Development of a Highly-sensitive/ Broad-band Servo-type Seismometers using Magnetic Levitation

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Abstract

- *The aim of this study is to realize a highly-sensitive/wideband seismometer for new seismological-observational network. We have developed an astatic rotational pendulum using magnetic levitation for removing the parasitic resonances of a spring to support a pendulum weight form a gravity force and the thermal dependence of the spring constant. The principle is as follows. A cylindrical plunger permanent magnet has a weight at one side of its end edge. The plunger magnet is inserted into a uniform magnetic field generated by a window-frame-type permanent magnet and attached to two crossed leaf spring hinges outside the magnet bore. Magnetic forces occurred by the magnetic field counterbalance a gravity force at the weight. A prototype seismometer using the rotational pendulum has a velocity feedback control system of a weight position, a magnetic spring, and, a capacitance position detector. To realize the stable operation of the rotational pendulum without the unnecessary movements of the plunger magnet, the magnetic field uniformity of the window-frame magnet reached 10^{-4} by devising its pole shape. The thermal dependence of the magnetic field strength was compensated as much as $9 \times 10^{-5}/ ^{\circ}C$ by Ni-Fe metal, having a negative coefficient of permeability. The natural period of the prototype was 10 s at the maximum and was able to be changed from 5 s to 8 s with the magnetic spring. These values of the period are consistent with theoretical calculations. Observations using this seismometer have been recently carried out. The results of the observations showed that the noise level of the seismometer was less than 10^{-9} m/s in the frequency range over 1 Hz.*

Purpose of Development

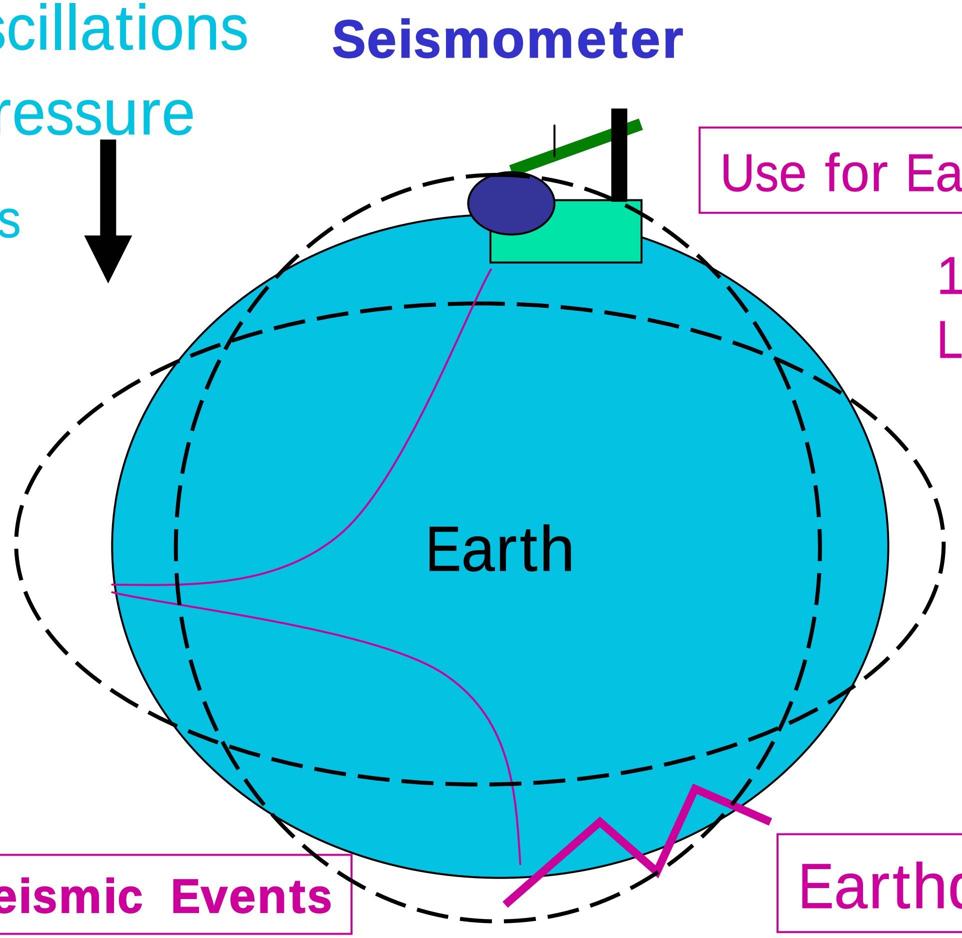
To observe cheaply easily the vertical / Horizontal components of normal free oscillations of the Earth at many points.

Normal Free Oscillations

Atmospheric Pressure

Less than 10^{-10} m/s

Less than 0.01 Hz



Use for Earth Tomography

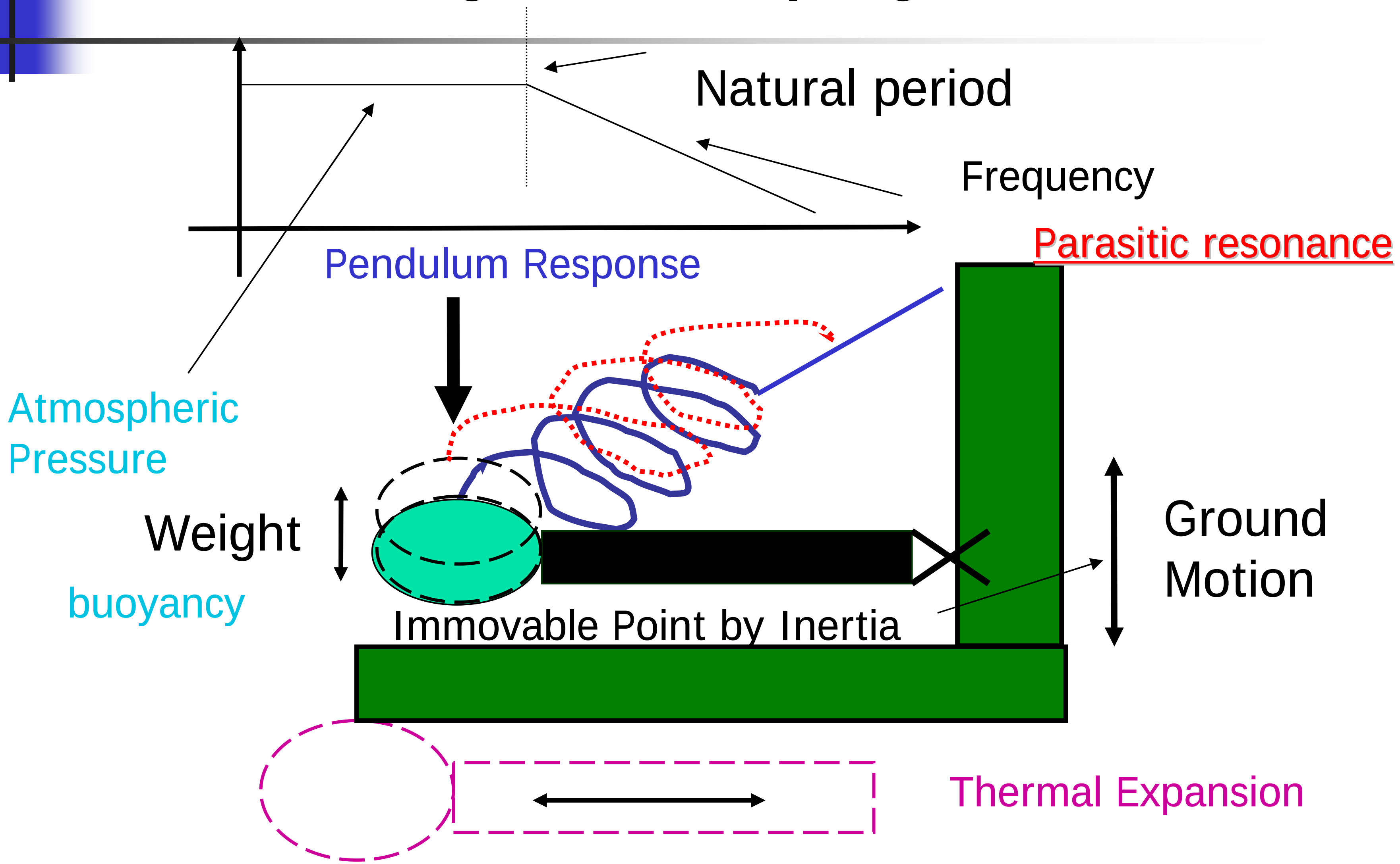
10^{-6} m/s

Less than 0.1 Hz

To observe Telseismic Events

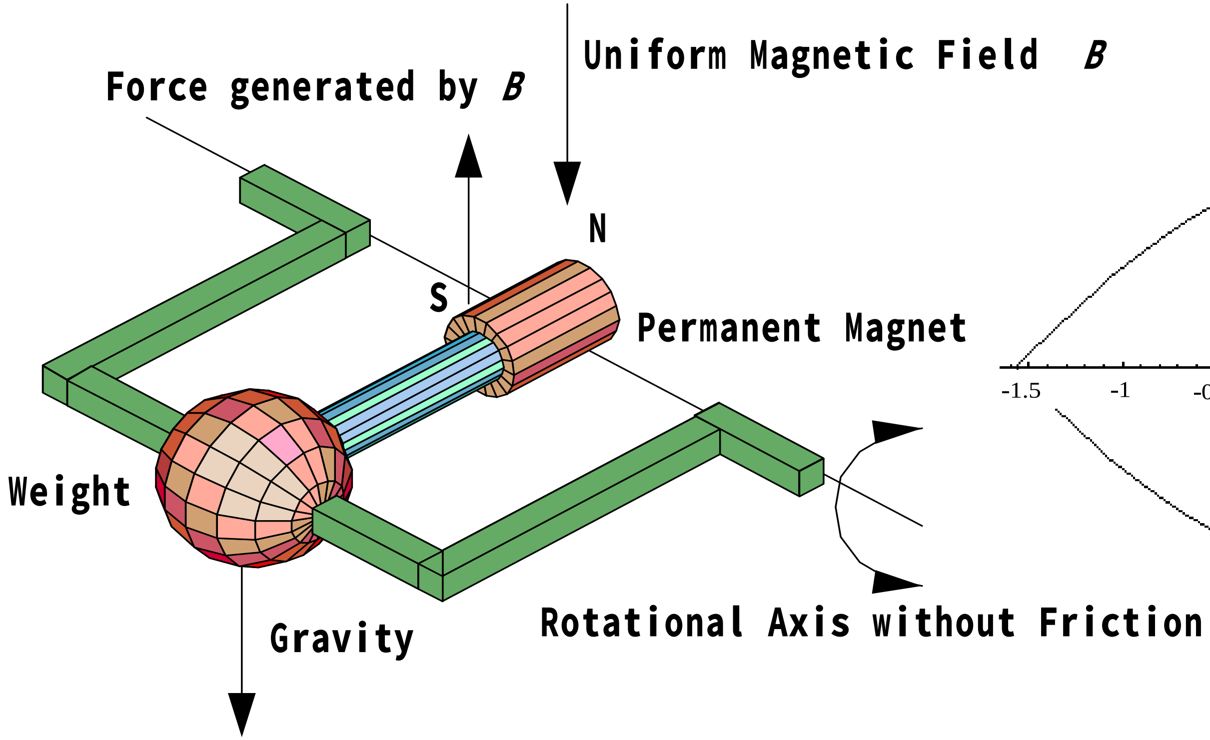
Traditional Seismometer

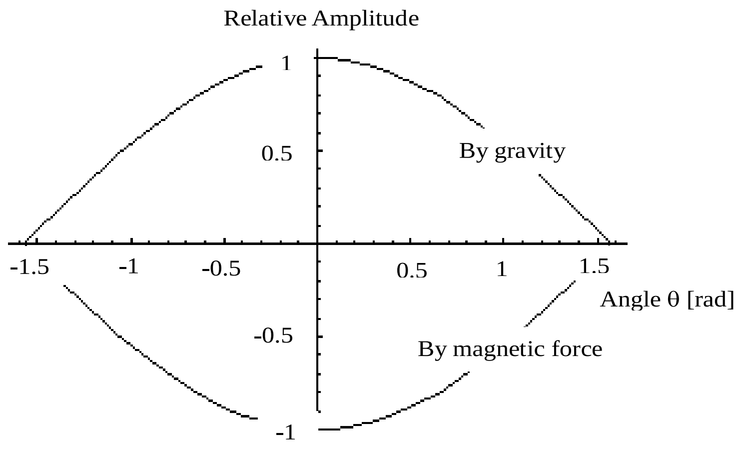
How to counterbalance gravity at a weight and a restoring force of a spring.



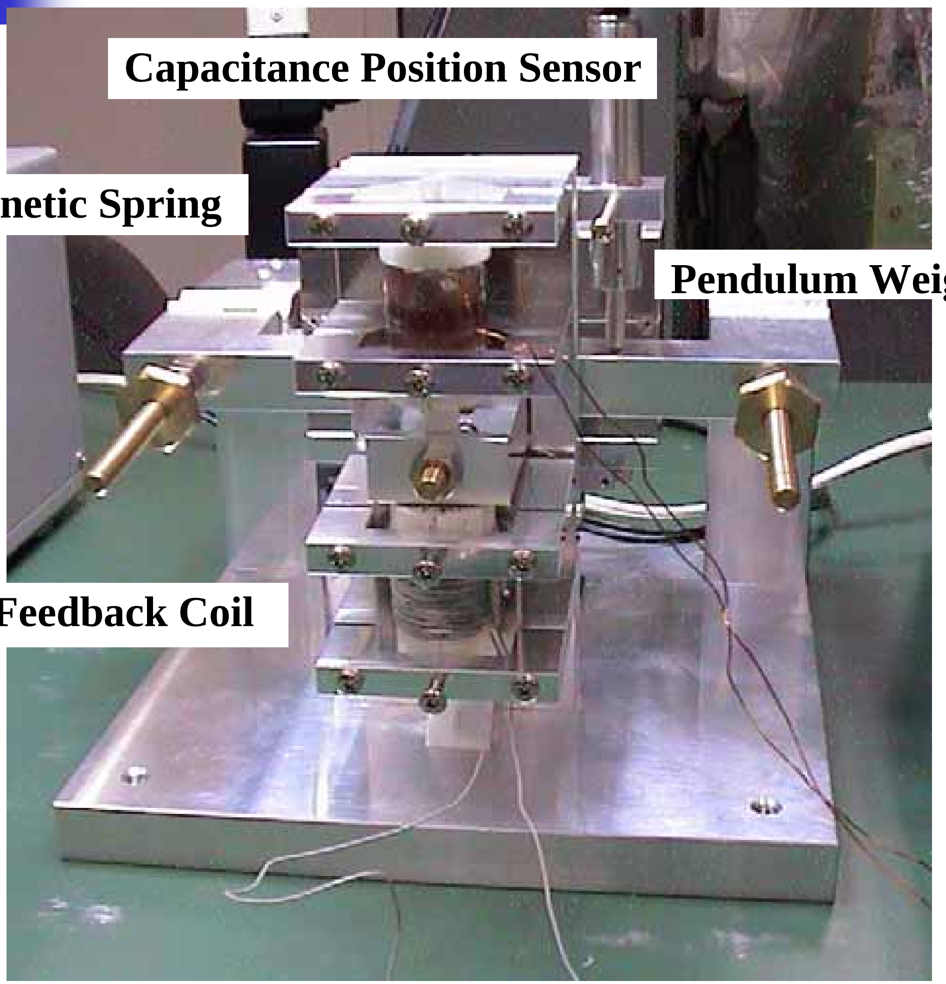
A principle of an astatic rotational pendulum using a plunger permanent magnet in a uniform magnetic field environment.

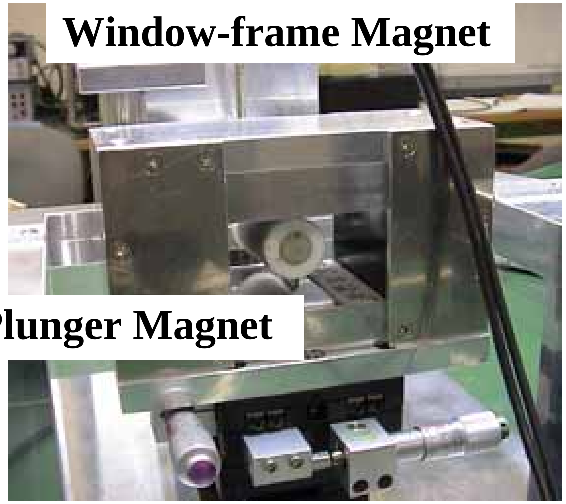
- The positive rotational moment of a plunger permanent magnet generated by a magnetic field *B* cancels a negative rotational moment acted at a weight by gravity.





The vertical component seismometer using an astatic rotational pendulum

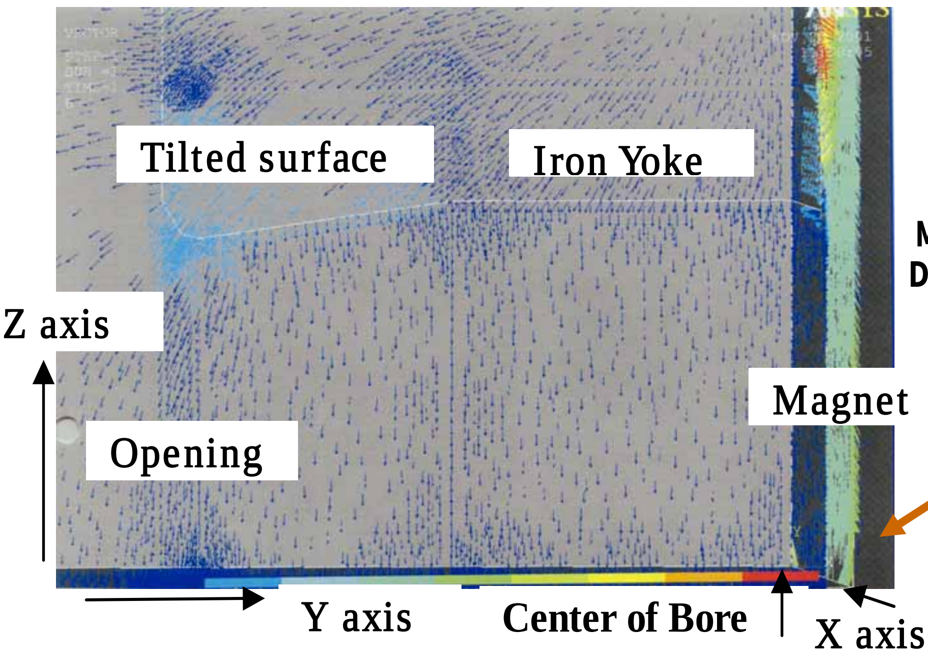


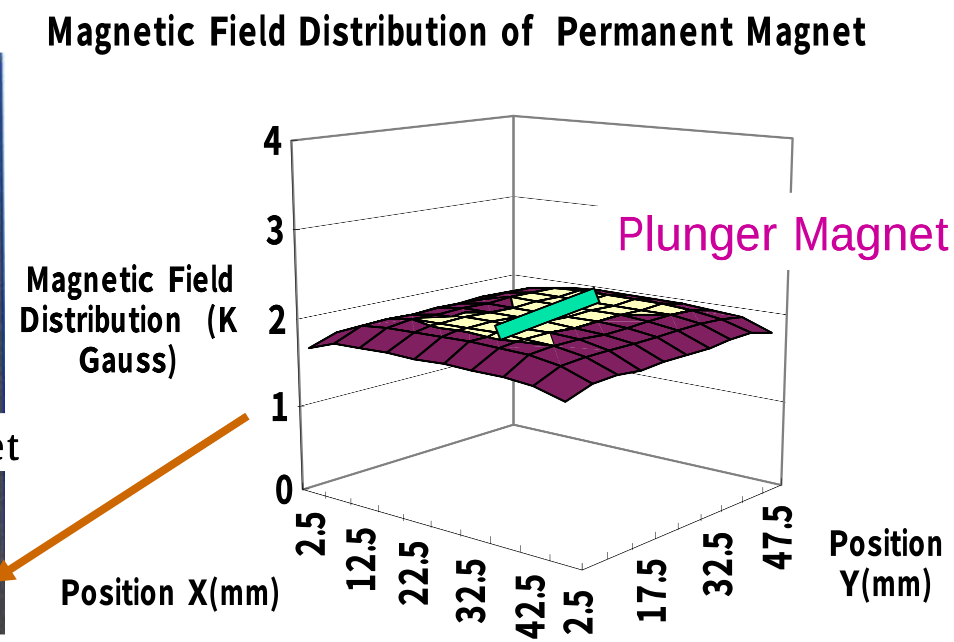


Free oscillation
Natural Period :
about 5s

The magnetic field distribution of the window-frame-type permanent magnet

- The uniformity of a magnetic field around the center plane, where the plunger magnet is placed, is 10^{-4}.



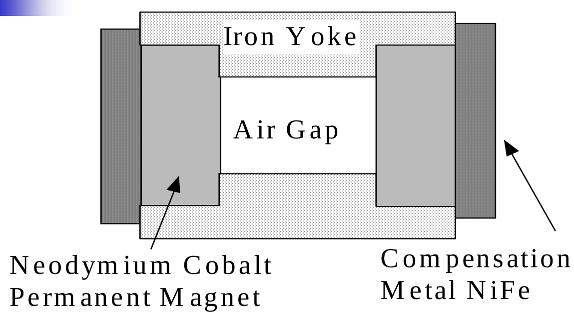


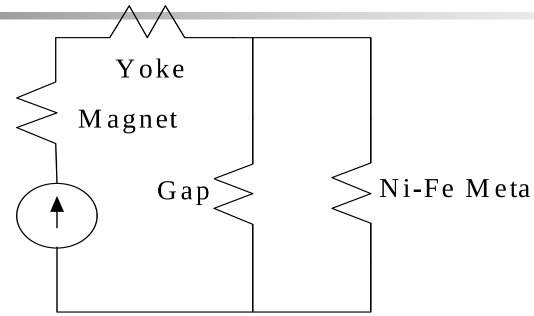
FEM calculation

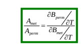
Measured data
Central Plane

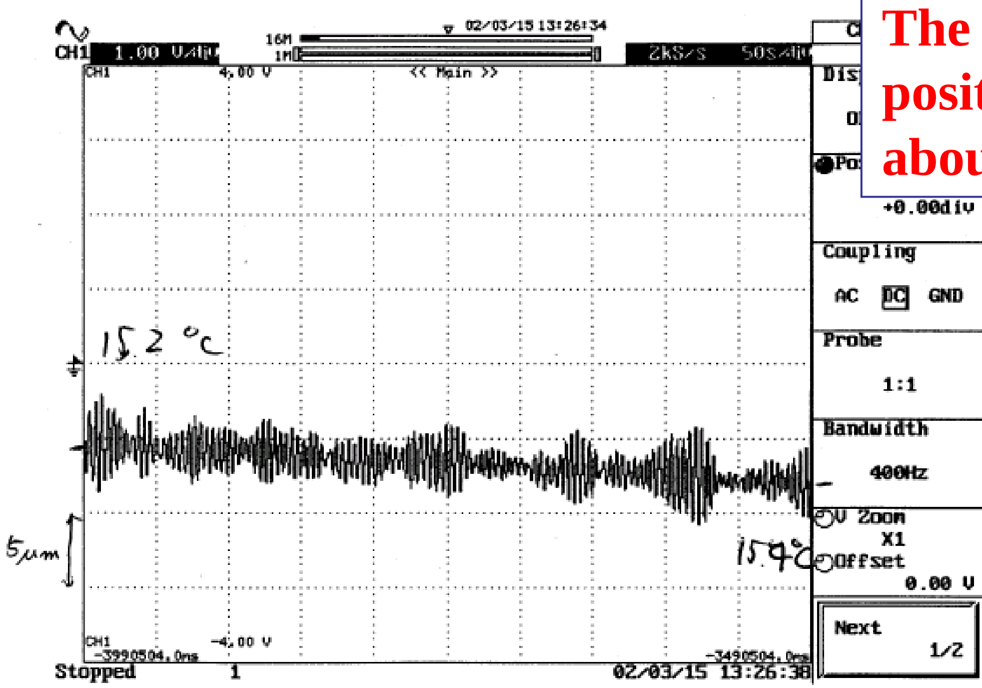
Compensation of temperature dependence of magnetic field strength by NiFe metal (for Window-frame Magnet)

Very old technique: A watt-hour meter uses it.









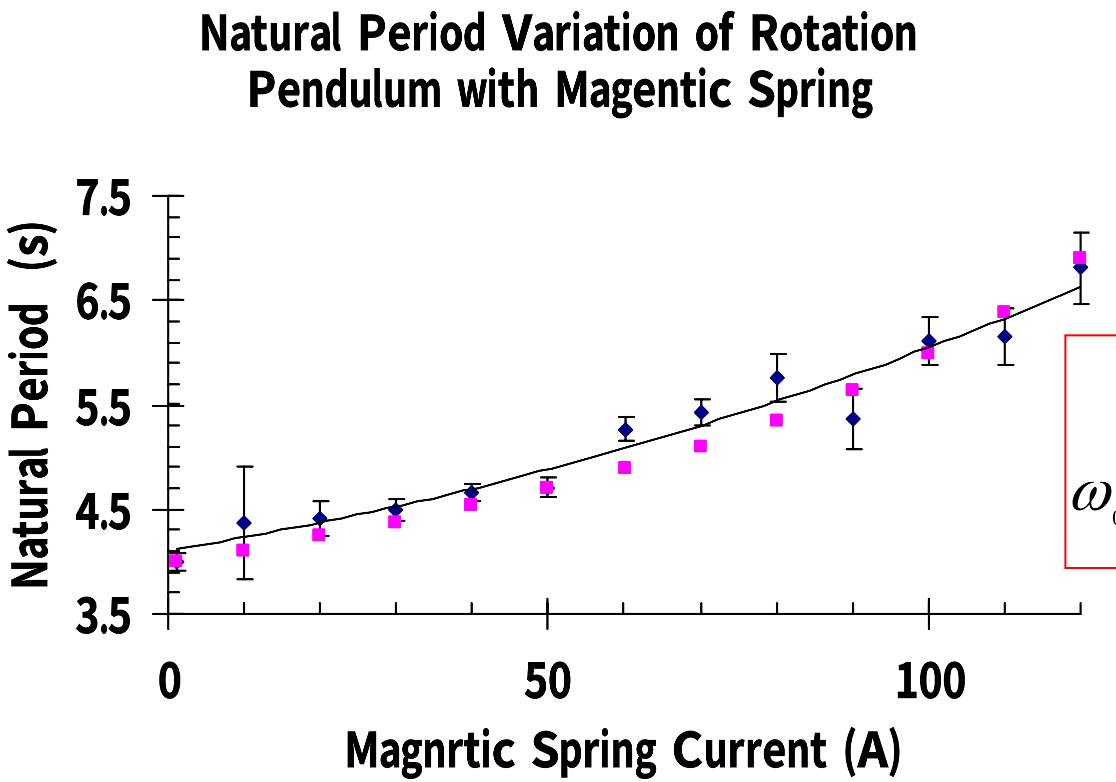
The movement of the pendulum weight position dependent on temperature is about 10 μm/degree.

The thermal dependence of magnetic field strength is less than 9 x 10-5 / K.

The vertical scale is 5 μm/div and the horizontal scale is 50s/div.

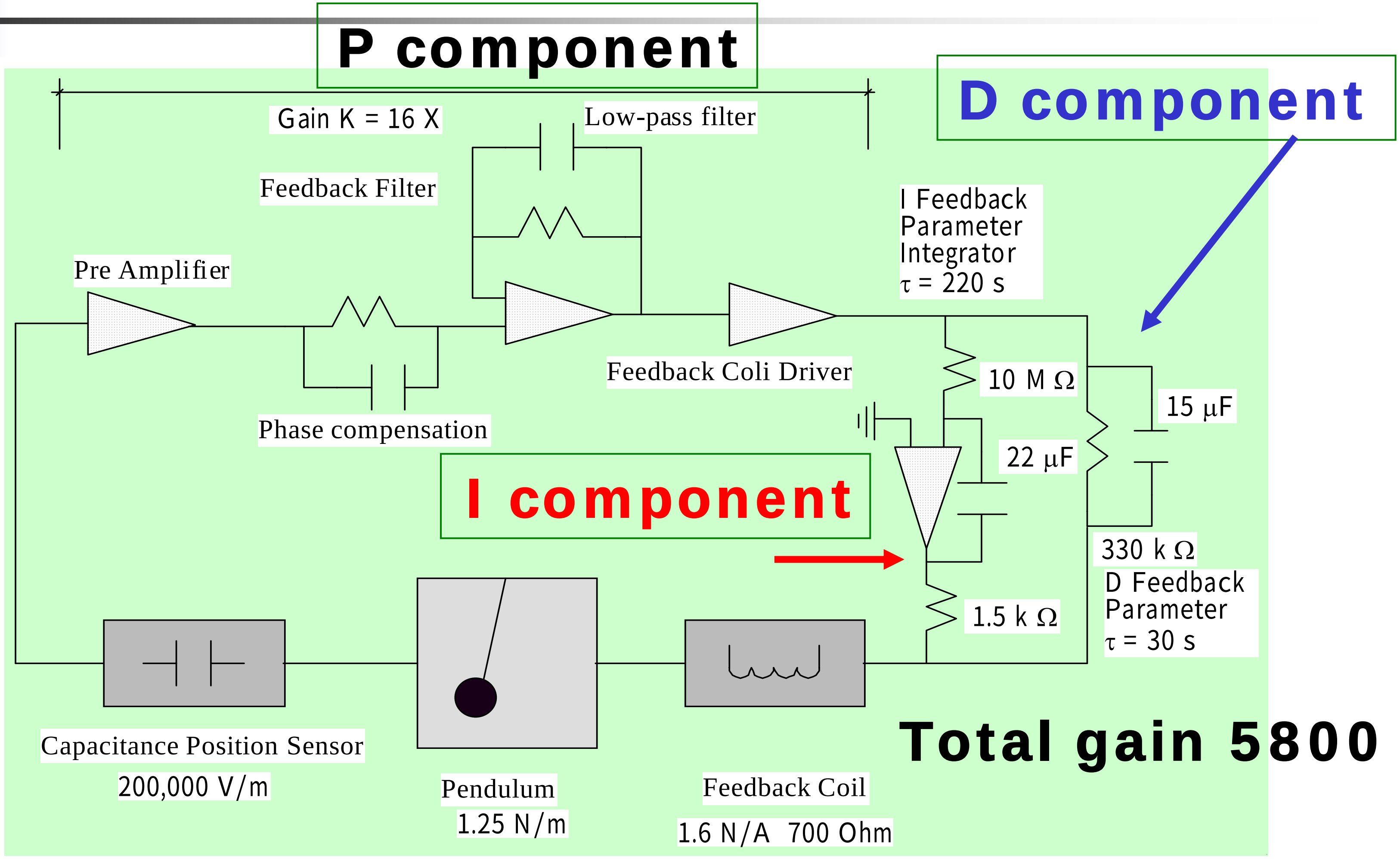
The change of the natural period of the rotational pendulum, when changing the current of the magnetic spring.

- The solid circle are experimental values and the pink solid squares are calculated values. This natural periods has been measured by the capacitance sensor 10 times. The error bars are standard deviations for 10 measurements. The black line is a curve fitted by a 2nd order polynomial.



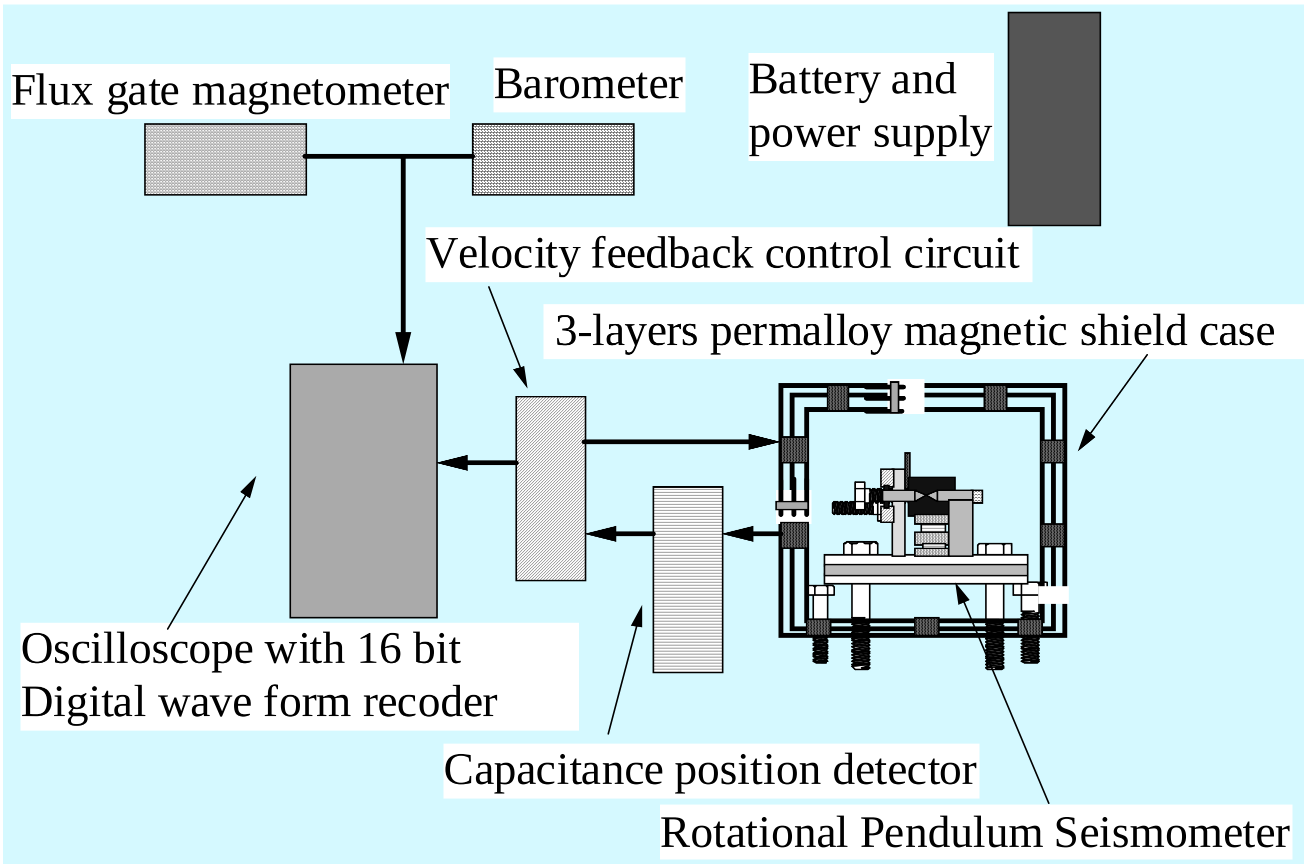
$$\omega_0 = \sqrt{\frac{\frac{4}{3}\frac{E I_s}{l} - \frac{n i m_p}{2r}}{I}}$$

The PID feedback system for the rotational pendulum

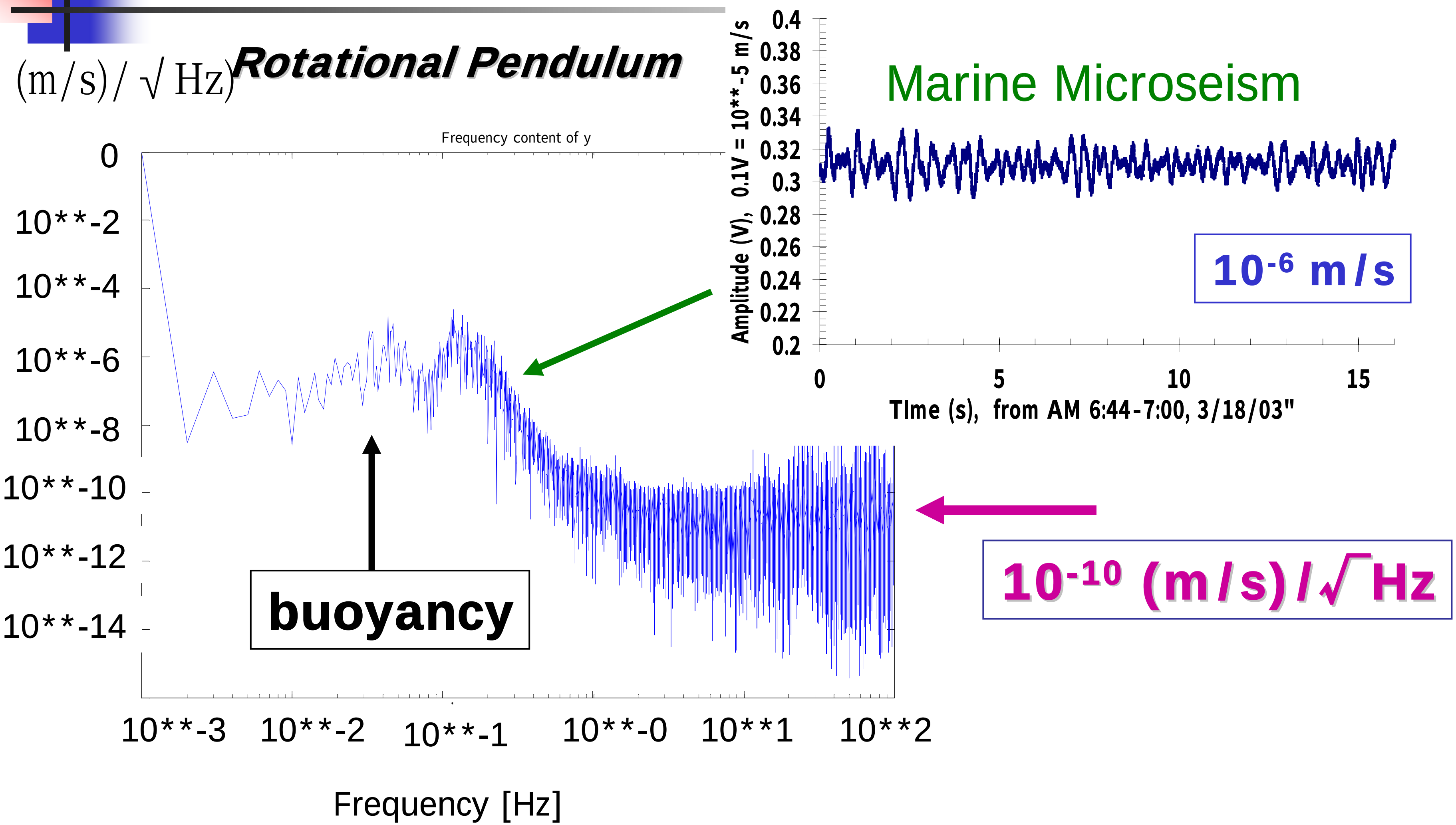


Observational set up for measuring the earth's background vibration noise

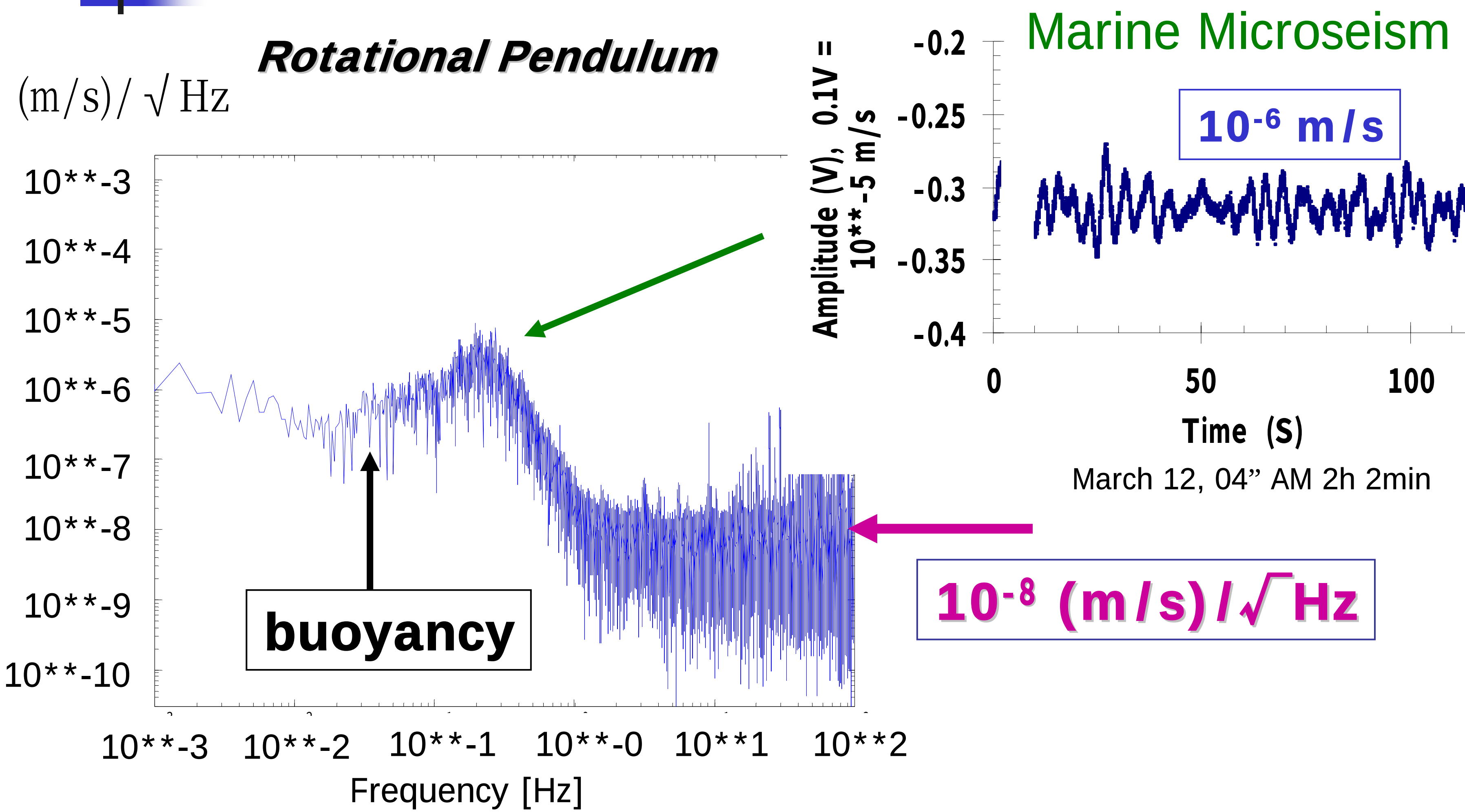
The noise was measured with the astatic rotational pendulum seismometer at Matushiro Observatory of Japan Meteorological Agency in March, 2003 and 2004.



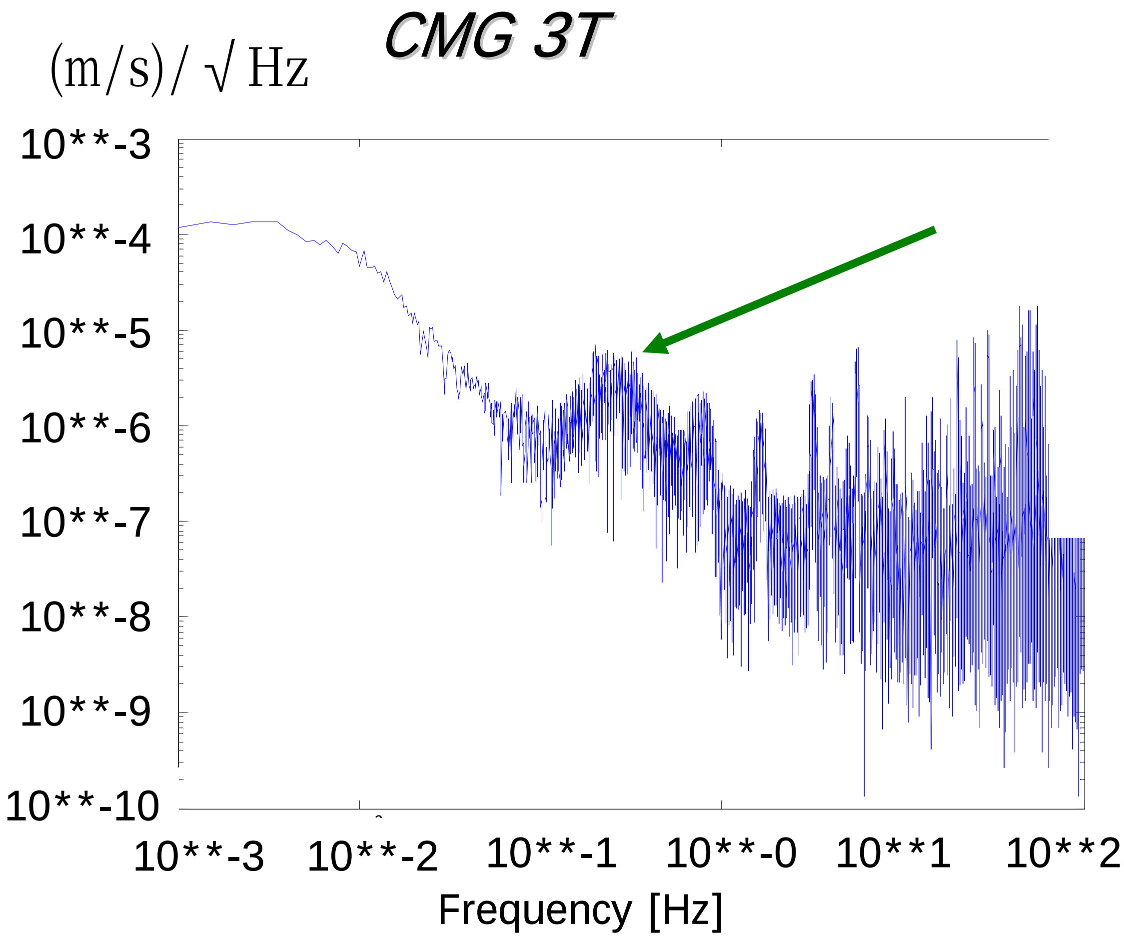
The wave form and the frequency spectrum of the earth's background vibration noise at Matushiro, March 03"

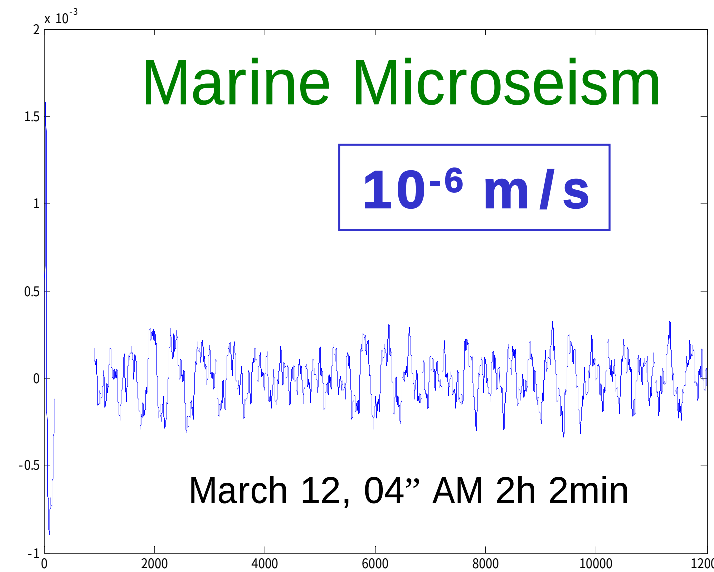


The wave form and the frequency spectrum of the earth's background vibration noise at Matushiro, March 04"



The wave form and the frequency spectrum of the earth's background vibration noise at Matushiro, March 04"





Filter between 0.1 Hz to 0.01 Hz

10^{-8} (m/s)/√Hz

Summary

We need further refinement to obtain the best data.

- We proofed the principle of the vertical astatic rotational pendulum.
- We successfully accomplished a long natural period of more than10 s.
- The magnetic field uniformity was about 10^{-4} in the bore of the window-frame magnet.
- The thermal dependence of magnetic field strength was less than 9×10^{-5} /K.
- **The noise level of the rotational pendulum seismometer in a frequency range over 1 Hz was less than 10^{-9} (m/s)/√ Hz.**

The rotational pendulum seismometer has an effect from a change in buoyancy caused by a variation of atmospheric pressure.

Make a chamber.

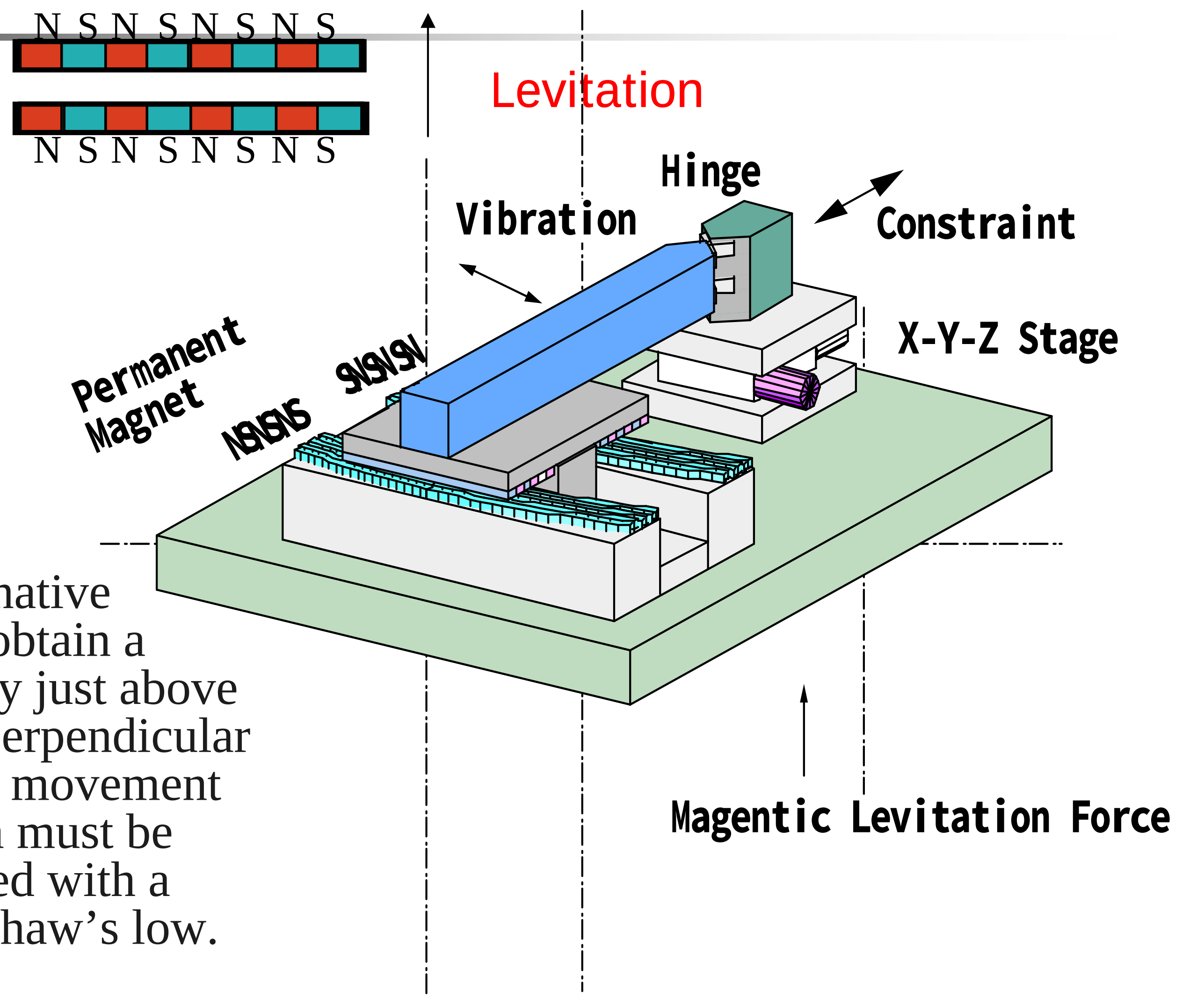
Another Developments

Abstract

Horizontal Component Seismometer with Magnetic Levitation

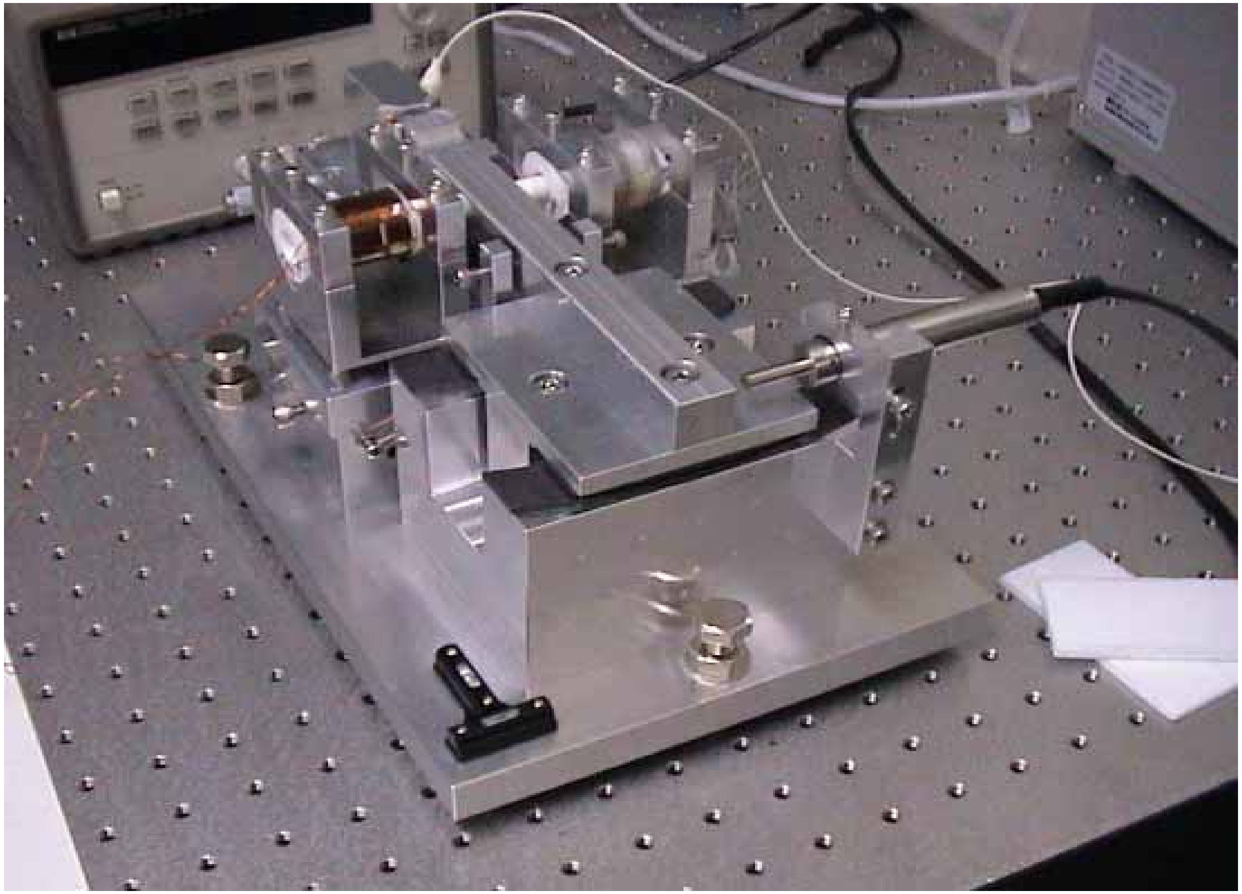
Development of new instruments with new ideas is important to open up a new window of earth science. In this study, we have developed a seismometer using a new principle to obtain further sensitivity than present one. This seismometer uses a horizontal pendulum having weak leaf-spring crossed hinges and using magnetic levitation for a pendulum weight. The levitation employs permanent magnets magnetized by N, S strip, alternatively. This pendulum has been built and evaluated by experiments. The results of the experiments are as follows. 1. The prototype of the pendulum achieved a natural period more than 11 s. 2. The natural period of the prototype was changed with a magnetic spring. These values of the period were consistent with theoretical calculations. 3. The prototype with a feedback control circuit, a feedback control coil and a capacitance displacement sensor worked as a servo-type seismometer. 4. The observations using the magnetic levitation seismometer have been carried out and showed capacity to measure microseisms.

A horizontal component seismometer with magnetic levitation using plane permanent magnets with NS alternative magnetization strips.



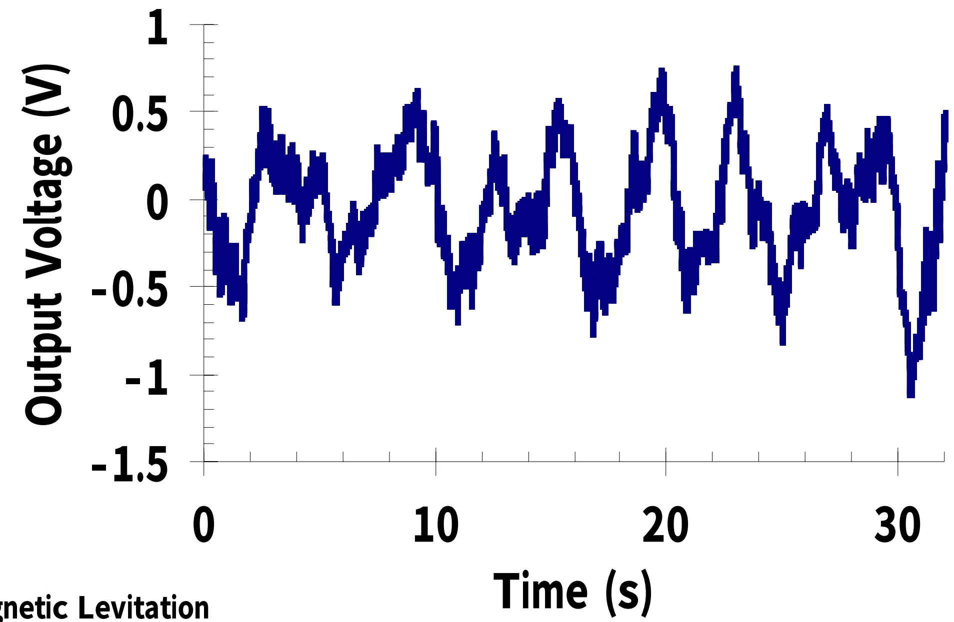
- By using the NS alternative magnetization, we can obtain a uniform potential energy just above the magnet surface. A perpendicular direction referred to the movement direction of a pendulum must be mechanically constrained with a hinge, because of Earnshaw’s low.

The picture of the horizontal component pendulum with magnetic levitation of the weight using the plane permanent magnets

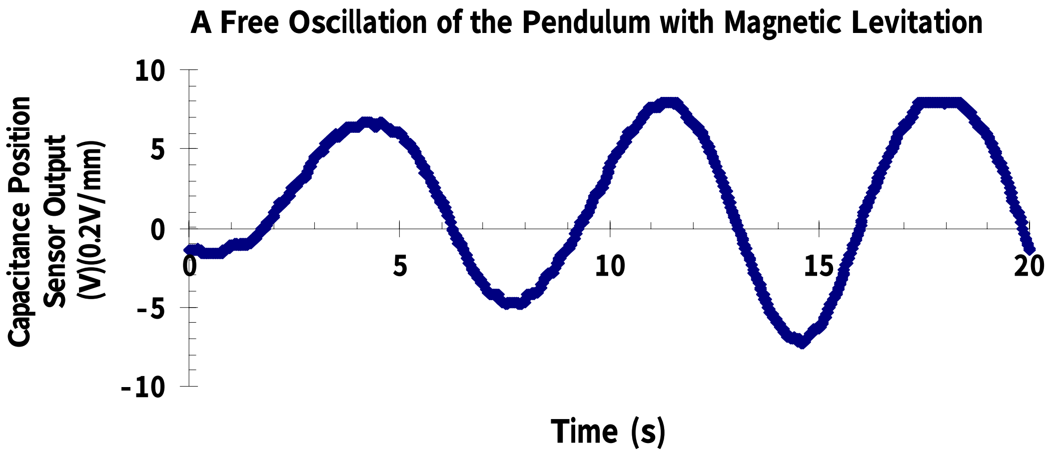


A free oscillation of the pendulum and an output signal of the horizontal servo-type seismometer with magnetic levitation for the weight

Marine Microseism



The wave form is measured by the capacitance position meter (0.2V/μm). The natural period of the pendulum is about 8 s.



Laser Scale Servo-type Seismometer