CMG-1T
OCEAN BOTTOM SEISMOMETER

OPERATOR'S GUIDE

REVISIONS

ISSUE	ECN	DATE	COMMENTS
A	First	15.05.96	
B		24.01.97	Add drawings and photos.
C		14.09.99	Addition of Appendix A

DESIGNED AND MANUFACTURED BY:

GÜRALP SYSTEMS LIMITED
3 MIDAS HOUSE
CALLEVA PARK
ALDERMASTON
READING
BERKS, RG7 8EA
ENGLAND

Telephone: +44 (0) 118 9819056 **Fax: +44 (0) 118 9819943**

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3 MIDAS HOUSE
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PROPRIETARY NOTICE

HOW THIS USER'S GUIDE IS ORGANISED

This user's guide is sectionalised with each section dealing with a specific topic.

Generally speaking, background material and technical explanations are found in the later sections, while practical instruction occurs at the beginning. A list of tables and specifications are found at the end of the manual.

Each section of the user's guide is kept, as nearly as possible, self-contained and free-standing so that the sections can be read in any order. General cross-references are provided where necessary, but complicated notation of the sections and paragraphs is avoided.

A very brief description of the user guides sections are given below but the contents page provides the titles of each section.

INTRODUCTION:	This section summarises the CMG-1T sensor, the levelling system and the micro-controller which controls the sensors and the levelling system.
QUICK START:	This section gives quick itemised procedures for unpacking, installing and **operating** the CMG-1T. **<u>The user can use this section to quickly deploy and operate the instrument.</u>**
OPERATION:	These sections make up the instructions to operate the CMG-1T sensor, with detailed description of the sensor and operation.

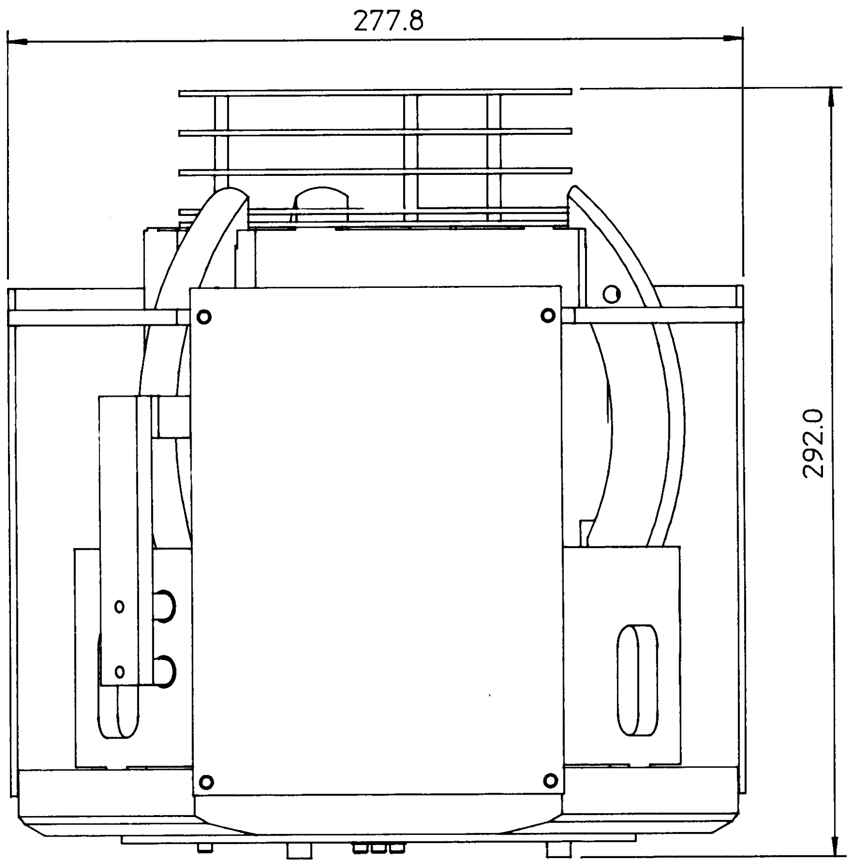
CONTENTS

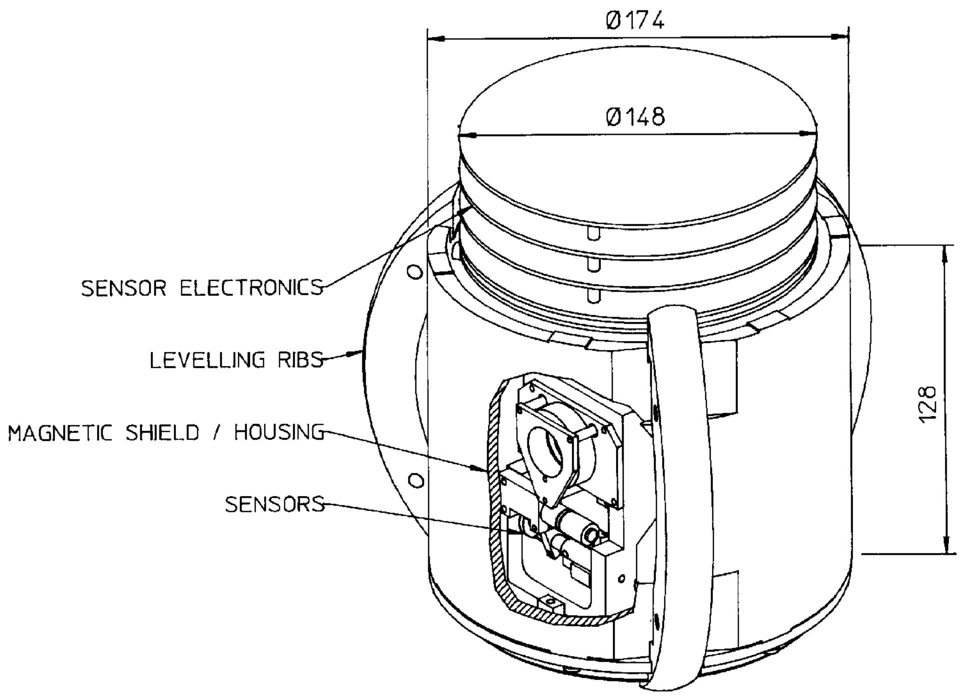
SECTION

1. INTRODUCTION

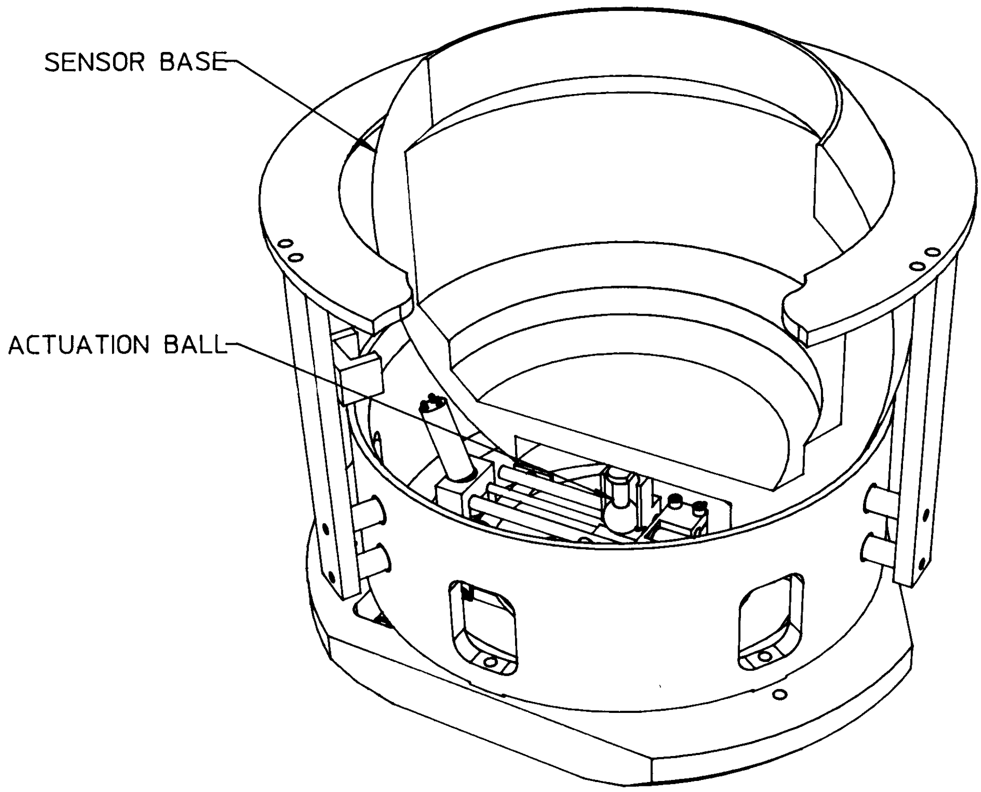
The qualities of Güralp Systems Limited's broadband sensors (Ref 1) clearly opened up a new era in ocean bottom and ocean bottom borehole seismology. A pilot experiment which deployed CMG-3 sensors (Refs 2 and 3) clearly indicated some of the advantages that can be ascertained from broadband sensors installed under water. The only disadvantage of CMG-3 as an ocean bottom instrument is the sensor mass locking mechanism. While the CMG-3 locking mechanism is adequate for most , if not all, conventional installations, due to increased reliability requirements, a new foolproof patented locking mechanism has been designed. The CMG-1T sensor uses this unique mass locking mechanism which virtually eliminates the possibility of sensor pivots or springs being damaged.

The CMG-1T OBS seismometer consists of three solid body CMG-1 seismometer components. The three component sensors are organised to be orthogonal to each other. The base plate of the sensors is fixed to the bottom plate of the levelling dish as shown in the following diagram. The analogue electronics for the sensors are stacked above the sensors. The OBS analogue electronics are specially designed to have low power consumption, and the quiescent current consumption of the sensor system is 26 mAmps from a 12 Volts supply.





The levelling dish structure has ± 30 degrees of levelling capability, with an accuracy of ± 0.2 degrees, and stability which is fit to be used as a levelling platform for a broadband sensor.



Individually each sensors outputs can be further zeroes within a range of ± 2.5 degrees. The horizontal sensors are levelled (or mass position output zeroed) by tilting the sensor bases, in the case of the vertical sensor the sensor boom position is controlled by the movement of the tip of the main load bearing spring.

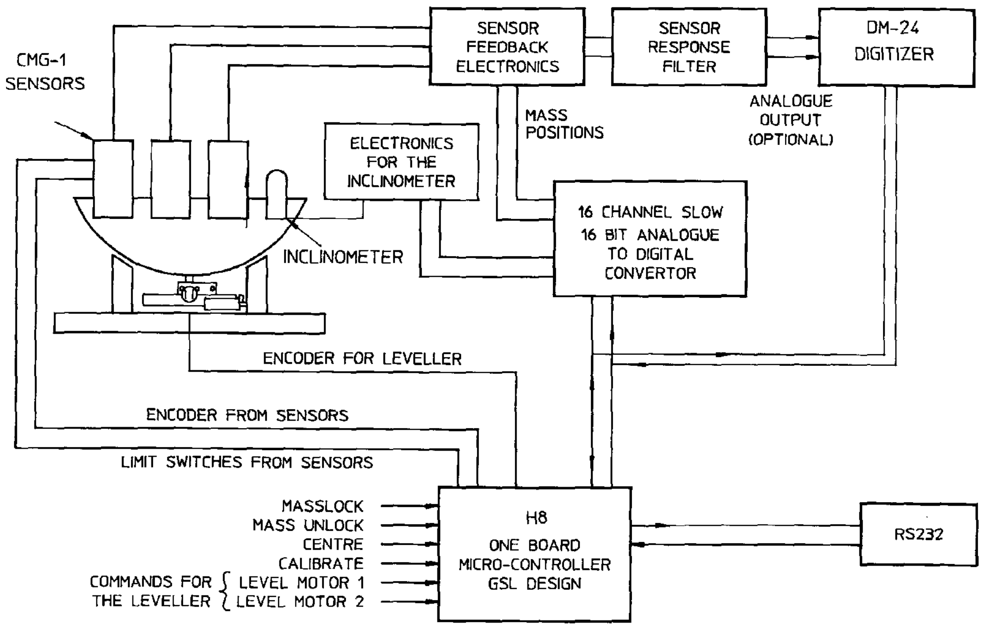
The sensor command functions are controlled with a single chip micro-controller, type H8 (Hitachi). The sensor function lock, unlock, centre and levelling bowl functions are all initiated with command words instructed through the system serial communication port.

A two axis inclinometer is used to measure the tilt of the sensor levelling bowl in the North/South and East/West directions. The inclinometer is interfaced to the micro-controller which ensures levelling of the sensor levelling bowl with a single English command **"LEVEL"**.

A two axis inclinometer is used to measure the tilt of the sensor base in the North/South and East/West directions.

The commands to operate the seismometer control functions, the digitizers and the data from the digitizers is communicated with a serial communication line.

In the case where an internal digitizer is used, the sensor outputs are digitized with a 24-bit digitizer and the data packets are time stamped at the source. A complete block diagram of the ocean bottom sensor is given below.



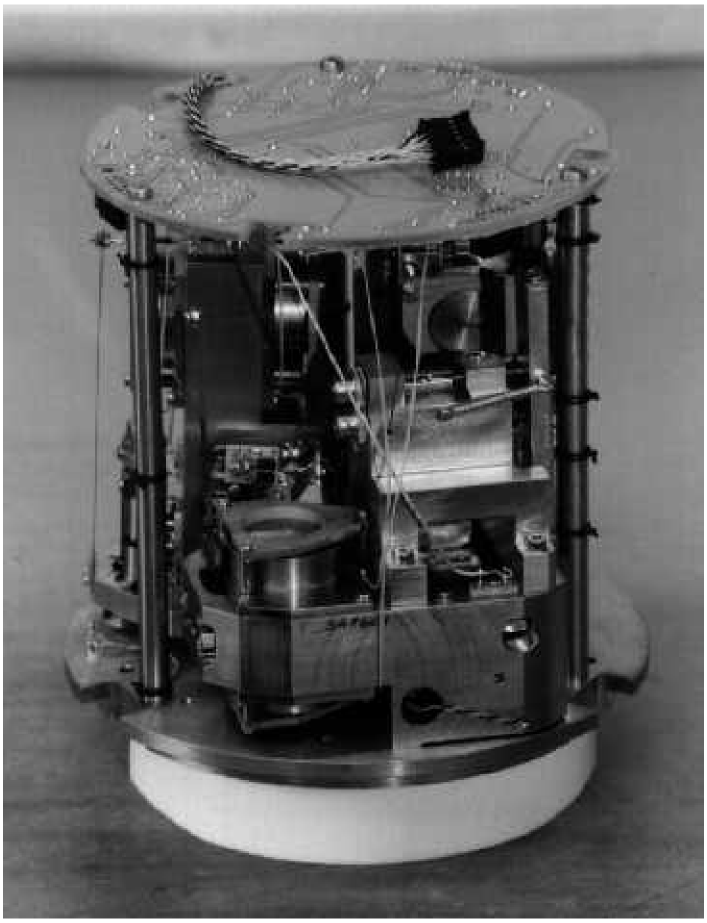
Ref 1: Which Broad Band seismometer in Ocean Bottom Observatory? Preliminary results of simultaneous recording of seismic signals using STS-1, STS-2, CMG-3 during May 1993 at St Sauveur (FRANCE)
S. Cacho et al.

Ref 2: The French Pilot experiment OFM/SISMOBS: First scientific results on noise level and event detection
Jean-Paul Montagner et al.

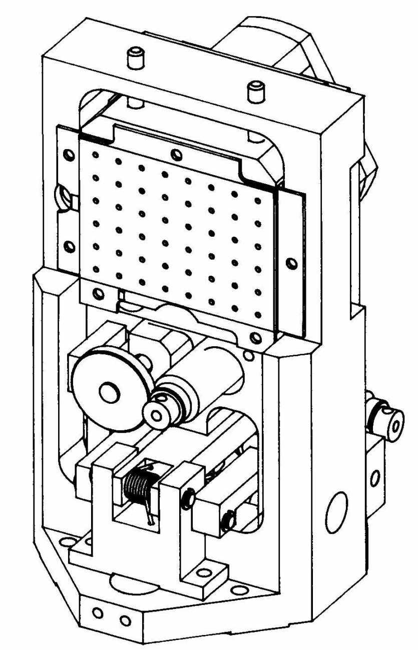
Ref 3: The Pilot experiment OFM/SISMOBS: A first step towards a permanent oceanic geophysical observatory
J.P. Montagner et al.

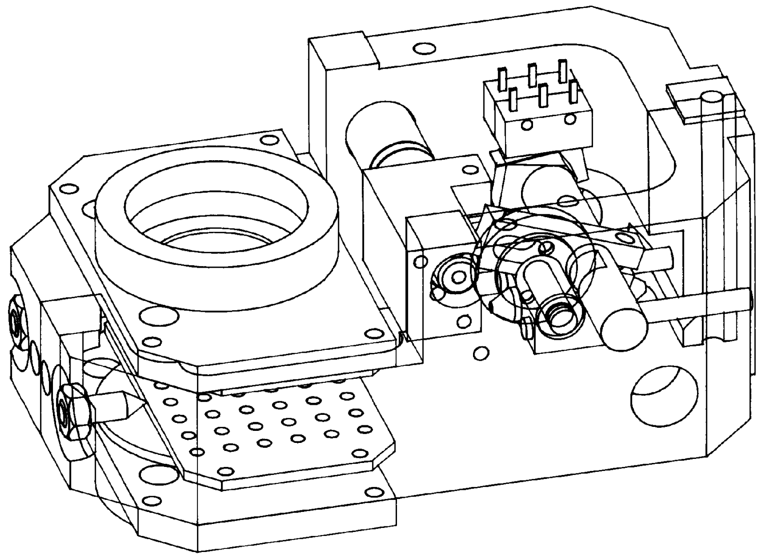
2. DESCRIPTION AND EXPLANATION OF THE MECHANICAL SENSOR SYSTEM

A photograph of the overall construction and layout of the seismometer are given here, together with some details of the individual sensors.



The horizontal and vertical sensors are based on a shared design, that of a leaf spring suspended boom supporting a transducer coil, the boom and coil forming the inertial mass. The boom consists of a solid machined beam which swings on a frictionless hinge. The system has no spurious resonances below 140 Hz. The vertical component instrument has a pre-stressed triangular support spring which supports the weight of the mass. The horizontal component sensors have un-stressed flat triangular springs, giving a natural period of about 1 second, while the vertical component sensor has a natural period of about 0.5 second. The effective mass is about 250g in each case. The small stiff springs and short boom lead to a very compact design permitting the designer to incorporate three instrument in a relatively compact case.





The adjustments required for operation consist of levelling the boom of the vertical sensor and tilting the bases of the horizontal sensors to centre the movements in their equilibrium positions. These adjustments are made by small DC motors operating through gear trains to tilt the bases of the horizontal sensors and to apply a small extra force to the vertical sensor's boom.

For transportation the masses have to be locked securely in their frames, taking the strain off the support hinges. The locking is performed by a small motor driven clamp in response to a control command.

The positions of the masses of all sensors are monitored by identical capacitative position sensors and it is the signals from these which form the basis of the seismometers’ mode of operation. The electronic processing of the mass position signals is carried out on circuit boards mounted in a screened compartment above the mechanical components. The main output voltages, proportional to ground-velocity, are transmitted out of the case on differential balanced lines, while the mass position signals are sent as single-ended circuits referred to analogue ground via the output plug. Coming into the case are the control signals which signal the control circuit to clamp or unclamp the masses and to start the levelling and zeroing sequences, running the motors to null the offset voltages from the transducers. There is also provision for applying a calibrating voltage to the force transducers to allow the deflection sensitivity to be measured.

The outer case is completely hermetically-sealed to the base by a compression ‘O’ ring joint and all electrical connections pass to the exterior via a glass sealed plug. The only mechanical adjustments on the case are the three levelling feet which can be locked in position without disturbing the setting. The tips of the feet carry insulating beads which prevent electrical ground loops from being set up inadvertently.

3. THE FEEDBACK SYSTEM DESCRIPTION

In a practical broadband seismometer the natural characteristics of the seismometer are never used. The period and damping of the sensor is completely determined by a feedback loop which supplies a counter-force to the inertial mass sufficient to oppose any overall motion. The force required to restrain the movement of the mass is then a measure of the inertial force exerted by the mass due to the ground motion.

The feedback control operates as described below:

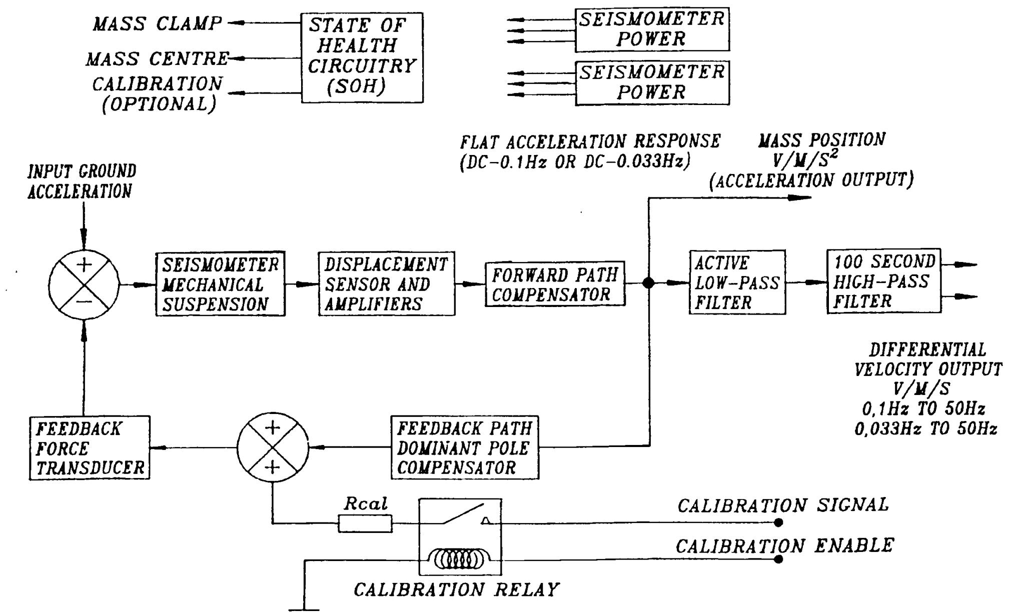
The capacitative position sensor provides a voltage proportional to the displacement of the mass from its equilibrium position. This voltage, after amplification, generates a current in the force transducer coil which tends to force the mass back to its equilibrium position. With a high loop gain the motion of the mass is effectively cancelled thus providing the force balance condition. The feedback voltage is then a measure of the force and thus of the acceleration applied to the mass.

In order to obtain stable operation over the whole frequency range the feedback loop phase shift has to be carefully controlled. This is achieved by compensation components in the forward and feedback paths as shown in the following block diagrams.

The CMG-1T sensor is supplied with one of two different types of feedback system. The main difference between the two systems is in the feedback electronics used to implement the required responses. In the HYBRID circuit the feedback components between the output signal and the seismometer mass consist only of a single capacitor in parallel with a resistor. This results in only a single pole at the specified frequency. The output of the seismometer at frequencies below this frequency is proportional to ground acceleration. This contrasts with the CONVENTIONAL RESPONSE feedback system which has an additional parallel feedback circuit consisting of a non-inverting integrator in series with a resistor. The response of the arrangement gives a double pole at the specific frequencies. In all cases, signal in frequency bands longer than the specified velocity corner frequencies (eg. 10 sec, 30 sec, 100 sec and 360 sec.) can be recorded using the mass position outputs. However, high pass circuitry is recommended to remove the sensor output offsets.

100 SEC AND 30 SEC HYBRID VELOCITY SENSOR

The block diagram for both of the hybrid systems is given below.



In comparison to a conventional feedback accelerometer the hybrid velocity response is obtained with a dominant single pole which is set at either 0.1 Hz or at 0.033 Hz. The dominant pole breaks the system response into two sections, the first one being flat to acceleration from dc to the dominant corner frequency (0.1 Hz or 0.033 Hz) and the second response flat to velocity starting from the dominant corner frequency until the high frequency cut off.

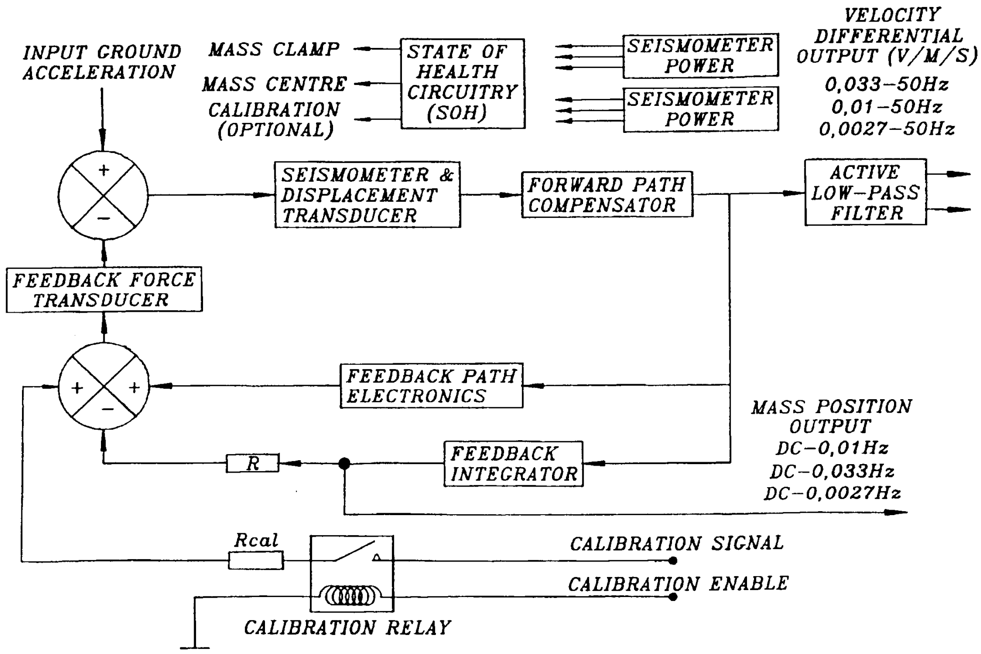
The high frequency cut off is realised with an active low pass filter. Without this low pass filter the sensor velocity response is flat up to 100 Hz.

As the hybrid system is dc coupled to remove any dc offsets a 0.01 Hz (100 sec) or 0.005 Hz (200 sec) active high pass filters are used. These filters are external to the sensor feedback loop.

The main advantage of such a system is to provide a stable response, particularly for portable systems, with a high saturation level at high frequencies and high dynamic range at the long periods.

30 SEC, 100 SEC AND 360 SEC VELOCITY SENSOR

The block diagram of the velocity responsive seismometer is given below. This block diagram is applicable to all the three types of velocity sensors.

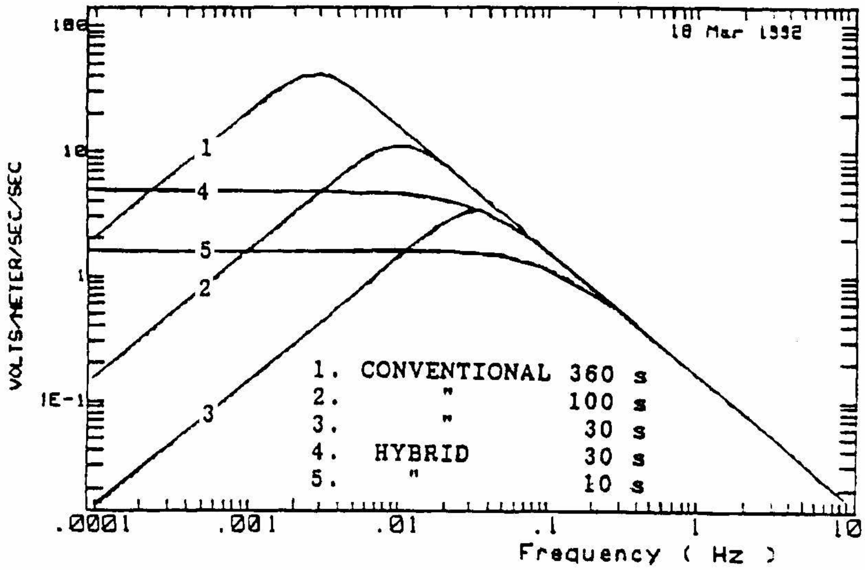


The system velocity responses are defined by a transfer function identical to that of a conventional long period sensor with a velocity transducer whose natural resonant frequency is set at 0.033 Hz, 0.01 Hz or 0.0027 Hz and the damping z at 0.707.

Similar to that of the hybrid system, the high frequency portion of the sensor response is determined with a low pass filter. The corner frequency of this low pass filter is specified by the user.

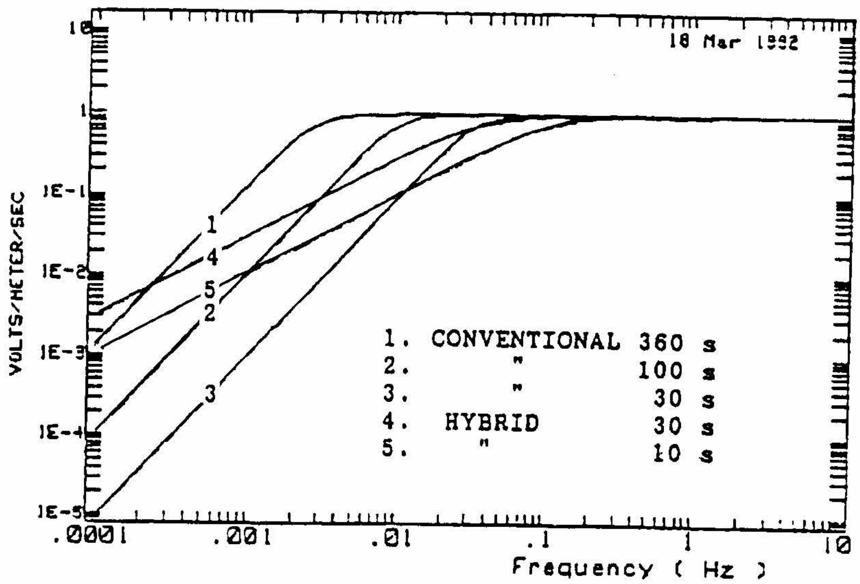
An output proportional to the ground acceleration is available from either of the above described sensor frequency responses. In a feedback seismometer with a displacement transducer it is essential to monitor the acceleration output as the position of the displacement transducer is provided by this output. Under normal operating conditions the displacement transducer needs to be in its 'NULL' 'CENTRED' or 'ZERO' position. The acceleration output (V/m/s^2) is also known as the sensor MASS POSITION as the displacement transducer is always attached to the sensor inertial mass.

The figures below gives the comparative response of a conventional velocity output broadband sensor and hybrid output broadband sensor. The family of curves shows the sensor output response to input acceleration in units of $V/m/s^2$. Curves 1, 2 and 3 are the conventional 360 sec, 100 sec and 30 sec responses and curves 4 and 5 are the hybrid 10 sec and 30 sec responses.



Relative Responses to Ground Acceleration.

Alternatively the system amplitude plots are given below as output against input velocity.



Relative Responses to Ground Velocity.

4. THE FORCE TRANSDUCER

Force feedback seismometers which use a coil and magnet system to generate the restoring feedback force are inherently dependent on the constancy of the field strength produced in the force transducer. The design of the magnetic circuit and the magnet/pole assembly is such that the field strength from the feedback transducer is constant over large deflections and current levels.

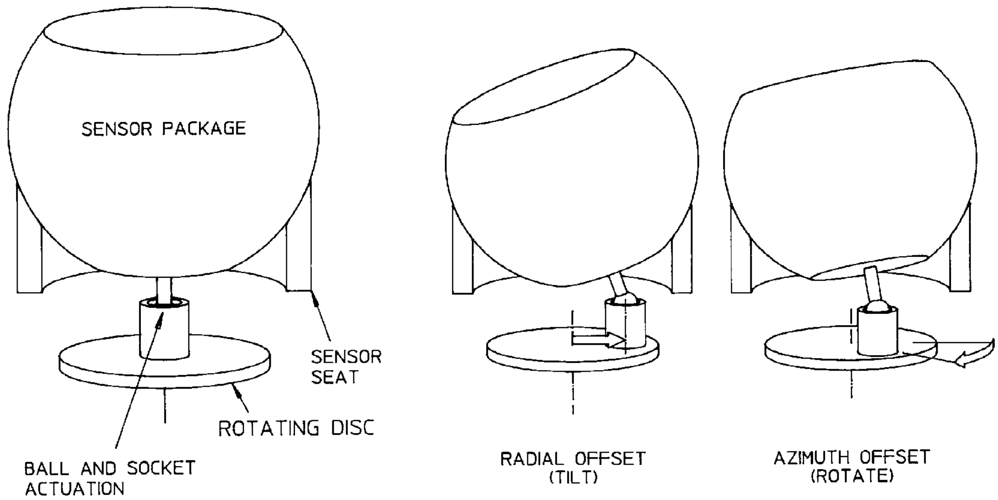
Tests have shown that the mechanical suspension system and the electronics of the CMG-3NSN is linear to better than 107 db (measured at ASL during USGS National Network evaluation in 1989).

5. LEVELLING PLATFORM

The large three-component CMG-1T seismometer base is fitted inside a levelling platform which is operated with 2 high torque dc motors.

The operating principle and the philosophy of the levelling platform is based on the natural stability provided by the bell and socket type construction joint. The three-component sensors are contained in a machined cavity inside a structure that resembles an inverted dome whose exterior is machined to a spherical form. The unit rests in a ring shaped bearing so that the dome can move freely in azimuth and tilt directions.

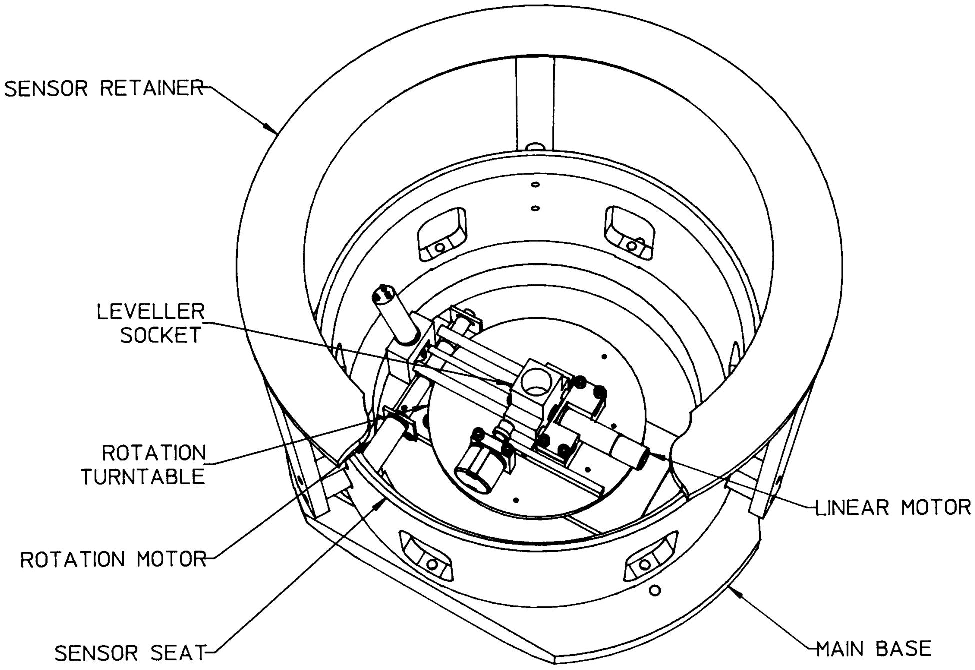
A metal post, mounted centrally under the dome, carries a machined ball which articulates with a cylindrical cavity in a driving block below it. The driving block, moving on a plane surface below the dome effectively translates the position of the dome expressed in spherical co-ordinates into positions on a plane expressed in polar co-ordinates. The described position mechanism consists of a turntable and a lead screw to drive the central block.



The described mechanism is more stable and more compact than the more usual gimbal arrangement and also has fewer moving parts. For broadband OBS seismometer applications the gimbal arrangement would not be sufficiently stable.

The rotary motion of the bowl is provided by a worm-drive driven by a dc motor. The tilt drive is provided by a 1 mm pitched lead screw which linearly positions the bearing block on a pair of parallel slides. The lead screw is also driven by a dc motor.

The required method of zeroing the bowl tilt is provided diagrammatically in the drawing below. The radial and azimuth adjustments are done until the 2 axes inclinometer outputs are brought as close to zero as possible. The radial offset tilt magnitude is calculated from the X, Y readings of the inclinometer and the azimuth position is determined from the sign information of the inclinometers.



Two sets of position sensors fitted to the motor shafts transmit the digital shaft position signals to a micro-processor to enable precise radial and azimuth movement without slippage. In fact, the position detectors are absolute and provide position information without losing information when the system is switched off.

6. LEVELLING PLATFORM INCLINOMETERS

The ± 30° levelling bowl drawing is given. Within the levelling bowl a 2 axis inclinometer is installed to provide the tilt of the bowl in two independent axes over the complete tilt range of the levelling bowl. The inclinometer outputs are not linearly related to the actual tilt but calibration information is provided to the user to establish the tilt of the bowl with reasonable accuracy. In actual fact, in this application, it is not required that the inclinometer output should be linearly related to the bowl tilt.

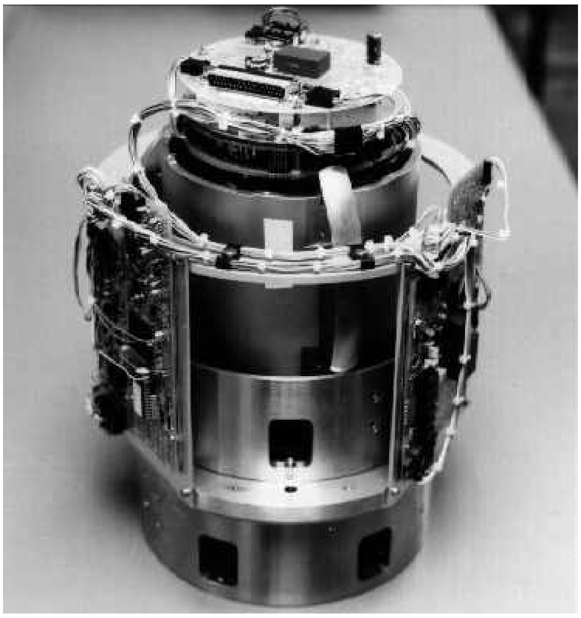
The inclinometer output varies over a voltage range of ± 4 Volts and the output impedance of the circuit is <10Ω. The average power consumption of the inclinometer circuitry is kept as low as possible. Normally the digital micro-processor circuitry is used to switch the inclinometer electronics off after the initial instrument installation. It is also accepted that it is unnecessary to re-use the levelling bowl after initial setting up as the individual sensor components themselves have ± 2.5° of levelling facility.

7. SYSTEM INPUT OUTPUT SIGNAL FORMAT AND CONNECTIONS.

The seismometer system outputs consist of the following:

a) Velocity output.
b) Mass position outputs.
c) Control command serial input/output.
d) Calibration signal.
e) System power supply.

The pin assignments for the sensor systems 37-way D type connector are shown in the photograph below.



Allocation of the pins is as follows:

20	V+ Velocity
23	V- Velocity
24	N+ Velocity
21	N- Velocity
22	E+ Velocity
25	E- Velocity
4	V Mass Position
5	N Mass Position
6	E Mass Position
8	Signal Ground
10	Calibration Signal
30	Calibration Enable
36	+Ve Sensor Power

Continued ....

33	+Ve Bowl/SOH Power

18	Sensor Power Return
14	Bowl/SOH Power Return (also ground for RS232)
13	Transmit Data
32	Receive Data

The seismometer velocity outputs and mass position outputs operate over a limited range of ± 4.4 Volts. This is due to the fact that the sensor electronics are operated with ± 5 Volts supply. The output impedance of the analogue output is set to be 94Ω.

The calibration document provides the sensor output responsivity, including the sensor frequency response.

The sensor analogue electronics power supply voltage can be from 10 to 36 Volts. An isolated dc-dc converter is used to power the sensor analogue electronics. The power consumption of the system under steady state condition is 26 milli Amps from 12 Volts (0.32 Watts). This level of power consumption is achieved without degradation in the sensor performance. However, during locking, unlocking and centring operations, the power consumption will increase substantially. To compensate for the large power fluctuations, internal power management is provided. (The power management unit is under development, 4th December, 1996.)

The sensor supply is completely separate from the bowl and levelling electronics. Under normal conditions, the bowl and levelling electronics are switched off immediately after installation.

The levelling and system status commands are described in the later sections.

In cases where the CMG-1T system is installed within a glass sphere, the sensor outputs are limited due to the limited number of connector pins. The following pin assignments must be used for the waterproof glass bowl connector.

1	V+ Vel
2	N+ Vel
3	E+ Vel
4	Sig Gnd
5	+V Sensor
6	0V Sensor/0V Bowl/RS232 Gnd
7	+V Bowl
8	Tx Data
9	Rx Data

8. SEISMOMETER AND LEVELLING BOWL CONTROL COMMANDS

The operation of the OBS system is carried out by a set of (English) command words entered from a computer terminal connected to the system serial port. The described commands control the operation of the OBS to lock the sensor masses, unlock the sensor masses and centre the seismometers once the sensor masses are unlocked.

Prior to unlocking the sensor masses the levelling bowl would be required to be levelled after system installation. The bowl levelling commands are Datum, level and, bowl-align.

All the commands consist of one or two words. With two word commands the first word is the parameter (qualifier) for the second which is the actual command to be executed.

SEISMOMETER COMMANDS

Three commands are available.

a) LOCK - initiates locking sequence.
b) UNLOCK - initiates the unlocking sequence.
c) CENTRE - initiates the mass centring sequence.

Each of these commands is preceded by a qualifier specifying the instrument to operate on.

Z - specifies vertical, (Z) sensor
N/S - specifies north/south. horizontal sensor
E/W - specifies east/west horizontal sensor
ALL - all 3 sensors execute command.

Examples: Z unlock - unlocks vertical sensor
ALL unlock - unlocks all the sensors
ALL centre - centres all the sensors.

BOWL LEVELLING COMMANDS

DATUM - sets bowl tilt and rotate positions to origin. The origin is described as no tilt and rotate datum position parallel to X axis.

LEVEL - returns the bowl to DATUM, after which automatically levels the bowl to within ± 0.3 degrees. The range of levelling is ± 30 degrees.

BOWL-ALIGN - This command can be used to correct small deviations

AFTER initial levelling. This command tries to reduce the accuracy of levelling better than ± 0.3 degrees. It can only be issued after the LEVEL command.

STATUS COMMANDS

HELP - displays all commands and parameters that are available.

SENSOR STATUS - reports the digitized mass position outputs of the sensors.

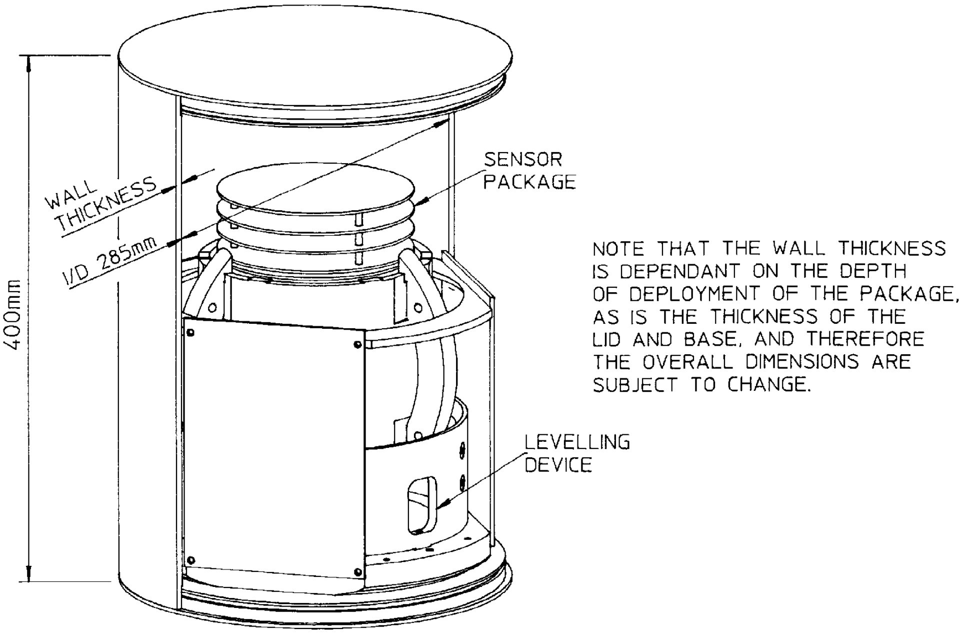
BOWL STATUS - reports the tilt and rotate orientation of the bowl and the X and Y inclinometer readings.

SYSTEM SERIAL PORT

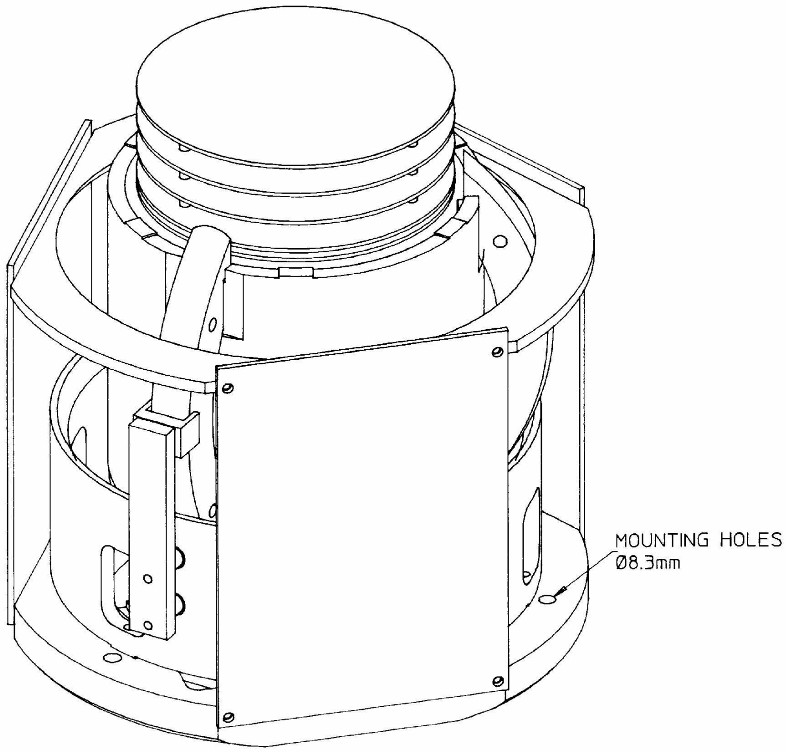
The baud rate of the serial line is 19,200 Baud 8 data bits, 1 stop bit, no parity and no handshake.

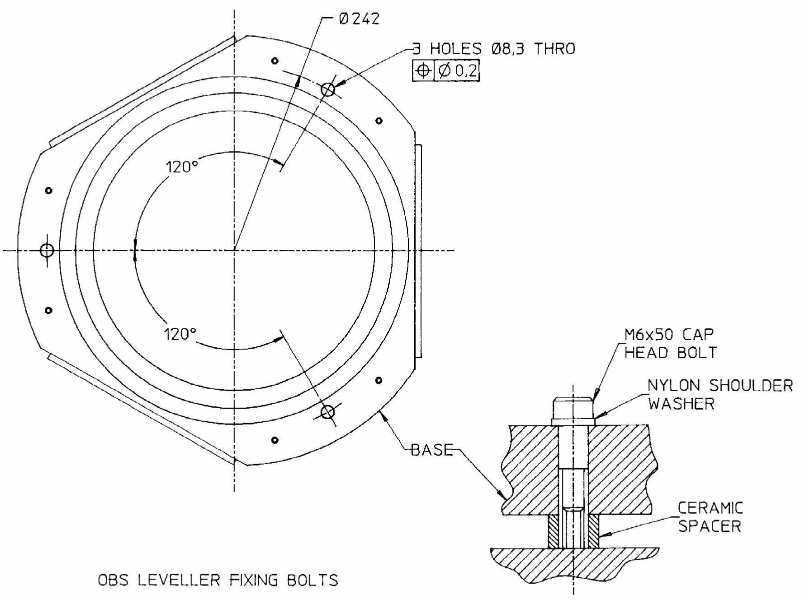
9. MOUNTING OF THE LEVELLING SYSTEM

Three fixing bolt positions are provided to fix the levelling system within a pressure housing, as shown in the diagram.



The positions of the mounting holes are given in the following drawings together with a suggested method of electrically isolating the levelling system from it's casing.



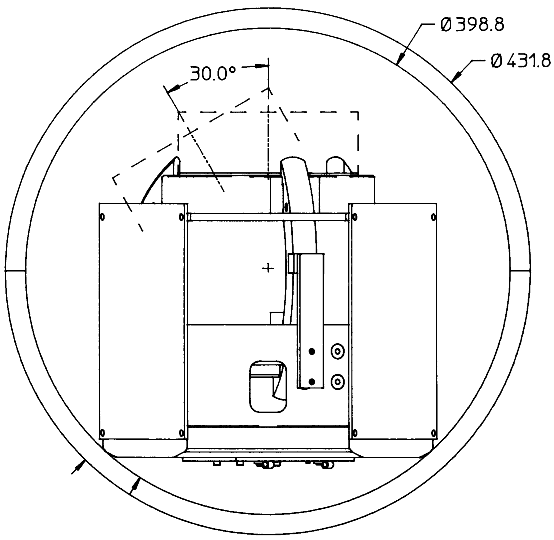


It is recommended that ceramic spacers with nylon shoulder washers are used to achieve a very high degree of insulation resistance, >>100MΩ.

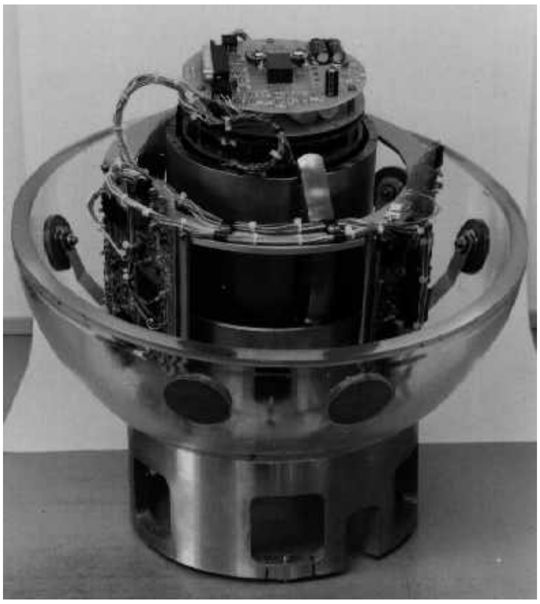
IMPORTANT Care must be taken not to rest the levelling system on it's base without spacers as wiring which exists at the bottom of the levelling system might be damaged.

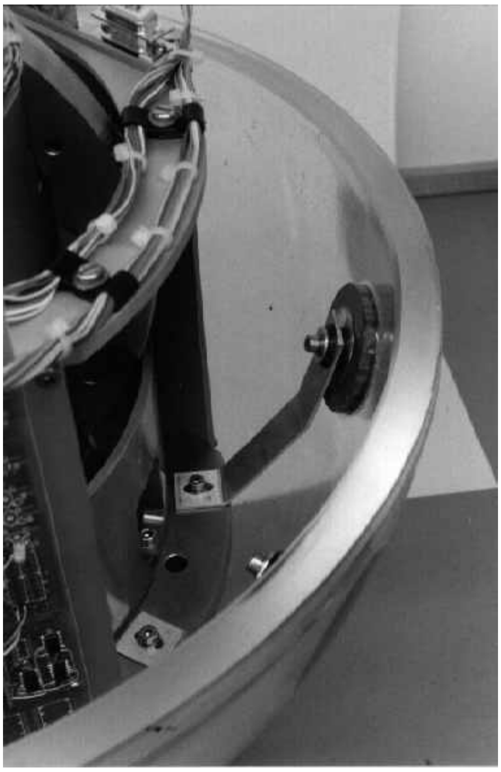
The installation of the levelling system together with the sensor requires care and precision. If the installation method within a casing is not completely straight forward Güralp Systems Limited will be prepared to comment on your particular design.

The levelling system can also be installed in a 17" glass sphere. A drawing of the overall glass bowl and levelling system is given in the following diagram.



Many methods can be used to restrain the movement of the levelling system within the glass bowl. The preferred method used by us is given in the following photographs.





A set of attachment points are glued to the inside of the glass sphere from which semi-flexible linkages are used to attach the bottom of the levelling platform to the glass sphere. Six separate holes are provided for such linkages.

APPENDIX A

CMG-1T OBS User Connections

15 Way D Plug On Power Board:	Function:
1	SOH +V Supply (10 to 36 Volts DC)
2	SOH 0V
3	Calibration Enable (Active Low)
4	Calibration Signal Input
5	Signal Ground
6	East / West Velocity Output
7	North / South Velocity Output
8	Vertical Velocity Output
9	Not Connected
10	RS232 Data Ground
11	RS232 Transmit From OBS
12	RS232 Receive To OBS
13	Not Connected
14	Instrument +V Supply (10 to 36 Volts DC)
15	Instrument 0V