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Technical Report

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DERIVING AN EMPIRICAL MODEL OF AN ELECTROHYDRAULIC ACTUATOR SYSTEM FROM FREQUENCY RESPONSE DATA

JUNE 1988

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This report describes a method for modeling an electrohydraulic actuator system from empirical data. A curve fit technique is used on frequency response data of the system. The transfer function (model) derived from the curve fit technique is then simulated to predict actuator motions for physical laboratory testing. The simulated results are compared with actual data measured during the testing of a 5-ton truck.

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PREFACE

I would like to thank the people from the Simulation Branch of the Testing Support Division for the following contributions: Mr. Murray and Mr. Donaskowski, for technical support of the hydraulics; Mr. Reusch and Mr. Ashworth, for technical support of the electronics and instrumentation; Mr. Reininger, for his support as chief of the staff.

Their support was very much appreciated, not only for the $2\frac{1}{2}$- and 5-ton truck test programs, but also for assistance in making the test measurements which are presented in this report.

In addition, I appreciate the assistance of the Technical Editorial Office in the publication of this report.

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1.0. INTRODUCTION

This report, prepared by the Analytical and Physical Simulation Branch of the Tank-Automotive Technology Directorate, describes an empirical approach to modeling the hydraulic/actuator portion of a physical simulation system. A frequency response curve fit technique is applied to measure actuator responses. The curve fit technique will not produce a general analytical model but will provide an empirical model which should incorporate the system's performance characteristics for many types of analyses.

2.0. OBJECTIVE

The objective of this study is to define a means of predicting the validity and fidelity of physical simulation testing before actual laboratory test runs are made.

In the past, the hydraulic/actuator system was assumed to be ideal where the actuator responds perfectly to the desired command signal. Motions were directly predicted from the command signals or the source from which the command signals were derived, but these prediction techniques did not account for the performance capabilities of the hydraulic/actuator system. The process used in the past gave inaccurate predictions of accelerations for simulation tests which contained high-frequency components (i.e., frequencies beyond the system's bandwidth).

3.0. CONCLUSIONS

The model technique discussed in this report predicts the accelerations of the actuator with a good degree of accuracy. The measured data shows slightly higher accelerations than the model prediction. A Power Spectral Density (PSD) analysis illustrates that these differences are caused by noise in the measured data. The measured accelerations have higher frequency content than the system is capable of producing.

4.0. RECOMMENDATIONS

Improvement in the empirical model analysis should be made by conducting a separate test plan independently of the truck test and by using better quality accelerometers.

The results of this analysis could lead to studies made on improving the physical simulation performance beyond the current capabilities. For example, a process could be developed which would enhance the frequency content of command signals to compensate for the limited bandwidth of the system. This would be beneficial for test programs in which high-frequency motion is essential, such as track and suspension tests. The truck test presented here did not require high-frequency motion primarily because the truck cab was the area of concern. Any high-frequency motion in the truck wheel spindles was absorbed by the suspension system, resulting in negligible effects on truck cab motions.

5.0. DISCUSSION

5.1. General

The empirical model derived in this report uses a frequency response curve fit technique. It is not considered a general analytical model in any sense.

A general analytical model would require deriving equations for the entire system by physical relationships. The curve fit method is much more easily obtained because it is based on measured data and does not rely on unknown parameters which often hamper analytical modeling. A general analytical model is more powerful for many applications due to the fact that system alterations cannot easily be incorporated into an empirical model. The curve fit technique presented here accurately simulates the response for the linear operating regions of a system. This method is a good starting point for a general analytical model development effort. The development of the hydraulic portion of the more general analytical model was started during the writing of this report.

This work is actually a part of the physical simulation validation effort and is independent of studies validating the analytical vehicle models used to produce command signals for laboratory testing. The results of this study can be used to better describe the physical simulation performance and can also be used to improve the prediction of the actuator motions for a given command signal. For example, actuator accelerations can be accurately predicted with a hydraulic/actuator model. Simulating the hydraulic/actuator system response beforehand can save test runs and may point to potential problems with the test. By using a math model, signal conditioning requirements can also be predetermined before actual test runs are conducted.

This empirical model study was conducted during the actual physical testing of a 5-ton truck so that actual measured test data could be compared to model results. Thus, analysis and data presented here are from the 5-ton truck laboratory testing. The 5-ton truck test was conducted to evaluate the structural integrity of the truck cab and machine gun mount subject to dynamic forces induced when the vehicle traverses typical cross-country terrain profiles. The machine gun mount is known as the MK19 MOD3 grenade machine gun support kit and has been through many design modifications.

In addition, similar analysis was conducted with respect to Tank Test Bed Autoloader testing. The comparison of the model output and tests showed the desired motion to be identical to the actuator response. The agreement between model prediction and actual tests is not surprising because frequency content in the turret region of a heavy armored tank is much below the hydraulic system bandwidth. Thus the hydrauilc actuator system easily responded to the desired motions (command signals) during the autoloader tests.

(Note: This report documents the first attempt to model the physical simulation tests and can be used as a reference for anyone interested in doing this for future test projects. It is assumed that the reader has some fundamental background in system theory and is familiar with the physical simulation techniques used in laboratory testing which are described in two reports: "M9 Driver's Hatch Simulation"[1] and "Simulation Test of the MK19 MOD3 Grenade Machine Gun Support Kit."[2])

5.2. Procedure

The procedure used to derive a model from frequency response data can be considered similar to the "black box experiment" conducted in a fundamental systems course. The system is treated like a black box where nothing is known of the system and the only access to the system is through its input and output signals. With the assumption that the system is linear, a math model can be derived by performing a frequency response measurement of the system. From the frequency response data, a transfer function is approximated, which describes the overall frequency characteristics. Once the transfer function is derived, a math model can easily be obtained. This procedure was used to model the hydraulic/actuator system used for the 5-ton truck test.

5.3. System Configuration

The empirical model developed describes the system configuration used for the 5-ton truck test. Shown in Figure 5-1 is the testing and measurement process which was used for both the subject of the modeling and to validate the model results. A Computer Automated Measurement and Control (CAMAC) system was used to create the actuator position command signals, and also to sample the actuator accelerations for further analysis. This was accomplished using D/A and A/D converters respectively. The command signals were created from analytical models of the truck traversing cross-country terrains. Their description is beyond the scope of this report. Further details on how these command signals were generated are described in the report "Simulation Test of the MK19 MOD3 Grenade Machine Gun Support Kit."[3] In this case, the command signals should only be considered as position command signals representing the desired actuator motion. When conducting tracked vehicle testing, the corresponding command signals are representative of a terrain time history at a given speed and are not dependent on analytical vehicle models.

The command signals generated are sent to a signal conditioner consisting of a filter box which was programmed as a 5th order elliptical

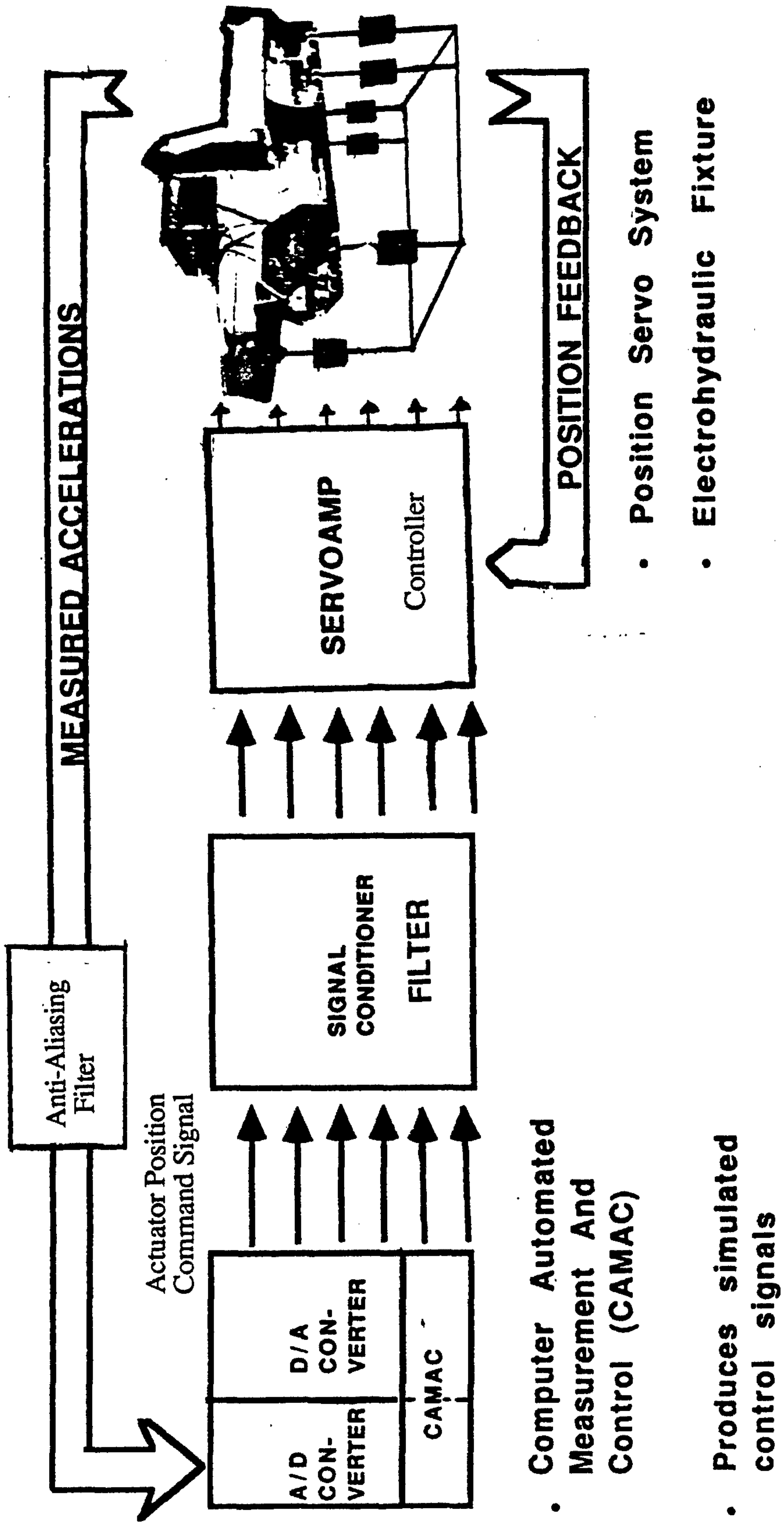


Figure 5-1. Testing and Measurement Process

low-pass filter at 6.5 Hz. This filter is more dominant in attenuating high frequencies than the actuator system itself and for our case will be considered as part of the system to be modeled. (The reasons for having this filter in the test are also explained in the report "Simulation Test of the MK19 MOD3 Grenade Machine Gun Support Kit."[4]) The filtered command signals are then sent to the servoamp controller which drives the actuators. The electrohydraulic system consists of a three-stage servo valve system with position feedback control for each actuator. The position sensors used for the main feedback loop are Linear Variable Differential Transformers (LVDTs), which measure the displacement of the actuators.

There are six separate signals that drive six independent actuators in the vertical direction for the truck test. The assumption was made that the actuators, which are fastened to the truck spindle fixtures, behave independently. We are deriving a simple model, where only one command signal and hydraulic actuator was modeled to demonstrate its capabilities at this time.

5.4. Frequency Response Curve Fit

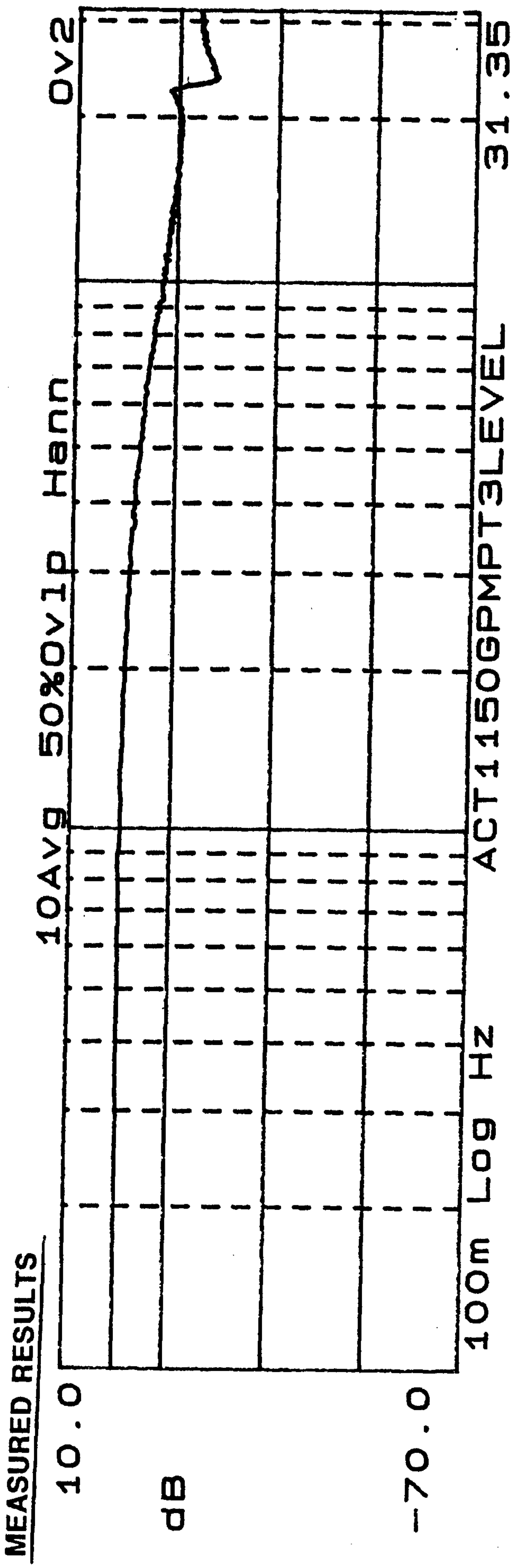
Both the filter (Signal Conditioner) and the entire hydraulic/actuator system will be modeled separately. Figure 5-2 shows the frequency response for a typical hydraulic/actuator system used in the physical simulation laboratory. The bandwidth is in the 6-Hz range (- 3 Db). This response is considered the closed loop response and is obtained by the input signal being put into the servoamp controller and the output being the actuator position measured by the LVDT. The peak at 21 Hz is believed to be the pilot valve resonance. This measurement was made using a white noise-random signal as input. Various forms of frequency response measurements were made which resulted in negligible differences. As an example, several different reasonable levels of input commands resulted in the same frequency response. This describes a system which is quite linear within its operating range.

Figure 5-2 also shows the results of the frequency curve fit model. There are many frequency analyzers and curve fit programs available. The measurements and curve fit processes presented here were done on a Hewlett Packard-3562A Signal Analyzer and are described in detail in "3562A Dynamic Signal Analyzer-Operating Manual."[5]

Figure 5-3 shows the same analysis for the filter system. The phase was also comparable between the measured frequency response and curve fit model. The curve fit process is based on a weighting sequence which was set to be distributed evenly for the frequency range shown. The number of poles and zeroes required for the fit may be debatable. However, it is apparent from the results that the poles and zeroes in Table 5-1 are more than sufficient for this type of analysis.

5.5. Empirical Math Model Development

The poles and zeroes obtained from the frequency response curve fit are now formulated into an empirical math model for simulation. Figure 5-4



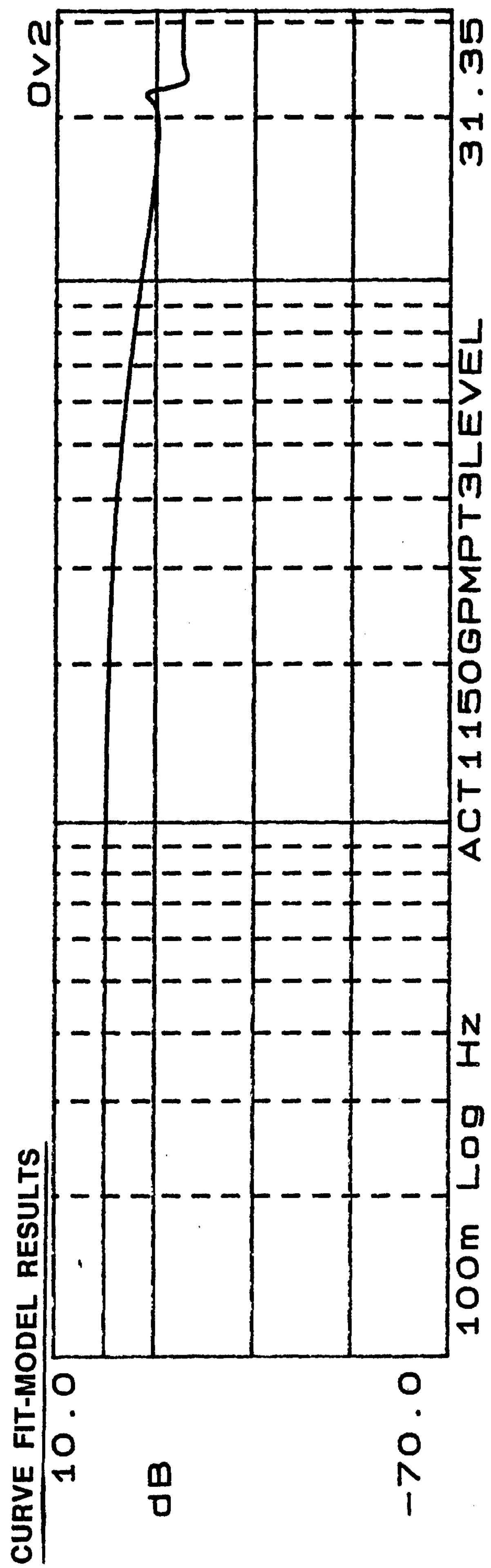


Figure 5-2. Actuator Frequency Response

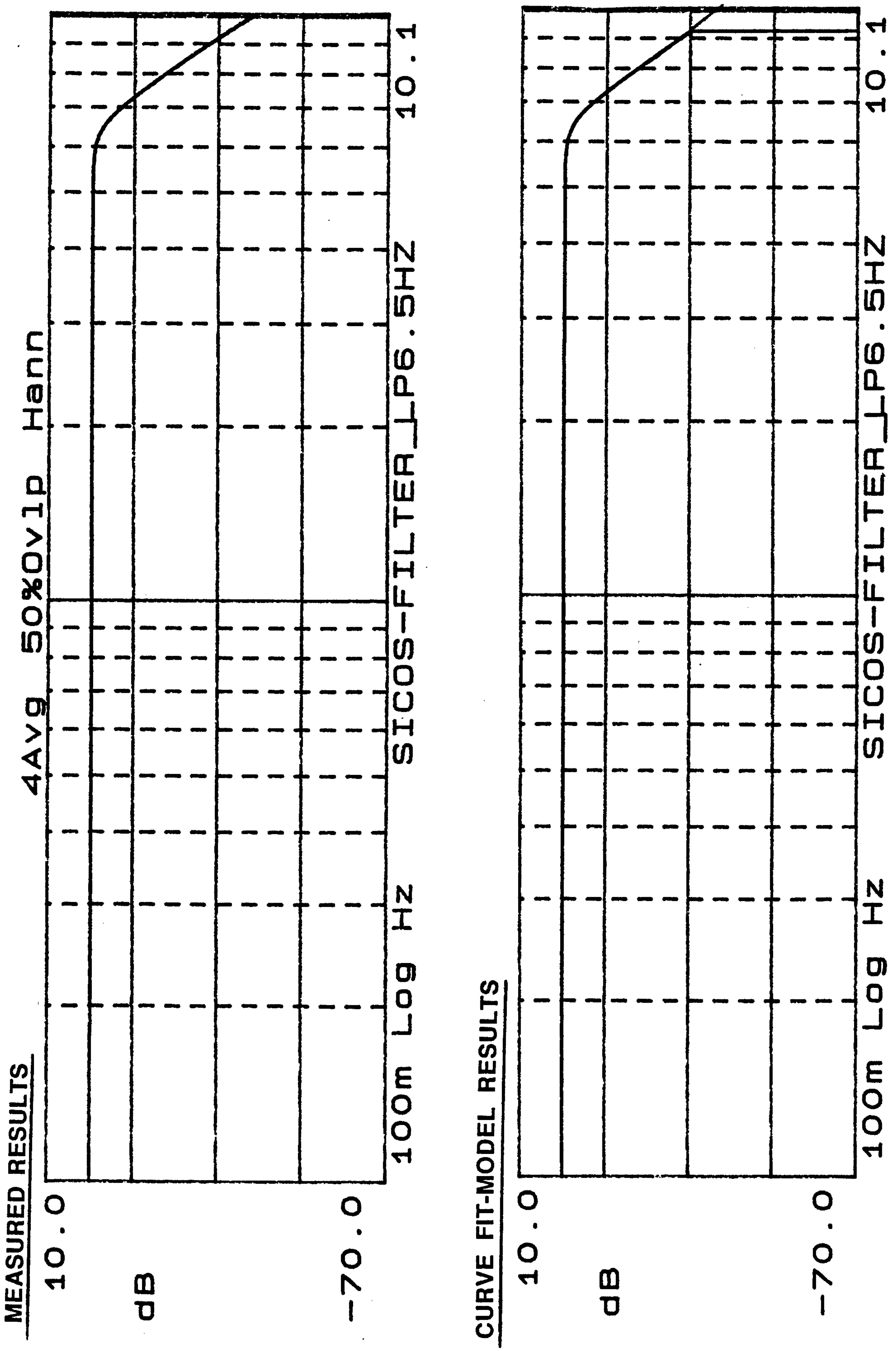


Figure 5-3. Filter Frequency Response

Table 5-1. Frequency Response Curve Fit

Hydraulic/Actuator System (Unloaded)

Lead Coefficient -50323.04

	Real	Imaginary
Zeroes	226.9	+/- 144.6
	-4.7	
Poles	-29.2	
	-3.7	+/- 140.8
	-532.8	+/- 358.6

Filter - (Used as Signal Conditioner)

Lead Coefficient 51.20

	Real	Imaginary
Zeroes	57.6	+/- 59.3
	5.7	+/- 69.4
Poles	-24.1	+/- 12.8
	-16.8	+/- 32.8
	-6.2	+/- 40.6

Note: All poles and zeroes shown were obtained from the Hewlett Packard Analyzer and multiplied by 2π for proper S domain formulation.

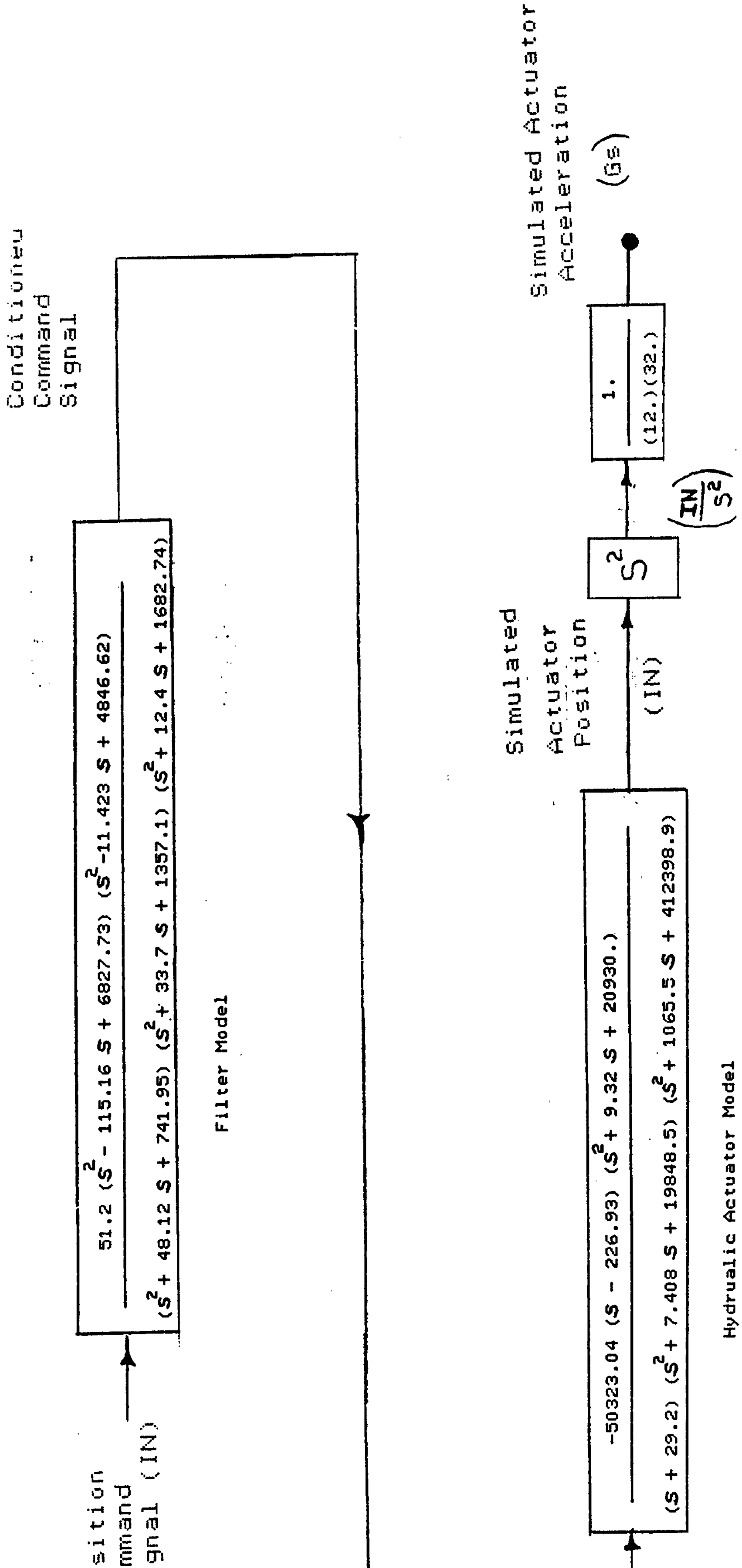


Figure 5-4. Simulation Block Diagram

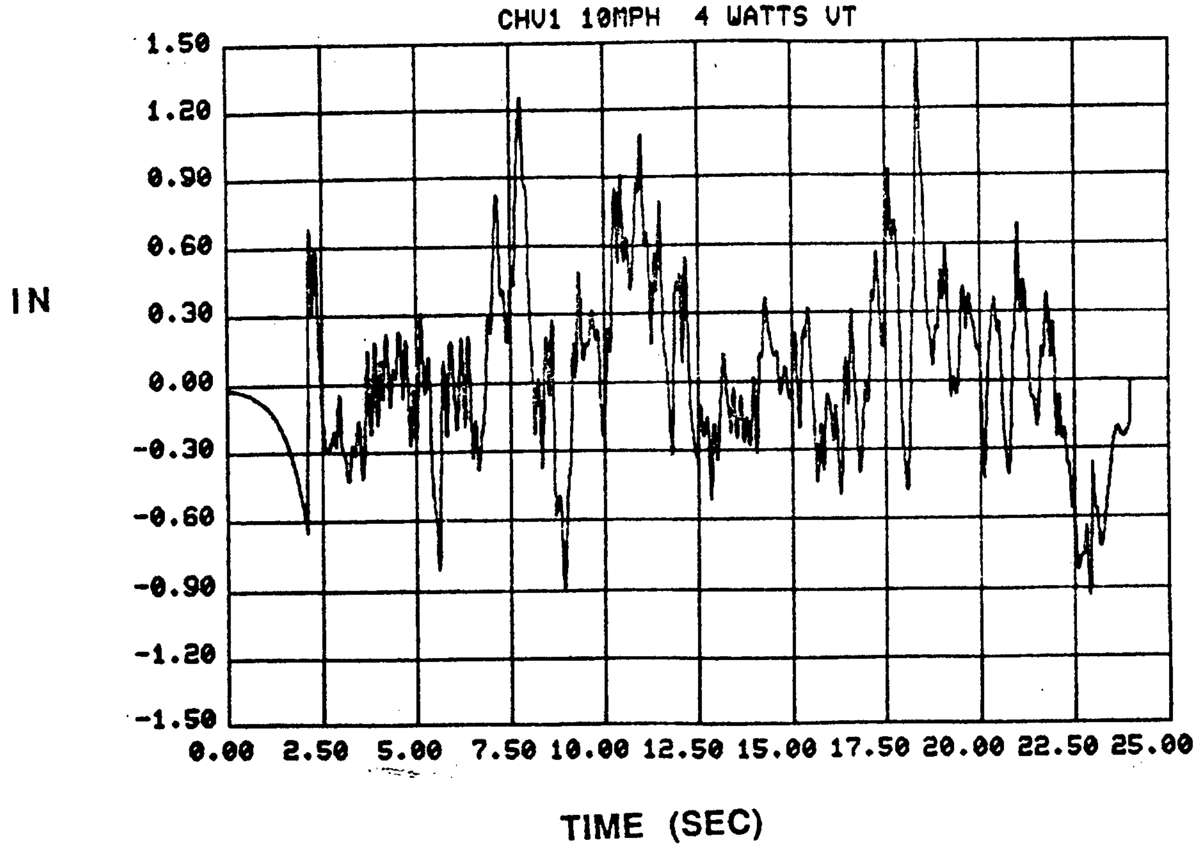
shows the simulation block diagram which describes the model in terms of Laplace transforms. The transfer functions derived from this process for both the filter and hydraulic actuator system are given. Many forms of computer software are available to simulate this type of model. The one chosen for this analysis is the Advanced Continuous Simulation Language (ACSL). Details on how to use ACSL are contained in "Advanced Continuous Simulation Language (ACSL) - Reference Manual."[6] (See the addendum for a listing of the ACSL coding used to simulate the system model.) FORTRAN subroutines were added to process input data and output data in Engineering Research Division (ERD) format which is commonly used by the System Simulation and Technology Division. ERD format has been selected as a common data format used for all physical simulation and analysis software. One reason why it was used in this analysis was to allow ACSL to read in the same files which were processed by CAMAC for command signals. In fact, the D/A converter is simulated in ACSL in the same manner as the (CAMAC) command signals used in the testing.

5.6. Model and Test Data Comparison

Figure 5-5 shows a typical command signal used for the 5-ton truck test. This particular one is simulating the Churchville 1 course at 10 mph and represents the displacement of the front right wheel spindle. These command signals are reproduced at 100 samples/sec. for both the testing and the model simulation. Figure 5-5 also shows the results of the ACSL simulation which describes the actuator response to the given command signal. Note that the higher frequency waveforms and peaks are attenuated, which is what would be expected. Strip chart recordings of the test data had demonstrated about the same wave form. The second derivative of these data was taken to determine the spindle acceleration and is shown in Figure 5-6. The second derivative was derived separately from ACSL using a rise over run (slope) relationship. The measured acceleration from the test is also shown for comparison. The waveforms generally have the same shape but the measured data have higher acceleration peaks. The accelerometers/instrumentation used for this measurement have apparent noise problems associated with them from previous tests. Complex high-frequency components have been recorded in the past. Performance specifications of the accelerometers are not known in regards to noise. Table 5-2 shows the results of the study in terms of RMS values for the entire time histories.

The measured data have higher magnitudes than the simulated results for most cases. This is especially true for the peak values. It is strongly believed that the noise of the accelerometers has created this discrepancy. For a better comparison, a PSD analysis was conducted and the results are illustrated in Figures 5-7, 5-8 and 5-9. These PSDs were obtained from a computer program which directly evaluates the time history and transforms it into Fourier coefficients. No window averaging techniques were used. Zeroes were added to the end of the data so that the number of points was equal to a power of 2 for calculation purposes. This may change the magnitudes but will not affect the comparisons being made. The simulation and test data were digitized at

ACTUATOR POSITION COMMAND SIGNAL



SIMULATED ACTUATOR POSITION RESPONSE

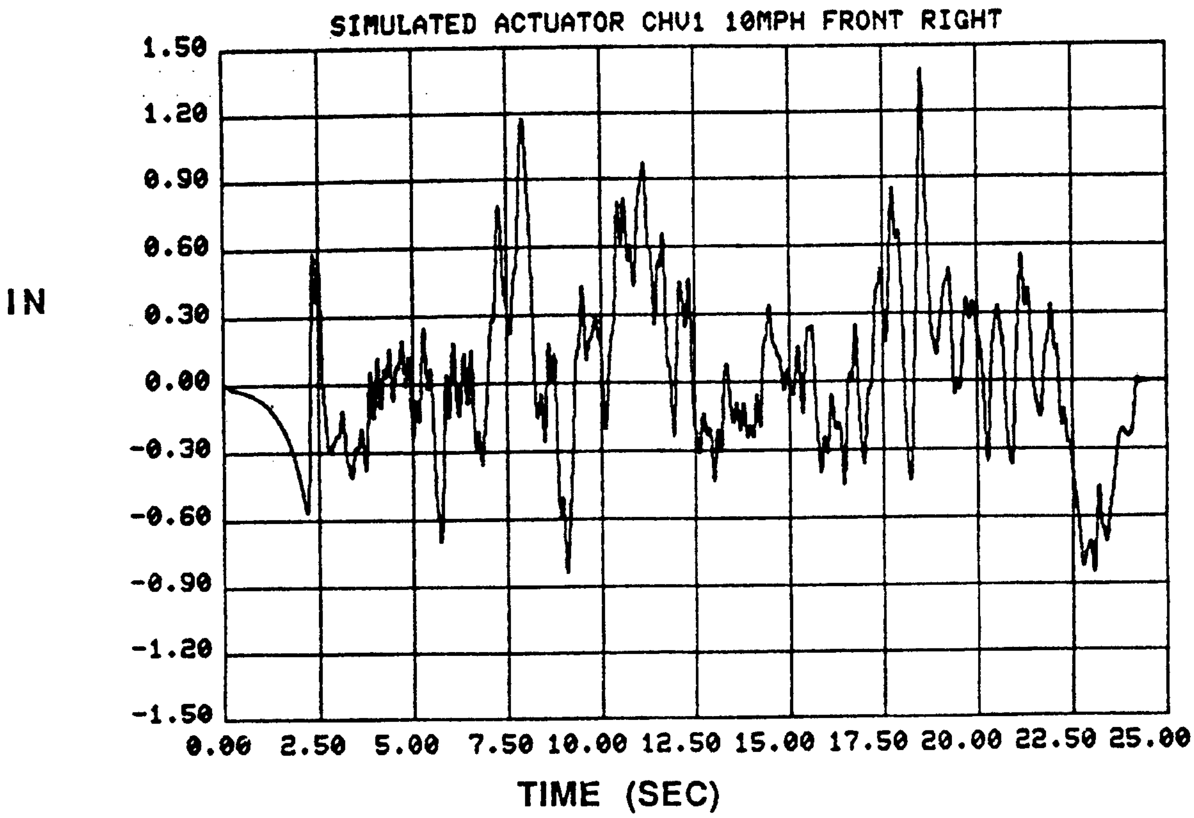
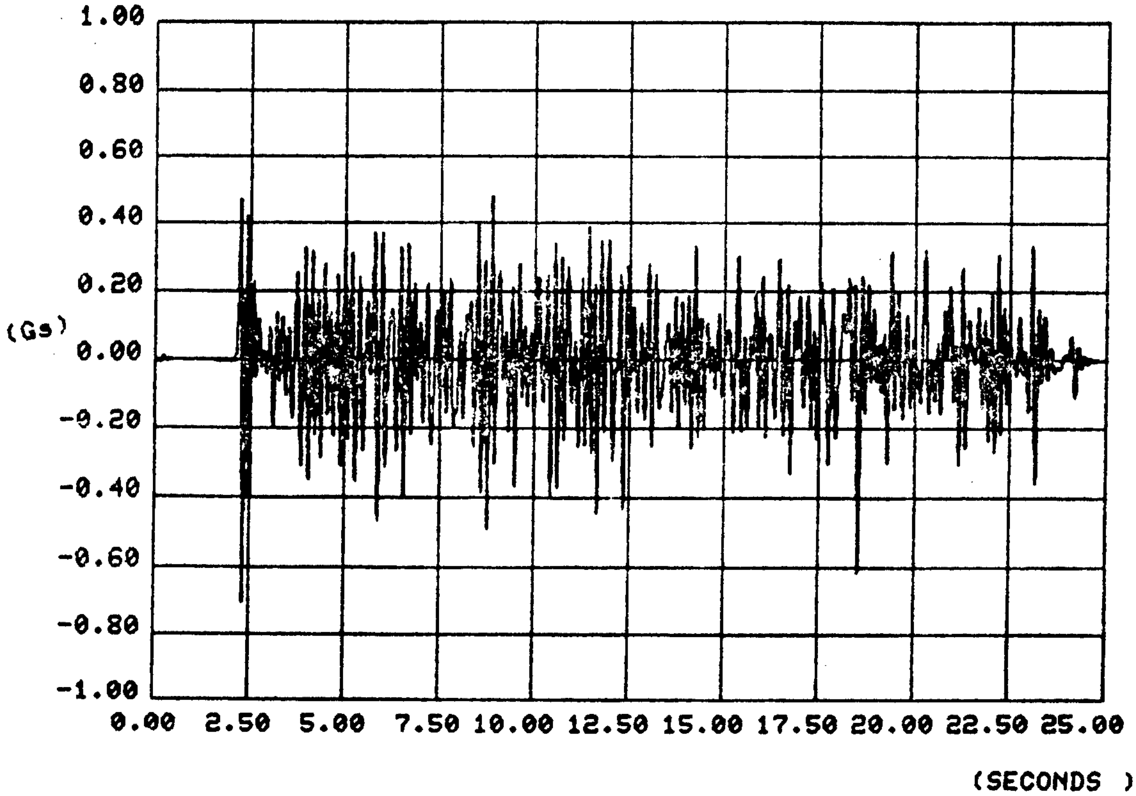


Figure 5-5. Test Run--CHV1 10 mph

Simulated Actuator Acceleration



Measured Actuator Acceleration

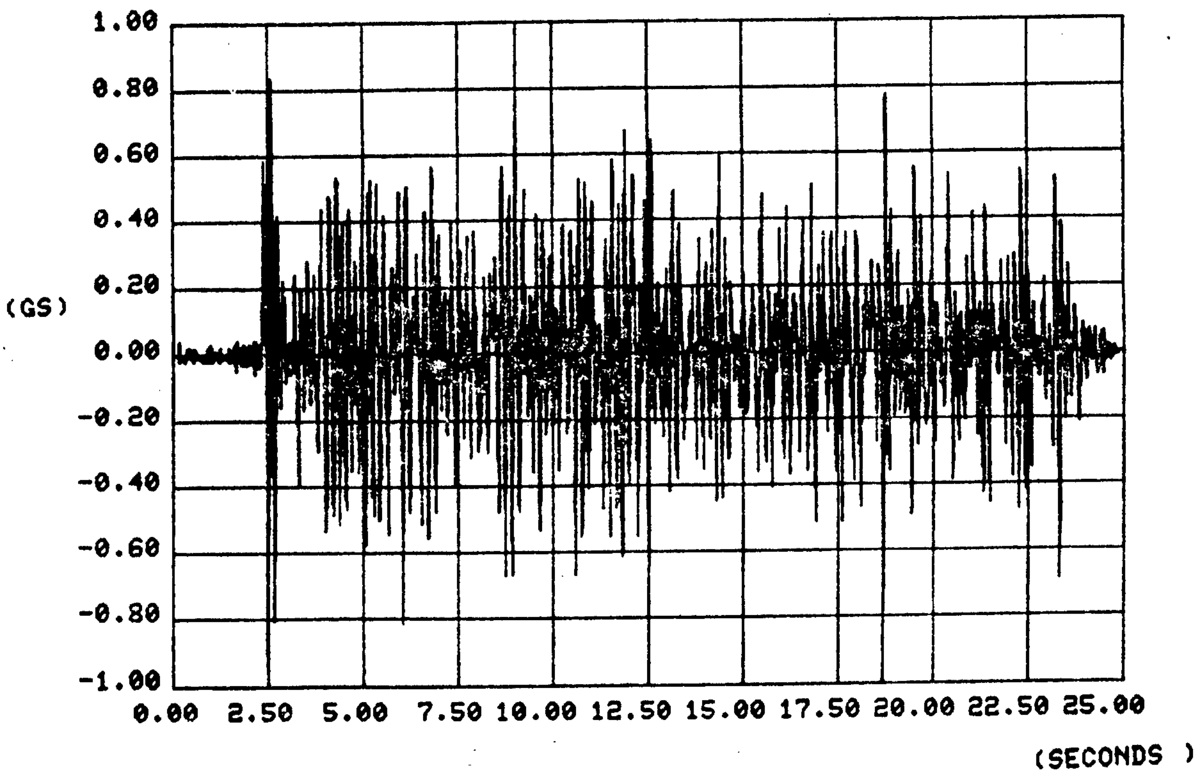
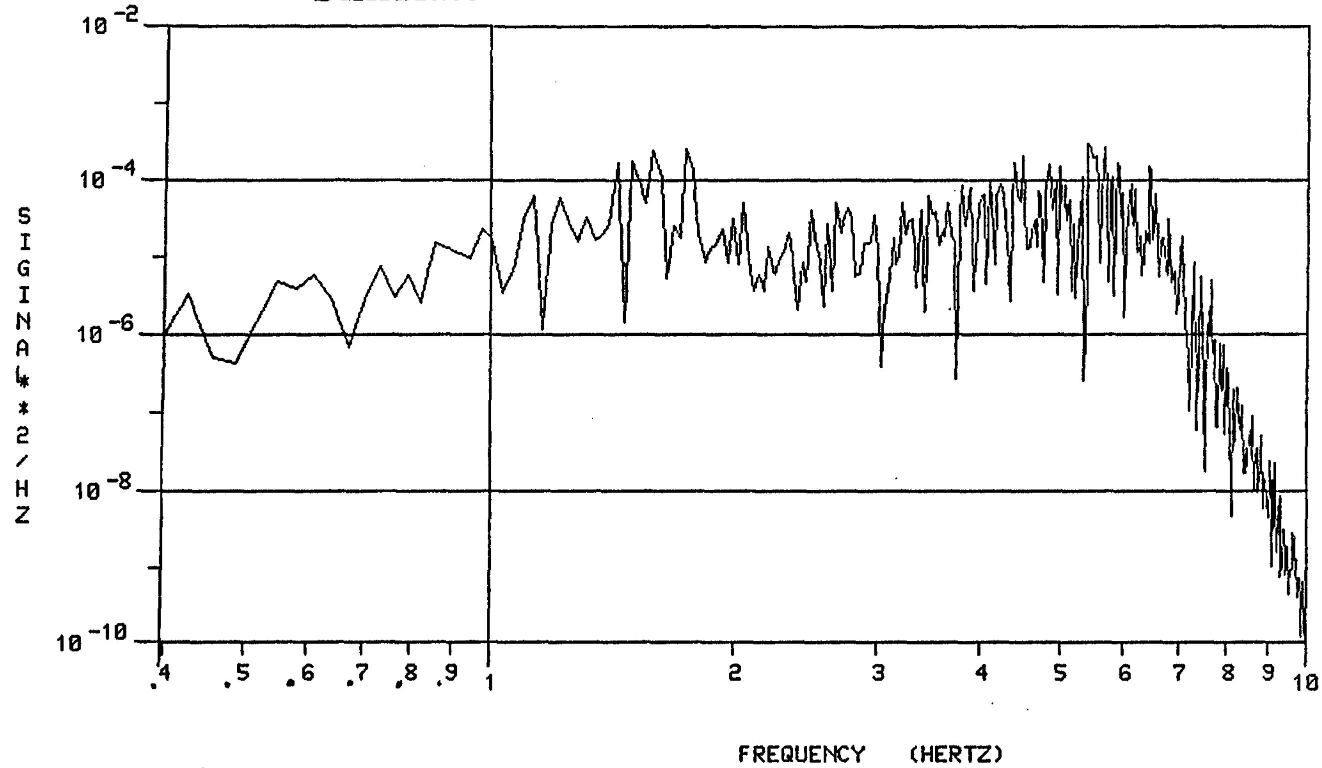


Figure 5-6. Test Run--CHV1 10 mph

Table 5-2. Measured and Simulated Results for a 5-Ton Truck Test Front Right Spindle Acceleration (Gs)

		MODEL PREDICTION	MEASURED
CHV1 10 MPH	RMS	.16	.22
APG 37 20 MPH	RMS	.15	.16
CHV1 30 HPH	RMS	.18	.16
APG9 8 MPH	RMS	.18	.24
FORT KNOX 8 MPH	RMS	.19	.19

Simulated Actuator Acceleration



Measured Actuator Acceleration

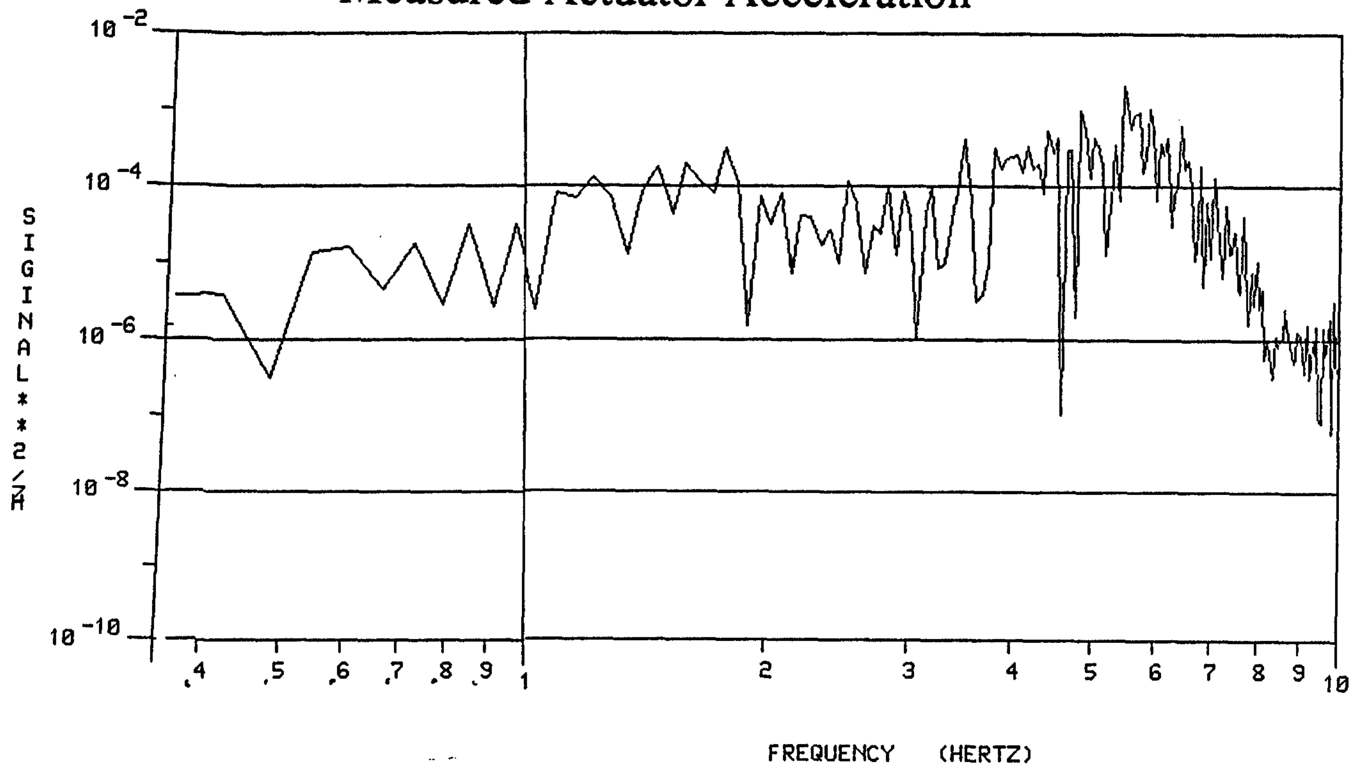
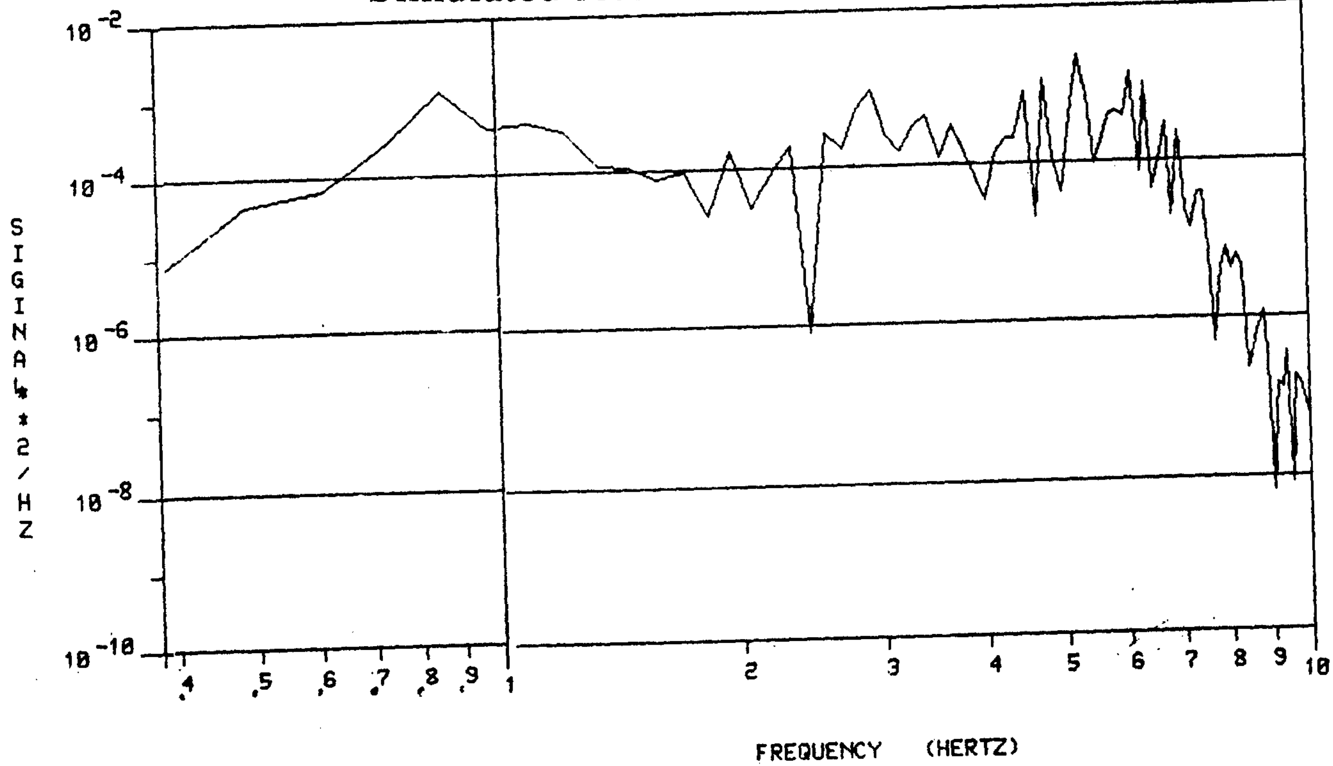


Figure 5-7. Power Spectral Density Test Run--CHV1 10 mph

Simulated Actuator Acceleration



Measured Actuator Acceleration

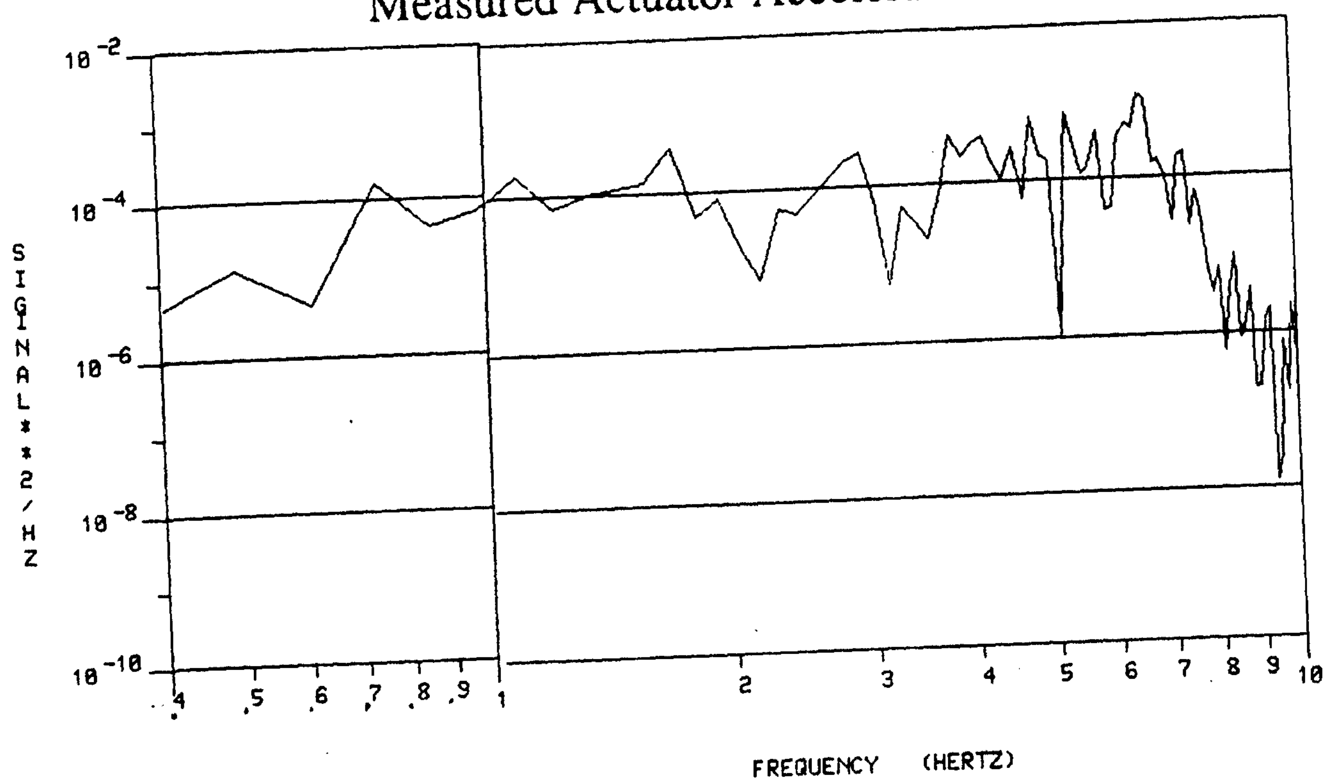
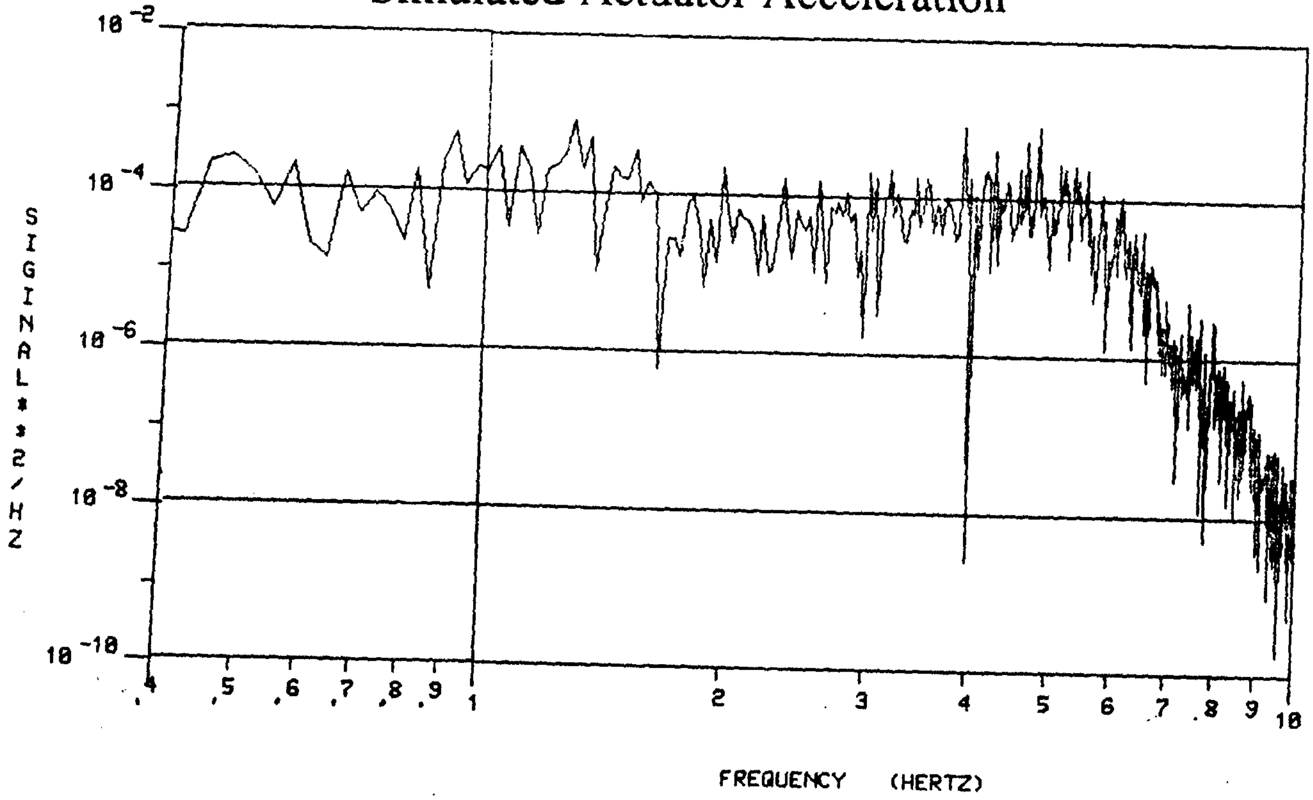


Figure 5-8. Power Spectral Density Test Run--CHV6 30 mph

Simulated Actuator Acceleration



Measured Actuator Acceleration

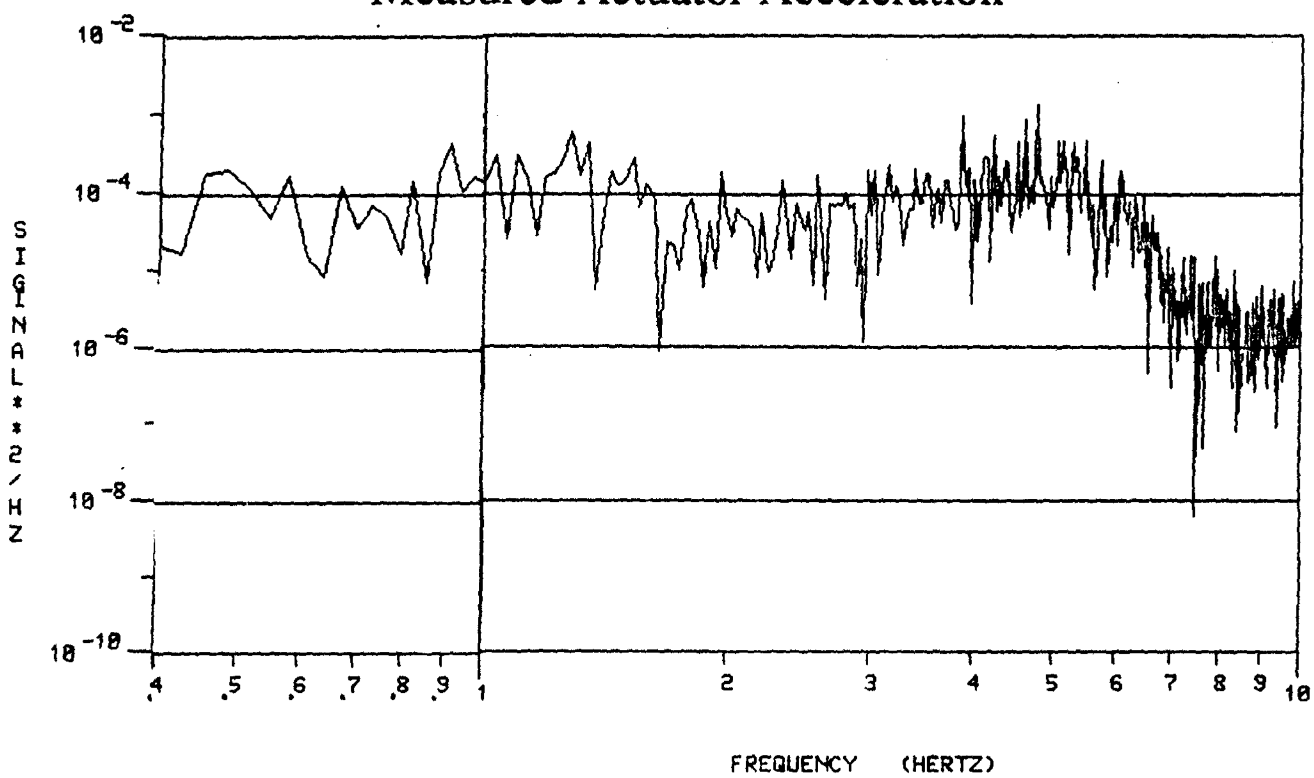


Figure 5-9. Power Spectral Density Test Run--APG9 8 mph

the same rate of .004 seconds/sample. The PSDs generally compare well between the measured data and model results. There are slight discrepancies but the major differences show up above the 8-Hz region where the model results continue to drop in magnitude as would be expected at the higher frequencies. However, the measured data reached a plateau where they remain until the anti-aliasing filter cut off frequency of 30 Hz (not shown) attenuates it. This points more to noise on the measured data which seems to be random in nature as it exhibits white noise characteristics.

LIST OF REFERNECES

1 Zywiol, Harry, "M9 Driver's Hatch Simulation," RDE Center Technical Report No. 13228, U.S. Army Tank-Automotive Command, Warren, MI (December, 1986)

2 Helinski, A.L., "Simulation Test of the MK19 MOD3 Grenade Machine Gun Support Kit," RDE Center Technical Report No. 13297, U.S. Army Tank-Automotive Command, Warren, MI (October, 1987)

3 Helinski, A.L., "Simulation Test of the MK19 MOD3 Grenade Machine Gun Support Kit," RDE Center Technical Report No. 13297, U.S. Army Tank-Automotive Command, Warren, MI (October, 1987)

4 Helinski, A.L., "Simulation Test of the MK19 MOD3 Grenade Machine Gun Support Kit," RDE Center Technical Report No. 13297, U.S. Army Tank-Automotive Command, Warren, MI (October, 1987)

5 Hewlett Packard, "356A Dynamic Signal Analyzer--Operating Manual"

6 Mitchell and Gauthier Associates, "Advanced Continuous Simulation Language (ASCL) - Reference Manual," (1986)

ADDENDUM

```
program TRUCK_ACT_FILTER
"                                                                       "
"       This ACSL program was used to simulate the Filter / Actuator    "
"       system used on the 5 ton truck testing.  This program is used   "
"       to run time simulations to evaluate the transient response of   "
"       the system.  The transfer function coefficients were derived    "
"       from frequency response measurements applying a curve fit       "
"       algorthm utilizing a Hewlett Packard-signal analyzer.           "
"       Model - 3562A                                                   "
"                                                                       "
"       This program first reads in a ERD formatted file which is the   "
"       same files used in the testing (Subroutine READERD).            "
"       A discrete portion of the program simulates the D/A converter   "
"       used in the test.  The output is sampled and written out in     "
"       ERD format (Subroutine WRITEERD) so further analysis can be     "
"       conducted.                                                      "
"                                                                       "
"       The following is the block diagram configuration in terms of    "
"       Laplace Transforms which was used in this simulation:           "
"                                                                       "
"                                                                       "
"                                                                       "
"......................................................................."
"......................................................................."
"       FILTER MODEL:                                                   "
"                                                                       "
"                                                                       "
"                   +----------------------+                            "
"                   |         51.2         |                            "
"         INF1      |                      |      INF3                  "
"                   |                      |                            "
"      -------------| ---------------------|----------                  "
"                   |     2                |                            "
"                   |    S + 48.12 S + 741.95                           "
"                   +----------------------+                            "
"                                                                       "
"                   +----------------------+                            "
"                   |     2                |                            "
"         INF3      |    S - 115.16 S + 6827.73       INF4              "
"                   |                      |                            "
"      -------------|  --------------------|----------                  "
"                   |     2                |                            "
"                   |    S + 33.7   S + 1357.1                          "
"                   +----------------------+                            "
"                                                                       "
"                                                                       "
"                                                                       "
"                   +----------------------+                            "
"                   |     2                |                            "
"         INF4      |    S - 11.42 S + 4846.62        INF5              "
"                   |                      |                            "
"      -------------|  --------------------|----------                  "
"                   |     2                |                            "
"                   |    S + 12.4   S + 1682.74                         "
"                   +----------------------+                            "
"                                                                       "
"                                                                       "
"                                                                       "
"......................................................................."
"......................................................................."
"          ACTUATOR MODEL:                                              "
"                                                                       "
```

ACTUATOR MODEL:

```
"                                                                     "
"              INF5  -50323.04 ( S - 226.93 )  INS3                   "
"                   ---------------------------                       "
"                          ( S + 29.2 )                               "
"                                                                     "
"                      2                                              "
"              INS3   S + 9.32 S + 20930.       INS4                  "
"                   ---------------------------                       "
"                      2                                              "
"                     S + 7.408 S + 19848.5                           "
"                                                                     "
"              INS4             1.                OUTS                "
"                   ---------------------------                       "
"                      2                                              "
"                     S  +1065.5 S + 412398.9                         "
"                                                                     "
"......................................................................"
   cinterval cint=0.01
   REAL INPUT(7000),OUTPUT(7000)
   INTEGER INDEX1,INDEX2,NSAMP,NMSAMP   $"USED FOR SAMPLING INDEX"
" The following arrays "
"        are used to describe the transfer function coefficient"
   ARRAY FTF3N(3),FTF3D(3),FTF4D(3),FTF4N(3)
   ARRAY STF3N(3),STF3D(3),STF2N(2),STF2D(2)
   CONSTANT STF3N=1.0,9.32,20930.
   CONSTANT STF3D=1.0,7.408,19848.5
   CONSTANT STF2N=1.0,-226.93
   CONSTANT STF2D=1.0,29.2
   CONSTANT FTF3N=1.0,-115.16,6827.73
   CONSTANT FTF3D=1.0,33.7,1357.1
   CONSTANT FTF4N=1.0,-11.42,4846.62
   CONSTANT FTF4D=1.0,12.4,1682.74
INITIAL
   INDEX1=0
   INDEX2=0
   NMSAMP=7000 $"NUMBER OF SAMPLES OF SAMPLED OUTPUT"
"*********************************************************"
"************   READ IN COMMAND DATA   ****************"
"*********************************************************"
   PROCEDURAL(NSAMP,INPUT)
   CALL READERD(NSAMP,INPUT=)
   END $" OF PROCEDURAL"
"***********************************************************"
END $" OF INITIAL "
DISCRETE SAMPLE
"***********************************************************"
"******  CREATE THE COMMAND SIGNAL *********************"
"****** BY SIMULATING A D/A CONVERTER (100 POINTS/SEC)***"
     INTERVAL DTSAMP=.01
     INDEX1=INDEX1+1
     INF1=INPUT(INDEX1)    $" D/A CONVERTER OUTPUT - INF1"
"************************************************************"
END $"OF DISCRETE SAMP 1"
```

```
DERIVATIVE
"**********************************************************"
"****************  FILTER MODEL : *************************"
"****************  INPUT   : INF1     OUTPUT : INF5 *********"
     INF3=51.2*1.348E-3*CMPXPL(1.348E-3,.065,INF1,0.,0.)
     INF4=TRAN(2,2,FTF3N,FTF3D,INF3)
     INF5=TRAN(2,2,FTF4N,FTF4D,INF4)
"**********************************************************"
"**************** ACTUATOR MODEL : ************************"
"****************  INPUT : INF5     OUTPUT : OUTS *********"
     INS3=-50323.04*TRAN(1,1,STF2N,STF2D,INF5)
     INS4=TRAN(2,2,STF3N,STF3D,INS3)
     OUTS=2.425E-6*CMPXPL(2.425E-6,2.584E-3,INS4,0.,0.)
"**********************************************************"
END $"OF DERIVATIVE"
DISCRETE SAMPLE
"***********************************************************"
"**** SAMPLE THE OUTPUT SIGNAL OUTS **********************"
"**** OUTPUT IS DISCRETE ARRAY OF OUTS *******************"
     INTERVAL DTSMP=.004
     STEP=.004
     INDEX2=INDEX2+1
     OUTPUT(INDEX2)=OUTS
END $"OF DISCRETE SAMP 2"
DERIVATIVE
     termt(INDEX2 .GE. NMSAMP)
END $"OF DERIVATIVE"
TERMINAL
"************* WRITE OUT SAMPLED DATA IN ERD FILE ******"
     CALL WRITEERD(=STEP,INDEX2,OUTPUT)
"*******************************************************"
END $"OF TERMINAL"
END $"OF PROGRAM"
```

```
      SUBROUTINE READERD(NSAMP,DATAINPUT)
*
*     THIS SUBROUTINE USED TO READ IN ERD DATA FILE AS
*     INPUT INTO ACSL.
*
*    CALL AT "INITIAL" PART OF ACSL
*    INCLUDE AT "END" OF ACSL.
*
*
*
      CHARACTER*80 ERD_TITLE,LONG,TITLE,DUMMY80
      CHARACTER*64 ERD_FILE,HDR_FILE,ERD_FILE_O,HDR_FILE_O
      CHARACTER*32 LONG_NAME(12),DUMMY32
      CHARACTER*12 DUMMY
      CHARACTER*8 SHORT_NAME(12),UNIT_NAME(12),XUNIT,DUMMY8
      CHARACTER*4 ERD,HDR
      CHARACTER*1 COMMA,REPLY
      REAL*4 SCALE(12),OFFSET(12),DATA(12,30000)
```

```
      REAL RMS(12),SMEAN(12),DATAINPUT(30000)
      INTEGER*2 ERD_UNIT,HDR_UNIT,IDATA(12)
      LOGICAL*4 TIME
      LOGICAL*1 NEWCHAN,RECHAN
      DATA ERD_UNIT,HDR_UNIT/10,11/
      ERD = '.ERD'
      HDR = '.HDR'
*****************************************************************
*
* Determine the name of the input data file
*
10    WRITE(5,20)
20    FORMAT(///,' This subroutine will send a channel of a '
     +'ERD file',/,' to an ACSL simulation',/,
     +' Enter file name to send to ACSL?')
      READ(5,30) ERD_FILE
30    FORMAT(A32)
      CALL STR$TRIM(HDR_FILE,ERD_FILE,LENGTH)
      HDR_FILE(LENGTH+1:LENGTH+4) = HDR
      ERD_FILE(LENGTH+1:LENGTH+4) = ERD
*
* Open the data file, print the header characteristics, and determine if
* this is the correct data file
*
      OPEN(HDR_UNIT,FILE=HDR_FILE,FORM='FORMATTED',
     +        SHARED,STATUS='OLD',ERR=210)
*
* Read the header data
*
      READ(HDR_UNIT,60) DUMMY
60    FORMAT(A12)
      READ(HDR_UNIT,70) ERD_TITLE
70    FORMAT(A80)
      READ(HDR_UNIT,80) NCHAN,COMMA,NSAMP,COMMA,NLINES,COMMA,NBIN,
     +              COMMA,NBYTE,COMMA,KEYNUM,COMMA,STEP,COMMA,KEYOPT
80    FORMAT(6(I7,A),E13.6,A,I7)
      READ(HDR_UNIT,90) SCALE(1),(COMMA,SCALE(L),L=2,NCHAN)
      READ(HDR_UNIT,90) OFFSET(1),(COMMA,OFFSET(L),L=2,NCHAN)
      READ(HDR_UNIT,100) (SHORT_NAME(L),L=1,NCHAN)
      READ(HDR_UNIT,110) (LONG_NAME(L),L=1,NCHAN)
      READ(HDR_UNIT,100) (UNIT_NAME(L),L=1,NCHAN)
90    FORMAT(18(E13.6,A))
100   FORMAT(31(A8))
110   FORMAT(7(A32))
*
* Write out the header information
*
      WRITE(5,120) ERD_TITLE,NCHAN,NSAMP,STEP
120   FORMAT(//,' The title for this file is:',/,' ',A80,//,' There are
     +',I2,' channels of data.',/,' There are ',I7,' samples for each da
     +ta channel.',/,' The step size is ',F8.5,' seconds.',//)
*
* See if there are more than 16 channels to plot
*
*****************************************************************
      IF (NCHAN .GT. 16) THEN
         TYPE*,'There are more than 16 channels to EDIT.'
         TYPE*,'Please  FORGET ABOUT IT'
         CLOSE (HDR_UNIT)
         STOP
```

```
          ENDIF
*
* Write out the additional descriptor lines
*
      IF (NLINES .GT. 0) THEN
         TYPE*,'The following are the optional descriptor lines:'
         DO 130 L=1,NLINES
            READ(HDR_UNIT,70) LONG
            WRITE(5,125) LONG
125         FORMAT(' ',A80)
130         CONTINUE
         ENDIF
*
* Is this the correct data file
*
      WRITE(5,140)
140   FORMAT(//,'$Is this the correct data file to EVALUATE (y or n)?
     +')
      READ(5,150) REPLY
150   FORMAT(A)
      IF (REPLY .EQ. 'N' .OR. REPLY .EQ. 'n') THEN
         CLOSE(HDR_UNIT)
         WRITE(5,160)
160      FORMAT(/,'$Do you wish to look at another file (y or n)? ')
         READ(5,150) REPLY
         IF (REPLY .EQ. 'N' .OR. REPLY .EQ. 'n') STOP
         GOTO 10
         ENDIF
*
* Open the data part of the file
*
      IF (KEYNUM .EQ. 5) THEN
         OPEN(ERD_UNIT,FILE=ERD_FILE,STATUS='OLD'
     +          ,SHARED,FORM='FORMATTED')
        ELSE
         OPEN(ERD_UNIT,FILE=ERD_FILE,STATUS='OLD'
     +          ,SHARED,FORM='UNFORMATTED')
        ENDIF
      CLOSE(HDR_UNIT)
*
* Read the data
*
      J = 0
170   J=J+1
         IF (KEYNUM .EQ. 5) THEN

            READ(ERD_UNIT,180,ERR=220,END=230) (DATA(I,J),I=1,NCHAN)
180         FORMAT(19(E13.6))

          ELSE

            IF (KEYNUM .EQ. 0) THEN
               READ(ERD_UNIT,ERR=220,END=230) (IDATA(I),I=1,NCHAN)
               DO 190 K=1,NCHAN
                  DATA(K,J) = FLOATI(IDATA(K))
190               CONTINUE
             ELSE
               READ(ERD_UNIT,ERR=220,END=230) (DATA(I,J),I=1,NCHAN)
             ENDIF
```

```
          ENDIF

          GOTO 170
*
*
*
210    TYPE*,'Error opening data file'
       STOP
*
220    TYPE*,'Error reading data in file'
230    CLOSE(ERD_UNIT)
*
*********** DATA IS READ IN, NOW START EVALUATION *******
*
*** Convert UNscaled and UNbiased data to proper values
       DO 6002 I=1,NCHAN
          DO 6003 J=1,NSAMP
             DATA(I,J) = DATA(I,J) / SCALE(I) + OFFSET(I)
6003      CONTINUE
             SCALE(I)=1.
             OFFSET(I)=0.
6002     CONTINUE
*************************************************************
*************************************************************
567       WRITE(5,1018)
1018      FORMAT(//,'***** CHANNELS *******',//)
          DO 1050 JI=1,NCHAN
          IF(JI .EQ. 6 .OR. JI .EQ. 12 .OR. JI .EQ. 18 .OR.
     +    JI .EQ. 24 .OR. JI .EQ. 30 .OR. JI .EQ. 36) THEN
            WRITE(5,1032)
            READ(5,*)
          ENDIF
          WRITE(5,1060)JI,LONG_NAME(JI),UNIT_NAME(JI)
1060      FORMAT(/,' CHANNEL ',I2,/,1X,A32,/,1X,A8)
1050      CONTINUE
          WRITE(5,1032)
1032      FORMAT(/,'*********  HIT RETURN ********')
          READ(5,*)
***************************************************************
*
*      ASK WHICH CHANNEL YOU DESIRE TO SEND TO ACSL
*
          WRITE(5,5538)
5538      FORMAT(' Which channel do you desire to send',
     +    ' to ACSL')
          READ(5,*)ICHANACSL
*************************************************************
          DO 1777 ISMP=1,NSAMP
           DATAINPUT(ISMP)=DATA(ICHANACSL,ISMP)
1777      CONTINUE
***************************************************************
          RETURN
*
          END
```

```
      SUBROUTINE WRITEERD(STEP,NSAMP,OUTPUT)
C         This subroutine simply writes out data arrays
C         in ERD format.
C
C           CALL at TERMINAL portion of ACSL
C           Include at end of ACSL listing
C
      CHARACTER*80 ERD_TITLE,LONG,TITLE,DUMMY80
      CHARACTER*64 ERD_FILE,HDR_FILE,ERD_FILE_O,HDR_FILE_O
      CHARACTER*32 LONG_NAME(16),DUMMY32
      CHARACTER*12 DUMMY
      CHARACTER*8 SHORT_NAME(16),UNIT_NAME(16),XUNIT,DUMMY8
      CHARACTER*4 ERD,HDR
      CHARACTER*1 COMMA,REPLY
      CHARACTER*2 IOPERATE(20)
      DIMENSION SMAX(18),SMIN(18)
      REAL*4 SCALE(16),OFFSET(16),DATA(16,30000)
      REAL RMS(16),SMEAN(16),OUTPUT(30000)
      INTEGER*4 START_SAMP_ELIM,END_SAMP_ELIM
      INTEGER*2 ERD_UNIT,HDR_UNIT,IDATA(16)
      LOGICAL*4 TIME
      LOGICAL*1 NEWCHAN,RECHAN
      DATA ERD_UNIT,HDR_UNIT/10,11/
      ERD = '.ERD'
      HDR = '.HDR'
*****************************************************************
*
      WRITE(5,1881)
1881  FORMAT(///,' ENTER how many channels are output')
      READ(5,*)NCHAN
*
      DO 1998 J=1,NCHAN
       WRITE(5,1888)J
1888   FORMAT(///,' ENTER the LONG NAME for channel ',I2)
       READ(5,1889)LONG_NAME(J)
1889   FORMAT(A32)
       WRITE(5,1992)J
1992   FORMAT(//,' ENTER the SHORT NAME for channel ',I2)
       READ(5,1920)SHORT_NAME(J)
1920   FORMAT(A8)
       WRITE(5,1993)J
1993   FORMAT(//,' ENTER the UNIT NAME for channel ',I2)
       READ(5,1920)UNIT_NAME(J)
*
       OFFSET(J)=0.
       SCALE(J)=1.
*
1998  CONTINUE
*
       DO 1766 ISMP=1,NSAMP
          DATA(1,ISMP)=OUTPUT(ISMP)
1766   CONTINUE
*
      WRITE(5,201)
201   FORMAT(//,' Indicate how new data file is to be stored.',/,
     +'       0 = 2 byte integer (binary)',/,
     +'       1 = 4 byte floating point (binary)',/,
```

```
     +'      2 = 8 byte floating point (binary)',/,
     +'      3 = 8 byte complex (binary)',/,
     +'      4 = 16 byte complex (binary)',/,
     +'      5 = formatted floating point.  The format is (Nchannels)E13.
     +6',/,'$Enter selection (0-5):(1 CHOSEN MOST COMMONLY) ')
      READ (5,*) KEYNUM
*
* do not let the user choose complex numbers
*
      IF (KEYNUM .EQ. 3 .OR. KEYNUM .EQ. 4) THEN
         TYPE*,' '
         TYPE*,'Choose another format besides complex numbers.'
       ELSE IF(KEYNUM .LT. 0 .OR. KEYNUM .GT. 5) THEN
         TYPE*,' '
         TYPE*;'Selection out of range.'
       ENDIF
*
* open and create files
*
*
* begin writing header information
*
      WRITE(5,265)
265   FORMAT(//,'$Enter name of the data file to write to: ',
     +/,'  ERD FORMAT ASSUMED')
      READ(5,267) ERD_FILE_O
267   FORMAT(A32)
* Create the two file names
*
        WRITE(5,4446)
4446    FORMAT('  Enter ERD title?')
        READ(5,4447)ERD_TITLE
4447    FORMAT(A80)
      HDR_FILE_O = ERD_FILE_O
      CALL STR$TRIM(HDR_FILE_O,ERD_FILE_O,LENGTH)
      HDR_FILE_O(LENGTH+1:LENGTH+4) = HDR
      ERD_FILE_O(LENGTH+1:LENGTH+4) = ERD
      OPEN(HDR_UNIT,FILE=HDR_FILE_O,STATUS='UNKNOWN',
     + FORM='FORMATTED',RECL=256)
*
* WRITE OUT HEADER DATA
*
*
*   UNKNOWN KNOWNS
*
      DUMMY = 'ERDFILEV1.00'
      KEYOPT=0
      NLINES=0
      NBIN=-1
      NBIN=-1
      NBYTE=-1
      COMMA=','
      WRITE(HDR_UNIT,270).DUMMY
270   FORMAT(A12)
      WRITE(HDR_UNIT,280) ERD_TITLE
280   FORMAT(A80)
      WRITE(HDR_UNIT,290) NCHAN,COMMA,NSAMP,COMMA,NLINES,COMMA,NBIN,
     &             COMMA,NBYTE,COMMA,KEYNUM,COMMA,STEP,COMMA,KEYOPT
290   FORMAT(6(I7,A),E13.6,A,I7)
      WRITE(HDR_UNIT,300) SCALE(1),((COMMA,SCALE(J)),J=2,NCHAN)
```

```
300    FORMAT(18(E13.6,A))
       WRITE(HDR_UNIT,300) OFFSET(1),((COMMA,OFFSET(J)),J=2,NCHAN)
       WRITE(HDR_UNIT,310) (SHORT_NAME(J),J=1,NCHAN)
310    FORMAT(31(A8))
       WRITE(HDR_UNIT,320) (LONG_NAME(J),J=1,NCHAN)
320    FORMAT(7(A32))
       WRITE(HDR_UNIT,310) (UNIT_NAME(J),J=1,NCHAN)
*
* write 9+ lines to file
*
C        TYPE*,' '
       IF(NLINES .EQ. 0) GOTO 330
*        TYPE*,'Enter additional descriptor lines'
        DO 330 J=1,NLINES
*          READ(5,280) LONG
        WRITE(HDR_UNIT,6560)J,SHORT_NAME(J),RMS(J),SMEAN(J)
6560    FORMAT(' CHAN ',I2,3X,A8,3X,' RMS= ',E15.3,4X,' MEAN= ',E15.3)
330       CONTINUE
*
       CLOSE(HDR_UNIT)

* write  data to file
*
       IF (KEYNUM .EQ. 5) THEN
         OPEN(ERD_UNIT,FILE=ERD_FILE_O,FORM='FORMATTED',
     +    STATUS='UNKNOWN', RECL=256)
         ELSE
         OPEN(ERD_UNIT,FILE=ERD_FILE_O,FORM='UNFORMATTED',
     +   STATUS='UNKNOWN', RECL=256)
         ENDIF
* 2 byte integer
*
       IF (KEYNUM .EQ. 0) THEN
          DO 350 J=1,NSAMP
         WRITE(ERD_UNIT,ERR=406)
     +             (IIFIX(DATA(L,J)),L=1,NCHAN)
350         CONTINUE
*
* 4 byte floation - binary
*
        ELSE IF (KEYNUM .EQ. 1) THEN
          DO 370 J=1,NSAMP
             WRITE(ERD_UNIT,ERR=406)
     +                (DATA(L,J),L=1,NCHAN)
370          CONTINUE
*
* 8 byte floating - binary
*
        ELSE IF(KEYNUM .EQ. 2) THEN
          DO 390 J=1,NSAMP
          WRITE(ERD_UNIT,ERR=406)
     +             (DBLE(DATA(L,J)),L=1,NCHAN)
390          CONTINUE
*
* formatted output
*
        ELSE
          DO 410 J=1,NSAMP
            WRITE(ERD_UNIT,405,ERR=406)
     +                (DATA(L,J),L=1,NCHAN)
```

```
410          CONTINUE
405       FORMAT(19(E13.6))
          GOTO 35
406       WRITE(5,407) J-1
407       FORMAT(/,' There were ',I10,' records written out before the fi
     +le filled up.',/,' Change NSAMP in the header file accordingly.')
        ENDIF
   35   CLOSE(ERD_UNIT)
*
        RETURN
*
        END
```

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