Very-Broad-Band Feedback Seismometers

STS-1V/VBB / STS-1H/VBB

CH-8422 Pfungen / Switzerland

G. STRECKEISEN AG MESSGERÄTE

The STS-1V/VBB and STS-1H/VBB seismometers are highly sensitive, remotely controlled seismic sensors for observatory use. Their extremely high dynamic range and their stable transfer characteristics make them ideal for a wide range of applications. The basic response of the instrument is flat to ground velocity from 0.1 to 360 sec period. The whole spectrum of teleseismic signals, from 0.1 sec to about 1 hour period, is resolved in the output signal and can be recorded in a single digital data stream when a suitable digitizer is used.

The sensors can be converted to a free period of 20 sec with internal jumpers. Except for the upper corner frequency which is 10 Hz in place of 5 Hz, the response is then identical to that of the 20 sec STS-1V and STS-1H seismometers.

THE STS-1V/VBB / STS-1H/VBB SEISMOMETERS OFFER

- HIGHEST DYNAMIC RANGE
- RESOLUTION OF GROUND NOISE FROM SHORT PERIODS TO THE FREE-MODE BAND
- A SIMPLE AND STABLE TRANSFER FUNCTION THAT DOES NOT NEED TO BE ADJUSTED AFTER INSTALLATION
- PRECISE CALIBRATION BY THE MANUFACTURER
- INEXPENSIVE SURFACE INSTALLATION
- ELECTRONICS SEPARATE FROM THE MECHANICAL SENSOR, I. E. ALWAYS ACCESSIBLE
- REMOTE POSITION CONTROL AND MASS CENTERING
- SELF-TEST MODE (FREE ELECTRICAL OSCILLATIONS OF THE CLOSED-LOOP SYSTEM)
- SHIELDING AGAINST ENVIRONMENTAL DISTURBANCES

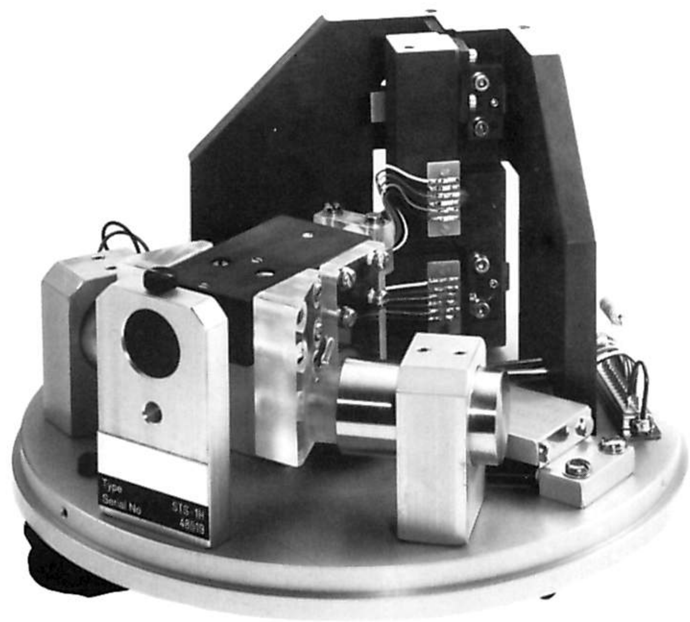
Principle of Operation

The STS-1V/VBB / STS-1H/VBB seismometers are force-balance seismometers. This design principle is now more or less standard in high-performance seismometers, and means that the boom is always kept close to its center position by an electrically generated restoring force. While in conventional seismometers the deviation of the boom from its center position measures the seismic signal, in a force-balance seismometer the output signal is derived from the electric voltage or current that is required to keep the boom centered. In this way problems of linearity, dynamic range and stability are transferred from the mechanical system to the electronic feedback circuit where they are much easier to solve. Only the resolution still depends on the mechanical part.

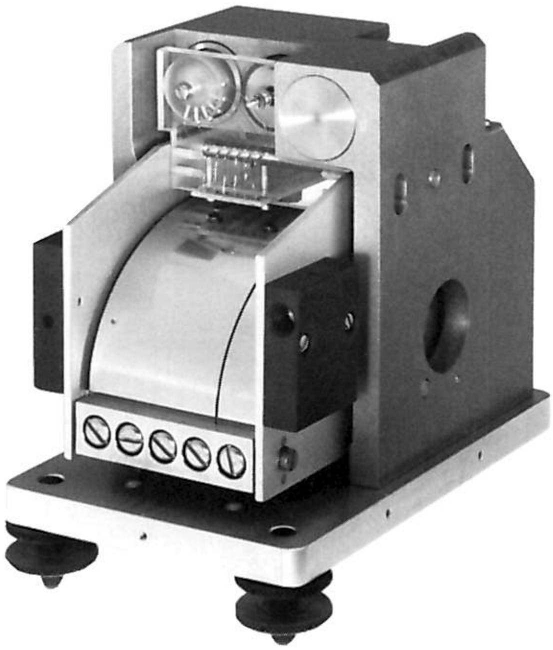
Our sensors are small but massive long-period pendulums with an inertial mass of 600 g. The boom position is sensed by a displacement traducer of the differential-transformer type (LVDT). A combination of integral, proportional and differential feedback force is generated by sending appropriate currents through two moving-coil transducers. A great variety of transfer functions can be realized in this way, but not all of them are equally favourable in terms of dynamic range. We chose a transfer function whose mathematical form is already familiar to seismologists, namely that of a 360 sec long-period seismometer combined with a 0.1sec short-period recording galvanometer or low-pass filter.

The Mechanical Design of our Sensors

As horizontals we use simple "garden-gate"pendulums of about 10 cm boom length, with an almost vertical axis of rotation defined by two pairs of crossed hinges. Due to the massive construction they are virtually free of parasitic resonances. The horizontals are centered by moving up or down one of the three legs under remote control.



The vertical sensors are similar to La Coste long-period seismometers in their properties, but the spring is different. We use an originally flat, semicircularly bent leaf spring in place of the helical zero-length spring invented by La Coste. In a proper geometric arrangement, such a leaf spring produces a very small and linear restoring force so that relatively long free periods can be obtained. The fundamental parasitic resonance is around 80 Hz. Boom centering is done with a small weight moving along a spindle in the boom. The motor is fixed to the frame and disengages from the boom after each rotation. A massive aluminum case provides sufficient thermal inertia to suppress short-term temperature fluctuations.



Shielding against Variations in Temperature, Air Pressure and Magnetic Field

The sensitivity of a long-period seismometer depends to a large extent on efficient shielding against temperature, air pressure and magnetic stray fields. The vertical sensor is enclosed in a Permalloy shield because its spring is sensitive to magnetic fields. All sensors are surrounded by an outer aluminum case in thermal contact with the ground which makes a thermostat dispensable. The sensors are installed inside 25 cm diameter glass bell jars resting on a thick glass plate. The latter is cemented to the ground for good thermal and mechanical contact. The glass bell is evacuated and sealed after installation. This arrangement was chosen in order to safely eliminate pressure variations and air convection in the sensor, and deformation of its frame by the air pressure. Thermal insulation is completed by a layer of fiber cotton around the glass bell, heat-reflecting blankets and a styrofoam box.

The sensors are designed as observatory instruments and are not transportable with the vacuum bell mounted, but can easily be moved when the shields are disassembled.

Feedback Electronics

The feedback electronics are housed in a moisture-proof enclosure (110x 200 x 265 mm) that must be installed within 2 meters from the sensor. Three moisture-proof connectors are provided for connection to the mechanical sensor, to the outside world (power supply, recorder, remote control), and to the Monitor Instrument which is used only during the installation. The feedback electronics include a voltage stabilizer, the LVDT electronics, feedback elements, a motor control circuit for mass centering, and line drivers. The apparent free period of the sensor can be selected to be 20 sec or 360 sec by jumpers. The free period is set to 360 sec by the manufacturer.

A special battery-operated version of the feedback electronics (MGF1, maximum gravity feedback) is available for a precise vertical alignment of the vertical sensor. This alignment is otherwise difficult in the 360 sec mode (but can also be done with the normal electronics in the 20 sec mode). The MGF1 has a built-in digital voltmeter but no electric outputs and cannot be used for seismic recording.

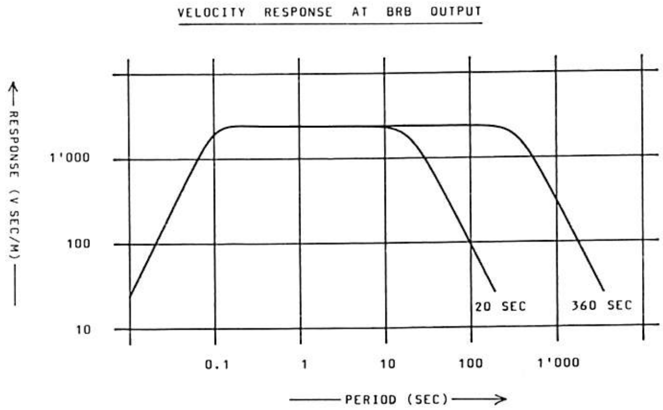
Monitor Instrument MON1 (optional)

Since the sensor is in most cases remotely powered and controlled, it is desirable to have access to some control and test points immediately at the site of installation. These are provided by the Monitor Instrument MON1. It contains a two-range pointer voltmeter for position control and gives access to power and to different outputs of the feedback system. It also permits mass centering and operation of the seismometer without damping. The Monitor Instrument MON1 must be connected to the central connector of the feedback electronics.

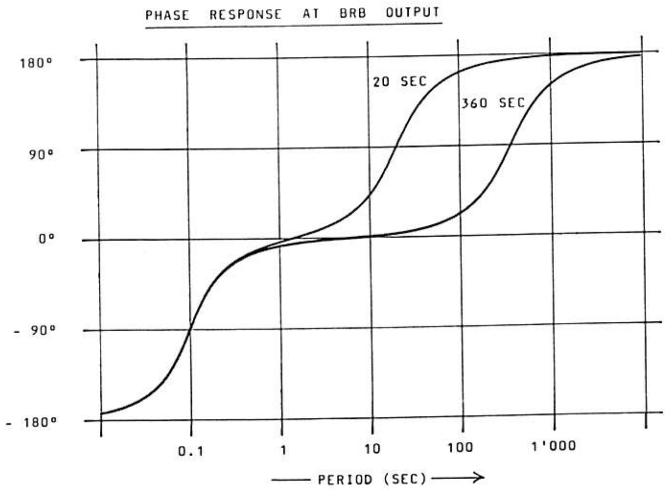
Frequency Response and Dynamic Range

The amplitude and phase response of all STS-1V/VBB / STS-1H/VBB sensors is identical (see the two following figures). It is specified in closed analytical form in the seismometer manual.

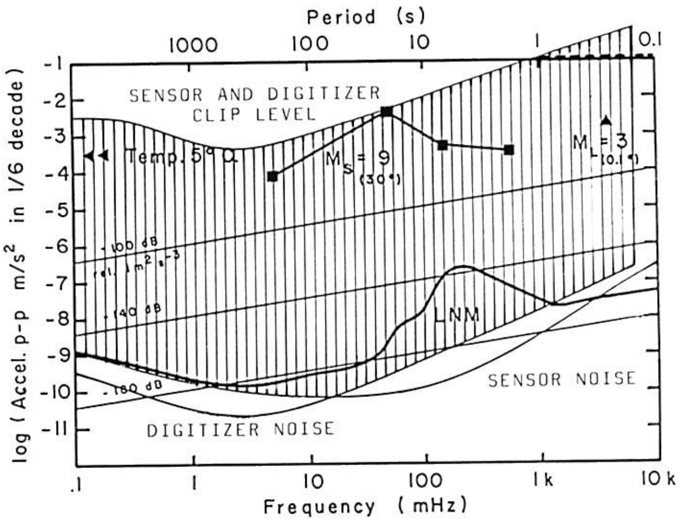
Velocity response at BRB output



Phase response at BRB output



The large dynamic range of the instrument (in the 360 sec mode) is illustrated in the figure below, in which peak-to-peak noise levels have been determined as six times the rms level in a bandwidth of 1/6 decade.



Dynamic range of a digital VBB seismograph based on a STS 1 VBB seismometer and a "Quantagrator" 24 bit digitizer. The heavy line LNM represents the vertical low-noise model by Peterson and Tilgner.

The curve "LNM" represents the low-noise model by Petersen and Tilgner (1985) for the vertical component; short-period noise at most stations is significantly higher. Maximum expected amplitudes from a magnitude 9 earthquake at 30° distance are also indicated.

Suggestions for Digital Recording

In order to make full use of the bandwidth and the dynamic range of the sensor, the differential VBB output signal of ± 20 V must be digitized with a resolution of 2.5 µV and at a rate of at least 20 samples per second. The dynamic range of the digitizer must then correspond to a numerical range of 2^{24} counts. High-resolution, 24 bit digitizers with adequate specifications are now available; they provide the simplest and best solution because they need no gain adjustments and no anti-aliasing filters. Satisfactory systems can also be built with gain-ranging digitizers with a resolution of at least 12 bits. These must, however, be carefully and repeatedly adjusted to avoid offset and gain errors; they also require analog anti-aliasing filters which limit the passband to usually one quarter of the sampling rate, so that a passband up to 10 Hz can only be achieved with a sampling rate of 40 Hz or more. The response of the feedback system at the upper corner frequency, 10 Hz, is such that it can replace one second-order stage of a seventh-order Butterworth anti-aliasing filter.

Specifications

Shielding

Weights	Glass base plate for vertical and horizontal sensor	9.0 kg
	Permalloy shield for vertical sensor	1.8 kg
	Aluminum shield for vertical and horizontal sensor	0.8 kg
	Glass bell for vertical and horizontal sensor	3.5 kg to 5.0 kg
	Complete shielding of vertical sensor Complete shielding of horizontal sensor	15.1 kg to 16.6 kg 13.3 kg to 14.8 kg
Dimensions	Glass plate for vertical and horizontal sensor	35 x 35 x 2 cm
	Permalloy shield for vertical sensor	Diameter 21.5 cm Height 19 cm
	Aluminum shield for vertical and horizontal sensor	Diameter 22 cm Height 21 cm
	Glass bell for vertical and horizontal sensor	Diameter and heigth inside min.25 cm
Minimum space required for istallation		50 x 50 cm, 60 cm high

Mechanical Sensors

Weights	Vertical sensor with cover Horizontal sensor with cover	4 kg 5.5 kg
Dimensions	Vertical sensor with cover Horizontal sensor with cover	12 x 17 x 18 cm Diameter 20 cm Height 16 cm
Mechanical free period	Vertical and horizontal sensor	Virtually infinite
Parasitic resonances	Vertical sensor Horizontal sensor	above 70 Hz none found
Boom centering	Vertical and horizontal sensor	by 12 V DC motor, remotely controlled

Feedback Electronics in Moisture-Proof Enclosure

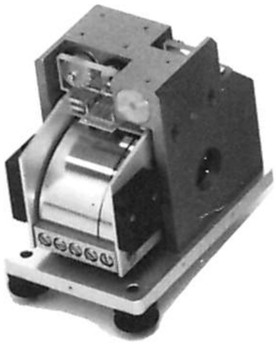
Weight	3.6 kg
Dimensions	11 x 20 x 26.5 cm
Power requirement	± 15 V / 120 mA when using built-in stabilization circuit
Connectors	17pin connector for signal outputs and control inputs 14pin connector for Monitor Instrument MON1 17pin connector to sensor
Cable length	2 meters between Feedback Electronics and sensor

Electro-Mechanical Specifications

Response	Flat to ground velocity at a responsivity of 2 x 1200 V sec/m ± 10% (the exact value is specified by the manufacturer for each instrument)
Long-period corner	20 or 360 sec ± 1%, jumper selectable (second-order cutoff with 0.707 ± 1% of critical damping)
Short-period corner	0.1 sec (second-order cutoff with 0.623 of critical damping)
Accuracy of phase calibration	10^{-3} cycles or 5 msec (whichever is more) in the passband
Resolution	The instruments resolve minimum ground noise (Low-Noise Model of Peterson & Tilgner 1985) from 3 Hz to 0.3 mHz if properly installed and shielded
Clip level	± 8 mm/sec ground motion (0.1 - 360 sec), increasing outside the passband
Dynamic range	> 140 dB
Calibration coil	100 Ohms, 2.2 m sec^{-2} A^{-1} Maximum current 30 mA, current divider 1:1000 selectable
Temperature range	15° ± 5° C without mass recentering

Components Delivered

A vertical seismometer STS-1V/VBB includes the following components:



Vertical sensor with cover

Seismometer
feedback electronics

Permalloy-shield
(for vertical sensor only)

Aluminum shield

Cable between sensor
and electronics

Glass plate and glass bell

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