105-F West Dudleytown Road, Bloomfield, CT 06002, USA; 1-860-242-8177; Fax: 1-860-242-7812
info@pmdsci.com; sales@pmdsci.com; www.pmdsci.com

High Resolution Seismometer Insensitive to Extremely Strong Magnetic Fields

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Miniaturized, high-resolution, broadband seismometers completely insensitive to extremely strong magnetic fields should find important applications in the advanced high energy accelerator physics. All modern *electromechanical* seismometers use a fixed magnet and moving coil combination in their feedback. In this configuration weak or even moderate external magnetic fields have little or no effect on the sensor performance. In the vast majority of the current higher resolution seismometers a capacitive transducer performs the motion-to-electric signal conversion. However, when the external magnetic field becomes comparable to that acting inside the electrodynamic system of the seismometer, performance of the latter grows from a poor one to complete failure. Indeed, implementation of a seismometer with capacitive converter without feedback and high sensitivity is extremely difficult, if at all possible. An efficient capacitive converter requires extremely precise tracking of the inertial mass position due to very small gaps between the capacitor's plates. Evidently, increasing distances between plates results in sharp drop in resolution. Similar considerations are fully applicable to the use of opto-electrical converters.

The use of an electrochemical sensor in beam focusing systems presented several difficult challenges.

- We could not use any ferromagnetic materials in the inertial mass suspension.
- Both vertical and horizontal sensor versions were required.
- The sensor is exposed to very high levels of hard radiation that could affect the elastic membranes which contribute very significantly to the transfer function. At the same time our usual way of sensor calibration seemed to be impossible to employ because of the exceptionally strong external magnetic fields.
- Finally, sensor dimensions were severely restricted

To overcome the suspension problem we decided from the outset to use a light inertial mass that could be supported solely by the sensor's membranes. A very important additional advantage of such suspension is that the same sensor can be used as vertical or horizontal.

A special miniaturized version of the standard electrochemical sensor was develop and tested successfully (Fig. 1).

Figure 1. A standard electrochemical sensor and its miniaturized version.

The most difficult and time consuming parts of the small sensor development were the design of a smaller than usual transducer with increased mesh electrode thickness in order to compensate for a smaller area and the design of the membranes. The latter must satisfy two mutually opposite conditions: be sufficiently rigid in order to support the inertial mass and, at the same time, sufficiently soft to provide for broader frequency response in the infra-low frequency region.

The next exceptionally important step was radiation testing. This was done by our partners – the SLAC team. We built a prototype sensor that we calibrated extremely thoroughly and provided the transfer function to SLAC. The latter exposed the sensor to the same cumulative radiation dose as that which can be expected after a few years of deployment in the beam focusing system environment. After the exposition the sensor's transfer function was checked and the changes turned out to be well within the measurement error margins.

By that time we have also determined the optimal membrane materials – a special butyl rubber type elastomer that was developed in co-operation with the Stockwell Rubber Co. of Philadelphia, PA. and equally suitable elastomer Santoprene that we developed in co-operation with Aero Rubber Co. of Tinley Park, IL.

Additional feature of the SLAC prototype was external electronics. Indeed, it would be much more expensive to use radiation hardened components in the amplifier and still possibly get uncertain results in terms of the transfer function stability. Also, placing electronic board together with the sensor would make it even more difficult to stay within the required seismometer dimensions. Therefore the electronics was placed in a separate enclosure connected to the sensor via a shielded twisted pair cable.

Our major concern was providing in-situ calibration means to the user. Indeed, since the sensor becomes radioactive after a prolonged exposure to hard radiation we cannot be confident that the transfer function stays stable over long time intervals. As mentioned above, the use of any permanent magnet/coil arrangement is impossible. At first we experimented with piezocrystal delivering a short mechanical pulse to the membrane. Unfortunately, we could not generate identical pulses consistently and thus have a known input signal. After much deliberation we came up with a rather simple and rather elegant solution. Please turn your attention to Fig. 2., 3 and 4.

The calibration coil, same as that used in our standard seismic sensors, is firmly attached to the inertial mass. During normal operation of the sensor this coil is not connected anywhere. Right under this coil an electromagnet is placed. This magnet consists of a pot core made of a very (magnetically) soft ferrite and a magnetizing coil similar to the calibration one. Once again, during normal operation of the sensor this coil is not connected anywhere. Whenever the accelerator is not in service the sensor can be calibrated. The first step should assure that there is no residual magnetization in the core. In order to demagnetize the core a small ac voltage is applied to the magnetizing coil terminals for a short period of time. After that a small (a few Volts) dc voltage is applied to the same terminals and thus we have at our disposal a permanent magnetic field acting along the sensor's axis. Now a function generator or a pulse source (for example a 1.5V battery) can be connected to the calibration coils terminals and a complete transfer function can be measured.

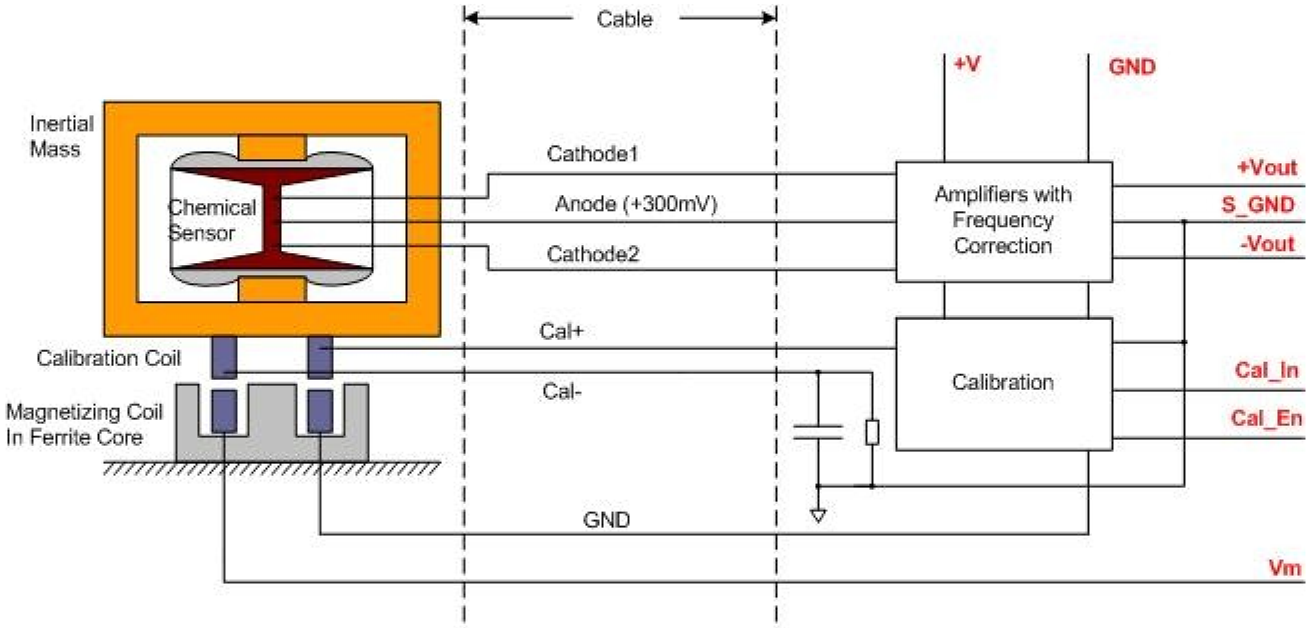

Figure 2. Sensor block-diagram

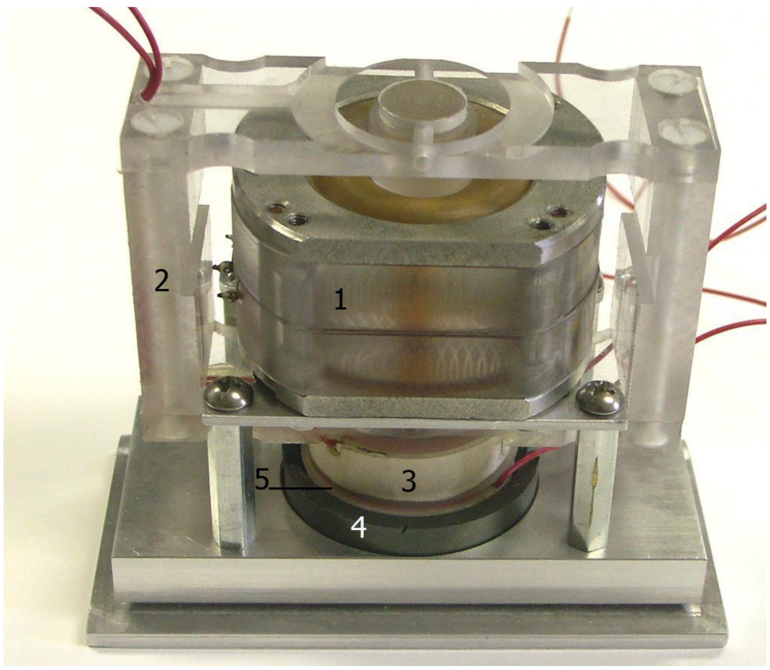

Figure 3. Sensor with calibration assembly:
1 – sensor; 2 – inertial mass; 3 – calibration coil (attached to the inertial mass); 4 – soft ferrite pot core; 5 – magnetizing coil.

Figure 4: Sensor and external electronics.

Several sensors per the above description have been produced. Two of them were sent to SLAC, another two sold to LAPP. We are fully prepared to manufacture these sensors in any quantities.

Conclusion:

The project objectives have been met and indeed exceeded. Multiple prototypes have been successfully tested by the SLAC team. Several new concepts devised during the instrument development have been tested and implemented in the final pre-production seismometers. Several of the latter have been sold to the French LAPP team.