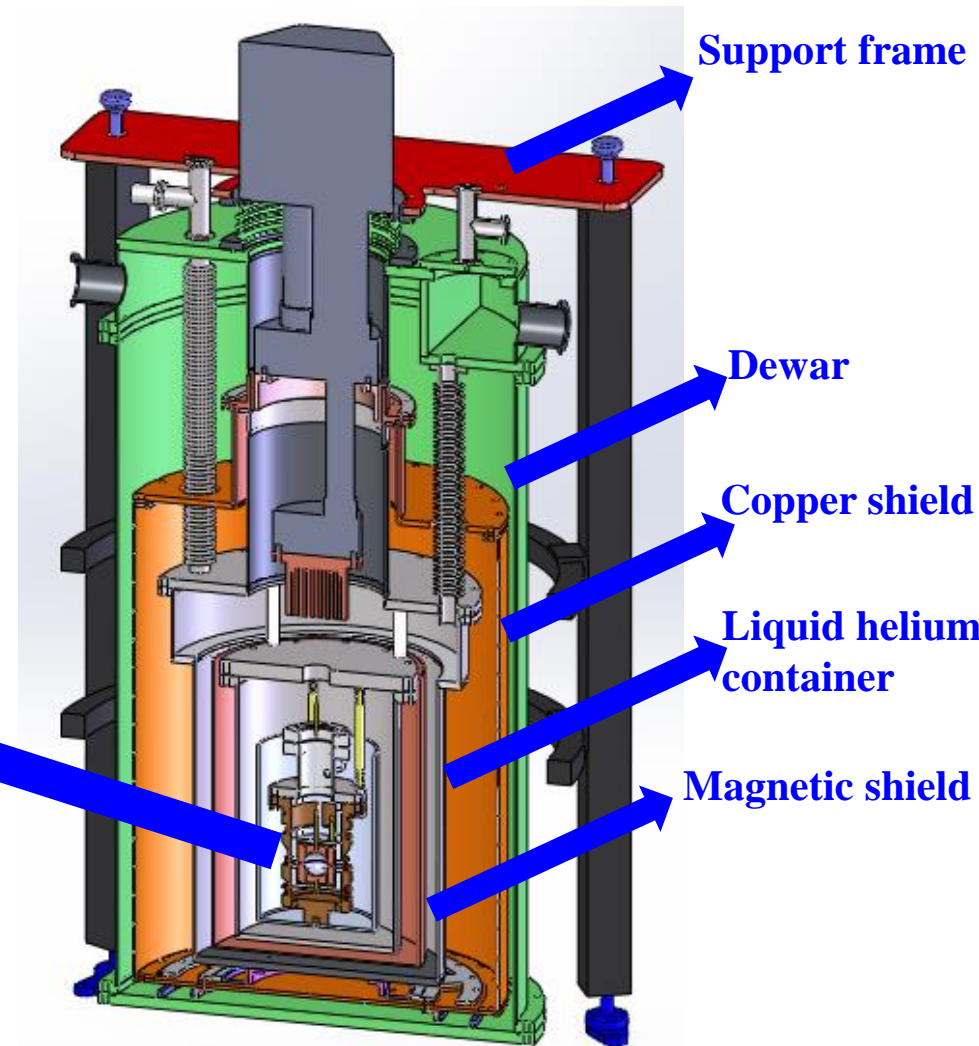
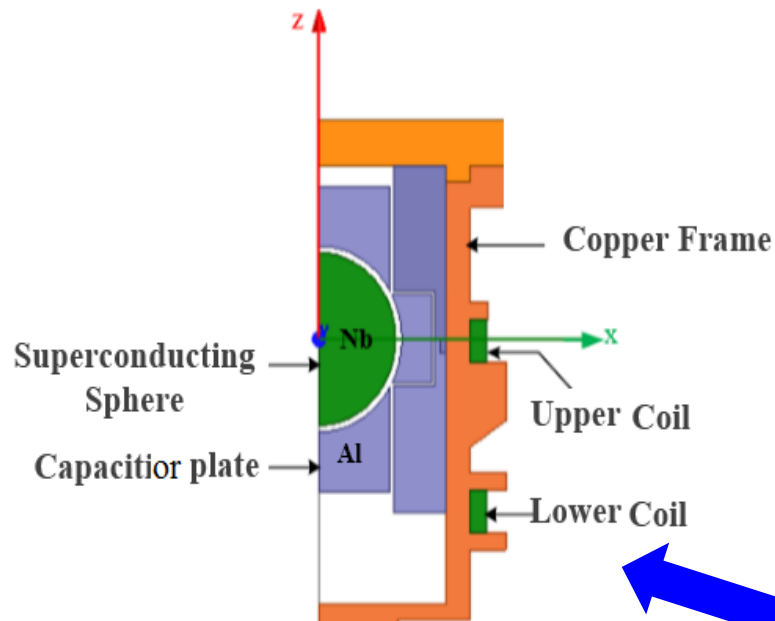
$$\Delta g = \frac{\text{grad} f(z) \cdot \Delta d}{m} \quad (1)$$

Here d is the displacement of sphere, g is the gravity, m is the mass of sphere, $f(z)$ is magnetic force in gravity direction.

Resolution of displacement sensor	Force gradient (N/m)	Sensitivity of gravity measurement
10^{-9}m	$1.5 \cdot 10^{-1}$	$1 \mu\text{Gal}$
	$1.5 \cdot 10^{-2}$	$0.1 \mu\text{Gal}$
	$1.5 \cdot 10^{-3}$	$0.01 \mu\text{Gal}$
10^{-10}m	$1.5 \cdot 10^{-1}$	$0.1 \mu\text{Gal}$
	$1.5 \cdot 10^{-2}$	$0.01 \mu\text{Gal}$
	$1.5 \cdot 10^{-3}$	1nGal

$$1 \mu\text{Gal} = 10^{-9} g$$

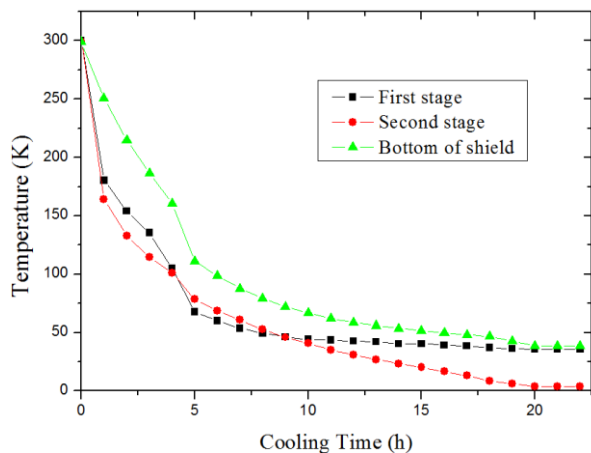
Construction of the system



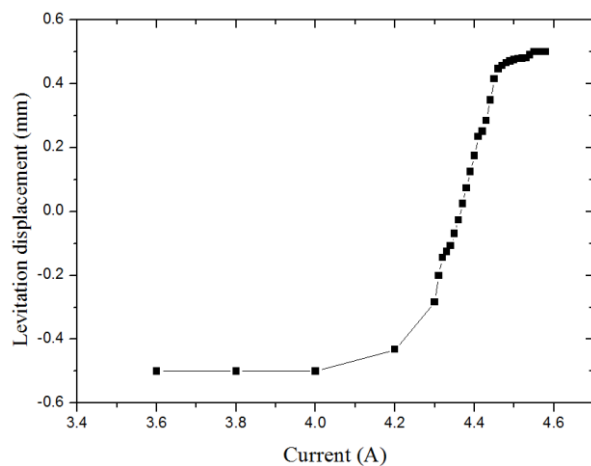
Manufacture of parts of levitation system



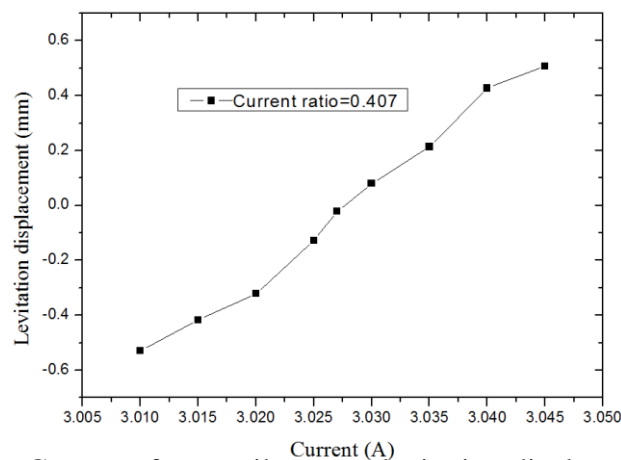
Test of the system



Temperature trace during the cooling-down process.

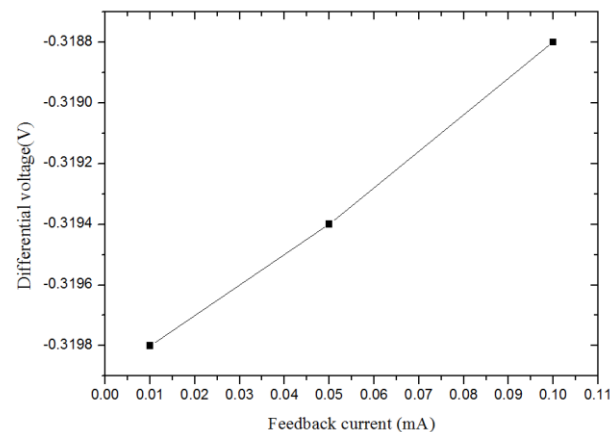
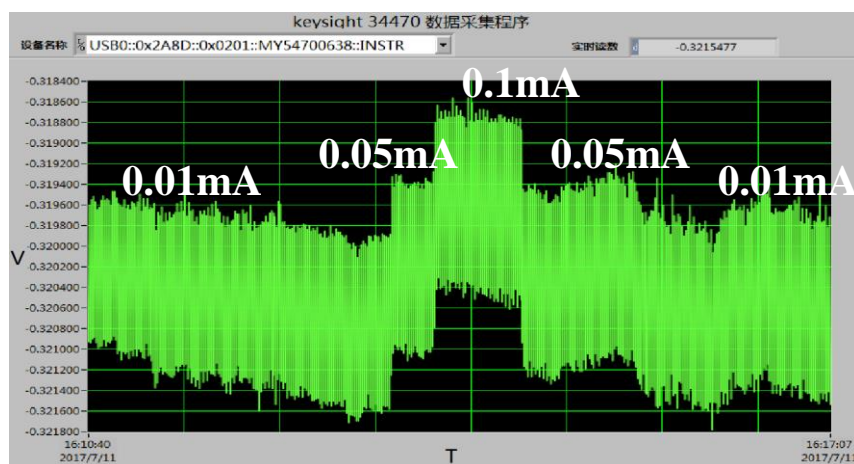
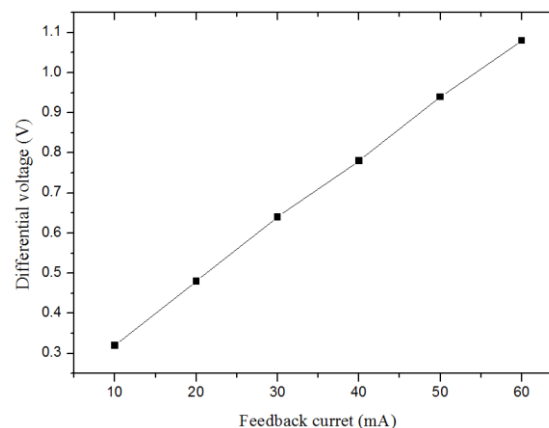
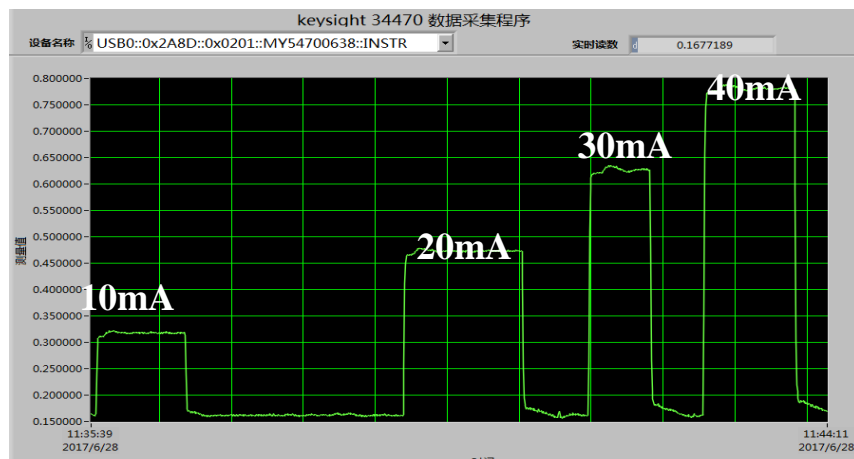


Current of lower coil versus levitation displacement.



Current of two coils versus levitation displacement of sphere

Measurement results



- The response step results of sphere with exciting pulse current from 0.01 mA, 0.05 mA to 0.1 mA and from 10 mA, 20 mA, 30 mA to 40 mA.
- The sensitivity of levitation displacement measurement is about 10^{-5} mm respond to differential of 0.1 mV.
- Based the formula (1), we can obtain the sensitivity of gravity measurement is about $10^{-9}g$.

Conclusions

- A superconducting levitation system for gravity measurement has been designed and tested which used the levitation of a superconducting sphere by the magnetic field of two superconducting coils.
- The test results show that the system is allowed about $10^{-9} g$ sensitivity.
- The next work is to measure some earth waves with different periods.

Thank you for your attention!

