State-of-the-art Digital Seismograph

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VolksMeter -- a seismometer / tiltmeter that evolved out of fundamental physics research

The Instrument is being exhibited at this conference

Business Partners:

Les LaZar, Zoltech Corp. (Mechanical)
Larry Cochrane, Webtronics (Electronics & Software)
One Example of Pendulum research spanning nearly two decades – Compound pendulum used to study Internal friction

These studies discovered that Internal friction limits the performance of seismometers at low frequencies:

Some relevant publications:


upper mass

axis

lower mass

sensor
Second example of a pendulum used in physics research
(generically similar to instruments used in late 19th century)

Simple pendulum used to study diurnal (non-tidal) signals continuously over an 18-month interval

Early work was by George Darwin, Son of famous English biologist in Collaboration with physics great, Lord Kelvin
Top view of the two-pendulum VolksMeter
Close-up photograph of a Sensor

The patented symmetric differential capacitive (SDC) sensor, operating on the basis of area-variation, rather than gap-spacing-variation, is one form of the first fully-differential capacitive sensor.

Resolution: 0.4 nrad (0.1 nm), Dynamic range > 130 dB
Why was a simple compound pendulum chosen?

• Superior mechanical stability.
• Simple construction.
• Simple precision calibration.
• Easy to use.
• Reduced mechanical sensitivity, previously unacceptable, overcome by latest electronics technology [SDC sensor plus capacitance to digital converter (CDC)].
Details of a pendulum axis

Tungsten carbide sphere

Screw provides lateral adjustment of the moving electrode relative to the static electrode set at the bottom end of the pendulum.
Moving electrode of SDC sensor
Example calibration data

Each step determined by 1/4 turn of a calibration screw.

Data yields for the calibration constant:
(for 24 bit operation)
2300 pF/rad = 2.35 x 10^9 counts/rad.
Illustration of d.c. response

Response to body weight deformation of concrete slab on which instruments rests
(square wave generated by stepping back & forth on opposite sides of the instrument)
Pendulum free-decay without damping magnets
(illustrates sensor linearity—harmonic distortion below 60 dB)
Digital electronics CPU architecture

Volsmeter Block Diagram

- CPU
  - DSPic30F3014
- CDC CH1 SPI BUS
- CDC CH2 SPI BUS
- RS-232 HOST CHANNEL
- RS-232 GPS CHANNEL
- 1 PPS INPUT
- Power Supply
- +5VDC
- AD7745 CHANNEL 1
  - CIN+
  - CIN-
  - EXCA
  - EXCB
- AD7745 CHANNEL 2
  - CIN+
  - CIN-
  - EXCA
  - EXCB
- RS232 LEVEL CONVERTER
  - HOST CHANNEL
  - GPS CHANNEL
  - 1PPS SIGNAL
- TX/RX
- USB 2.0

DC POWER 9 to 28VDC
UART for USB ‘plug and play’ computer operation
Example connection--Fully-differential sensor
(Peters patent U.S. 5,461,319)
to the Capacitance-to-Digital-Converter
(Analog Devices AD7745)

rectangular geometry (as opposed to what is used with the pendulum)
illustrating connections to the static plates of a single element SDC sensor

Output = (Cx - Cy) - (Cw - Cv)
       = 2 (Cx - Cy)
One key advantage of digital electronics

VolksMeter with fully-digital electronics

\[ \frac{1}{f^{0.23}} \]

SDC sensor with synchronous detection

\[ \frac{1}{f^{0.72}} \]

SDC sensor without synchronous detection

\[ \text{classic } \frac{1}{f} \]
VolksMeter Noise compared to earth background

From Fig. 7, horizontal component only, J. Berger & P. Davis, J. Geophys. Res. Vol. 109, B11307 (2004).
Advantage of a position sensor over a conventional velocity sensor at low frequencies

Influence of Sensor and Pendulum characteristics on Instrument Equivalent Noise Power Spectral Density

- **blue:** present Volksmeter configuration using a position sensor
- **red:** if the Volksmeter used a velocity sensor
- **green:** if the pendulum's period were 10 s and used a velocity sensor

40 dB SNR increase for T > 10 s
Position sensor also takes advantage of a pendulum’s tilt response at low frequencies

Voltsmeter pendulum, natural frequency = 0.918 Hz

**Advantage of Position sensing at Low Frequencies**

[Plots of Instrument Equivalent Noise Spectral Density (true power)]
Response to local earthquakes (two events, same helicord)

Power Spectral Density plot of first Earthquake of Mag. 4.5 (2nd earthquake Mag. 3.9)

Helicord records -- each event 160 km northerly distant from instrument having N-S pendulum orientation
Comparison of Volksmeter teleseismic response to a commercial broadband instrument

USGS Broadband (STS-1), no filter (one of 3 display types realtime at http://jclahr.com/science/psn/cor/index.html)

Data from station COR (Corvalis, Oregon)
Advantage of the Integrated signal for the real-time observation of teleseismic earthquakes

(Event is the Hawaii earthquake of 15 October 2006, Mag. 6.7, observed in Macon, Georgia)

Spectra: blue--clamped pendulum, red--raw position data, green--integral of position after high-pass filtering
Illustration of difference in the time domain—raw data vs integrated signal
Illustration of the broadband features of the Volksmeter (response during demise of tropical storm Paul)

Helicord record, Instrument at Redwood City, CA

Power Spectral Densities
(32K points from pair of 6 h segments)
VolksMeter Operational Attributes

Triad of features integrated in a uniquely synergetic package:

2. Latest technology (fully differential capacitive) sensor
3. Award-winning acquisition electronics
4. Powerful, user-friendly acquisition (WinSDR) and analysis (WinQuake) software (also compatible with USGS seismic recording package, “Earthworm”)

• Providing good earthquake records, both local and teleseismic, while
• Yielding a new window on the world of very-low-frequency earth motions and
• Providing means to easily generate TRUE power spectral densities)
Example of WinQuake generated figures (records following storm passage)
Illustration of the ease with which filtering is done (here low-pass at 0.1 Hz)
Illustration of added-versatility through easy-exportation of data to Excel