PORTABLE SHORT-PERIOD SEISMOMETER MODEL GS-13

OPERATION AND MAINTENANCE MANUAL

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GEOTECH INSTRUMENTS, LLC

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PORTABLE SHORT-PERIOD SEISMOMETER, MODEL GS-13

Stock Number 990-55400-9800

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TABLE OF CONTENTS

	Page
1. GENERAL DESCRIPTION	1-1
1.1 Purpose of the Equipment	1-1
1.2 Description of the Equipment	1-1
1.3 Specifications	1-1
1.3.1 Operating Characteristics	1-1
1.3.2 Physical Characteristics	1-2
1.3.3 Connectors	1-2
1.4 Equipment Supplied	1-3
2. INSTALLATION	2-1
2.1 General	2-1
2.2 Unpacking	2-1
2.3 Setting Up the Seismometer	2-2
3. OPERATION	3-1
3.1 Principles of Operation	3-1
3.2 Controls and Indicators	3-1
3.2.1 Period Adjust	3-1
3.2.2 Mass-Position Indicator	3-1
3.2.3 Mass-Position Adjustment (Vertical Operation)	3-1
3.2.4 Bubble Level	3-3
3.2.5 Mass Lock	3-3
3.3 Operating Procedures	3-3
3.3.1 Removing the Instrument Cover	3-3
3.3.2 Horizontal Operation	3-3
3.3.3 Vertical Operation	3-5
3.4 Use of the Normalizing Circuit (02 Version)	3-7
3.4.1 Purpose	3-7
3.4.2 Normalized Calibration Motor Constant	3-7
3.4.3 Normalized Main Coil Generator Constant	3-8
3.5 Normalized Circuit Example	3-8
3.5.1 Example Parameters	3-8
3.5.2 Determine Calibration Capacitor	3-9
3.5.3 Determine Resistor Network	3-9
3.5.4 Example of Net Calibration Sensitivity	3-9
3.6 Use of the Pre-Amp/Calibration Board, Pre-Amp Circuit (03 Version)	3-10
4. OPERATING TESTS	4-1
4.1 Natural Frequency	4-1
4.2 Open-Circuit Damping	4-1
4.3 Critical Damping Resistance (CDR) for Vertical Operation	4-2

TABLE OF CONTENTS. Continued

	Page
4.4 CDR for Horizontal Operation	4-6
4.5 CDRX (Critical Damping Resistance, External)	4-8
4.6 Determining the Main Coil Generator Constant, G	4-8
4.7 Determining Motor Constant, $G_{main\ coil}$, of the Calibration Coil	4-8
4.8 Determining Equivalent Earth Motion	4-9
5. MAINTENANCE	5-1
5.1 General	5-1
5.2 Removing and Replacing the Cover	5-1
5.3 Changing the Calibration Coil-Magnet Assembly	5-2
5.4 Changing Delta Rods	5-2
5.5 Changing Springs	5-2
5.6 Replacing Damaged Flexures	5-4
5.6.1 To Replace a Cantilever-To-Spring Flexure	5-4
5.6.2 To Replace a Damaged Cantilever-To-Base Flexure	5-4
5.6.3 To Replace a Damaged Cantilever-To-Mass Flexure	5-5
5.7 Replacing the Main Coil-Magnet Assembly	5-5
6. CALIBRATION COMPONENTS	6-1
6.1 Input Data	6-1
6.1.1 General	6-1
6.1.2 Seismometer Constants	6-1
6.1.3 Desired Results	6-1
6.2 Calibration Computations	6-1
6.2.1 Acceleration Calibration	6-2
6.2.2 Velocity Calibration	6-2
6.2.3 Computer Results	6-3
6.3 Output Computations	6-3
6.3.1 Output Calibration	6-3
6.3.2 Output Results	6-3
6.3.3 Output Capacitor	6-3
7. FREQUENCY RESPONSE/POLES AND ZEROS	7-1

ILLUSTRATIONS

Figure

Figure		Page
1-1	Portable Short-Period Seismometer, Model GS-13	1-4
2-1	Schematic Diagram, GS-13 Seismometer	2-3
2-2	Schematic, Pre-Amp/Calibration Board	2-4
3-1	Controls and Indicators	3-2
3-2	Removing (Or Replacing) the Cover	3-4
3-3	Flexure Detachment for Horizontal Operation	3-6
4-1	Vertical Weight Lift	4-4
4-2	Determining Percent Overshoot	4-5
4-3	Horizontal Weight Lift	4-7
7-1	01, 02 Relative Amplitude Response for .707 Damping	7-2
7-2	01, 02 Phase Response for .707 Damping	7-3
7-3	03 Amplitude Response .05 - 50 Hz, 500 V/m/s^2	7-4
7-4	03 Phase Response .05 - 50 Hz	7-5

TABLES

Table

Table		Page
4-1	Typical λ vs R Values	4-2
4-2	Typical λ vs Percent Overshoot Values	4-5
7-1	Poles and Zeros	7-1

- - Notes - -

1. DESCRIPTION

1.1 PURPOSE OF THE EQUIPMENT

The Portable Short-Period Seismometer, Model GS-13, is designed for use in field operations where a small, light-weight, short-period, moving-coil type seismometer is desired. The seismometer may be operated in either the horizontal or vertical position, and the period is adjustable from 1.33 to 0.91 second (0.75 to 1.1 Hz). The seismometer is equipped with a calibration coil. The 02 version has provisions for standardized sensitivity, velocity calibration, and weight-lift calibrations. The 03 version is electronically overdamped to provide a flat acceleration response.

1.2 DESCRIPTION OF THE EQUIPMENT

The seismometer weighs less than 25 pounds and has a nominal 5-kilogram mass. The cover and electrical connections are watertight so that the instrument may be submerged in up to 100 feet of water without leakage. All operational adjustments are external to the instrument. Included are adjustments for the period, mass position, and instrument leveling. A mass lock, a mass-position indicator, and a bubble level are also provided. The instrument is shown in figure 1-1.

1.3 SPECIFICATIONS

1.3.1 Operating Characteristics

Mode of operaton	Convertible, vertical to horizontal
Natural period	Adjustable from 0.91 to 1.33 sec
Natural frequency	Adjustable from 0.75 to 1.1 Hz
Tilt (vertical mode)	Operates within 4° of vertical, at 0.8 Hz natural frequency
Weight of inertial mass	5 kg (ll lb) Nominal
Spring rate	(Approx. 10 to 1 lever), 3.82 newton/mm (21.8 lb/in.) $\pm$5%
Temperature range	-50 to +60°C (-60 to 140°F)

Transducer	
Type	Moving coil (velocity)
Damping	Electromagnetic
Generator constant (Main Coil)	2180 ± 545 Vs/m
Generator coil cal error	±2% max
Open circuit damping	0.02 relative max.
Coil resistance	9100 ± 700 ohms
Calibration coil	
Motor constant (Cal Coil)	4.5 ± 0.9 N/A
Calibration coil cal error	±2% max
Resistance	29 ± 2 ohms at 25°C
Power (03 Version Only)	
Voltage	±12 to ± 15 Vdc
Current	10 mA nominal
Frequency Response/Poles and Zeros	See section 7

1.3.2 Physical Characteristics

Basic dimensions	
Height	0.378m (15 in.)
Diameter	0.167m (6.625 in.)
Net weight	10.4 kg (24 lb)
Shipping weight	13.6 kg (34 lb)
Shipping volume	0.036 m^3 (1.5 ft^3)
Seismometer bulk specific gravity	1.82

1.3.3 Connectors

Output receptacle PT02CE-14-18P

1.4 EQUIPMENT SUPPLIED

1 Portable Short-Period Seismometer, Model GS-13

1 Mating connector, PT06CE-14-18S

1 Operation and maintenance manual, 990-55400-9800

1 Calibration Kit, No. 21323

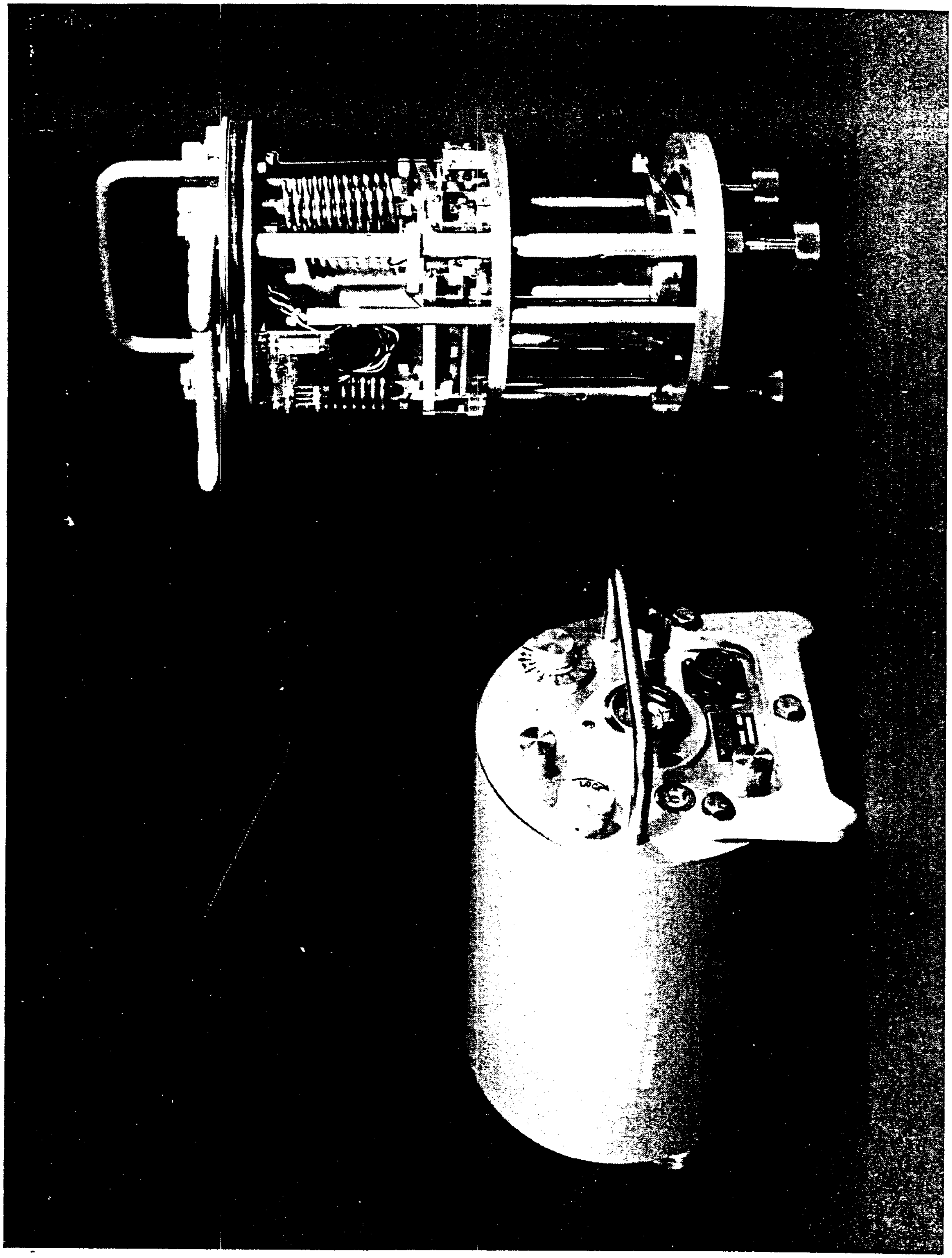

Figure 1-1. Portable Short-Period Seismometer, Model GS-13

2. INSTALLATION

2.1 GENERAL

The Model GS-13 seismometer is a very stable instrument. When properly installed, it may be expected to operate without further adjustment for several years. General considerations in the use and placement of any seismometer are outlined below.

a. Normally, a seismometer is placed on bedrock, on a pier anchored to bedrock, or in a vault anchored to bedrock.

b. If the maximum possible magnification is to be realized, the location must be in a quiet zone away from cultural noise.

c. The instrument should not be exposed to direct sunlight and should be sheltered from wind.

d. The instrument location should have a thermally stable atmosphere.

e. If the instrument is to be placed where access will be difficult, all necessary tests can be performed before the seismometer is placed in its final location.

f. If the seismometer is used in a portable metal vault, at least 2 feet of earth should be placed on top of the vault for thermal stability and isolation from wind noise.

g. Cables and wiring should be installed with maximum separation between power and signal cables to minimize stray pickup. Shielded twisted-pair cable may be used for indoor signal cables and spiral-four has been used for outdoor service. Shields of the signal cables should be grounded at both ends.

2.2 UNPACKING

The seismometer is packed in a reusable container and is shipped in the vertical position with the mass locked. It is assembled ready for vertical mode operation so that there is no need to remove the instrument cover unless it is to be inspected or changed for horizontal mode operation. If the cover is to be removed, see paragraph 3.3.1. Visually inspect the outside of the seismometer for any apparent damage. If damage is apparent and the instrument will not operate, return it to the manufacturer or an appropriate maintenance depot.

NOTE

When moving the instrument, always be sure that the mass is locked.

2.3 SETTING UP THE SEISMOMETER

a. Place the instrument in its permanent position. If operated in the horizontal mode, the axis of the seismometer should be carefully aligned with a known bearing to determine direction of arriving signals. See paragraph 3.3.2 for conversion to horizontal mode operation.

b. Unlock the mass by turning the mass lock knob counterclockwise as far as it will go. Use the bubble level for leveling a vertical instrument and adjust mass position according to the procedure outlined in paragraph 3.2.3. Level a horizontal instrument by adjusting the movable foot until the mass is centered.

CAUTION ! !

Unlock mass slowly and **do not** move mass rapidly by hand or other means. Do not move seismometer with mass unlocked. The high generator constant of the GS-13 seismometer is capable of generating hundreds of volts if mass is moved rapidly. These high voltage levels can cause damage to internal and external electronics attached to the seismometer. This caution is particularly important for the -02 and -03 versions.

c. Electrical connections to the instrument are made through the connector furnished. Connection depends on the version and are described as follows:

-01 Version

A downward motion of the mass (away from the handle) should produce a positive voltage at pin K of the connector relative to pin L. These pins are the connection to the signal coil.
A positive voltage applied to pin G relative to pin H should produce a downward motion of the mass (away from the handle).

-02 Version

This version has the 990-60364-0101 Pre-Amp/Calibration Board installed. This version of the board does not have the pre-amp components installed. The purpose of the -02 version is to allow normalizing the output sensitivities to the same value. The calibration sensitivities can also be normalized.

For this version, jumper pin A to pin L, and pin J to pin K, iin the mating connector, The signal output will now be on pins B and C with B, positive with respect to C for downward motion of the mass (away from the handle).

For a normalized calibration signal (velocity or acceleration) jumper pin H to U. A positive voltage applied to pin G relative to pin N should produce a downward motion of the mass (away from the handle). See section 3.4.2 and 3.5 for details on setting velocity or acceleration calibration sensitivity.

-03 Version

This version has the 990-60364-0101 Pre-Amp/Calibration Board installed. This version of the board has the Pre-Amp components installed.

A dc power source of ± 12 to ± 15 Vdc and common is required. Connect positive voltage to pin D and the negative voltage to pin F. Connect power common to pin R. The output signal will be on pins K and L with K, positive, relative to L for downward motion of the mass (away from the handle).

For the calibration signal, jumper pin H to pin U, in the mating connector. A positive voltage applied to pin G relative to pin N should produce a downward motion of the mass (away from the handle). See section 3.4.2 and 3.5 for details on setting calibration sensivity.

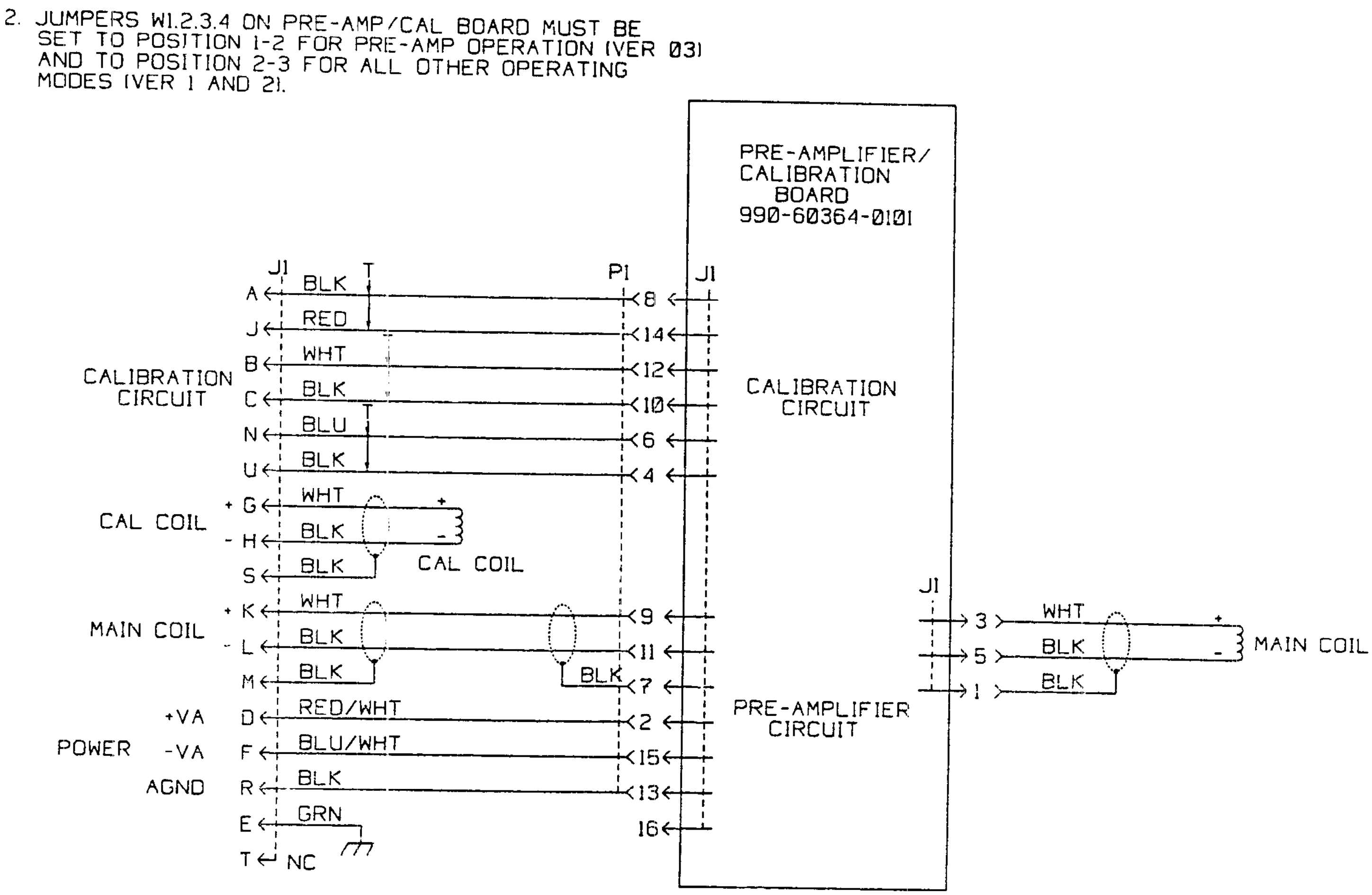

Figure 2-1 Schematic Diagram, GS-13 Seismometer

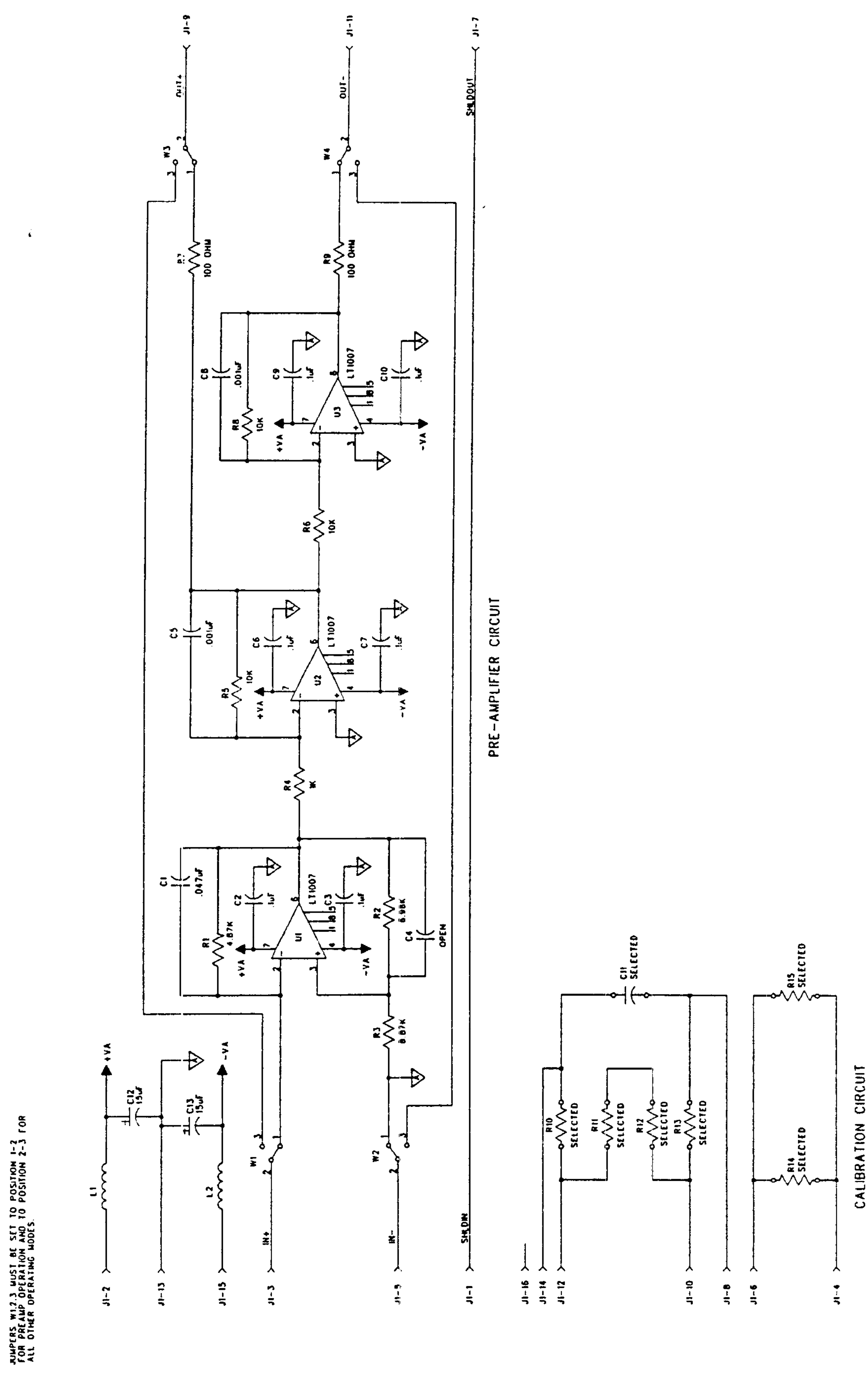

Figure 2-2 Schematic, Pre-Amp/Calibration Board

3. OPERATION

3.1 PRINCIPLES OF OPERATION

For vertical mode installation, the seismometer mass is supported by three stiff springs attached to toggle action cantilevers. The cantilevers impart a relatively low spring rate to the mass due to a 9.4:1 lever ratio between the mass and spring attachments. The mass is constrained to move along the axis of the coil by stiffened wires called delta rods, three at each end of the mass. One end of a seventh delta rod is attached to the mass and is one part of the period adjust mechanism. The other end of this rod is axially pulled or pushed by means of a torsion rod imparting tangential loading in the delta-rod system. Varying the twist in the torsion rod varies the period of the mass.

The seismometer is equipped with an electromagnetic calibrator which consists of a calibration coil fixed to the instrument frame and a permanent magnet attached to the mass.

3.2 CONTROLS AND INDICATORS

Figure 3-1 shows the location of the controls and indicators which are described in the following paragraphs.

3.2.1 Period Adjust

This control permits adjustment of the natural period of the instrument from 0.91 to 1.33 seconds. Clockwise rotation of the control will cause the period to decrease while counterclockwise rotation will increase the period. A socket-head cap screw in the dial body is used to clamp the control after adjustment.

3.2.2 Mass-Position Indicator

This indicator may be used to determine the mass position. Upon looking directly into the indicator, a red circle and three concentric black rings can be seen. The red circle changes diameter as the mass position changes. When the mass is against the upper stop (vertical operation), the red circle coincides with the largest black ring and when the mass is against the lower stop the red circle coincides with the smallest black ring. When the mass is centered the red circle coincides with the center black ring. NOTE: For the overdamped -03 version the mass position will move slowly into position after each adjustment. Wait a few seconds after each adjustment to determine new setting.

3.2.3 Mass-Position Adjustment (vertical operation)

The mass position of the vertical mode instrument may be adjusted by rotating the spring tension adjust. Clockwise rotation of the knob moves the mass up.

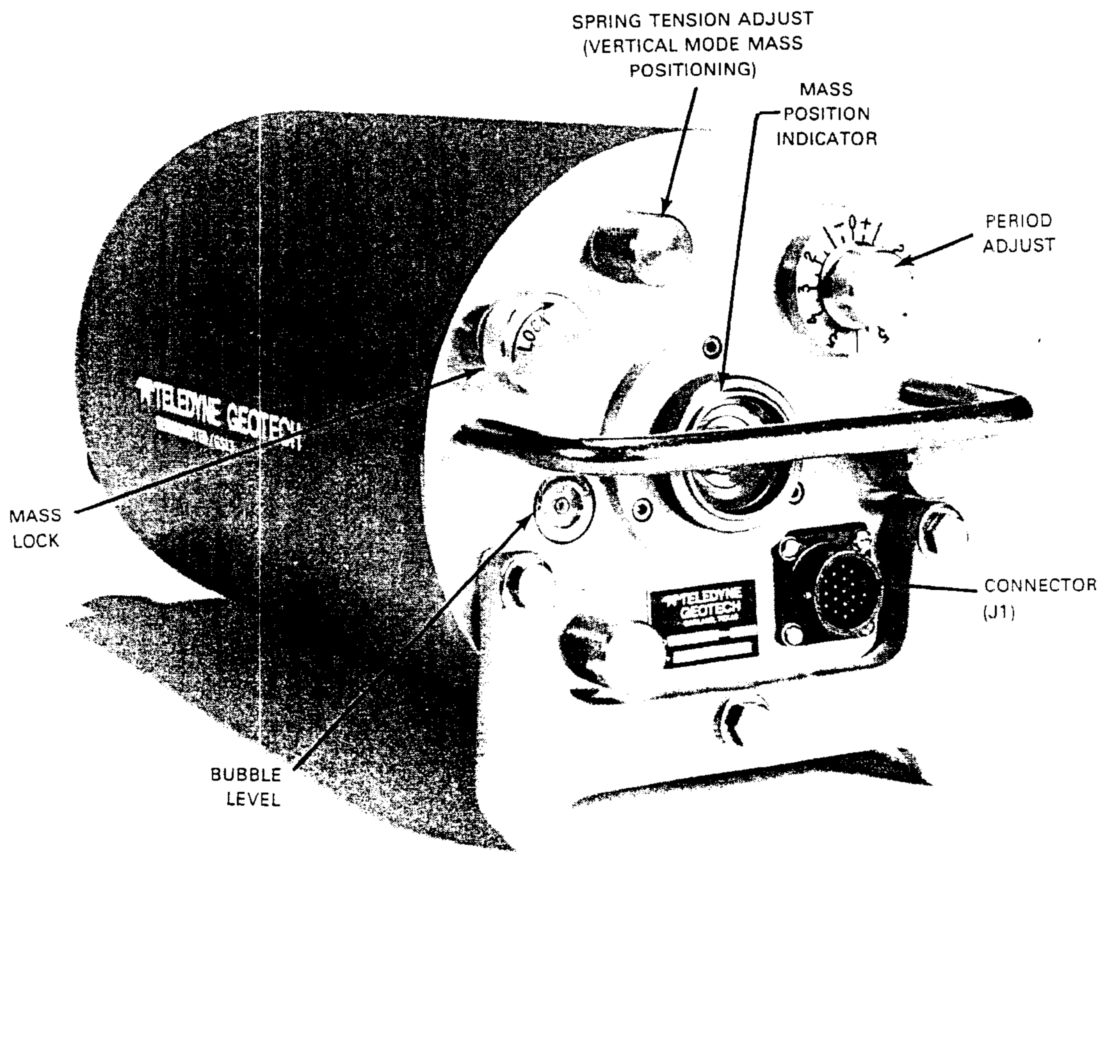

Figure 3-1 Control and Indicators

3.2.4 Bubble Level

This indicator is used to determine the vertical alignment of the instrument in the vertical mode.

3.2.5 Mass Lock

This control is used to lock the inertial mass. When the knob is rotated fully clockwise, the mass is locked firmly against the upper limit stop. It should be rotated fully counterclockwise to unlock the mass, and give the seismometer the maximum operating range.

3.3 OPERATING PROCEDURES

The GS-13 seismometer is a very sturdy instrument but is also very sensitive and should be handled accordingly. The following procedures apply to both horizontal and vertical operation:

a. The inertial mass should always be locked when the instrument is being moved or major adjustments are being made.

b. Cleanliness of the internal parts and O-rings is essential for proper operation.

c. All operational adjustments and indicators are externally located to minimize the need for removing the seismometer cover. The cover should not be removed in a dirty or dusty atmosphere or where small magnetic particles may be attracted to the magnet.

3.3.1 Removing the Instrument Cover

The cover may be removed from the instrument by removing the following items

from the vertical legs;

a. Three seismometer feet,

b. Three lock rings,

c. Three hex jam nuts,

d. Three seal retainers and three leg gaskets.

The cover may then be pulled off the seismometer as shown in figure 3-2. When replacing the cover, be sure that the three leg gaskets are properly located against the cover and around the leg.

3.3.2 Horizontal Operation

As previously stated, the seismometer is assembled and shipped ready for vertical operation. If the instrument is to be used in the horizontal mode, convert it as follows:

Figure 3-2 Removing (Or Replacing) The Cover

a. Lock the mass and remove the instrument cover as directed in paragraph 3.3.1.

b. Set the seismometer in a vertical position.

c. Referring to figure 3-3, unfasten each of the three flexures from the cantilever assembly by removing the screw and washer and the flexure clamp. Press down on the mass end of the cantilever until all tension is removed from the flexure. Carefully work the flexure off the locating pin. Let each cantilever rise to rest against its cantilever stop. Store the flexure clamps and screws in the tapped hole provided in the top of each cantilever stop. The flexures, when free of the locating pin, should flex back out of the way of the cantilevers. If any one of the three flexures touches any part of the cantilever assemblies, gently bend it back over a large radius until it will clear when released.

d. Replace the cover assembly being careful to clean and lubricate the large O-ring which seals the open end of the cover to the seismometer. Install the seal retainers and hex nuts to secure the cover.

e. Install one seismometer foot and lock ring on the horizontal adjust leg.

f. Install the remaining two feet on the vertical legs to prevent damage to the leg threads.

g. Place the seismometer in its anticipated operating position. Maintain accessibility to the instrument controls and mass-position indicator.

h. Adjust the mass position by raising or lowering the seismometer foot on the horizontal adjust leg, Normally, the mass is centered between the stops. When the period is adjusted and the mass position attained, run one lock ring on the horizontal leg up tight against the horizontal foot support to lock the leg, and the other lock ring down tight against the foot. Angular tilt about the center axis of the seismometer is not critical.

NOTE

Large scale period adjustments may affect the mass position setting. Therefore, it may be ncessary to adjust both the mass position and natural period alternately until the desired period is attained at the desired mass position.

3.3.3 Vertical Operation

To change the seismometer from horizontal to vertical operation, reverse the steps given in paragraph 3.3.2. Level the seismometer using the vertical feet as adjustment devices. A bubble level is located in the top of the instrument to facilitate this adjustment. Center the mass between

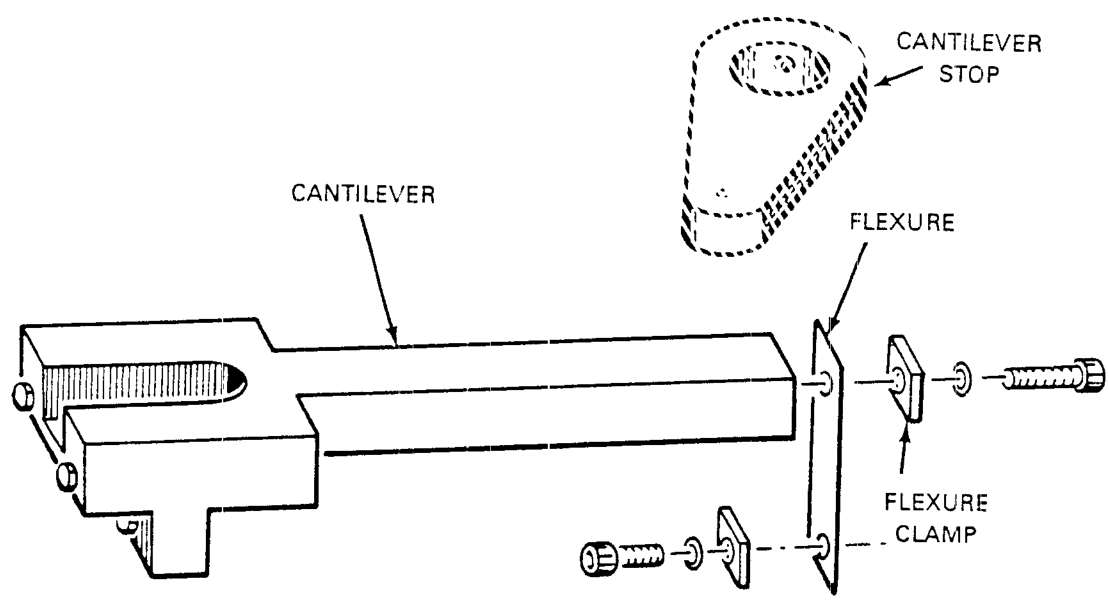

Figure 3-3 Flexure Detachment For Horizontal Operation

the limit stops by rotating the knurled mass-position knob (see paragraph 3.2.3) clockwise to raise the mass and counterclockwise to lower the mass. Determine the mass position using the mass-position indicator (see paragraph 3.2.2). Do not continue to turn the mass-position adjust knob after the mass has encountered a stop, or when the mass is locked.

3.4 USE OF THE NORMALIZING CIRCUIT (02 Version)

3.4.1 Purpose

The Pre-Amp/Calibration Board provides a network that permits the effective generator constant, Ge, to be normalized to a convenient value for all instruments in a set. In addition, it provides a point at which impedance elements may be installed to normalize the calibration motor constant. The circuit schematic is given in figure 2.2. A work sheet for selecting components is located in section 6.0.

3.4.2 Normalized Calibration Motor Constant

It is frequently convenient to select an impedance, Zc, very large compared to the calibration coil resistance, R_{cal}, and drive the calibration coil through this impedance from a voltage source; so the current can be assumed to be determined completely by Zc and the applied voltage. If it is desired that the calibration input be equivalent to acceleration for a given voltage, independent of frequency, Zc would be selected to be a large resistor so that coil current would be proportional to the input voltage. If it is desired that the calibration input be equivalent to velocity for a given input voltage, independent of frequency, Zc would be selected to be a capacitor with a large reactance at the highest frequency of interest. The coil current would then be proportional to the differentiated input voltage. The constant velocity calibration is most favorable for the 01 and 02 versions of the GS-13 Seismometer, to best match the expected earth background noise over the short period frequency range. The required capacitor value can be determined from:

$$Cc = (M/G_{cal\ coil}) \times (v/V)$$

where: v/V is the desired calibration sensitivity in meters per second per volt
M is the inertial mass
$G_{cal\ coil}$ is the motor constant in Newtons per Ampere.

For the 03 version a calibration signal proportional to acceleration may be preferred. The resistor required for this application can be determined from:

$$Rc = (G_{cal\ coil}/M) / (a/A) - R_{cal}$$

where: a/A is the desired calibration sensivity in (meter/s^2) / volt.
M is the inertial mass
$G_{cal\ coil}$ is the motor constant in Newtons per Ampere
R_{cal} is the calibration coil resistance

Resistor Rc should be selected large compared to the calibration coil resistance, so that the calibration signal will act as a current source.

3.4.3 Normalized Main Coil Generator Constant (02 Version)

The total instrument damping constant, λ_t, consists of the internal damping constant λ_i, as caused by R_i, and the damping caused by the total series load resistance, R_t. If the resistors are selected for the desired net damping, they can then be divided to provide a selected net instrument sensistivity, or a net equivalent generator constant, Ge; provided that $Ge < G_{main\ coil}$.

It is given that the total series damping resistance, R_t, as a function of the desired damping constant, λ_t, is:

$$R_t = R10 + R11 + R12 + R13 + R_{main\ coil} = \frac{G^2_{main\ coil}}{2\omega_o M(\lambda_o - \lambda_i)}$$

where: for the GS-13, $\omega_o = 6.283$, M = 5 kg, and $R_{main\ coil}$ is the measured main coil resistance.

It can also be seen that the effective generator constant, Ge, is determined by voltage dividers such that:

$$Ge = G_{main\ coil} * (R11 + R12)/R_t$$

As a result:

$$R11 + R12 = KGe$$

$$R10 + R13 = K\,(G_{main\ coil} - Ge) - R_{main\ coil}$$

where:

$$K = \frac{G_{main\ coil}}{2\omega_o M(\lambda_t - \lambda_i)}$$

Note that it is possible for these equations to yield a negative value for R10 + R13, where the coil resistance is too large to yield the desired Ge. If so, it will be necessary to select a lower value for Ge. Also note that the instrument must be connected to an amplifier with input impedance high enough to provide a negligible load. Otherwise, the external load impedance must be taken into account.

3.5 NORMALIZED COMPONENT EXAMPLE

3.5.1 Example Parameters

Assume that a particular instrument has the following reported parameters:

Open Circuit Damping, λ_i	0.0152
Inertial Mass, M	5 kg

Main Coil Resistance, $R_{main\ coil}$	9067 ohms
Main Coil Generator Constant, $G_{main\ coil}$	2279.1 Vs/m
Calibration Coil Motor Constant, $G_{cal\ coil}$	4.802 N/A

3.5.2 Determine Calibration Capacitor or Resistor

Assume that the desired constant velocity calibration sensitivity is 2 x 10^{-6} m/s/V. The calibration capacitor value will be:

$$Cc = \frac{5 \times 2 \times 10^{-6}}{4.802} = 2.082\mu F$$

This value may be achieved by installing a precision 2.0 μF capacitor and trimming it with another small selected capacitor in parallel. Provisions are made on the component board for trimming in this manner. The capacitor must be placed in the R 14 and R15 position of the Pre-Amp/Calibration board.

If a constant acceleration calibration sensitivity of 1 x 10^{-5} (m/s^2)/volt, the required resistance will be:

$$Rc = \frac{4.802}{5 \times 1 \times 10^{-5}} = 96.04\text{K Ohm}$$

This value can be achieved by installing one or two (in parallel) resistors in the R14 and R15 position of the Pre-Amp/Calibration board.

3.5.3 Determine Resistor Network for Ge

Assume that the desired effective generator constant, Ge, is 2000 Vs/m and the desired net damping factor, λ_n, is 0.75.

$$K = \frac{2279.1}{2 \times 6.283 \times 5 \times (0.75 - 0.0152)} = 49.36$$

$$R10 + R13 = 49.36\ (2279.1 - 2000) - 9067 = 4711 \text{ ohms}$$

$$R11 + R12 = 49.36 \times 2000 = 98720 \text{ ohms}$$

3.5.4 Example of Net Calibration Sensitivity

From the above example, if a 5 V p-p signal is applied to the calibration circuit, it will produce an equivalent earth motion of 10 x 10^{-6} m/s. This input will produce an instrument output of 2000 Vs/m x 10 x 10^{-6} m/s = 20 mV p-p at frequencies well above the instrument natural frequency.

3.6 USE OF THE PRE-AMPLIFIER CIRCUIT (VERSION 03)

The amplifier of the 03 version is designed to electronically over damp the GS-13 to provide a flat response to ground acceleration from .02 to 50 Hz with a sensitivity of 500 $V/(m/s^2)$.

To use this feature ± 12 to ± 15 Vdc power must be applied to pins J1-2 and J1-15 respectively and power common must be connected to pin J1-13. See schematic figure 2-1. Jumpers W1, W2, W3, and W4 must be connected as shown in schematic. Note that for 02 version the components for this amplifier are not installed on the board.

4. OPERATING TESTS

NOTE

The following procedures assume the calibration component board has been disconnected from the circuit and the connections are made directly to the indicated coil terminals.

4.1 NATURAL FREQUENCY (01, 02 Versions)

To determine the natural frequency of the seismometer the easiest setup is to use an amplifier and graphic recorder. If the amplifier's input resistance appreciably damps the seismometer, it is recommended that a large series resistor be inserted in the circuit.

Excite the seismometer mass into oscillation with a weight lift (reference sections 4.3 and 4.4) or by a momentary dc pulse applied to the calibration coil. Record several cycles as the seismometer mass decays to rest at its free period. Determine the time required for several complete cycles and divide that time by the number of cycles to get the natural frequency. The natural frequency is normally expressed in Hz (Hertz).

4.2 OPEN-CIRCUIT DAMPING (01, 02 Versions)

The internal losses of the GS-13 with the standard coil will impart a damping of less than 3% of critical damping.

To determine the open-circuit damping of the seismometer, proceed as follows:

a. Use the test setup for determining natural frequency, making certain that the circuit resistance external to the seismometer is equal to or greater than 2000 times the resistance of the seismometer coil.

b. Excite the mass into oscillation with weight lift or by a momentary dc pulse applied to the calibration coil.

c. Record the output of the seismometer as the mass oscillation decays due to internal losses. The envelope of the decay curve should be logarithmic; that is the ratio between the p-p values of adjacent full cycles should be same. If the decay curve is triangular (straight sides to the envelope) there is frictional damping which must be removed before proceeding. (Check for physical rubbing of parts in the mass-suspension system or dirt in the gap. Review section 5 on maintanance for additional information.)

d. Measure the peak-to-peak amplitudes of any two consecutive full unclipped cycles, such as the fourth and fifth, and calculate their ratio:

$$R = \frac{\text{Peak - to - peak amplitude of fourth cycle}}{\text{Peak - to - peak amplitude of fifth cycle}} = \frac{X_4}{X_5} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

e. The natural (base e) logarithm of the ratio is related to the circuit relative damping, λ_o by the formula:

$$1n(R) = 2\pi\lambda_0 \,/\, \sqrt{1-\lambda_o^2}$$

For the GS-13 seismometer λ_0 is less than 0.1, so the term $\sqrt{1-\lambda_o^2}$ is between 1.0 and 0.995, and may be considered as 1.0. This allows the open-circuit damping to be computed by the simple formula:

$$\lambda_0 = 1n(R) \,/\, 2\pi$$

The relative damping, λ_0, corresponding to typical values of R are given in table 4.1

Table 4.1 Typical λ_0 vs R values

R	λ_0
1.0	0.000
1.1	0.015
1.2	0.029
1.3	0.042
1.4	0.053
1.5	0.064
1.6	0.075

4.3 CRITICAL DAMPING RESISTANCE (CDR) FOR VERTICAL OPERATION (01 and 02 Versions)

A spring-mass system is said to be critically damped when it approaches its final position at the greatest possible rate (least amount of time), without going beyond (without overshoot).

The GS-13 seismometer employs an electromagnetic transducer consisting of a moving coil in a magnetic field. The seismometer is damped by an external load resistance placed across the coil terminals.

The total circuit resistance (R_t) which produces ciritical damping of the seismometer mass is known as the cirtical damping resistance (CDR). The CDR may be used to calculate the total circuit resistance required for any desired damping other than critical.

The CDR of the instrument may be determined by proceeding as follows:

a. Lock the mass and measure the resistance of the seismometer coil.

b. Connect the seismometer to the amplifier-recorder and shunt the recorder input as necessary to bring the resistance to about 150,000 ohms. The amplifier-recorder must be in a dc responsive condition to get the proper results from this test.

c. Unlock the mass and center it if necessary. Adjust period as desired.

d. Unscrew the mass-position indicator cap so that weight lifts can be made from the weight lift platform (see figure 4-1).

e. Attach a length of nylon thread to one of the test weights supplied. Weights and nylon thread are supplied with the calibration kit which is stored in a plastic vial in the seismometer shipping crate.

f. Lower the weight onto the weight lift table. See figure 4-1. Allow the output to return to normal.

g. Lift the weight sharply. The movement must be as nearly vertical as possible. If the weight strikes any portion of the seismometer, repeat the lift.

h. The resultant record should be similar to that shown in figure 4-2.

i. Repeat the weight lifts and adjust the resistive load on the seismometer until the percent of overshoot is about 20 to 25%. Measure the resistive load on the seismometer. This includes both the shunt resistor and the amplifier input resistance. Add the load value to the coil resistance to get R_t.

j. Enter table 4-2 with the percent overshoot and determine λ. The quantity λ is the ratio of actual damping to critical damping.

k. Calculate the CDR using the relation, CDR = $R_t \times \lambda$. This method is applicable to any velocity seismometer.

l. Once the CDR has been established for a seismometer having a given natural frequency, the total circuit resistance (R_t) required for any desired relative damping, λ_T, may be calculated as follows:

$$R_t = \mathrm{CDR}/\lambda_T$$

The foregoing calculations neglect damping due to internal losses, which may be appreciable for high-impedance coils. When it is required to consider these losses, proceed as follows.

m. Determine the open-circuit damping using the procedure outlined in section 4.2.

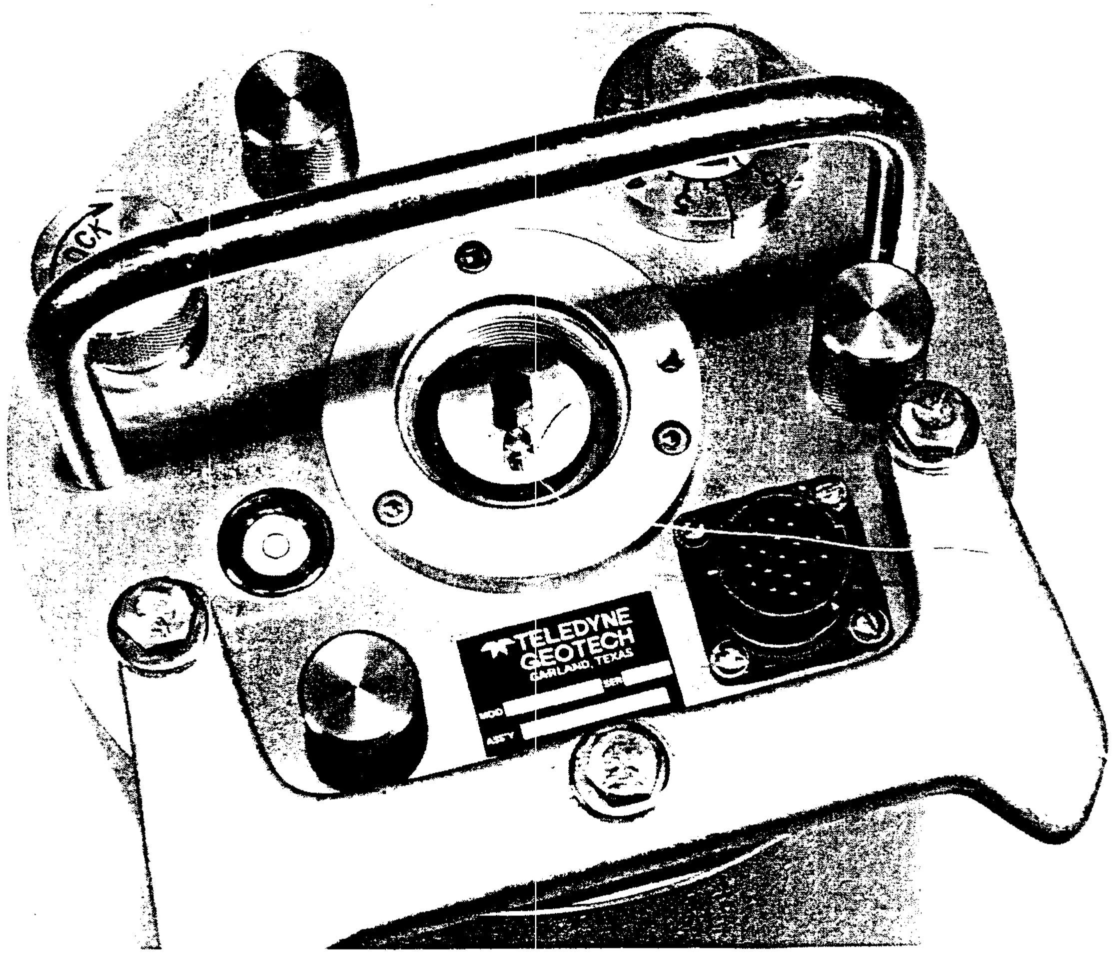

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Figure 4-1 Vertical Weight Lift

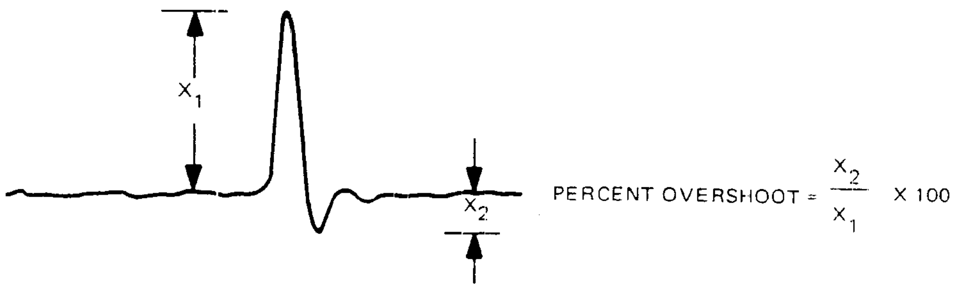

Figure 4-2 Determining Percent Overshoot

Table 4-2 Typical λ vs Percent Overshoot Values

% overshoot	λ	% overshoot	λ	% overshoot	λ
10.8	0.577	15.5	0.511	20.0	0.455
11.0	0.575	16.0	0.504	20.5	0.449
11.5	0.567	16.5	0.497	21.0	0.444
12.0	0.560	17.0	0.491	21.5	0.439
12.5	0.551	17.5	0.485	22.0	0.434
13.0	0.544	18.0	0.479	22.5	0.429
13.5	0.537	18.5	0.473	23.0	0.424
14.0	0.530	19.0	0.467	24.0	0.414
14.5	0.524	19.5	0.461	25.0	0.404
15.0	0.518				

n. Determine the relative damping, λ_1, and note the total circuit resistance corresponding to λ_1 (not the CDR) as in steps a through j of this section.

o. Calculate the required total circuit resistance R_t for any desired relative damping, λ_t, by using the following relations:

$$R_t = R_1 \times (\lambda_1 - \lambda_0) / (\lambda_1 - \lambda_0)$$

wherein:

R_t = total circuit resistance required to produce the desired relative damping λ_t.

R_1 = total circuit resistance required to produce the relative damping, λ_1 (from step n)

λ_0 = open circuit damping (from step m)

λ_1 = relative damping obtained with total circuit resistance, R_1 (from step n)

λ_t = relative damping desired of seismometer.

4.4 CDR FOR HORIZONTAL OPERATION (01 and 02 Versions)

To determine the CDR for horizontal operation, perform the following steps:

a. Repeat steps a, b, and c of paragraph 4.3.

b. Thread the hex nut onto the horizontal weight lift hook (both items are supplied in the calibration kit).

c. Unscrew the mass-position indicator cap.

d. Screw the horizontal weight-lift hook into the threaded hole in the calibration-coil support a few turns and lock it with the jam nut so that the flat is in line with the center axis of the seismometer.

e. Tie the weight in the center of an 8-inch length of the nylon thread and run one loose end through the hole in the mass-position indicating post.

f. Run the other loose end over the edge of the flat and through the hole in the horizontal weight-lift hook as shown in figure 4-3.

g. Adjust each thread end so that a 90° angle is formed and the weight is the same distance from each end. A few turns around the hook and a simple overhand knot on the post will secure the thread.

h. When the seismometer output has settled to normal backgound noise, as seen on the recorder, lift the weight sharply with a small piece of cardboard or other stiff material. The weight should not strike the weight-lift hook; if it does, repeat the lift. The resulting record should be similar to that shown in figure 4.2.

i. Continue weight lifts and adjust the resistive load on the seismometer until the percent overshoot is 20 to 25%. Repeat steps j and k of section 4.3 to determine the CDR. Where open-circuit damping must be considered, refer to steps m through o of section 4.3

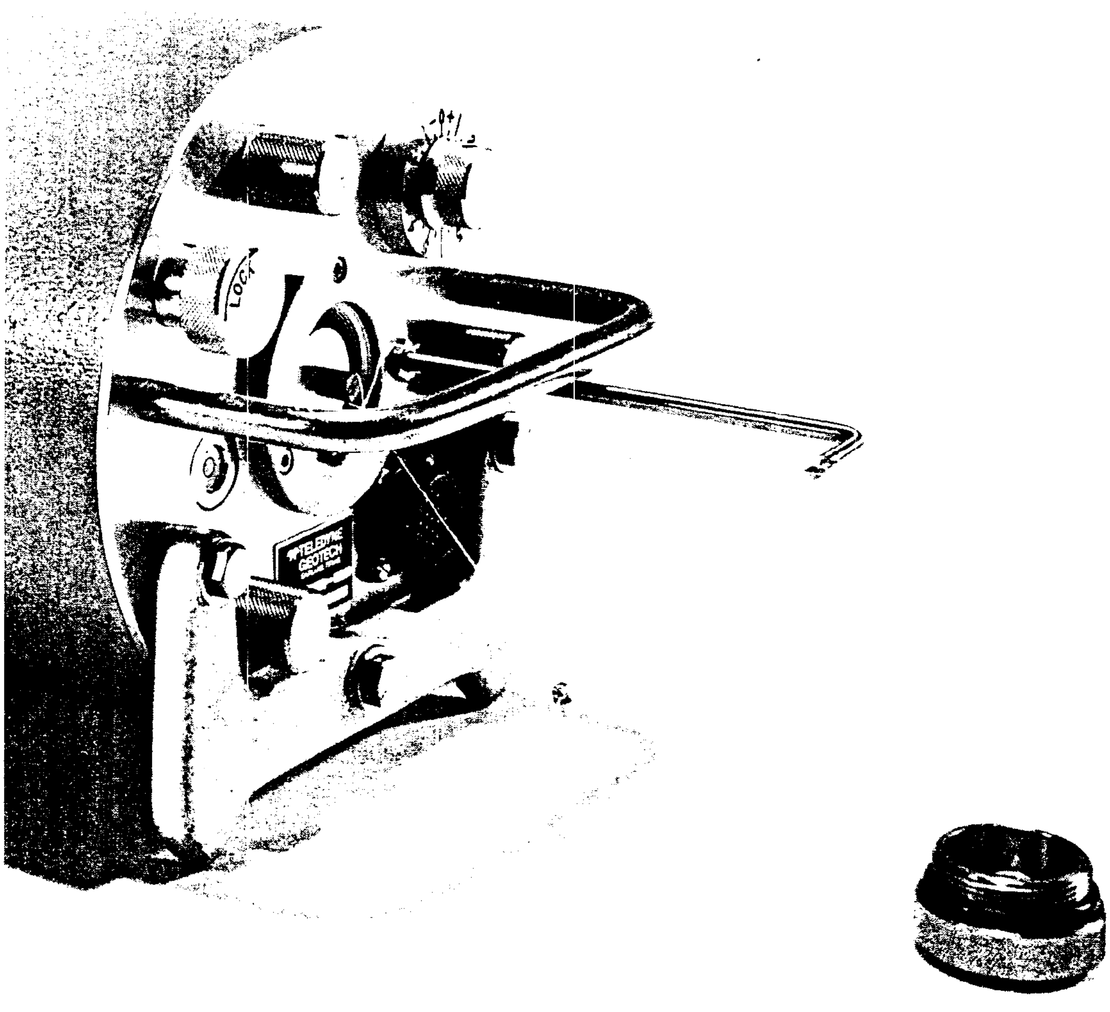

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Figure 4-3. Horizontal Weight Lift

4.5 CDRX (CRITICAL DAMPING RESISTANCE, EXTERNAL) (01 and 02 Versions)

Determine the CDRX from the relation: CDRX = CDR - $R_{main\ coil}$

4.6 DETERMINING THE MAIN COIL GENERATOR CONSTANT, $G_{main\ coil}$

Determine the generator constant from the relation:

$$G_{main\ coil} = \sqrt{4\pi f_0 M(CDR)} \text{ V - sec / meter}$$

where:

f_0 = natural frequency of the seismometer in Hz.

M = mass of the inertial mass in kg (5 kg for GS-13 seismometer)

CDR = critical damping resistance in ohms, corresponding to natural frequency, f_0.

4.7 DETERMINING MOTOR CONSTANT, $G_{cal\ coil}$, OF THE CALIBRATION COIL

To determine the motor constant, $G_{cal\ coil}$, of the calibration coil, proceed as follows:

a. Place the seismometer and recording systems in operation. Short any component on Pre-Amp/Calibration that are in position R14 and R15.

b. Make several weight lifts, and record the X_m (zero-to-peak amlitude) trace for each weight lift.

c. Apply dc pulses to the calibration coil and adjust the current, i_p, until the X_i (zero-to-peak) trace amplitude is within 10 percent of the X_m trace amplitude. Record X_i and note i_p.

d. Calculate the motor constant, $G_{cal\ coil}$, of the calibration coil, using the average of three or more weight lifts:

$$G_{cal\ coil} = \frac{980 \times 10^{-5} \mathrm{Wt} X_i,}{i_p X_m} \text{ newtons / ampere}$$

where: $G_{cal\ coil}$ = motor constant of cal coil, newtons/ampere

X_i = zero-to-peak trace amplitude in millimeters due to current i_p

i_p = dc current in calibration coil, zero-to-peak, in amperes

X_m = zero-to-peak trace amplitude in millimeters due to weight lift, Wt(eff)

Wt = weight lifted, in grams

For vertical seismometers, Wt = weight lifted, in grams

For horizontal seismometers, $Wt = \dfrac{\text{weight lifted, in grams}}{2}$

NOTE

> When calculating the calibration coil motor constant, $G_{cal\ coil}$, care must be exercised to use only the traces made when the weight is lifted. Also only dc pulse traces deflecting in the same direction as the lifted weight traces should be utilized. Reverse leads to the calibration coils if necessary to achieve this relation.

4.8 DETERMINING EQUIVALENT EARTH MOTION

When the motor constant of the calibration coil has been determined, the equivalent sinusoidal earth motion produced by a sinusoidal signal in the calibration coil can be determined by the following relation:

$$y = \frac{G_{cal\ coil}\, i \times 10^6}{4\pi^2 f^2 M}$$

where:

y = equivalent earth motion in microns, peak-to-peak

$G_{cal\ coil}$ = calibration coil motor constant, newtons/ampere

i = current through the calibration coil, amperes, peak-to-peak

f = frequency of calibration signal

M = seismometer mass in kilograms (5 kg for GS-13)

- - Notes - -

5. MAINTENANCE

5.1 GENERAL

The design of the GS-13 seismometer is such that complete disassembly of the instrument should not be necessary and disassembly beyond the limits outlined in this section should be avoided. If it appears that further disassembly is needed, the instrument should be returned to the manufacturer for repair and readjustment. Each seismometer is carefully assembled with parts selected to give the best performance; therefore, parts removed should be replaced in their original locations. The following precautions should be observed when disassembling the seismometer as noted above:

a. Assembly area should be clean and free of dirt or metal chips, particularly magnetic metal chips.

b. The calibration magnet-coil assembly should be handled carefully to avoid sharp blows. It should not be disassembled as it requires special tooling for reassembly.

c. The main magnet-coil assembly should never be disassembled since it can be damaged if the proper fixures and procedures are not used.

d. The O-rings and O-ring grooves should be kept free of dirt, chips, and other foreign matter. On installation, the O-rings should be lubricated with a suitable O-ring lubricant.

e. Before attempting any maintenance on this seismometer the operations section, parts 3.1, 3.2, and 3.3 should be read and thoroughly understood.

5.2 REMOVING AND REPLACING THE COVER

Instructions for removing and replacing the cover are given in paragraph 3.3.1.

5.3 CHANGING THE CALIBRATION COIL-MAGNET ASSEMBLY

To remove the calibration coil proceed as follows:

a. Remove the mass indicator cap assembly.

b. Remove mass-position indicator cap and weight-lift table.

c. Note the orientation of the 10-32 tapped hole in calibration-coil support, then remove the three No. 6-32 x 1/2 socket head cap screws.

d. Unsolder the leads from the terminals.

e. Remove calibration-coil support and coil-magnet assembly.

f. Screw the new calibration coil-magnet assembly into the main coil-magnet assembly.

g. Install the cal-coil support orientating the 10-32 tapped hole to the right hand side when looking at the end of the seismometer in a horizontal position. Fasten the cal assembly so that the coil is centered in the gap.

h. Resolder the leads.

i. Before reinstalling the mass indicator cap, lubricate the O-rings. Clean all dirt and foreign matter from the O-ring groove and inspect for any nicks, scratches, or burrs that would prevent O-rings from forming a seal.

j. After reassembly of the support structure check cal polarity. Positive voltage on pin G with return on pin H should move the mass down (towards the foot of the case).

5.4 CHANGING DELTA RODS

Delta rods which are distorted or broken should be replaced. If only the small diameter wire is bent, it can be straightened and replaced in the seismometer. To remove damaged delta rods, proceed as follows:

a. Lock the mass

b. Remove the cover

c. Remove the damaged delta rods by loosening the 4-40 x 3/16 socket head cap screws.

CAUTION

Do not remove all six delta rods at one time. At least 2 delta rods, 1 upper and 1 lower, should be left in place.

d. Fit the new delta rods so that: the wires rest in their grooves in the clamping blocks, the two ends of each delta rod lie in the same plane to form one straight line, and the stiffened section is centrally disposed (0.250 each end) between the clamping blocks.

e. Ensure that all clamps are straight and that all screws are tight.

5.5 CHANGING SPRINGS

To change the springs, proceed as follows:

a. Lock the mass.

b. Remove the cover.

c. Release the springs until all tension is off the flexures. To release the springs, turn the spring adjust nuts counterclockwise. Hold the spring to keep it from turning when the antirotation pin comes out of the guide slot in the upper tension screw assembly.

d. Remove the 2-56 x 1/4 socket head screws and flexure clamp at the upper end of the cantilever-to-spring flexure.

e. Work the flexure off the flexure pin in the spring connector.

f. Pull up on the spring adjust nut and turn it counterclockwise until the nut comes off the spring assembly.

g. Carefully remove the spring assembly from the seismometer.

h. Before replacing the spring assemblies; clean the O-ring grooves, lubricate the O-rings with light silicone oil or other suitable lubricant, and place the O-ring in the groove.

i. Extend the threaded end of the spring assembly through the hole in the upper frame plate. The flexure pin in the spring connector should be pointing to the left of the observer. Place the teflon washers over the stud and screw the spring adjust nut onto the stud. Three to five turns will be sufficient. Push the spring adjust nut into the O-ring.

j. Lower or raise the spring assembly until the flexure pin will pass through the hole in the upper end of flexure.

k. Clamp the flexure to the spring assembly with the flexure clamp and a 2-56 x 1/4 socket-head screw. Do not tighten the screw at this time.

l. Turn the spring adjust nut clockwise until a small amount of tension is on all flexures. Hold the spring from rotating until the pin enters the guide slot on all adjustments.

m. Make certain that the cantilever and flexures are straight. It may be necessary to loosen all screws holding the flexures. When the cantilevers and flexures are straight, tighten the screws making sure that the clamps are straight with their flexures. Take care not to misalign the cantilever and spring.

n. Make sure that the spring guide pins line up with spring guides, then tighten the spring adjust nuts until the dowel pins are approximately 1/8-inch from the bottom of the groove in spring guides. Unlock the mass.

o. Center the mass between the stops, taking care to keep the elongation in all springs equal.

CAUTION

Make sure no part of the spring assembly is rubbing against the cantilevers. The spring assembly should be centered in the yoke of the cantilever.

5.6 REPLACING DAMAGED FLEXURES

5.6.1 To Replace a Cantilever-To-Spring Flexure

a. Lock the mass.

b. Remove the cover.

c. Remove all tension from the flexures (see step 5.5.c).

d. Remove the 2-56 x 1/4 socket-head cap screws and flexure clamp at the upper and lower end of the flexure.

e. Remove the damaged flexure and replace it with a new one.

f. Clamp the flexure to the spring assembly and cantilever with the flexure clamps and 2-56 x 1/4 socket-head screws. Do not tighten the screws at this time.

g. Repeat steps 5.5 e through 5.5 o.

5.6.2 To Replace A Damaged Cantilever-To-Base Flexure

a. Remove all tension from the flexures (see step 5.5.c).

b. Remove the 2-56 x 1/4 socket-head cap screws and flexure clamp from the botton of the flexure.

c. Remove the 2-56 x 3/8 socket-head cap screws and flexure clamp from the top of the flexure.

d. Remove the damaged flexure and replace it with a new one.

e. Clamp the flexure to the cantilever with a 2-56 x 3/8 socket-head screw and the flexure clamp. Clamp the flexure to the middle frame plate assembly with the 2-56 x 1/4 socket-head screw and flexure clamp. Do not tighten the screws at this time.

f. Repeat steps 5.5 e through 5.5 o.

5.6.3 To Replace A Damaged Cantilever-To-Mass Flexure

a. Remove all tension from the flexures (see step 5.5.c).

b. Remove the 2-56 x 3/8 socket-head screw from the top of the flexure (if the seismometer is in the vertical operation mode).

c. Remove the 2-56 x 1/4 socket-head screw from the bottom of the flexure.

d. Remove the damaged flexure and replace it with a new one.

NOTE

The flexure should be installed with the bend away from the cantilever.

e. Clamp the flexure to the cantilever with a 2-56 x 3/8 socket-head screw and the flexure clamp. Clamp the flexure to the calibration magnet and mass assembly with a 2-56 x 1/4 socket-head screw. Do not tighten either screw at this time.

f. Repeat steps 5.5 e through 5.5 o.

5.7 REPLACING THE MAIN COIL-MAGNET ASSEMBLY

This requires tools and fixtures that are not available for customer use and should not be done in the field.

- - Notes - -

6. CALIBRATION COMPONENTS

6.1 INPUT DATA

6.1.1 General

This procedure is applicable to 02 version and must be applied individually to each seismometer since the resulting component values are computed from the basic test results of the individual seismometers.

6.1.2 Seismometer Constants

Seismometer Serial Number	________________	
Main Coil Generator Constant	$G_{main\ coil}$ = ________________	Vs/m
Main Coil Resistance	$R_{main\ coil}$ = ________________	Ohms
Open Circuit Damping	λ_i = ________________	Relative
Open Circuit Frequency	ω_o = ________________	Hz
Cal Coil Motor Constant	$G_{cal\ coil}$ = ________________	N/A
Cal Coil Resistance	$R_{cal\ coil}$ = ________________	Ohms
Seismometer Mass	M = ________________	kg

6.1.3 Desired Results

Damping	λ_t = ________________	Relative
Output Sensitivity	Ge = ________________	Vs/m
Operational Load	R_L = ________________	Ohms
Calibration Sensitivity	v/V = ________________	(m/s/s)/V
or	a/V = ________________	(m/s)/V

6.2 CALIBRATION COMPUTATIONS

6.2.1 Acceleration Calibration

To obtain a desired relationship between the applied calibration voltage and seismometer mass acceleration, a calibration resistor needs to be installed at position R14 or R15 with the other position left open. The value of the calibration resistor R_c, is computed using the equation:

$$R_c = [G_{cal\ coil}/(M \times a/V)] - R_{cal\ coil}$$

where:

$G_{cal\ coil}$ = the cal coil motor constant

M = seismometer mass

a/V = the desired acceleration sensitivity

$R_{cal\ coil}$ = cal coil resistance

The calculation must result in a positive value for R_c, and ideally R_c should be much larger than $R_{cal\ coil}$. The resistor used should be the nearest value in the 1%, high-stability, film, resistor series.

6.2.2 Velocity Calibration

To obtain a desired relationship between the applied calibration voltage and the seismometer mass velocity, calibration capacitor(s) need to be installed at positions R14 and/or R15. The value of the calibration capacitor, C_c, is computed using the equation:

$$C_c = (M \times v/V)/ G_{cal\ coil}$$

where:

M = seismometer mass

v/V = the desired velocity sensitivity

$G_{cal\ coil}$ = the cal coil motor constant

The constraint on the C_c value is that its impedance must be large compared to the cal coil resistance at the highest frequency of use. The test for this restriction is the equation:

$$TEST = 1 - 50 \times F_{max} \times R_{cal} \times C_c$$

where:

F_{max} = the maximum cal frequency

R_{cal} = cal coil resistance

C_c = calibration capacitance

The calculation must result in a positive value for TEST. The capacitor in the R14 position is normally chosen to represent the bulk of the requirement, and the capacitor in the R15 position is selected to bring the combination as close as possible to the required value.

6.2.3 Computed Results

R_c = ______________________________ Ohms, or

C_c = ______________________________ microfarads

6.3 OUTPUT COMPUTATIONS

6.3.1 Output Calibration

To obtain a desired output sensitivity from the known seismometer constants, it is first necessary to compute and test two functions:

$$F1 = (Ge \times G_{main\ coil}) / [12.57 \times \omega_o \times (\lambda_t - \lambda_i) \times M]$$

and

$$F2 = G_{main\ coil} / Ge$$

The computed value of F1 must be smaller than R_L, and the computed value of F2 must be larger than one (1).

If both conditions are met then:

$$R10 + R13 = [(F2-1) \times F1] - R_{main\ coil}$$

and

$$R11 + R12 = R_L \times F1 / (R_L - F1)$$

Note that if the loading effect of R_L is considered negligible; then F1 is always smaller and the value of R11 + R12 = F1.

R10 and R13 as well as R11 and R12 are normally selected to be about equal values, but one of each pair could be a short with the other being the required resistance. The resistors used should be the nearest value in the 1%, high-stability, film, resistor series.

6.3.2 Output Results

R10 + R13 =_____________ Ohms

R11 + R12 =_____________ Ohms

6.3.3 Output Capacitor

The output capacitor, C11, has two effects on the apparent seismometer output. One effect is to form a low-pass filter and thus to reduce the high frequency noise in the output. The second effect is to reduce the apparent free period of the seismometer. This capacitor is not installed except in special applications.

In estimating the filter effect it should be noted that the seismometer coil has both resistance and inductance. The resistance is about 9000 ohms and the inductance about 50 Hy. A 0.1 microfarad capacitor will give noticable high frequency noise reduction at about 70 Hz. The noise will then drop about 12 dB per octave as a result of the L-C combination.

The moving mass system of the seismometer, as seen by the electrical output terminals, makes the mass look like about a 1.0 microfarad capacitor. Thus, a 0.1 microfarad added capacitor increases the apparent mass by 10% which effectively lowers the free period by 5%. It also has the effect of lowering the apparent generator constant.

7. FREQUENCY RESPONSE/POLES AND ZEROS

7.1 Amplitude and Phase Response Curves

This section contains graphs of the amplitude and phase response of the different versions, and a table of their respective poles ans zeros.

Table 7-1 Poles and Zeros

Version	Response Type	Poles rad/s	Zeros rad/s	Gain
01	Flat Velocity	$\lambda_t\omega_o + j\omega_o\sqrt{1-\lambda_t^2}$	0+j0	$\frac{G_{\text{main coil}} R_{XD}}{(R_{\text{main coil}} + R_{XD})} \frac{\text{volts}}{(\text{meter}/\text{s})}$
		$\lambda_t\omega_o - j\omega_o\sqrt{1-\lambda_t^2}$	0+j0	
02	Flat Velocity	$\lambda_t\omega_o + j\omega_o\sqrt{1-\lambda_t^2}$	0+j0	$Ge\frac{\text{volts}}{(\text{meter}/\text{s})}$
		$\lambda_t\omega_o - j\omega_o\sqrt{1-\lambda_t^2}$	0+j0	
03	Flat acceleration	.125	0+j0	$500\frac{\text{Volts}}{(\text{meter}/\text{s}^2)}$
		314.16		

where:

λ_t = Operating damping ratio (eg. .707).

$\omega_o = 2\pi f_0$

f_0 = Natural frequency of seismometer.

$j = \sqrt{-1}$

$G_{\text{main coil}}$ = Open circuit main coil generator constant.

Ge = Normalized main coil generator constant.

$R_{\text{main coil}}$ = Main coil generator constant.

R_{XD} = External damping resistor = $R_t - R_{\text{main coil}}$

R_t = Total circuit resistance for damping λ_t.

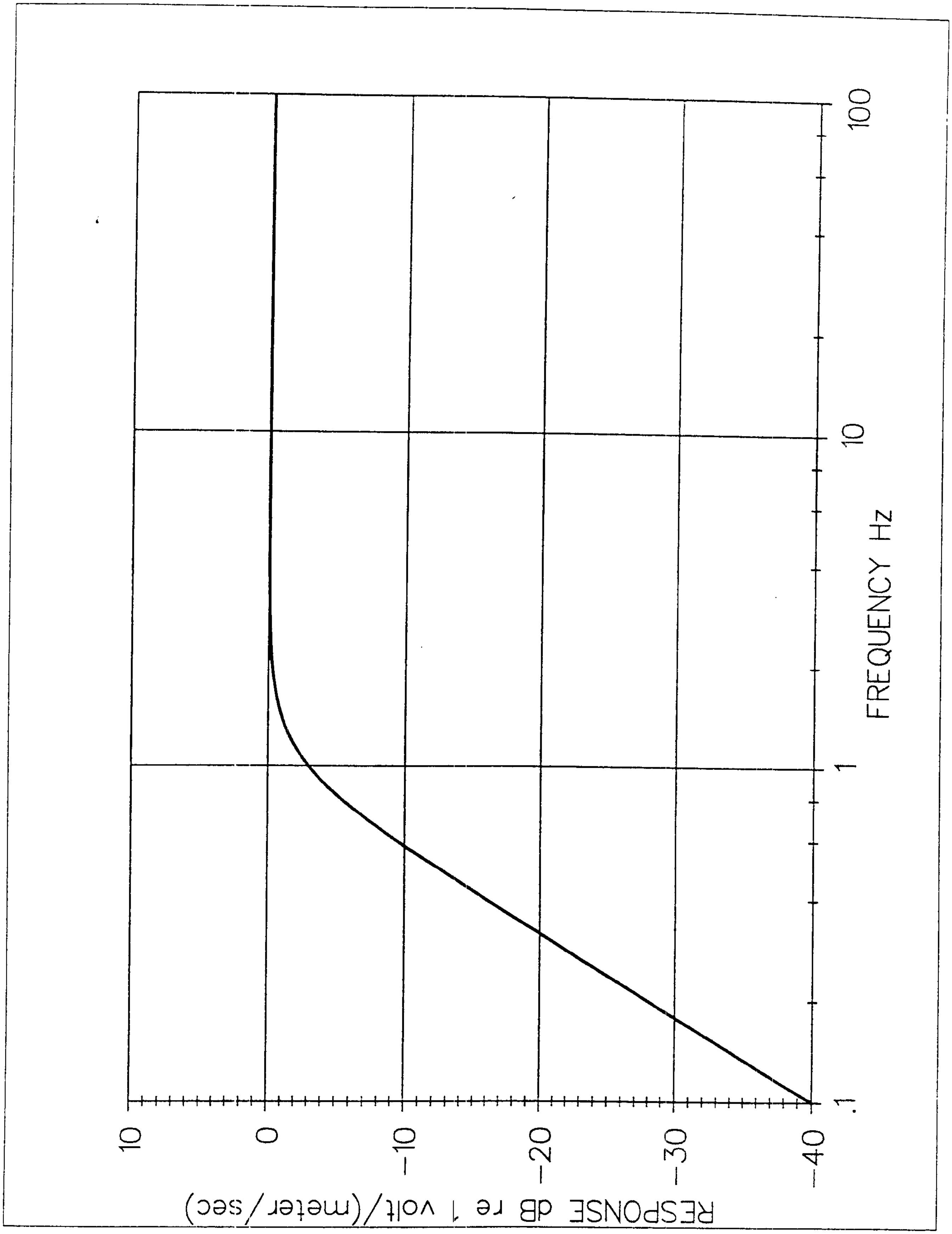

Figure 7-1 01, 02 Relative Amplitude Response for .707 Damping

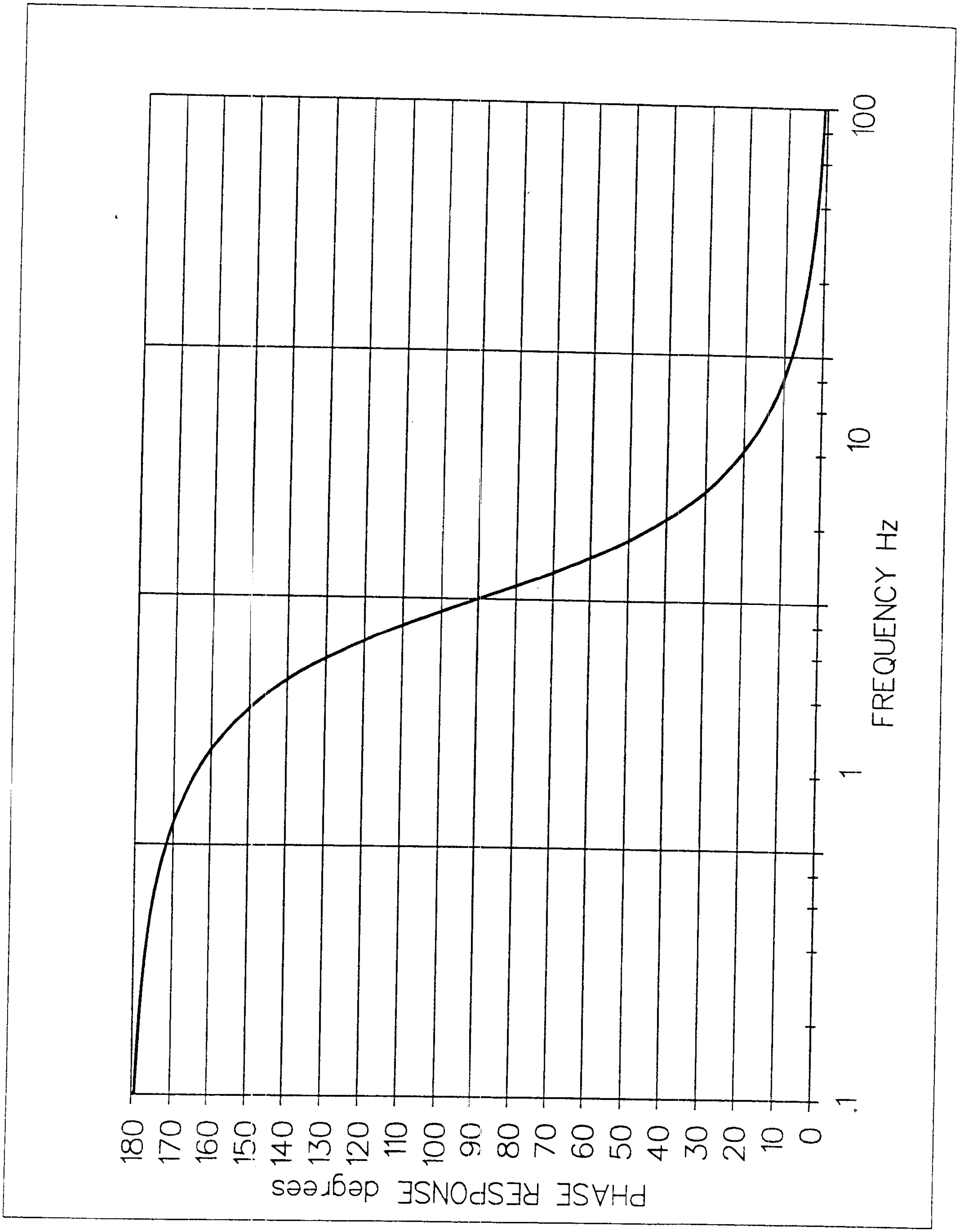

Figure 7-2 01, 02 Phase Response for .707 Damping

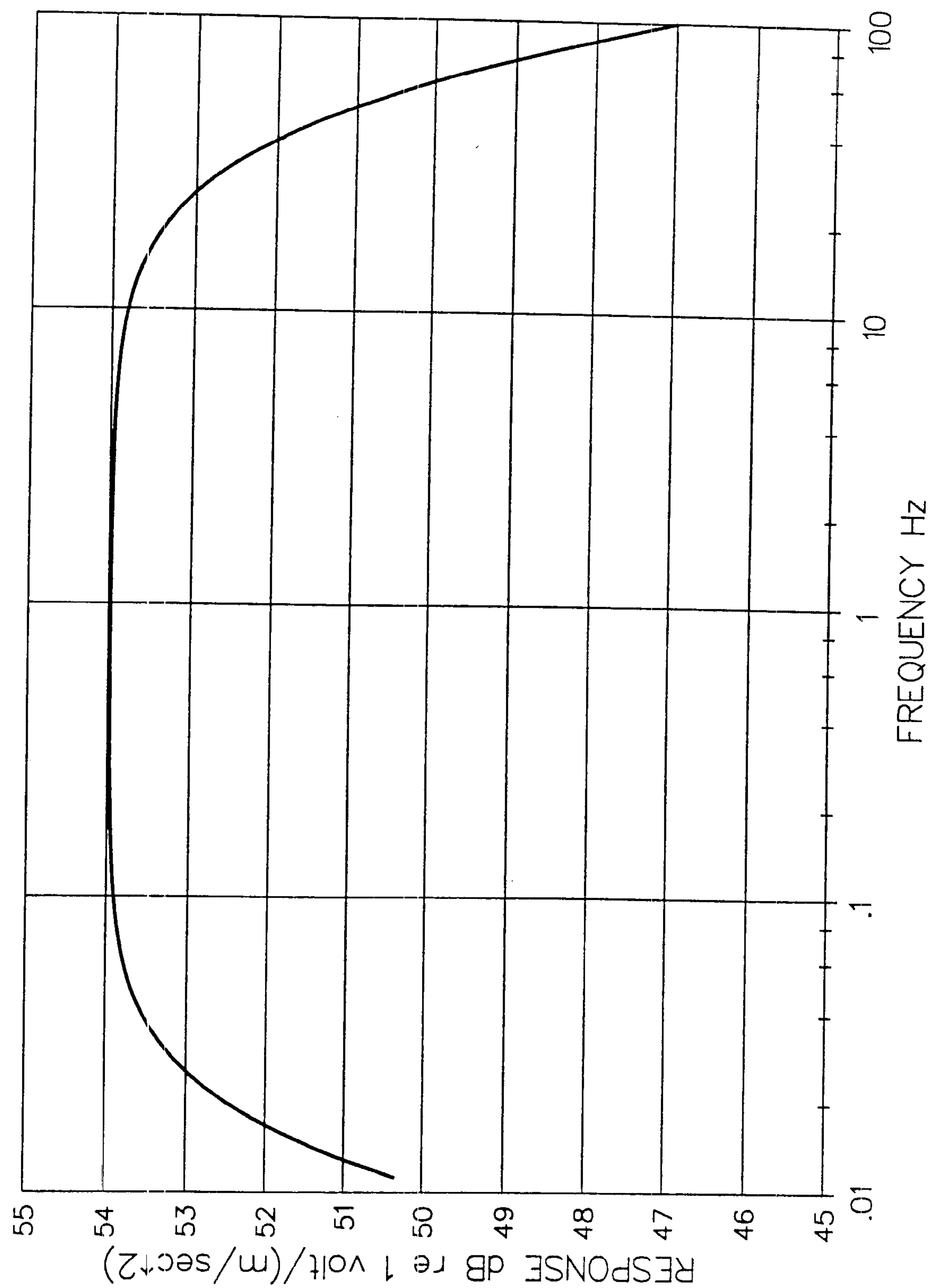

Figure 7-3 03 Amplitude Response .05 - 50 Hz, 500 $V/m/s^2$

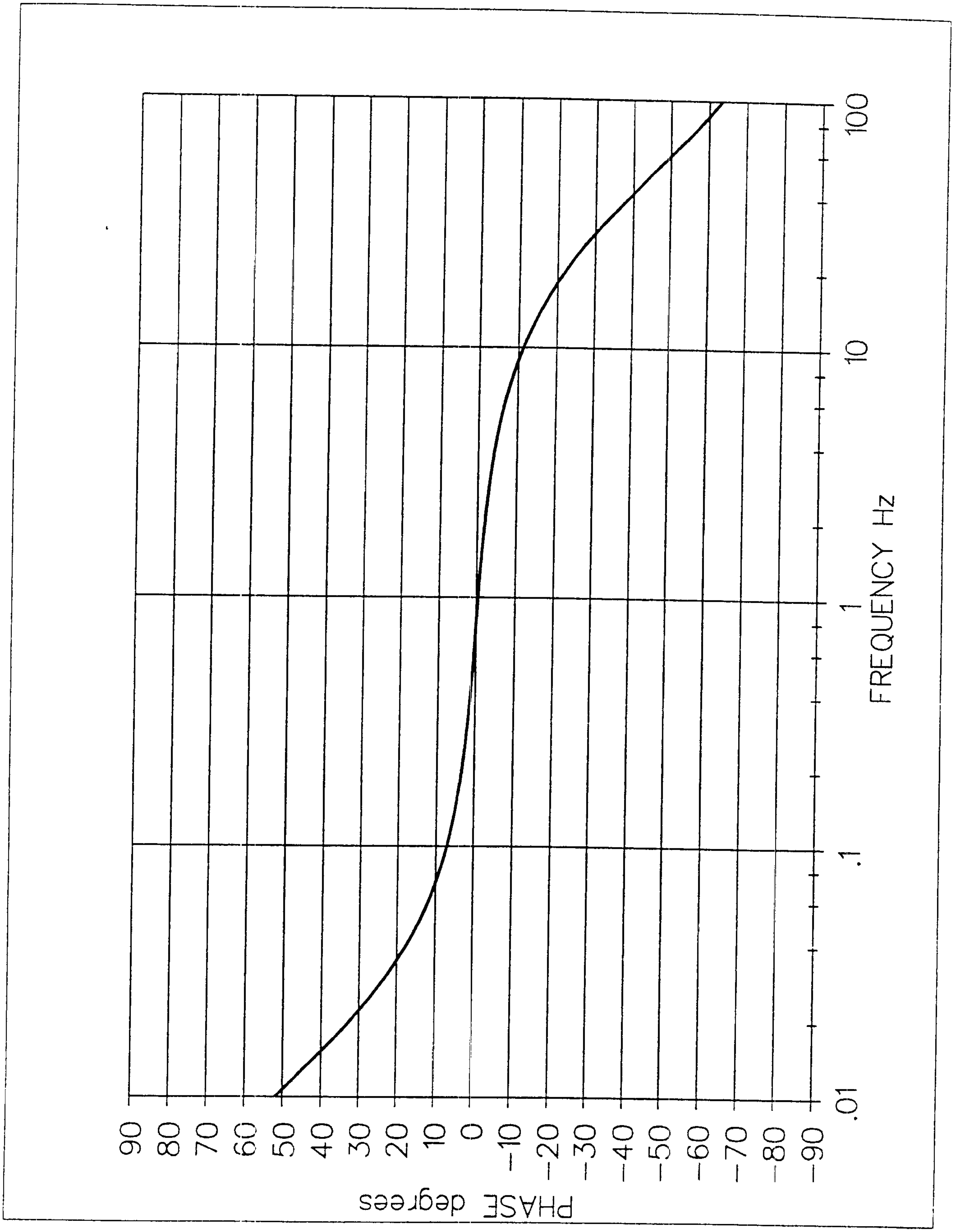

Figure 7-4 03 Phase Response .05 - 50 Hz

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