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Vibration field-to-lab: Impact of time measurement intervals on intensity

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VIBRATION FIELD-TO-LAB™: IMPACT OF TIME MEASUREMENT INTERVALS ON INTENSITY

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M.S. DEGREE THESIS

The M.S. Degree Thesis of Frank J. Magnifico and Jay D. Gerondale has been examined and approved by the thesis committee as satisfactory for the thesis requirements for the Master of Science Degree.

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DEDICATION

With love and gratitude, we dedicate this thesis to our wives and children without whose patience, support and understanding of the countless hours and late nights, this paper would not have been possible.

To Julie, Madisyn and Zachary, thanks for providing great joy and happiness everyday, while providing a meaning to life.

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ABSTRACT

The objective of this study was to determine what impact various time measurement intervals would have on intensity levels in the trucking environment. The study was limited to timer triggered data collection associated with semi trailer vibration. The study then examined the relationship between established wake-up time intervals and the resultant intensities and PSD plots for the same field trip. In order to accomplish this, it was necessary to use multiple recorders. Each recorder was to be set with a specific time trigger threshold for recording data.

Two vibration environments were analyzed using Saver™ vibration recording equipment. One environment was limited to short trips of less than four hours and the second test environment consisted of long trucking runs in excess of thirty hours. After a significant amount of data was collected, a statistical analysis was then completed to determine what the effects of varying the time intervals had on intensity.

Several different elements of the data were discussed. Namely, they were standard deviation, ANOVA, percent difference, Field-to-Lab™, and PSD comparisons. Each element provided more insight into the affect of varying the time trigger interval. If each element were isolated, arriving at a conclusion with a high level of confidence would be difficult. However, evaluating all the elements together point the data in a single direction and indicate that varying the time measurement interval does have an impact on the calculated intensity for Field-to-Lab™ vibration analysis.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
G	Measurement of Intensity
ID	Inner Dimensions
L	Liter
N	Number of Events
OD	Outer Dimensions
oz	Ounce
PSD	Power Spectral Density
rms	Root mean square

INTRODUCTION

In order to protect products in today's logistics, handling, and transportation environment, it is necessary for packaging design engineers to utilize all available tools. The ultimate goal of the packaging engineer is to have the optimum package design with the lowest possible price attributable to packaging while ensuring total customer satisfaction from the end user. Product weight, size, fragility, and composition are all critical pieces of information that help to optimize the type of product protection. Other critical product protection information includes shock and vibration that the product will encounter in the distribution system.

Recording and characterizing random shock and vibration in the distribution environment has become relatively easy over the past few years. The increase in the understanding of the environment is due to the major role that technology has played. Today, there are several types of shock and vibration recording equipment to choose from. The available equipment is compact, lightweight, and can record a plethora of shock and vibration related data. One such field recorder is the Saver™ by Dallas Instruments. The Saver™ can measure and record shock and vibration accelerations on three axes, drop heights, humidity, temperature, and time (Dallas Instruments, 1998). Utilizing the Saver™ results in compilation of data in a convenient remote manner. The Saver™ software allows the user to develop and set a unique set of test protocols specific to the user's needs.

One of the benefits of using shock and vibration recorders is the ability to collect field data and reproduce it in the laboratory. It is then possible to simulate the distribution system that a particular product will encounter based upon the field data. For example, if a company normally ships their product via truck from Philadelphia, Pennsylvania to Orlando, Florida, then the company can utilize the Saver™ technology to record shock and vibration data during one of their shipments. Once analyzed, the calculated data and resultant Power Spectral Density (PSD) profile is loaded onto computer controlled laboratory vibration equipment. It is now possible to evaluate the package design by simply placing the product on the vibration platform and running the computer program for the Philadelphia to Orlando shipment.

In the example above, the normal Philadelphia to Orlando shipment may take 18 hours to drive by truck. Simulating that exact shipment in the lab will also take 18 hours (excluding test equipment set up time). However, there is another benefit of utilizing Saver™ technology. This testing process might be acceptable if only evaluating one package design. But if a company has numerous designs, test evaluations will be time consuming and costly. Utilizing Saver™ and Field-to-Lab™ methodology developed by Lansmont Corporation, the 18-hour test mentioned above can possibly be compressed into approximately 3.5 hours. As a result, the Field-to-Lab™ methodology can save companies significant time and money.

1.0 OVERVIEW

When utilizing Field-to-Lab™ methodology, it is necessary to determine and standardize the test parameters and protocols specific to the application. For establishing a Field-to-Lab™ test for simulating a truck route, there are numerous elements to consider prior to starting testing. Some of the key equipment configuration elements include:

- Saver™ unit memory
- Mounting the Saver™
- Mounting location
- Trip length
- Memory partitions
- Signal trigger threshold
- Time trigger threshold

The time trigger threshold is of particular importance. During a lecture on Field-to-Lab™ methodology, it was discussed that the actual number of readings taken during and actual field vibration experiment affect neither the calculated Power Spectral Density (PSD) plot nor the resulting test intensity (Grms). Lecture participants were told to take a leap of faith regarding the analysis (Kipp, 1999). One possible rationale was that the overall intensities average out over the time of the trip. Follow-up queries left more questions than answers. Since there was no formal documented Field-to-Lab™ experiments conducted for analyzing the same trip with varying time trigger data collection units, then the only way to verify the theory was to conduct such an experiment. The results of such an experiment will have an impact to the confidence level for all future Field-to-Lab™ simulations.

1.1 Statement of Problem

Time measurement interval (in the time domain) does not have an impact on the calculated intensity and PSD plot for Field-to-Lab™ vibration analysis.

1.2 Hypothesis

H = Varying the time measurement interval will not have an impact on the calculated intensity and PSD plot for Field-to-Lab™ vibration analysis.

H_0 = Varying the time measurement interval will have an impact on the calculated intensity and PSD plot for Field-to-Lab™ vibration analysis.

2.0 EXPERIMENT

The intent of the experiment was to examine the relationship between established wake-up time intervals and the resultant intensities and PSD plots for the same field trip. In order to accomplish this, it was necessary to use multiple recorders. Each recorder was to be set with a specific time trigger threshold for recording data. A repeatable standardized test procedure was also necessary. The standardized test procedure consisted of the following elements:

- Use of 4 Saver^{TM} units
- Standardized Saver^{TM} set-up configuration protocols
- Standardized sampling rates for each Saver^{TM} unit
- Use of established trucking routes
- Standardized trailer suspension
- Standardized Saver^{TM} mounting & location for long and short duration experiments
- Similar loads for shipments

2.1 Test Equipment

For the experiment, 4 Saver^{TM} units were used. Figure 2-1 depicts a typical Saver^{TM} unit that was used for testing. Each unit had different maximum memory capacities. The 4 Saver^{TM} units used in the test are represented in Table 2-1. From hence forth, the Saver^{TM} units will be referred to as unit 1, unit 2, unit 4, or unit 8.

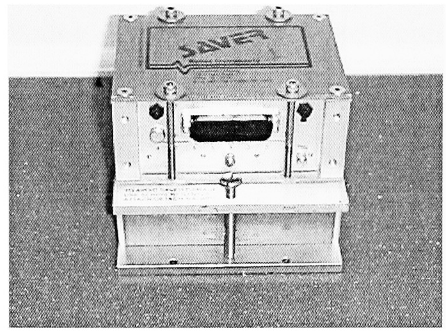


Figure 2-1: Saver™ Unit/Magnetic Mount

Saver™ Unit Number	Saver™ Identification Number	Saver™ Serial Number	Memory in megabytes (max)	Calibration Due Date
1	0417-007	9410-02	1.048576	3/18/00
2	0425-004	9505-14	2.097152	3/18/00
4	0430-008	9604-05	4.194304	3/23/00
8	0442-028	9811-04	8.388608	new

Table 2-1: Saver™ Unit Characteristics

2.1.1 Test Equipment Configuration

Each Saver™ unit was configured with basically the same set-up protocol for both long and short duration runs. The only parameter that varied for each unit was the wake-up time trigger interval. The final Equipment Set-up Protocol was derived using the SaverWare™ software that coincides with Saver™ set-up, use, and subsequent analysis. The benefit of the protocol and gateway set-ups is the ability to store the same set-up and upload it to the Saver™ for each test run. One important protocol element was the Shock and Vibration Gateway Set-up.

The Shock and Vibration Gateway Set-ups were:

Shock Recorder Setup: Record Time: 500msec

Event Analysis: Triaxial Resultant

Vibration Recorder Set-up: Analysis Range: 250 Hz

Number of Analysis Lines: 200

Estimated trip length: 3hrs (short)

36 hrs (long)

Another element was the Advanced Set-up. In this portion of the protocol, the memory allocations for Time-Triggered data and Signal-Triggered data were established. Once wake-up intervals were developed, the memory partitions were consequently established. Table 2-2 lists the wake-up intervals, memory partitions, and corresponding number of events for each unit. The complete Equipment Set-up Protocol is detailed in Appendix A.

UNIT	Wake-up Interval: SHORT TRIPS (seconds)	Wake-up Interval: LONG TRIPS (minutes)	Memory Partition: TIME TRIGGER (%)	Number of Events: TIME TRIGGER (max)	Memory Partition: SIGNAL TRIGGER (%)	Number of Events: SIGNAL TRIGGER (max)
1	360	59	11	37	89	300
2	120	20	16	108	84	569
4	30	5	31	419	69	937
8	5	1	81	2192	19	515

Table 2-2: Wake-up Intervals, Memory Partitions, and Events

2.2 Tractor-Trailer Configuration

In order to standardize the test procedure, it was necessary to establish the criteria for standardizing the tractor-trailer configuration to the maximum extent. The goal was to minimize variation. General characteristics for tractor-trailers were size, weight and suspension. Though it was not possible to use the same exact tractor and trailer for all the test runs, similar equipment was used for all runs.

2.2.1 Tractor-Trailer Specifications

For the purposes of the tests, tractor-trailers like the ones depicted in Figures 2-2 and 2-3 were used for short and long duration test runs, respectively. Specifically, the trailers used for short duration test runs 1-10 and 12-15 were the same approximate size, weight and suspension. The trailer used for run 11 was slightly larger. All long duration runs used the same tractor-trailer configuration. Actual tractor-trailer characteristics are detailed in Table 2-3. All trailers had leaf-spring suspensions, with the exception of run 17 that had an air ride suspension.

Figure 2-2: Short duration tractor-trailer

Figure 2-3: Long duration tractor-trailer

Run Number	Run Duration	Trailer L x W OD (ft)	Trailer Width * ID (in)	Trailer Weight (approximate) (lbs)	Tractor Weight (approximate) (lbs)
1-10, 12-15	Short	48 x 8	Range: 90 - 91	14,200	20,000
11	Short	48 x 8.5	98.5	17,400	20,000
16-19	Long	53 x 8.5	99	14,700	18,000

* Note: Short duration trailers had wood panels along sides to protect lower walls. The thickness of the wood panels varied slightly.

Table 2-3: Tractor-Trailer Characteristics

2.3 Test Procedure

The test procedure consisted of placing the configured (section 2.1.1) Saver™ units in the rear of the trailers for both the short and long duration trips. Due to the fact that all the trailers used had steel plates that extended 3 –5 feet from the trailer doors, it was necessary to use magnetic mounts (Figure 2-4) in order to affix the units to the trailer bed. The Saver™ unit/magnetic mount coupling is illustrated in Figure 2-1. The units were attached to the magnetic mounts with 4 – 8 x 32 x 2.5 inches socket cap screws and 4 flat washers.

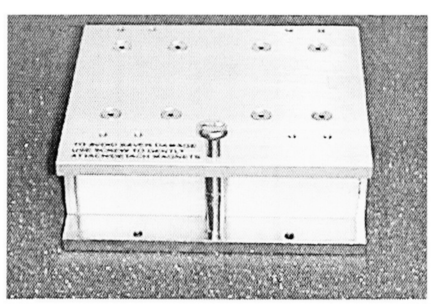


Figure 2-4: Magnetic Mount

The Saver™ units/magnetic mounts were then affixed to the trailer bed. The units were aligned in the same plane (Figure 2-5). For the short duration runs, the units were placed 7-3/4 inches from rear door closing point of the trailer. For long duration runs, the units were placed 17-1/2 inches from rear closing point of the trailer. In all cases, the units were centered from left to right. The spacing between the mounts was 3/8 inches (Figure 2-6). A 3/8-inch spacer was used in order to ensure standardized spacing for each run.

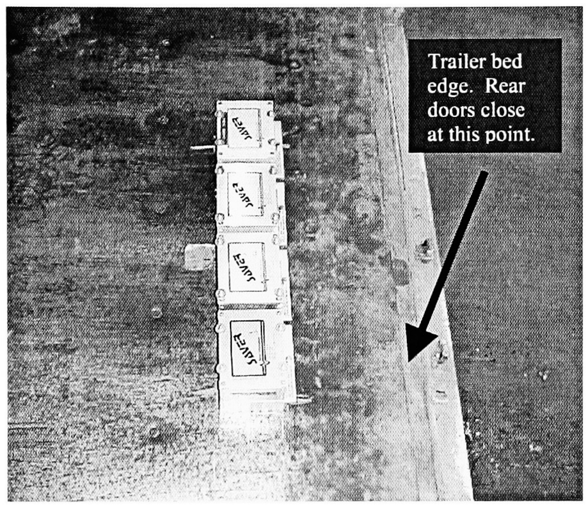


Figure 2-5: Saver™ /Mount Alignment

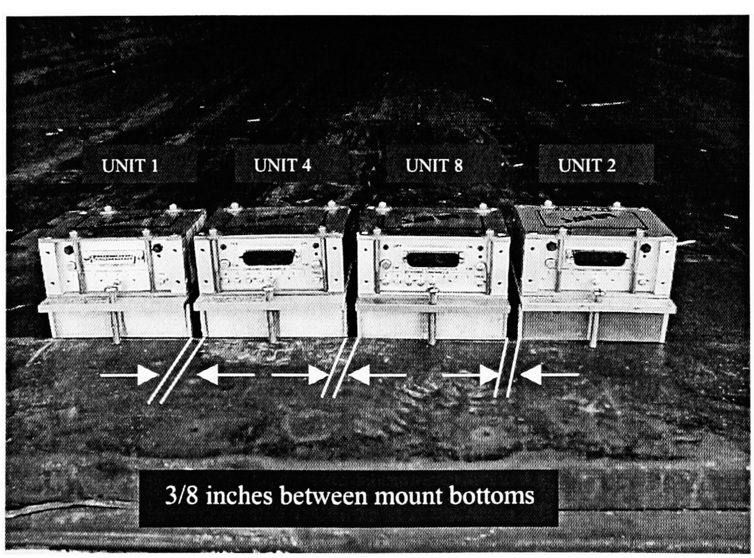


Figure 2-6: Saver™ /Mount Spacing

Just prior to departure, the units were turned on. For all runs, there was at least a 2-minute lag before the units started to record data. Once tractor-trailers reached their destination, the units were turned off. All units were removed from the trailer bed and data was subsequently downloaded to laptop computers. The complete download protocol is detailed in Appendix A. Once the download data files were created, the units were then reset. Resetting the units consisted of uploading the Equipment Set-up Protocol that corresponded to each unit and adjusting the internal date/time, if necessary.

2.4 Truck Routes

The truck routes for the runs utilized can be categorized as follows:

Philadelphia, PA	→	Scranton, PA	(Short Duration)
Scranton, PA	→	Philadelphia, PA	(Short Duration)
Philadelphia, PA	→	Moonachie, NJ	(Short Duration)
Moonachie, NJ	→	Philadelphia, PA	(Short Duration)
Edison, NJ	→	Philadelphia, PA	(Short Duration)
Pharr, TX	→	Salt Lake City, UT	(Long Duration)

2.4.1 Pennsylvania – New Jersey

Truck routes for short duration runs are standard daily deliveries established by Pepsi-Cola Corporation, Philadelphia, PA. Directions for the Philadelphia, PA to Scranton, PA run follows. Return runs were reverse directions.

Start: 11701 Roosevelt Boulevard, Philadelphia PA

End: 3015 North Main Street, Scranton, PA

Directions: "Take Route 1 North (Roosevelt Blvd) 4 miles to I-276 West (Pennsylvania Turnpike). Take I-276 West 18 miles to I-476 North. Take I-476 North 92.4 miles to Exit 37 (Route 81). Take Route 81 North to Exit 56 (Main Street/Dickson City); at bottom of ramp turn left. Scranton Pepsi is approximately 1 mile on right, enter first driveway" (Pepsi-Cola Corp., 1998).

Directions for the Philadelphia, PA to Moonachie, NJ runs follows. Return runs were reverse directions.

Start: 11701 Roosevelt Boulevard, Philadelphia PA

End: 3 Empire Boulevard, Moonachie, NJ

Directions: "Take Route 1 North (Roosevelt Blvd) 4 miles to I-276 East (Pennsylvania Turnpike). Take Pennsylvania Turnpike to I-95 North (New Jersey Turnpike). Take New Jersey Turnpike North to Western Spur to Exit 16W. After paying toll, stay right and take service road to Route 3 East. Take first exit Route 3 West / Route 120 North, cross over Route 3 and stay in left lane for Route 120 North. Follow Route 120 North to Route 503 North (Washington Avenue). Take Route 503 North to the Moonachie Avenue/Empire Boulevard exit. Follow around to stop sign at Empire Boulevard, turn left, Moonachie Pepsi is on right" (Pepsi-Cola Corp., 1998).

2.4.2 <u>Texas - Utah</u>

Truck routes for long duration runs are standard deliveries established by Bard Access Systems, Incorporated. Directions for the Pharr, TX to Salt Lake City, UT run follows. These runs were one-way deliveries.

Start: 201 West Anaya Road, Pharr, TX

End: 5425 West Amelia Earhart Drive, Salt Lake City, UT

Directions: Take Route 281 North to I-37 North. In San Antonio, TX take I-10 West and follow to Route 83 North. Stay on Route 83 North for 56 miles and take Route 87 North. In Lamesa, TX, take Route 137 North. Follow Route 137 North for approximately 35 miles and take Route 385 North. Stay on Route 385 for 50 miles and take Route 84 West. Stay on 84 West and cross into New Mexico. Take I-40 West in Santa Rosa, New Mexico. Stay on 40 West for approximately 253 miles. Follow Route 666 North/West through Colorado and into Utah. Once in Utah, follow Route 666 for 18 miles and take Route 191 North. In Crescent Junction take I-70 West. Stay on I-70 West for 25 miles and take Route 6 West. Follow Route 6 West to I-15 North. Follow I-15 North for approximately 50 miles and take I-80 West. Take Exit 114 off I-80, merge onto Wright Brothers Drive and turn right onto West Amelia Earhart Drive.

2.5 Load Types and Configurations

There were different types of loads and configurations for both short and long duration runs. For the 19 different runs, there were eight different load types. Load types are defined for the purposes of the experiment as varying the product and the volume of product. The result of varied product and volume is varied product weights. There were similar shipment loads, but the only runs that had exactly the same trailer weights were empty loads.

2.5.1 Short Duration Runs

Short duration run loads were shipments of Pepsi-Cola Corporation products. There were 15 short duration runs and the products shipped consisted of one of the following seven types:

- 12-packs of 12-oz cans (soda-filled cans)
- cases of 20-oz bottles (24 filled bottles per case)
- cases of 16-oz and 1- liter bottles (24 soda-filled bottles per case)
- 2-liter shelves
- pallets (42 x 36-inches)
- empty

The load /pallet configurations varied based upon the type of shipment listed above. With the exception of the 12-oz filled cans and 16-oz, 20-oz and 1-liter filled bottles, pallets of product were placed 2 across starting at the trailer nose. Once the last pallets were placed in the trailer, the loads were secured with a nylon strap attached to both sides and extended across the entire trailer width. The load/pallet configurations for the filled cans and bottles are detailed in Appendix B.

2.5.2 Long Duration Runs

Long duration run loads were shipments of Bard Access Systems central venous catheters. Catheter configurations varied. There were 4 long duration runs with trailer contents either 1/3 full or full. As with the short duration runs, pallets of product were placed 2 across starting at the trailer nose. Pallets had a 42 x 48-inch footprint. Pallet loads were also secured with nylon strapping.

3.0 DATA ANALYSIS

The test results of the experiment described in chapter 2.0 are detailed in Table 3-1. There were 4 units recording data for all 19 runs. However, unit 2 malfunctioned for all runs. Therefore, unit 2 data was disregarded. Also, runs 14 and 18 both had unsecured loads where product hit all 4 Saver™ units during the shipments. Hence, the data recorded for runs 14 and 18 were also disregarded. A sample of the actual equipment set-up is depicted in Figure 3-1.

The intensities, listed in Table 3-1, were calculated for channel 3 of the SaverWare™ program. Channel 3 represents the vertical (top-to-bottom) direction of the trailer bed. In assessing the variation of the units recording data for the same run, channel 3 provides data for the most severe motion. Channels 1 and 2 represent left-to-right and front-to-back motion, respectively. Motion in channels 1 and 2 is present in all runs. However, there is a higher probability that a product will incur more damage due to the motion in the vertical direction. Therefore, all analyzed data corresponds to channel 3.

An assumption that was made in collecting and comparing data from the multiple Saver™ units is that there is a negligible difference in recording data by the units. It was impossible to mount all the units in the same exact location. The units were spaced 3/8-inches apart in the same plane. Since the measurements of most concern are those in the vertical direction (channel 3), then it was assumed there is negligible difference if the units are placed next to one another. The critical factor in the equipment set-up and resulting data collection is to ensure that the units are aligned in the same lateral plane.

Run Number	Intensity Unit 1 (G_{rms})	Intensity Unit 4 (G_{rms})	Intensity Unit 8 (G_{rms})	Product Weight (lbs)	Trailer Contents	Driver	Run Duration
1	No Data	0.34	0.32	46,006	12 pack cans	BM	Short
2	0.38	0.35	0.37	6,000	Pallets	BM	Short
3	0.27	0.25	0.26	46,230	12 pack cans	BM	Short
4	0.37	0.36	0.38	0	Empty	BM	Short
5	0.31	0.37	0.36	46,144	12 pack cans	BM	Short
6	0.34	0.46	0.42	0	Empty	BM	Short
7	0.34	0.31	0.31	47,047	12 pack cans	JL	Short
8	0.32	0.40	0.37	0	Empty	JL	Short
9	0.33	0.35	0.38	45,547	20 oz bottles	JS	Short
10	0.31	0.33	0.35	13,255	2 liter shelves	JS	Short
11	0.48	0.38	0.33	47,530	16 oz/1 L	JS	Short
12	0.31	0.29	0.26	15,069	2 liter shelves	JS	Short
13	0.42	0.33	0.32	47,487	20 oz bottles	JS	Short
15	0.27	0.31	0.29	46,899	20 oz bottles	JS	Short
16	0.23	0.29	0.27	4,250	Catheters	Juan	Long
17	0.15	0.17	0.16	3,300	Catheters	Juan	Long
19	0.21	0.27	0.26	6,380	Catheters	Eloy	Long

Table 3-1: Test Data

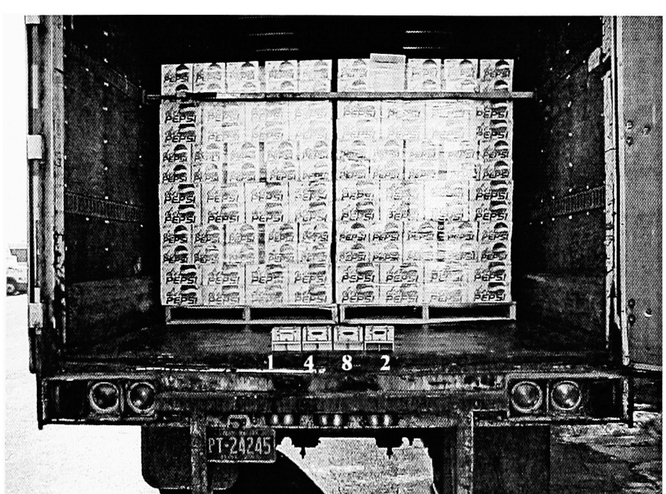


Figure 3-1: Equipment Set-up
(Unit numbers appear in white)

The Table 3-1 intensities (G_{rms}) were calculated internally utilizing SaverWare™ software. This software accompanied the Saver™ units and is industry accepted. The Analysis Protocol that was used to calculate the intensities using the SaverWare™ software is detailed in Appendix A. The key attribute of the protocol was the deselecting of all events less than 0.04 G_{rms}. The rationale for selecting 0.04 G_{rms} as a threshold for data analysis is that a tractor-trailer idling at rest typically has intensity readings of 0.04 – 0.01 G_{rms}. Events below 0.04 G_{rms} indicate a stop during a run. Examples of stops during a run can be due to traffic, lights, tolls, stop signs, driver breaks, merges, and turn preparation. As such, utilizing data while the vehicle is at rest only dampens the calculated Grms. In short, such data is not value-added. Additionally, only events that occurred within the designated start and finish of each run were included in the analyses.

3.1 Calculated Data

Table 3-2 data were calculated utilizing the data listed in Table 3-1 for units 1, 4, and 8. The assumption that was made in calculating Table 3-2 data is that unit 8 data is the most accurate and complete of the 3 units due to the fact that it recorded the largest number of events for each run. Hence, unit 8 is the standard for which all data was compared to within each run.

Data listed in columns 3 and 5 of Table 3-2 were calculated using the following formula:

$$\text{Difference From Unit x} = Grms_{\textit{unit x}} - Grms_{\textit{unit 8}}$$

Unit x refers to either unit 1 or 4 for a particular run.

The percent difference from unit 8 (Table 3-2, columns 4 and 6) was calculated using the formula below:

$$\frac{\left| Grms_{unit\ x} - Grms_{unit\ 8} \right|}{Grms_{unit\ 8}} \quad X \quad 100$$

Run Number	Unit 8 (*Standard*) G_{rms}	Difference from Unit 4	Difference from Unit 4 %	Difference from Unit 1	Difference from Unit 1 %
1	0.32	0.02	6.3	-	-
2	0.37	-0.02	5.4	0.01	2.7
3	0.26	-0.01	3.8	0.01	3.8
4	0.38	-0.02	5.3	-0.01	2.6
5	0.36	0.01	2.8	-0.05	13.9
6	0.42	0.04	9.5	-0.08	19.0
7	0.31	0.00	0.0	0.03	9.7
8	0.37	0.03	8.1	-0.05	13.5
9	0.38	-0.03	7.9	-0.05	13.2
10	0.35	-0.02	5.7	-0.04	11.4
11	0.33	0.05	15.2	0.15	45.5
12	0.26	0.03	11.5	0.05	19.2
13	0.32	0.01	3.1	0.10	31.3
15	0.29	0.02	6.9	-0.02	6.9
16	0.27	0.02	7.4	-0.04	14.8
17	0.16	0.01	6.3	-0.01	6.3
19	0.26	0.01	3.8	-0.05	19.2

Table 3-2: Calculated Data

3.2 Statistical Analysis within Runs

Utilizing the intensities listed in Table 3-1, the average mean and standard deviation were calculated for each run based on SaverWare™ results. The results are included in Table 3-3. Basic statistical formulas were used to calculate the values. The mean and standard deviation were calculated using the formulas below. For standard deviation, *X* refers to the specific intensities within a run and *n* is the number of data points (units) within a run.

MEAN: $$\overline{X} = \frac{(Grms_{unit\ 1} + Grms_{unit\ 4} + Grms_{unit\ 8})}{3}$$

STANDARD DEVIATION: (Naiman, 1992)

$$= \sqrt{\frac{\text{sum}\,(X - \overline{X})^2}{n - 1}}$$

Run Number	Mean	Standard Deviation	3 sigma
1	0.33	0.01	0.03
2	0.37	0.02	0.06
3	0.26	0.01	0.03
4	0.37	0.01	0.03
5	0.35	0.03	0.09
6	0.41	0.06	0.18
7	0.32	0.02	0.06
8	0.36	0.04	0.12
9	0.35	0.03	0.09
10	0.33	0.02	0.06
11	0.40	0.08	0.24
12	0.29	0.03	0.09
13	0.36	0.06	0.18
15	0.29	0.02	0.06
16	0.26	0.03	0.09
17	0.16	0.01	0.03
19	0.25	0.03	0.09

Table 3-3: Mean and Standard Deviation by Run

3.3 Statistical Analysis by Unit

In many investigations it is necessary to compare several populations simultaneously. The Analysis of Variance (ANOVA) is a statistical method used to identify variation within the populations. The ANOVA tests for the equality of population means when classification is by one variable. Once this is established the one-way ANOVA allows for comparison of the differences among the means of multiple data sets. After the mean is established, the approximate center of the distribution of the data is then located. It is at this point that the analysis begins (Wortman, 1997).

Utilizing the ANOVA you can take multiple sets of data and statistically determine if the sample is representative of the population. The population is the larger body of data that is the research target. The ability to determine the data set's mean and variation is a significant factor in determining if the sample is representative of the population (DeVor, 1992).

In this specific testing cycle, the ANOVA was utilized to draw conclusions between the various Saver™ units within a specific run. Each of the test run data was treated individually and calculated independently. The data was extracted from the Saver™ software, exported into Minitab statistical software and calculated. Minitab uses multiple comparisons and presents them as a set of confidence intervals. This allows the assessment of the practical significance (visual identification) of differences among means in addition to statistical significance. A one-way (unstacked) ANOVA was then used to determine if the data collected from Saver™ units 1, 4 and 8 were from the same population. Using a confidence interval of 95% and pooled standard deviation the data was calculated to determine statistically the amount of variation and if they are from the same population. The ANOVA also identifies variation among the individual test units. The data specific testing is addressed in chapter 4 and detailed in Table 3-4. The following table addresses the ANOVA results both graphically and statistically.

Run	Unit	N	Mean	Standard Deviation	Individual 95% Cis For Mean Based on Pooled Std. Dev.
1	Unit 4	270	0.31	0.16	-------+---------+---------+---------
	Unit 8	1411	0.29	0.15	(-------------*-------------)
					(------*-----)
					-------+---------+---------+---------
					0.288 0.300 0.312
2	Unit 1	22	0.32	0.23	---+---------+---------+---------+---
	Unit 4	252	0.30	0.18	(--------------*--------------)
	Unit 8	1318	0.32	0.19	(----*---)
					(-*-)
					---+---------+---------+---------+---
					0.250 0.300 0.350 0.400
3	Unit 1	24	0.24	0.11	-----+---------+---------+---------+-
	Unit 4	269	0.23	0.11	(--------------*-------------)
	Unit 8	1391	0.23	0.12	(---*----)
					(--*-)
					-----+---------+---------+---------+-
					0.210 0.240 0.270 0.300
4	Unit 1	22	0.33	0.17	-+---------+---------+---------+-----
	Unit 4	257	0.31	0.18	(---------------*--------------)
	Unit 8	1329	0.32	0.21	(----*----)
					(--*-)
					-+---------+---------+---------+-----
					0.250 0.300 0.350 0.400
5	Unit 1	24	0.28	0.13	--------+---------+---------+--------
	Unit 4	271	0.34	0.15	(--------------*--------------)
	Unit 8	1418	0.31	0.17	(----*----)
					(-*-)
					--------+---------+---------+--------
					0.240 0.280 0.320
6	Unit 1	23	0.31	0.14	------+---------+---------+---------+
	Unit 4	259	0.37	0.27	(--------------*---------------)
	Unit 8	1338	0.35	0.24	(----*----)
					(-*-)
					------+---------+---------+---------+
					0.240 0.300 0.360 0.420

7	Unit 1	26	0.30	0.17	--+---------+---------+---------+---- (--------------*---------------) (----*---) (-*-) --+---------+---------+---------+---- 0.245 0.280 0.315 0.350
	Unit 4	307	0.28	0.15	
	Unit 8	1592	0.28	0.15	
8	Unit 1	24	0.30	0.11	----+---------+---------+---------+-- (-------------*-------------) (---*---) (*-) ----+---------+---------+---------+-- 0.250 0.300 0.350 0.400
	Unit 4	279	0.36	0.18	
	Unit 8	1437	0.33	0.17	
9	Unit 1	16	0.30	0.15	--------+---------+---------+-------- (---------------*----------------) (----*----) (-*-) --------+---------+---------+-------- 0.250 0.300 0.350
	Unit 4	194	0.32	0.15	
	Unit 8	1006	0.34	0.17	
10	Unit 1	15	0.31	0.09	---+---------+---------+---------+--- (----------------*----------------) (-----*----) (--*-) ---+---------+---------+---------+--- 0.240 0.280 0.320 0.360
	Unit 4	174	0.31	0.12	
	Unit 8	906	0.32	0.15	
11	Unit 1	16	0.37	0.32	-----+---------+---------+---------+- (---------------*----------------) (----*----) (-*--) -----+---------+---------+---------+- 0.300 0.350 0.400 0.450
	Unit 4	181	0.34	0.18	
	Unit 8	943	0.29	0.16	
12	Unit 1	15	0.29	0.12	------+---------+---------+---------+ (---------------*-----------------) (----*----) (--*-) ------+---------+---------+---------+ 0.245 0.280 0.315 0.350
	Unit 4	183	0.27	0.12	
	Unit 8	951	0.23	0.12	
13	Unit 1	14	0.35	0.23	--------+---------+---------+-------- (-------------*-------------) (---*---) (-*-) --------+---------+---------+-------- 0.300 0.360 0.420
	Unit 4	191	0.28	0.18	
	Unit 8	994	0.28	0.16	

15	Unit 1	14	0.25	0.09	-----+---------+---------+---------+- (---------------*----------------) (----*----) (-*-) -----+---------+---------+---------+- 0.200 0.240 0.280 0.320
	Unit 4	179	0.27	0.14	
	Unit 8	928	0.26	0.13	
16	Unit 1	24	0.22	0.08	---+---------+---------+---------+--- (------------*------------) (---*---) (-*-) ---+---------+---------+---------+--- 0.180 0.210 0.240 0.270
	Unit 4	269	0.26	0.13	
	Unit 8	1538	0.25	0.10	
17	Unit 1	27	0.14	0.05	---+---------+---------+---------+--- (------------*-------------) (---*----) (-*-) ---+---------+---------+---------+--- 0.120 0.135 0.150 0.165
	Unit 4	310	0.16	0.06	
	Unit 8	1539	0.15	0.06	
19	Unit 1	32	0.19	0.10	---------+---------+---------+------- (---------*---------) (---*---) (-*) ---------+---------+---------+------- 0.180 0.210 0.240
	Unit 4	291	0.25	0.10	
	Unit 8	1354	0.25	0.09	

Table 3-4: Mean and Standard Deviation by Unit

3.4 PSD Analysis

PSD analysis is a frequency domain representation of random vibration data (Kipp, 1999). Specifically, PSD results from the conversion of recorded acceleration data (G) in the time domain into average intensities (G^2/Hz) in the frequency domain (Hz). The benefits from utilizing PSD analysis include:

- Ability to identify frequencies where vibration is more intense

- Ability to compile data from multiple recordings/trips for higher statistical significance
- Ability to use resultant PSD profile in automated vibration test equipment

The resultant PSD curves per Saver™ unit per run were calculated and plotted for channel 3 utilizing the industry accepted SaverWare™ software program. The plots for runs 1-13, 15-17, and 19 are detailed in Appendix C. PSD plot interpretations are summarized in section 4.5.

4.0 DISCUSSION

After collecting the data from the 17 total runs (runs 14 and 18 omitted, see 3.0), it was organized and analyzed. The data was analyzed to determine if the three Saver™ units tracked the trip Grms in an identical manner. Upon further analysis, all test units that were placed in the same trailers on the same trip with varying timer-triggered responses, had various Grms response results.

4.1 Standard Deviation

The standard deviation data detailed in Table 3-3 indicate that there is little variation from the mean intensities for the 17 runs. Standard deviations of 0.01 to 0.04 appear to be indicative of small variation. Over 82% of the calculated standard deviations are in that small variation range. Consequently, since the standard deviation is the square root of the variance (Naiman, 1992), then the variance is essentially zero. This appears to indicate that varying the time interval has no impact on intensity. However, it is necessary to note that the means listed in Table 3-3 represent an average of averages. This is due to the fact that the intensities listed for each run in Table 3-1 were already averages calculated by the SaverWare™ program.

4.2 Data Trend Analysis

After investigating the individual data points in each run group using an Analysis of Variance (section 3-3), there were two definite trends in the confidence interval. The first trend was identified by the size of the confidence interval in relation to the sample size

(Table 3-4). In units 4 and 8, the true mean could be identified within a small range. As the sample rate decreases the true mean becomes more difficult to identify.

The second trend identified in Table 3-4 was the shifting of the mean in relation to the run and sample size. When the sampling rate increased (units 4 and 8), the run means would shift together in the same direction to define the true mean. As the sample size decreased (unit 1), the shift of the mean became more random in nature and harder to identify.

When analyzing the data and calculating the standard deviation within the individual data sets, within the runs, a trend was identified that the larger the data set, the larger the standard deviation (Table 3-4). This trend is believed to indicate the capturing of more rough spots in the roads and therefore causing a large separation in the data points. The spikes (rough roads) are believed to be significant in relation to the flat road on the larger data sets therefore causing the larger standard deviation. When sampling less frequently, the amount of data points that are further away from the mean are not captured, therefore reducing the standard deviation. The larger sampling plan captures more spikes and valleys in the data sets, while the smaller sampling plan captures smooth roads with fewer spikes and valleys and reduces the data variation.

4.3 Percent Difference

As mentioned in section 3.0, unit 8 is assumed to be the most accurate recorder based upon the selected and standardized sampling rates chosen for the experiment. Table 3-2 details the results of the intensity comparisons of units 1 and 4 to unit 8. As a reminder, unit 8 recorded the most events per run followed by unit 4, then unit 1. For unit 4, all but 2 runs were within 10% of the corresponding intensity of unit 8. Runs 11 and 12 differed by 15.2% and 11.5%, respectively. However when comparing the unit 1 data, the percent difference is significantly larger. In the original test protocol, it was decided that a difference greater than 10% would be considered significant. This was determined to account for any test unit noise and rounding errors that may occur. Specifically, only 6 runs were within 10% of the corresponding intensity of unit 8. The other 10 runs had a percent difference range of 11.4% to 45.5%.

Figure 4-1 is a graphical representation of Table 3-3 calculated data. Figure 4-1 indicates that the Saver™ units that had the larger (more frequent) sampling plans tended to track in a similar manner in relation to individual trips, but still maintained a relative separation in value. The unit that recorded the least data points showed the largest variation (i.e., unit 1). The same trend can be seen in Figure 4-2, which is a graphical representation of the actual test data listed in Table 3-1.

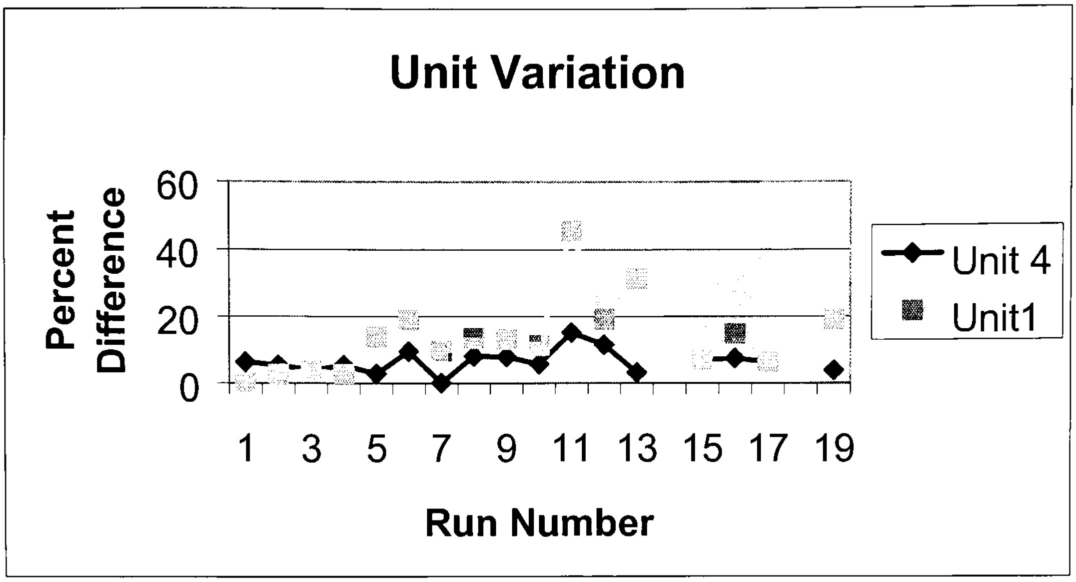


Figure 4-1: Unit Variation: Percent Difference vs. Run

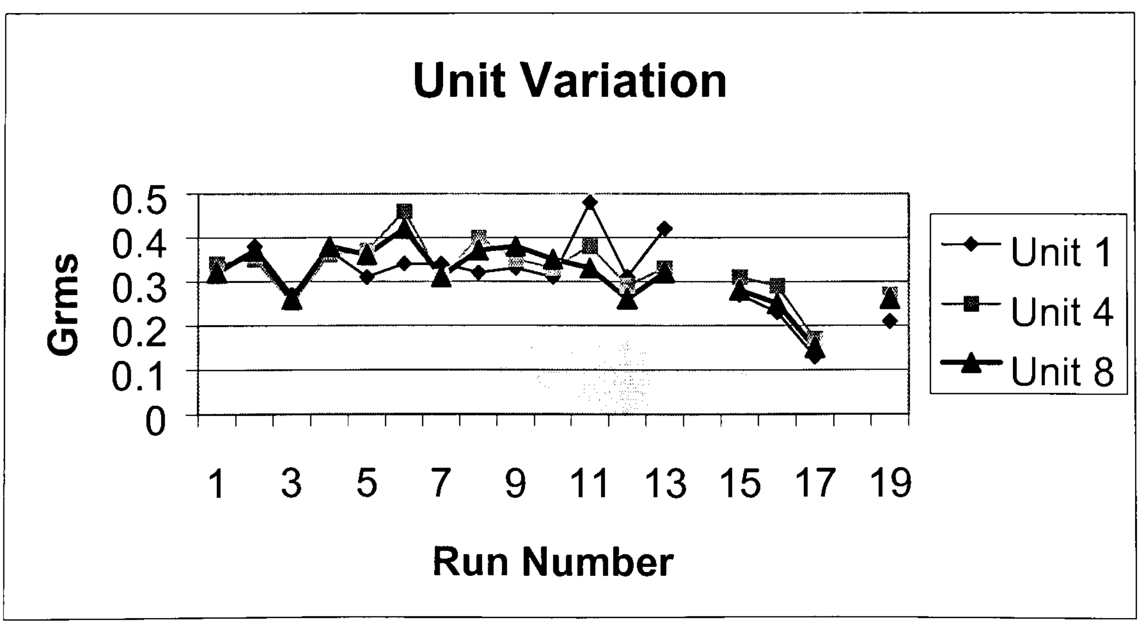


Figure 4-2: Unit Variation: Average Intensity vs. Run

4.4 Field-to-Lab™

The Field-to-Lab™ methodology and Saver™ technology together provide an opportunity to take a real time extended vibration test and compress it into a desired fraction of the time. This is accomplished by uploading a resultant PSD profile derived from actual field data recorded by a Saver™ unit. The PSD profile and intensity is compiled using SaverWare™ software. Then utilizing Field-to-Lab™ methodology and formulas, calculate a desired increased intensity. Consequently, the original "real time" test is conducted in a shorter time period but using a higher intensity, essentially achieving the same goal.

However, the data in Table 3-2 and Figure 4-1 show that there is a percent difference based upon the sampling rate of the Saver™ units. In fact, the intensities can vary by the exact same percent(s) listed in Table 3-2. The actual percent difference will vary based upon the time triggered sampling rate programmed into the Saver™ unit. Specifically, Field-to-Lab™ intensities can vary from 0% to 45.5% based upon the sampling rate for the same test. Additionally, the calculated Field-to-Lab™ intensity will be off by a constant. That constant is the square root of the desired time compression ratio.

4.5 PSD

The PSD plots that correspond to the 17 runs under analysis are detailed in Figures C-1 to C-50 in Appendix C. In comparing the PSD plots for each run, the following observations were made.

- All PSD plots within a run followed the same basic curve
- Runs 9, 11 and 13 had small offsets, though they followed the same basic curve
- Key common curve peak ranges: 3 - 5 Hz; 15 –25 Hz; 40 - 70 Hz
- Main curves trail off in 100 –250 Hz range

Offset or shifts in the curves were relatively small based upon graph scale. This is an expected result since the basic shape of the PSD plot is a representation of the structural characteristics of the tractor-trailer. The overall common curve peak ranges detailed above refer to the tractor-trailers' suspension, tires, and trailer bed, respectively. In short, PSD plots displayed some variation that was not considered significant. Figures 4-3 and 4-4 depict examples of PSD variation within each run as described above. Superimposing PSD plots for Saver™ units 1, 4 and 8 onto one plot generated Figures 4-3 and 4-4.

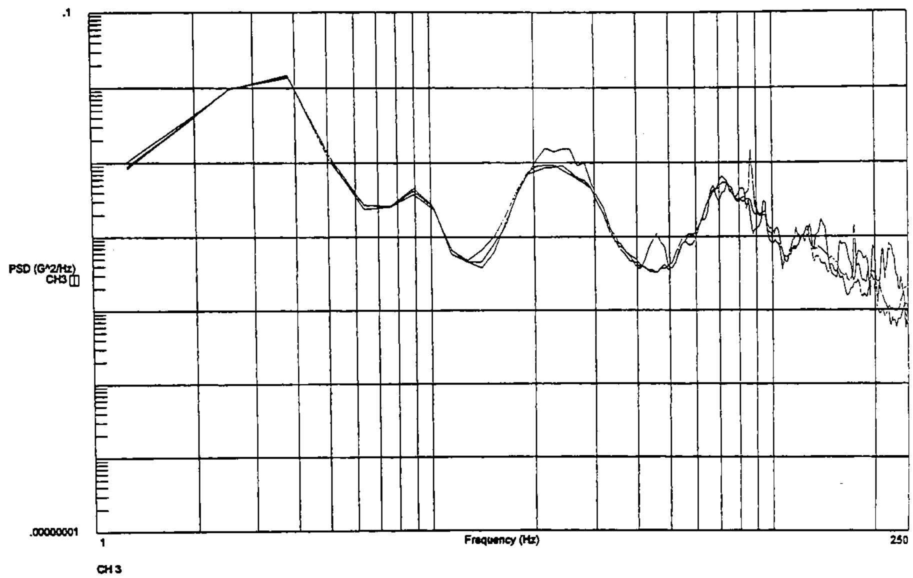


Figure 4-3: PSD Plot: Run 3

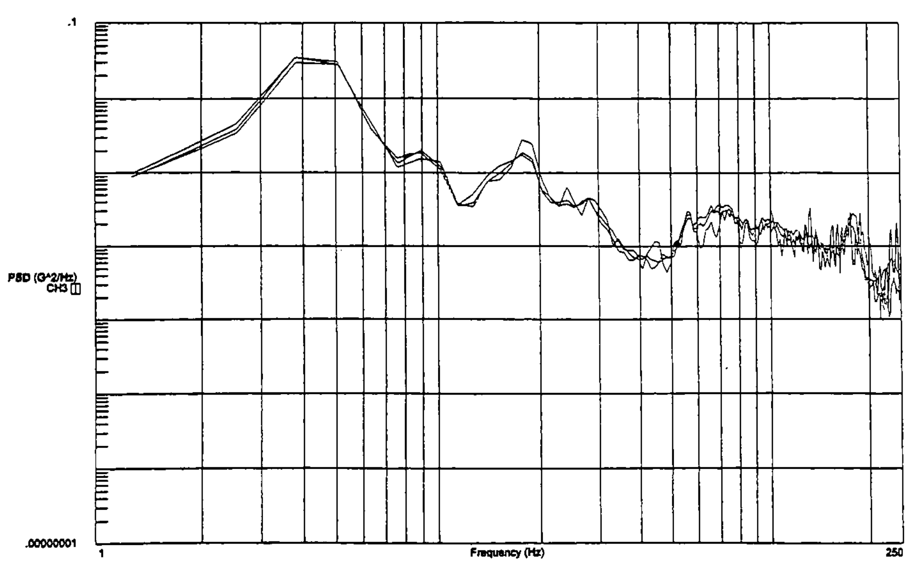


Figure 4-4: PSD Plot: Run 4

5.0 CONCLUSIONS AND RECOMMENDATIONS

The roads traveled across in this study were well maintained and relatively smooth overall. Though there were sections of rough spots. When sampling more frequently it is easier to capture the good portions of the road in addition to the rough portions that is where the damage most frequently occurs. The product may travel through the majority of the trip on smooth roads and survive without damage. By utilizing the reduced sampling plan formats it is possible to miss the spots in the road that will cause product damage and therefore not protect adequately. The one issue that arises with the larger sampling plan is that the rough spots have an overall reduced Grms. The reduced Grms is created by the long stretches of smooth road with minimal vibration thereby reducing the average trip Grms. The benefit of the larger sampling plan is the ability to isolate and analyze the portions of the trip that will most likely affect the product. In theory, analyzing the individual data points help to isolate the rough roads and high Grms portions of the trip. Analyzing the data in this manner is the only way the true magnitude of the trip is realized. Simply taking the intensity value that the software creates may lead you false conclusions about the distribution environment. The majority of the damage occurs during the rough portions of the trip that a reduced sampling plan may miss entirely. Therefore, taking the straight Grms created from the software for the trip and designing a package around it, may result in inappropriate packaging for the product. Essentially, the package design will not be optimized.

In 4.0, different elements of the data were discussed. Namely, they were standard deviation, ANOVA, percent difference, Field-to-Lab™, and PSD comparisons. Each element provided more insight into the affect of varying the time trigger interval. If each element were isolated, arriving at a conclusion with a high level of confidence would be difficult. However, evaluating all the elements together point the data in a single direction. To summarize, the standard deviation analysis discussed in 4.1 appears to indicate that there is no impact of varying the time trigger interval. There is, however, the "average of averages" to consider. The more data is averaged, the higher the probability the resultant data will appear to track.

Evaluating the ANOVA results, some trends start becoming evident. First, the units recording the most events per run (units 4 and 8) had true means that could be identified within a small range. Second, column 6 of Table 3-4 illustrates how the run means shift in the same direction for units 4 and 8. Unit 1's decreased sample size resulted in a more random shift of the mean. In short, the ANOVA results are indicating that there is some impact of varying the time trigger interval.

The impact of varying the time trigger interval becomes clearer with the percent difference analysis. Assuming unit 8 to be the most accurate and subsequently comparing unit 8's intensities to units 1 and 4, the trends indicated by ANOVA become prominent. Unit 4 intensities (compared to unit 8) vary by less than 10% in 15 of the 17 runs. However, unit 1 intensities vary by less than 10% in only 6 runs. Specifically, the percent difference range for unit 1 is 11.4% - 45.5%. This definitely indicates that varying the time trigger interval impacts intensity. Field-to-Lab™ formulas that rely on the calculated intensities for laboratory tests will also be off by the same 11.4% to 45.5% if unit 1 intensities are used instead of unit 8 intensities.

In conclusion, it has been determined that varying the time measurement interval does have an impact on the calculated intensity for Field-to-Lab™ vibration analysis. However, there is negligible impact for PSD plots within a run (see 4.5) for Field-to-Lab™ vibration analysis. The significance of the sampling rate impact has not been determined, nor has an optimum sampling rate for time triggered analysis been determined from this study.

Additionally, in order to optimize data collection based upon the impact of time measurement interval variance, it is recommended that ranges be established based upon trip length time. For example, a range could be established as follows:

Trip length (hr)	Saver™ sampling rate (sec)
1	A – B
2	B – C
3	C – D
4	D – E
Etc.	

Lastly, test runs could be segmented to analyze different portions of the trip utilizing various time measurement intervals. The time measurement intervals could be established based upon the road surface (i.e., smooth sections/rough sections). All above topics are recommended for further research.

APPENDIX A: PROTOCOLS

A.1 Equipment Set-up Protocol

A1.1 Preliminary Steps

A. Place new batteries in each Saver™ unit.
B. Load-up Saverware™ software.

A.1.2 Detailed Procedure

A. For each unit do the following:
   1. Connect turned-off unit to computer using supplied cables.
   2. Turn Saver™ on
   3. Click on ***Set Up Gateways***
   4. Click on ***Shock/Vib***
   5. Click on ***Query Unit***
      NOTE: Now in ***Instrument Configuration***
   6. Click ***OK***
   7. If unit has never been selected (i.e., stored on computer) Click ***Yes***
   8. Screen title: ***Shock & Vibration Gateway Setup***

      Settings:

Shock Recorder Set-up	Record Time:	500 msec
	Event Analysis:	Triaxial Resultant
Vibration Recorder Set-up	Analysis Range:	250 Hz
	# of Analysis Lines:	200
	Estimated Trip Length:	3 hours (short) 36 hours (long)

   9. Click OK
   10. Screen title: ***Trip Text*** – Make notes as appropriate
   11. Click OK
   12. Click on ***Advanced Set-up***
   13. Screen title: ***Advanced Saver Set-up – Saver Memory Partitions***
       a. Perform set-up for Time-Triggered Data first (i.e., right side of screen)
          i. Set wake-up intervals as follows:

             Short Duration Runs:
             - For 1 meg unit: set to 6 minutes
             - For 2 meg unit: set to 2 minutes
             - For 4 meg unit: set to 30 seconds
             - For 8 meg unit: set to 5 seconds

<u>Long Duration Runs</u>:
- For 1 meg unit: set to 59 minutes
- For 2 meg unit: set to 20 minutes
- For 4 meg unit: set to 5 minutes
- For 8 meg unit: set to 1 minute

ii. Set ***Samples/Sec***: 651
iii. Set ***Sample Size***: 512
iv. Ensure that ***Record Waveform*** and ***Record T/H and Static Channels*** are "x" ed
v. Set ***Data Analysis Type*** to: ***Vibration –PSD***
vi. Set ***Data Retention Mode*** to: ***Stop When Full***
vii. Time Triggered Memory Allocation for both 3 and 36 hour runs is as follows:
- For 1 meg unit: set to 11% (37 events)
- For 2 meg unit: set to 16% (108 events)
- For 4 meg unit: set to 31% (419 events)
- For 8 meg unit: set to 81% (2192 events)

b. <u>Perform set-up for Signal Triggered Data</u> (i.e., left side of screen)
i. Set ***Samples/Sec***: 1024
ii. Set ***Sample Size***: 512
iii. Set ***Signal Pre-Trigger***: 25%
iv. Set ***Signal Pre-Trigger Compression***: ***1*** to ***1***
v. Ensure ***Record Waveform*** is "x" ed
vi. Set ***Data Analysis Type*** to ***Shock-Acceleration-vs-Velocity Ch***
vii. Set ***Data Retention Mode*** to ***Max Overwrite Min when Full***
viii. Signal Triggered Memory Allocation for both 3 and 36 hour runs is as follows:
- For unit 1: now already set to 89% (300 events)
- For unit 2: now already set to 84% (569 events)
- For unit 4: now already set to 69% (937 events)
- For unit 8: now already set to 19% (515 events)

14. Click ***OK***
15. Click on ***Edit Channels***
16. Screen title: ***Channel Map***
    a. First edit Channel 1 – center of screen (use arrows)
    b. Set ***Full Scale*** to ***50 Gs***
    c. Set ***Filter Frequency*** to 260 Hz
    d. Ensure that ***Trigger Options*** are set to ***Primary Trigger Group and Outside Levels***
    <u>Also</u>:
    - ❖ Ensure ***Channels to Sample-Signal Trigger*** is set to 1 thru 3
        - Ensure ***Samples/Sec*** is set to 1024

- ❖ Ensure ***Channels to Sample-Timer Trigger*** 1 thru 3
  - Ensure ***Sample/Sec*** is set to 651

e. Set trigger levels to ***Above 1.0 G's or below –1.0 G's***.
   This will make trigger levels symmetrical at +1G or –1G

f. Ensure that ***Max Mode Signal Trigger*** and ***Max Mode Timer Trigger*** are "x" ed

g. ***Primary Charge Amp*** should also be selected.

h. Follow A Through G for channels 2 and 3
   16 E is probably the only thing that needs to be changed. Once others were set for Channel 1, they should remain.

17. Click ***OK***
18. Click ***Save Set-Up***
    a. Create a filename for each unit. Use 1, 2, 4, and 8 as part of extension to identify data easily.
19. Once saved, click ***Exit Set-up***
20. Turn off Saver™ unit
21. Follow 1-19 for the remaining units
22. Exit Set-up

A.2 Download Protocol

A.2.1 Detailed Procedure

A. For each unit do the following:

1. Start Saverware™ software
2. Connect turned-off Saver™ unit to computer using supplied cable
3. Turn Saver™ on
4. Click on ***Talk to Instrument***
5. Click on ***Check Status*** (assess)
6. Click ***OK*** to exit Check Status
7. Click ***Read back Data***
8. Data is now being downloaded to computer
9. When data transfer is complete, answer "No" to "process the data now?" and process the data later.
10. Once clicking no, there will be a prompt to save the file. It will have a ".DI1" file extension. It is necessary to give some meaning to your filename so you can easily open and compare the data for each successive run.
11. Once files are saved click ***EXIT Hang up***
12. Resetting the units: Reset by uploading the existing files created using the Equipment Set up Protocol file.
13. Click on ***Setup Gateways***
14. Click on ***Load Setup***
15. Click on the setup file previously created that corresponds to the unit being reset. It has a .si1 file extension.
16. Click ***OK***
17. Click ***Send to Saver***
18. Screen title: ***Setup Saver Clock***
19. There are 2 times displayed: one for the Saver™ clock time and date, the other is for a delayed startup time and date. Set the top clock only. It is the Saver's™ internal clock. Use mouse to click into the time/date box. Set the time. Do this consistently so that all units read the same time at the start of the tests.
20. Click OK, and another screen pops up, Click ***OK***
21. Verification step: Go back into *Talk to Instrument* and then click *Check Status*. Once there, verify the set time and ensure that the recorded events for signal and time triggered partitions are at zero.
22. If everything is correct, Click ***OK***
23. Click ***EXIT Hang up***
24. Turn off Saver™ unit
25. Disconnect Saver™ from cable
26. Follow 2-25 for remaining units

A.3 Analysis Protocol

A.3.1 Detailed Procedure

A. For each data file do the following:
1. Start Saverware™ software
2. Click ***Analysis*** button on ***Main Menu***
3. Screen Title: ***Open***
4. Click on saved data file (*filename*.di1)
5. Screen Title: ***Process Events***
6. Answer ***Yes*** to: ***Would you like to perform the default Data Analysis?*** [SIGNAL TRIGGERED DATA: Shock – Acceleration vs Velocity Change] [TIMER TRIGGERED DATA: Vibration – PSD]
7. Saverware™ now processes timer and signal triggered data partitions
8. ***Quickhistory*** bar graph (for Signal triggered data) appears on screen
9. Click ***Analysis*** at the top of screen
10. Click ***Timer Triggered Memory Partition***
11. ***Quickhistory*** bar graph (for Timer triggered data) appears on screen [Note: This graph will stay on screen, unless manually closed.]
12. Deselect channels 1 and 2 under ***Display Channel*** (top – right side of screen)
13. Click ***Analysis*** at top of screen
14. Click ***Select Events for Summary***
15. Click ***Deselect All Events***
16. Click ***Analysis***
17. Click ***Select Events for Summary***
18. Click ***By Quickhistory Level***
19. ***Select Events Greater than of Equal to*** **0.04** $\mathbf{G_{rms}}$ for all events
20. Click ***OK***
21. Click ***Analysis***
22. Click ***Select Events for Summary***
23. Click ***By Event Number***
24. Screen Title: ***Summary Events***
25. Click ***De-Select Events*** and specify range of events not applying to experiment -(judgement call) [Note: This step may have to be repeated depending upon which events need to be deselected.]
26. Click ***OK***
27. Click ***Analysis***
28. Click ***Summary Analysis***
29. Screen Title: ***Summary Analysis*** [PSD Plot now appears on screen]
30. ***Intensity*** shows at bottom center of screen

APPENDIX B: PALLET LOAD CONFIGURATIONS

B.1 Load/Pallet Configurations

B.1.1 Loading Pattern for 12 Pack Cans - filled with soda: See Figure B-1 below.

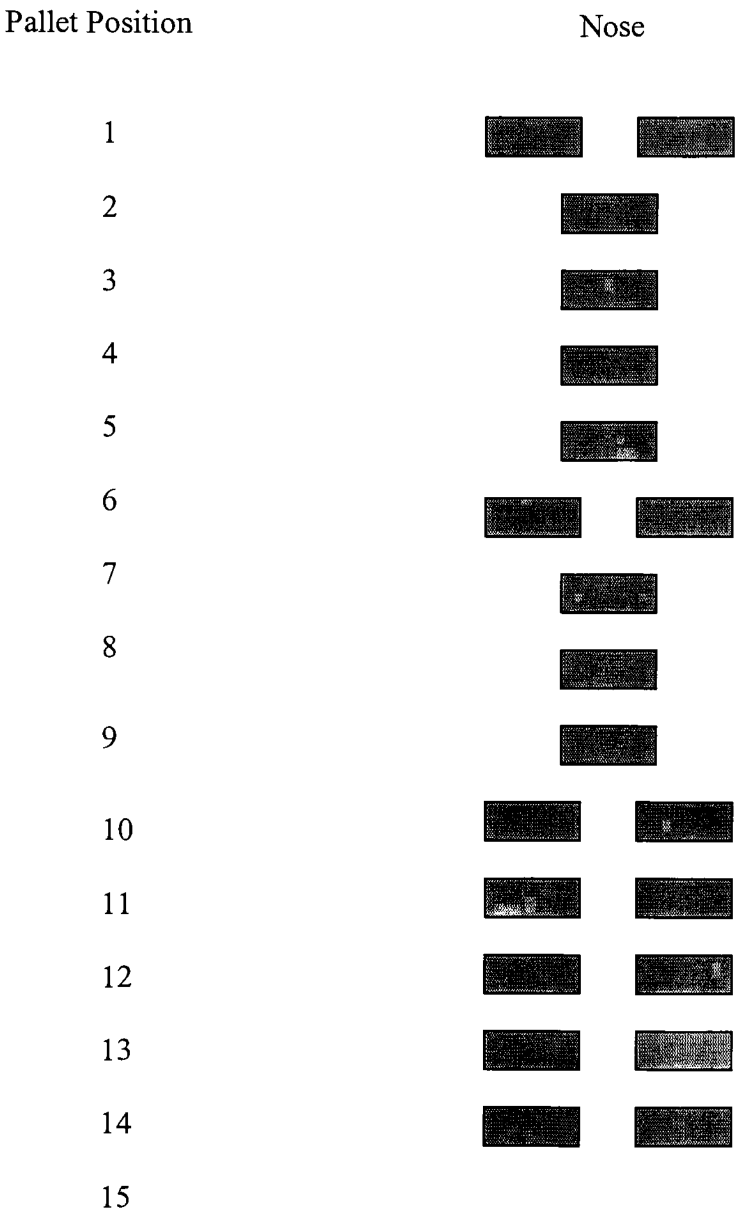


Figure B-1: 12 Pack Cans Loading Pattern (Pepsi-Cola Corp, 2000)

B.1.2 Loading Pattern: 20 ounce/1-liter Bottles - filled with soda: See Figure B-2 below.

Pallet Position

Nose

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

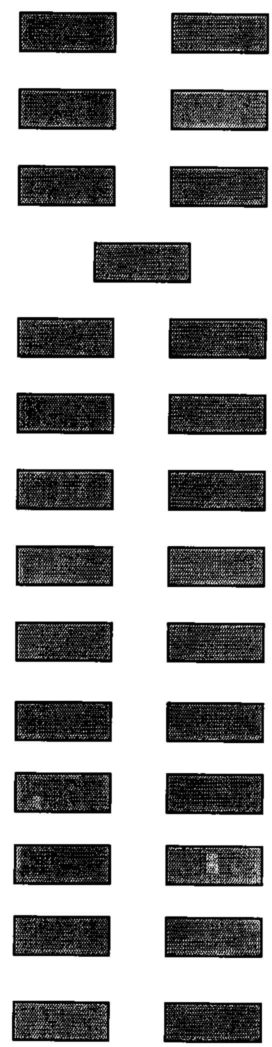


Figure B-2: 20 oz/1-Liter Bottles Loading Pattern (Pepsi-Cola Corp, 2000)

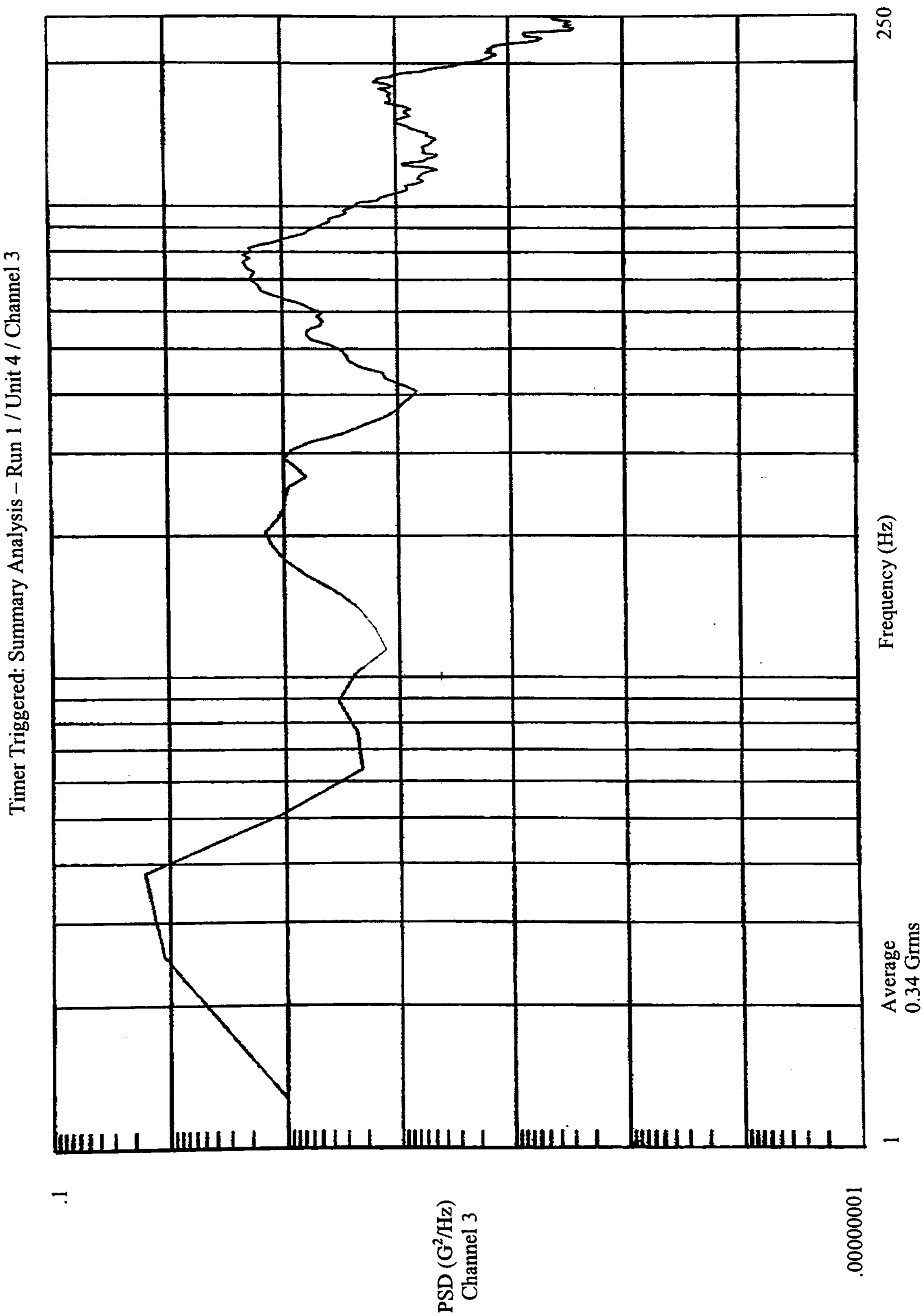


Figure C-1: Run 1 / Unit 4

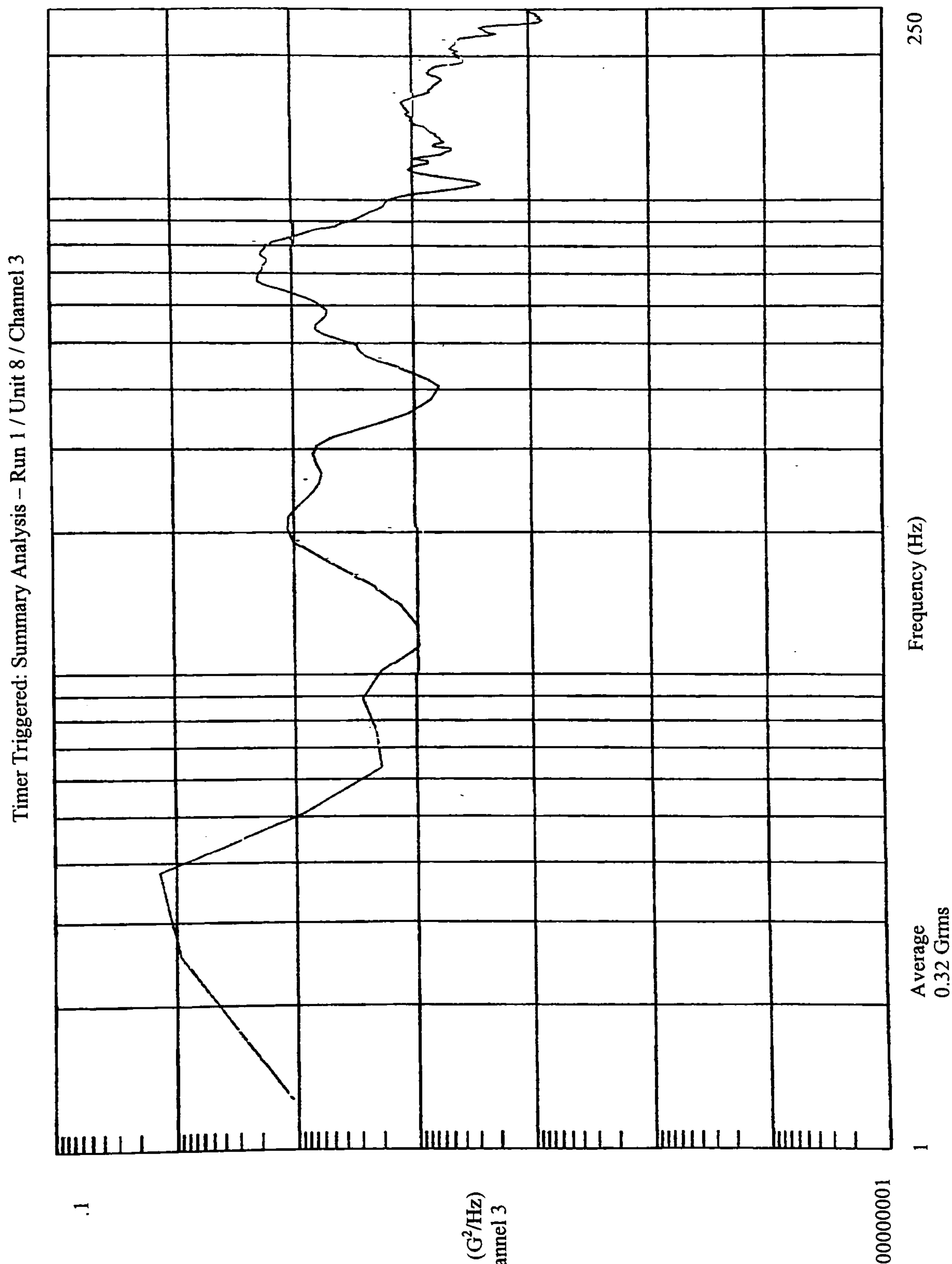


Figure C-2: Run 1 / Unit 8

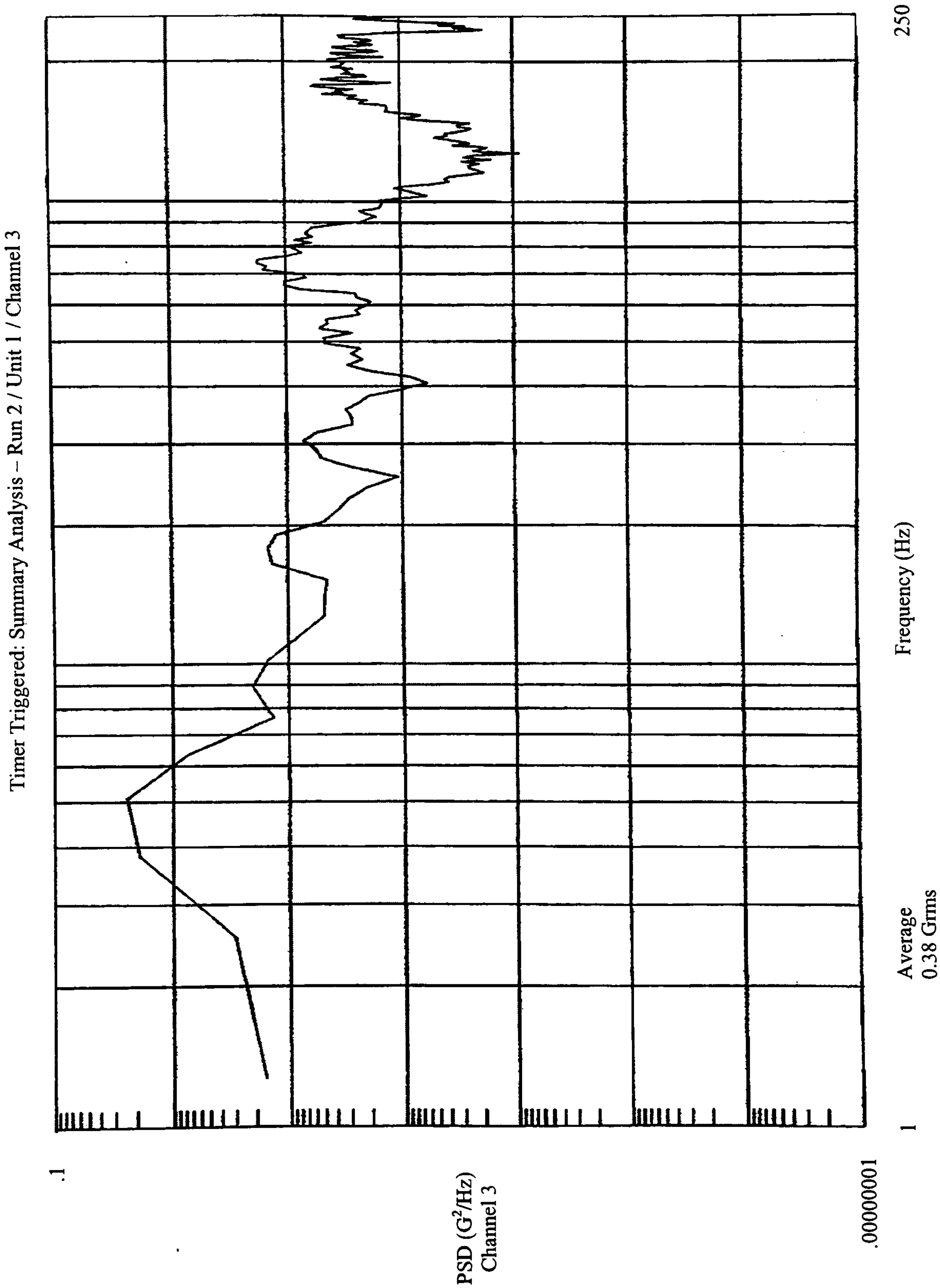


Figure C-3: Run 2 / Unit 1

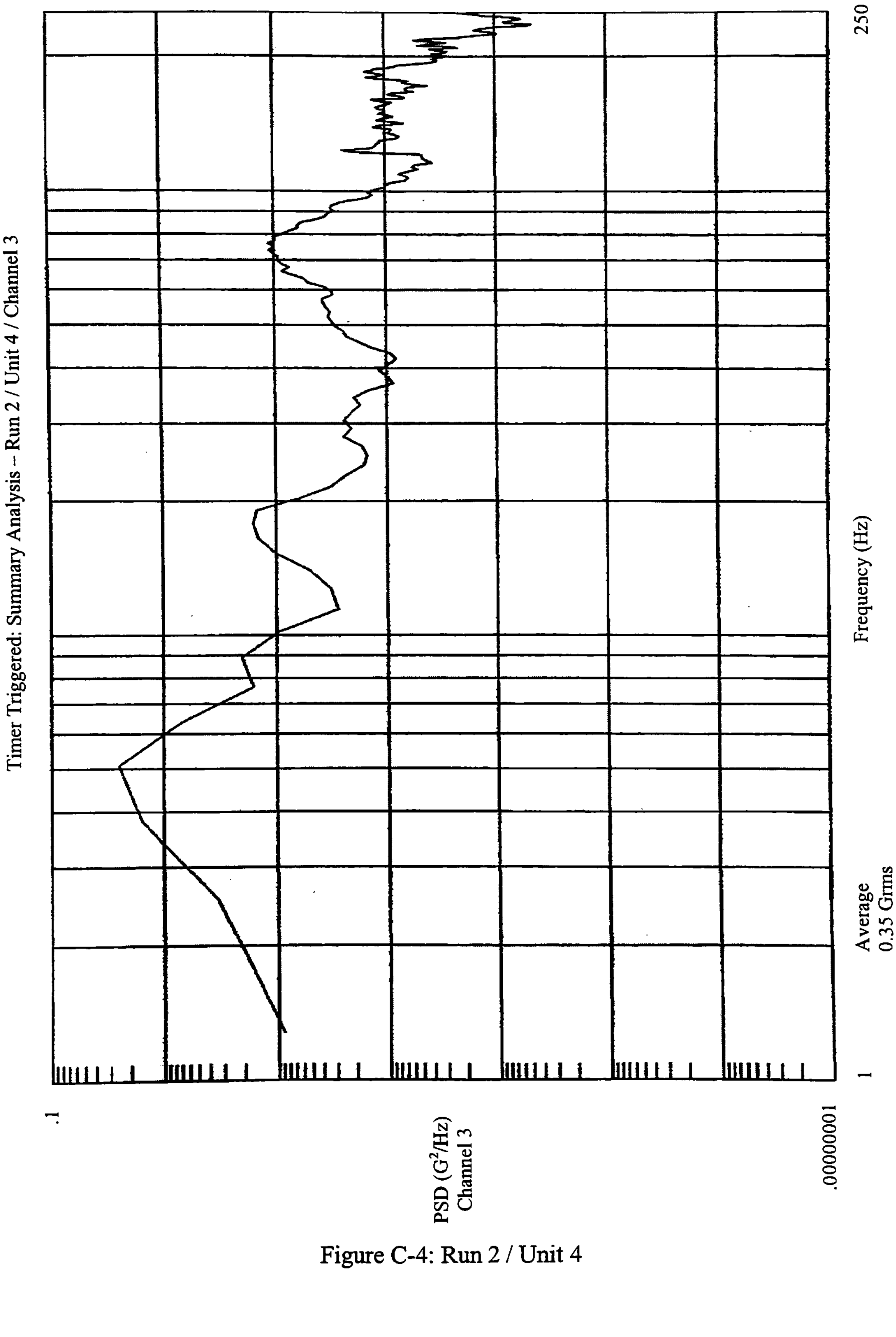


Figure C-4: Run 2 / Unit 4

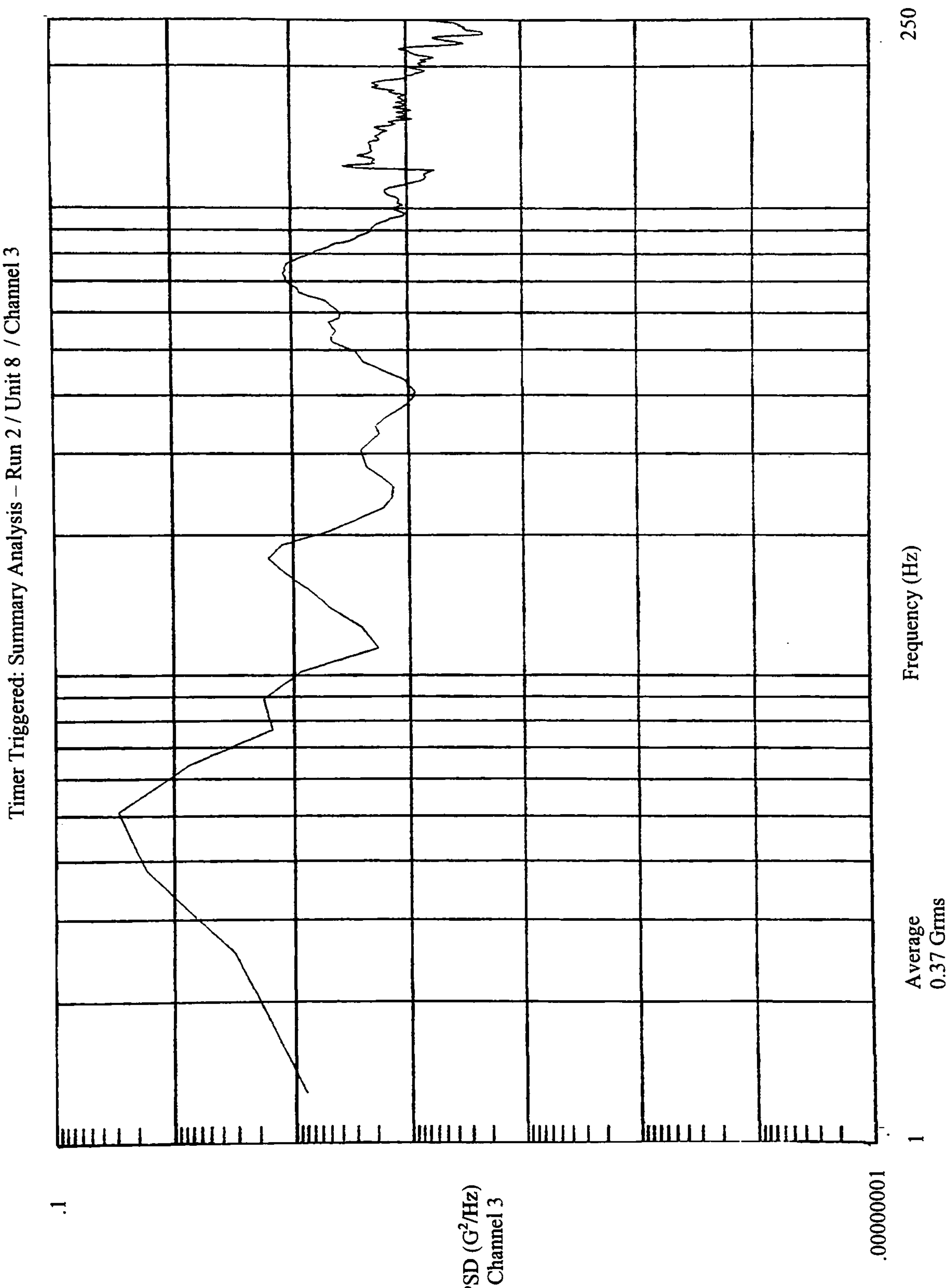


Figure C-5: Run 2 / Unit 8

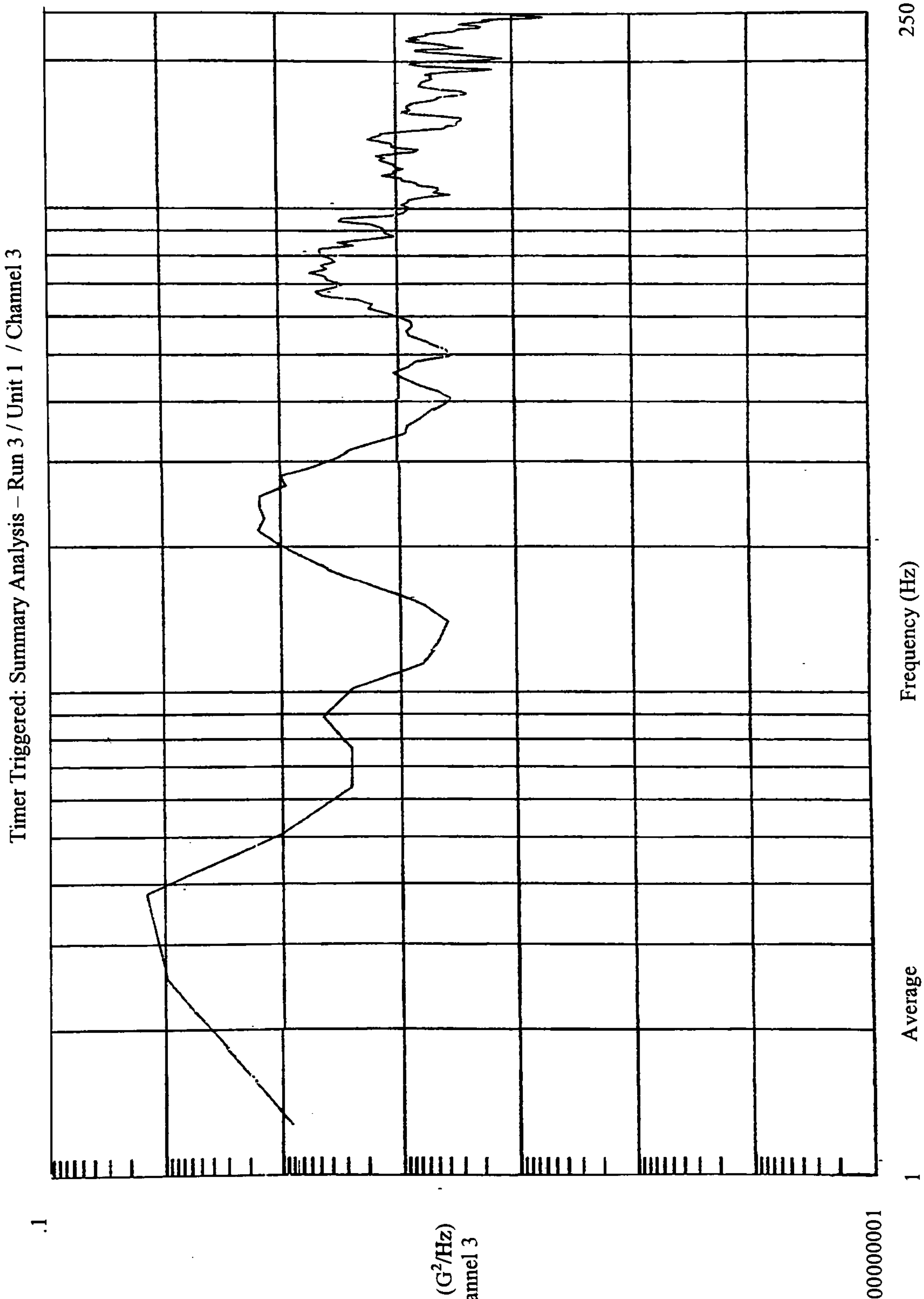


Figure C-6: Run 3 / Unit 1

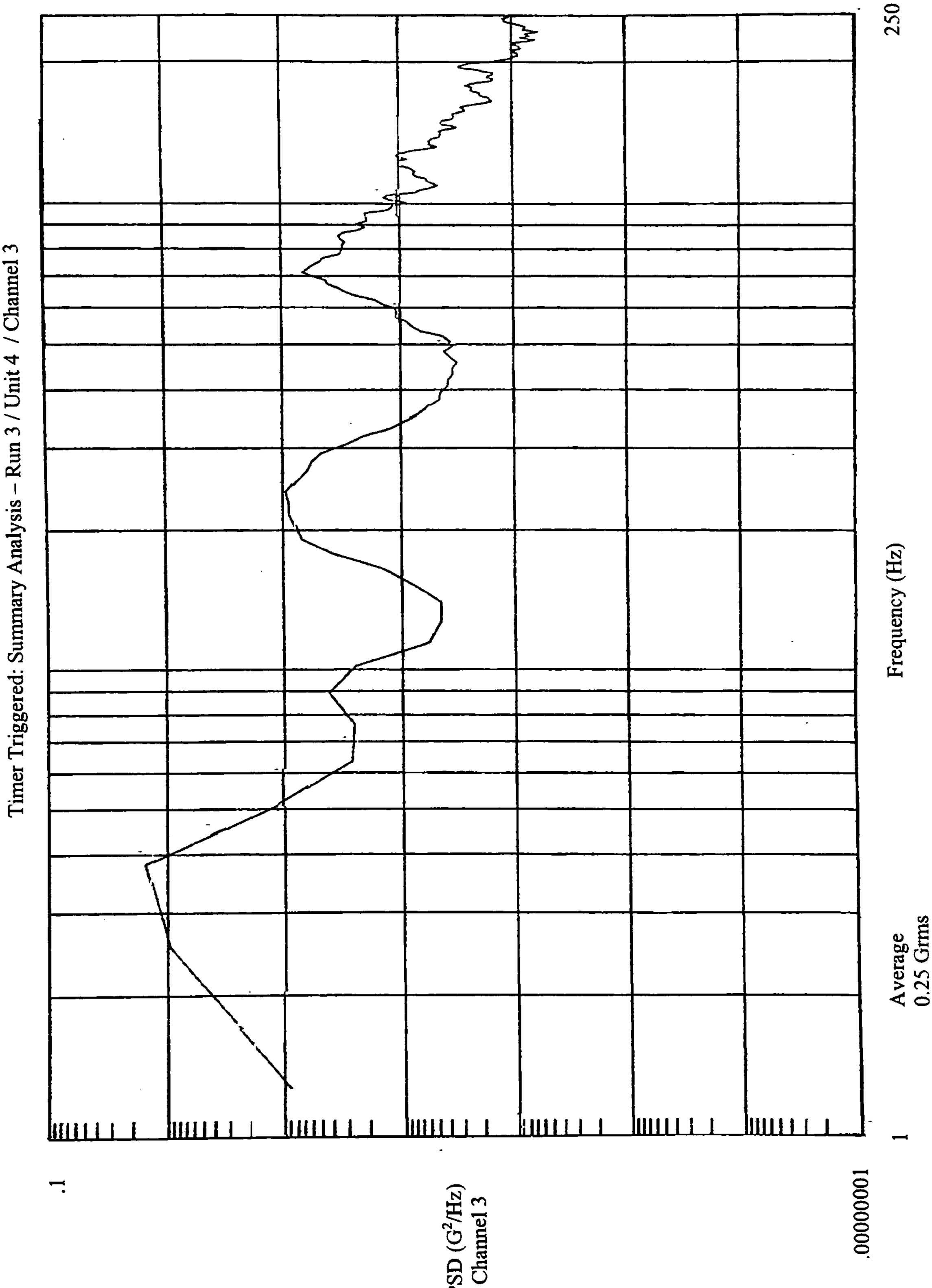


Figure C-7: Run 3 / Unit 4

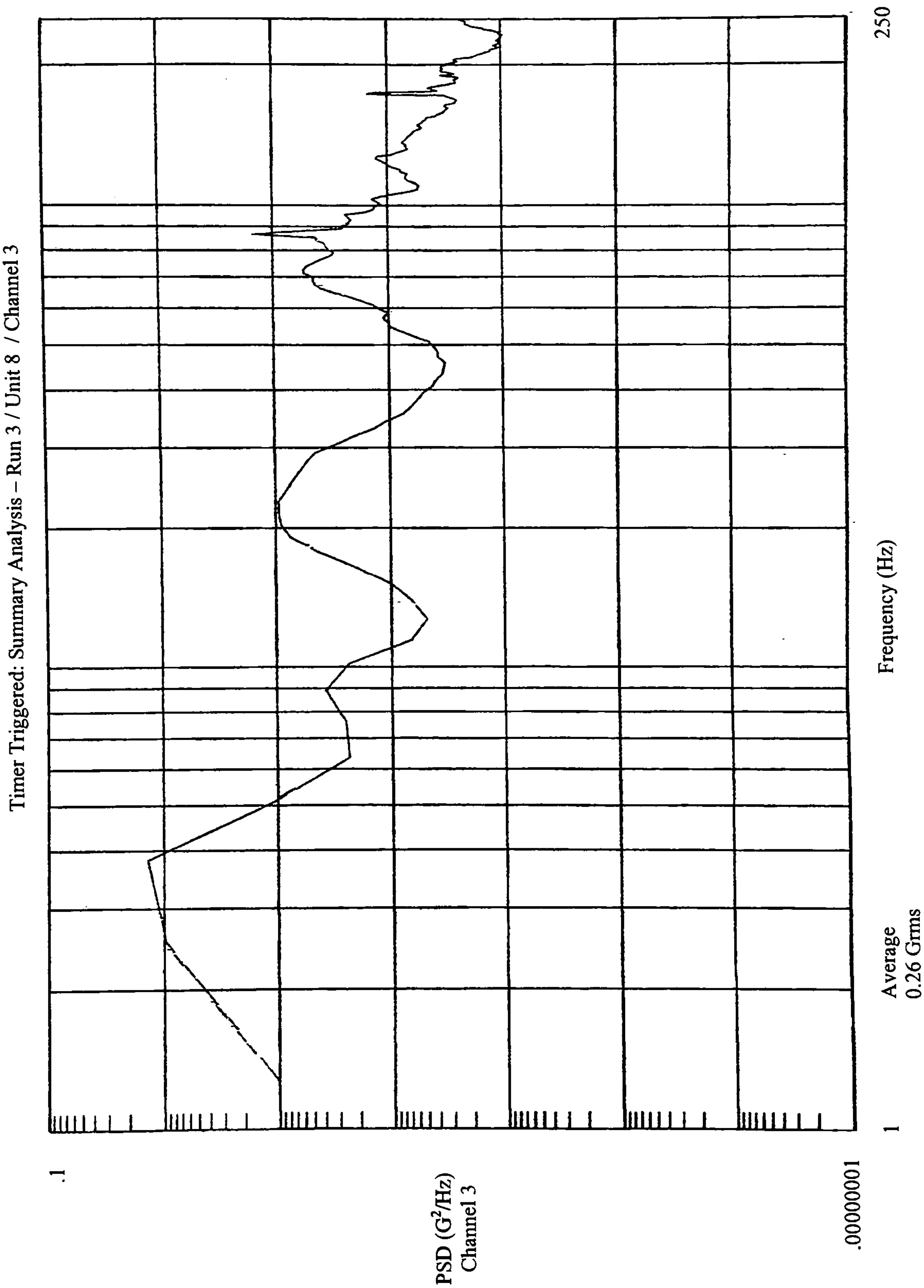


Figure C-8: Run 3 / Unit 8

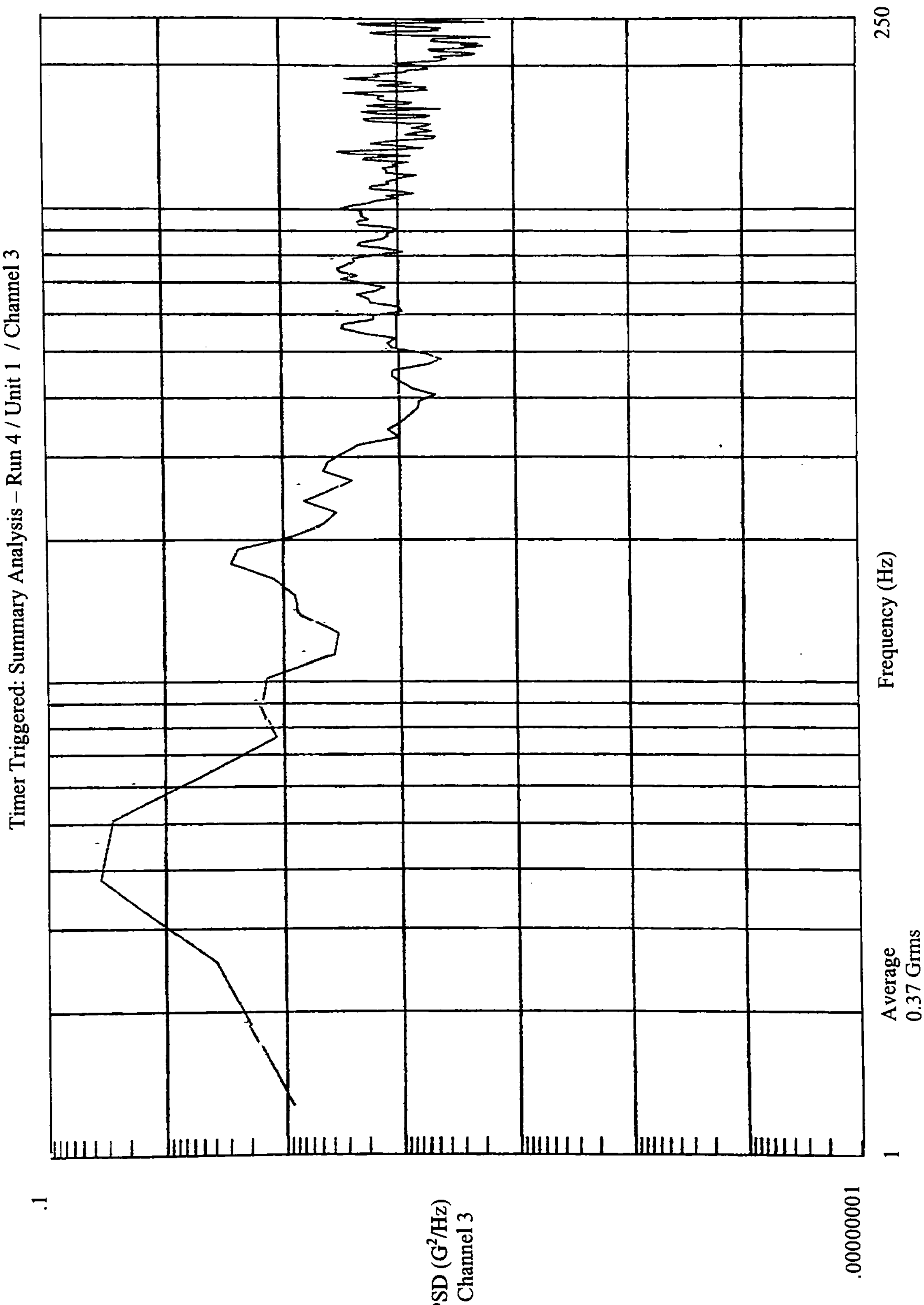


Figure C-9: Run 4 / Unit 1

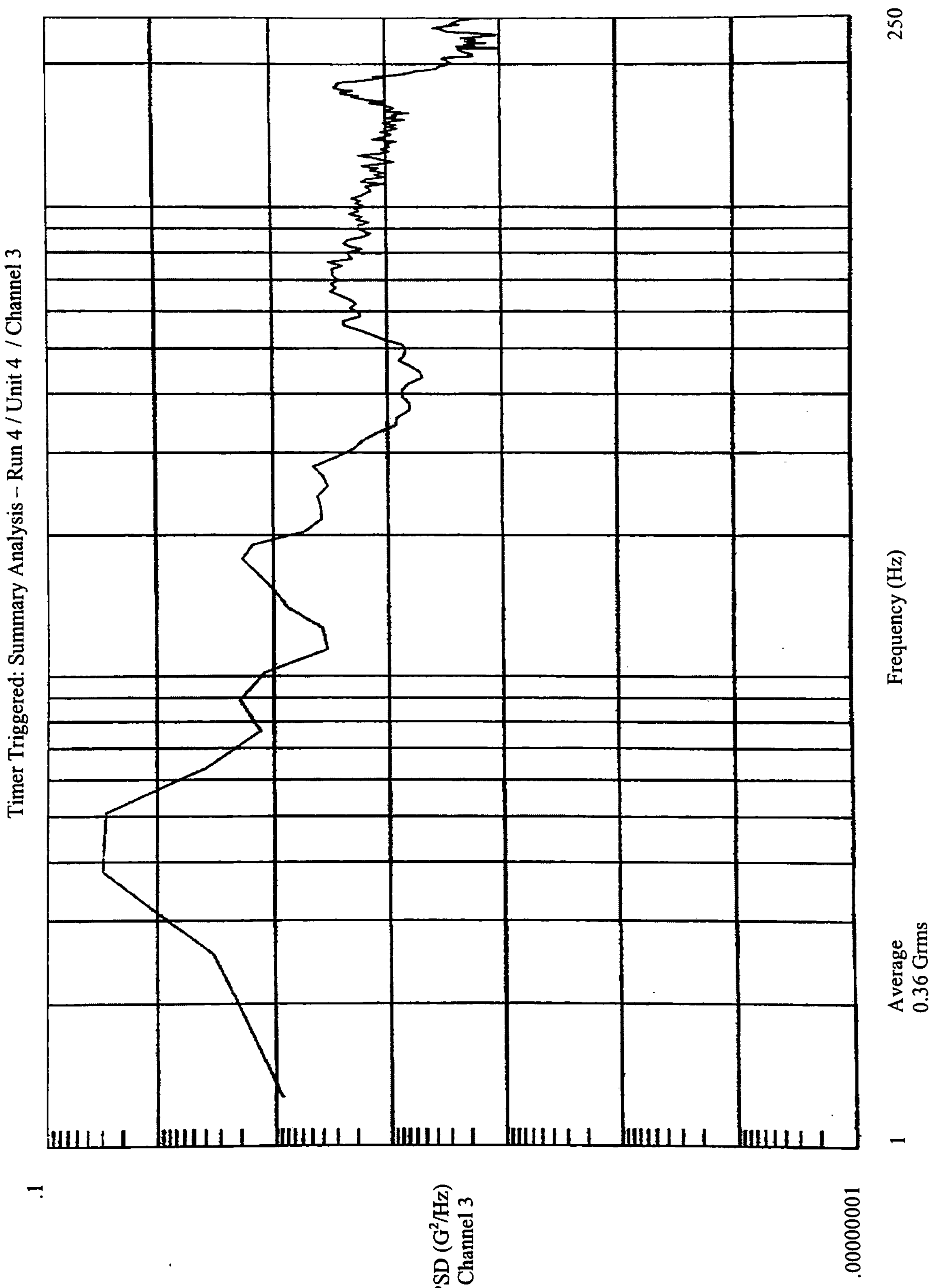


Figure C-10: Run 4 / Unit 4

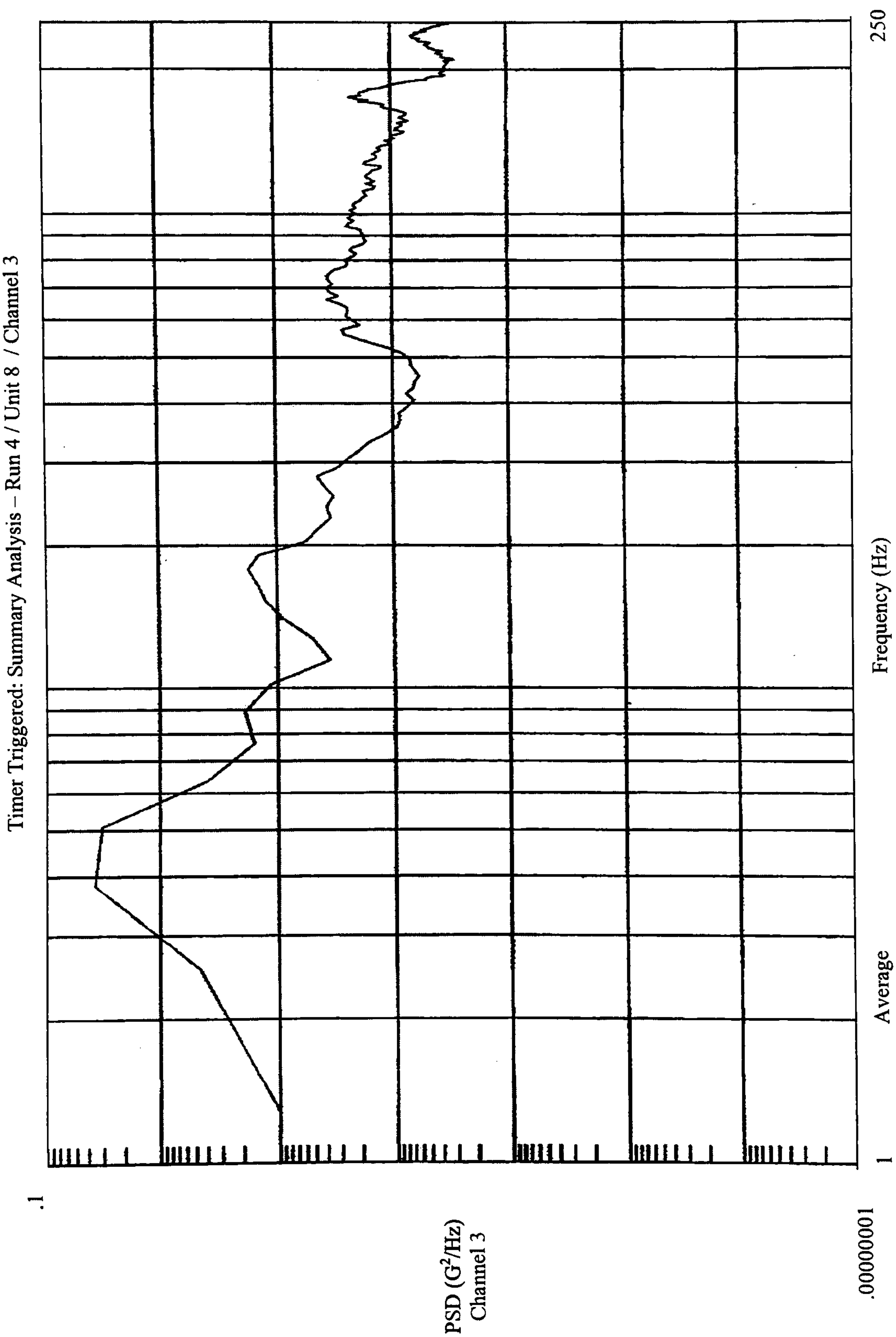


Figure C-11: Run 4 / Unit 8

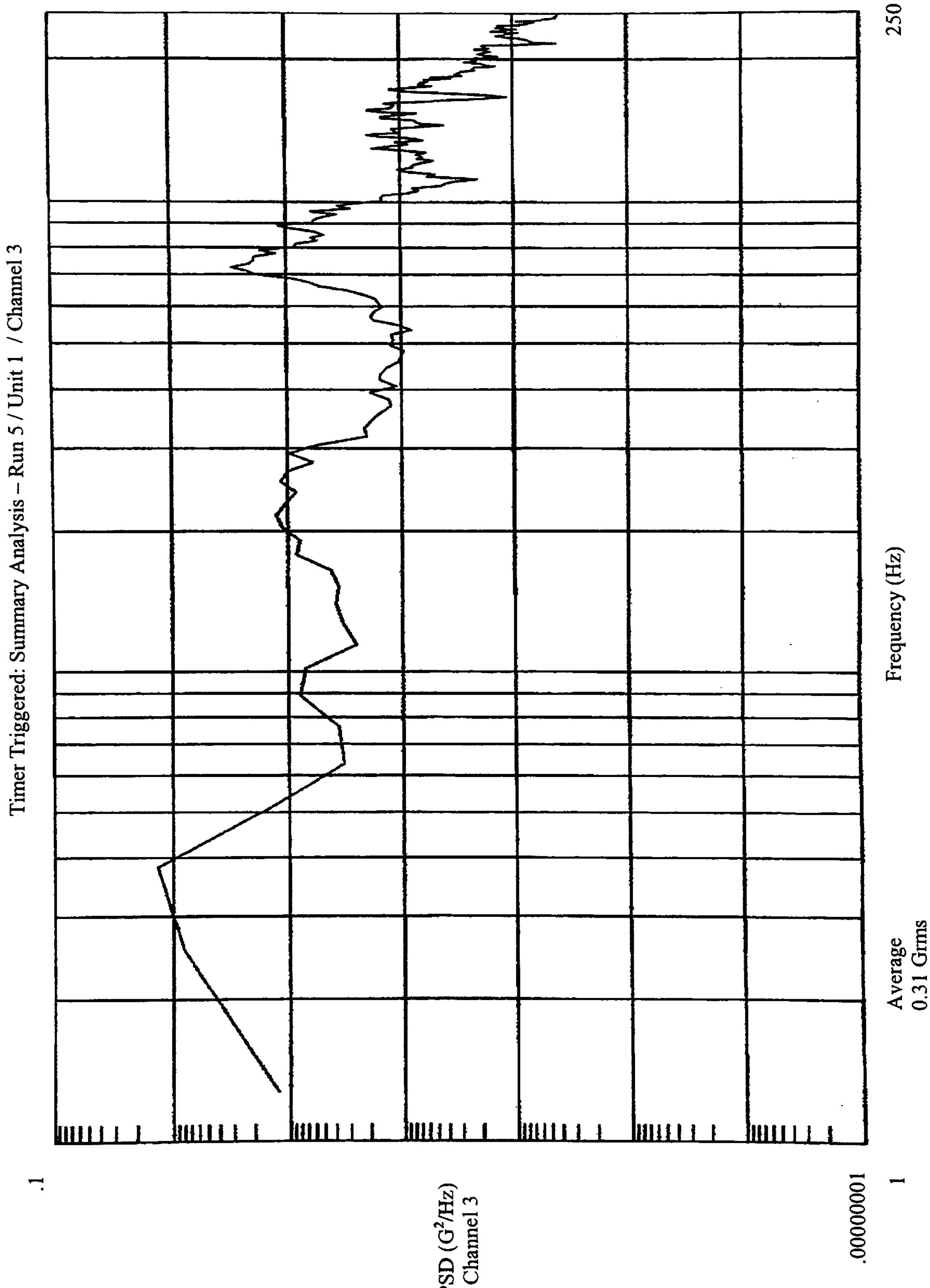


Figure C-12: Run 5 / Unit 1

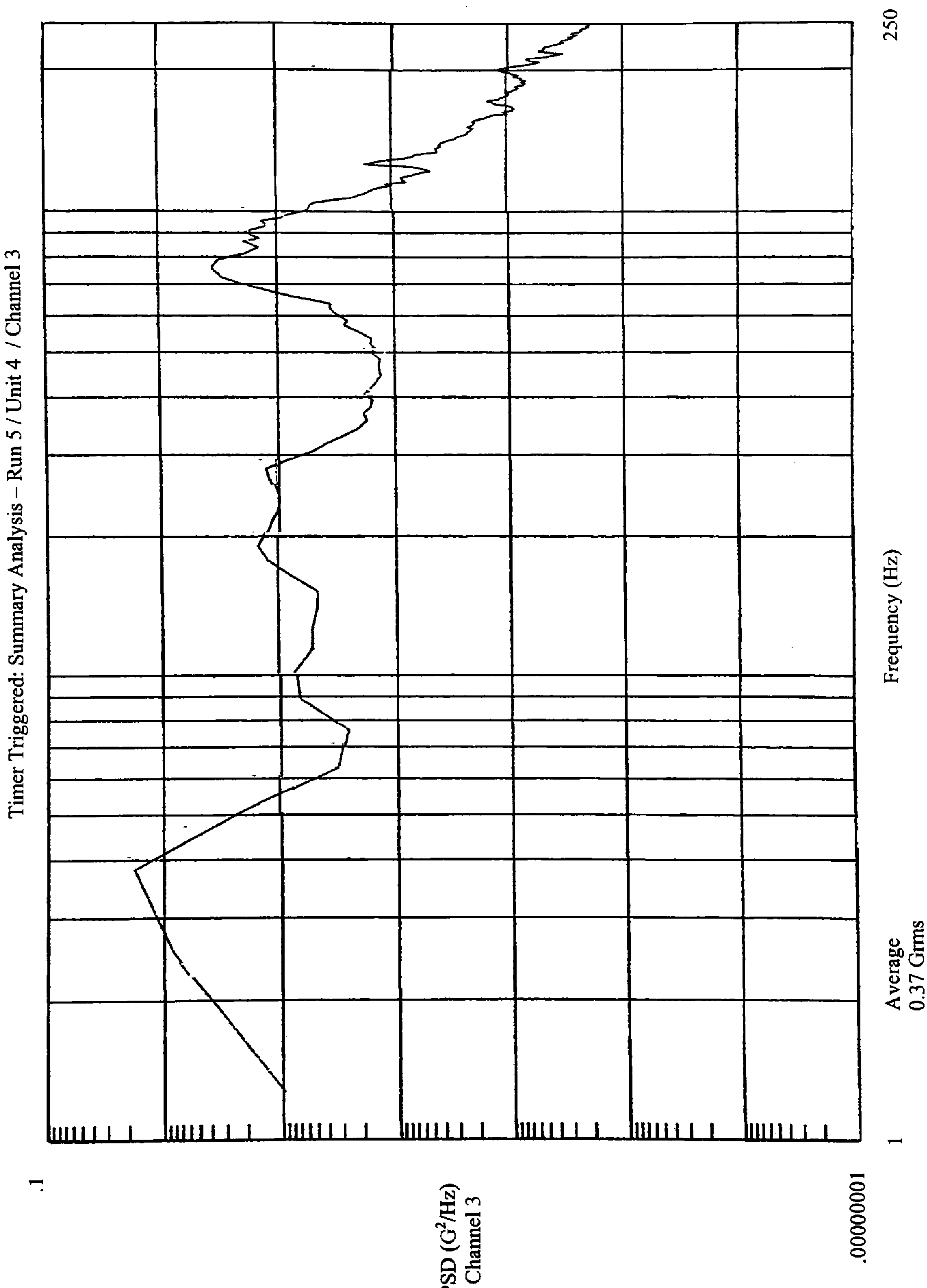


Figure C-13: Run 5 / Unit 4

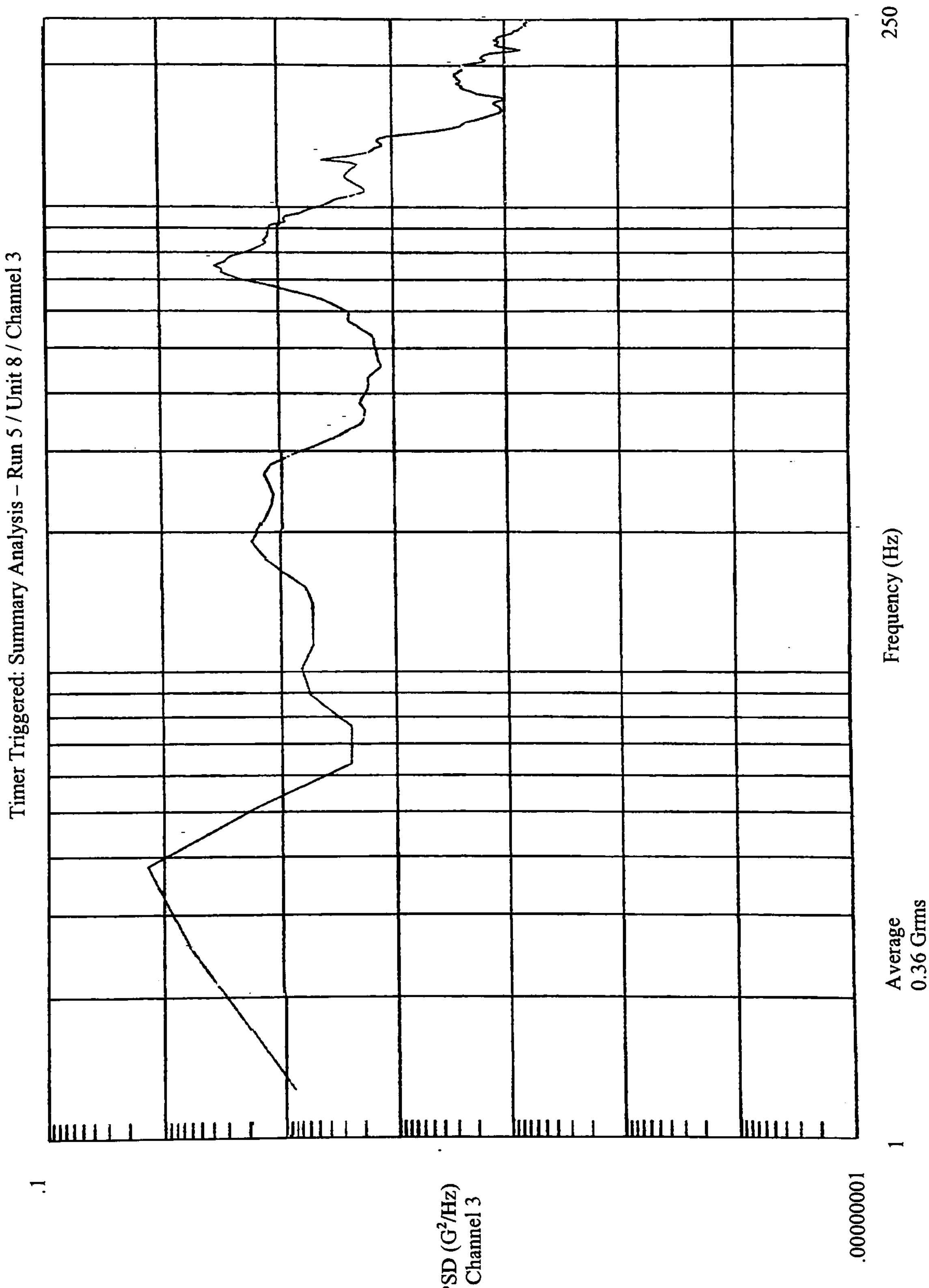


Figure C-14: Run 5 / Unit 8

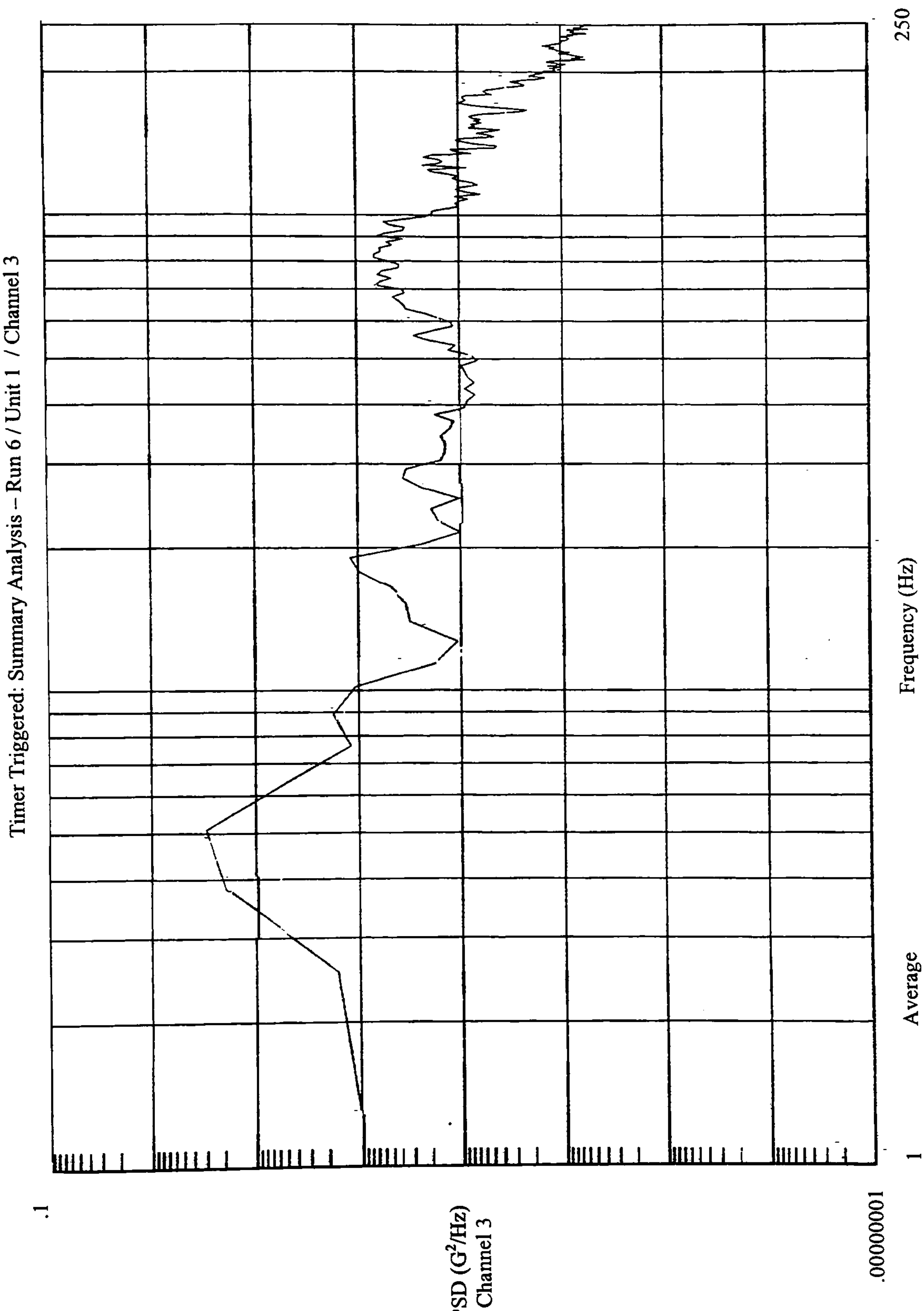


Figure C-15: Run 6 / Unit 1

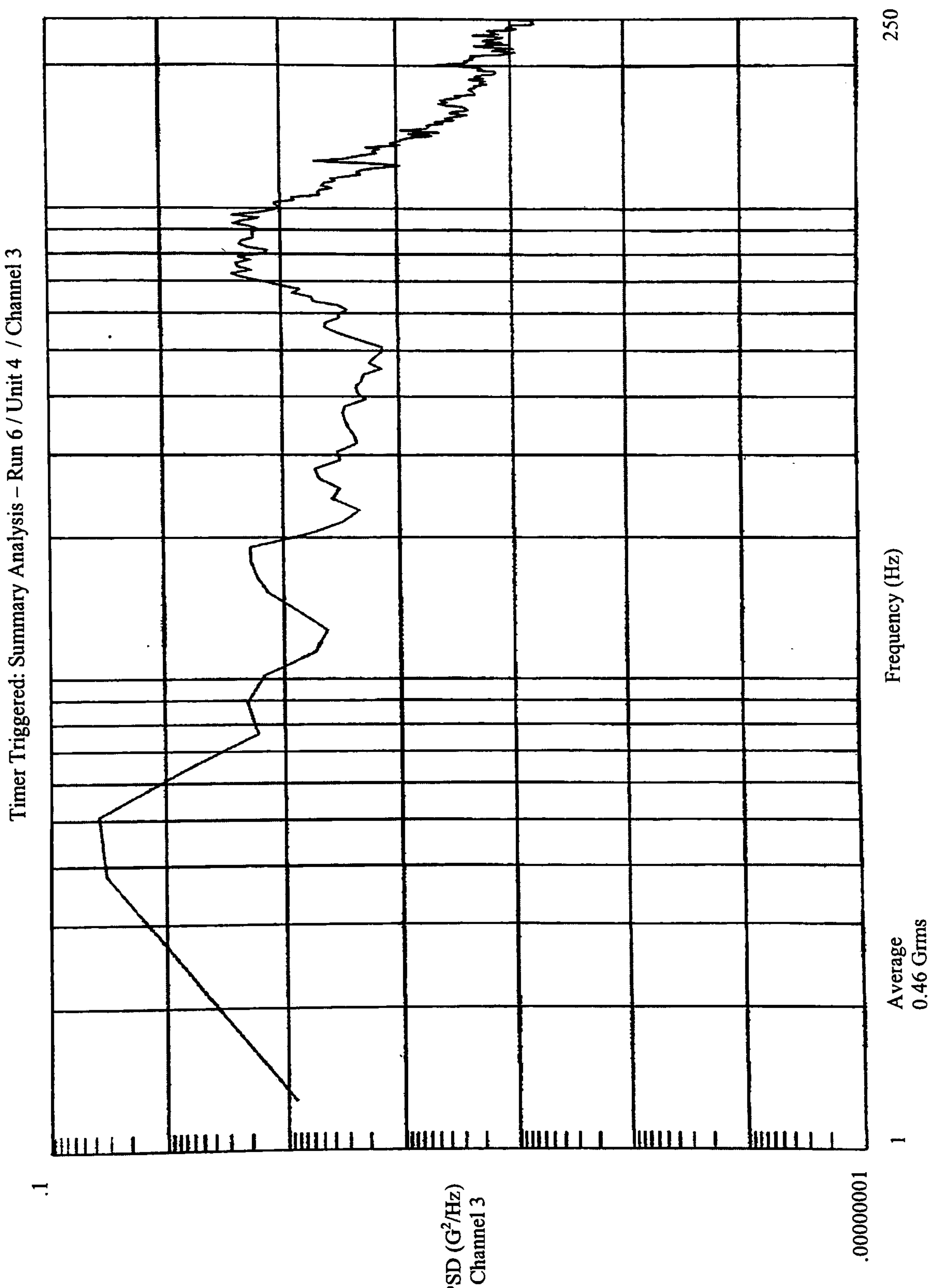


Figure C-16: Run 6 / Unit 4

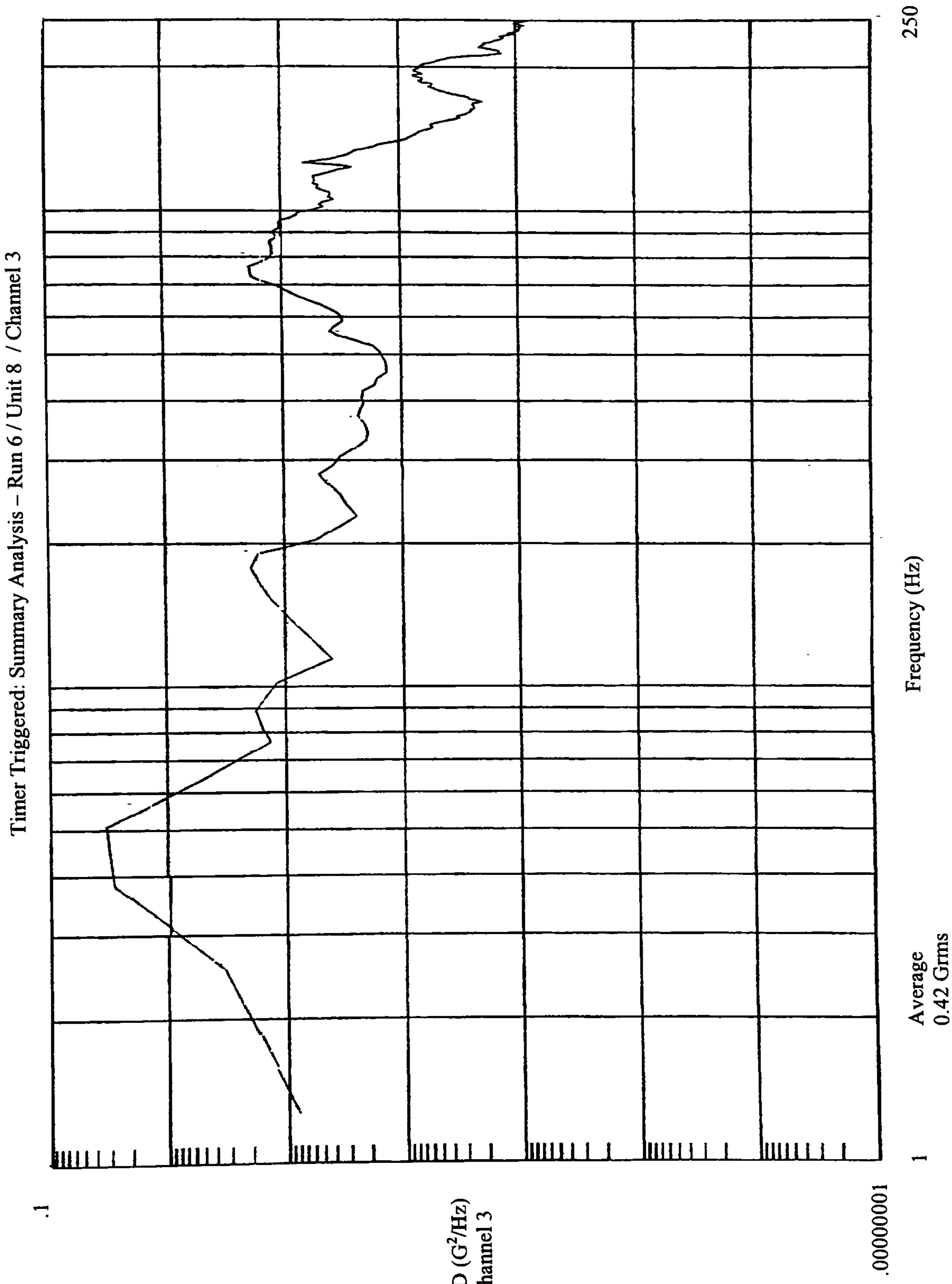


Figure C-17: Run 6 / Unit 8

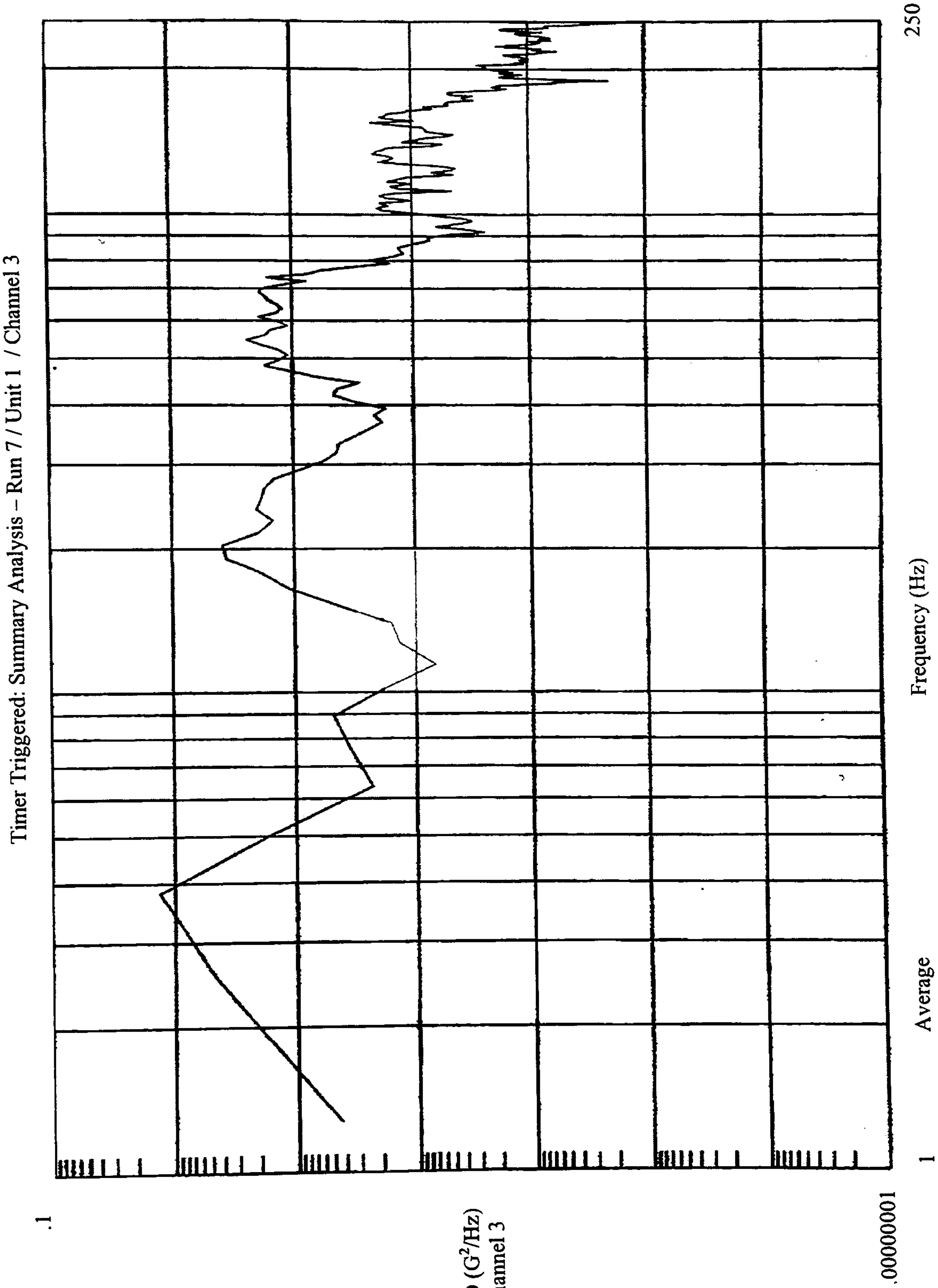


Figure C-18: Run 7 / Unit 1

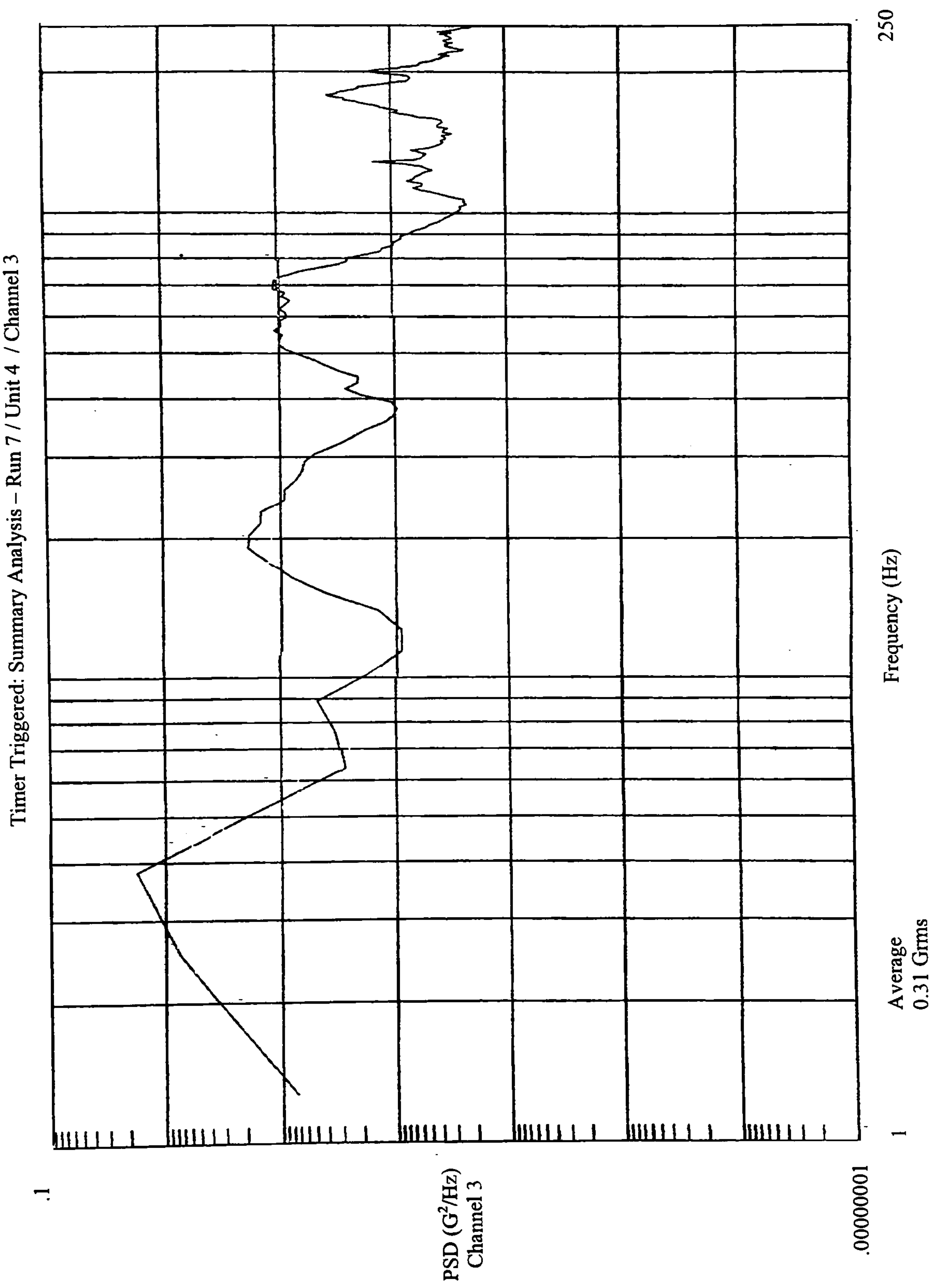


Figure C-19: Run 7 / Unit 4

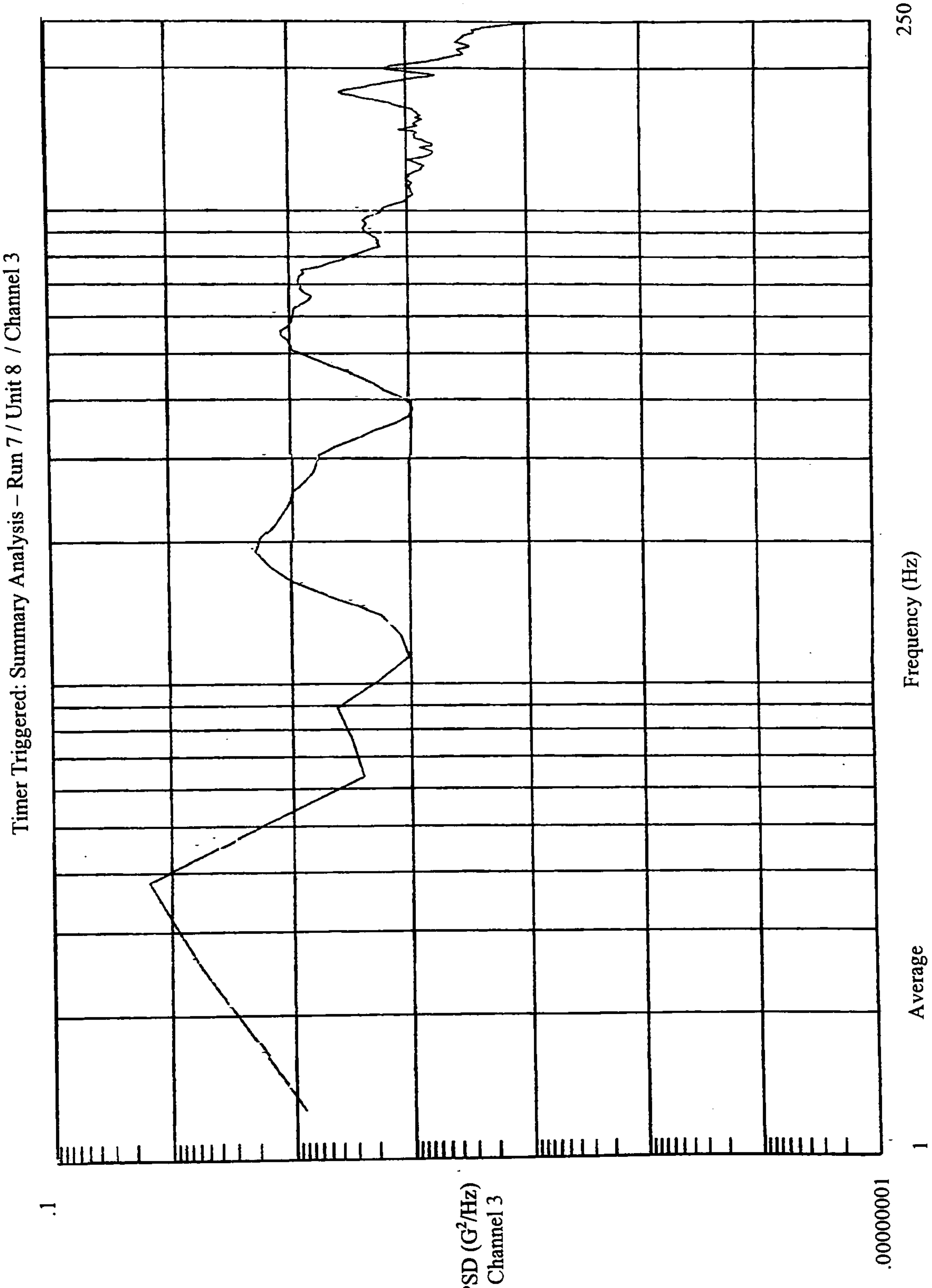


Figure C-20: Run 7 / Unit 8

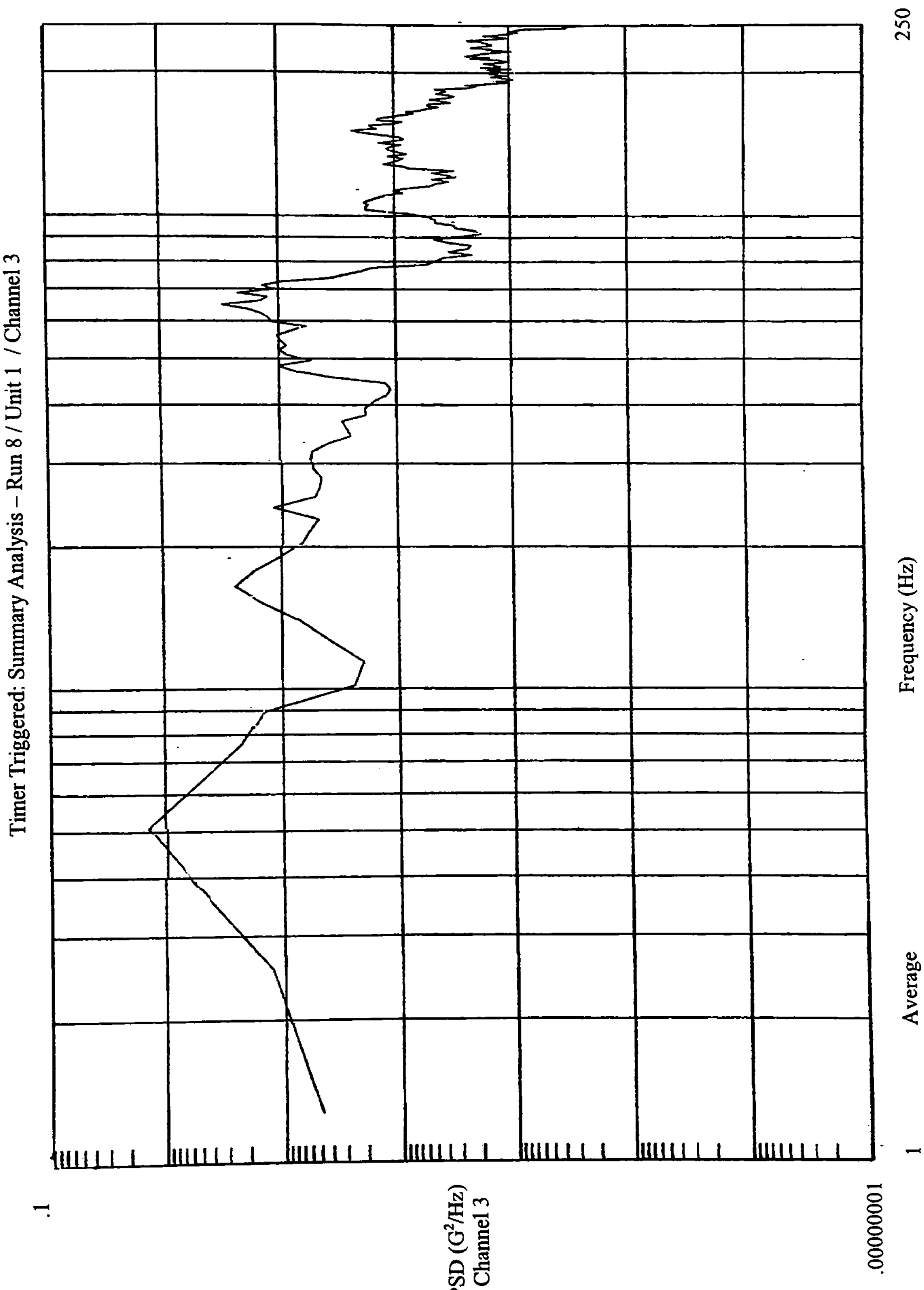


Figure C-21: Run 8 / Unit 1

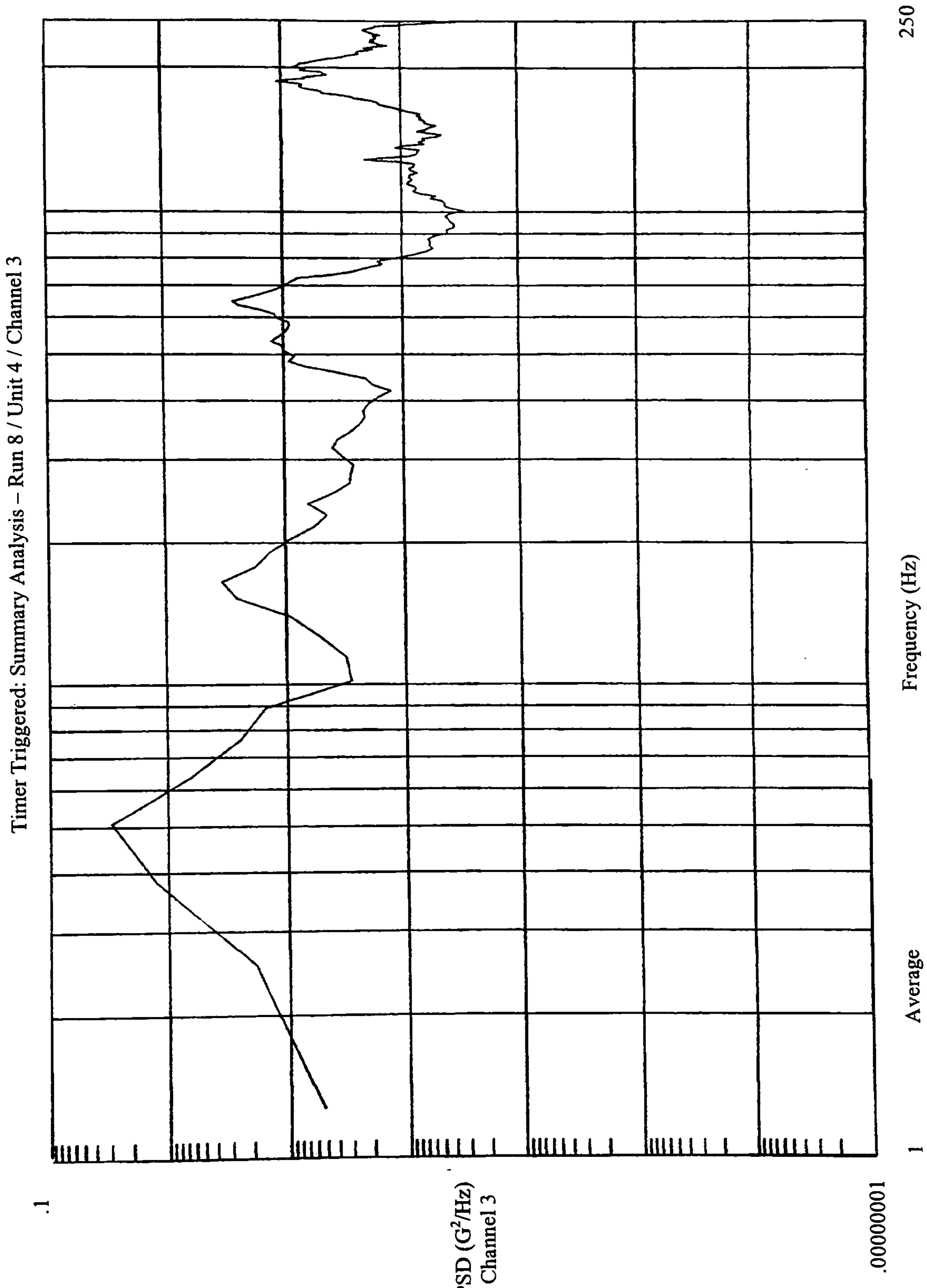


Figure C-22: Run 8 / Unit 4

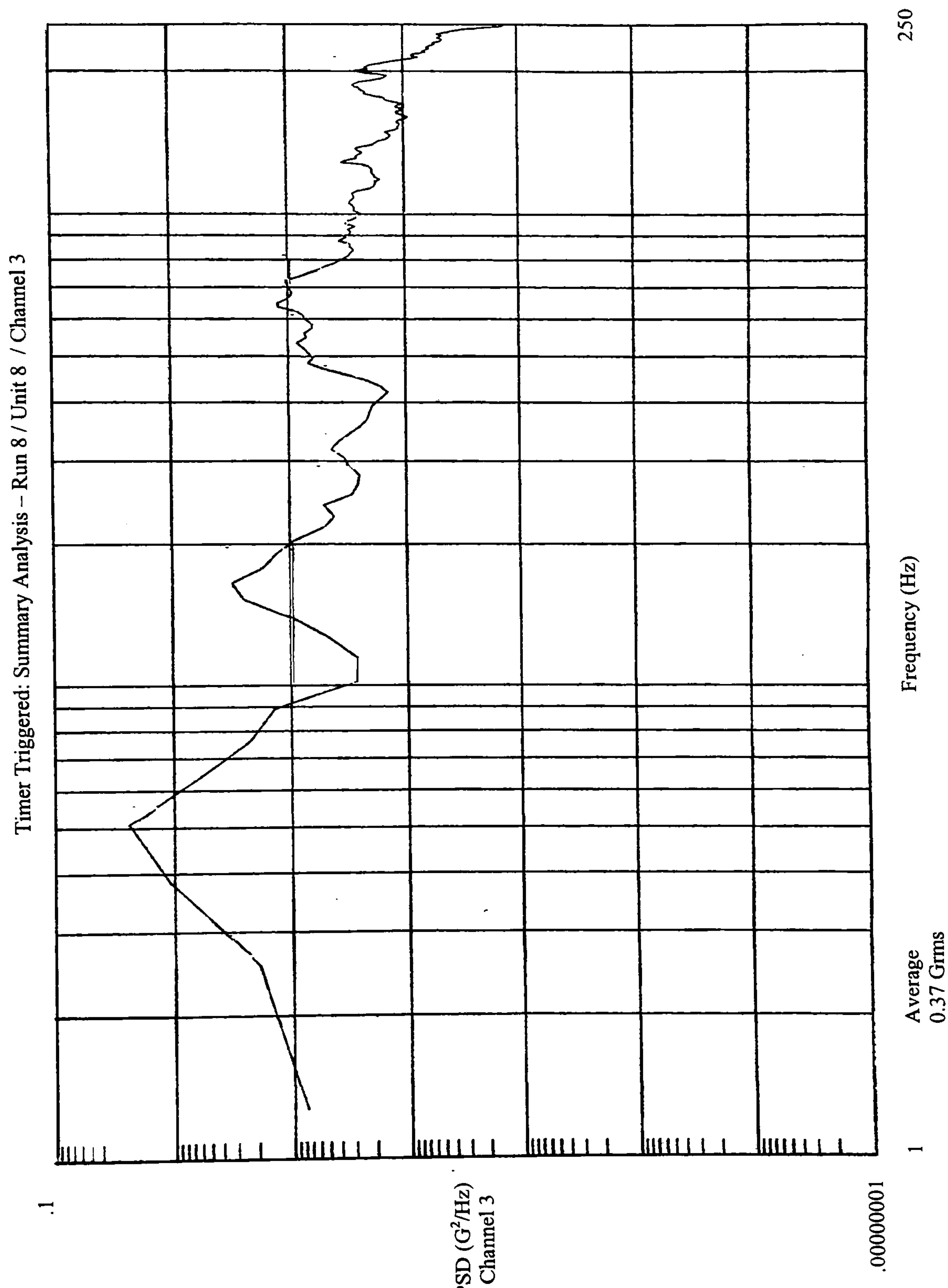


Figure C-23: Run 8 / Unit 8

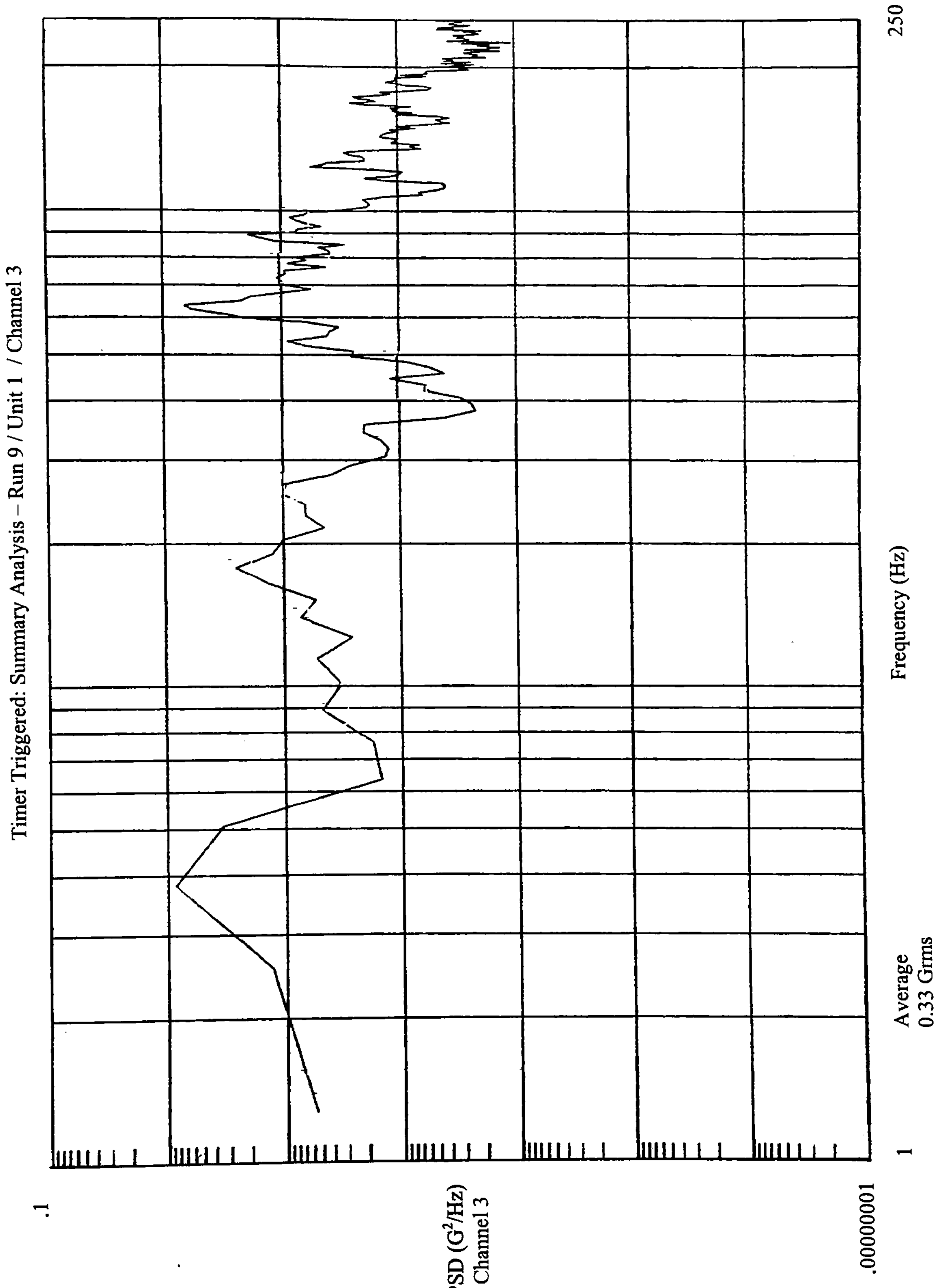


Figure C-24: Run 9 / Unit 1

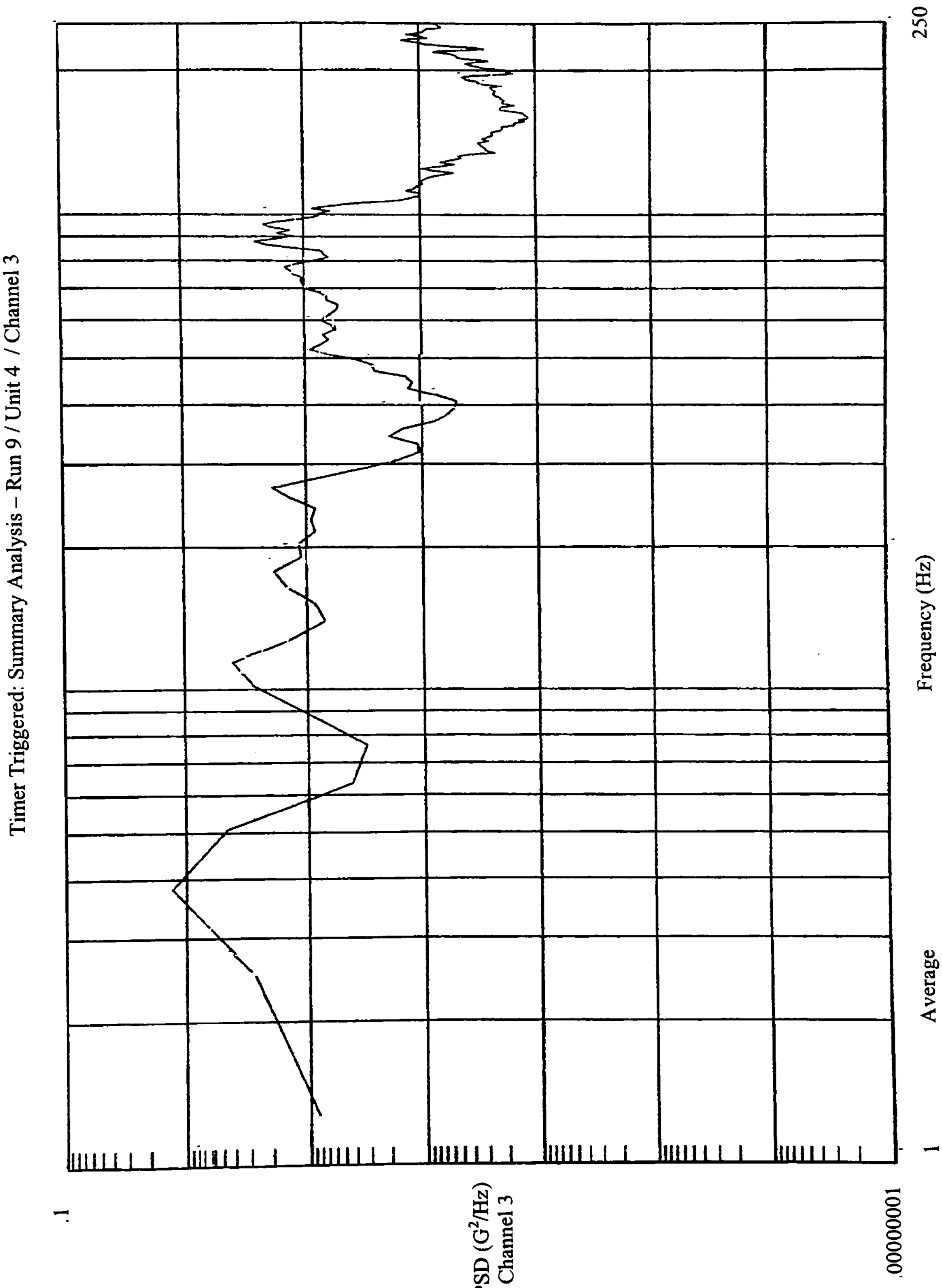


Figure C-25: Run 9 / Unit 4

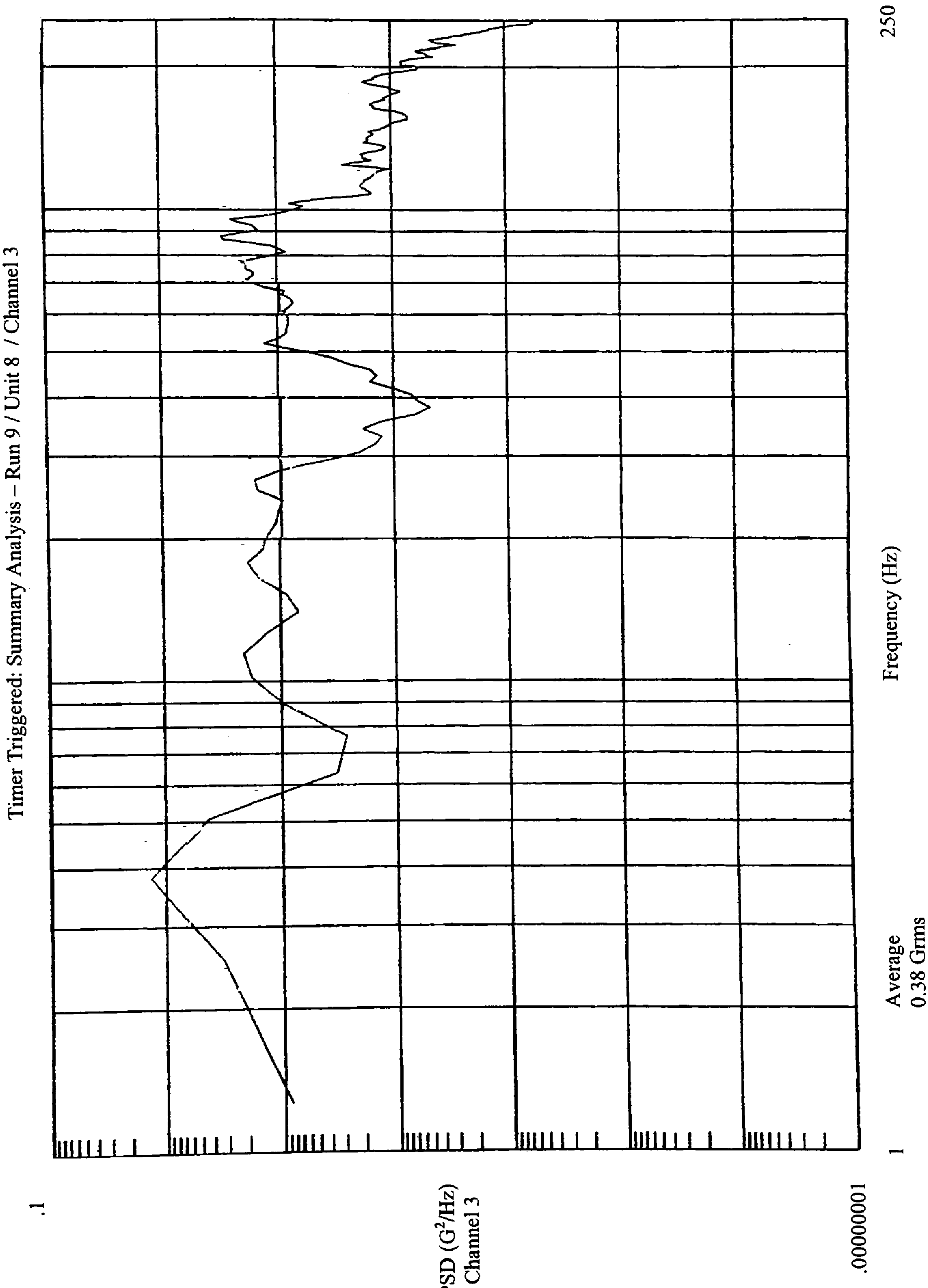


Figure C-26: Run 9 / Unit 8

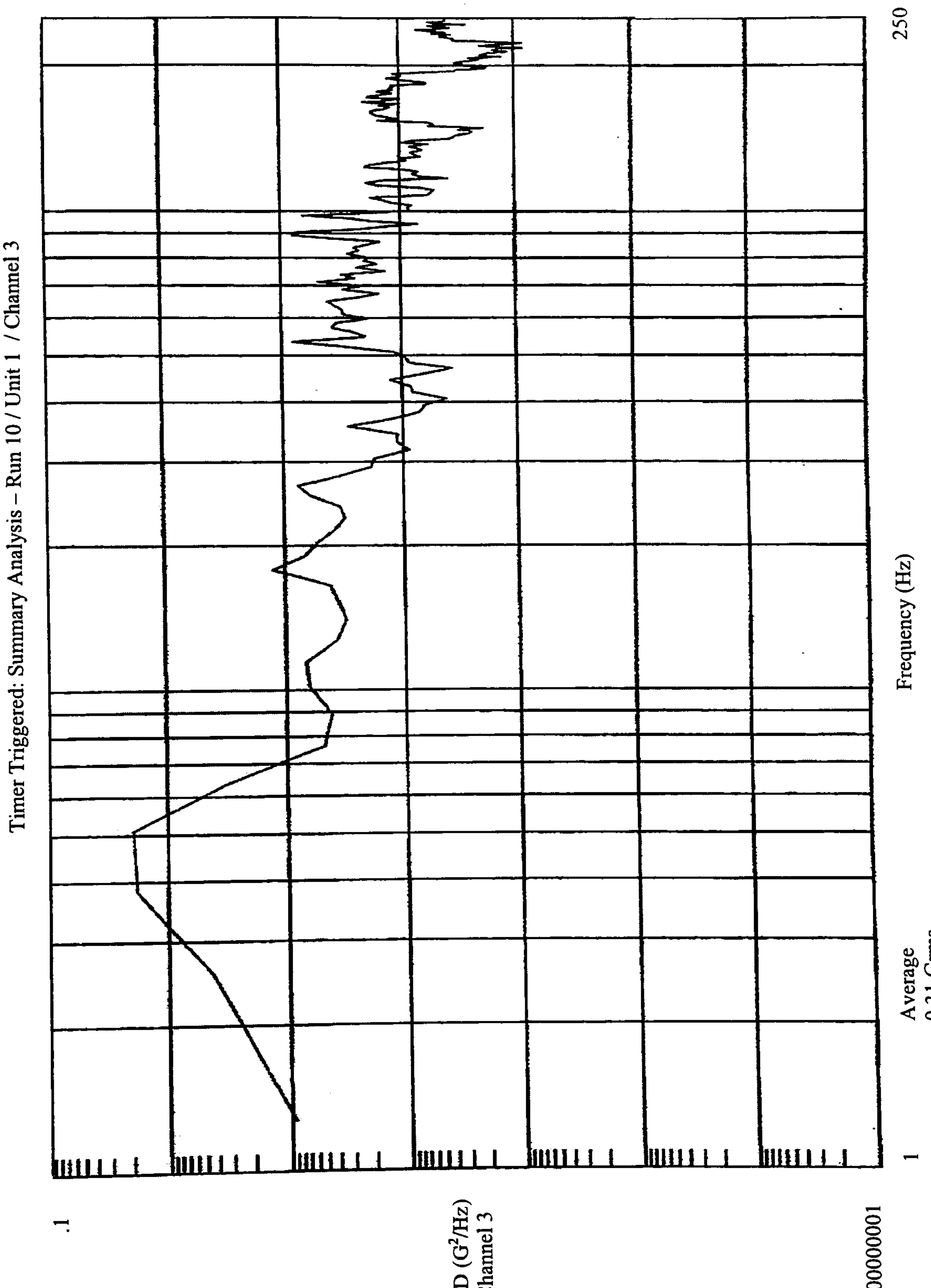
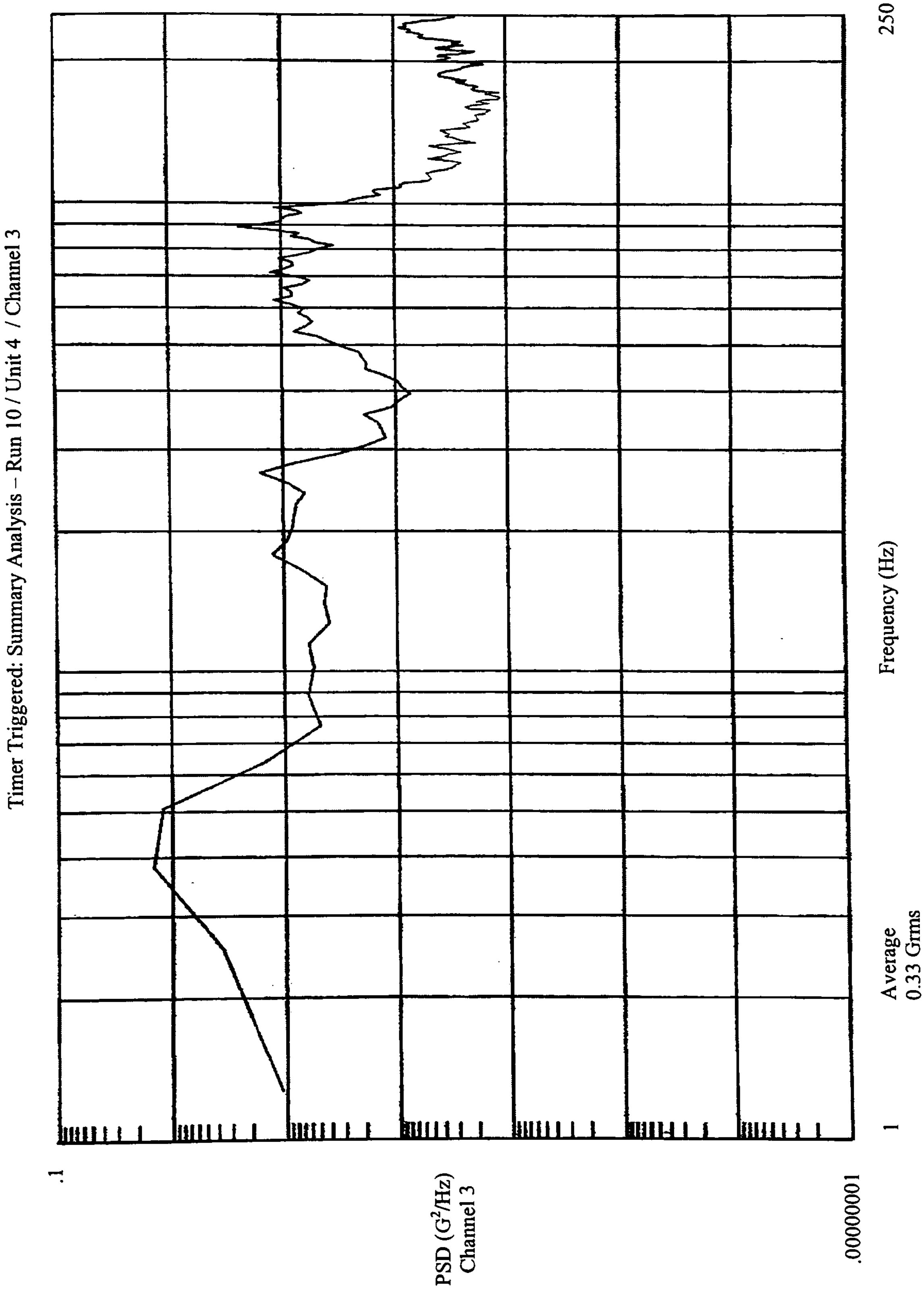


Figure C-27: Run 10 / Unit 1



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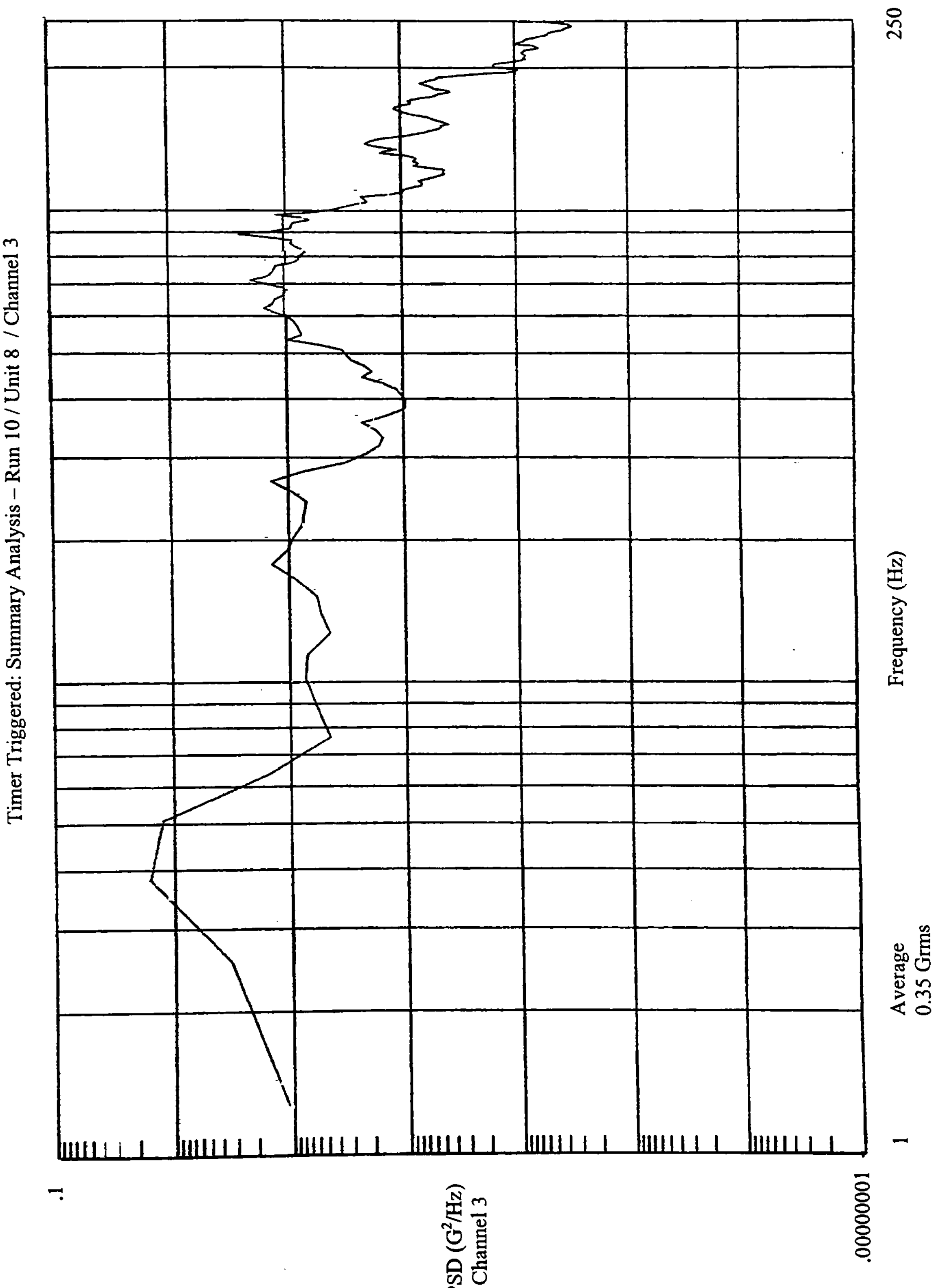


Figure C-29: Run 10 / Unit 8

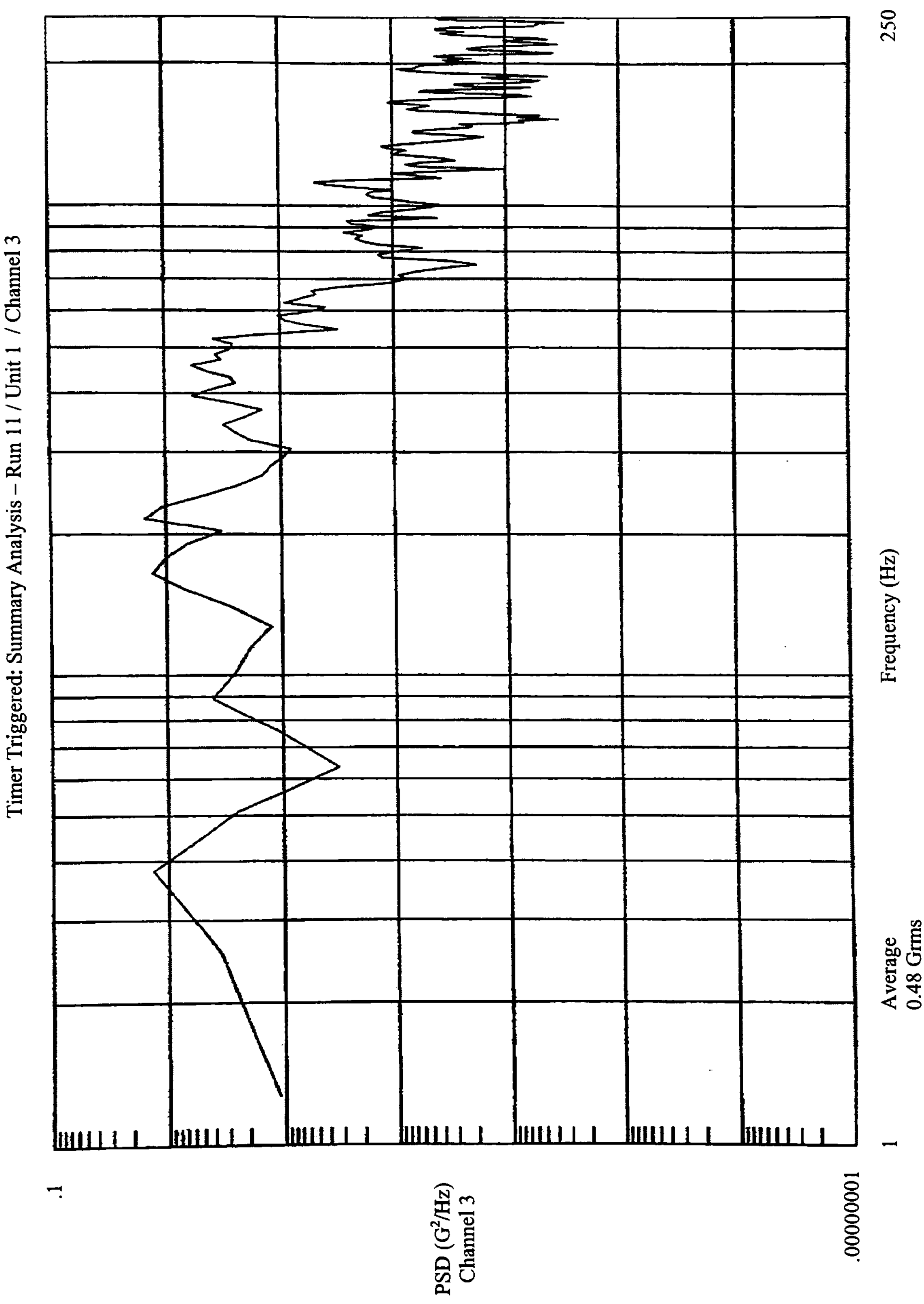
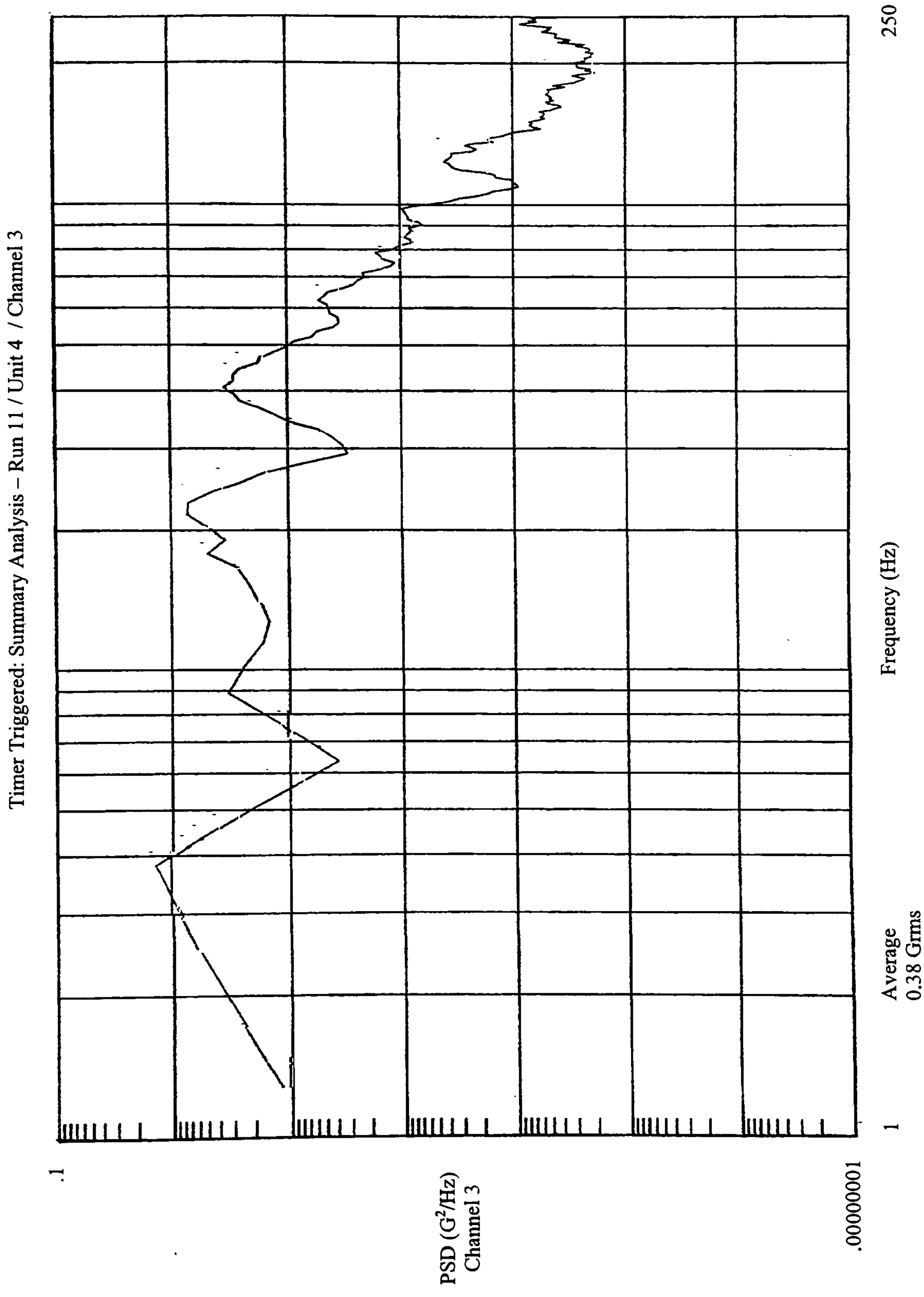


Figure C-30: Run 11 / Unit 1



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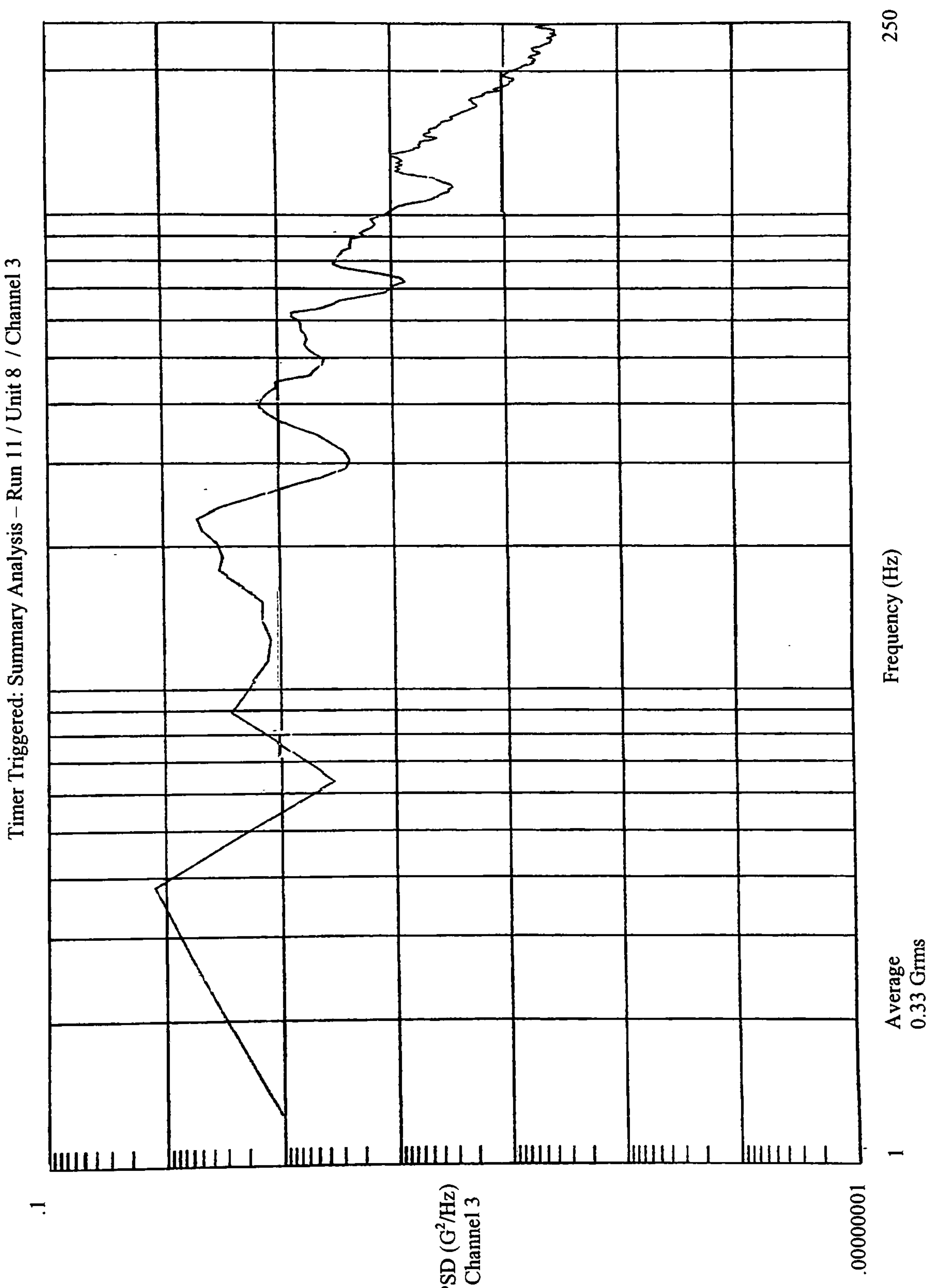

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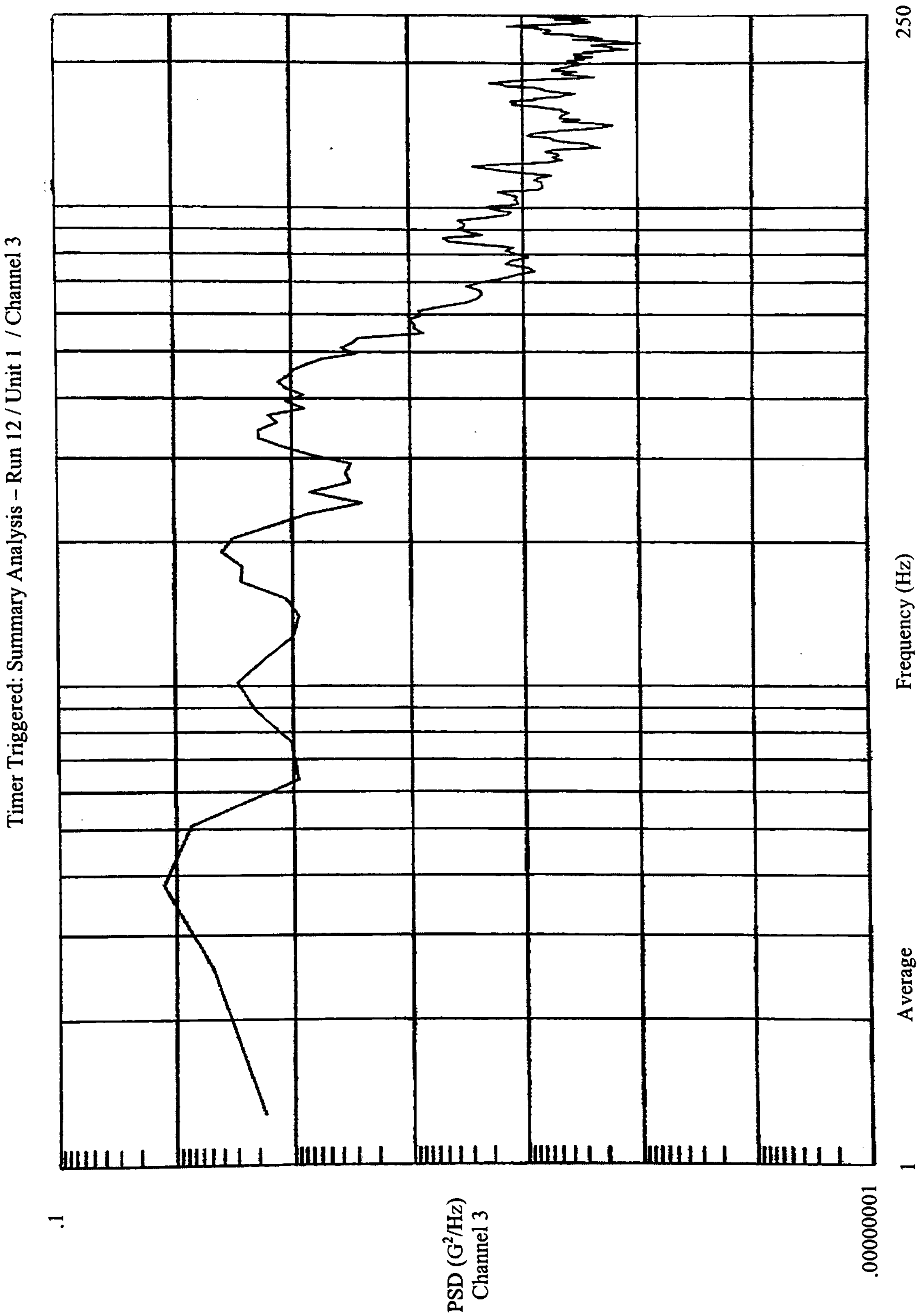


Figure C-33: Run 12 / Unit 1

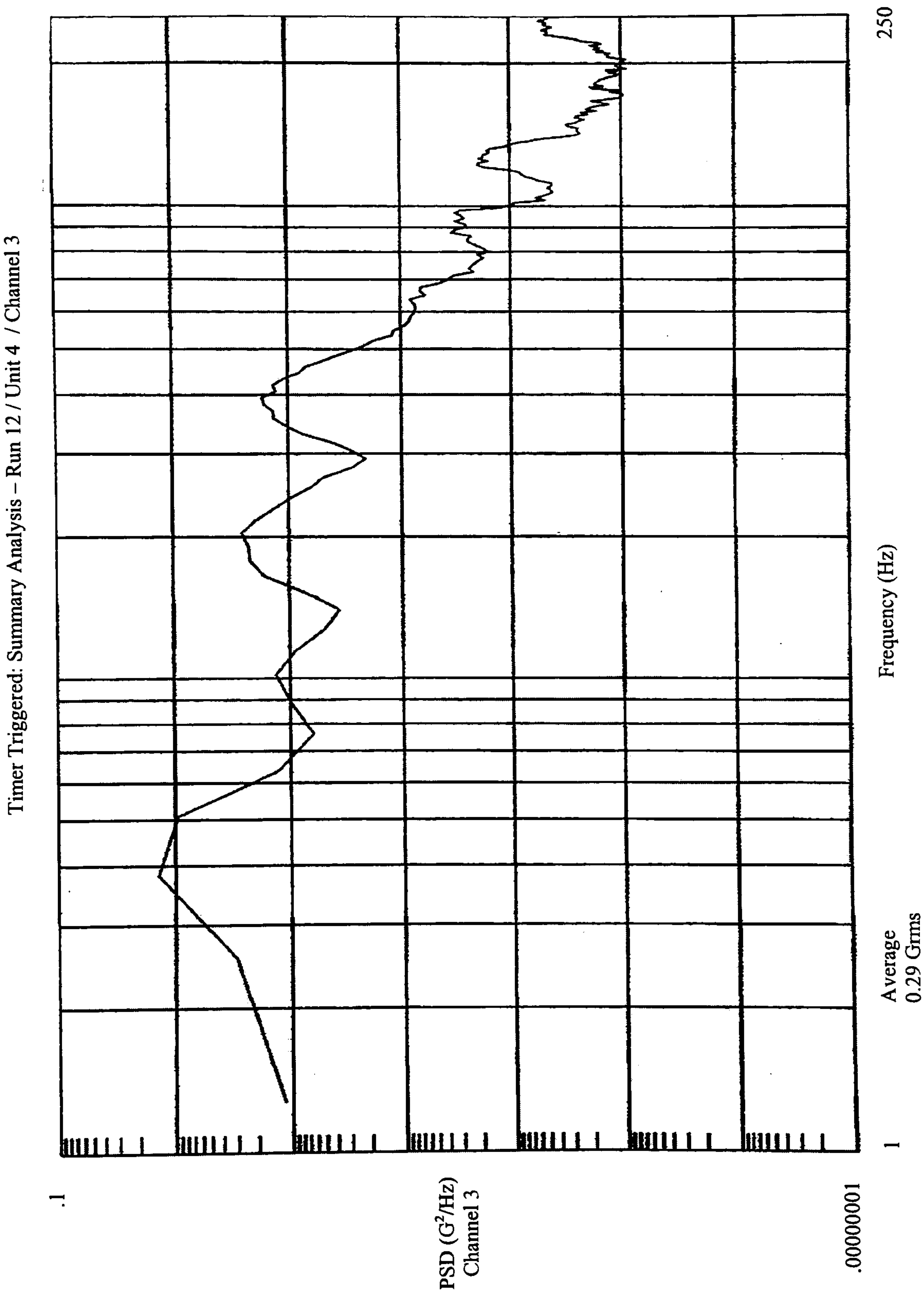


Figure C-34: Run 12 / Unit 4

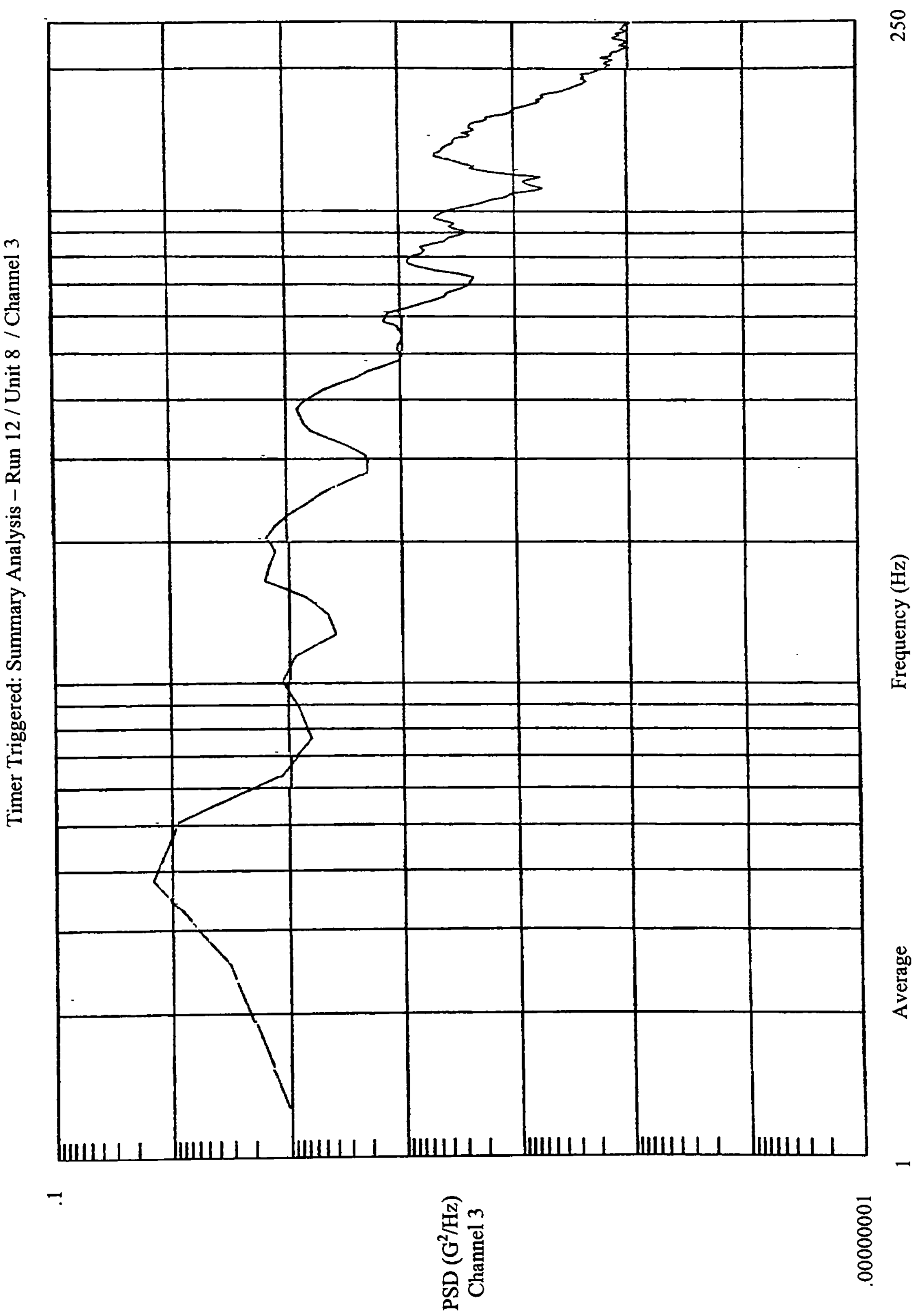


Figure C-35: Run 12 / Unit 8

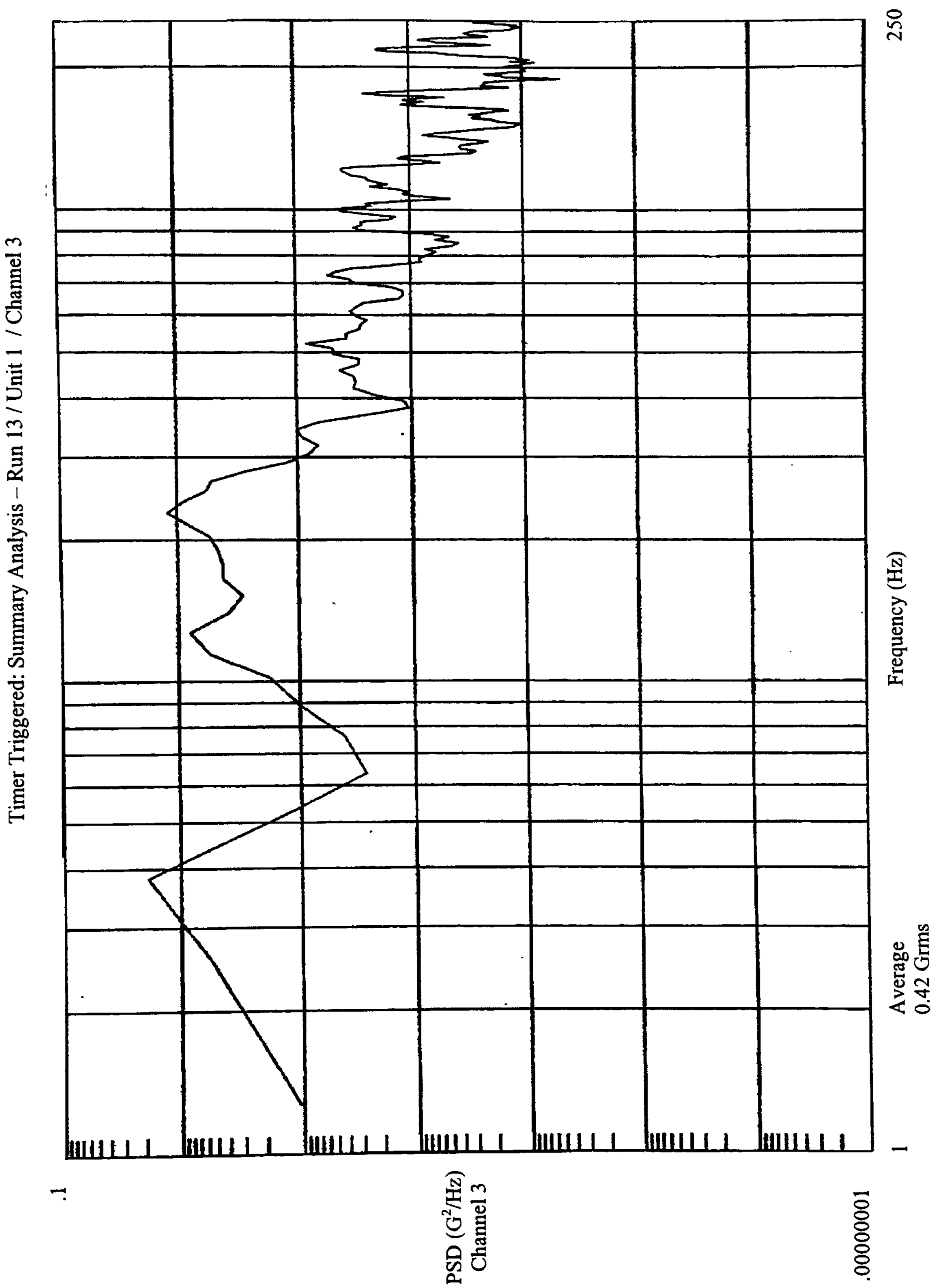


Figure C-36: Run 13 / Unit 1

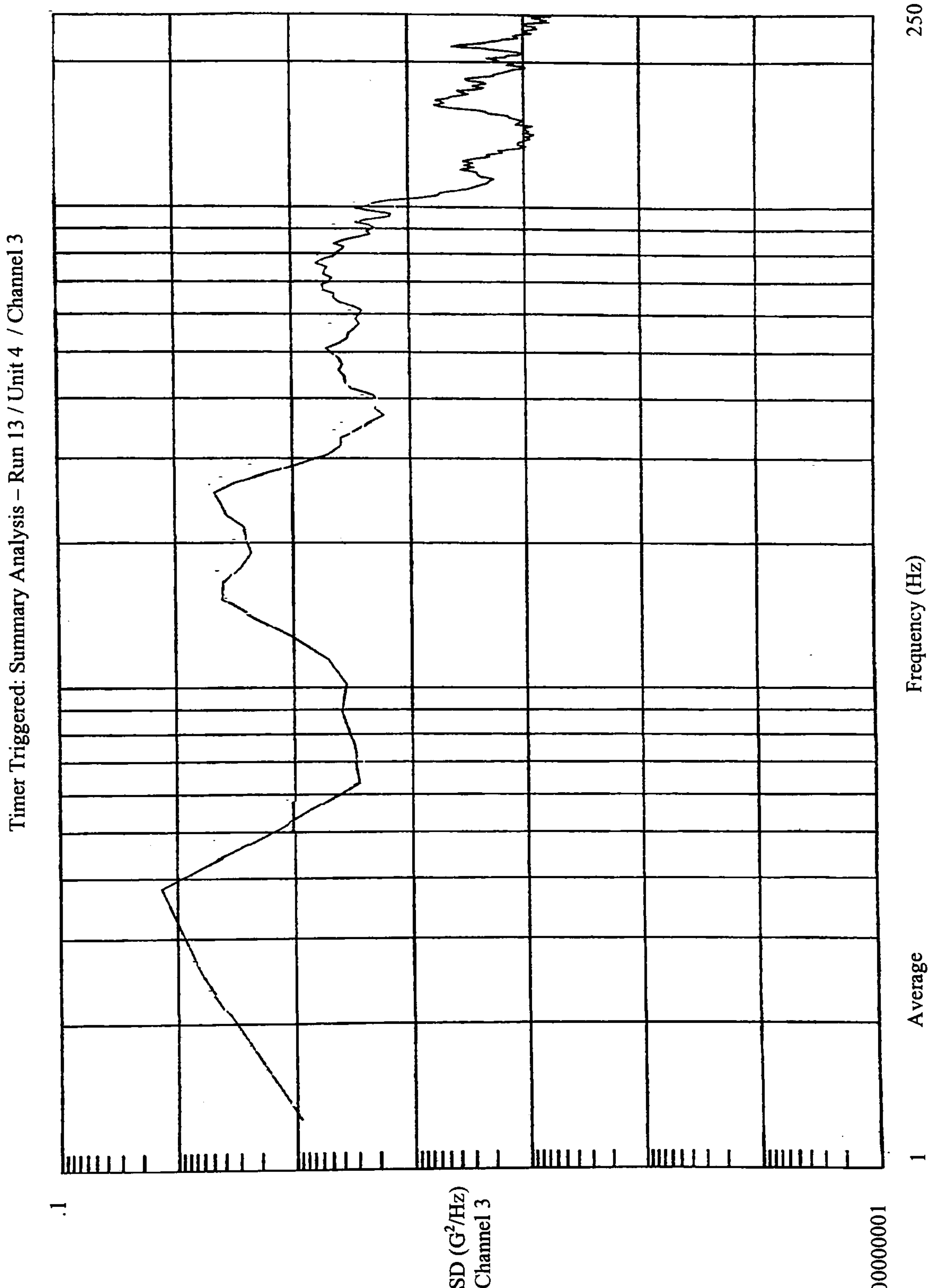


Figure C-37: Run 13 / Unit 4

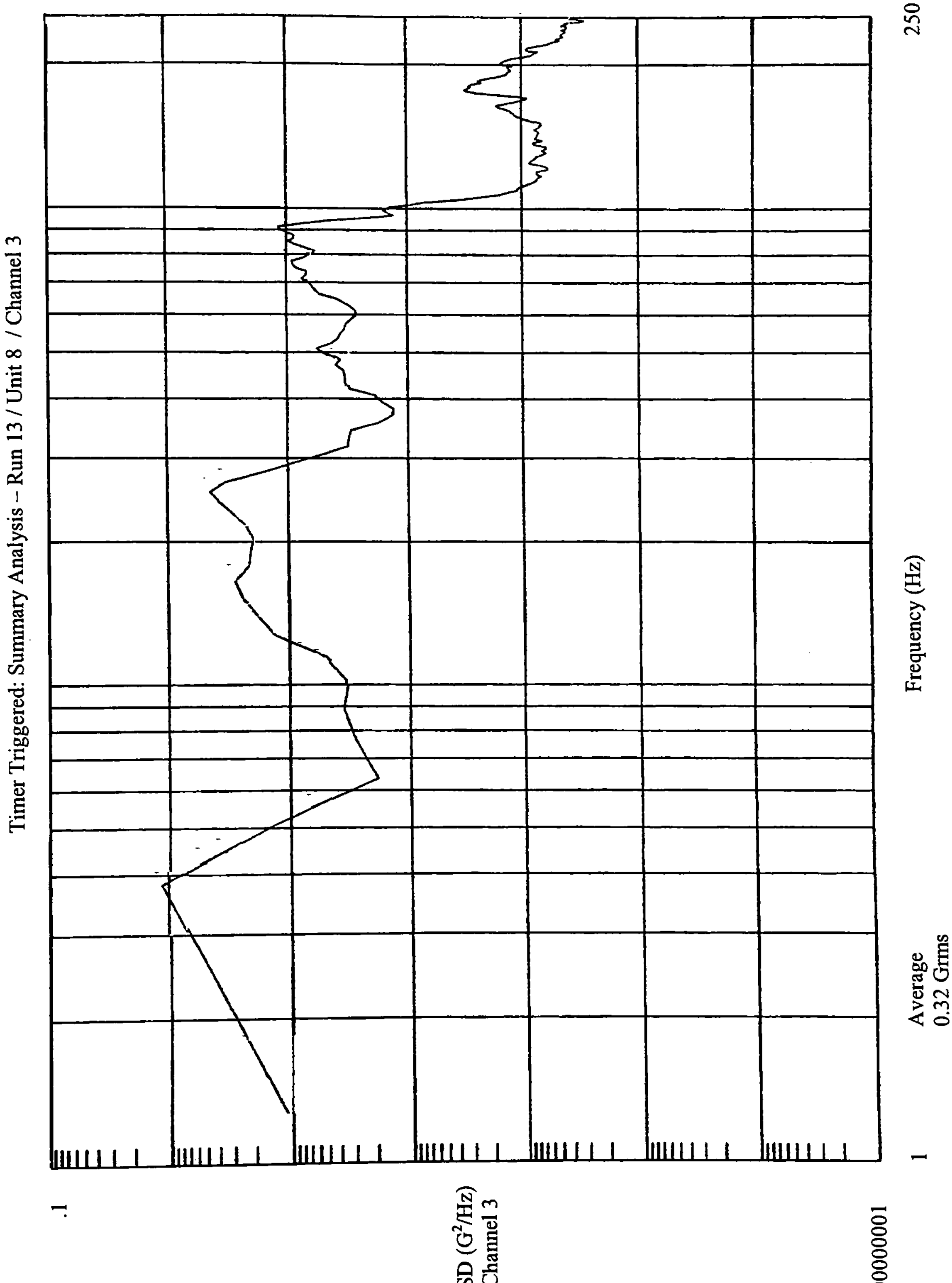


Figure C-38: Run 13 / Unit 8

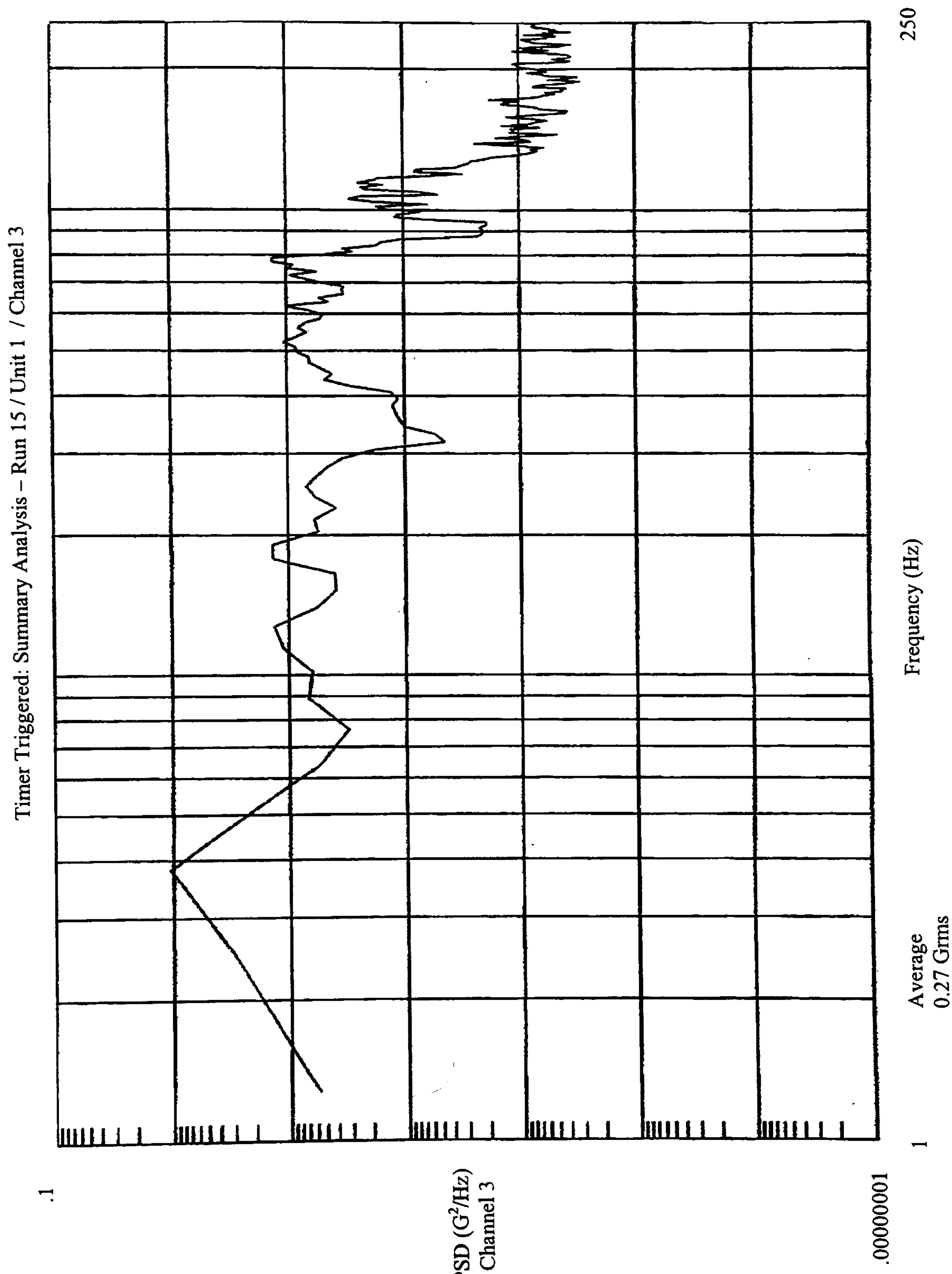


Figure C-39: Run 15 / Unit 1

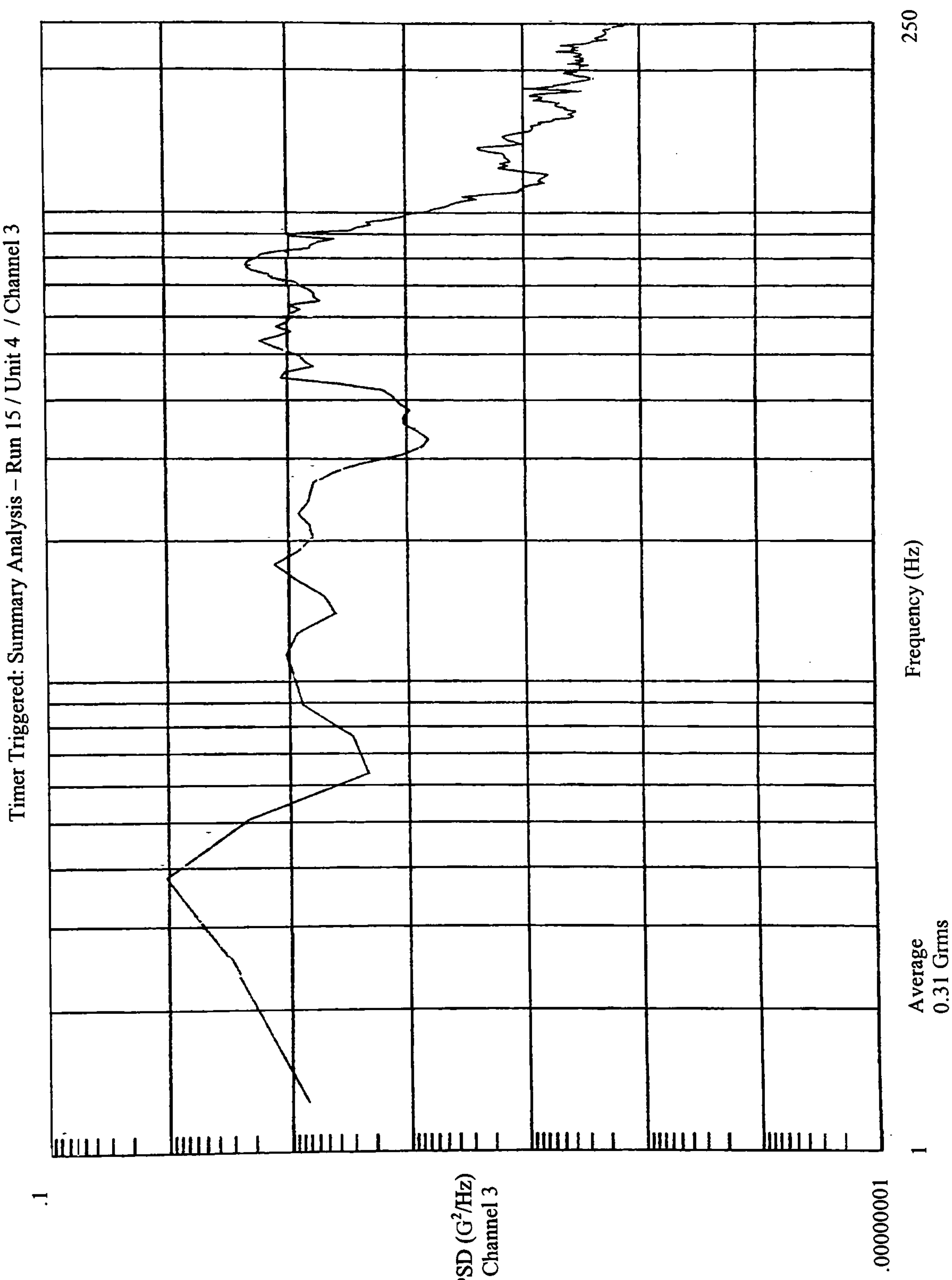


Figure C-40: Run 15 / Unit 4

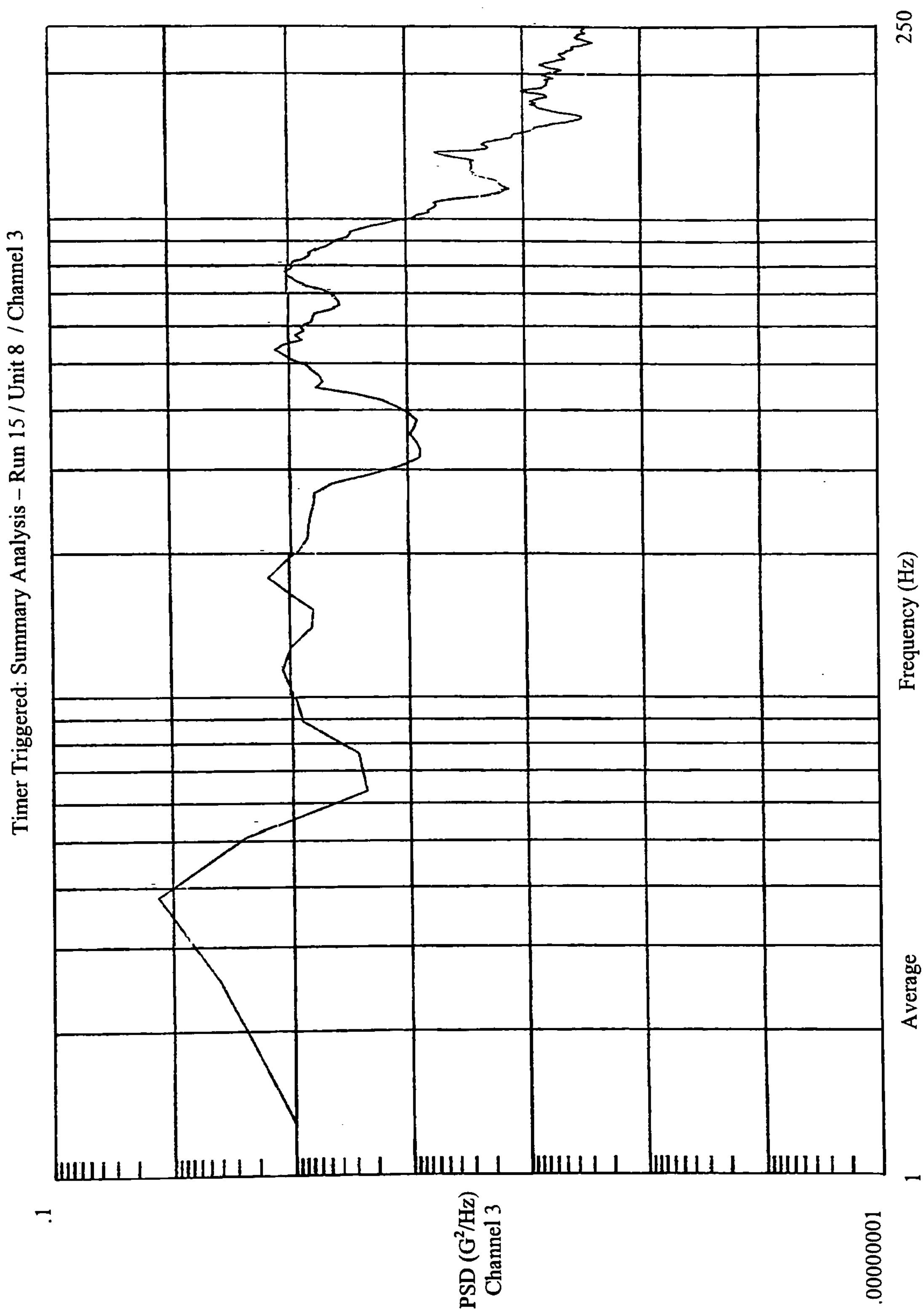


Figure C-41: Run 15 / Unit 8

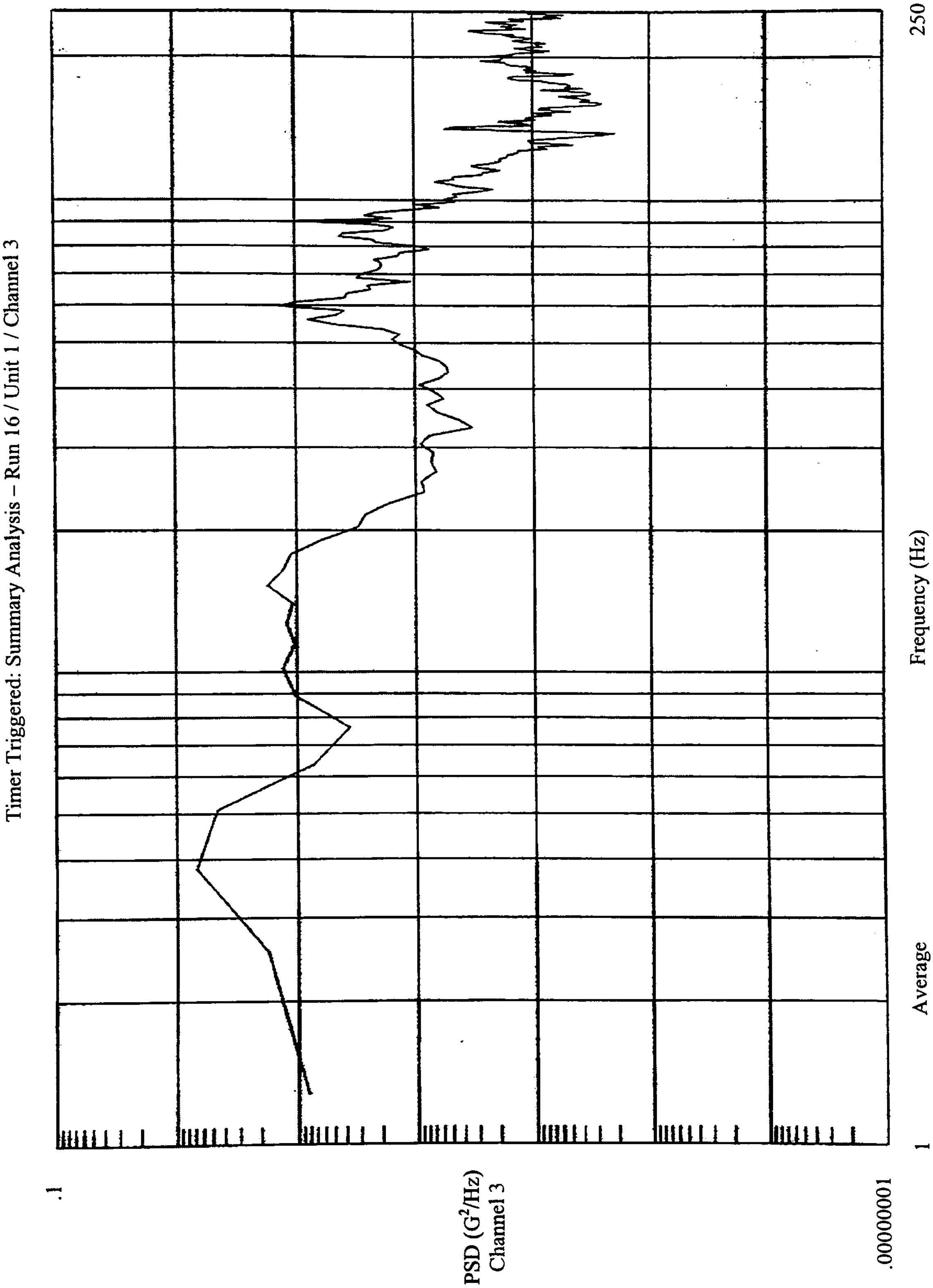


Figure C-42: Run 16 / Unit 1

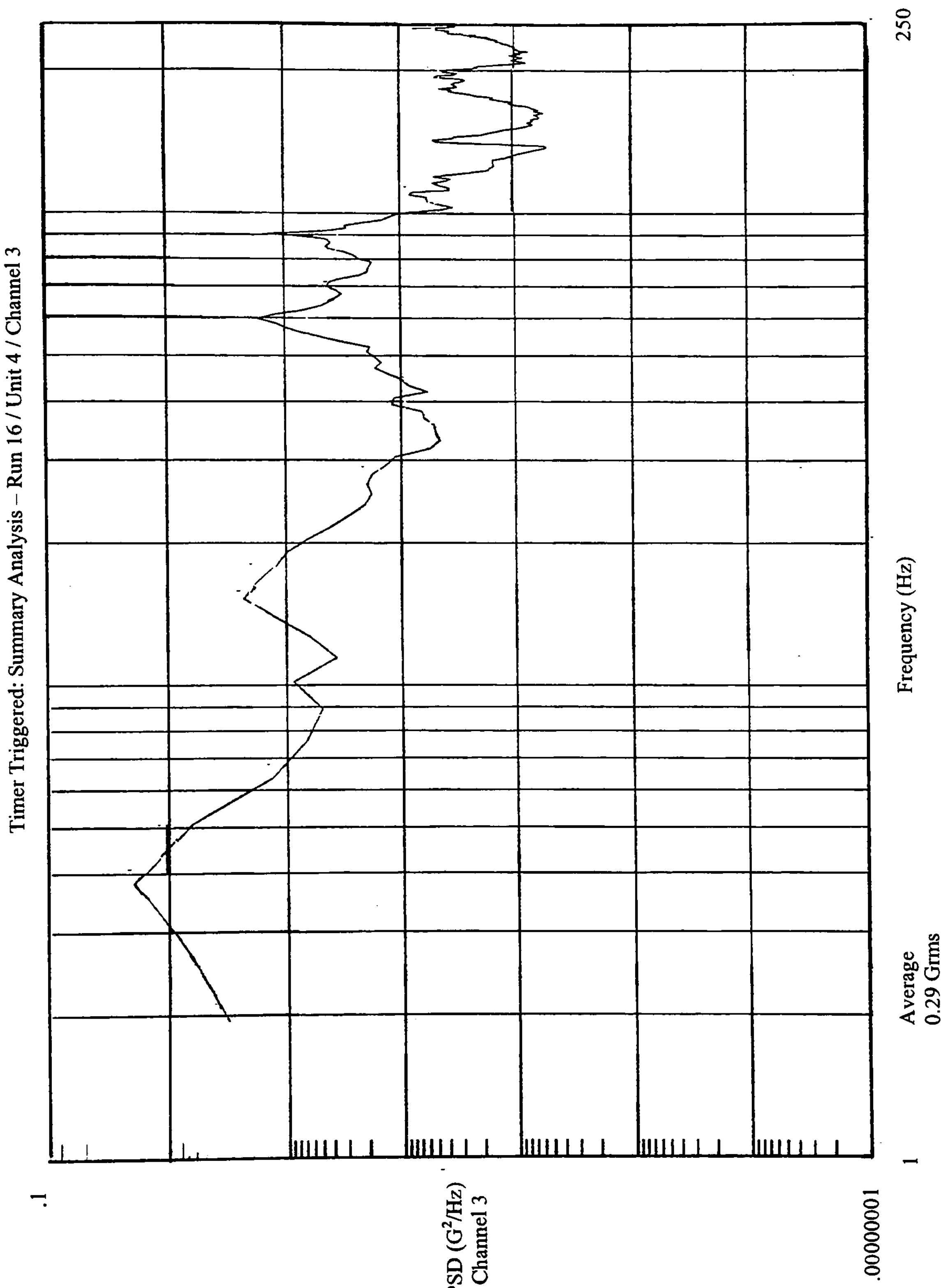
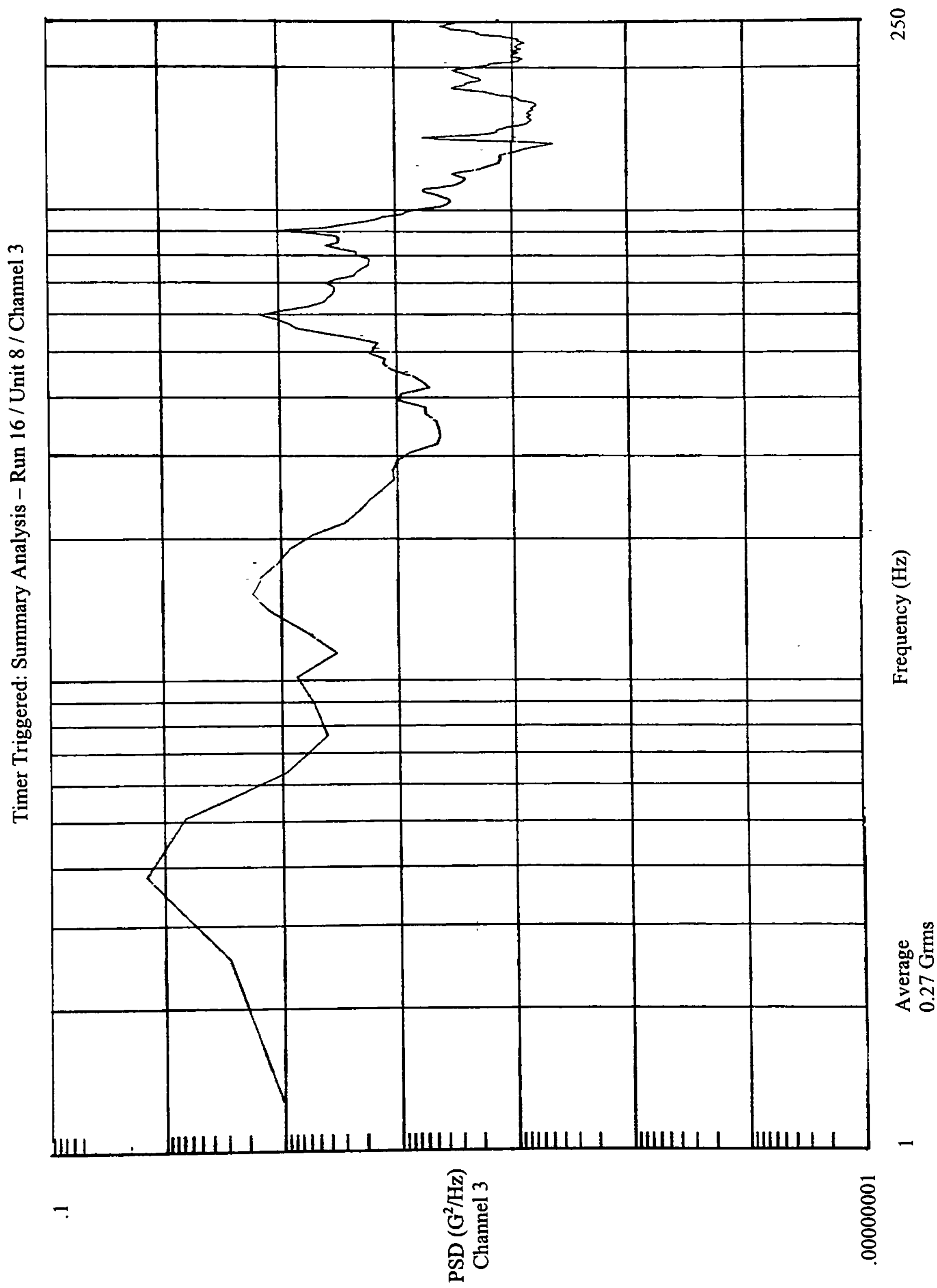


Figure C-43: Run 16 / Unit 4



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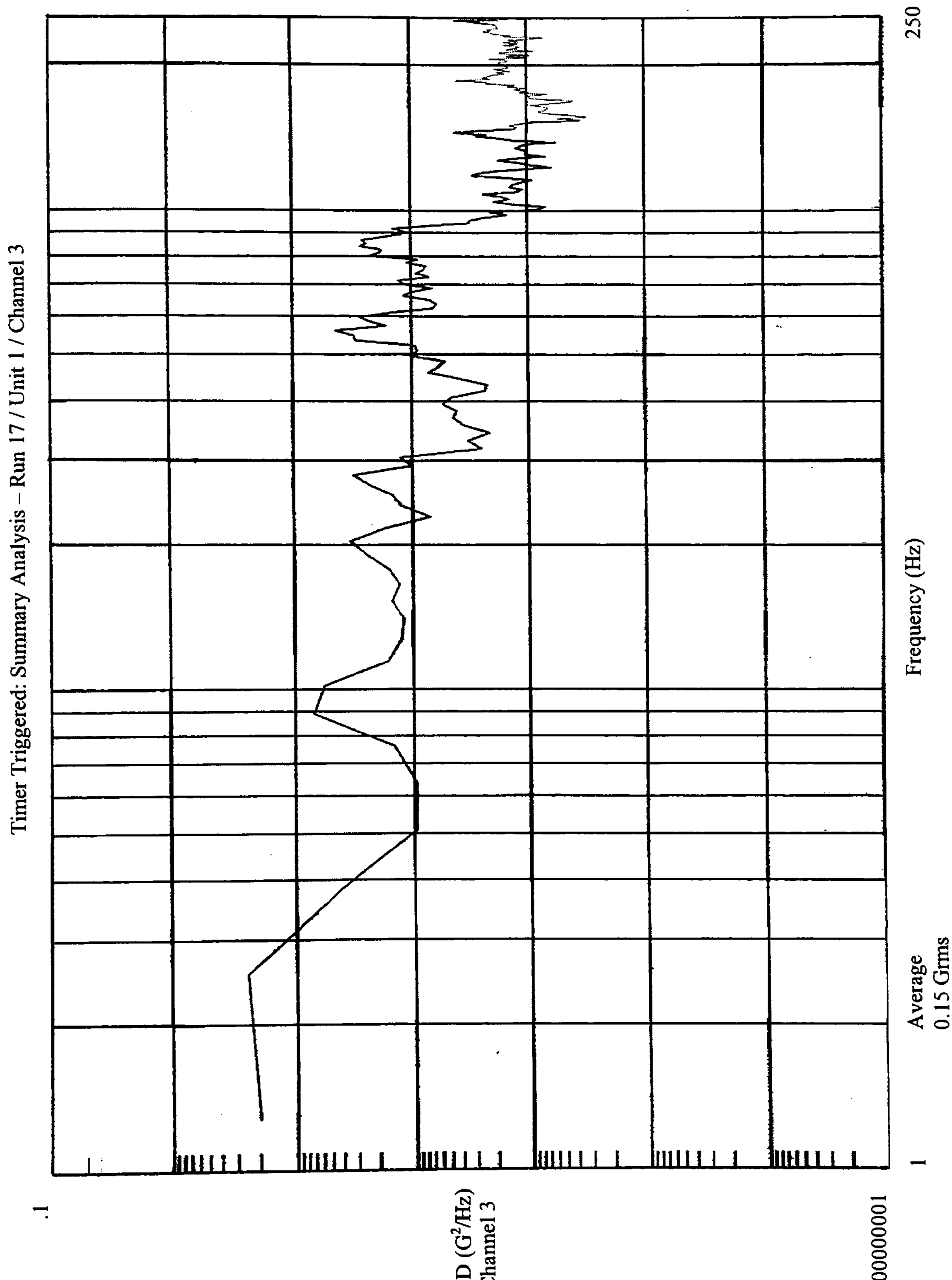

Figure C-45: Run 17 / Unit 1

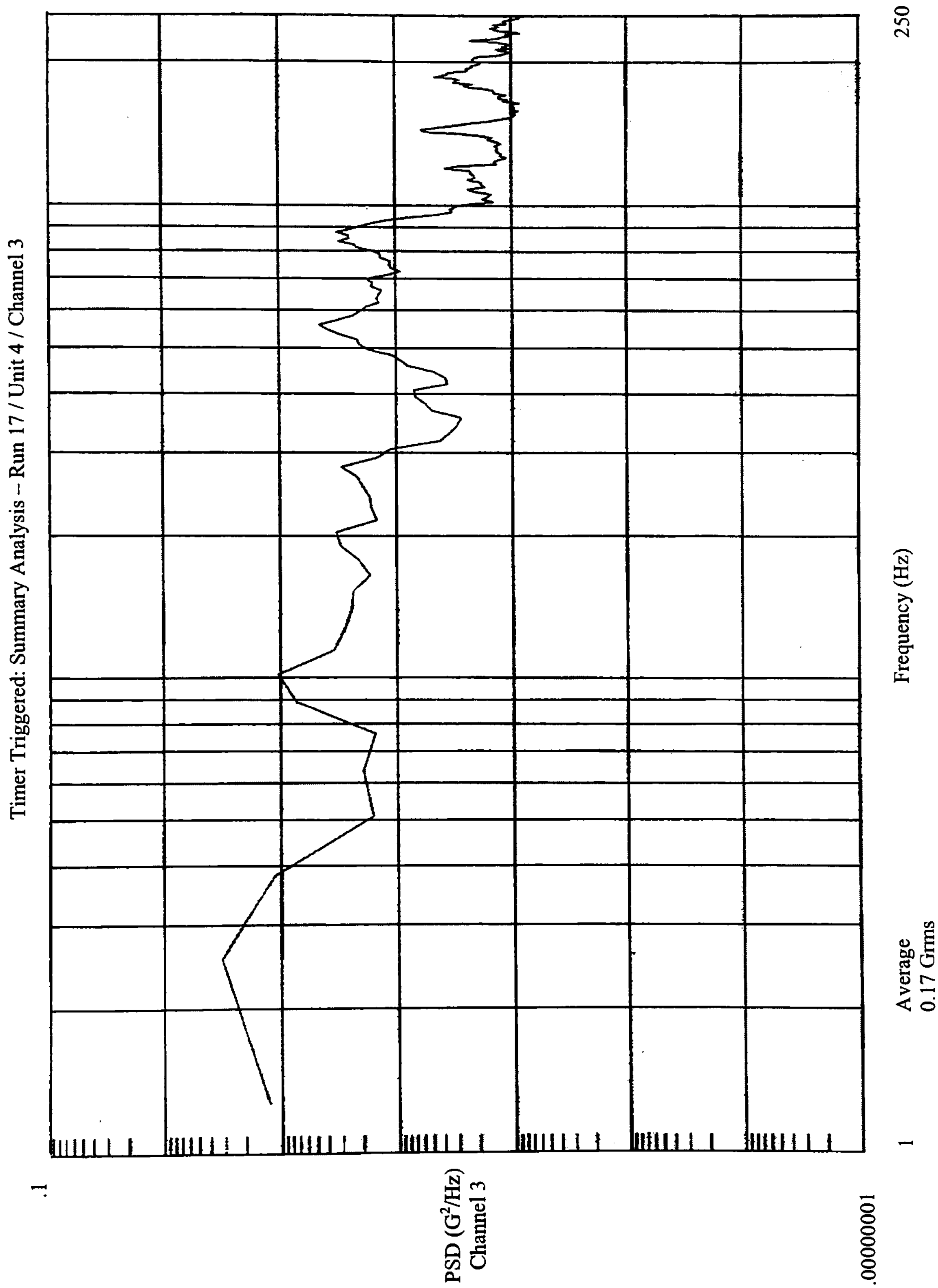

Figure C-46: Run 17 / Unit 4

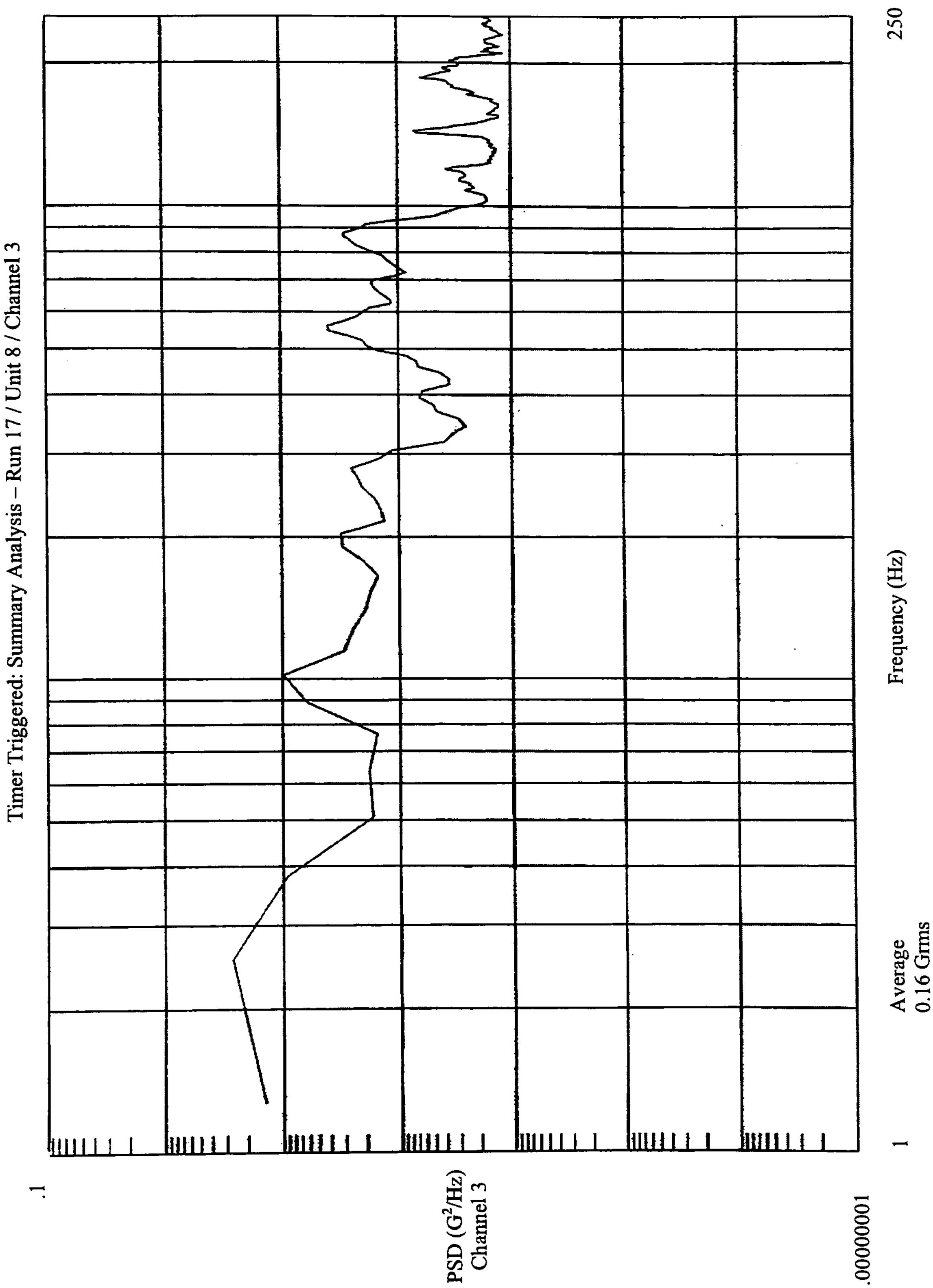

Figure C-47: Run 17 / Unit 8

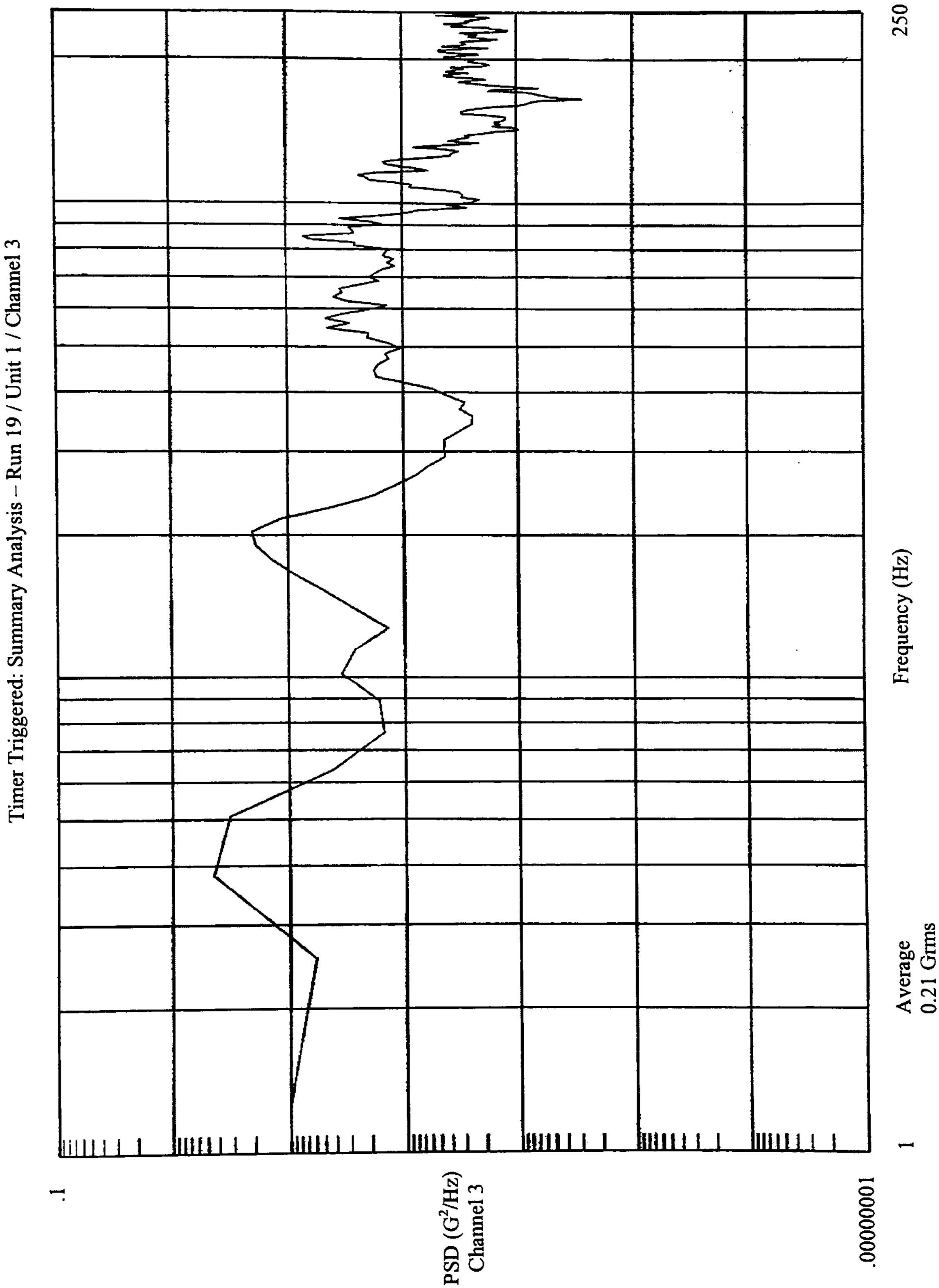

Figure C-48: Run 19 / Unit 1

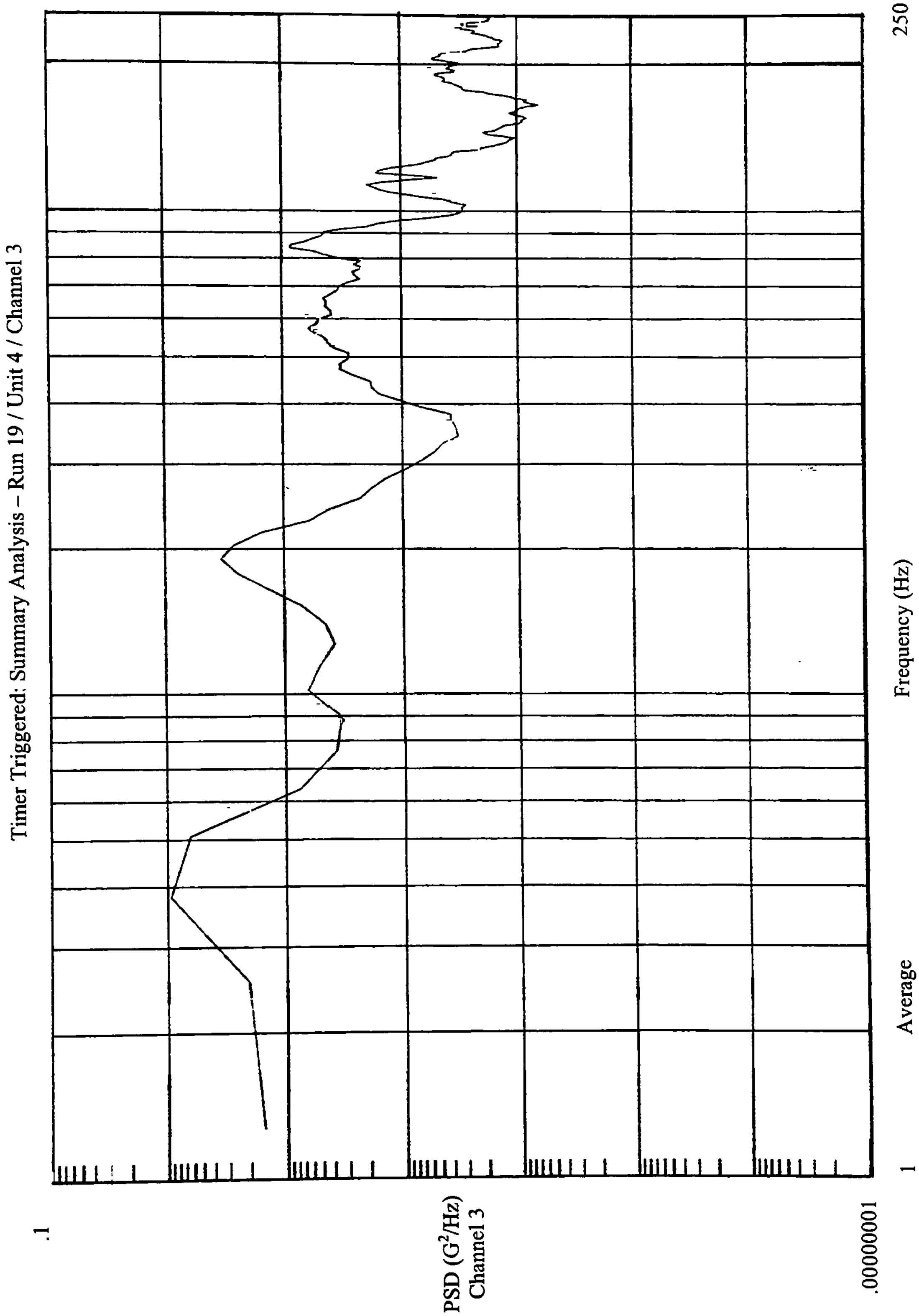

Figure C-49: Run 19 / Unit 4

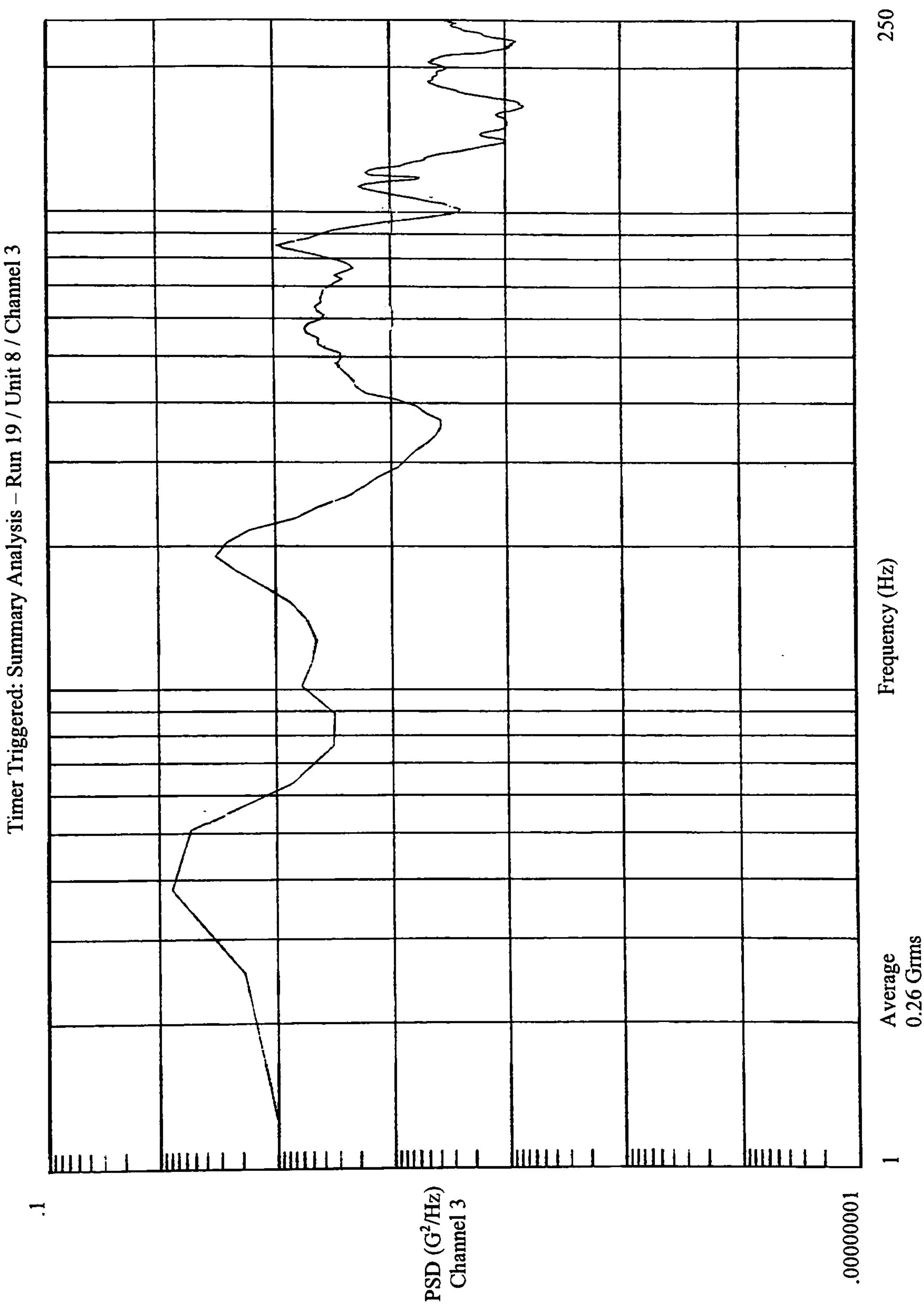

Figure C-50: Run 19 / Unit 8

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