

TRANSPORTATION OF VIBRATION SENSITIVE EQUIPMENT BY HIGHWAY TRAILER ON AN INTERMODAL RAILCAR VOLUME I



FINAL REPORT

JULY 1979

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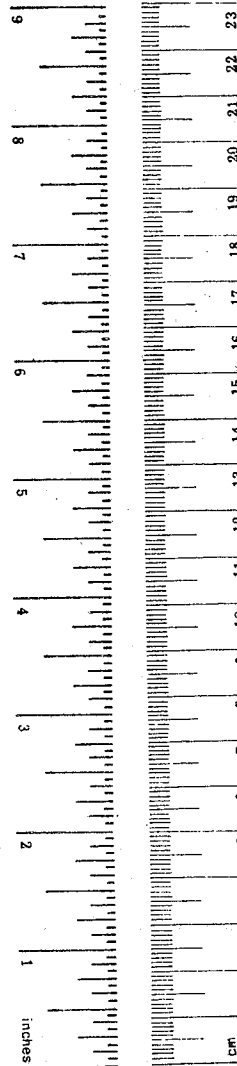
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16. Abstract This report includes the results of a cooperative research project between Government and industry to explore the potential for the use of highway trailers on intermodal railcars (Trailer on Flatcar) or (TOFC) to transport vibration sensitive lading. The industrial participants in the study were the Boston and Maine Railroad, the Digital Equipment Corporation and Mooney Moving and Storage (representing Allied Van Lines). The purpose of the project was to characterize the operating environment of TOFC during the transport of vibration-sensitive teletypewriters. To this end, the lading, two types of trailers and the conventional TOFC flatcar were instrumented to quantify the shock and vibration environment during typical over-the-road revenue operation. The trailers used were a conventional railroad-owned leaf-spring trailer and an air-ride moving van. Various measurements of the accelerations experienced by the lading as well as the TOFC components were taken during the road test. The test was conducted using a special train operating over sections of the main line tracks and yards of the B&M Railroad between Boston and Mechanicville, NY. Test equipment, test procedures and data processing techniques used are discussed in the report. The results of the test indicated that the ride quality of both types of trailers are similar and that TOFC is feasible for the transportation of vibration-sensitive equipment. Test results contained in the report provide useful information to traffic managers and packaging engineers. For complete test data refer also to Report No. FRA/ORD-79/05.II Volume II - Test Data. Volume I contains test data for only one test zone (Number 3).					
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 exactly. For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13,10-286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

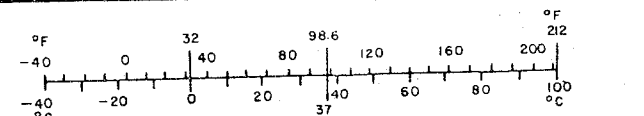


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1.0 INTRODUCTION

1.1 BACKGROUND

This report describes the results of a full-scale test conducted to determine the vibration input to lading during typical Trailer on Flatcar (TOFC) operation. The research was a cooperative program between the Federal Railroad Administration (FRA) and three different types of private industry; the manufacturer, the railroad and the common carrier trucker.

The industry participants were the Boston and Maine Railroad (B&M), Digital Equipment Corporation (DEC), and Mooney Moving and Storage representing Allied Van Lines. The B&M Railroad supplied all railcars and dummy loads, the data acquisition/support car and the locomotive that made up the test train as well as the facilities and support required during pretest activity. DEC furnished the test lading (144 production teletypewriters) which had been subjected to rigorous quality control both before and after the conduct of the test. Mooney Moving and Storage provided an Air-Ride trailer and all highway transportation required.

The research described in this report is referred to as the Piggyback Evaluation Project (PEP). These four organizations pooled both resources and talent to study the intermodal transportation system as a potential means for reducing cost and energy consumption. FRA, through its contractor, provided instrumentation and engineering expertise to make the required measurements, and all required data processing and analysis.

The PEP project provided a systematic investigation to date of the use of intermodal rail to transport what has been considered vibration-sensitive items, electronic components.

(unsuitable for this mode of transportation). The investigation involved the conventional leaf-spring trailer and an Air-Ride trailer.

1.2 PURPOSE

The primary goal of this investigation was to assess the potential of the intermodal rail system as a means for transporting vibration-sensitive items.

Specifically, the following three objectives were established:

- To quantify the acceleration input to TOFC lading during typical revenue operation.
- To provide data for comparing the ride quality of a conventional leaf-spring trailer and an Air-Ride trailer during TOFC operation.
- To measure the acceleration on one lading item to provide an assessment of the adequacy of vibration test profiles derived in the laboratory.

1.3 TEST DESCRIPTION

A full-scale test was conducted on the B&M Railroad using a special test train made up of a locomotive, three buffer flatcars, a test flatcar, a Budd passenger car modified to serve as a data acquisition car, and a caboose. Two test runs were conducted, one with the leaf-spring trailer instrumented and the other with the Air-Ride trailer instrumented.

1.4 TRAILERS

One of the objectives of the project was to provide data to compare the ride quality of a leaf-spring trailer to that of an Air-Ride trailer in TOFC operation. Both were standard 40-foot trailers presently in wide use in the industry. They did, however, have one significant difference. The leaf-spring trailer was of standard, flat-bed, van-type construction while

the Air-Ride trailer was the drop-frame, van type. It was decided, early in the planning stages, that these two types of construction are generally representative of their respective suspension systems. Therefore, comparison could be made using the two different type beds.

The leaf-spring trailer used in this study was a standard, 40-foot, Z-Van manufactured by Freuhauf (serial number BMZ 202447) and is shown in Figure 1-1. The trailer was eight feet wide with an overall height of 13 feet, 5 inches and weighed 12,400 pounds empty. Lading (Figure 1-3) consisted of 78 production teletypewriters weighing approximately 150 pounds each including packaging. This resulted in a trailer gross weight of 24,100 pounds.

The Z-Van trailer has a selection of 15 positions for the suspension system. The forward-most position was used during this study and tire pressure was maintained at 80 psi in all eight tires.

The air-suspension trailer is shown in Figure 1-2. The overall dimensions are the same as those of the leaf-spring trailer. The air supply on the data acquisition car was used to maintain the pressure in the air bags while the trailer was on the flatcar.

1.5 TEST TRAIN

A special test train was made up expressly for this test. The use of a special train provided control over speed and train handling while furnishing typical train action inputs to the test vehicle. The test train consisted of a locomotive, three buffer flatcars, a TTAX flatcar with the instrumented trailers, a Budd passenger car serving as the data acquisition vehicle, and a caboose as shown in Figure 1-4.

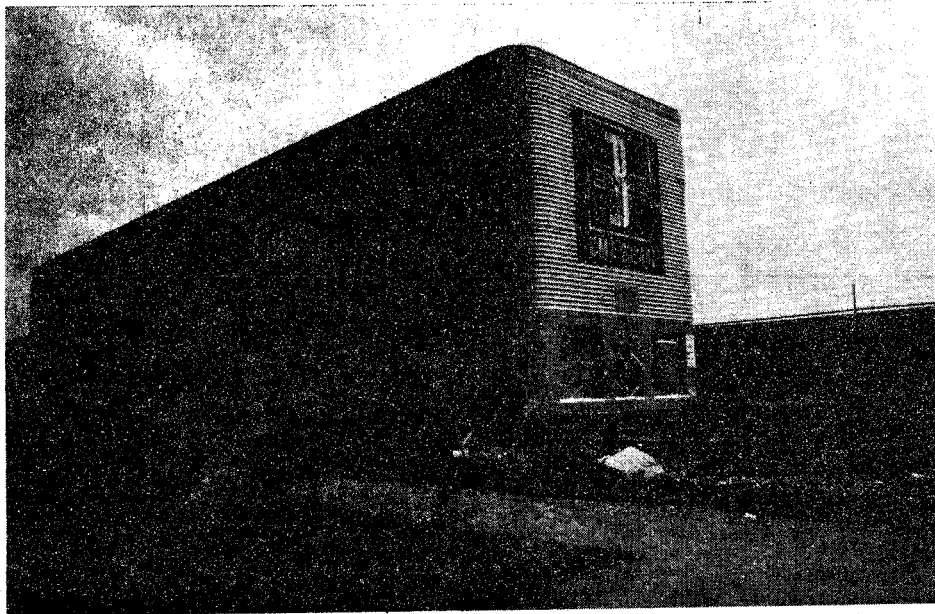


Figure 1-1. Leaf-Spring Trailer

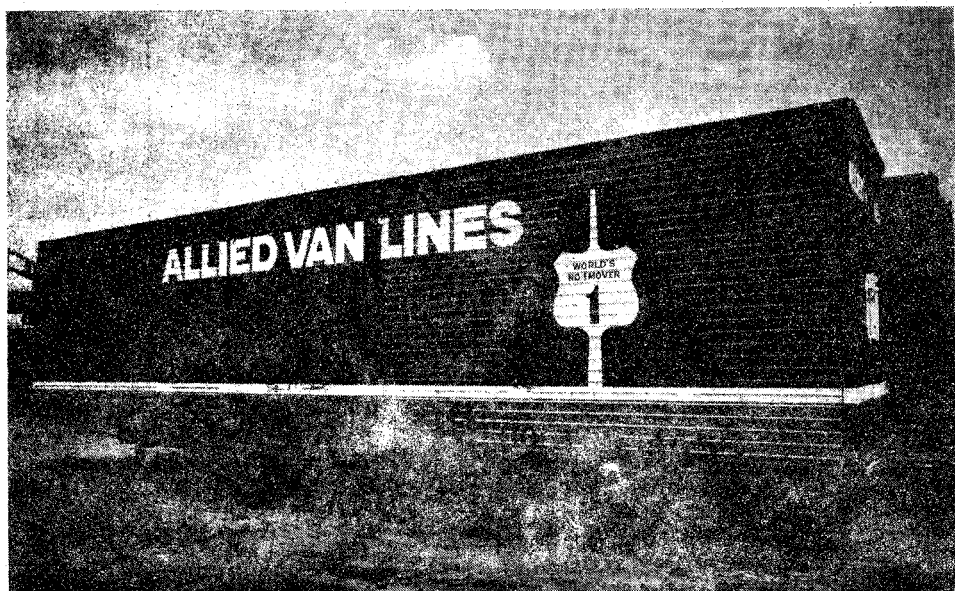
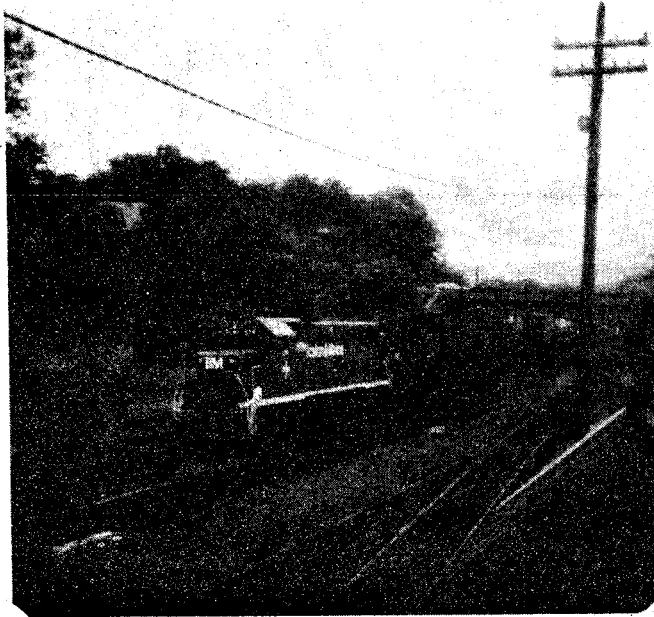


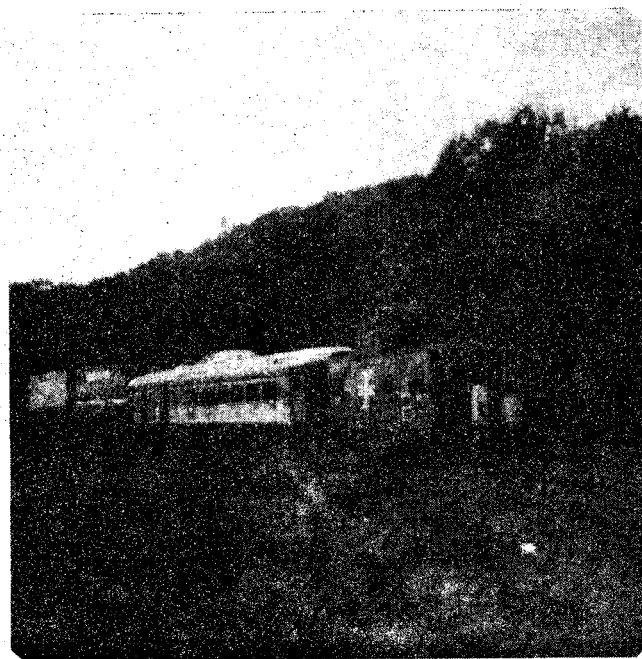
Figure 1-2. Air-Ride Trailer



Figure 1-3. Lading In The Trailer



FRONT



REAR

Figure 1-4. Test Train

The locomotive used for this test was a GP-40 manufactured by General Motors. This unit is capable of generating 3,000 continuous horsepower for traction and has a maximum speed of 71 mph. The three flatcars used as buffers between the locomotive and the test flatcar were all of the TTX type. The first and third were loaded with two empty Z-Van trailers each. The middle or second flatcar was loaded with steel trusses. This make up of buffer cars was chosen to duplicate normal train action and normal aerodynamic inputs to the test vehicle and the trailers.

The test flatcar was TTAX 974281 and was selected only on the basis of being representative of flatcars in intermodal use. No special specifications or restrictions were placed on the car nor was any special maintenance performed. The TTAX flatcar is a general purpose, flush-deck flatcar with moveable fold-away container pedestals and knock-down hitch and bridge plates. It is capable of carrying trailers or containers and combinations of both. The car has an overall length of 80 feet, 4 inches, a lightweight of 68,700 pounds and a capacity of 150,000 pounds. The trucks were standard, 70-ton, three-piece freight trucks. Figure 1-5 shows the flatcar with the test trailers configured for testing.

The data acquisition/support car (shown in Figure 1-6), was a diesel-powered passenger car manufactured by the Budd Company. The forward compartment normally used for postal service was converted to a service area with one table on which the data acquisition system was mounted.

1.6 TEST PROGRAM

The test program consisted of two test runs, one westbound on 12 July 1978 and the other eastbound on 14 July 1978. During the westbound run, the leaf-spring trailer was instrumented.

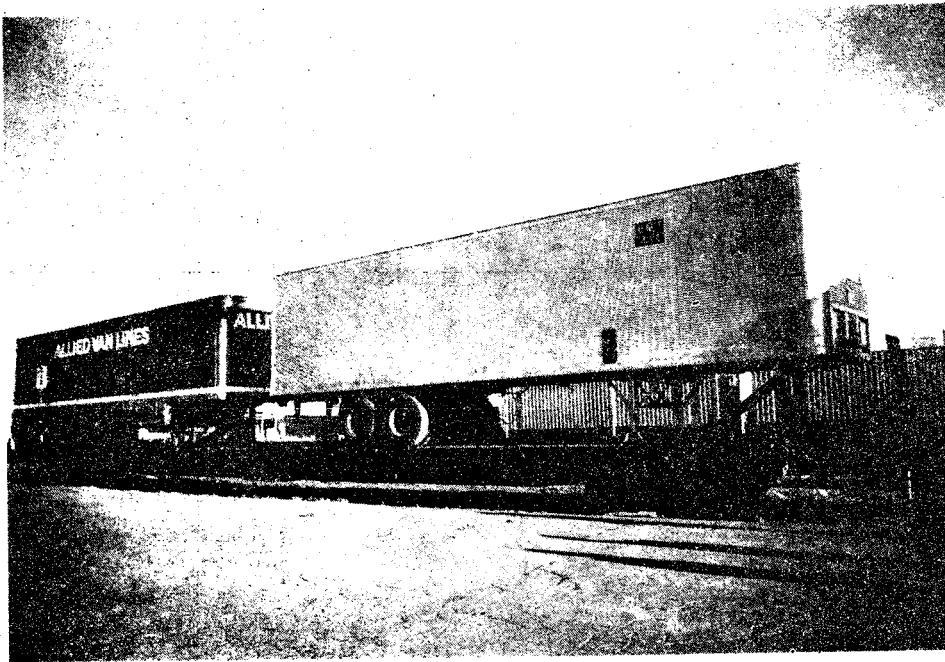


Figure 1-5. TTAX Flatcar in TOFC Configuration

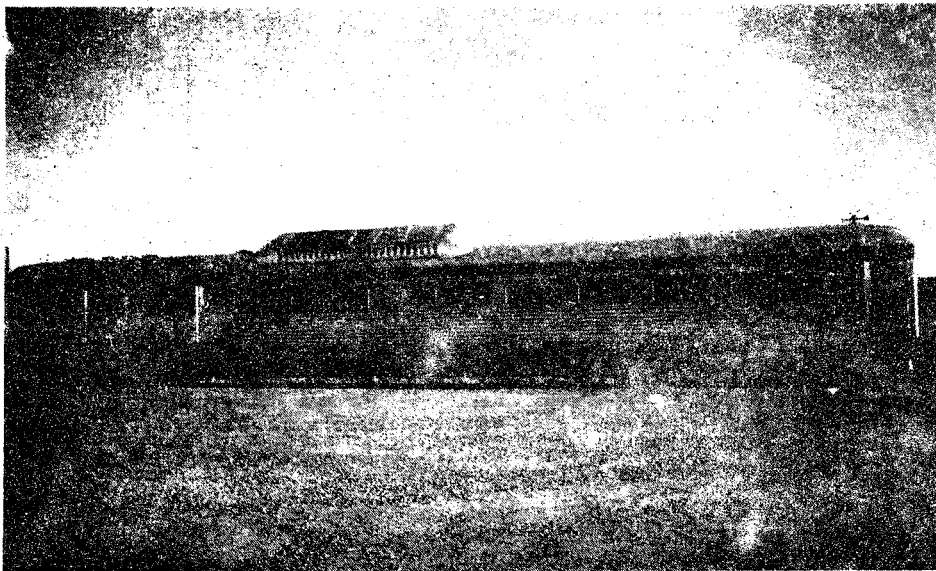


Figure 1-6. Data Acquisition Car

During the eastbound run, the Air-Ride trailer was instrumented. Both test runs were conducted on the Boston and Maine Railroad's Fitchburg mainline between Cambridge, MA (MP 2) and Mechanicville, NY (MP 188).

2.0 TEST EQUIPMENT AND PROCEDURES

2.1 GENERAL

Primary instrumentation consisted of 12 linear, servo-accelerometers (ten mounted to the trailer floor, one mounted to the trailer roof, and one mounted on a lading pallet). These accelerometers were aligned along orthogonal axes: One in the direction of travel, four in the lateral direction and seven in the vertical direction. Accelerations were measured along the trailer centerline and along one side of the trailer at three longitudinal positions: at the kingpin, at mid-trailer, and at the rear. The signals from the accelerometers were recorded on an instrumentation-grade, analog, tape recorder located in the data acquisition car.

Secondary instrumentation consisted of four mechanical accelographs. These devices are essentially a simple, spring-mounted seismic mass with a stylus tip. The movement of the mass, which is proportional to acceleration, is recorded on a specially treated hemispherical disc. This system required no other support equipment and provided a permanent record of the magnitude and direction of peak accelerations in the plane of the disc.

The section of the analog data, which represented test segments of most interest (as recommended by B&M and as indicated by test observations) were digitized. Seven test zones were chosen from the collected data as representative of the overall operation. The digital data was reproduced in analog form for validation and time domain analysis. Following this the data was reduced to the following formats:

- One average power spectral density (in the frequency band 0 to 124 Hz) per test zone.

- One Probability Density Estimate per test zone including the 95 percent and 99 percent levels.
- One root-mean-square history per test zone.

2.2 INSTRUMENTATION

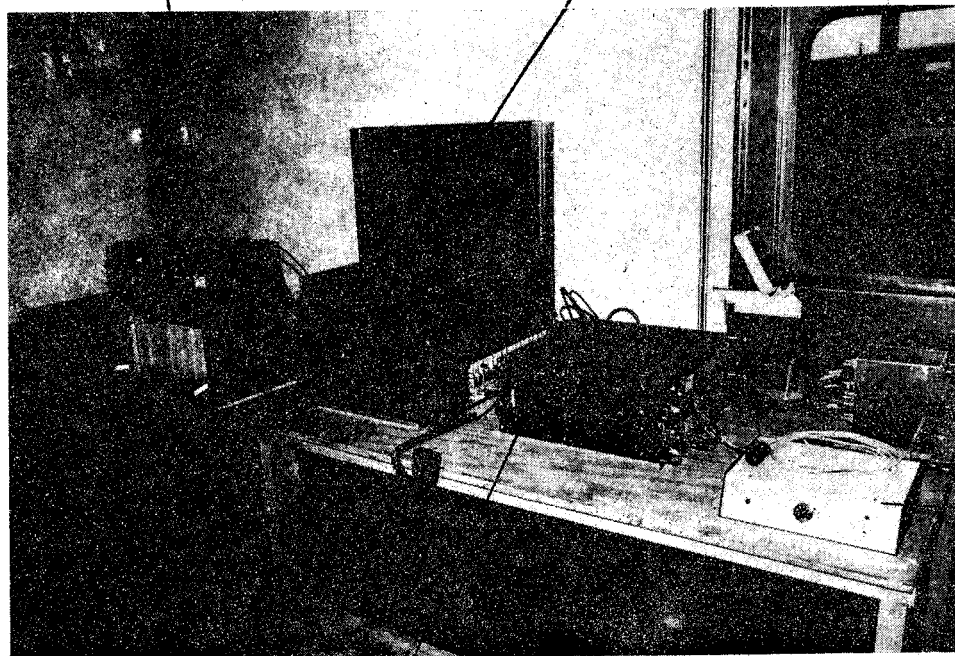
The instrumentation used to measure and record the vibration levels on the trailer floor during TOFC operation consisted of four primary components: the transducers, the signal conditioning electronics, the recorder and the analog strip-chart recorder (Figure 2-1). Figure 2-2 is a schematic of the instrumentation with the components in their approximate relative locations.

The primary transducer used in this study was the Schaevitz 5g, linear, servo-accelerometer shown in Figure 2-3. Two different models of this accelerometer were used. Accelerations measured in the vertical direction required the use of an accelerometer compensated for gravity. Schaevitz Model LSBCG-5 was used for vertical measurements since it gives a zero output when aligned with the local vertical. In the horizontal plane the uncompensated Schaevitz Model LSBC-5 was used.

Both models contain a jewel-pivoted, pendulous mass (Figure 2-4) which develops a torque about the axis of rotation when subjected to acceleration. The infinitesimal movement of the mass is sensed and an electrical signal is applied to a torque generator to produce an equilibrium condition with the acceleration-caused torque. The voltage required to generate the electrical torque is proportional to the applied acceleration. The advantage of the servo-accelerometer is that two main sources of error are eliminated, non-linear mechanical springs and displacement transducers.

SIX-CHANNEL STRIP
CHART RECORDER

14-CHANNEL BELL AND
HOWELL RECORDER



FILTER
CHASSIS

SPEED AND
DISTANCE
UNIT

Figure 2-1. Data Acquisition System

ACCELEROMETER SIGNAL
CONDITIONING CHASSIS

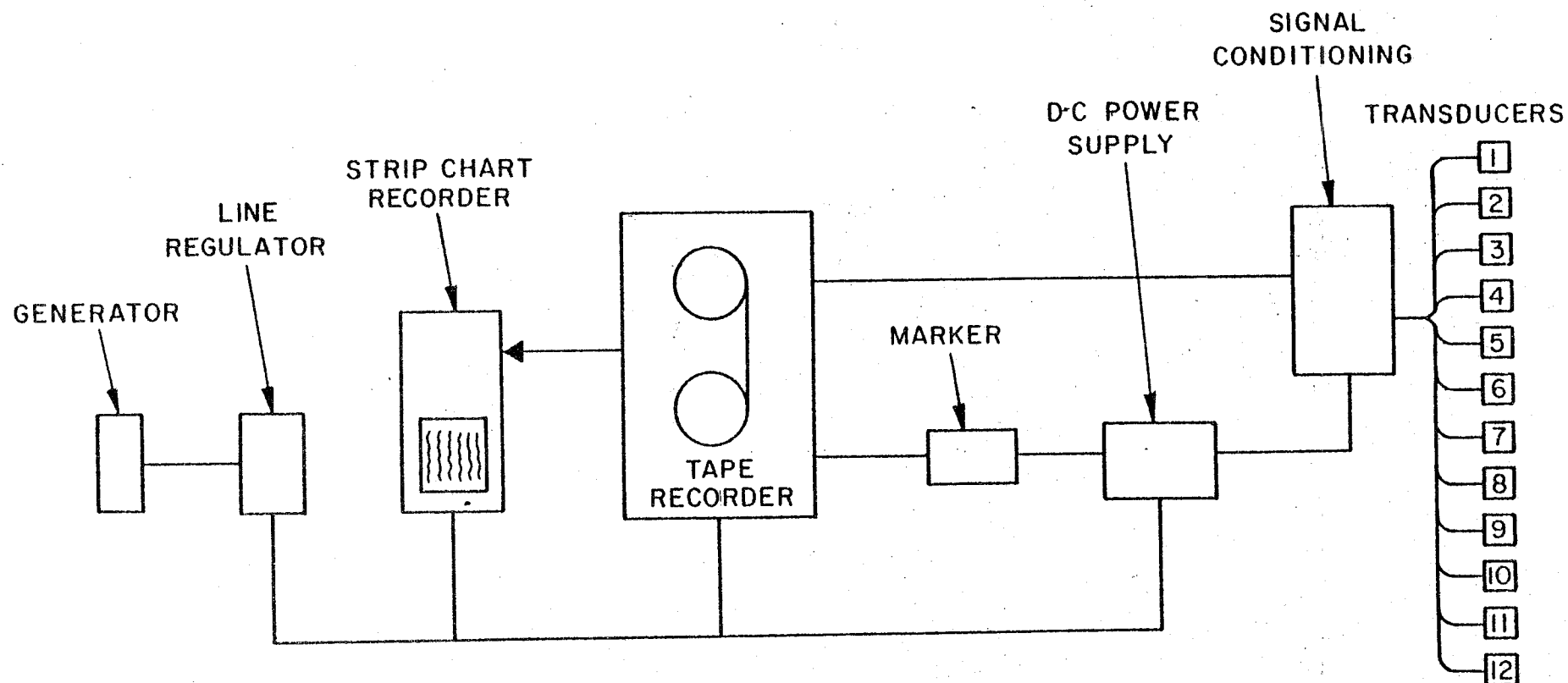


Figure 2-2. Schematic of Data Acquisition System

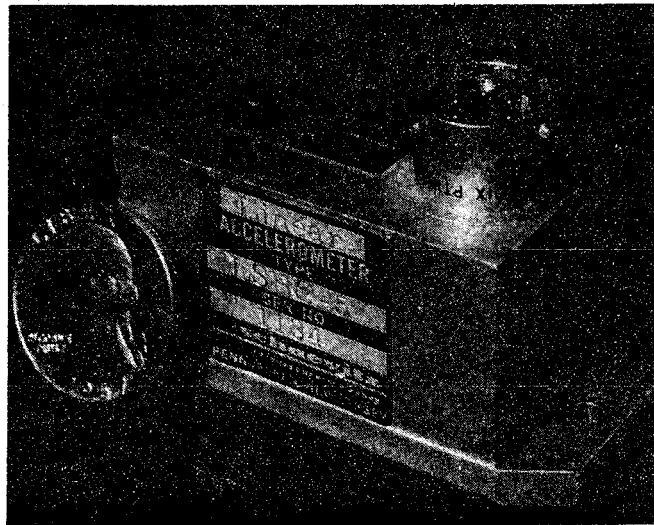


Figure 2-3. Servo-Accelerometer

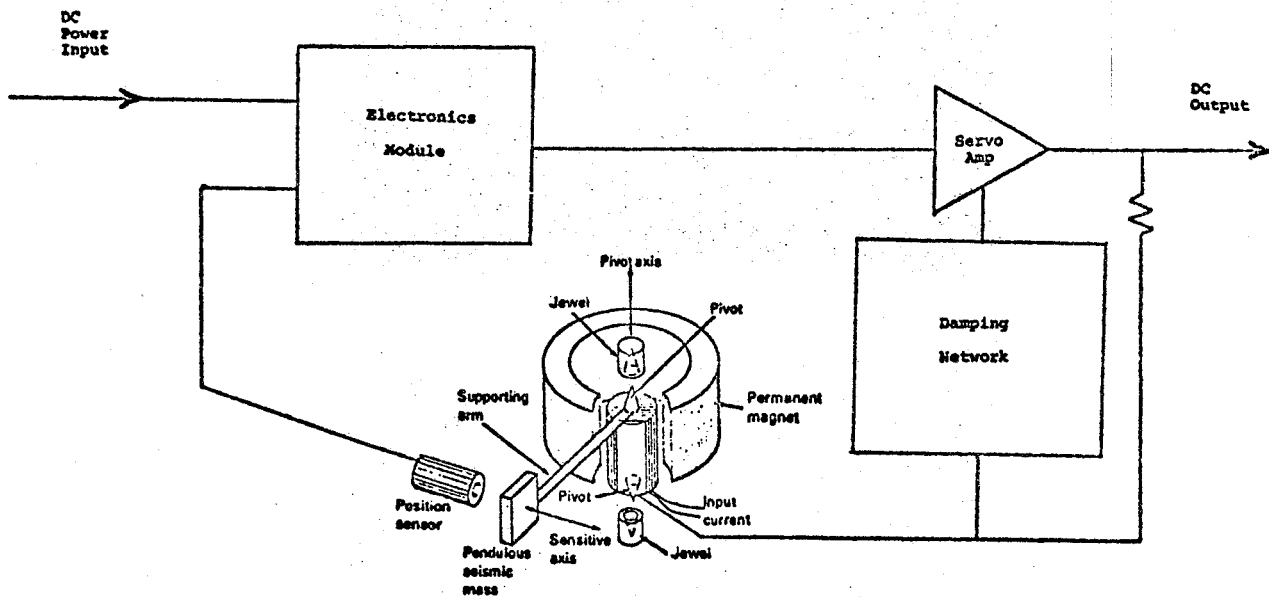


Figure 2-4. Schematic of Servo-Accelerometer

Both models of the linear accelerometer have a useable bandwidth from dc to approximately 140 Hz. A typical calibration response curve for one accelerometer used during the test is shown in Figure 2-5. Note that there is no amplitude overshoot.

This is due to the damping network which creates a damping coefficient that is approximately 74 percent of the critical value. The use of the damping network not only increases the usable bandwidth of the accelerometer but also increases its sensitivity. The accelerometer used on this test created a one-volt signal for each "g" (32.2 ft/sec^2). Cross axis sensitivity was specified by the manufacturer to be 0.001 volt/g, linearity ± 0.02 percent, axis alignment 0.001 volt, and the noise level to be less than 0.001 volt rms.

Signal conditioning consisted of supplying power (± 15 volts dc) to the transducers, low pass filtering the return signals and scaling to avoid saturation of the tape recorder. The filter was a single-pole, active filter (-6 dB/octave) with a corner frequency of 297 Hz. Since the tape recorder was limited to signals of 1.0 volt rms maximum, it was necessary to attenuate the signals before recording by a factor of 0.57 for all accelerometers except the lateral accelerometer mounted on the roof of the trailer. This unit was scaled down by 0.28. These are nominal values of the scaling factor, and all data channels were calibrated both prior to and after each test run to assure proper scaling.

Each accelerometer, mounted on the trailer floor, was first bolted to a 3/4-inch, exterior-grade, plywood, mounting board to insure proper contact with a plane surface. One such mount is shown in Figure 2-6(a). This mounting scheme was used for the horizontal and lateral accelerometers. In order to mount vertical accelerometers to the trailer floor, it was necessary

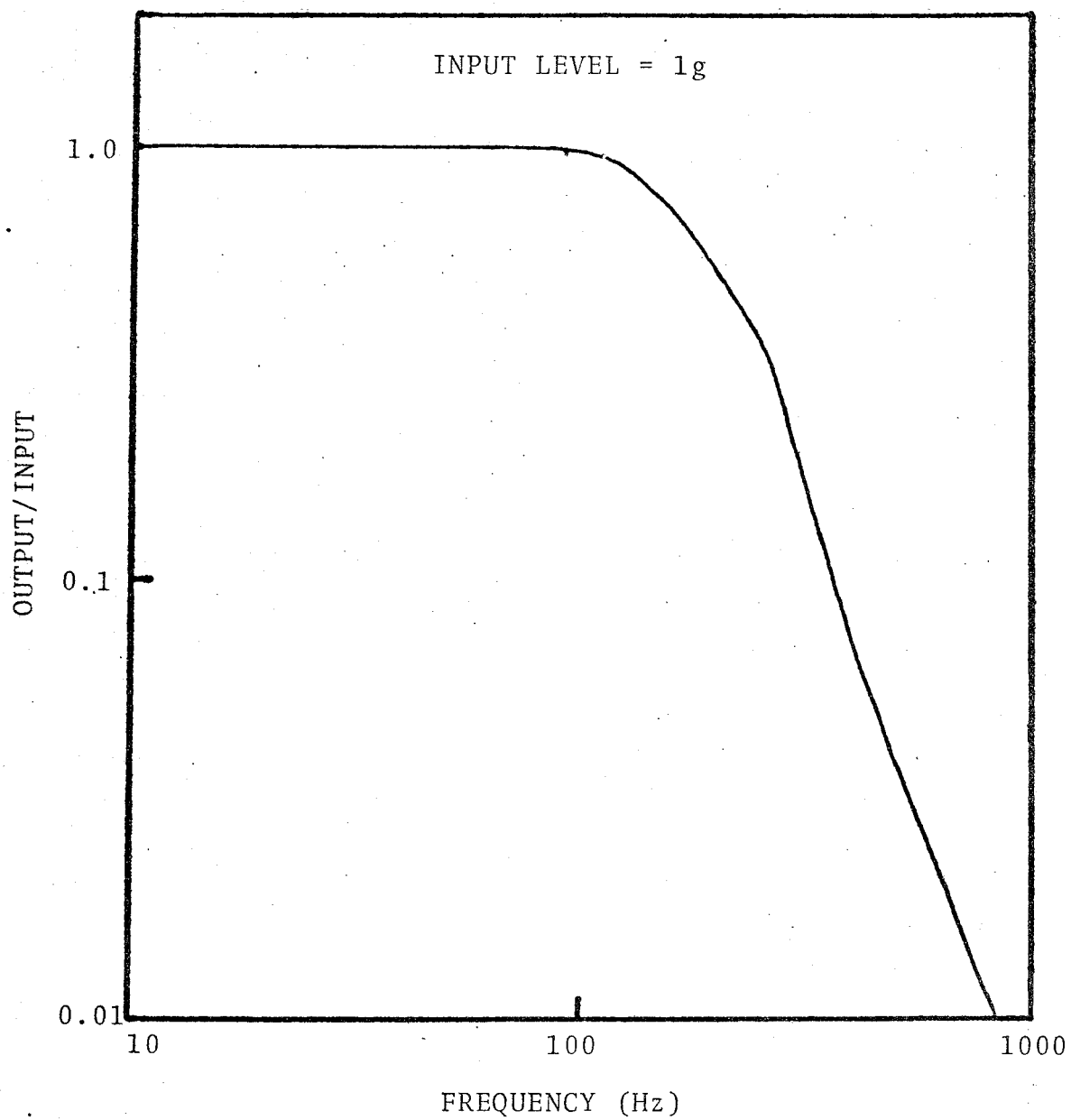


Figure 2-5. Calibration Response Curve

to bolt a 5-inch by 5-inch block, 5-7/8 inches high to the trailer floor as shown in Figure 2-6(b). The plywood mounting boards were then attached to the mounting block as shown in Figure 2-6(b). Figure 2-7 shows the accelerometers mounted on the trailer with the water/dust-proof covers in place.

The lateral accelerometer attached to the trailer roof was mounted in a mechanical isolator to avoid high-frequency input caused by local vibrations. The mechanical isolator is a cup-in-cup design with the inner cup isolated from the outer by firm, open-cell foam. The natural frequency of this system is approximately 150 Hz.

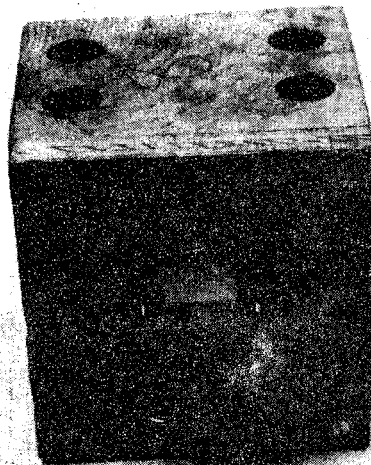
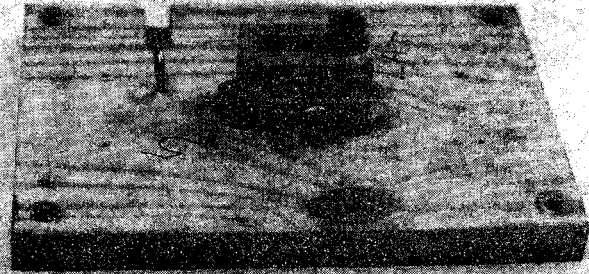
The lading accelerometer was bolted directly to the bottom of the pallet as shown in Figure 2-8. There is an arrow on the accelerometer indicating the axis of sensitivity, in this case vertical.

Although two trailers of slightly different construction were instrumented, the philosophy of transducer placement was the same and every effort was made to locate transducers in geometrically similar locations. This is shown schematically in Figure 2-9. Table 2-1 lists the description of each accelerometer station. Detailed accelerometer locations are shown in Figures 2-10 and 2-11.

Each accelerometer was cabled to a junction box which was bolted to the deck of the flatcar. The signals were routed to the data acquisition car via two cables of shielded-pair wire (61 pairs per cable). These cables were connected directly to the signal conditioning chassis.

Secondary instrumentation was comprised of four accelographs manufactured by Humphrey and located as shown in Figures

(a) Horizontal and Lateral
Accelerometer Mounting



(b) Vertical Accelerometer Mountings

Figure 2-6. Accelerometer Mounts

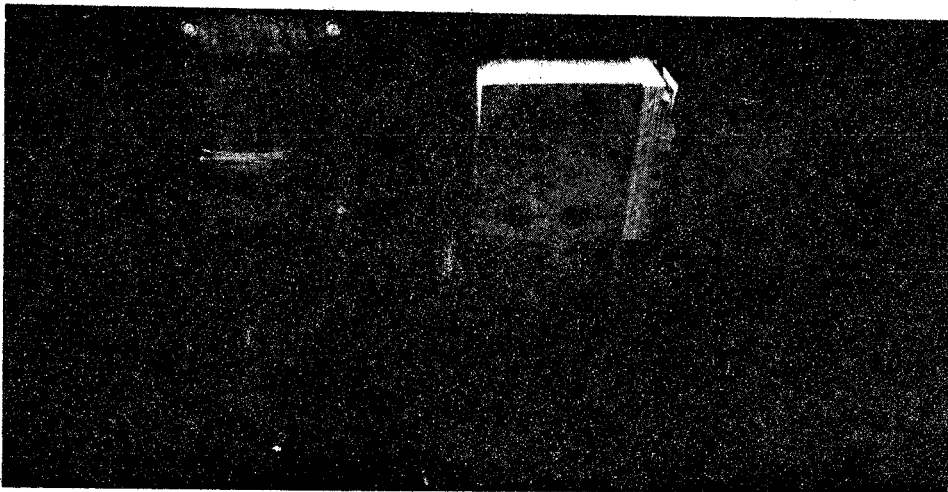


Figure 2-7. Accelerometers on Trailer

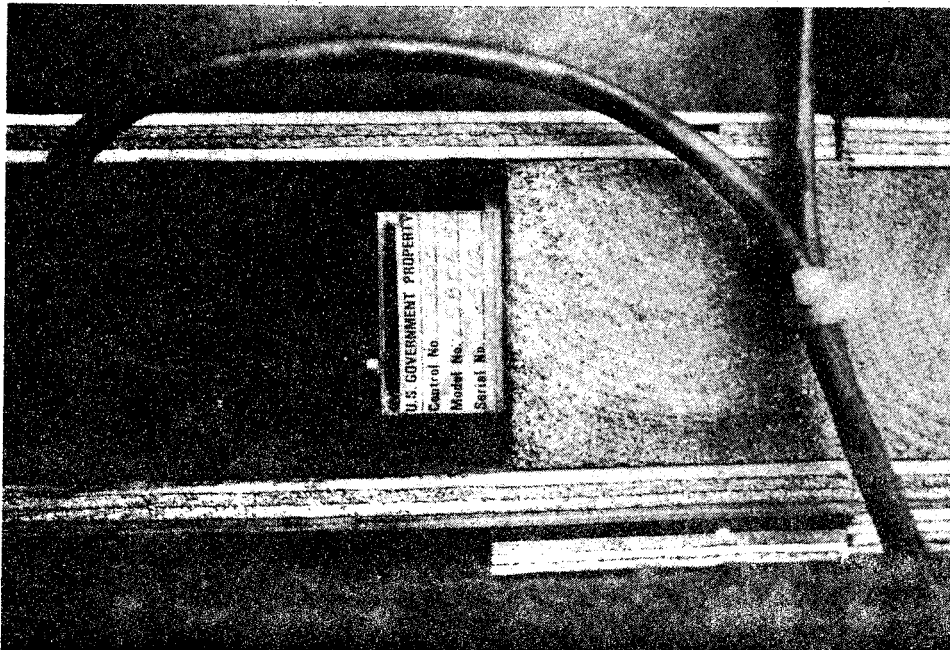


Figure 2-8. Lading Accelerometer

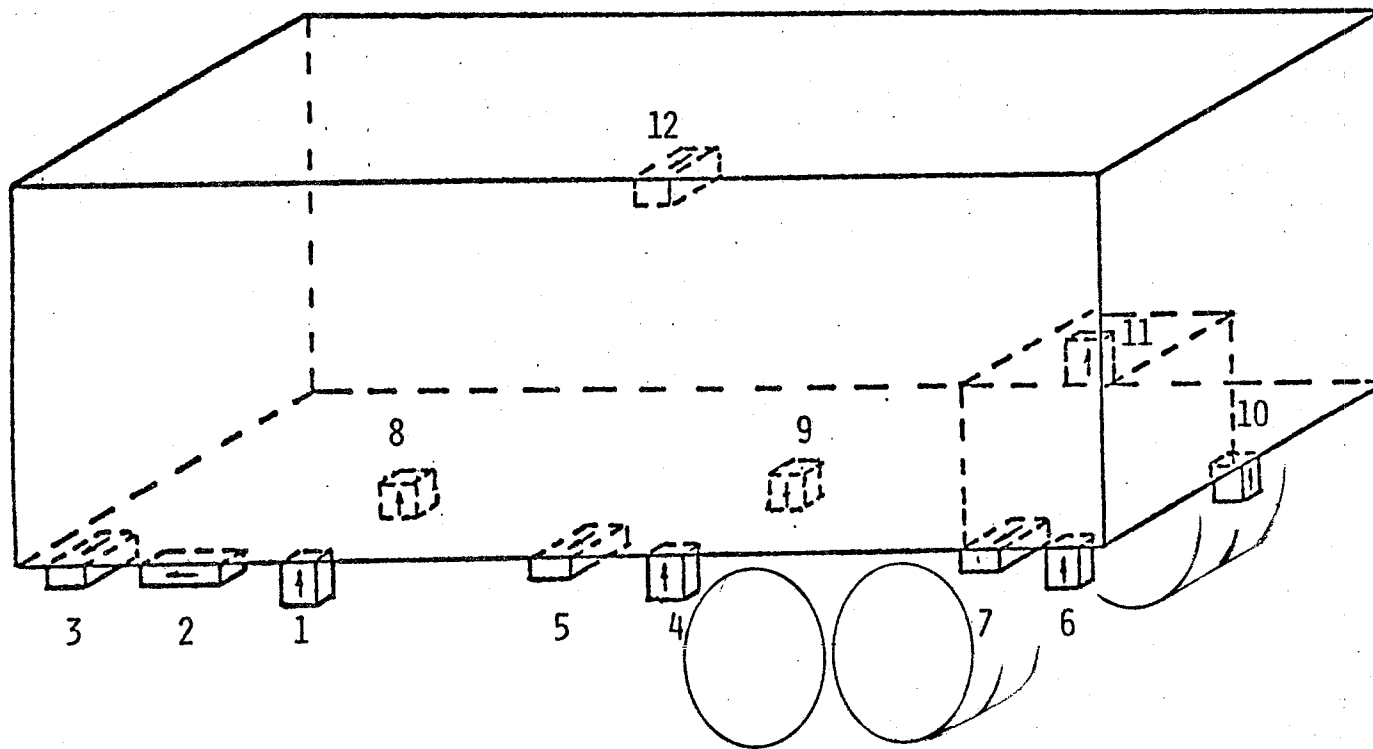


Figure 2-9. Schematic of Accelerometer Array

TABLE 2-1

SYSTEM NUMBER DESCRIPTION

STATION SYSTEM NUMBER	LONGITUDINAL LOCATION	LATERAL LOCATION	ORIENTATION OF SENSITIVE AXIS
1	FRONT	SIDE	VERTICAL
2	FRONT	SIDE	LONGITUDINAL
3	FRONT	SIDE	LATERAL
4	MIDDLE	SIDE	VERTICAL
5	MIDDLE	SIDE	LATERAL
6	REAR	SIDE	VERTICAL
7	REAR	SIDE	LATERAL
8	FRONT	CENTER	VERTICAL
9	MIDDLE	CENTER	VERTICAL
10	REAR	CENTER	VERTICAL
11	LADING		VERTICAL
12	TOP		LATERAL

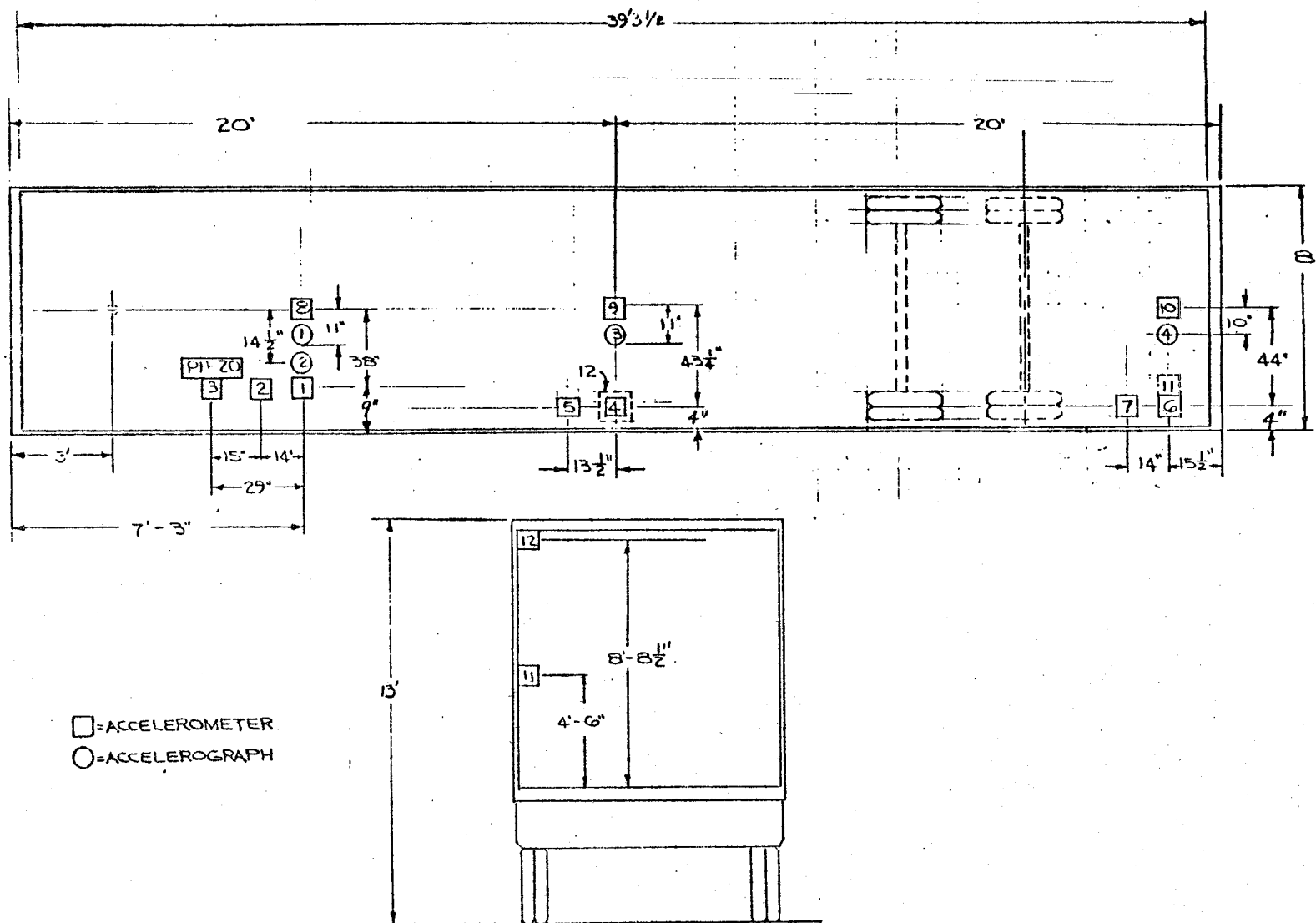


Figure 2-10. Leaf-Spring Trailer Instrumentation Array

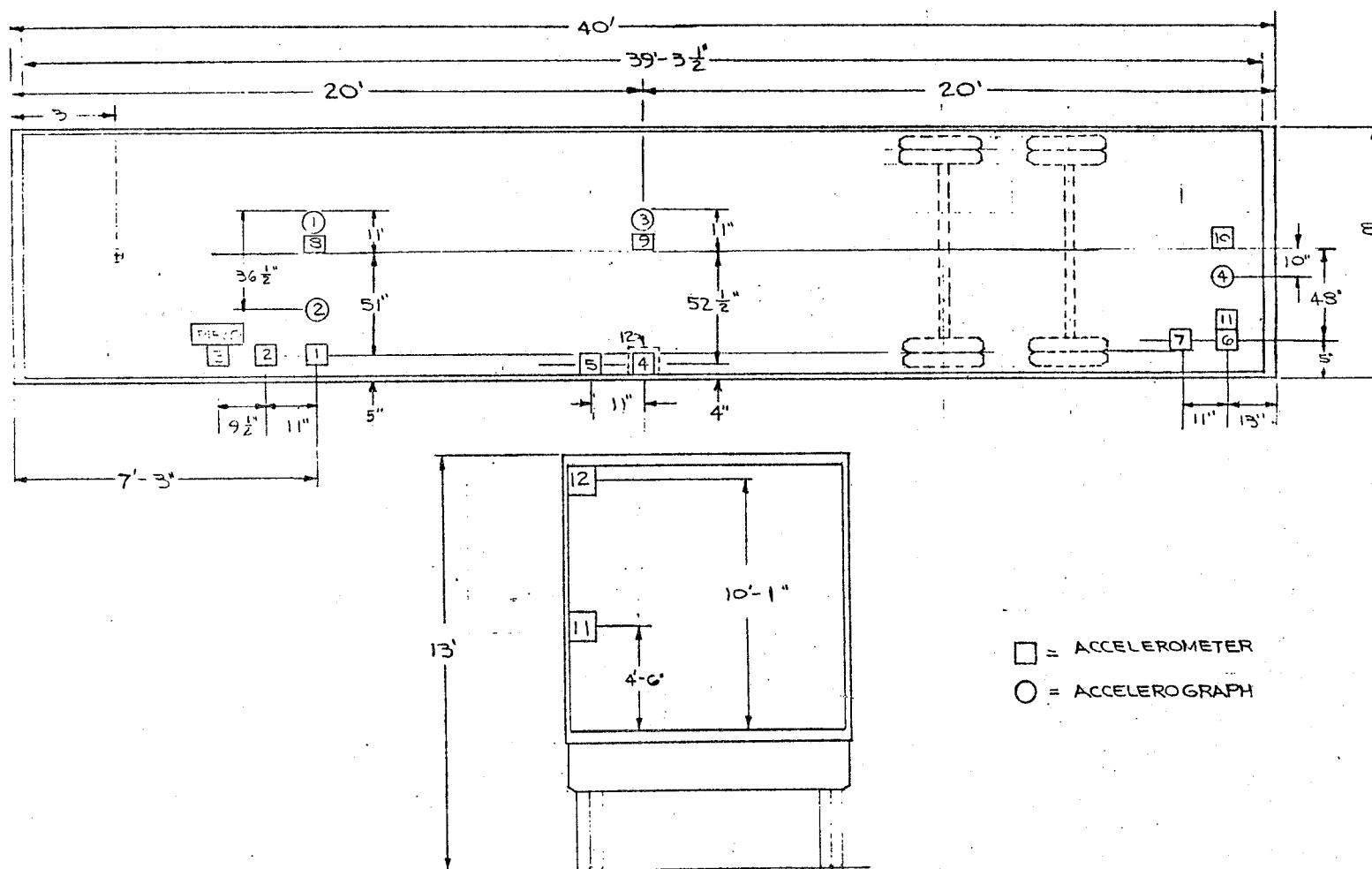


Figure 2-11. Air-Ride Trailer Instrumentation Array

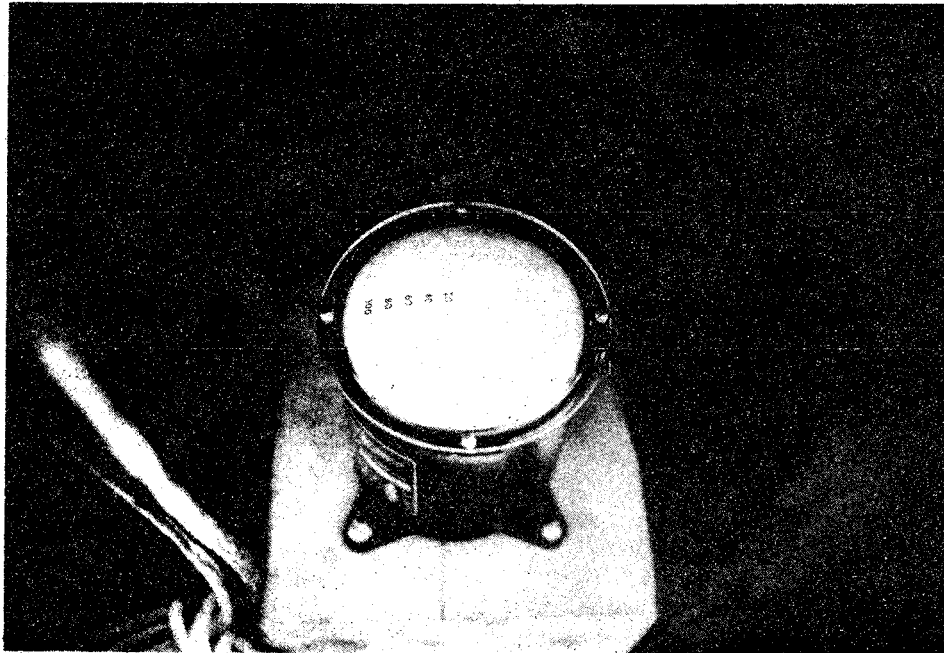
2-10 and 2-11. The accelograph consists of a seismic mass suspended on a cantilevered, wire spring which allows uniform sensitivity to all acceleration vectors in a given plane. The stylus mounted on the seismic mass traces the acceleration history on a replaceable recording disc, providing a record of the direction and magnitude of the acceleration.

The model selected for this test had a range of 10g (full-scale deflection) with an accuracy of ± 10 percent. The resonant frequency was only 18 Hz compared to the 140-Hz bandwidth of the servo-accelerometers. An accelograph is shown in Figure 2-12(a), and 2-12(b) shows an accelograph mounted to the floor of the trailer. Note that the accelograph was mounted opposite to a servo-accelerometer. This mounting scheme allowed a one-to-one comparison of the acceleration measured by these different types of transducers.

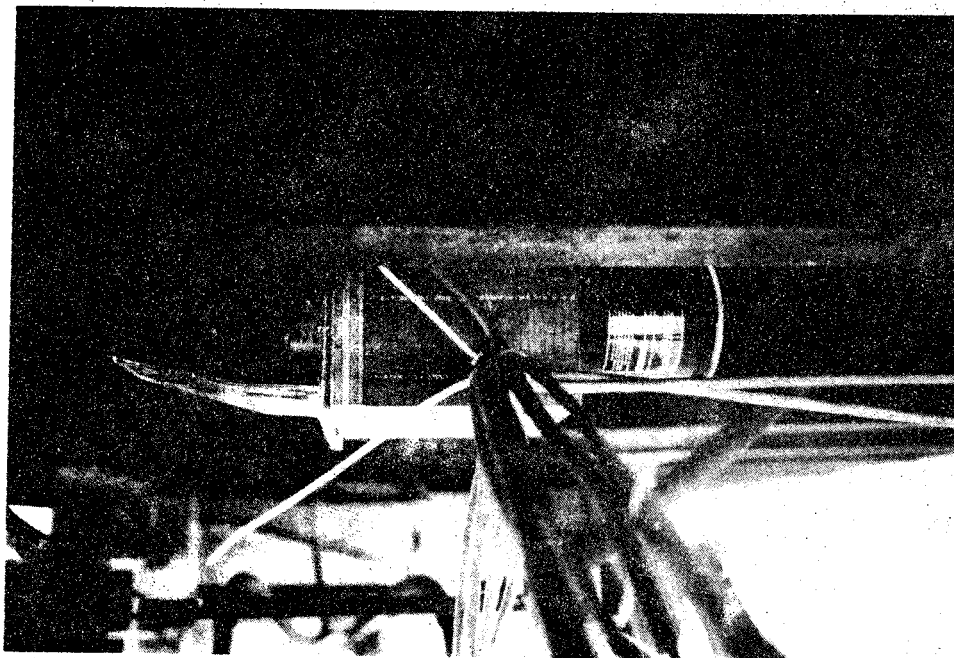
The signals coming from the signal conditioning chassis (filtered and scaled) were recorded using the Bell & Howell, 14-channel, instrumentation-grade, tape recorder (Model CPR-4010*) shown in Figure 2-13. The recorder was configured and calibrated for this research project according to the International Recording and Instrumentation Group (IRIG) Intermediate Band Specifications.

Data were recorded at 1-7/8 ips; the bandwidth was 0 to 625 Hz. An edge channel was available for voice annotation to aid in the location of desired data for processing. The tape recorder was equipped with two sets of magnetic heads, one for recording and one for playback. It was possible to play back a recorded signal approximately one-half second after it was recorded.

* For complete information and specifications refer to Operations and Maintenance Manual Type CPR-4010 Magnetic Tape Recorder/Reproducer, Report No. 992630-005, Bell & Howell, Instrumentation Division, Pasadena, CA.



Accelograph



Accelograph Mounted

Figure 2-12. Accelograph



Figure 2-13. Tape Recorder

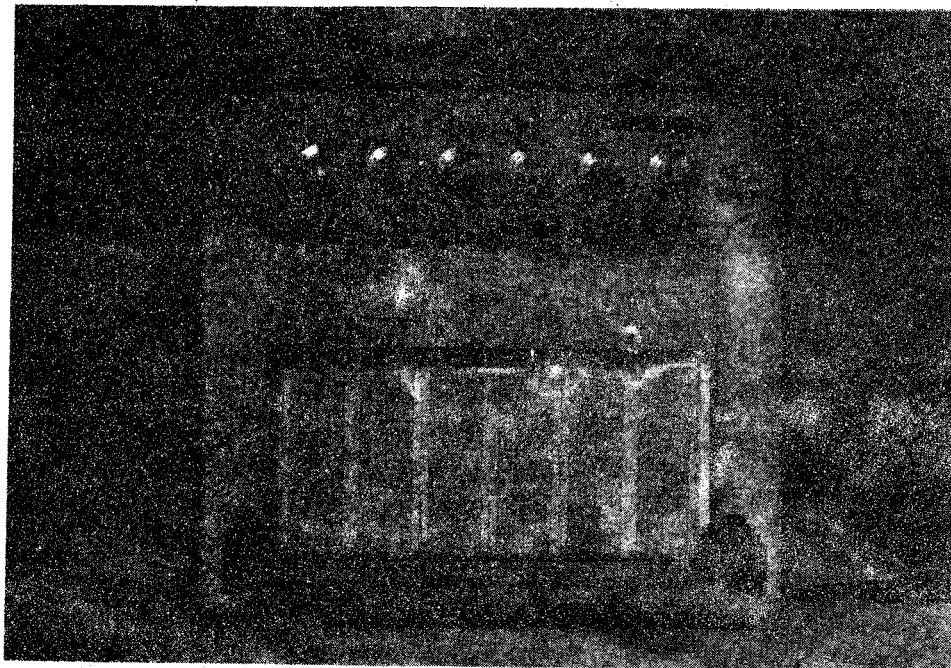


Figure 2-14. Strip-Chart Recorder

The six-channel, Brush, strip-chart recorder shown in Figure 2-14 was used to display the recorded data. This allowed verification of the data and a limited amount of real time analysis.

Power for the laboratory-grade equipment described above was supplied by a five-kilowatt, gasoline-driven generator and a line-voltage regulator that maintained the voltage between 117 and 123 volts ac with a minimum of fluctuation.

Speed and distance information was recorded simultaneously with the measured accelerations to provide a correlation between speed, track condition, track structures and lading vibrations. The instrumentation system, designed to record speed and distance automatically, failed due to mechanical difficulties. Therefore, speed and distance information was recorded using the voice and pulse channels.

Distance was obtained by noting the various landmarks in the test zones (mileposts, bridges, over and underpasses, crossings and switches). These landmarks are accurately located on railroad maps to ± 0.01 miles. The location of each landmark was entered manually on an assigned channel as a pulse.

Speed was obtained by three independent methods: from the locomotive, from the elapsed time between landmarks, and from the elapsed time required to traverse the distance between fixed numbers of rail ends. The instantaneous speed was obtained from the train engineer who radioed the speed of the consist (as measured at the locomotive) to the test car where it was recorded on a voice channel. The average speed was calculated using the elapsed time between landmarks and the elapsed time between fixed numbers of rail ends. A stopwatch was used to measure the elapsed time. The distance between landmarks is accurately listed on railroad maps, therefore, by dividing the distance between

landmarks by the length of time required to cover this distance, the average speed over that section of track was determined. The typical distance between landmarks was on the order of one mile. Therefore, the known length of the rail (39 feet) was used as a crosscheck. The nearly instantaneous speed was determined by dividing the elapsed time (to traverse a known number of rails lengths) into the distance covered by the known number of rail lengths. Usually, ten rail lengths were used (390 feet) to minimize errors.

All three speed calculations were compared and were found to be in good agreement. This indicates that speed was held constant in each test and was accurate to ± 2.5 miles per hour. The distance, recorded on the voice channel, was also found to be accurate to ± 0.02 miles with that recorded on the pulse channel.

2.3 PROCEDURES

The test procedure consisted of three primary operations: calibration, prior to and after each test run, data acquisition in pre-selected test zones at a nominal target speed, and data annotation.

The servo-accelerometers were calibrated both dynamically and statically. The dynamic calibration was performed by aligning the sensitive axis of the accelerometer with the local vertical, 90 degrees to the vertical, and 180 degrees to the vertical. This procedure imposes a $+1.0$, 0 , and $-1.0g$ input to each transducer to within ± 1.0 degree or ± 1.7 -percent accuracy. The system output was measured using a digital voltmeter and recorded in the calibration log.

Following the dynamic calibration, the transducers were mounted per test requirements. A known fixed current was supplied to the torque coil equivalent to $+2.5$, 0 , and $-2.5g$ (accelerometer 12 was calibrated at $+5.0$, 0 , and $-5.0g$) and

TABLE 2-2
TEST ZONES

MILEPOST	DESCRIPTION	SPEED (MPH)
2 - 4	Yard Operation	15
46 - 51	Switches and Turnouts	40
60 - 61	Rock and Roll	30
62 - 64	High Speed (Welded)	65
67 - 71	Negative Grade*	40
82 - 84	High Speed (Bolted)	55
114 - 118	Positive Grade*	40

*Grade is specified with respect to the westbound test.
For the eastbound test the sign of the slope changes.

the output was measured with the digital voltmeter and recorded in the calibration log. Both calibrations were system calibrations, i.e., the output was measured at the tape recorder input. Data were recorded continuously with special attention given to a set of test zones recommended by B&M. These test zones are listed in Table 2-2.

During data acquisition, the data were annotated in two ways. A voice channel on the tape recorded was used to note discrete events such as mileposts, bridges, crossings, switches, etc., and conditions such as time, speed, type and condition of track (e.g., welded or corrugated rail). Discrete events were also recorded using a manual pulse input to one of the 14 channels on the tape recorder. This channel was one of the channels displayed on the strip-chart recorder. Each pulse was labeled by hand, for correlation with the voice entry. Additionally, a hand-written log was kept to record specific events such as start and end of test, and other important events.

3.0 DATA PROCESSING

3.1 GENERAL

Data processing involved two processes, analog to digital conversion and data reduction. Data reduction is similarly broken down into two processes, time domain and frequency domain. These processes are discussed in this section.

Data were recorded during testing in analog form and reduction of the data was done using high-speed digital computers to convert the data from analog to digital form. As outlined in Section 2.3, there were seven test zones of interest. These were located within approximately ± 15 seconds by the use of annotation on the voice channel and the revolution counter. The analog data tape was digitized as described in the following paragraphs.

3.2 DIGITIZATION

The digitizing process sets a 12-bit word ($\pm 2^{11} = \pm 2048$ counts), equal to a 20-volt range or ± 10 volts. Recalling that the signals were limited by the recorder to 1.0 volt rms, it is obvious that the data must be amplified to make optimum use of the digital range. Therefore, the data were amplified by a factor of ten.

The analog signals were also filtered at 170 Hz (-3.0 dB) to avoid aliasing any high frequency energy content into the frequency band of interest (0 to 128 Hz). The filter used for this purpose was a four-pole (-24 dB/octave) Bessel filter, which provides linear phase shift below the corner frequency.

In order to assure the fidelity of the digital data up to 128 Hz, the analog data were digitized at a rate of 512 samples per second. Note that the digitizing frequency (f_d) is slightly more than three times the corner frequency

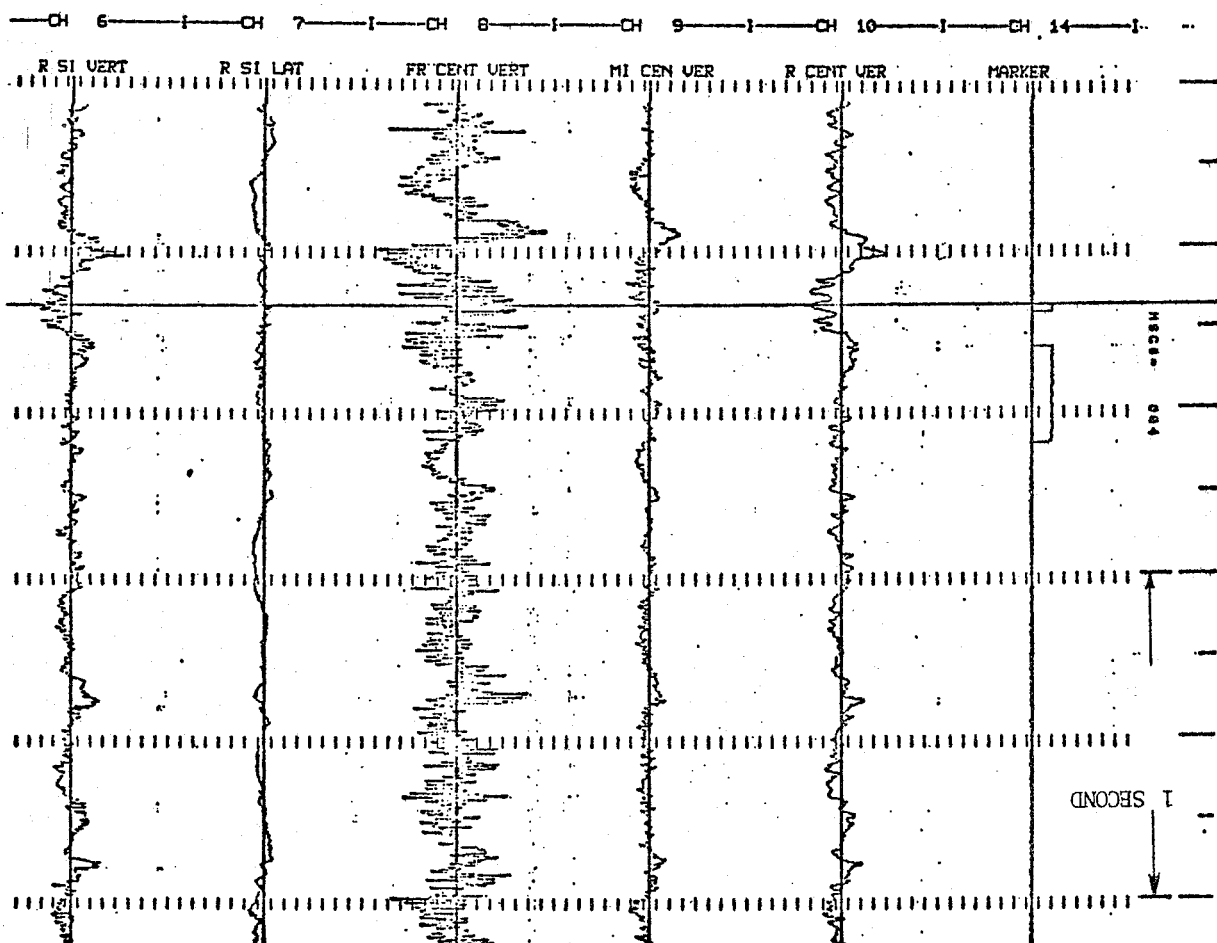
of the anti-aliasing-filter (f_a). This is 50 percent above the theoretical minimum for the ratio of f_d/f_a .

All twelve channels were sampled or scanned simultaneously and written on digital tape in groups of 128 scans (0.25 seconds) per data record. Additionally, the channel containing the marker pulse was digitized without amplification or filtering. Each test zone was digitized with 10 to 15 seconds extra at the beginning and end of the zone to create a data file.

Following the completion of the digitizing process, each data file was played back and reconstructed in quasi-analog form, six channels at a time. A sample of the quasi-analog reproduction is shown in Figure 3-1.

The reproduction process has two purposes. First, it permits a more exact location of the required data through the use of the marker channel. Figure 3-1 shows the pulse on the marker channel with a message number. The numbering of the pulses is done in the digital processing to facilitate location of pulses. In order to be certain that the desired data have been digitized, the time between all pulses in the zone is tabulated from the reproduction on the time base. The times between pulses are then compared with those on the strip chart recording made during the test. Because the sequence of marker pulses is randomly arranged, there is a unique pattern for any given segment of data. Thus, the data are precisely located (marker pulses are distance indicators) and the exact data records for processing are determined (one second = four records). The actual lengths of the test zone are listed in Table 3-1.

The second purpose of the analog reproduction is to allow inspection of the data to determine its physical reliability. Frequency content and magnitude were examined and compared



LEGEND:

R SI VERT - Right Side Vertical
 R SI LAT - Right Side Lateral
 FR CENT VERT - Front Center Vertical
 MI CENT VER - Middle Center Vertical
 R CENT VER - Right Center Vertical

Figure 3-1. Analog Reproduction

TABLE 3-1

EXACT TEST LOCATIONS

TEST ZONE	ACTUAL MILEPOSTS	ACTUAL TIME IN TEST ZONE (SECONDS)	AVERAGE SPEED (MPH)
1 WB	2.5 - 3.2	180	15
1 EB	3.24 - 2.5	180	15
2 WB	46 - 51	566	32
2 EB	51 - 46	604	30
3 WB	60 - 61	107	34
3 EB	61 - 60	85	42
4 WB	63 - 64	61	59
4 EB	62 - 61	61	59
5 WB	68 - 70.4	201	43
5 EB	118 - 114	377	38
6 WB	82 - 83.1	72	55
6 EB	83.1 - 82	72	55
7 WB	114 - 118	357	40
7 EB	70.4 - 68	209	41

qualitatively with the original strip chart. The amplitude of each channel is shown in Figure 3-1. Comparisons were also made to data collected on previous studies which were of a similar nature.

Once the data were precisely located and verified, the digital tape was ready for final data processing. This is described in the following section.

3.3 PRE-PROCESSING

As outlined in the preceeding sections, the digital data was made available on magnetic tape in the form of 12-bit, integer words. Before the actual data reduction was accomplished, it was necessary to scale the data to engineering units, in this case "g" (32.2 ft/sec). Scale factors were determined by curve-fitting both the pre-test and post-test calibration data (refer to Section 2.3) to a straight line. In general, six points were used, three from the pre-test and three from the post-test calibration. The slope of the line in units of g/v was used to convert the data to engineering units. In addition to the slope, the standard deviation (σ) was calculated and generally found to be small compared to the scale factor, thus indicating the linearity of the system.

Although the data were known physically to possess a zero or nearly zero mean value, the possibility of system bias did exist (e.g., d-c voltage offset). Therefore, the mean was removed from the data by calculating the mean for a set of data samples and subtracting from each sample of that set.

The preceeding operations were carried out on four records at a time which was equivalent to one second of data. Since the data were digitized at a rate of 512 samples per second, each of the four records contained 128 samples in one second of data. The zero-mean, scaled data in the computer memory core was then ready for actual data reduction and were processed in the time and frequency domains.

3.4 TIME DOMAIN PROCESSING

In the time-domain, processing consisted primarily of estimating the probability density function (PDF). This is the classifying or sorting of the data into incremental ranges or bins. From the PDF, the standard deviation was calculated as well as the 95 and 99 percentile levels.

Each data sample, X_j , is classified or sorted by amplitude to create a histogram. Thus, the histogram may be thought of as a vector H_i ($i = 1, 2, \dots, N$) with each element H_i representing the number of occurrences falling within the assigned incremental range of the element. The incremental range of each element is referred to as the bin width W , and specifying N uniform bins

$$W = (A_{\max} - A_{\min})/N$$

where A_{\max} and A_{\min} are the expected (or known) upper and lower limits for the entire set of data.

Thus, H_1 is the number of times that a minimum X_j satisfies the condition

$$A_{\min} \leq X_j \leq A_{\min} + W.$$

In general, H_i is the number of occurrences for which X_j (maximum or minimum) satisfies the condition

$$A_{\min} + (i - 1) W < X_j \leq A_{\min} + iW.$$

Following the completion of the filling of the vector H_i ($i = 1, 2, \dots, 200$) for this case, H_i is divided by the total number of data samples observed.

$$N = \sum H_i$$

Thus, the probability vector (P_i) is obtained from the expression

$$P_i = H_i/N$$

The probability density vector (D_i) is obtained by dividing each probability P_i by the bin width W .

$$D_i = P_i/W$$

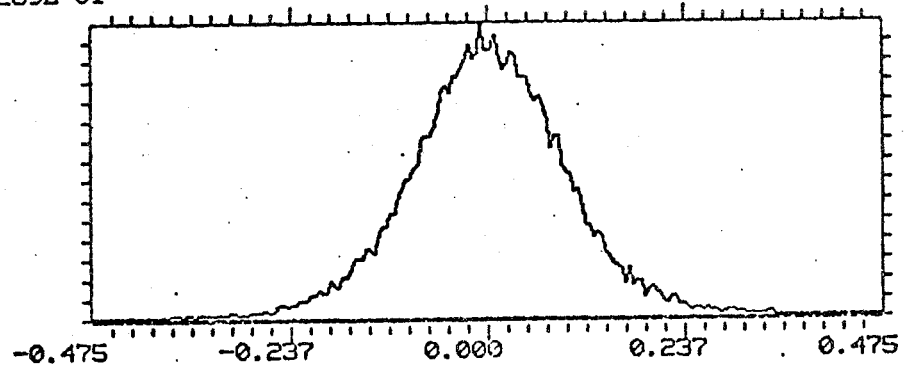
Thus, the probability density estimate indicates the percent probability of the acceleration amplitude lying in a given incremental range. Note that by the above definitions, the area under the PDF is equal to unity which simply means that all data in a given set have been considered.

The PDF estimate, an example of which is shown in Figure 3-2, is useful in determining absolute maximum acceleration and relative severity. The PDF can also be used to ascertain the validity of the sample length. From the Central Limit Theorem, it is known that the PDF of a set of independent random variables will be asymptotically Gaussian or normal. Inspection of the shape of the PDF estimates can be qualitatively used to determine if this condition has been met. Figure 3-2 shows a PDF estimate obtained from actual data and an ideal normal distribution calculated with the same mean and standard deviation.

The standard deviation, σ , is calculated from the expression

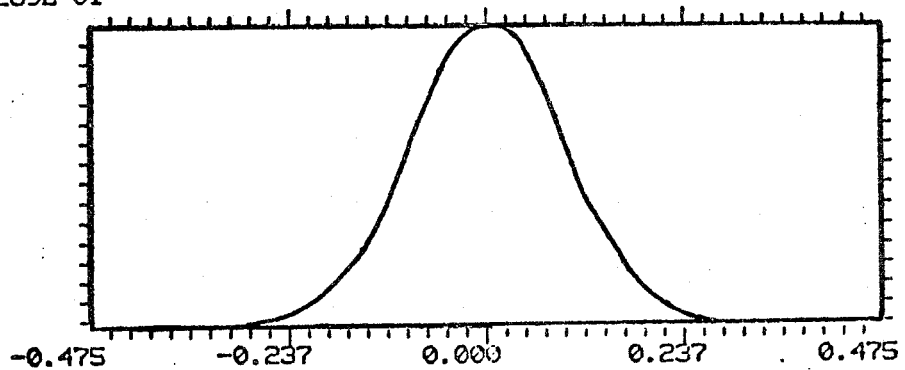
$$\sigma^2 = \sum_{i=1}^N (X_i - \mu)^2 / (N-1)$$

YMAX = .24289E 01



(a) Estimated Distribution

YMAX = .24289E 01



(b) Ideal Normal Distribution

Figure 3-2. Comparison of Ideal and Estimated Distributions

where $\mu = \sum_{i=1}^N X_i / N$

The 95 and 99 percentile levels denoted L_{95} and L_{99} , respectively, are determined from the probability vector as follows:

$$0.95 = \sum_{i=1}^{L_{95}} P_i \quad \text{and} \quad 0.99 = \sum_{i=1}^{L_{99}} P_i$$

3.5 FREQUENCY DOMAIN PROCESSING

In order to provide information on the frequency content of the data, a power spectral density (PSD) is calculated. Also the root mean square (rms) value is calculated from the PSD. Finally, a history is constructed of the rms value of the entire bandwidth of interest (0 - 128 Hz) and of the four octaves making up this bandwidth.

Because all of the above is accomplished in the frequency domain, each block of four records (one second) of data is Fourier transformed. The discrete Fourier transform may be written in indicial notation as:

$$S_k = \frac{1}{N} \sum_{j=0}^{N-1} X_j e^{-i 2\pi k j / N}$$

where $S_k = S(k\Delta f) (k=0,1,\dots,N/2),$

$$X_j = X(j\Delta t) (j=0,1,\dots,N), \Delta f = 1/(N\Delta t),$$

$$\text{and } i = \sqrt{-1}.$$

The result of the Fourier transform yields a set of $(N/2) + 1$ complex numbers where N is an even number of data samples transformed.* Each complex number may be imagined as the amplitude and phase angle associated with a certain frequency. Thus, the highest frequency of the spectrum (F) will be

$$F = (N/2)\Delta f = \frac{1}{2\Delta t}$$

since the first complex number is associated with $f=0$. Recalling that Δt is 1/512 second, $F = 256$ Hz which is twice the frequency of interest.

The power spectral density ($G(f)$) is then computed by multiplying $S(f)$ by its complex conjugate $S^*(f)$ and scaling by Δf .

$$G(f) = S(f)S^*(f)/\Delta f$$

Note that because S and x have the same dimensional units, the units of G are g^2/Hz .

Because the PSD's are calculated for one second intervals, it is necessary to average these over the test segments which are between 60 and 600 seconds in length. This is accomplished by adding the individual PSD's on a bin-by-bin basis and dividing each bin by the total number (M) of PSD's stacked. The averaged PSD, \bar{G}_i is given by:

$$\bar{G}_i = (1/M) \sum_{j=1}^M G_{ij}$$

where G_{ij} represents the j^{th} PSD or second of data.

* In this case, the first and last complex numbers have a zero imaginary part so that the resultant set of complex numbers contains exactly N unique numbers equal to the number of examples transformed. Hence, there is no loss (or gain) of information in the Fourier transform.

The average PSD is displayed using a linear-linear plot and a log-linear plot as shown in Figure 3-3. The linear ordinate G is in units of g^2/Hz with Y_{MAX} denoting the maximum value ($Y_{\text{MIN}}=0$). The logarithmic ordinate is in units of dB, $10 \log_{10} G$ re $1.0 g^2/\text{Hz}$. The abscissa in both cases is linear frequency in Hz.

The example shown in Figure 3-3 is the PSD of a digitized ideal sine wave which illustrates the use of this type of data display. The input function had a frequency of 70 Hz and an amplitude of 0.2 g. The frequency is easily recovered from Figure 3-3; however, a small calculation is required to recover the input amplitude. In this case Y_{MAX} , which equals $0.02 g^2/\text{Hz}$, corresponds to the only $G(f)$ which is non-zero and thus the integration or power (P) of this particular PSD is simply

$$P = G\Delta f$$

From the two relations above

$$A = (2G\Delta f)^{1/2}$$

On substitution of the values of $G(Y_{\text{MAX}})$ and f , the value of A is found to be 0.2 g. This simple case illustrates how the PSD can be used to determine both the frequency and amplitude content of any stochastic signal.

A summary of the maximum condition and the rms acceleration is given in the lower left corner. Mean square acceleration is obtained by numerical integration of the PSD from zero to 128 Hz. The square root of the mean square yields the rms acceleration A_{rms} .

$$A_{\text{rms}} = \left(\Delta f \sum_{i=1}^{128} G_i \right)^{1/2}$$

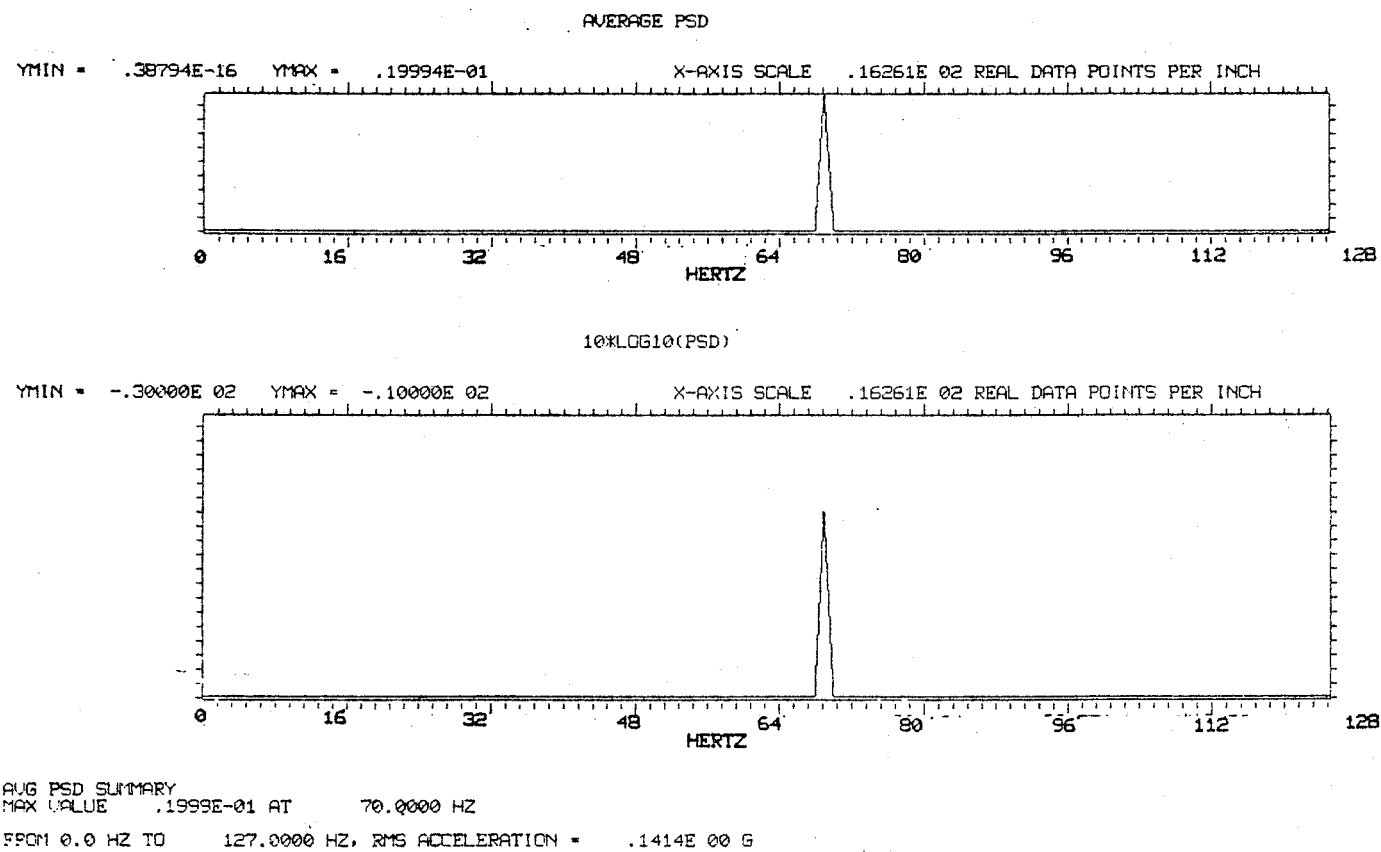


Figure 3-3. Power Spectral Density

The calculation of the rms history of the bandwidth (zero to 128 Hz) and the four octaves making up this bandwidth was accomplished in a manner similar to that of the average rms value. That is, for each second of data, the PSD is numerically integrated over the bandwidth zero to 128 Hz and also over four smaller bandwidths which represent approximately four octaves (by definition, an octave represents a doubling of frequency). Table 3-2 lists the octave bands.

The octave numbers are used in the plot of the rms history to identify a trace with its respective octave. The bandwidth zero to 128 Hz is identified by the number 5.

The program which produces the rms history plots also has the capability to change the rms integration-time-constant from one second to any integer multiple up to the entire time of the test zone (equivalent to the average rms value). The integration time constant used is given at the bottom of each plot as the parameter (T). This option is necessary to filter the data and to provide a clearer picture of changes during the test zone, and an indication of which octaves were most actively contributing to these changes.

TABLE 3-2
OCTAVE BANDS

OCTAVE NUMBER	LOWER FREQUENCY	UPPER FREQUENCY	BANDWIDTH
1	0	10	10
2	10	30	20
3	30	60	30
4	60	128	68

4.0 RESULTS AND DISCUSSION

Examples of the data obtained during the study are presented in the appendices at the end of this report. These are: Appendix A, Average Power Spectral Densities for Test Zone 3; Appendix B, RMS Histories for Test Zone 3; and Appendix C, Statistical Summaries (Time Domain) for Test Zone 3. Data presented in these appendices are grouped in terms of the westbound (leaf-spring) and eastbound (air-ride) tests. The complete data is available at the Railroad Information Service and Federal Railroad Administration Libraries. These data are further classified by the test zones as outlined in Table 2-2. Each plot is identified by its system number as described in Table 2-1. In the case of the PSD, this is supplemented by a three-word descriptor. The first word indicates the longitudinal station, front, middle, or rear. The second word indicates whether the accelerometer was mounted on the trailer centerline or at the side. The third word gives the orientation of the sensitive axis (longitudinal, lateral or vertical) of the accelerometer.

Before proceeding with the discussion of the results, a few general observations on the nature of the data should be made. First the data are generally found to be non-stationary. That is, one or more of the properties of the data vary significantly in each test segment. Referring* to Appendix B, it is readily apparent that the rms acceleration changes noticeably within test zones. Some test zones, such as Test Zone 3 during the eastbound test, show less variation than do others such as Test Zone 4 of the same test. The cause for the non-stationarity of the data is due to track condition and to train handling. Therefore, it is to be expected.

*All references to the appendices pertain to the complete set of appendices available at the Railroad Information Service and the Federal Railroad Administration Libraries.

Referring to Appendix C, it is evident that the probability density function estimates are very nearly Gaussian or normal. Figure 3-2 is an example of a comparison of an actual PDF estimate and an ideal normal distribution computed with the same mean (zero) and standard deviation. The significance of the normal distribution may be obtained from the Central Limit Theorem which shows that, under general conditions, a sufficiently large sample of an independent random data set will result in a normal distribution. Thus, there is some assurance that the present set of data are randomly independent and based on a statistically sufficient number of samples.

As a further check, the mean (μ) and the variation (σ^2) are related to the root-mean-square (r) by the relation,

$$\sigma^2 = r^2 + \mu^2$$

Because the mean is zero, this expression simplifies to show that the rms acceleration level is equal to the standard deviation. This point can be verified by comparing the rms value from the average PSD (Appendix A) with the corresponding value of the standard deviation (Appendix C). Generally, these two values were found to agree to within one percent. The cause for the difference was in the method used for calculating these parameters. Basically, the rms value is calculated in the frequency domain and limited to the bandwidth zero to 128 Hz. The standard deviation on the other hand is calculated in the time domain and corresponds to the bandwidth zero to 256 Hz. Thus, the standard deviation is, in this case, always slightly larger than the rms value. The differences are small (less than one percent) indicating a lack of power in the 128- to 256-Hz range.

With the preceeding in mind, the follliwng observations on the performance of the trailers can be made.

TABLE 4-1

WESTBOUND RMS ACCELERATION (g) -- LEAF-SPRING TRAILER

STATION	TZ 1	TZ 2	TZ 3	TZ 4	TZ 5	TZ 6	TZ 7
1	.0659	.1735	.1602	.2946	.1989	.1697	.1830
2	.0233	.0576	.0512	.0889	.0604	.0584	.0634
3	.0454	.0863	.0980	.1515	.0891	.0842	.0896
4	.0526	.1471	.1380	.2382	.1585	.1373	.1470
5	.0414	.0783	.0963	.1211	.0787	.0706	.0798
6	.0702	.2117	.1820	.3567	.2472	.1933	.2109
7	.0384	.0808	.1064	.1278	.0896	.0747	.0871
8	.1636	.4506	.4289	.6374	.4665	.4056	.4925
9	--	.1405	.1246	.2351	.1548	.1318	.1407
10	.0699	.2043	.1665	.3587	.2419	.1917	.2008
11	.0662	.1981	.1694	.3544	.2333	.1809	
12	.0690	.1514	.2071	.2084	.1510	.1200	.1532

TABLE 4-2

EASTBOUND RMS ACCELERATION (g) -- AIR-RIDE TRAILER

STATION	TZ 1	TZ 2	TZ 3	TZ 4	TZ 5	TZ 6	TZ 7
1	.0711	.1122	.1589	.1758	.1307	.2298	.1699
2	.0217	.0370	.0495	.0641	.0456	.0615	.0540
3	.0568	.0711	.0968	.0890	.0881	.0900	.0948
4	.0485	.0775	.1092	.1050	.0959	.1197	.1099
5	.0527	.0663	.0878	.0829	.0808	.0842	.0841
6	.0550	.1057	.1285	.1867	.1414	.2130	.1806
7	.0583	.0709	.0965	.0827	.0902	.0916	.0899
8	.1777	.3149	.4236	.4316	.4024	.5111	.4199
9	.0456	.0793	.1076	.1090	.0977	.1341	.1095
10	.0500	.1044	.1244	.1786	.1397	.2102	.1732
11	.0641	.1188	.1436	.2126	.1559	.2420	.2007
12	.0991	.1011	.1343	.1021	.1257	.1076	.1232

Also, as an overall observation for both trailers, the frequency content was found to be less than 30 Hz and usually less than 10 Hz, again with one exception. This was due to the fact that the mass of the trailers is relatively large and the suspension systems are designed relatively soft.

The exceptions to the two foregoing observations were found at Station 8 where the vertical accelerometer was located on the centerline of the trailers nearest the kingpin. The rms acceleration level at this position was as high as 0.5 g but more generally 0.4 g. There was also a significant amount of energy between 60 Hz and 90 Hz at this location. The power in this 30 Hz band was most probably due to the pedestal which supported the trailer kingpin. That is, the natural frequency of the pedestal was certainly above that of the trailer suspension system. In the vicinity of the kingpin, there was little or no attenuation of this relatively-high-frequency energy because of the hard mount. Moving away from the kingpin, the energy level in the high frequencies rapidly diminished. At Station 9, which was also on the centerline but at mid-trailer, there is almost no power in the 60- to 90-Hz range.

The rms acceleration levels presented in Tables 4-1 and 4-2 show that the average rms longitudinal acceleration was approximately 0.05 g, the lateral was 0.1 g and the vertical was 0.2 g. This ratio of 1:2:4 is in agreement with the findings of an earlier study.* The rms acceleration level at any given frequency over a 1.0-Hz band is less than that of the entire band, zero to 128 Hz. Typically these levels were one-half the wideband value or 0.03 g, and 0.01 g in the longitudinal, lateral and vertical directions, respectively, which yields the same ratio as before.

*Kenworthy, M.A., Edelman, J.; "Test Results Report - Lightweight Flatcar Evaluation Program, Volume II, Ride Vibration and Over-the-Road Tests". ENSCO, INC. DOT-FR-79-24; April 1979.

The results from this study correspond with the results of an earlier study. The following is a summary of the comparison based on the leaf-spring trailer.

- The predominant frequency of measured acceleration was less than five Hz in both studies. The accelerations measured in geometrically similar locations had frequencies within plus or minus one Hz. Near the kingpin, significant frequency content between 20 and 30 Hz was observed in both studies.
- The lowest rms accelerations in both the lateral and vertical directions were found in the middle of the trailer. (Positions Nos. 4 and 5 in this study, 11 and 15 in an earlier study). The rms values in these directions in a previous study had the same approximate distribution. In both cases, the rms values were high at the front and rear of the trailer and low in the middle.
- The largest measured lateral accelerations were at the top center of the trailer in both studies*. The rms lateral acceleration at the top center of the trailer was two to three times greater than that measured at the bottom center.
- The accelerations measured in the longitudinal direction are the lowest of the accelerations measured in both studies.

From these observations, it is evident that the results of both studies agree quite well. Even though the load weights of the trailers in the two studies were different, the trends in the collected measurements and the resultant data were quite similar.

*Ibid.

First, as a gross overall observation, the rms acceleration was less than 0.35 g on both trailers at all but one measurement station for all test zones. Refer to Appendix A and Tables 4-1 and 4-2. In fact, the average rms acceleration was approximately 0.1 g which compares with a 0.03 g rms acceleration level typically seen in passenger service.

Also of note in Tables 4-1 and 4-2 is the fact that vertical and lateral rms accelerations were at a minimum at the mid-trailer location for both trailers. This can be seen by comparing Stations 1, 4 and 6; 3, 5 and 7; and 8, 9 and 10. It appears that energy input at the ends of the trailer may be out of phase causing the trailer to pitch and yaw. Thus, the middle of the trailer seems to experience lower acceleration inputs due to a seesaw effect.

Station 12, the lateral accelerometer mounted at the top of the trailer over Station 5, exhibited the largest rms acceleration level among the lateral accelerometers. In the case of the leaf-spring trailer, the rms acceleration at Station 12 was generally twice that measured at Station 5. For the Air-Ride trailer the rms acceleration at Station 12 was 50 percent greater than at Station 5. During the test, both trailers were observed to roll in almost all test zones which accounts for the higher acceleration levels near the top of the trailers.

To this point, the discussion has dealt with rms acceleration which for a normally distributed data set encompasses approximately two thirds of the data. Tables 4-3 and 4-4 summarize the 99 percentile-level-accelerations. Again with the exception of Station 8, the 99 percentile-level-acceleration is less than 1.0 g and, generally, in the order of 0.25 g. The 99 percentile-level-acceleration at Station 8 is somewhat greater with a maximum of 1.8 g. The remaining observations made for the rms accelerations are for the most part valid for the 99 percentile-level-accelerations.

TABLE 4-3
WESTBOUND 99 PERCENTILE -- LEAF-SPRING TRAILER

Station	TZ 1	TZ 2	TZ 3	TZ 4	TZ 5	TZ 6	TZ 7
1	0.1960	0.4862	0.4101	0.8449	0.5363	0.4494	0.5090
2	0.0528	0.1164	0.1105	0.2687	0.1212	0.1159	0.1272
3	0.1218	0.2224	0.2513	0.4012	0.2306	0.1956	0.2373
4	0.1535	0.3974	0.3419	0.6630	0.4263	0.3485	0.3943
5	0.1050	0.1943	0.2276	0.3175	0.1912	0.1632	0.1950
6	0.1918	0.5509	0.4453	0.8928	0.6427	0.4746	0.5456
7	0.0965	0.1917	0.2357	0.3005	0.2041	0.1658	0.1992
8	0.4772	1.2943	1.1759	1.800*	1.3157	1.0554	1.4316
9	--	0.3852	0.3223	0.6339	0.4179	0.3321	0.3888
10	0.1947	0.5323	0.4080	0.8752	0.6214	0.4592	0.5094
11	0.1747	0.5118	0.4095	0.9059	0.6003	0.4496	--
12	0.1702	0.3561	0.4297	0.5148	0.3358	0.2892	0.3583

* Slightly clipped

TABLE 4-4
EASTBOUND 99 PERCENTILE -- AIR-RIDE TRAILER

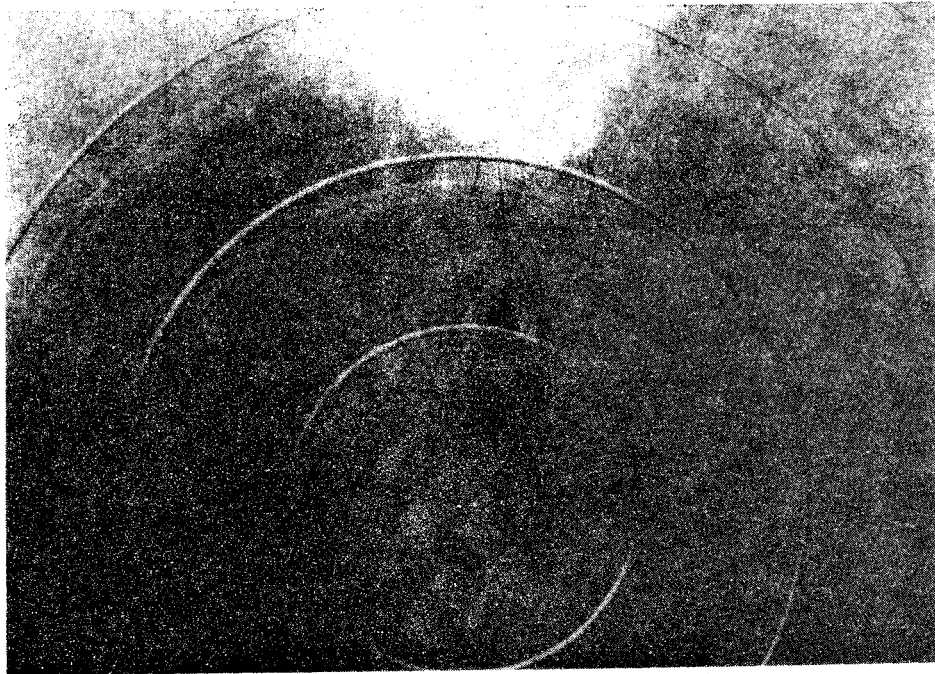
Station	TZ 1	TZ 2	TZ 3	TZ 4	TZ 5	TZ 6	TZ 7
1	0.2004	0.3440	0.4709	0.5879	0.3995	0.2498	0.5048
2	0.0577	0.1066	0.1189	0.1534	0.1233	0.0653	0.1692
3	0.1307	0.2077	0.2880	0.2742	0.2561	0.0940	0.2883
4	0.1211	0.2073	0.2689	0.3176	0.2570	0.1210	0.2709
5	0.1156	0.1592	0.2177	0.2251	0.1918	0.0845	0.2098
6	0.1316	0.3025	0.3187	0.5597	0.3983	0.2137	0.4847
7	0.1312	0.1897	0.2443	0.2236	0.2371	0.2340	0.2231
8	0.5558	0.9617	1.2722	1.3256	1.2161	1.6119	1.2676
9	0.1237	0.2129	0.2771	0.3107	0.2607	0.3571	0.2760
10	0.1279	0.2968	0.3092	0.5160	0.3992	0.5670	0.4740
11	0.1540	0.3319	0.3522	0.6298	0.4324	0.6561	0.5398
12	0.1472	0.2254	0.2971	0.2509	0.2828	0.2508	0.2675

Measurements made using the accelographs are in agreement with these observations. Figure 4-1 shows the eastbound test results* and indicates that, with the exception of the Station 1 accelograph, the peak-to-peak acceleration envelope is less than 1.0 g for the entire test run. Station 1 shows one excursion of approximately 3.0 g although it was not verified and may have been due to the installation procedure. The remainder of the envelopes, however, are approximately 3.0 g peak-to-peak which agrees with the 99 percentile-levels.

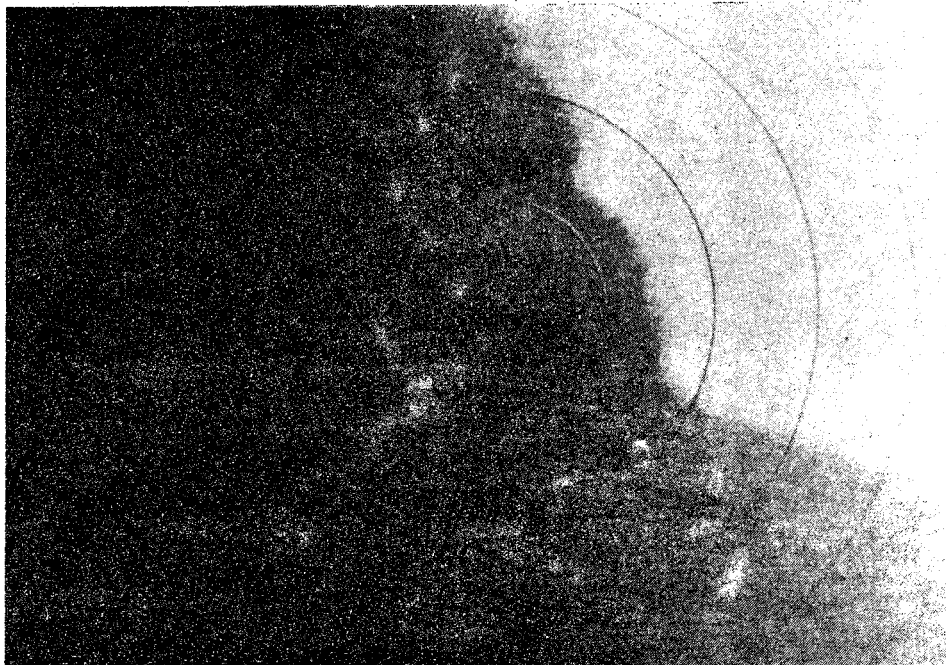
As previously noted, the data is non-stationary, thus making any comparison of trailer performance difficult. In fact, due to operational constraints, comparisons of the eastbound and westbound tests over Zones 4, 5 and 7 cannot be made at all. The acceleration inputs at Stations 2 and 8, however, may be used to determine a comparable case as follows. Station 2 is a measure of longitudinal acceleration which is almost entirely a function of train handling. Station 8, as discussed earlier, is almost independent of the trailer in question. Thus, for any test zone in which both trailers have the same levels of rms acceleration at these two stations and for which the data is reasonably stationary, a limited comparison may be made.

The best such example of a test zone which meets the above criteria is Test Zone 3, the rock and roll test zone. Figure 4-2 shows a bar graph comparison of the rms acceleration measured on both trailers. For the most part, it is obvious that the acceleration environment measured on these two trailers is very similar. The only noticeable differences are at Stations 6, 10 and 12. Since Stations 6 and 10 are

* Test scheduling did not permit similar documentation of the westbound accelograph results; however, the observations were the same as for the eastbound test.

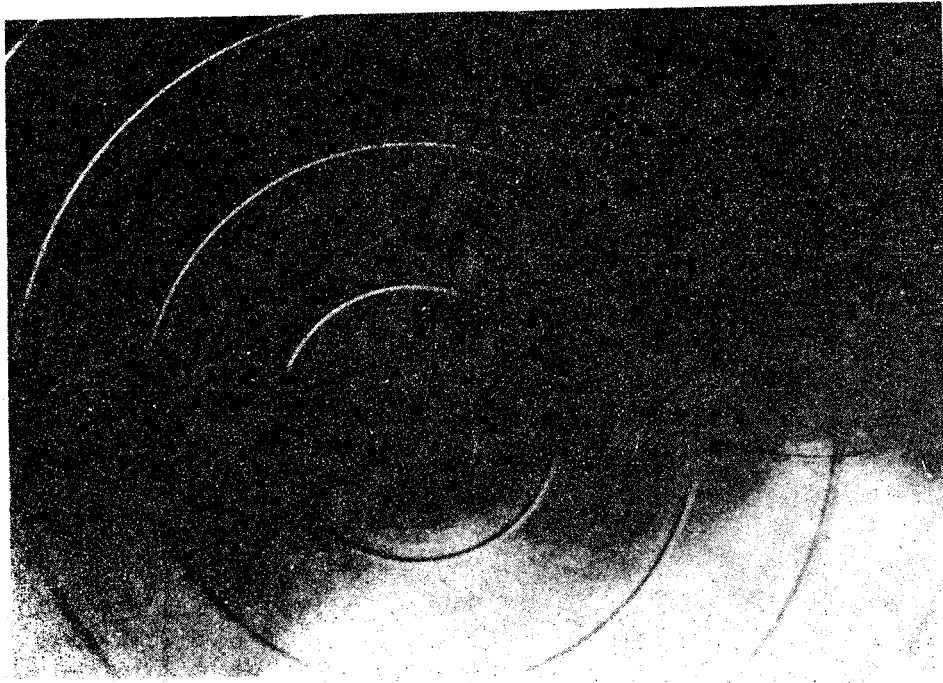


(a) Accelograph 1

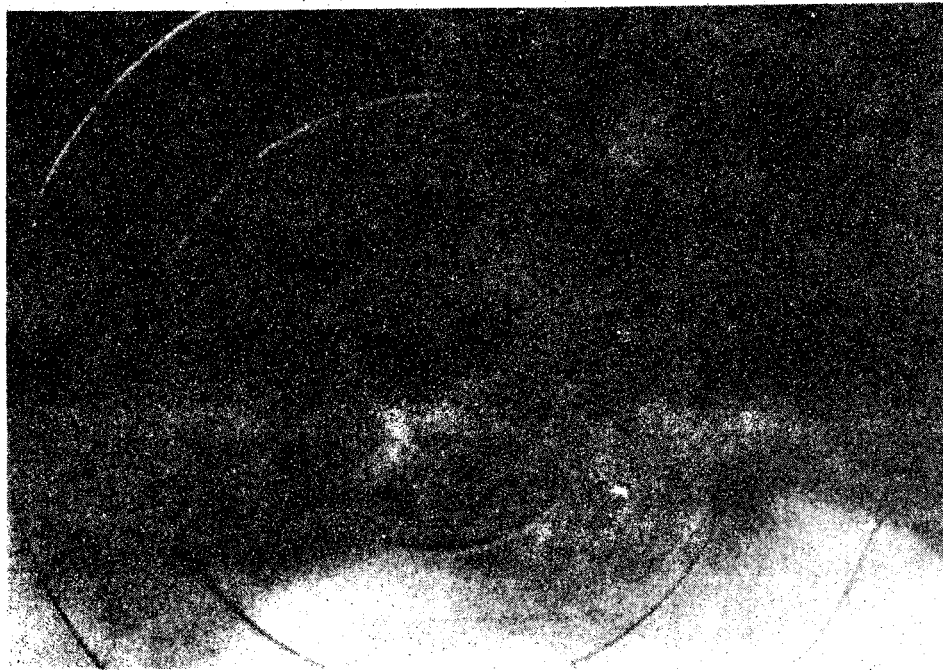


(b) Accelograph 2

Figure 4-1. Accelographic Test Results (Eastbound)



(c) Accelerograph 3



(d) Accelerograph 4

Figure 4-1 (cont). Accelerographic Test Results (Eastbound)

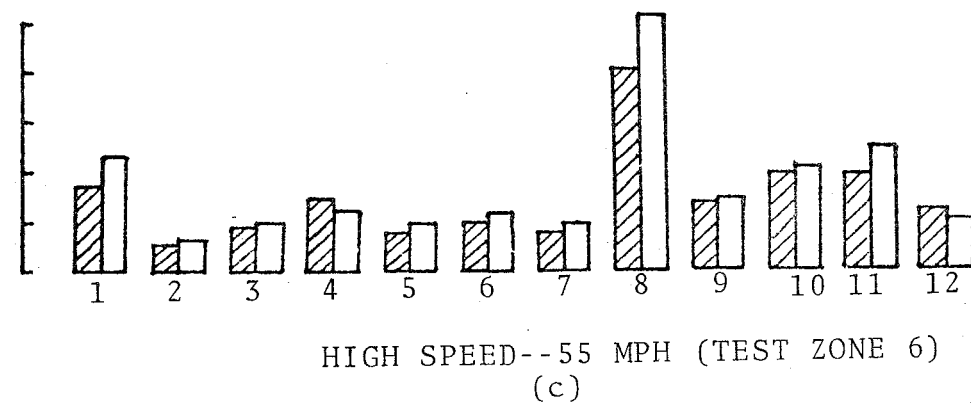
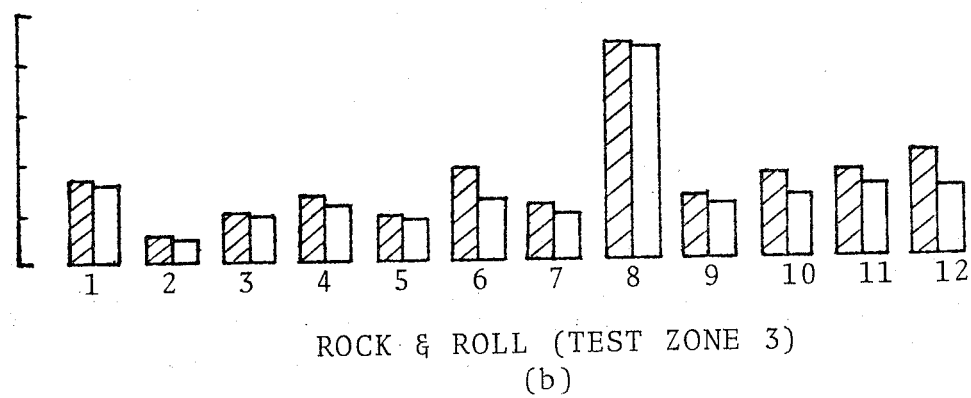
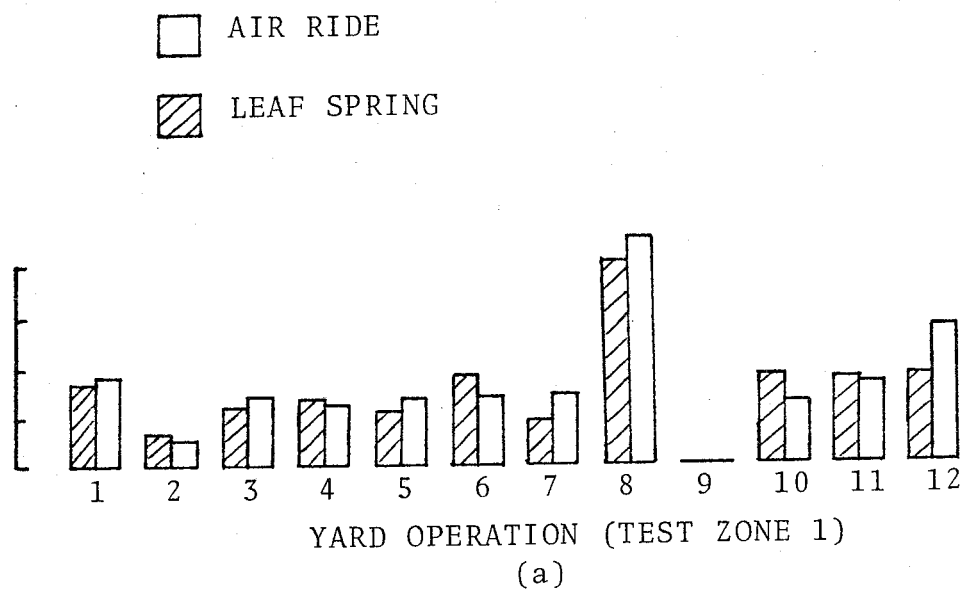


Figure 4-2. Trailer rms Acceleration Levels

vertical measurements at the rear of the trailer, it seems apparent that the Air-Ride suspension affords a somewhat better ride.

Similar comparisons were made for the low speed zone (1) and high speed zone (6) in Figures 4-2(a) and 4-2(c). Again, the overall acceleration environments on the two trailers were nearly identical. In Test Zone 1 where the speed was approximately 15 mph as compared to 30 mph in Test Zone 3, Station 12 appears to possess a higher acceleration level on the Air-Ride Trailer. In Test Zone 6 (55 mph) Stations 6 and 10 show comparable acceleration levels when compared to the situation in Test Zone 3.

One final comparative observation can be made by observing the ratio of accelerations at Stations 6 and 11. Station 11 was the lading measurement station while Station 6 was directly below this point on the trailer. Both stations measured vertical acceleration. The ratio of the accelerations measured at Stations 11 and 6 was 0.95 for the leaf-spring trailer and 1.12 for the Air-Ride Trailer. This indicates that some of the energy input to the leaf-spring trailer was attenuated before reaching the lading. In contrast, there was a slight amplification for the Air-Ride trailer. The cause of this difference is not readily apparent and may be due to the spectral distribution of energy, the stacking or packing of the lading or some other condition.

5.0 CONCLUSIONS

Acceleration data were collected to quantify the acceleration environments on a leaf-spring trailer and an air-suspension trailer during TOFC operation. This data was obtained not only under typical operating conditions but also, in one case, under extreme conditions, e.g., under a protected move during which the consist was operated at speeds greater than the posted class speed.

Detailed examination of the data showed it to be physically reasonable and the samples of data taken were statistically sufficient to represent the conditions investigated. The data were presented in the form of probability density functions (time domain), power spectral densities (frequency domain) and octave band rms history (time/frequency hybrid).

Analysis of the results showed that, under typical operating conditions, the rms acceleration was in general less than 0.1 g and the energy was generally below 30 Hz in frequency. This observation, however, was not valid near the kingpin or at speeds above 55 mph. Near the kingpin, the measured acceleration showed considerable energy between 60 Hz and 90 Hz and possessed a maximum rms value of 0.4 g to 0.5 g.

Peak accelerations were typically less than 0.5 g as measured by both the servo-accelerometers and the accelographs. Again, in the vicinity of the kingpin, peak levels were much higher (approaching 2.0 g in amplitude).

The middle of the trailer floor produced the lowest acceleration levels on both trailers. The measurement of lateral acceleration directly above this point on the trailer roof showed accelerations twice that of the floor level.

Although the air suspension trailer was observed to experience large lateral displacements during the test (especially in the rock-and-roll test zone - No. 3), the lateral acceleration levels were not appreciably greater than those of the leaf-spring trailer. This is due to the fact that the displacement took place at between 1.0 and 2.0 Hz as compared to the somewhat higher predominant frequency in the lateral motion of the leaf-spring trailer.

Overall, the acceleration levels of both trailers are comparable under the conditions studied. The air-suspension trailer, however, did seem to amplify the acceleration input slightly from the trailer floor to the lading. In contrast, the leaf-spring trailer attenuated the acceleration input to the lading slightly. The cause for this is not readily apparent and, as stated previously, the net differences were small.

Within the limited scope of this study, TOFC seems to be suitable for the transportation of vibration-sensitive equipment. The accelerations measured during the study were not excessively large and should not pose any problem in the transportation of this type of equipment. However, further studies should be conducted over a wider variety of terrain and longer distances to confirm these findings. The further studies should perhaps include a shipment of a cargo, similar to that used in this study from the east coast to the west coast.

It should be noted that the data and conclusions presented herein are applicable for yard and mainline operation. They do not apply to humping operations. Tests were not conducted in a humping yard, since this type of coupling is not likely to be used in TOFC operations.

APPENDIX A

AVERAGE POWER SPECTRAL DENSITIES
TEST ZONE 3

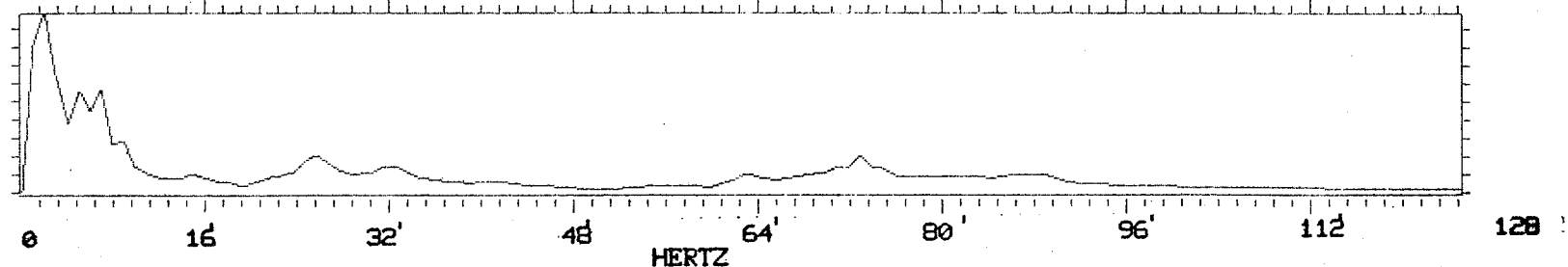
(Data of other test zones are available in Volume II of this Report)

TEST NO = 1 FRONT SIDE VERTICAL

AVERAGE PSD

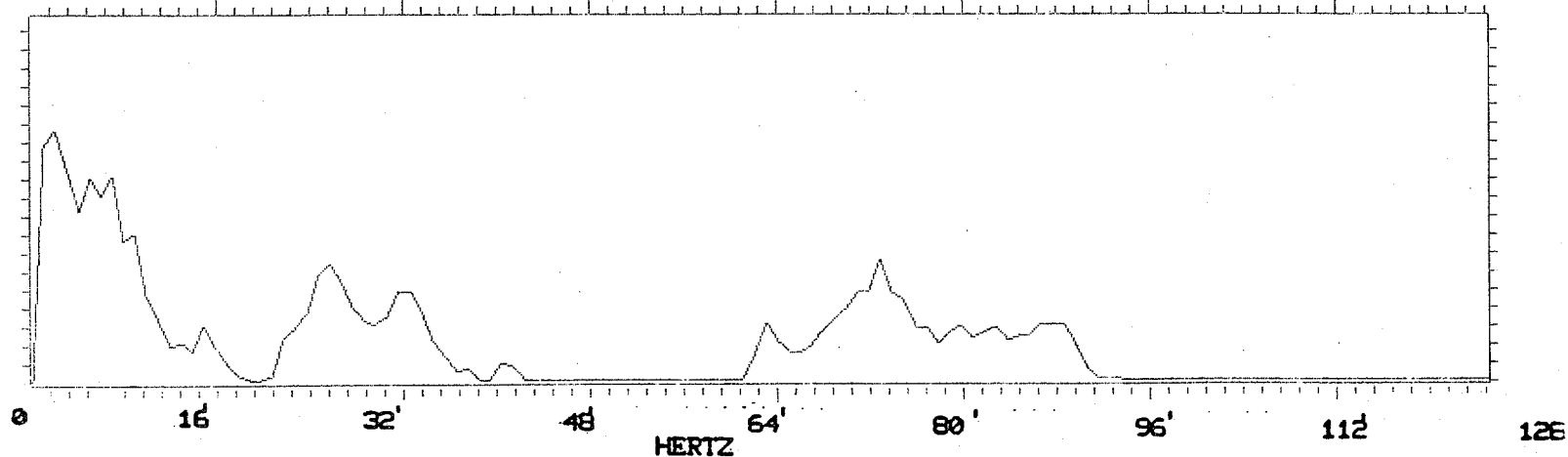
TZ 3 (WB)

YMIN = .67638E-15 YMAX = .22787E-02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY
MAX VALUE .22787E-02 AT 2.0000 HZ
FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1602E 00 G

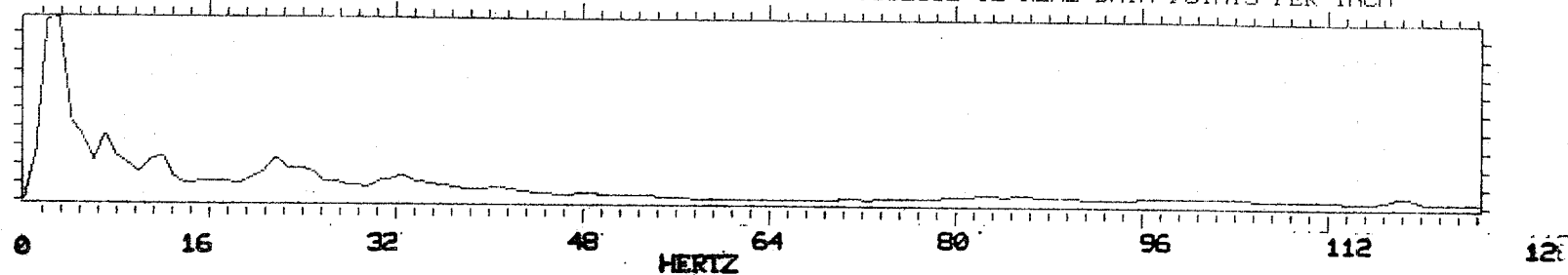
CHANNEL NO = 2 FRONT SIDE LONGTDNAL

AVERAGE PSD

TZ 3 (WB)

YMIN = .51788E-16 YMAX = .27629E-03

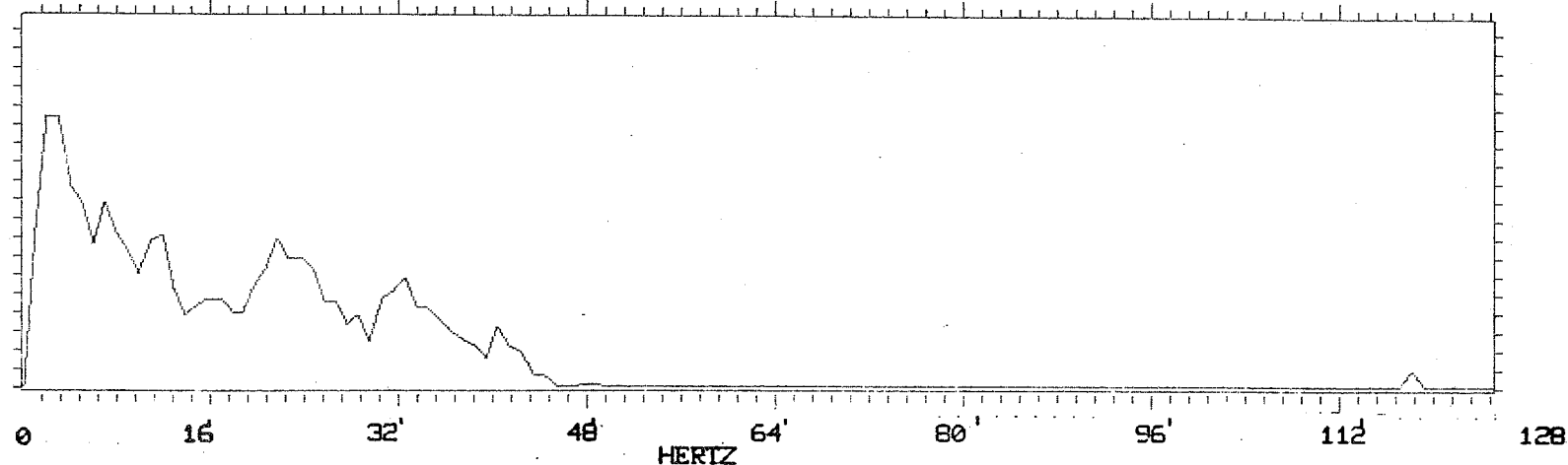
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.50000E 02 YMAX = -.30000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .2763E-03 AT 3.0000 HZ

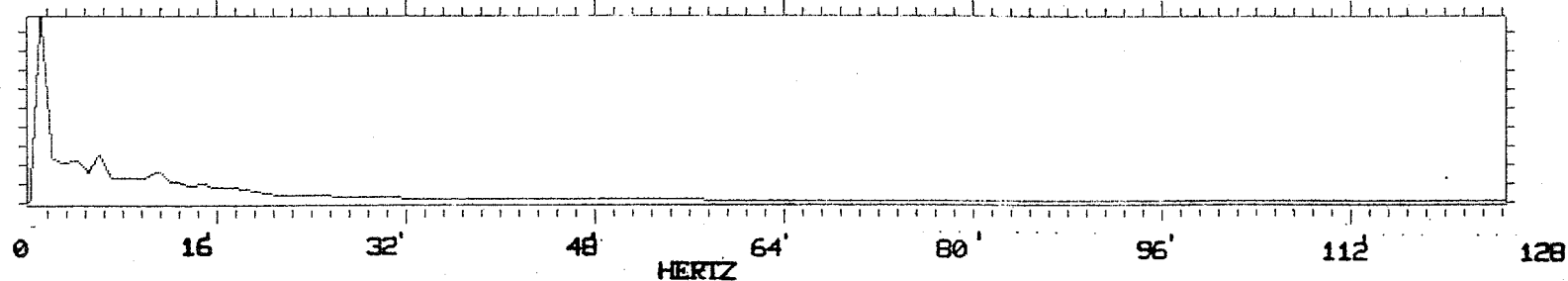
PSD 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .5119E-01 G

CHANNEL NO = 3 FRONT SIDE LATERAL

TZ 3 (WB)

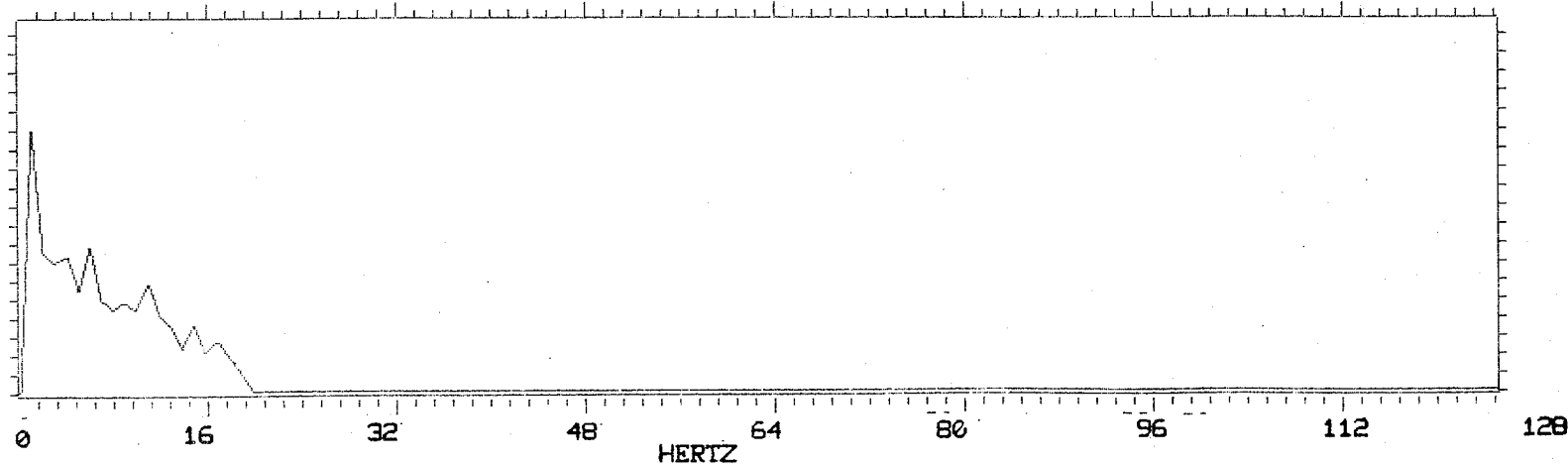
AVERAGE PSD

YMIN = .22099E-14 YMAX = .24772E-02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .2477E-02 AT 1.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .9802E-01 G

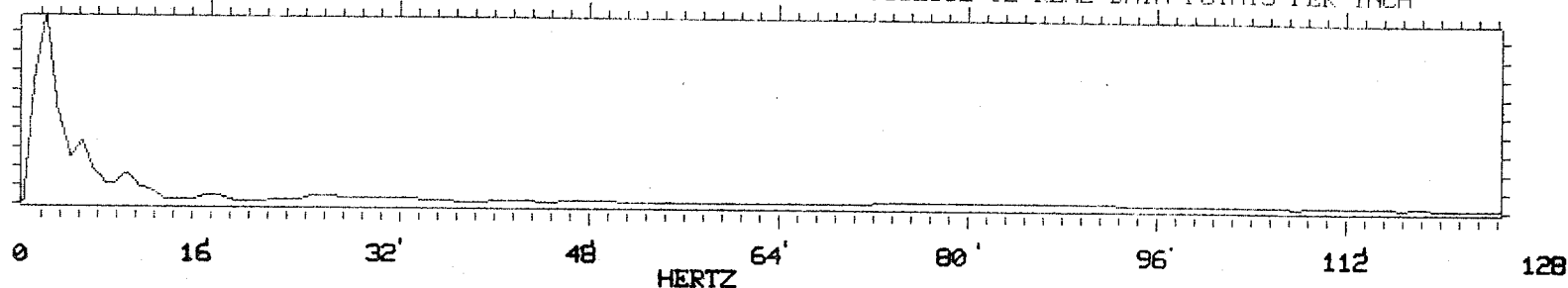
CHANNEL NO = 4 MID SIDE VERTICAL

AVERAGE PSD

TZ 3 (WB)

YMIN = .67164E-14 YMAX = .38472E-02

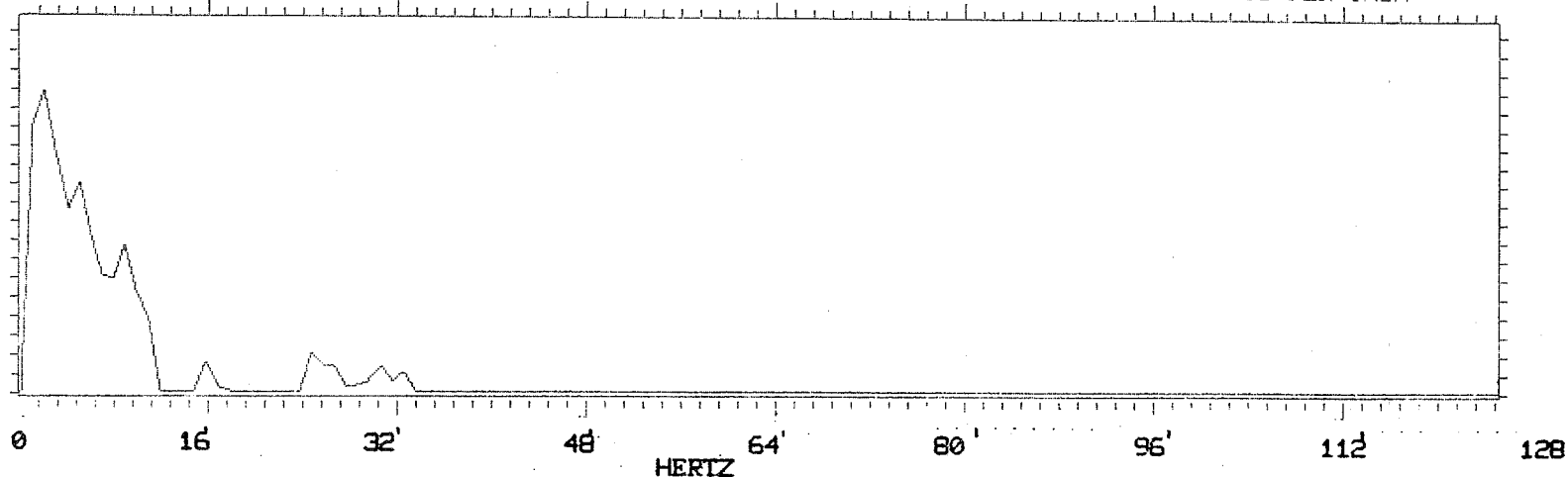
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



PSD SUMMARY

MAX VALUE .3047E-02 AT 2.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1380E 00 G

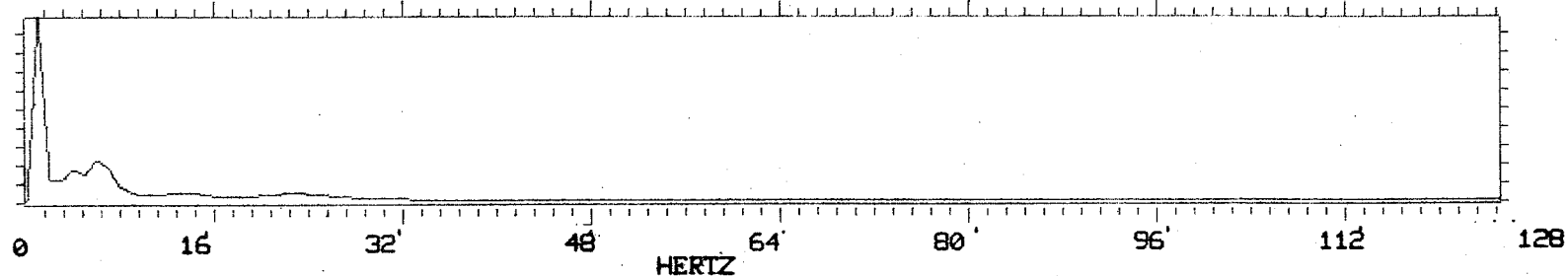
A-5

CHANNEL NO = 5 MID SIDE LATERAL

AVERAGE PSD

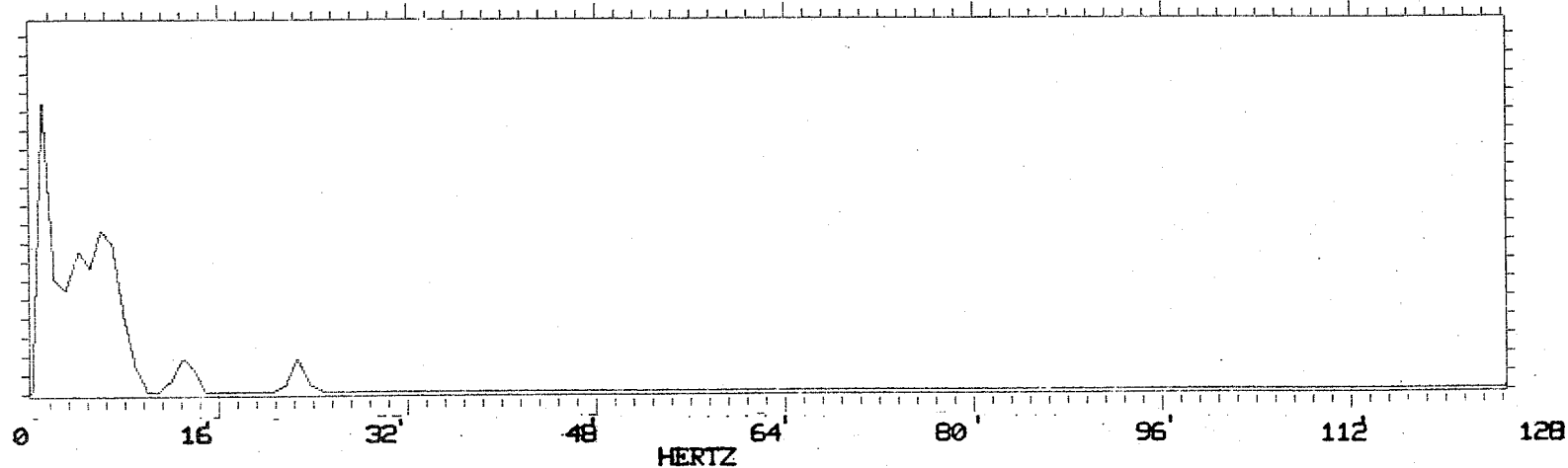
TZ 3 (WB)

YMIN = .47340E-14 YMAX = .34287E-02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .34287E-02 AT 1.0000 HZ

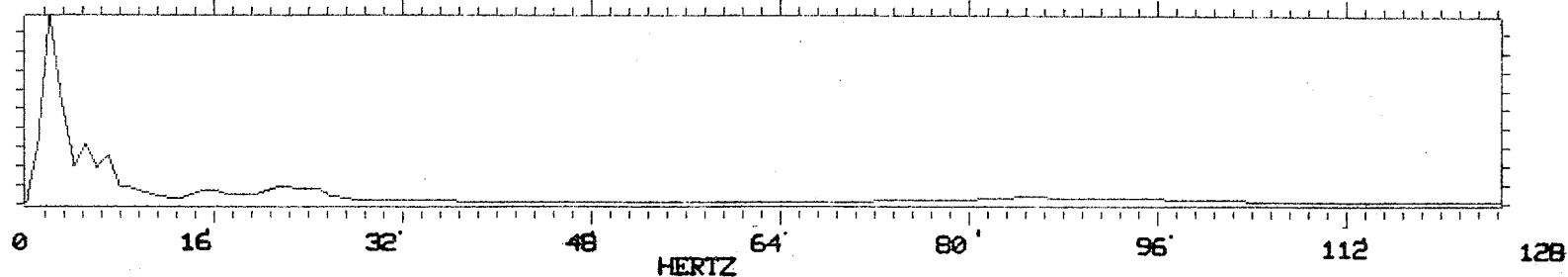
FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .9533E-01 G

CHANNEL NO = 6 REAR SIDE VERTICAL

TZ 3 (WB)

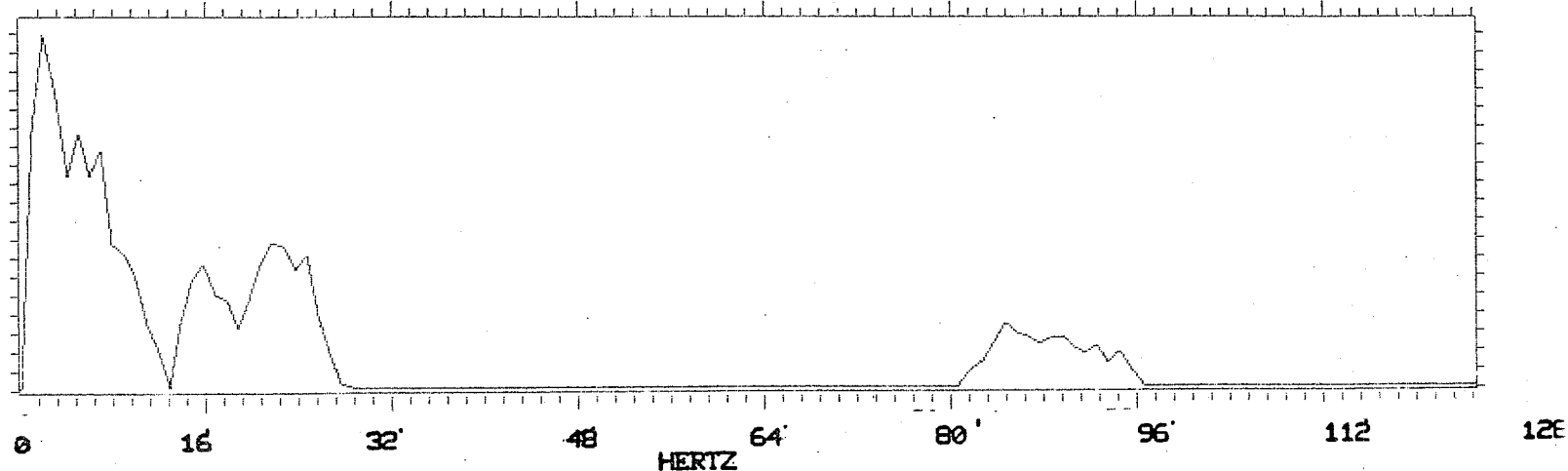
AVERAGE PSD

YMIN = .10876E-13 YMAX = .75835E-02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AVG PSD SUMMARY
MAX VALUE .7583E-02 AT 2.0000 HZ
FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1920E 00 G

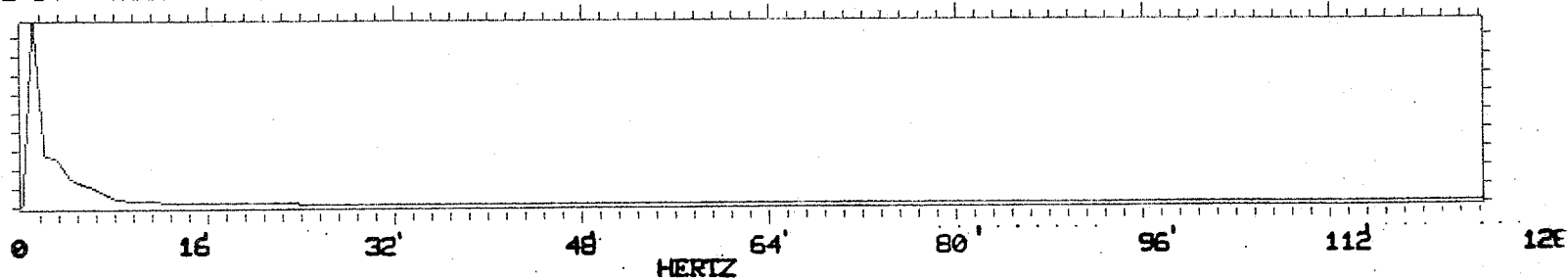
CHANNEL NO = 7 REAR SIDE LATERAL

TZ 3 (WB)

AVERAGE PSD

YMIN = .30224E-14 YMAX = .51950E-02

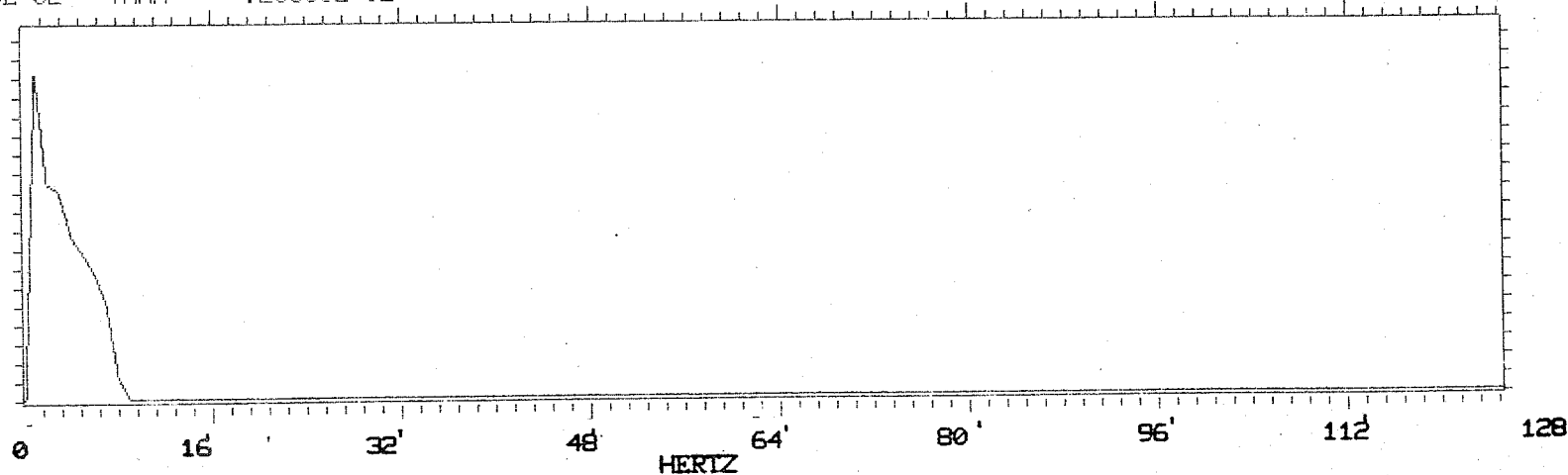
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .5195E-02 AT 1.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1064E 00 G

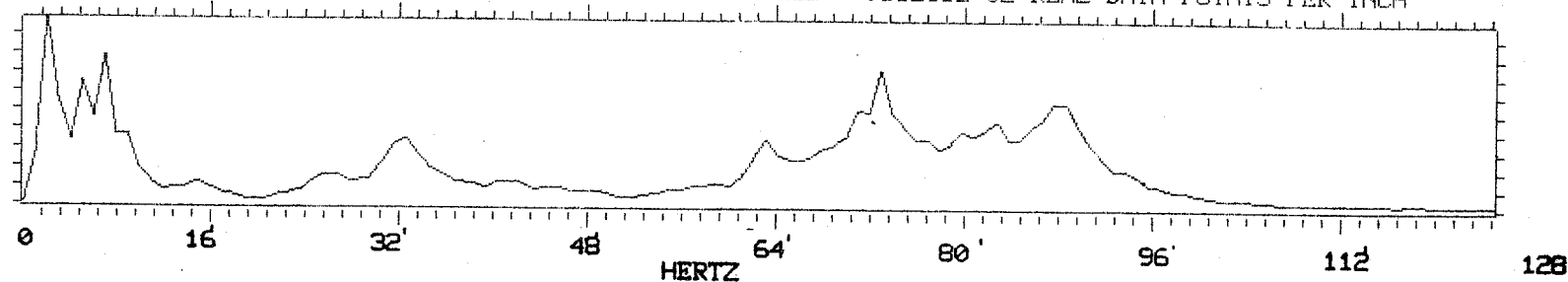
CHANNEL NO = 8 FRONT CENTER VERTICL

AVERAGE PSD

TZ 3 (WB)

YMIN = .68935E-14 YMAX = .78388E-02

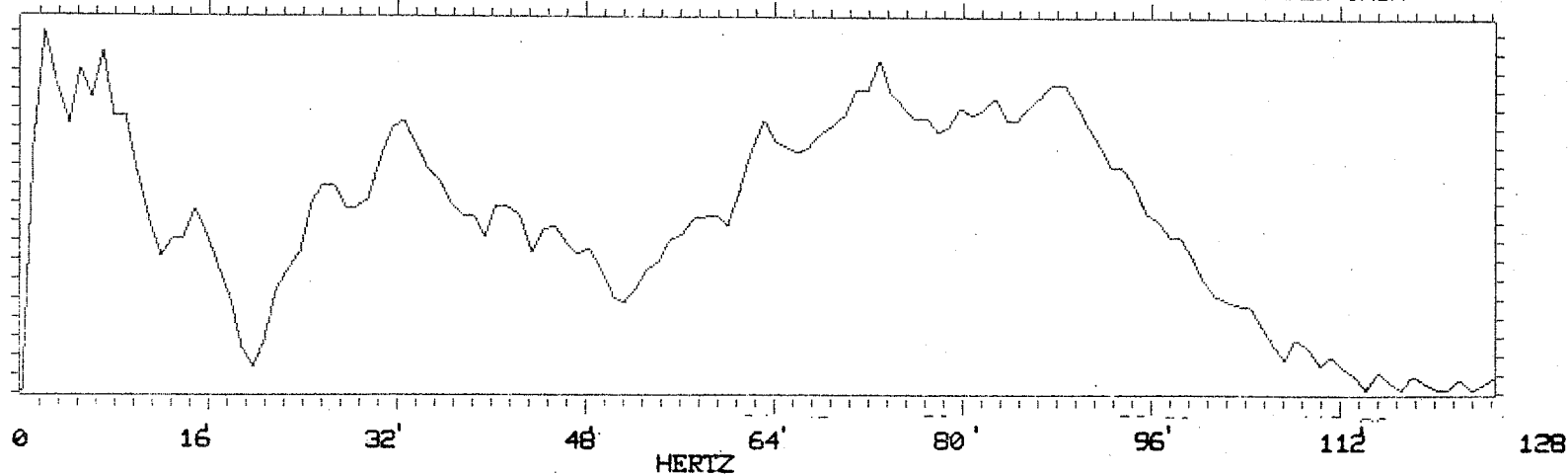
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .7839E-02 AT 2.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .4289E 00 G

A-9

CHANNEL NO = 9

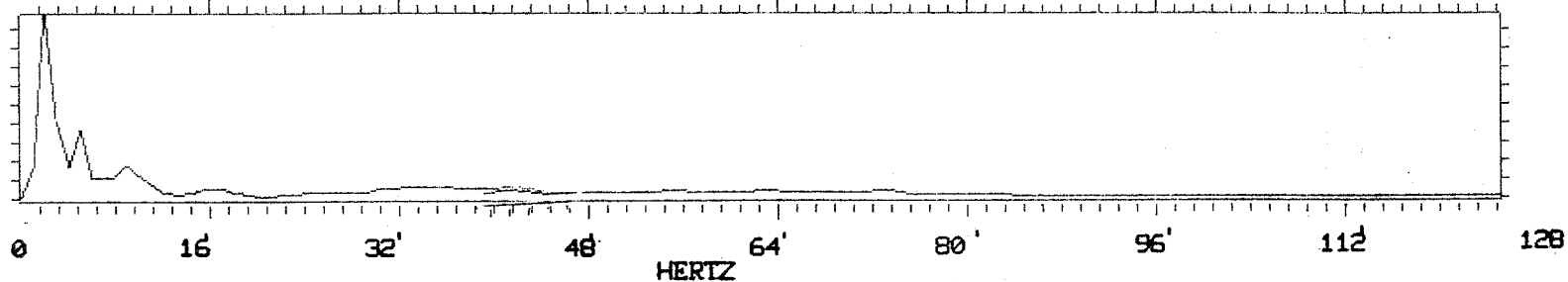
MID CENTER VERTICAL

TZ 3 (WB)

AVERAGE PSD

YMIN = .21561E-14 YMAX = .35355E-02

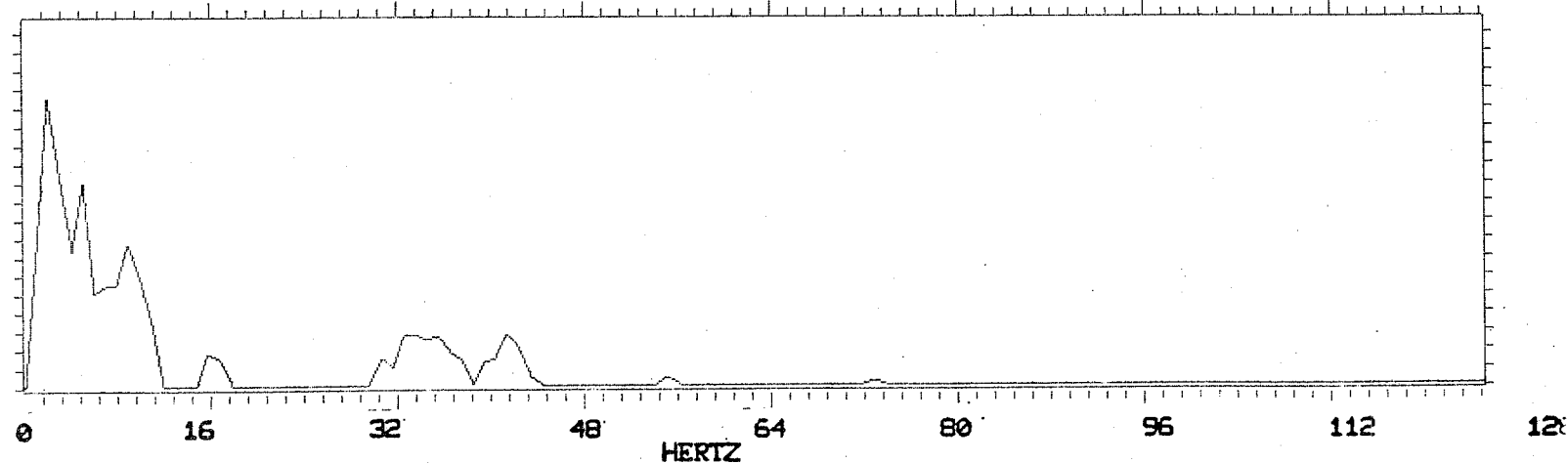
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



PSD SUMMARY

MAX VALUE .3535E-02 AT 2.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1246E 00 G

A-10

CHANNEL NO = 10

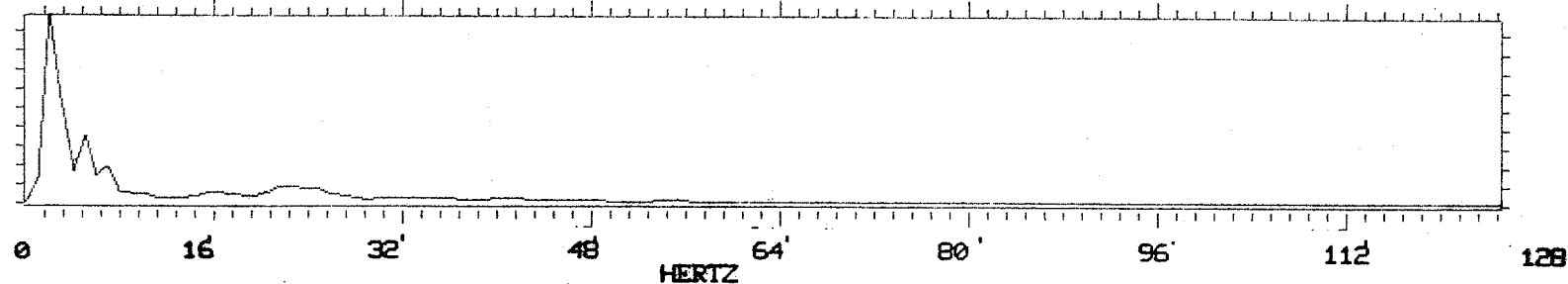
REAR CENTER VERTICAL

AVERAGE PSD

TZ 3 (WB)

YMIN = .59787E-14 YMAX = .75091E-02

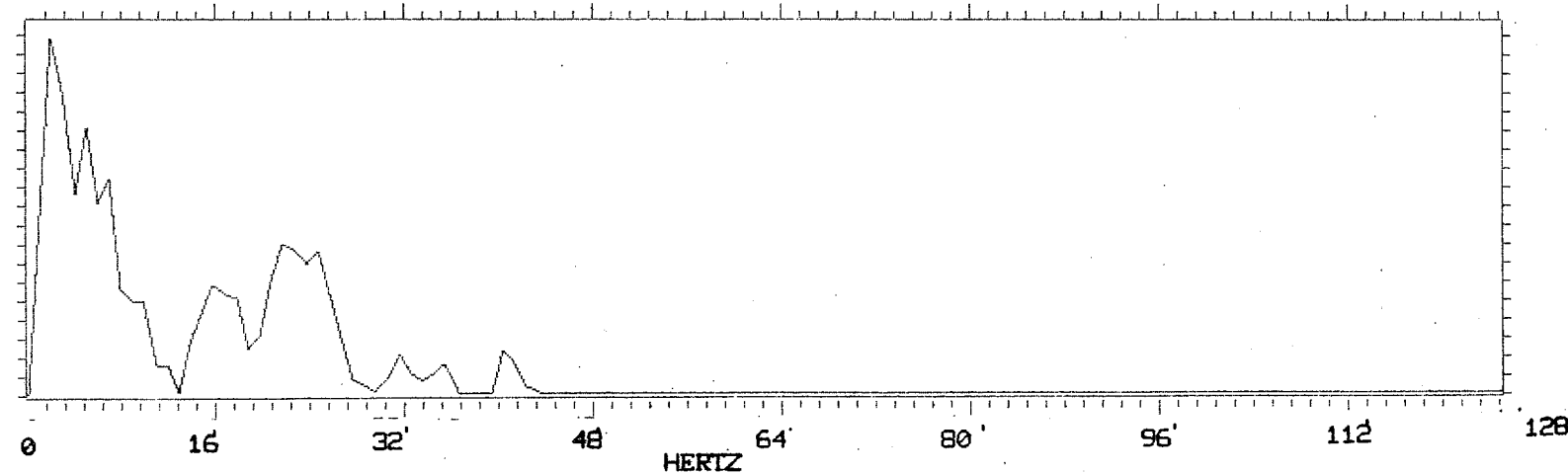
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



A-11

AUG PSD SUMMARY

MAX VALUE .7509E-02 AT 2.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1665E 00 G

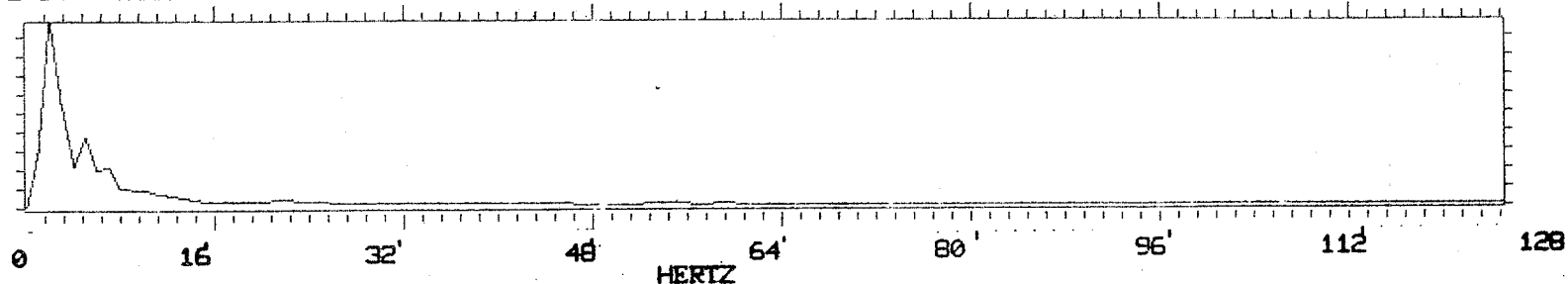
CHANNEL NO = 11 LADING VERTICAL

TZ 3 (WB)

AVERAGE PSD

YMIN = .52507E-14 YMAX = .76369E-02

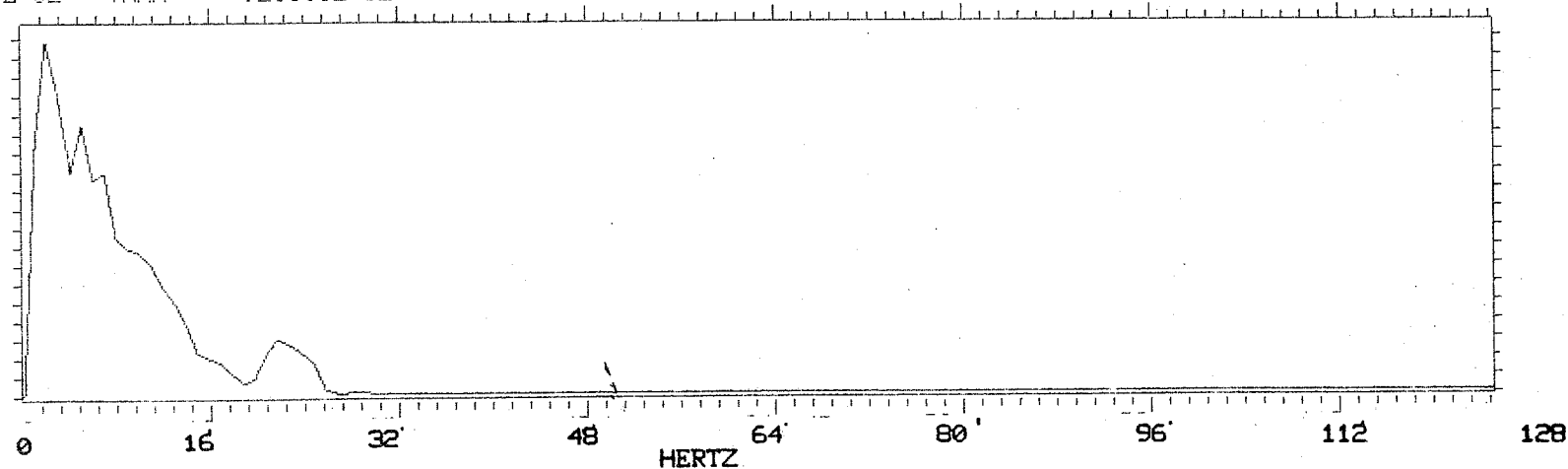
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*KLOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



A-12

PSD SUMMARY

MAX VALUE .7637E-02 AT 2.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1694E 00 G

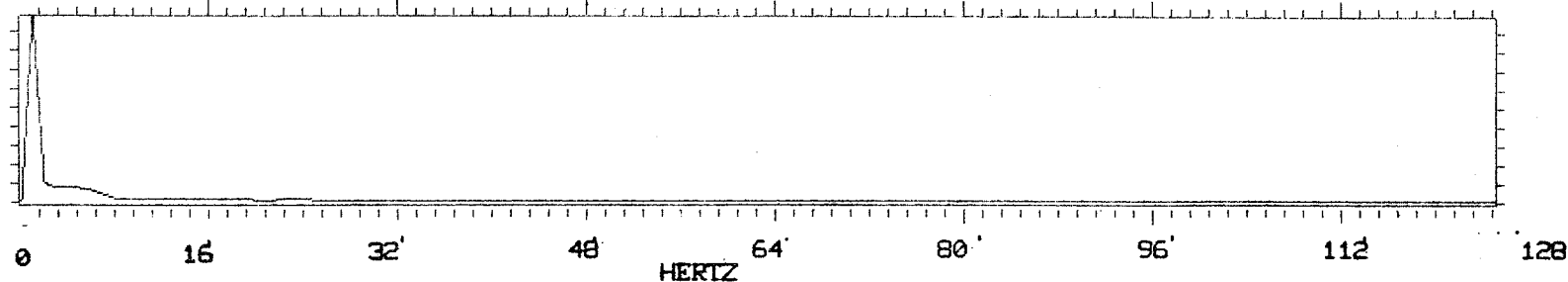
CHANNEL NO = 12 MID TOP LATERAL

TZ 3 (WB)

AVERAGE PSD

YMIN = .10040E-13 YMAX = .26262E-01

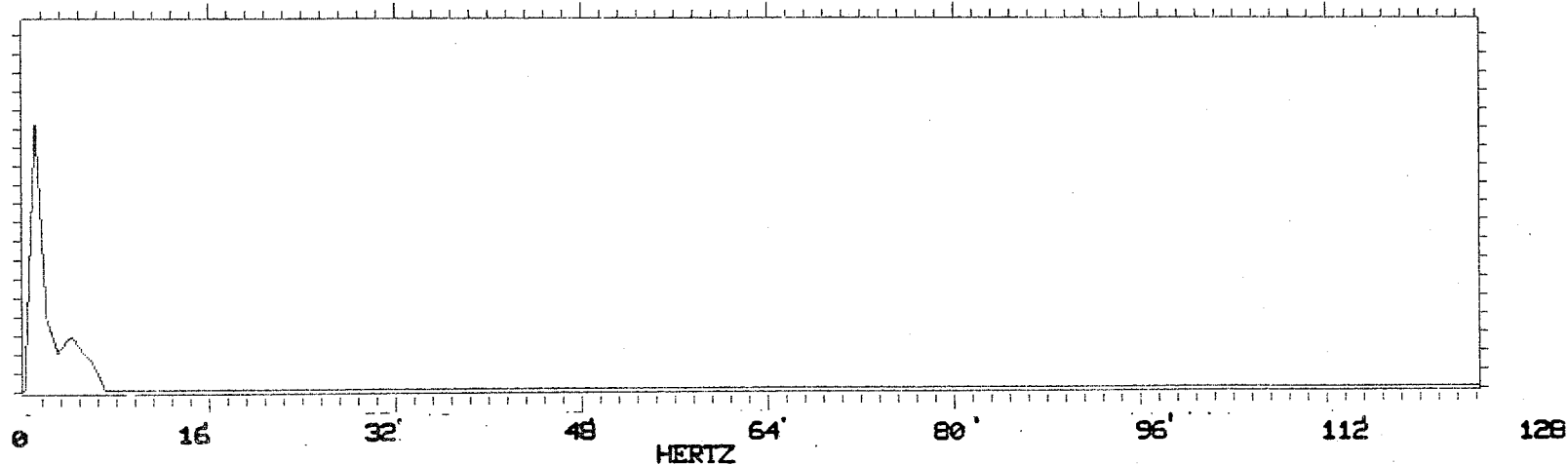
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10XLOG10(PSD)

YMIN = -.30000E 02 YMAX = -.10000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .2626E-01 AT 1.0000 HZ

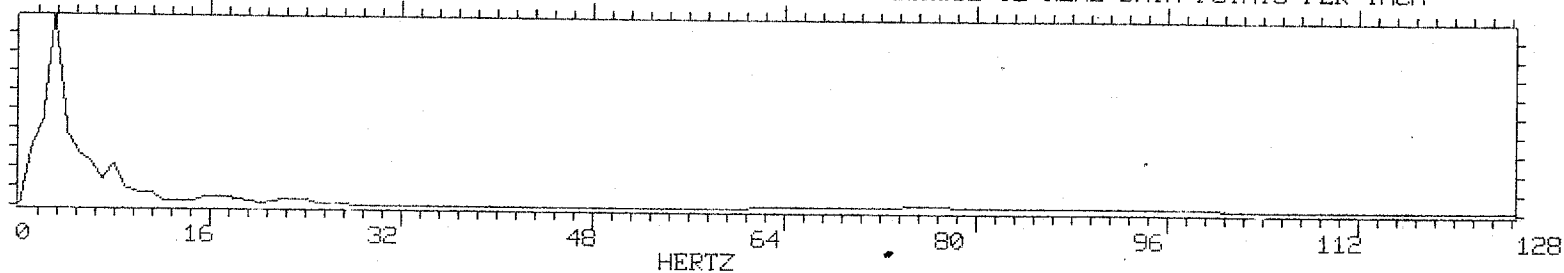
FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .2071E 00 G

CHANNEL NO = 1 FRONT SIDE VERTICAL

AVERAGE PSD

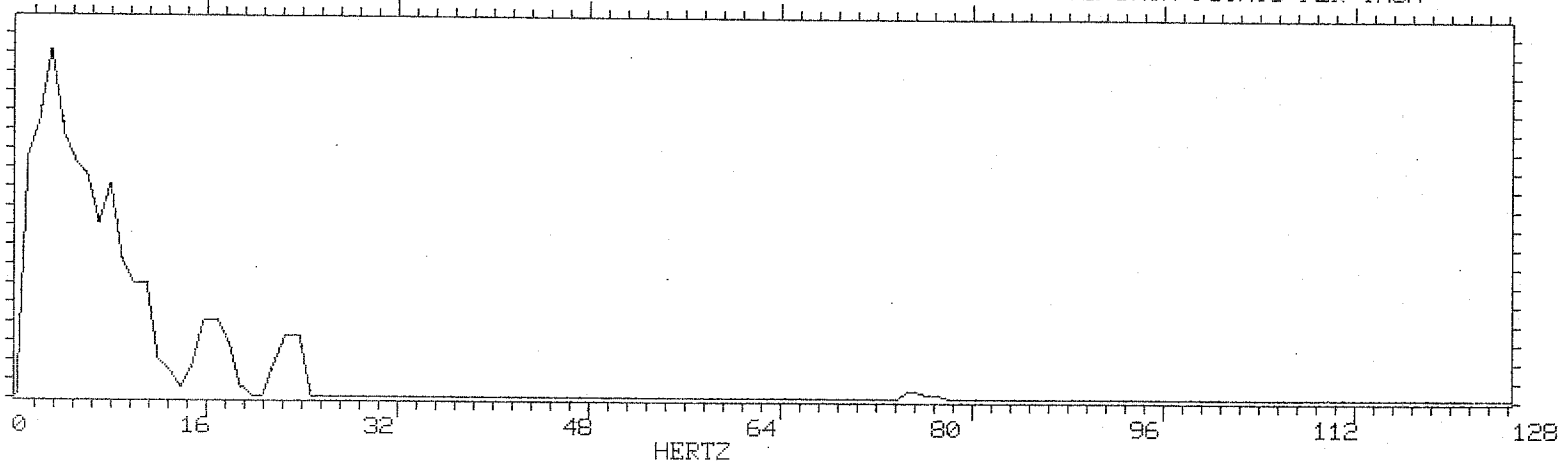
TZ 3 (EB)

YMIN = .16294E-14 YMAX = .64570E-02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .6457E-02 AT 3.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1589E 00 G

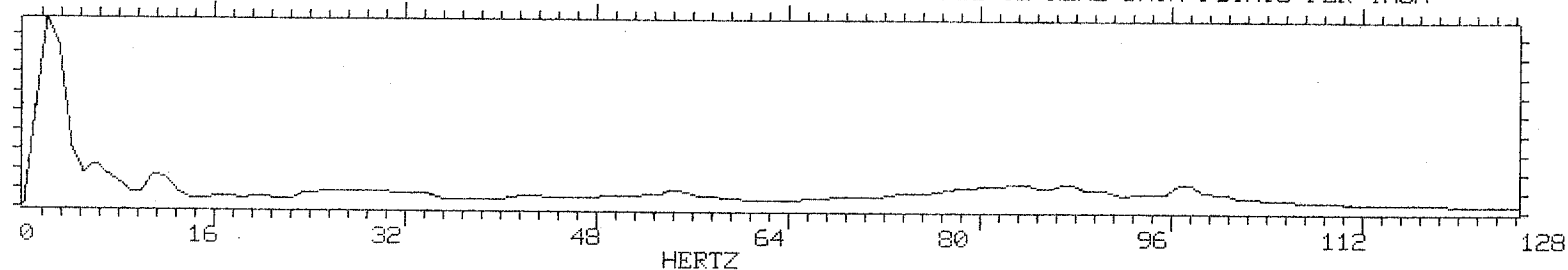
A-14

CHANNEL NO = 2 FRONT SIDE LONGTDNAL

AVERAGE PSD

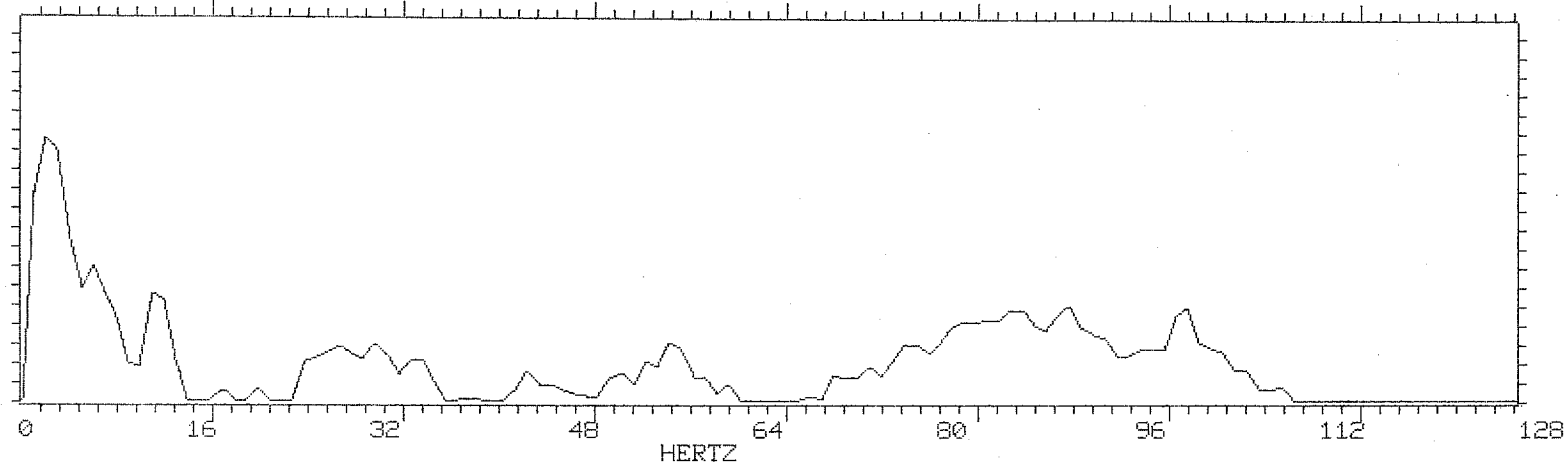
TZ 3 (EB)

YMIN = .41155E-15 YMAX = .22848E-03 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.50000E 02 YMAX = -.30000E 02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



A-15

AUG PSD SUMMARY

MAX VALUE .2285E-03 AT 2.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .4945E-01 G

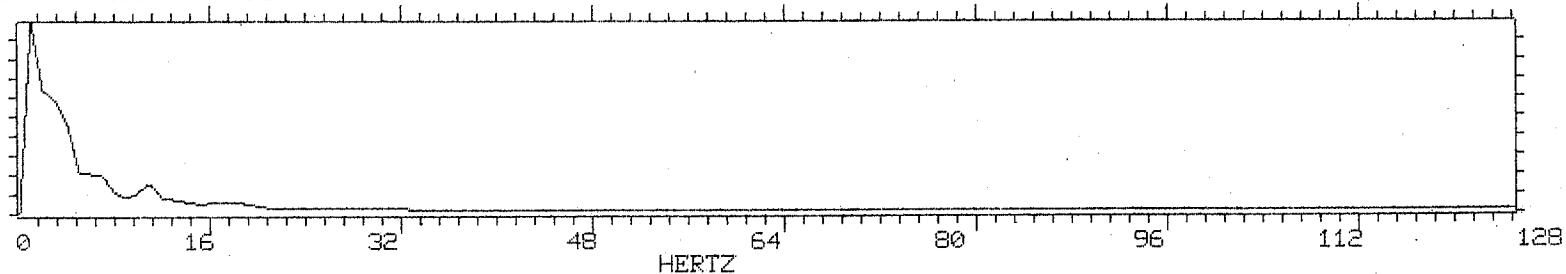
CHANNEL NO = 3 FRONT SIDE LATERAL

AVERAGE PSD

TZ 3 (EB)

YMIN = .11523E-14 YMAX = .18552E-02

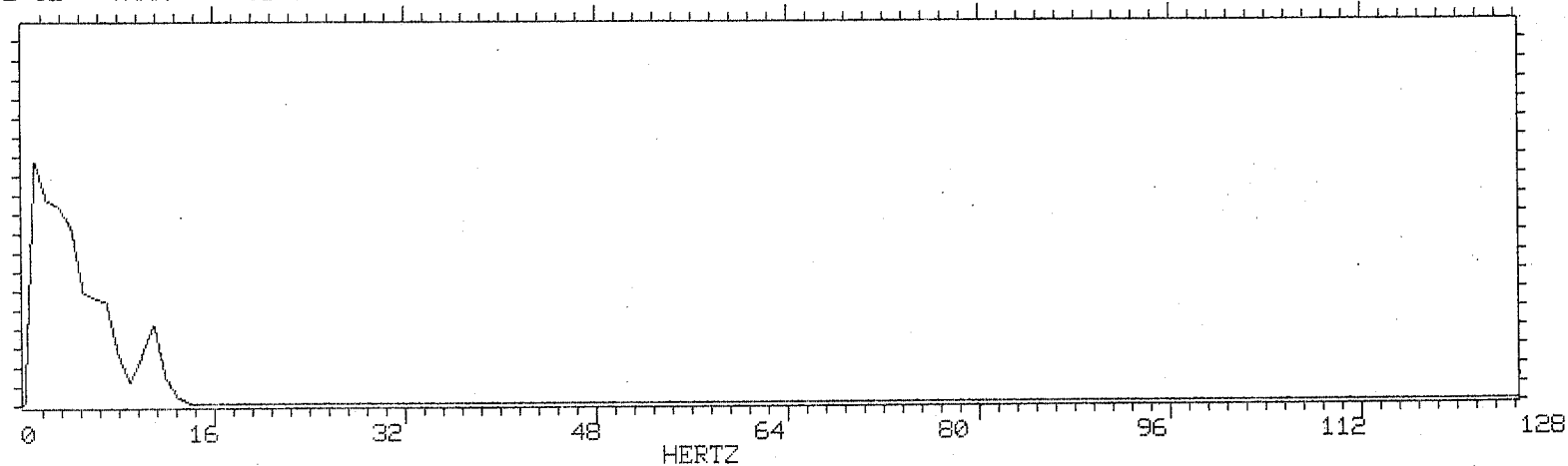
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .1855E-02 AT 1.0000 HZ

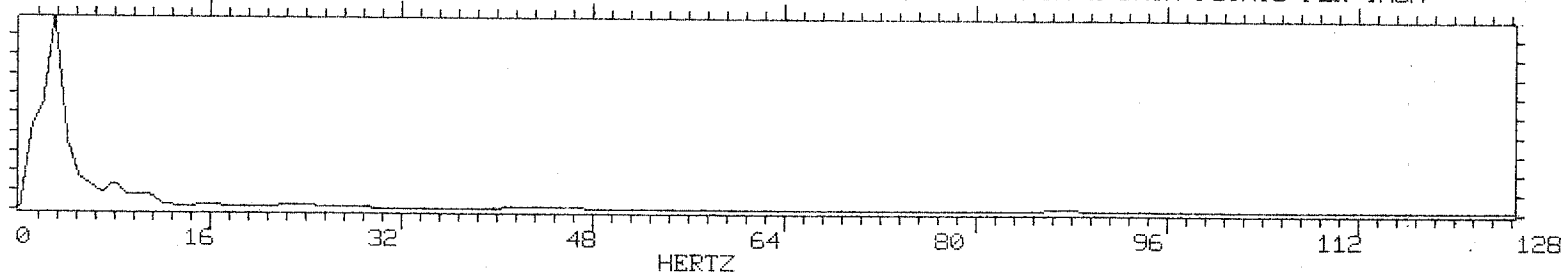
FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .9679E-01 G

CHANNEL NO = 4 MID SIDE VERTICAL

AVERAGE PSD

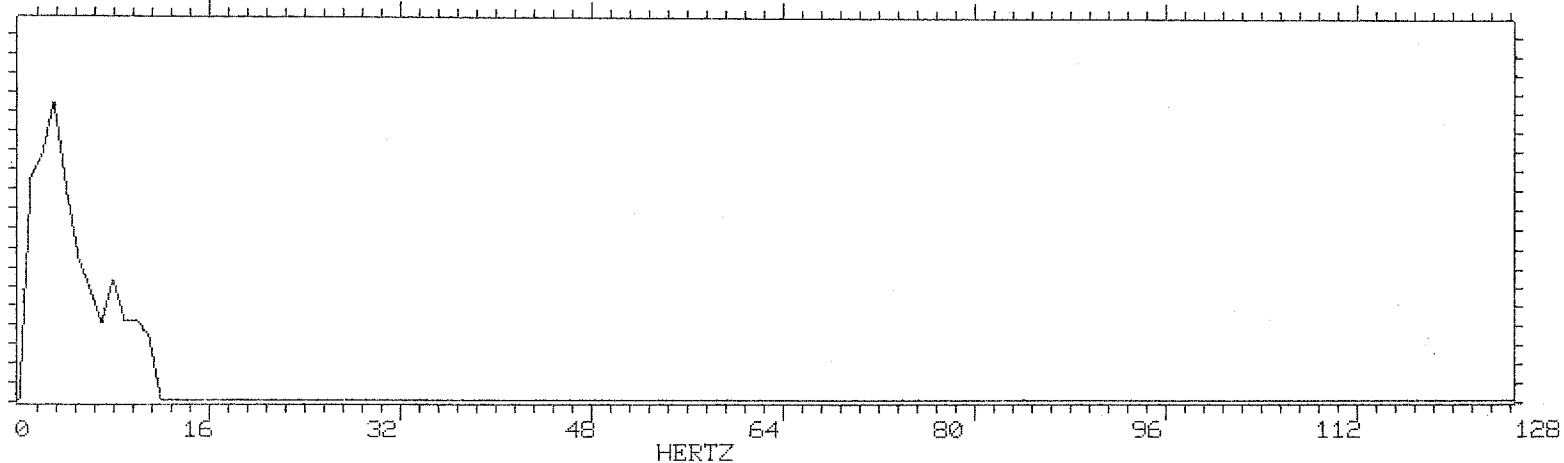
TZ 3 (EB)

YMIN = .23270E-14 YMAX = .34726E-02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .3473E-02 AT 3.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1092E 00 G

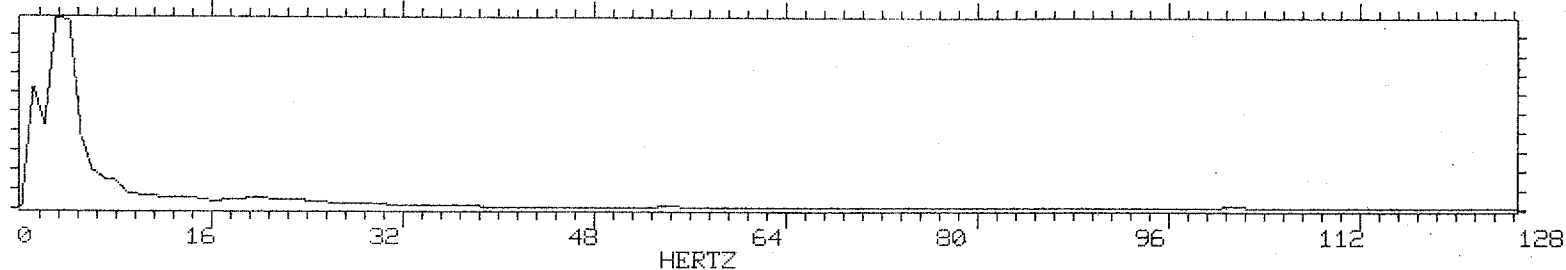
CHANNEL NO = 5 MID SIDE LATERAL

AVERAGE PSD

TZ 3 (EB)

YMIN = .43457E-14 YMAX = .15667E-02

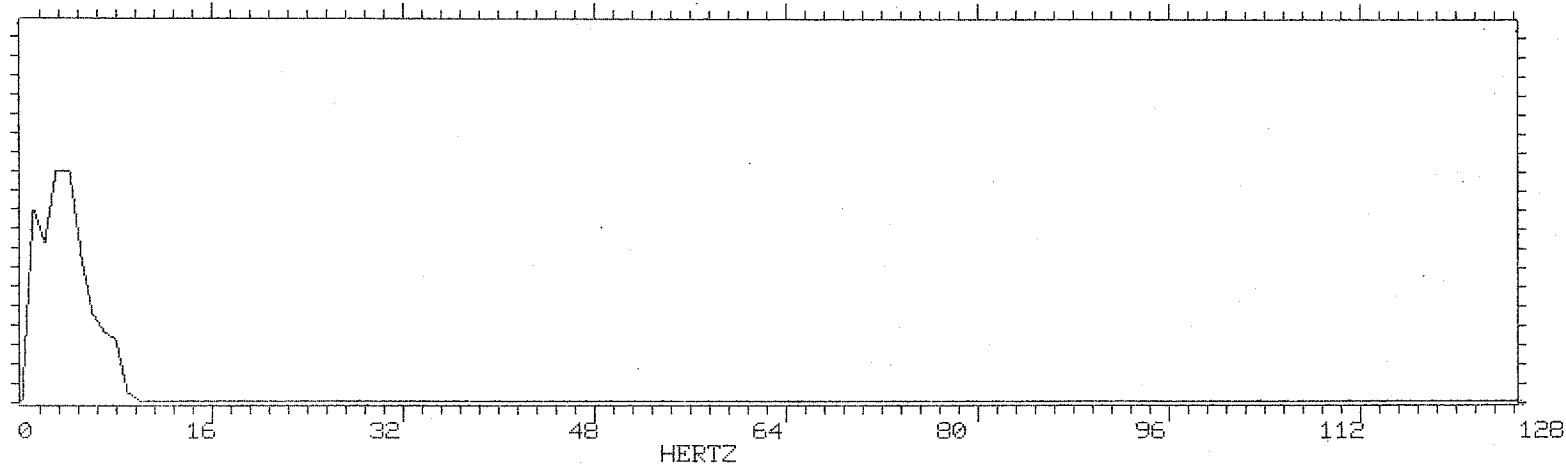
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .1567E-02 AT 3.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .8782E-01 G

A-18

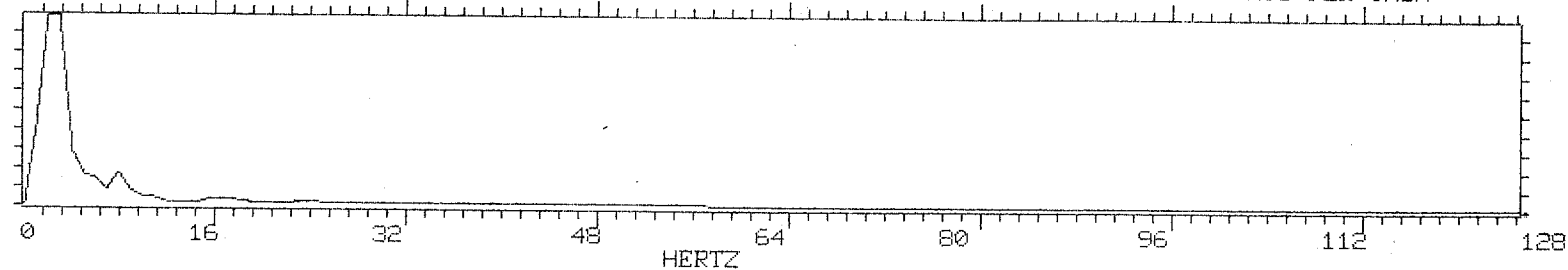
CHANNEL NO = 6 REAR SIDE VERTICAL

AVERAGE PSD

TZ 3 (EB)

YMIN = .66983E-14 YMAX = .42253E-02

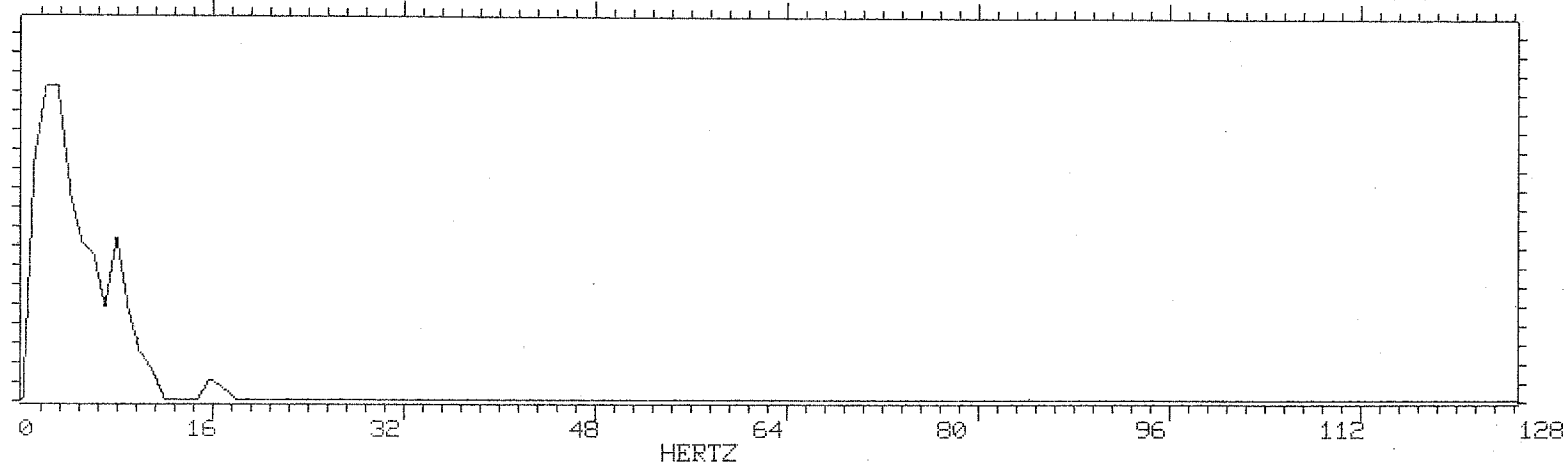
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .4225E-02 AT 3.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1285E 00 G

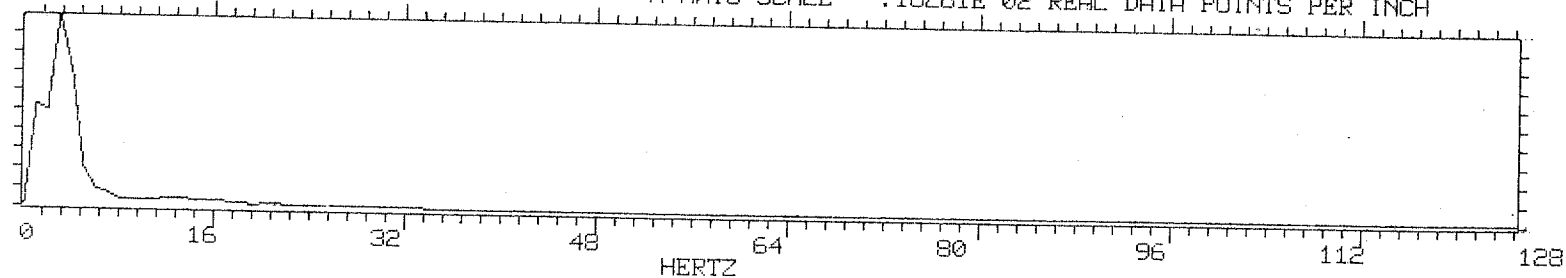
CHANNEL NO = 7 REAR SIDE LATERAL

AVERAGE PSD

TZ 3 (EB)

YMIN = .37649E-14 YMAX = .26003E-02

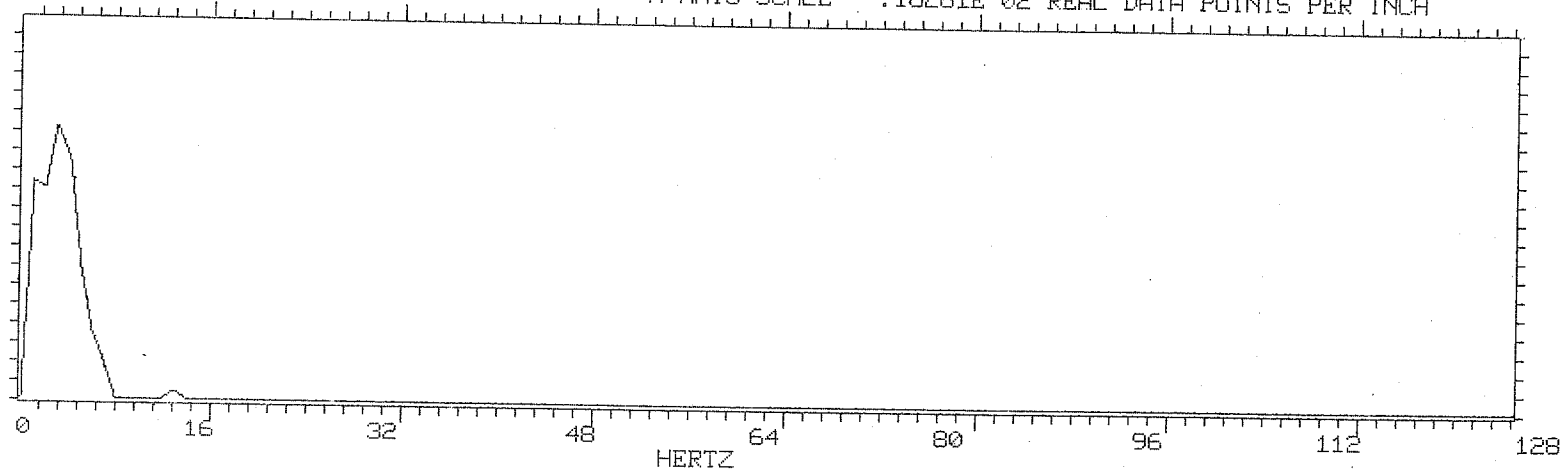
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .2600E-02 AT 3.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .9651E-01 G

CHANNEL NO = 8

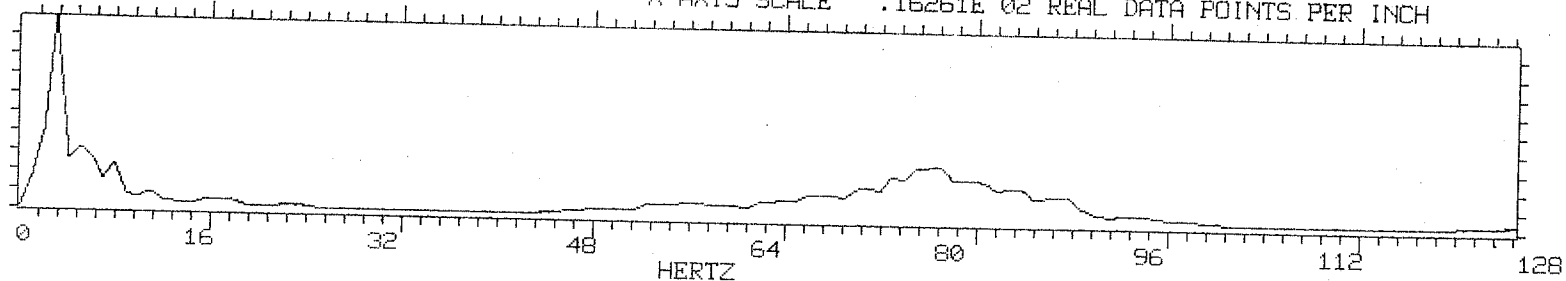
FRONT CENTER VERTICL

AVERAGE PSD

TZ 3 (EB)

YMIN = .19973E-14 YMAX = .18271E-01

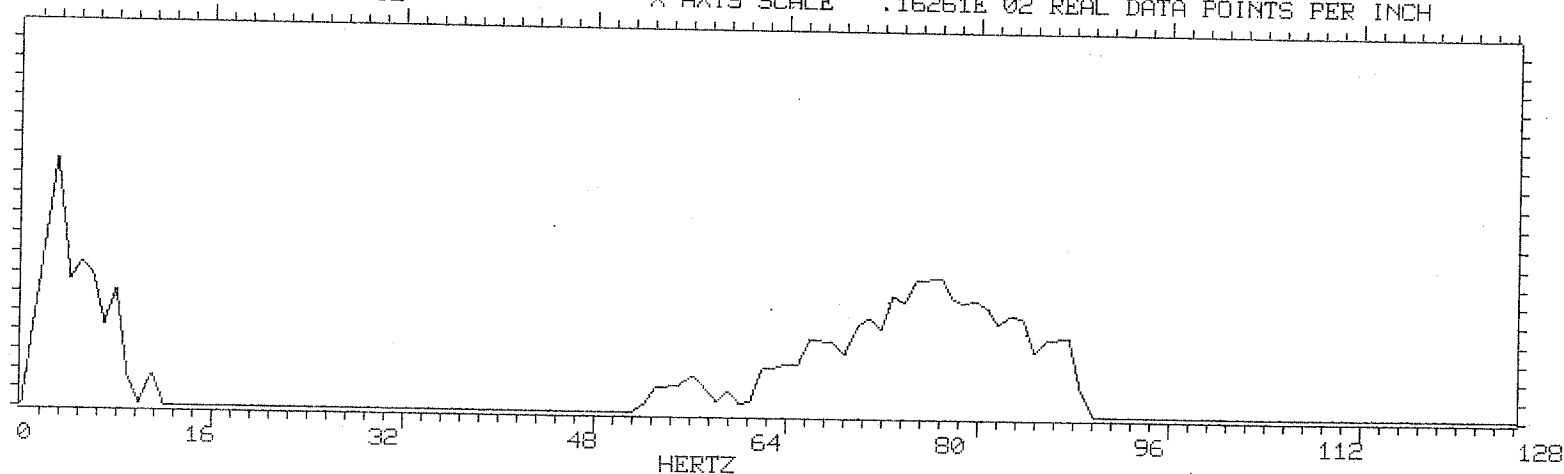
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



$10 \times \log_{10}(\text{PSD})$

YMIN = -.30000E 02 YMAX = -.10000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .1827E-01 AT 3.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .4236E 00 G

A-21

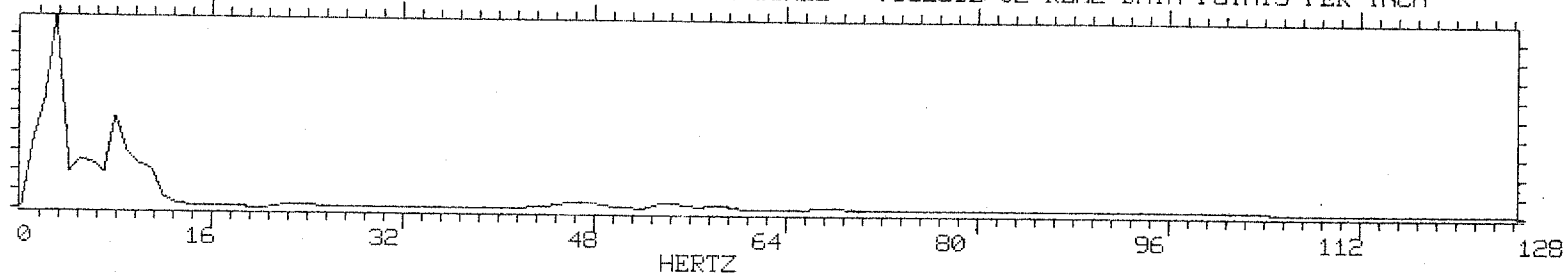
CHANNEL NO = 9 MID CENTER VERTICAL

AVERAGE PSD

TZ 3 (EB)

YMIN = .34734E-14 YMAX = .22310E-02

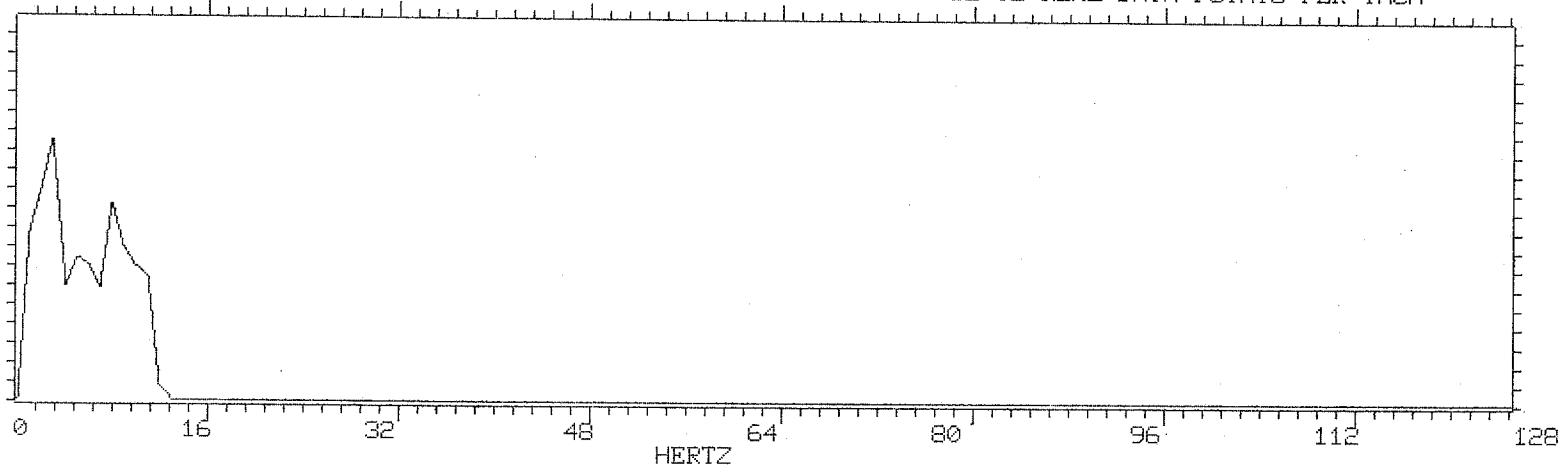
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .2231E-02 AT 3.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1076E 00 G

CHANNEL NO = 10

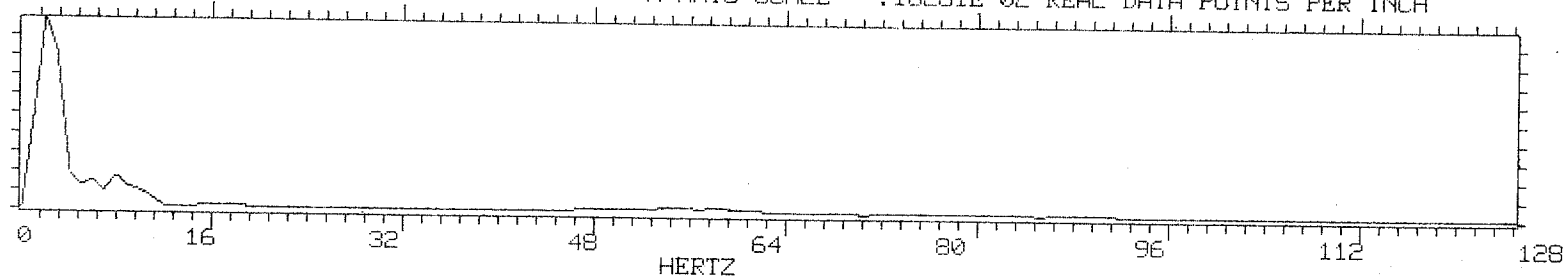
REAR CENTER VERTICAL

AVERAGE PSD

TZ 3 (EB)

YMIN = .12905E-14 YMAX = .37030E-02

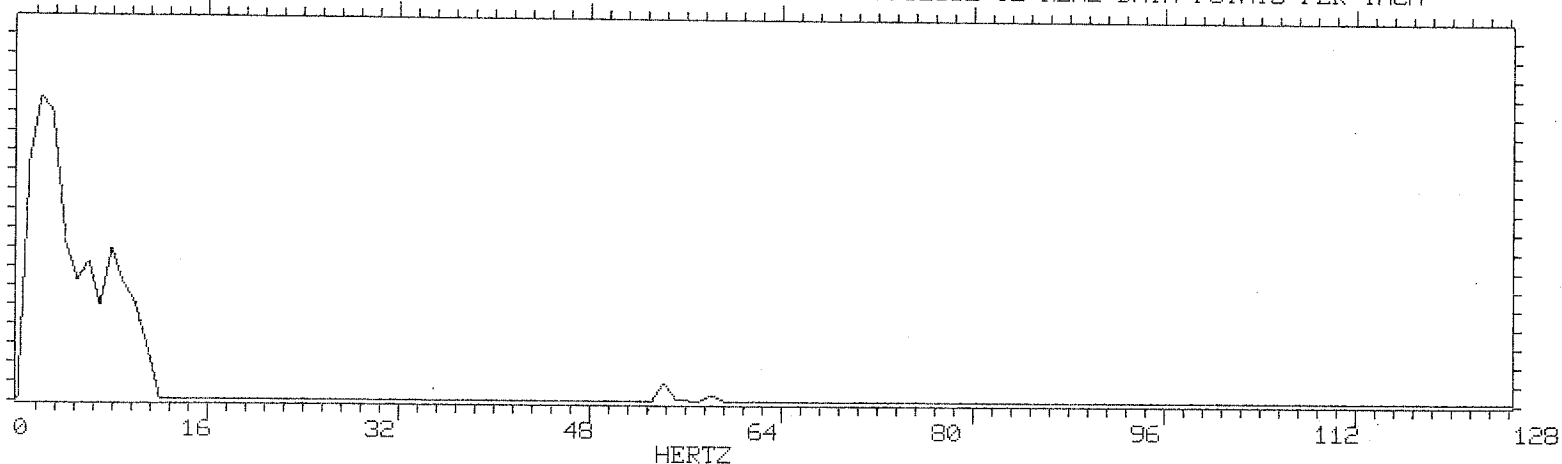
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .3703E-02 AT 2.0000 HZ

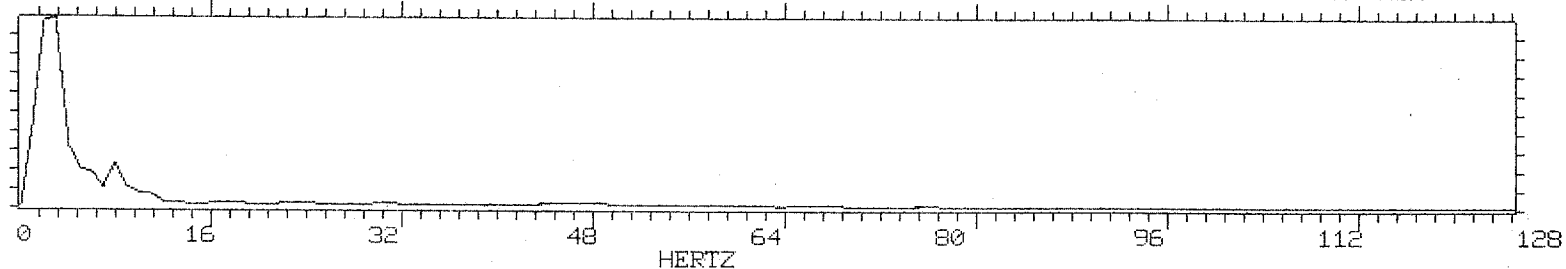
FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1244E 00 G

CHANNEL NO = 11 LADING VERTICAL

AVERAGE PSD

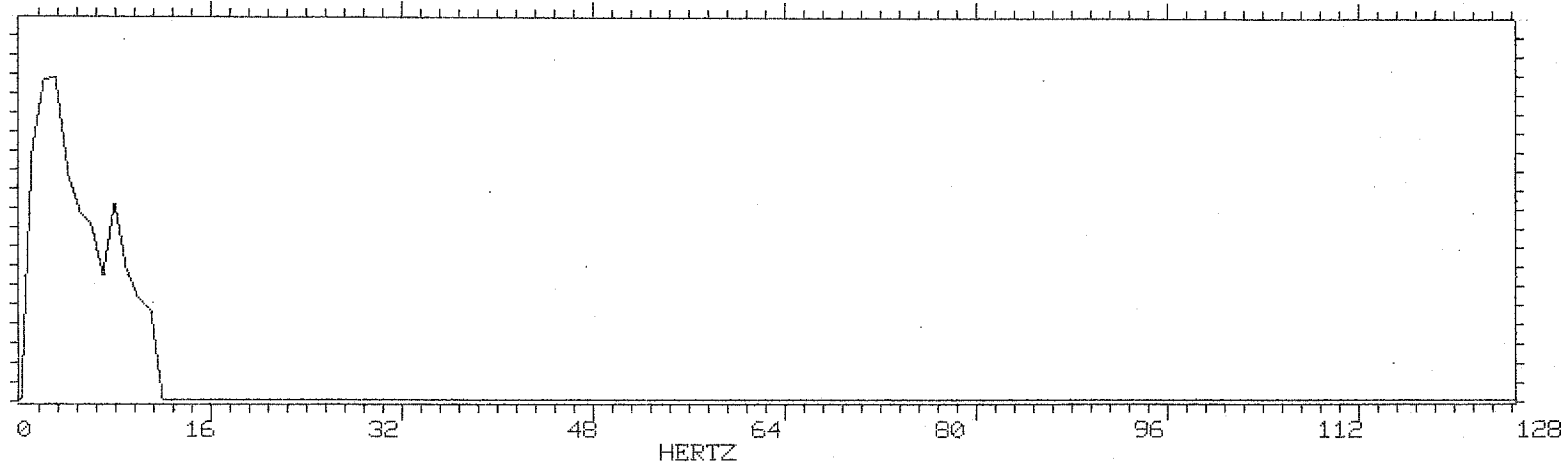
TZ 3 (EB)

YMIN = .99248E-14 YMAX = .47419E-02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02 X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

MAX VALUE .4742E-02 AT 3.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1436E 00 G

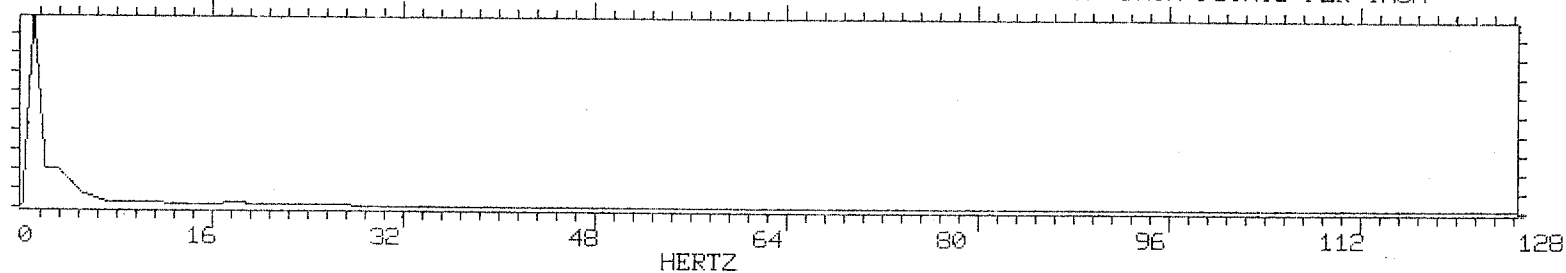
CHANNEL NO = 12 MID TOP LATERAL

AVERAGE PSD

TZ 3 (EB)

YMIN = .10483E-13 YMAX = .89056E-02

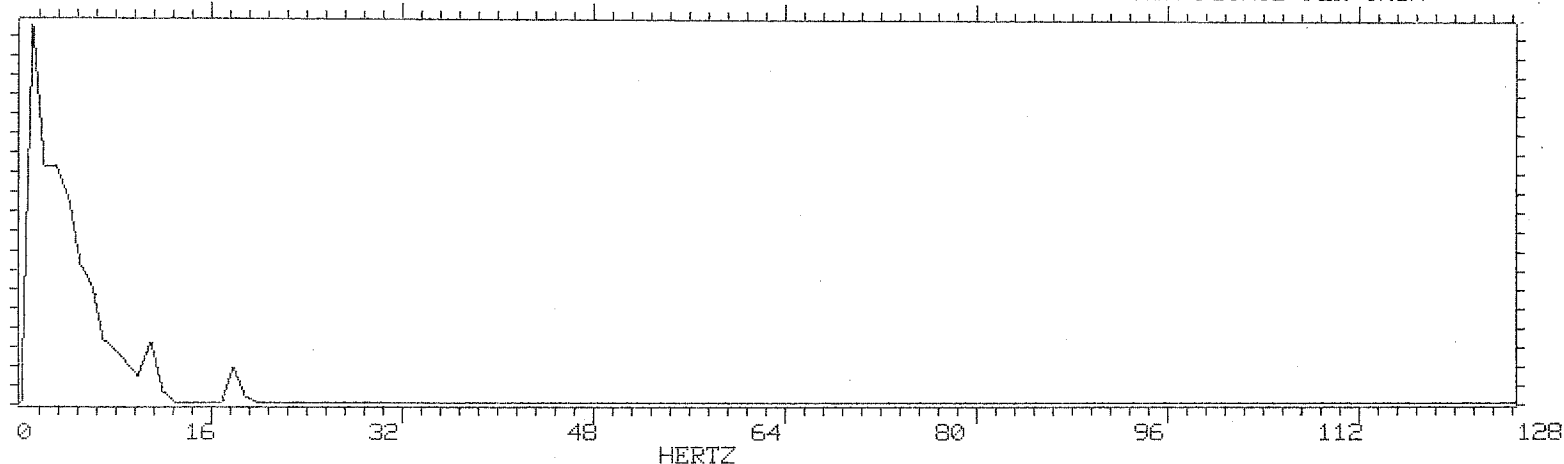
X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



10*LOG10(PSD)

YMIN = -.40000E 02 YMAX = -.20000E 02

X-AXIS SCALE .16261E 02 REAL DATA POINTS PER INCH



AUG PSD SUMMARY

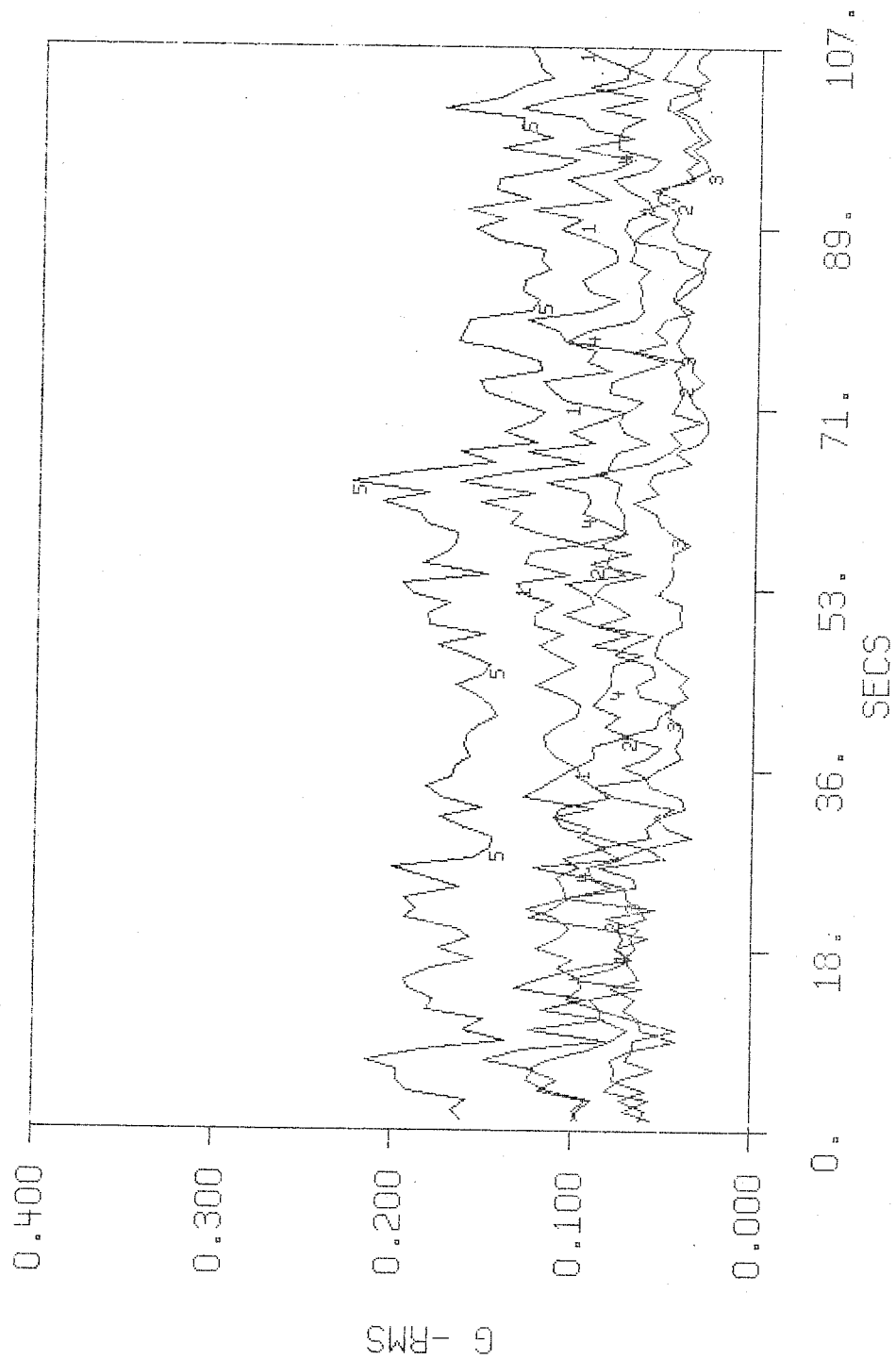
MAX VALUE .8906E-02 AT 1.0000 HZ

FROM 0.0 HZ TO 127.0000 HZ, RMS ACCELERATION = .1343E 00 G

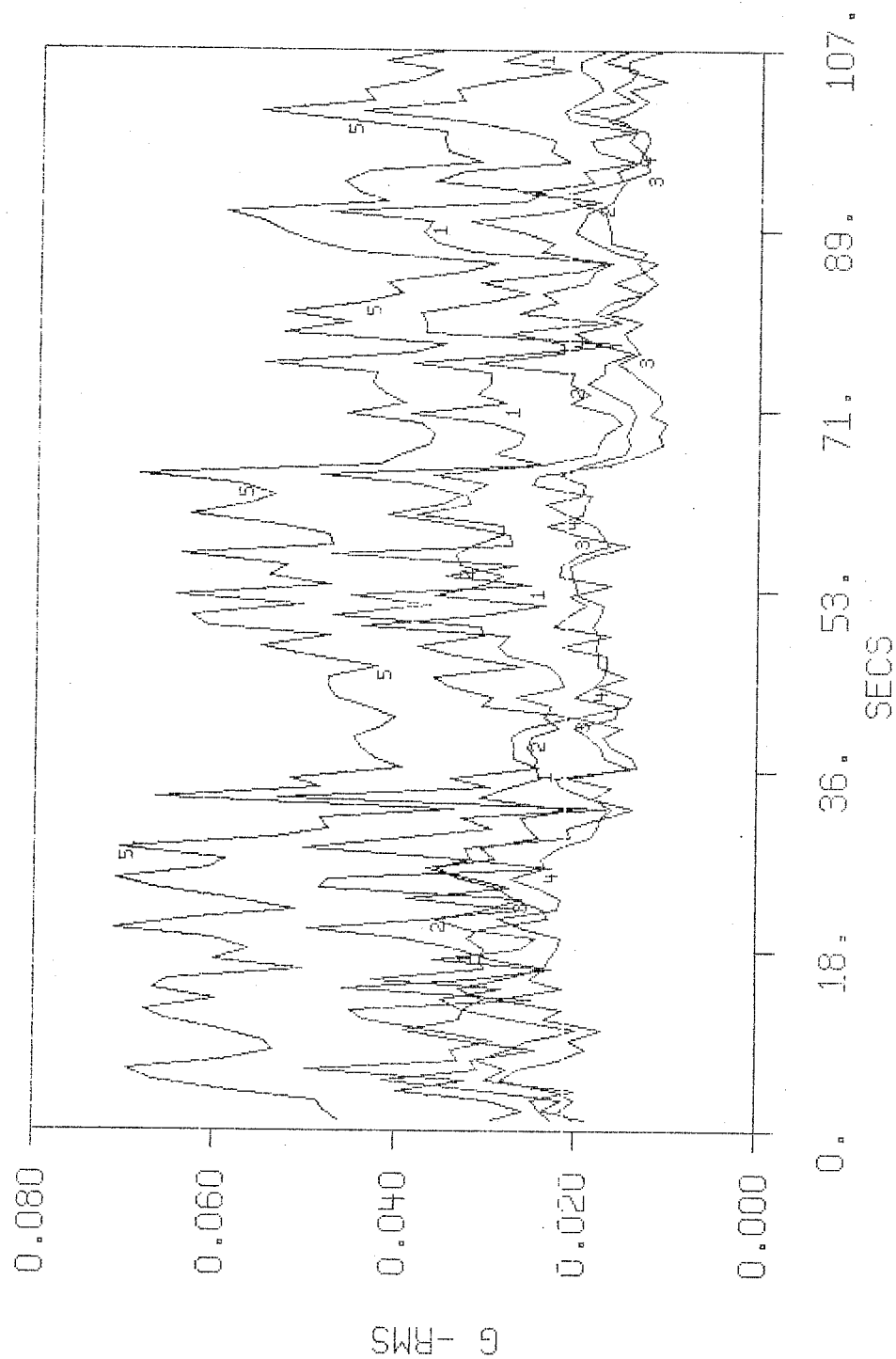
APPENDIX B

EXAMPLES OF RMS HISTORIES
TEST ZONE 3

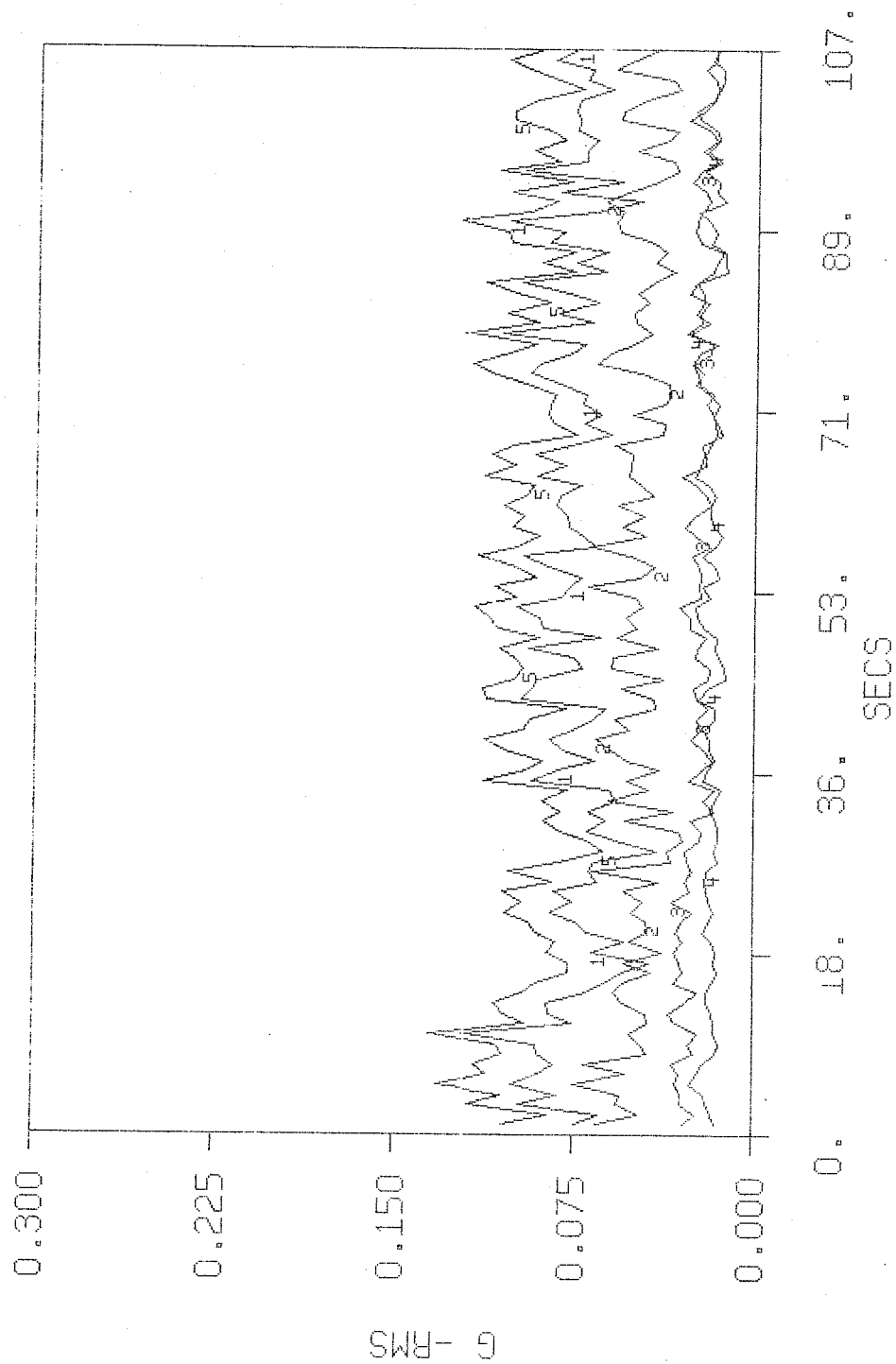
(Data of other test zones are available in Volume II of this Report)



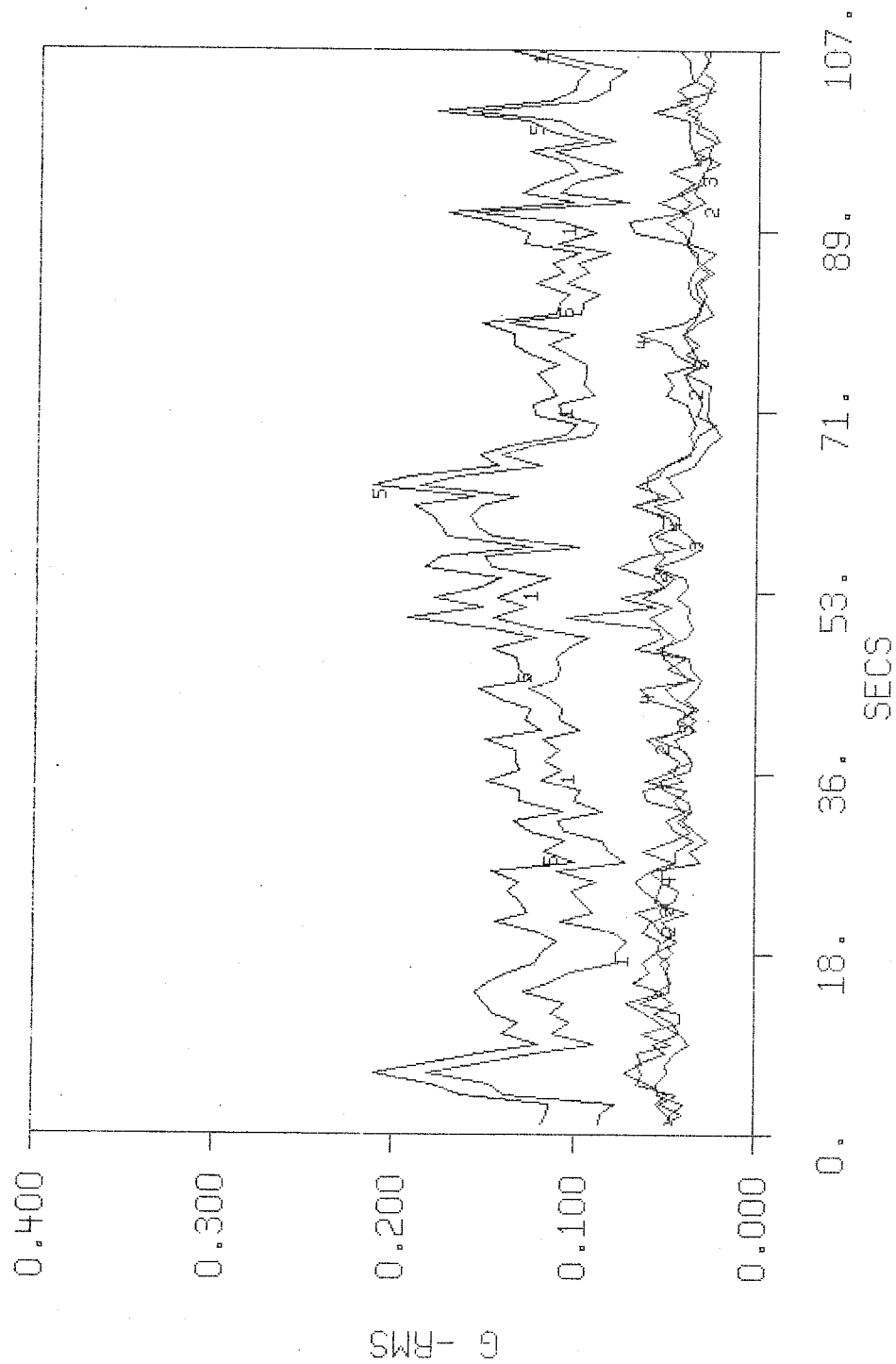
FRONT SIDE VERTICAL
 TZ=3 D=4 TP=3 FL=1



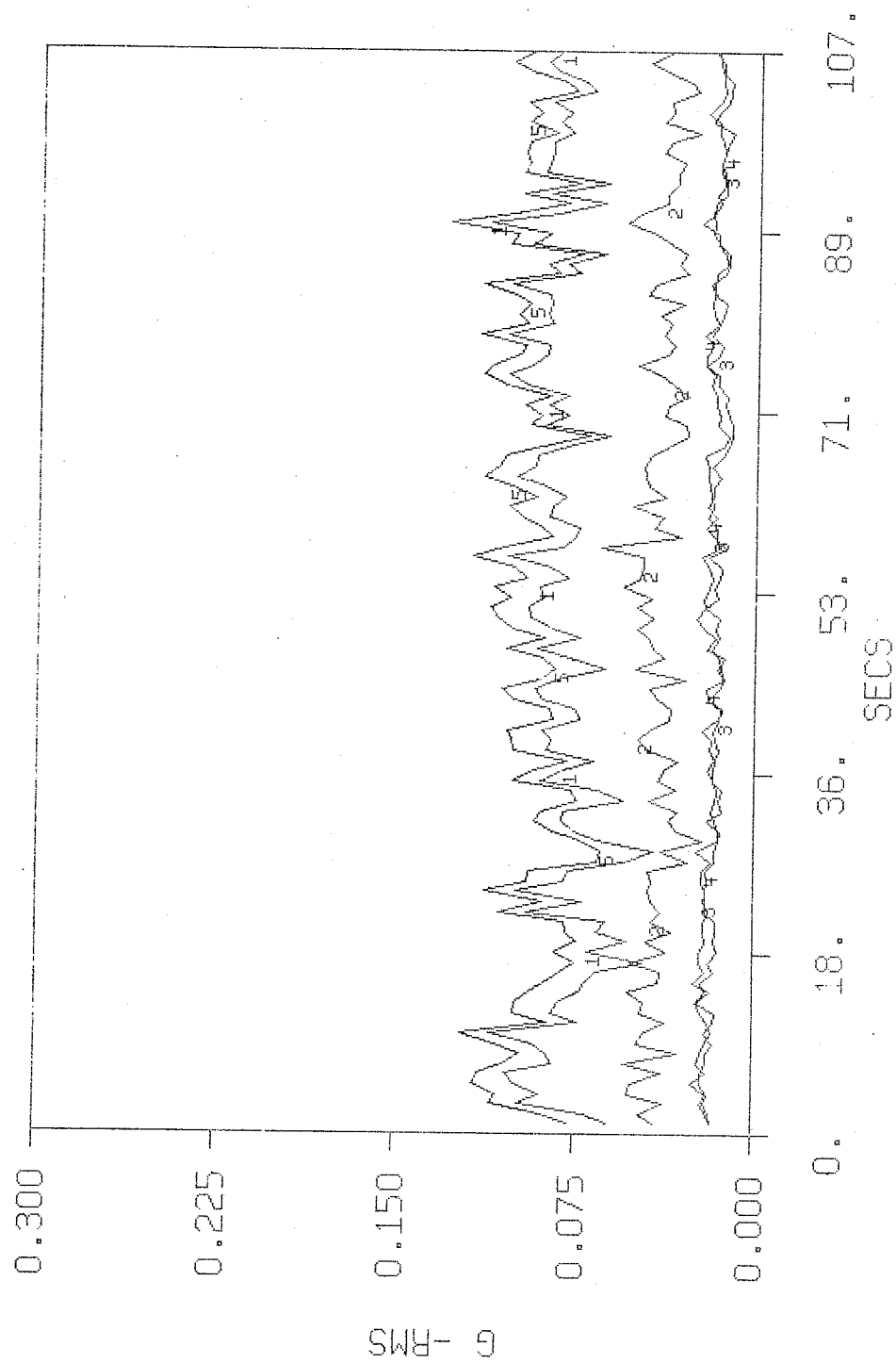
FRONT SIDE LONGITUDINAL
TZ=3 D=H 1P=3 FL=L



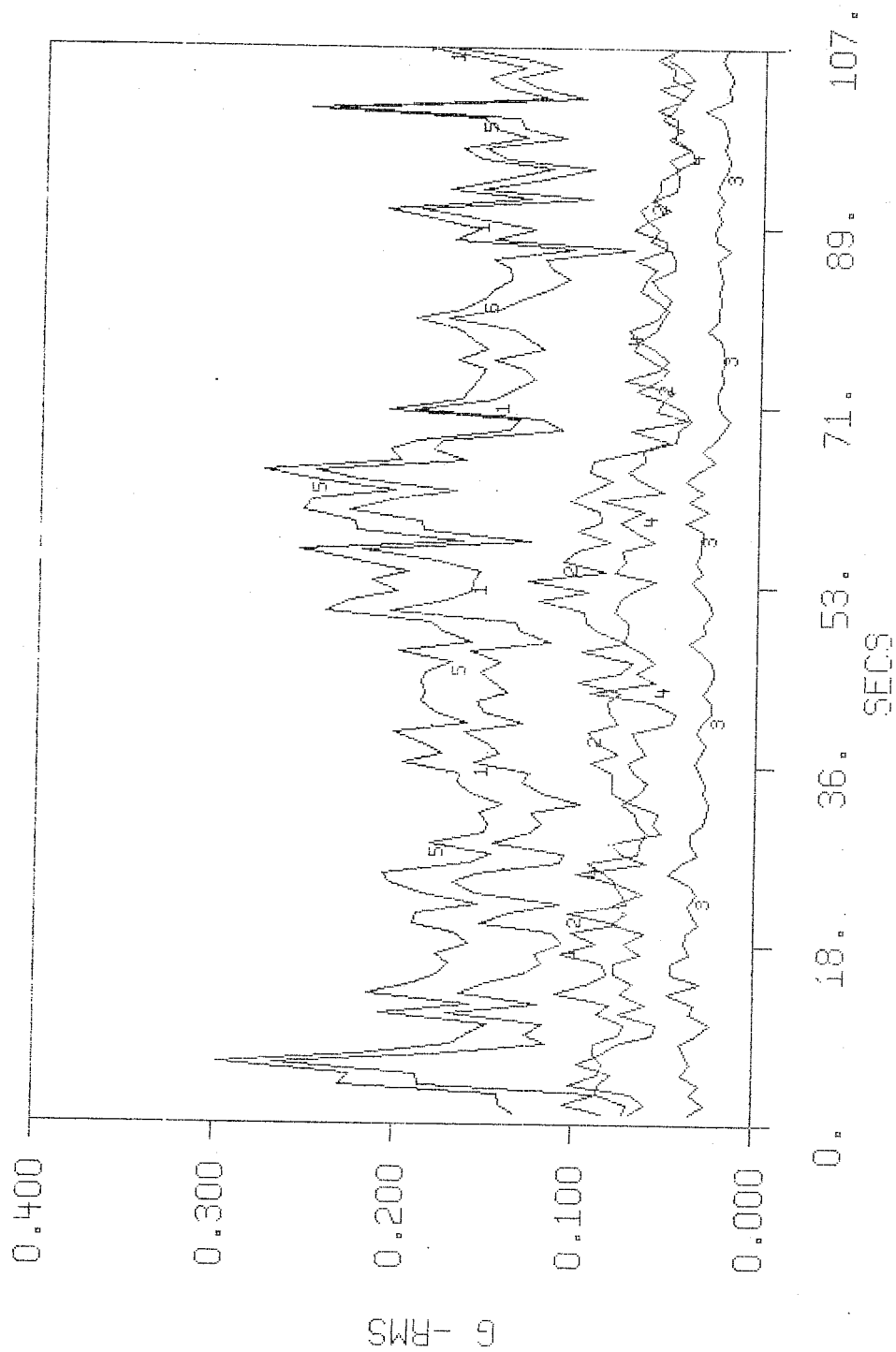
FRONT SIDE LATERAL
T7=3 D=4 TP=3 FL=1



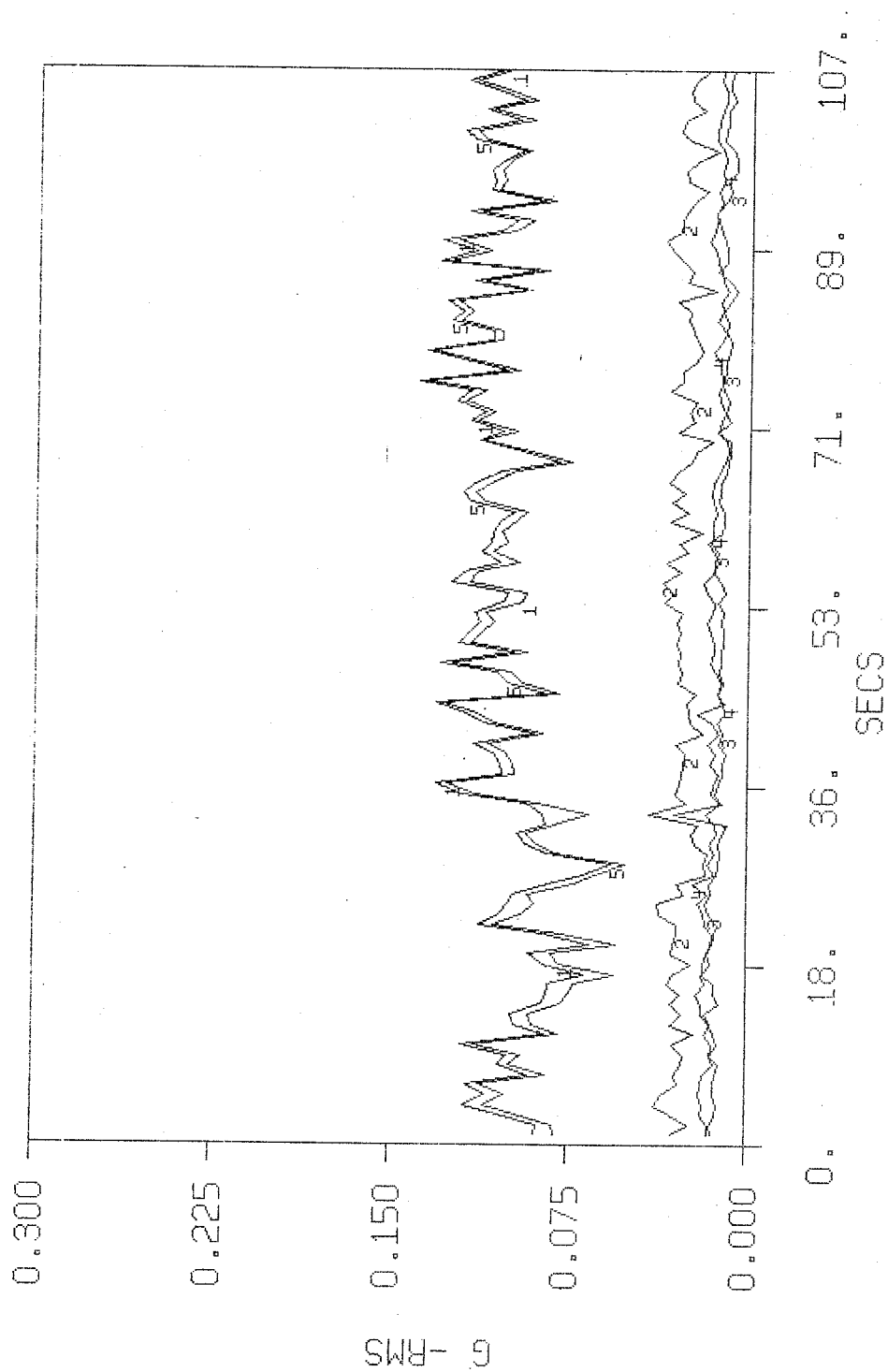
MID SIDE VERTICAL
TZ=3 D=N TP=3 FL=1



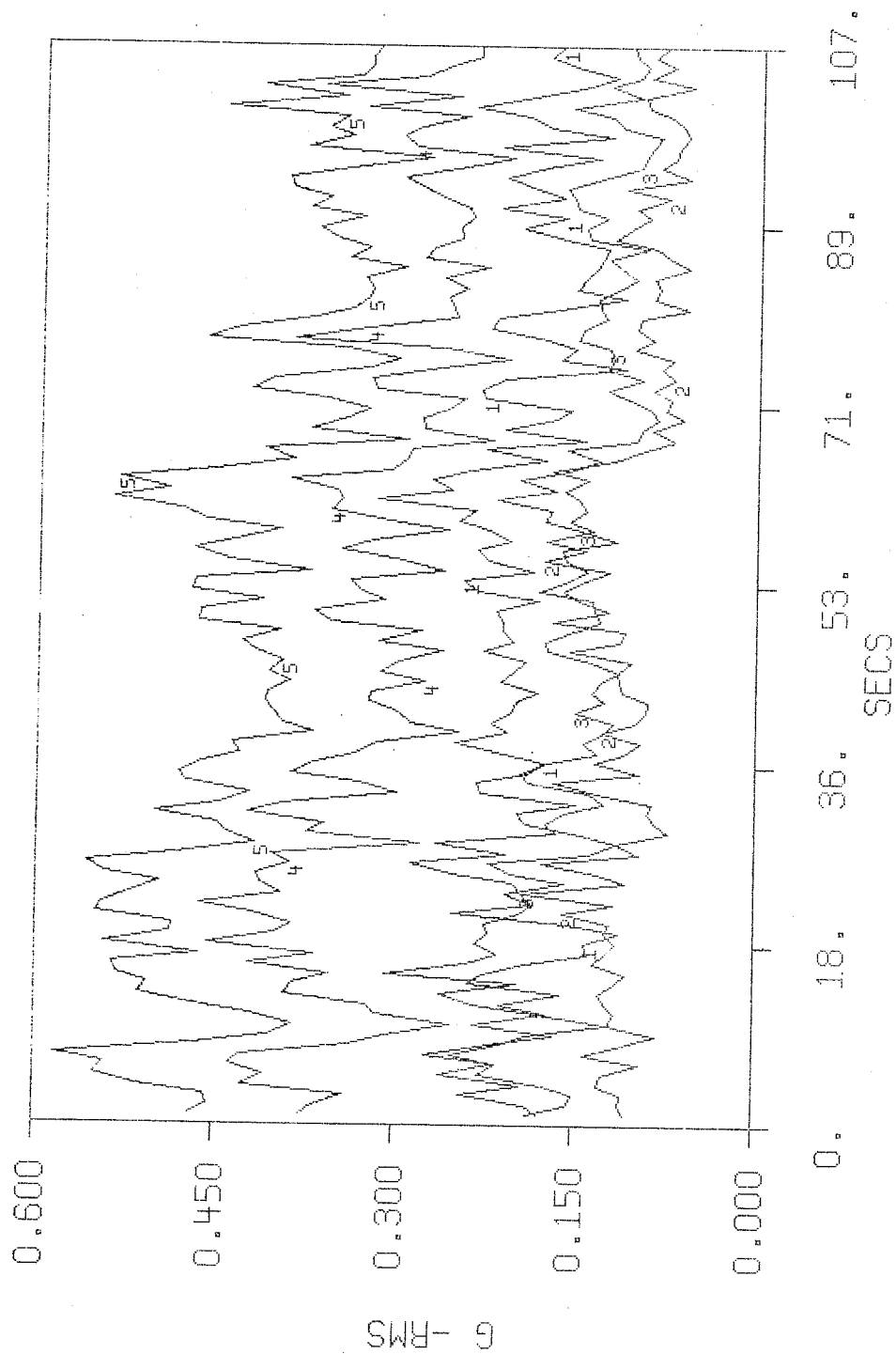
MID SIDE LATERAL
TZ=3 D=W TP=3 FL=1



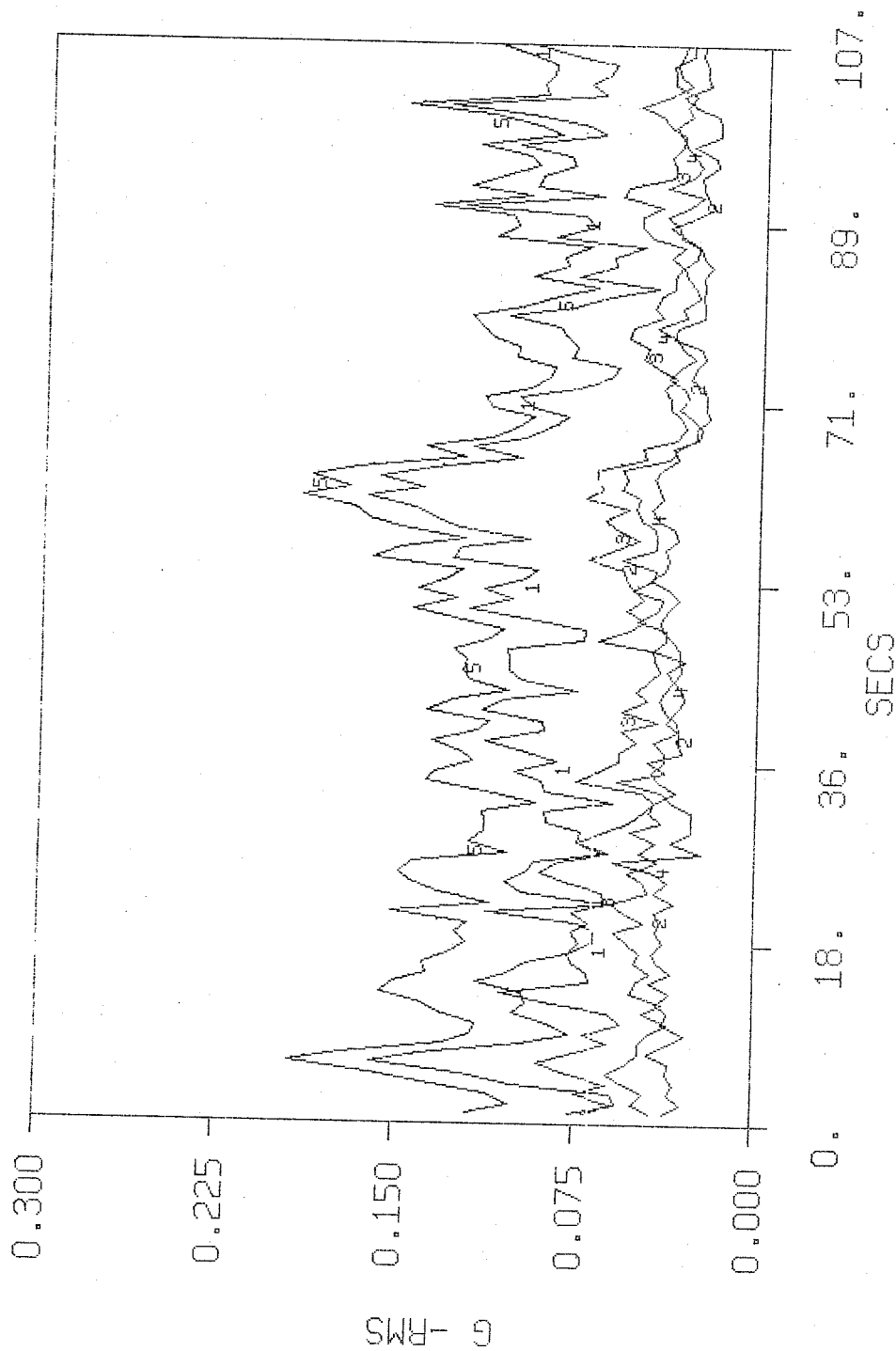
REAR SIDE VERTICAL
TZ=3 D=H TP=3 FL=1



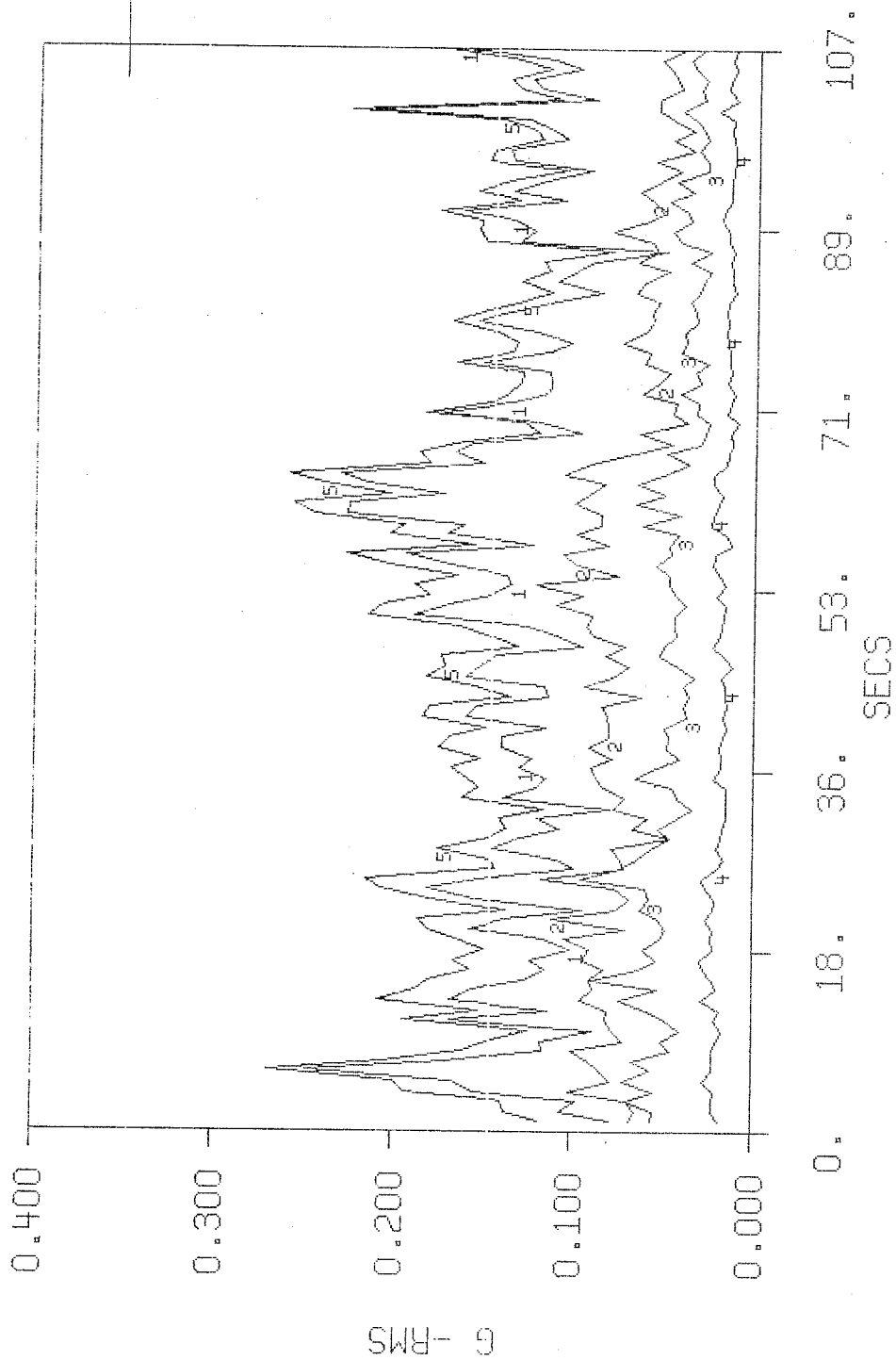
REAR SIDE LATERAL
 TZ=3 D=H TP=3 FL=1



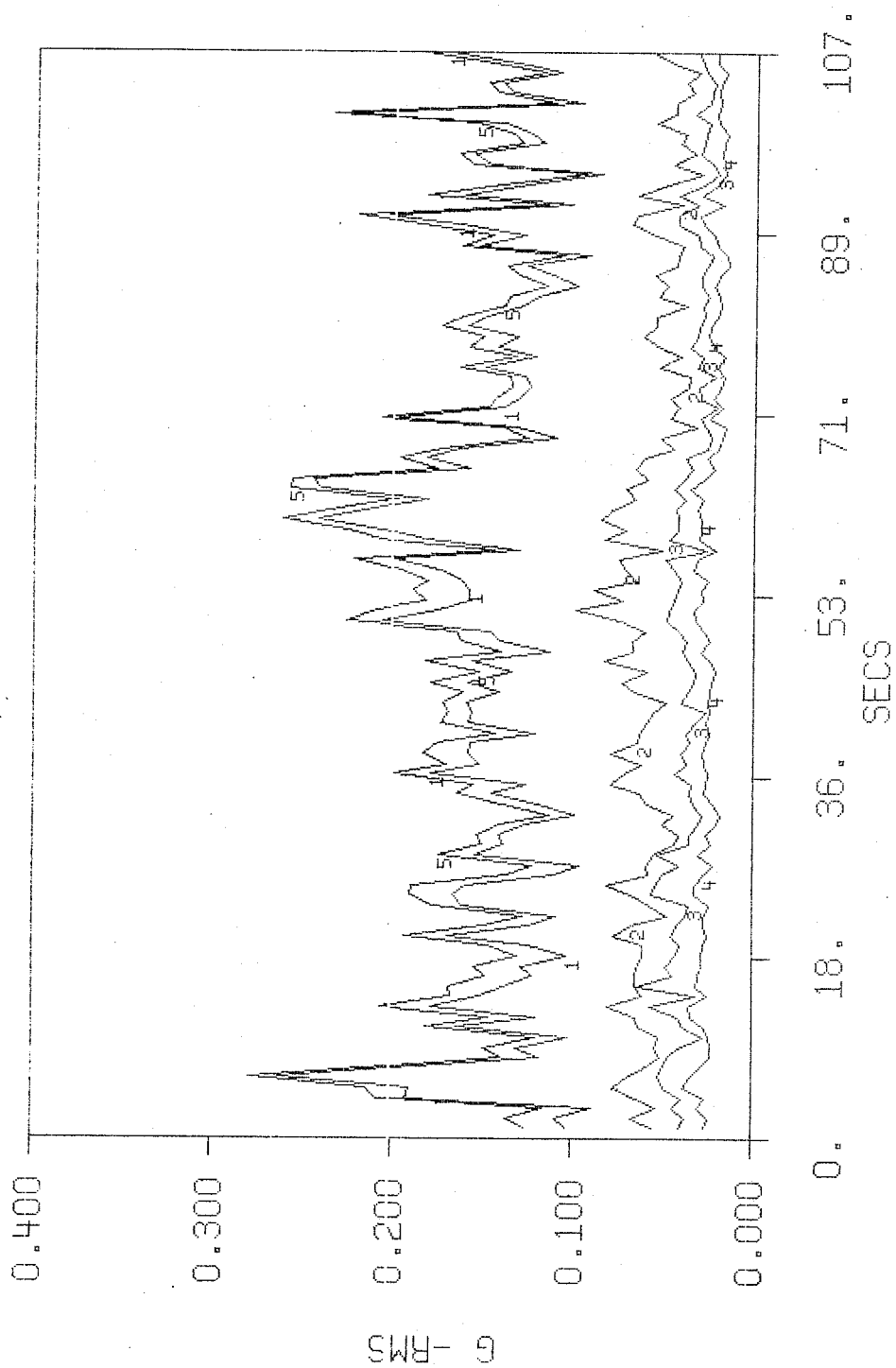
FRONT CENTER VERTICAL
 TZ=3 D=W TP=3 FL=1



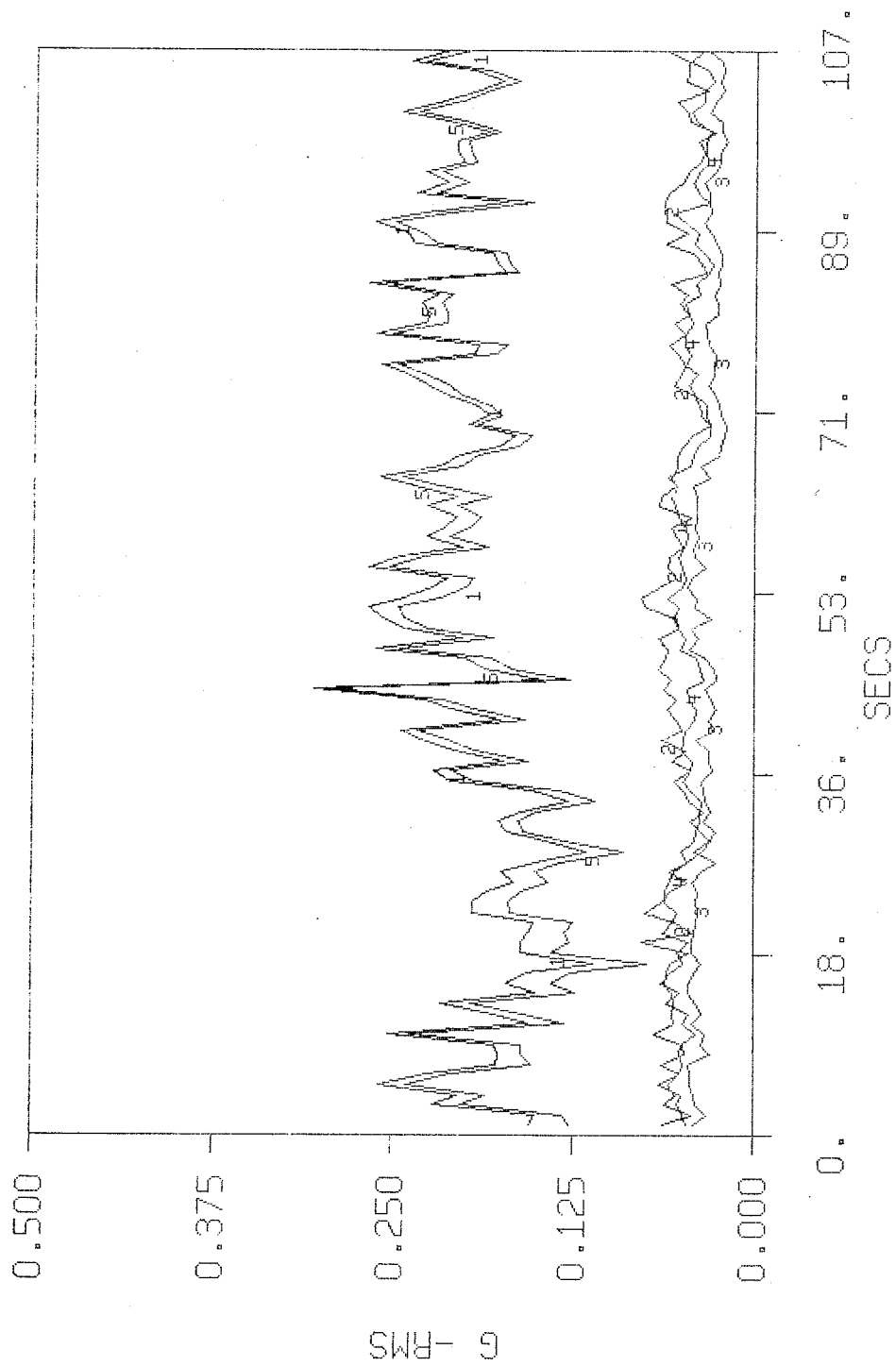
MID CENTER VERTICAL
 TZ-3 B-W TP-3 FL-1



REAR CENTER VERTICAL
TZ=3 D=M TP=3 FL=1

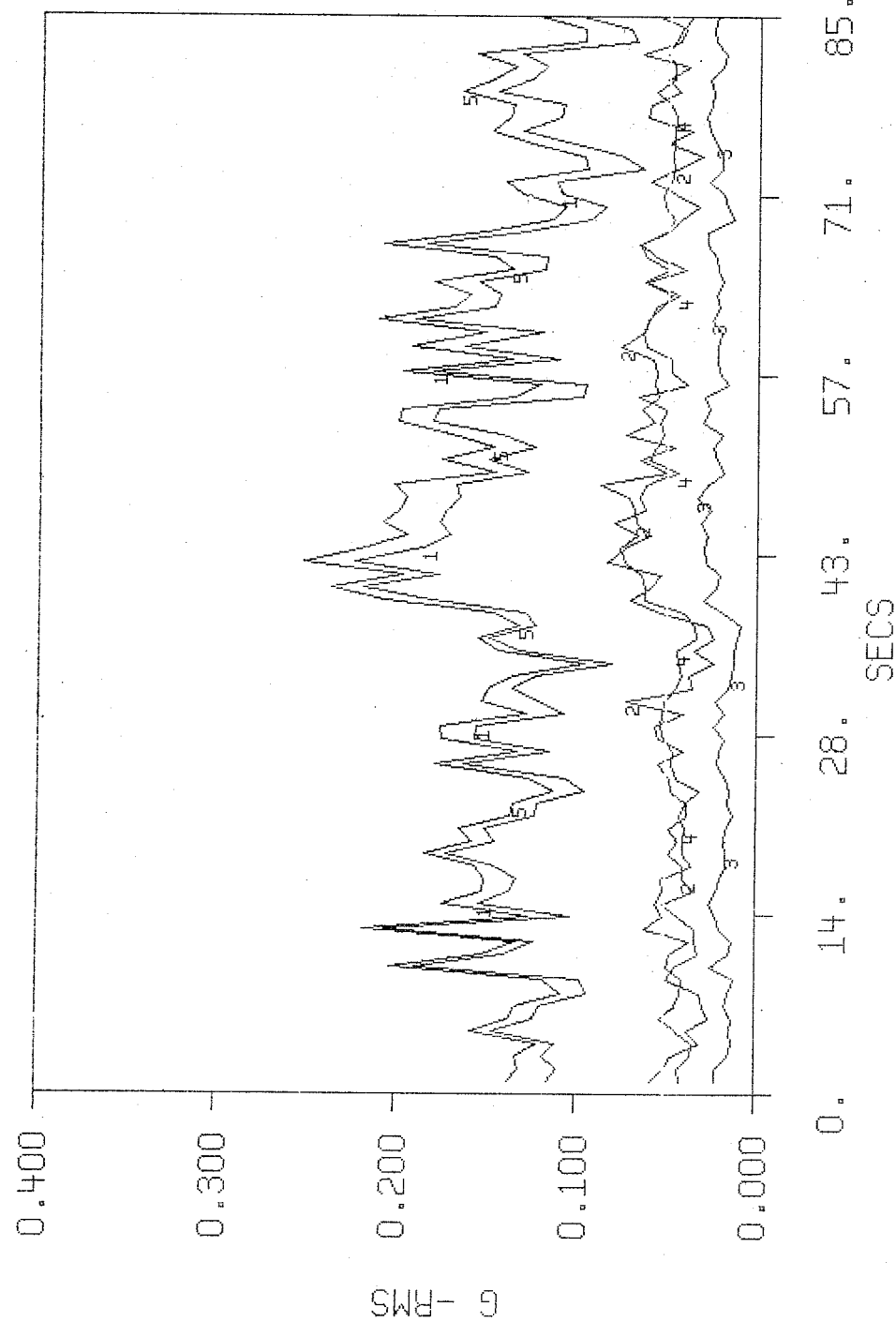


LADING VERTICAL
TZ=3 D=4 TP=3 FL=1



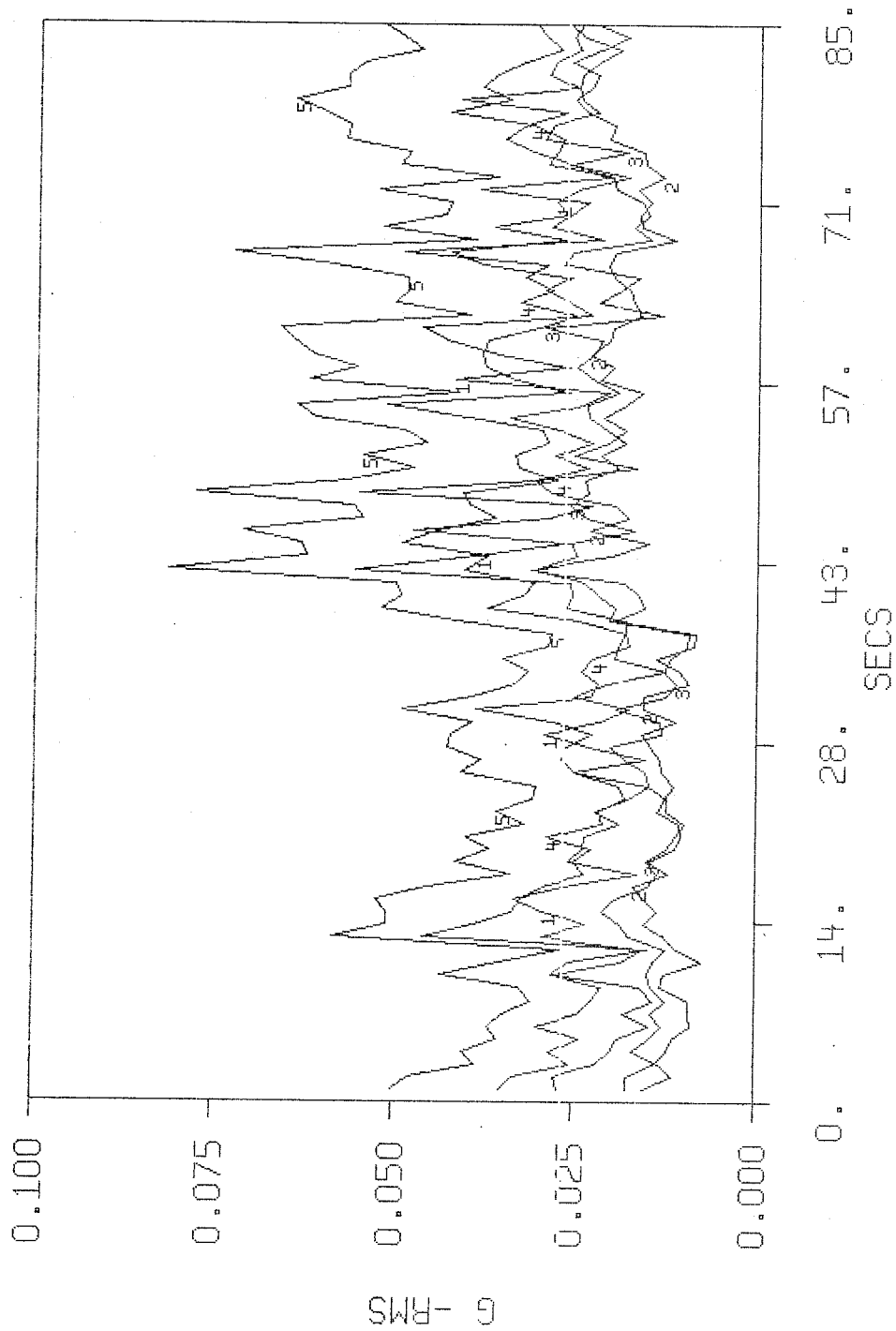
MID TOP LATERAL
 TZ=3 D=H TP=3 FL=1

TZ 3 (EB)

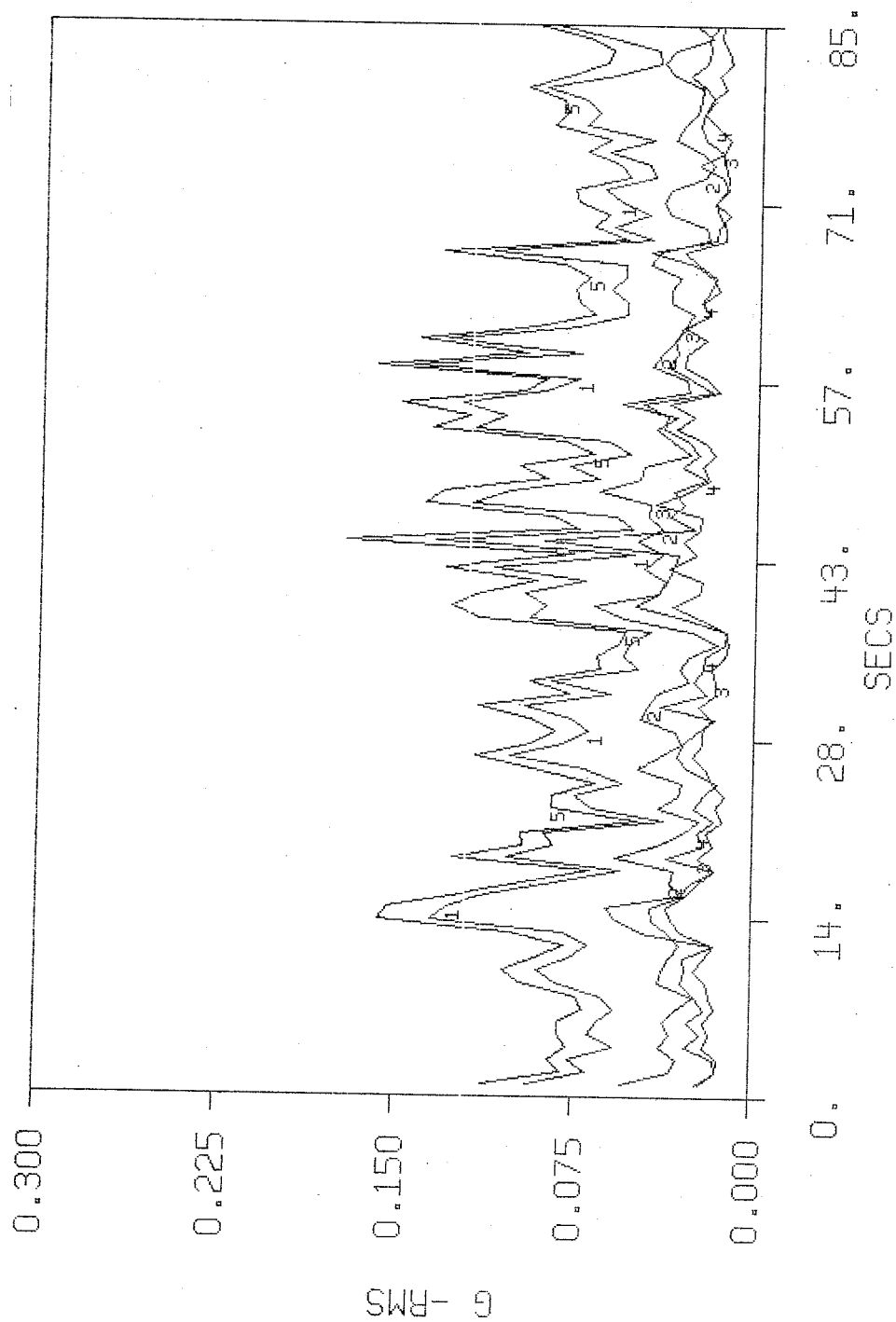


FRONT SIDE VERTICAL
 TZ = 3 D = EB TP = 2 FL = 3

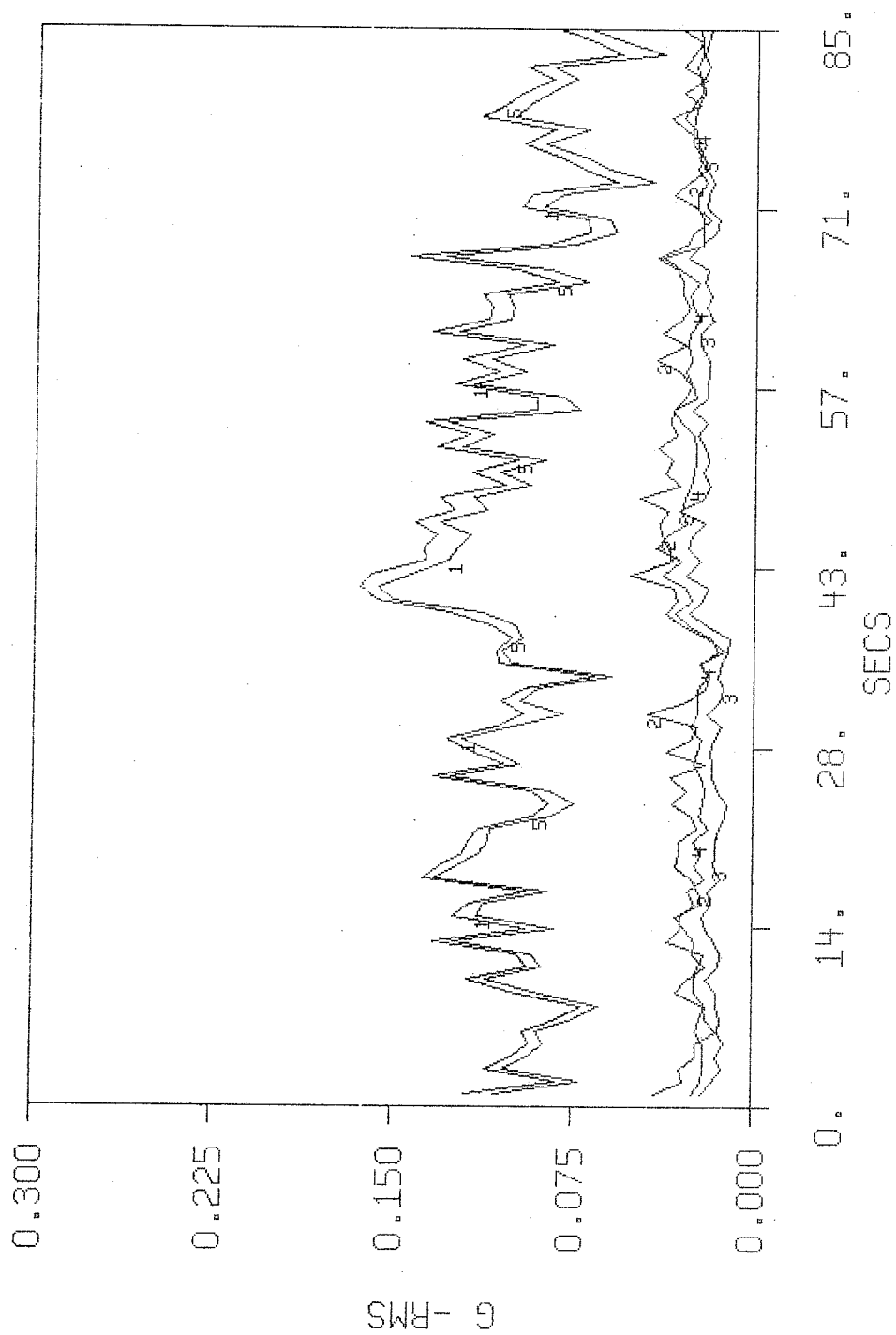
TZ 3 (EB)



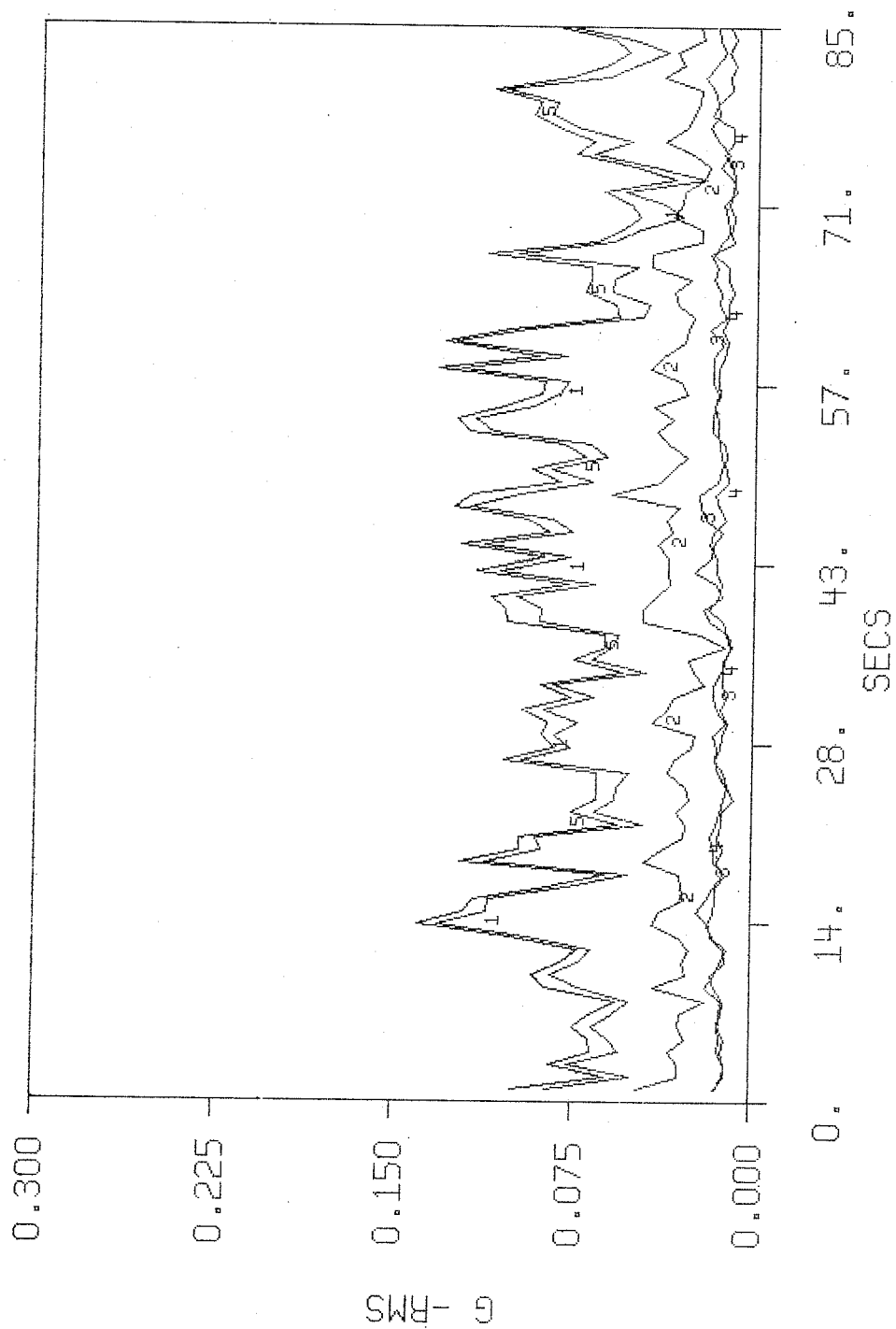
FRONT SIDE LONGITUDINAL
TZ = 3.0 = EB TP = 2 FL = 3



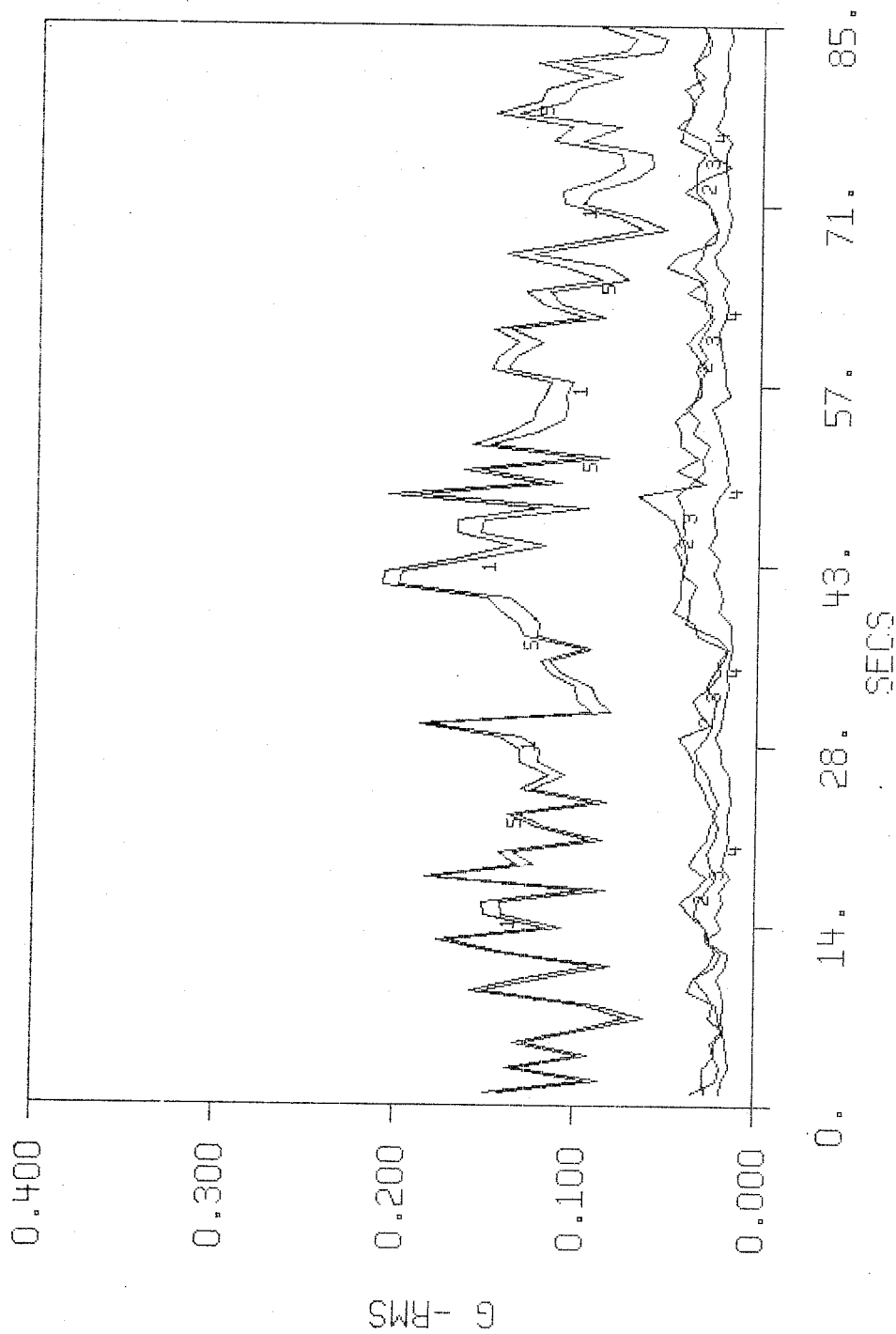
FRONT SIDE LATERAL
TZ = 3.0 = EB TP = 2 FL = 3



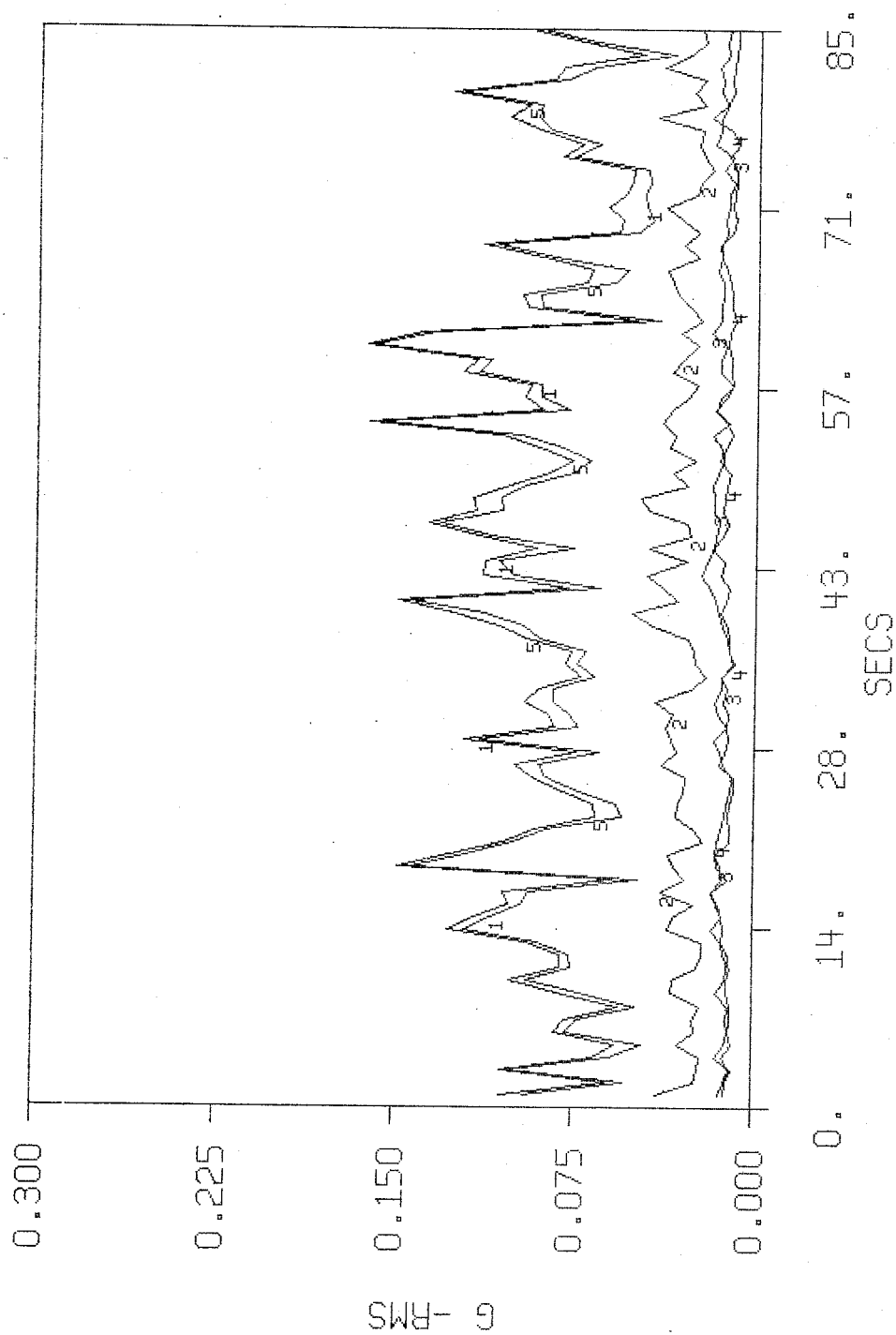
MID SIDE VERTICAL
 TZ = 3.0 = EB TP = 2 FL = 3



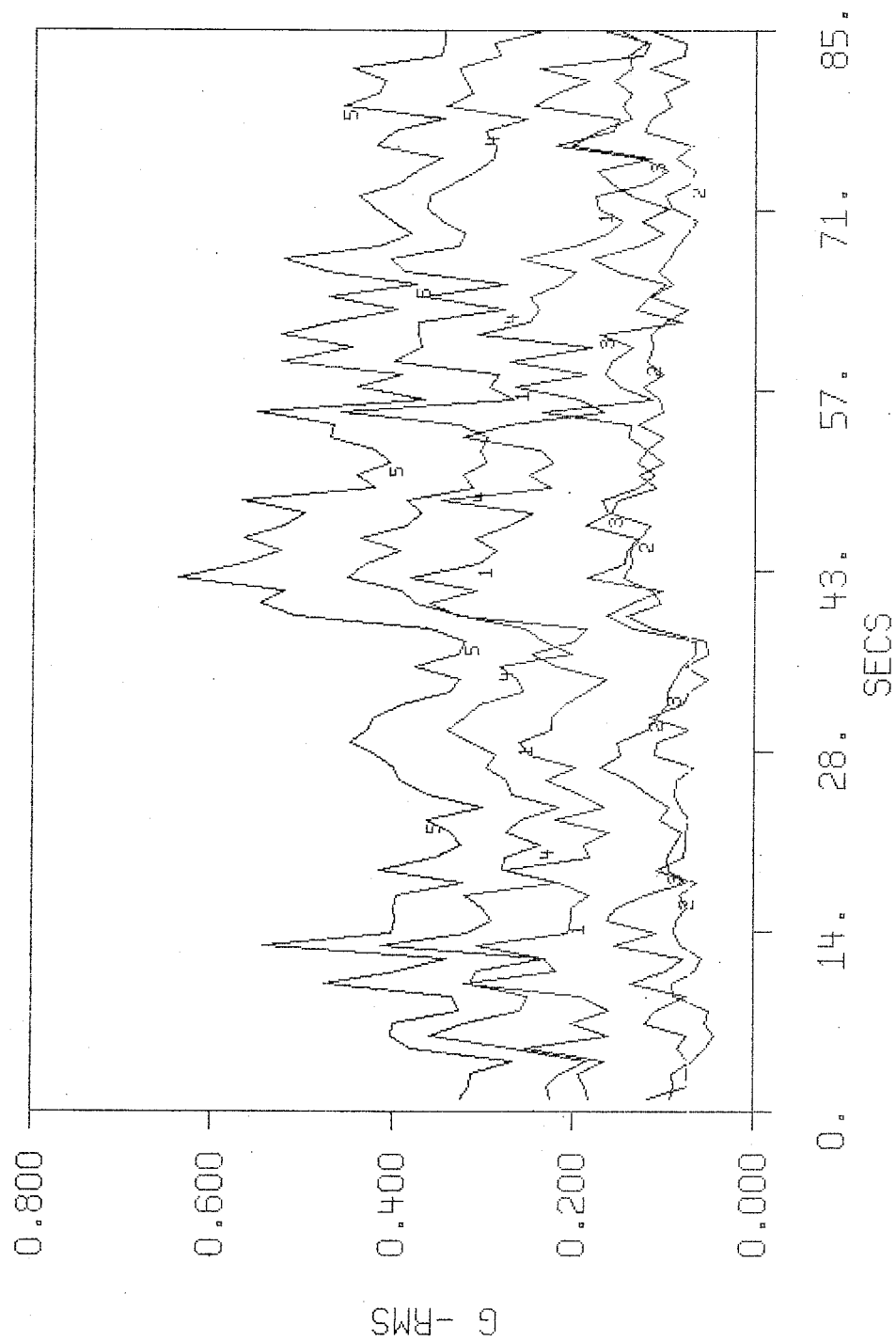
MID SIDE LATERAL
TZ = 3 D = EB TP = 2 FL = 3



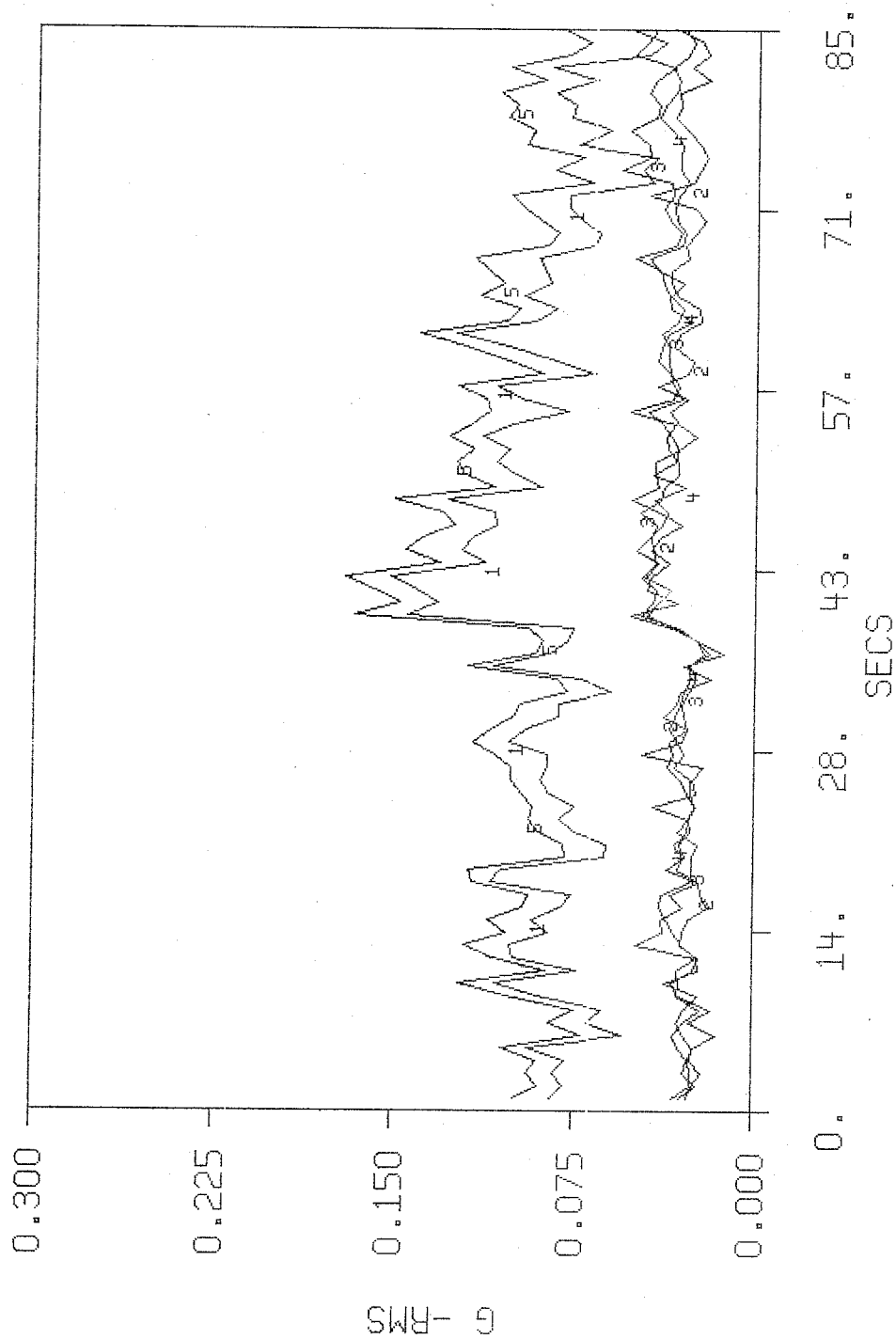
REAR SIDE VERTICAL
 TZ = 3 0 = EB TP = 2 FL = 3



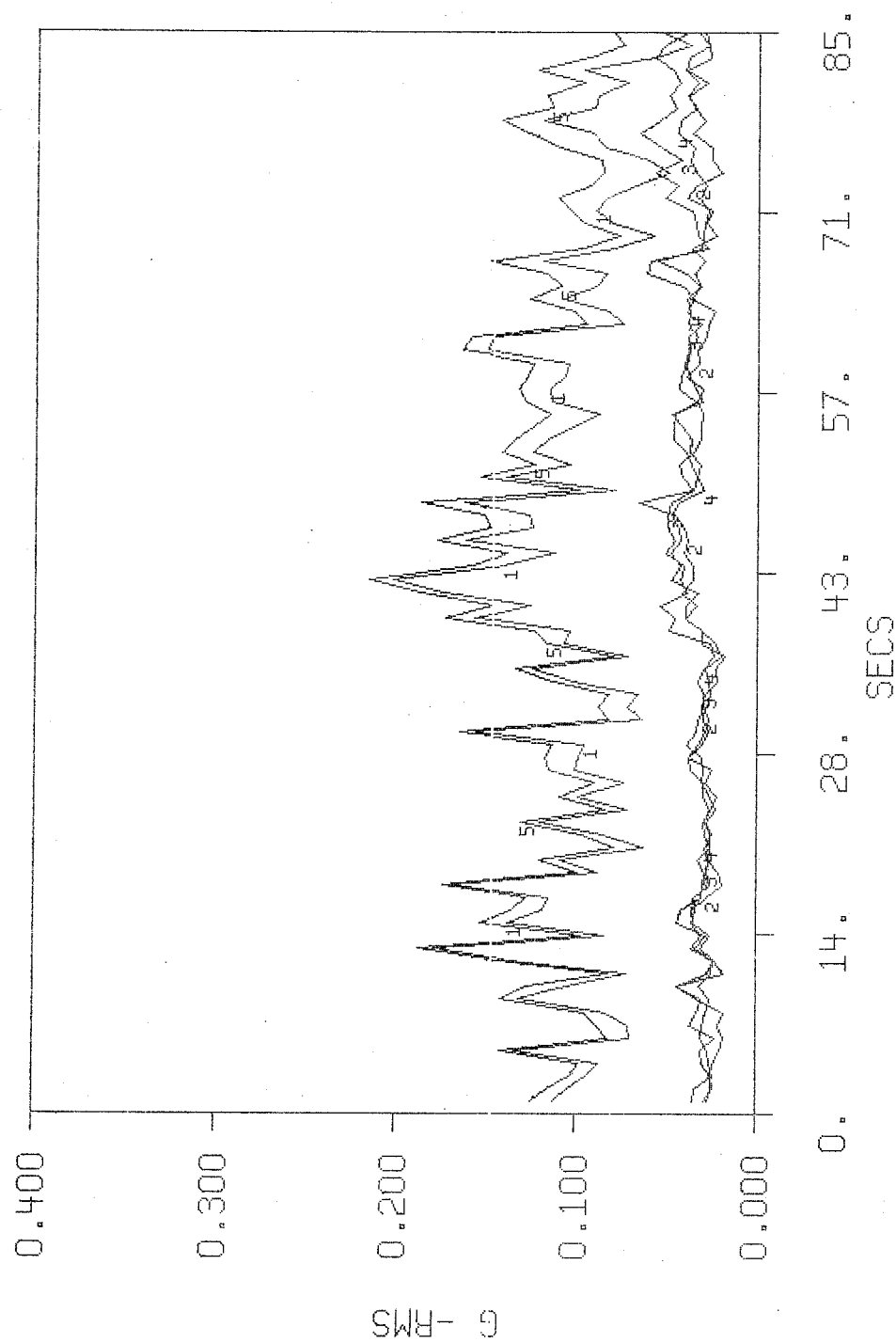
REAR SIDE LATERAL
 TZ = 3 0 = EB TP = 2 FL = 3



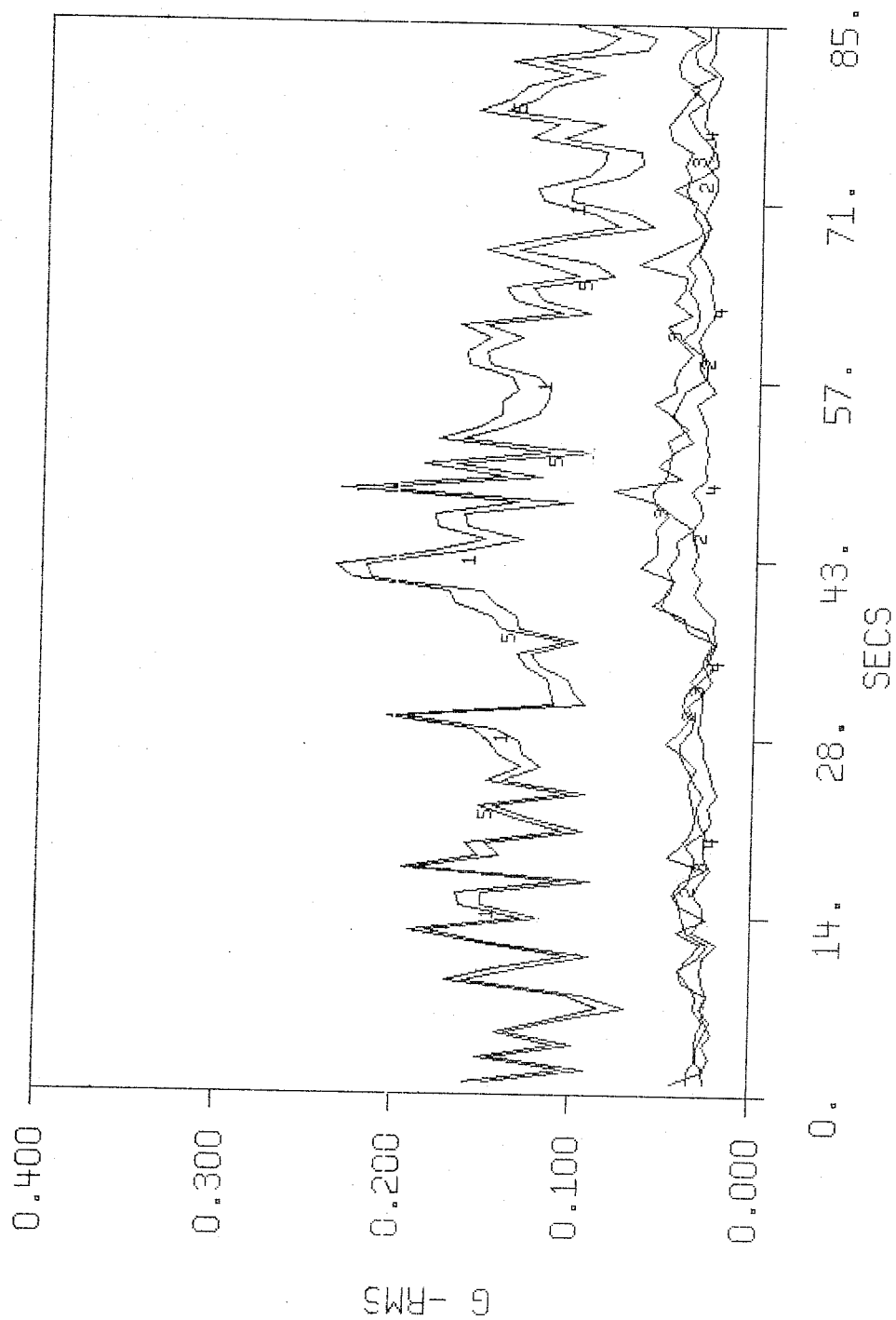
FRONT CENTER VERTICAL
 TZ = 3 D = EB TF = 2 FL = 3



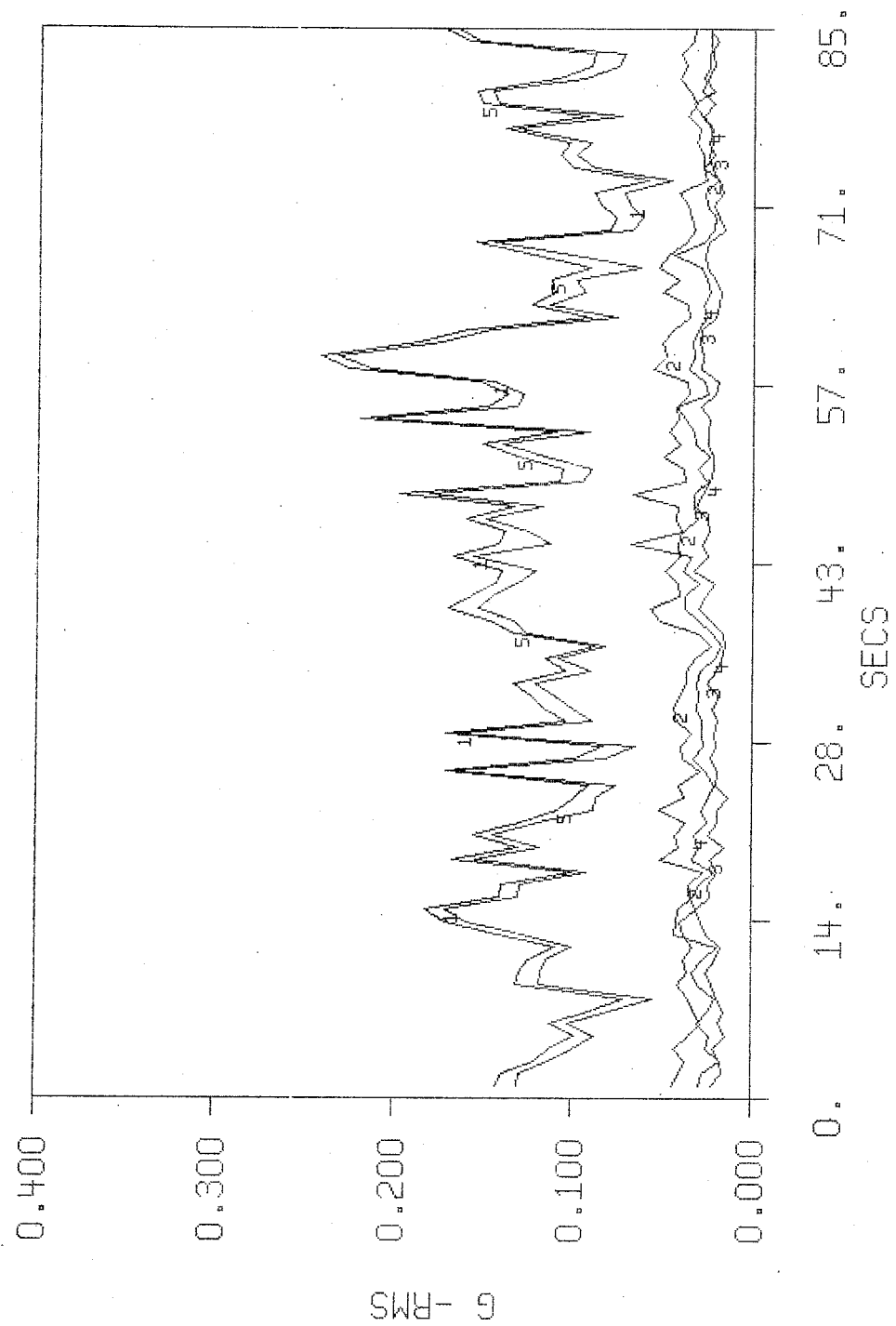
MID CENTER VERTICAL
 12-00-00 11-21-3



REAR CENTER VERTICAL
TZ = 9.0 = F8 IP = 2 FI = 3



LADING VERTICAL
 TP - 20 - FR TP - 7 EI - 2



MID TOP LATERAL

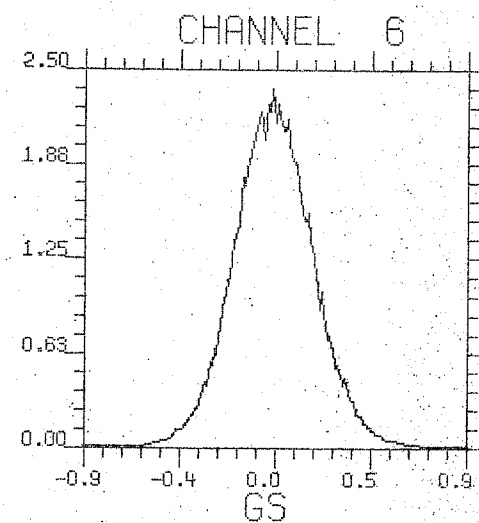
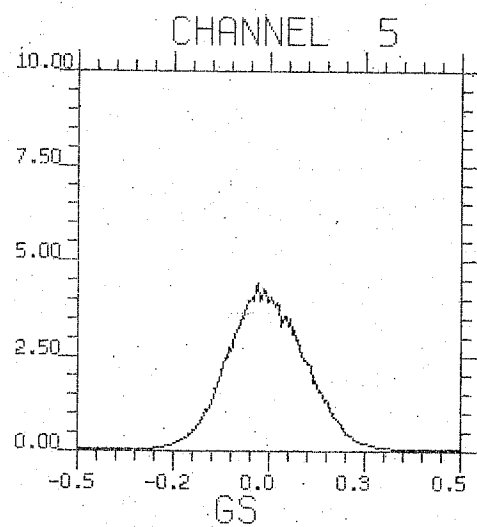
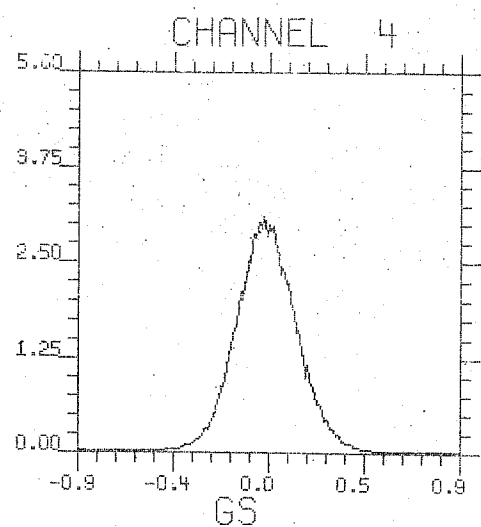
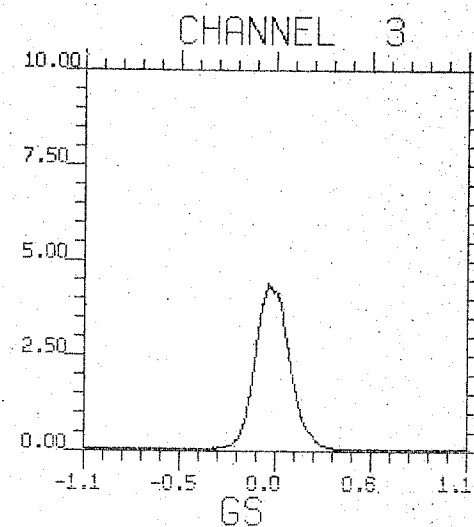
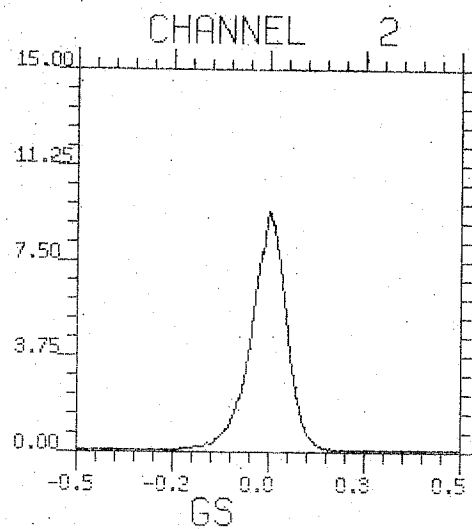
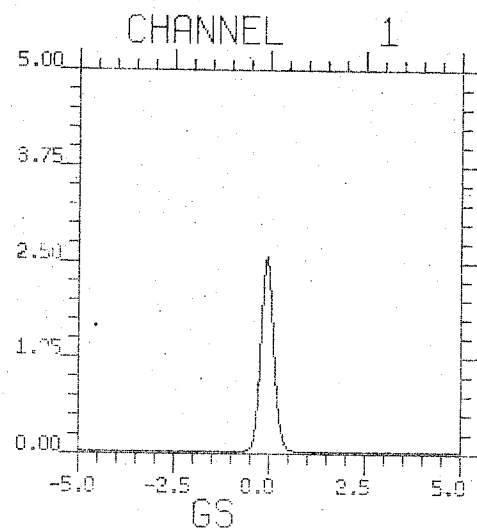
APPENDIX C

EXAMPLES OF STATISTICAL SUMMARIES
(TIME DOMAIN)
TEST ZONE 3

(Data of other test zones are available in Volume II of this report)

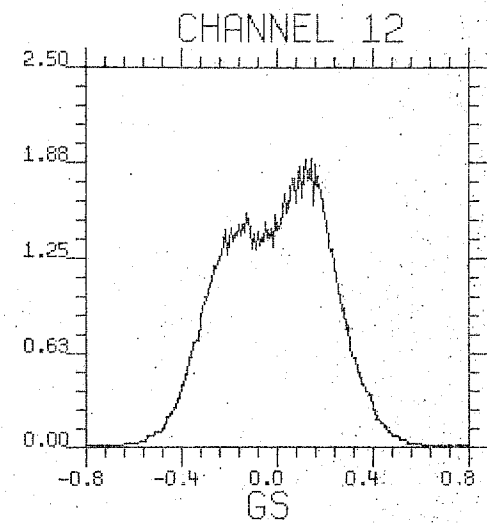
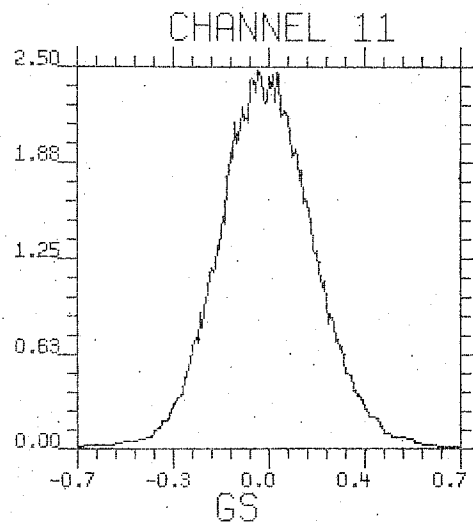
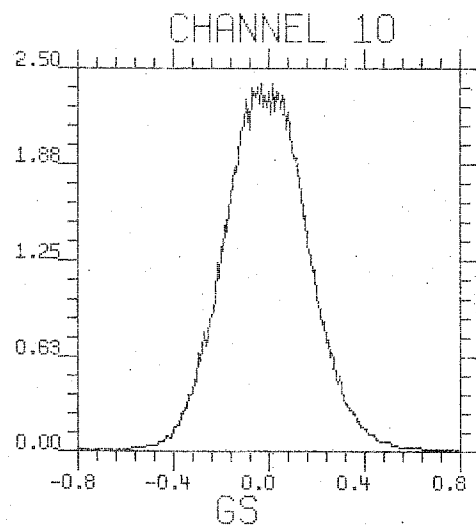
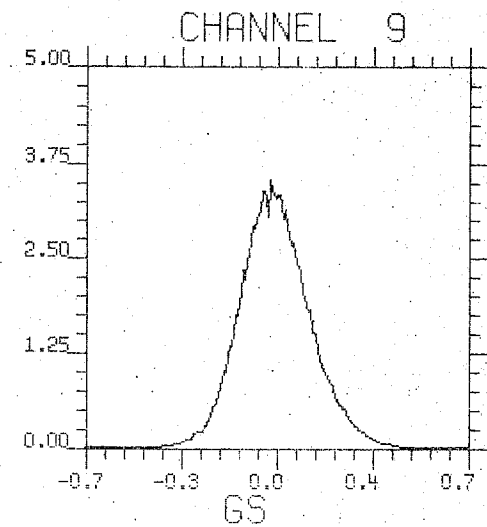
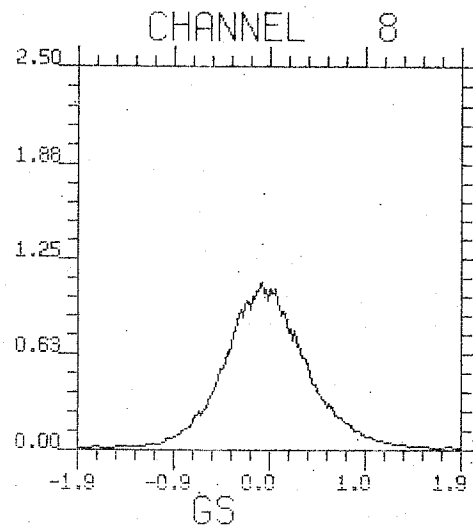
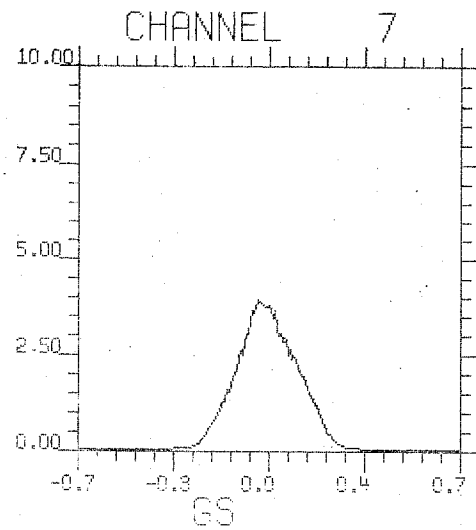
PROBABILITY DENSITY ESTIMATE

FILE01 TZ #3, R&R # 2 8/23/78
TP=3 FL=1 TZ=3 D=WB

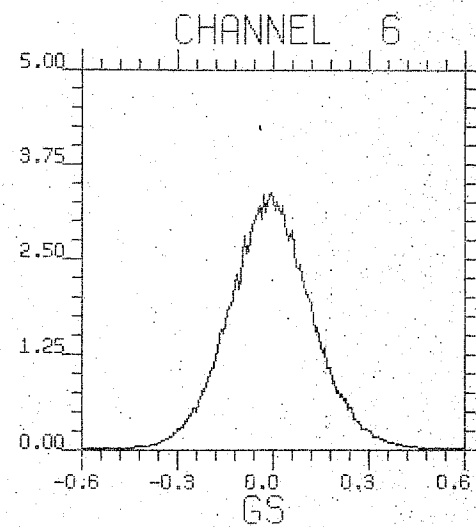
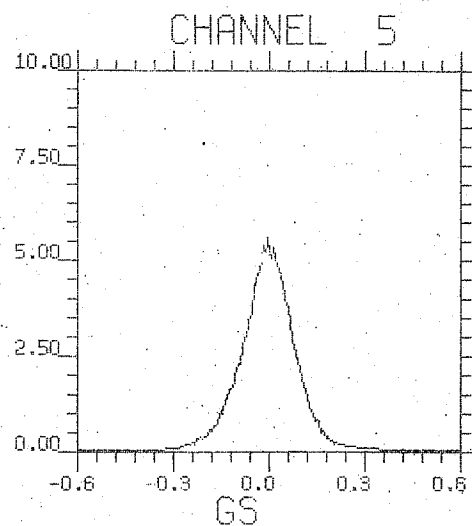
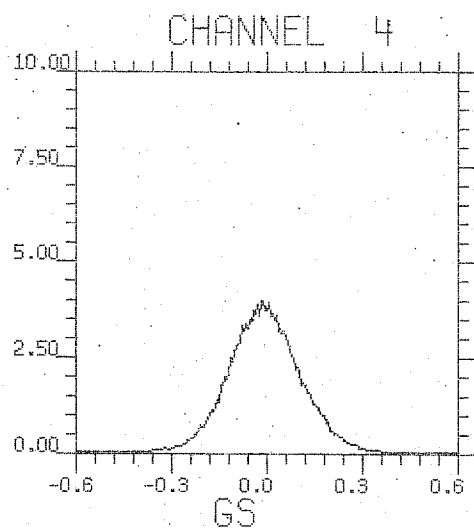
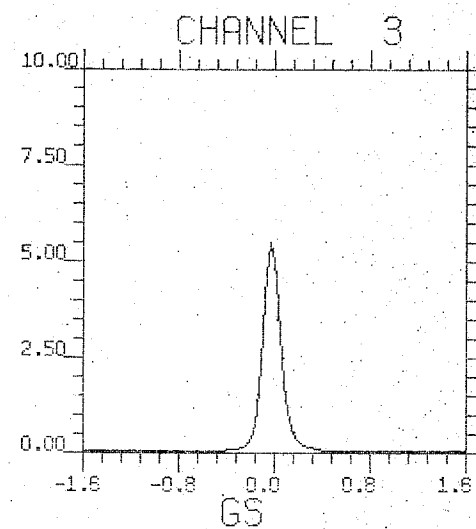
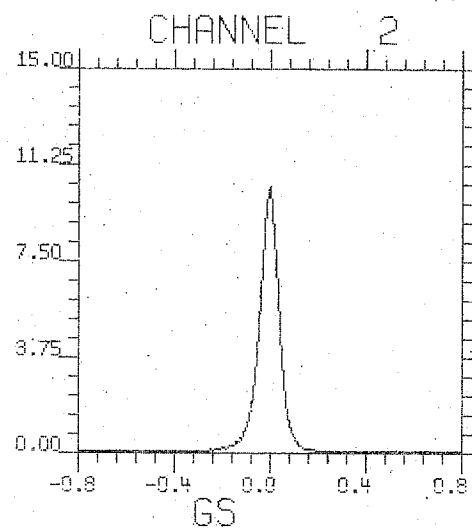
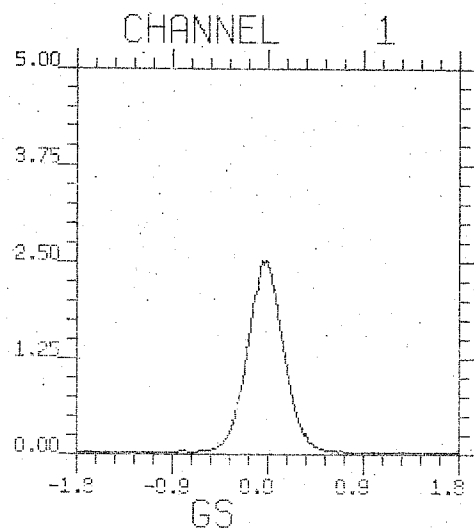


PROBABILITY DENSITY ESTIMATE

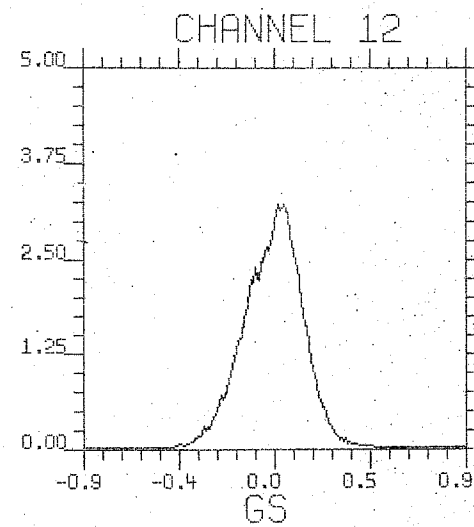
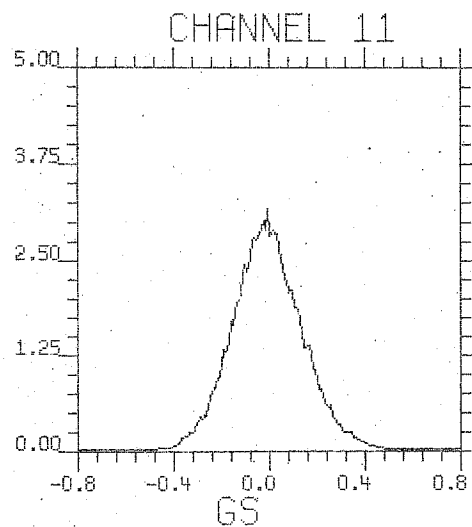
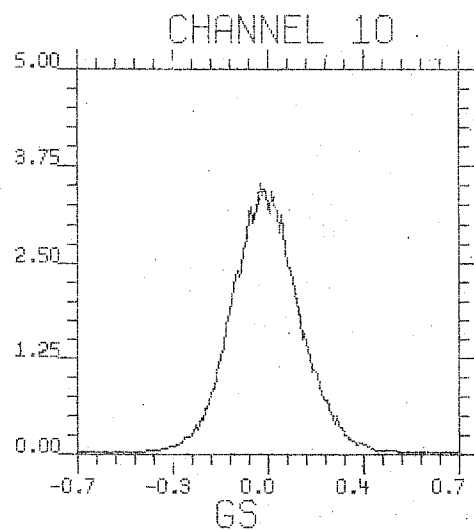
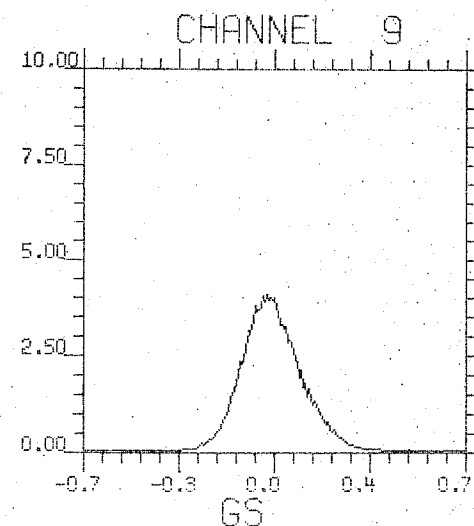
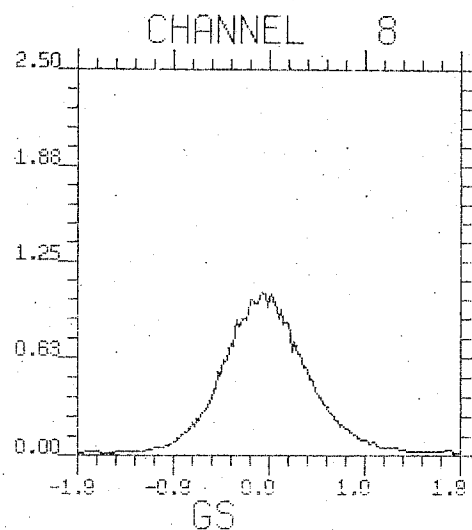
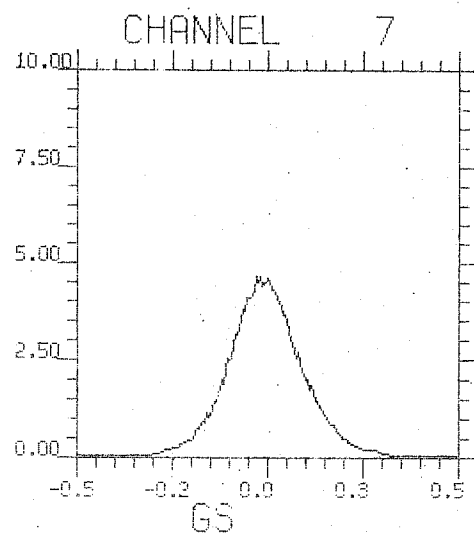
FILED1 TZ #3, R&R # 2 8/23/78
TP=3 FL=1 TZ=3 D=WB



PROBABILITY DENSITY ESTIMATE
FILE02 TZ #3.E, R&R #2, MF 61-60 8/25/78
TP=2 FL=3 TZ=3 D=EB



PROBABILITY DENSITY ESTIMATE
FILE02 TZ #3,E, R&R #2, MP 61-60 3/25/78
TP=2 FL=3 TZ=3 D=EB



VIBRATION ANALYSIS SUMMARY
 FILE01 TZ #3, R&R # 2 8/23/78
 TP=3 FL=1 TZ=3 D=WB

	CHANNEL GS 1	CHANNEL GS 2	CHANNEL GS 3
STANDARD DEVIATION	0.1827	0.0525	0.0988
95 PER CENT LEVEL	0.2599	0.0740	0.1594
99 PER CENT LEVEL	0.4101	0.1105	0.2513

	CHANNEL GS 4	CHANNEL GS 5	CHANNEL GS 6
STANDARD DEVIATION	0.1399	0.0969	0.1825
95 PER CENT LEVEL	0.2328	0.1596	0.3037
99 PER CENT LEVEL	0.3419	0.2276	0.4453

TIME PROCESSED 107.0 SECS

VIBRATION ANALYSIS SUMMARY
 FILE01 TZ #3, R&R # 2 8/23/78
 TP=3 FL=1 TZ=3 D=WB

	CHANNEL 7 GS	CHANNEL 8 GS	CHANNEL 9 GS
STANDARD DEVIATION	0.1070	0.4382	0.1263
95 PER CENT LEVEL	0.1755	0.7456	0.2160
99 PER CENT LEVEL	0.2357	1.1759	0.3223

	CHANNEL 10 GS	CHANNEL 11 GS	CHANNEL 12 GS
STANDARD DEVIATION	0.1670	0.1700	0.2102
95 PER CENT LEVEL	0.2734	0.2802	0.3222
99 PER CENT LEVEL	0.4080	0.4095	0.4297

TIME PROCESSED 107.0 SECS

VIBRATION ANALYSIS SUMMARY
 FILE02 TZ #3,E, R&R #2, MP 61-60 8/25/78
 TP=2 FL=3 TZ=3 D=EB

	CHANNEL 1 GS	CHANNEL 2 GS	CHANNEL 3 GS
STANDARD DEVIATION	0.1884	0.0517	0.1010
95 PER CENT LEVEL	0.2839	0.0695	0.1469
99 PER CENT LEVEL	0.4709	0.1189	0.2880

	CHANNEL 4 GS	CHANNEL 5 GS	CHANNEL 6 GS
STANDARD DEVIATION	0.1105	0.0881	0.1296
95 PER CENT LEVEL	0.1831	0.1341	0.2159
99 PER CENT LEVEL	0.2689	0.2177	0.3187

TIME PROCESSED 85.0 SECS

VIBRATION ANALYSIS SUMMARY
 FILE02 TZ #3,E, R&R #2, MP 61-60 8/25/78
 TP=2 FL=3 TZ=3 D=EB

	CHANNEL GS 7	CHANNEL GS 8	CHANNEL GS 9
STANDARD DEVIATION	0.0967	0.4540	0.1091
95 PER CENT LEVEL	0.1623	0.7596	0.1866
99 PER CENT LEVEL	0.2443	1.2722	0.2771

	CHANNEL 10 GS	CHANNEL 11 GS	CHANNEL 12 GS
STANDARD DEVIATION	0.1256	0.1439	0.1351
95 PER CENT LEVEL	0.2086	0.2387	0.2025
99 PER CENT LEVEL	0.3092	0.3522	0.2971

TIME PROCESSED 85.0 SECS

