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VSS DEMONSTRATION PROGRAM
PART: 1 SYSTEM PERFORMANCE EVALUATION

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FINAL REPORT

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15. Supplementary Notes

Part 2 will include a description of the verification process and related data, mathematical models, and computer programs.

16. Abstract

The Vertical Shaker System (VSS) is the initial test program to be conducted at the Rail Dynamics Laboratory. The objectives of this program are to demonstrate the performance and capabilities of the VSS and to accumulate test data to be used in checking the validity of analytical models. The experiments are performed on three different load configurations of a trailer-on-flatcar. The test program was found to be successful. Pretest planning, to specify input levels and motion requirements, was essential to effective VSS operation. Log books, used to record program events as they occurred, were found to be invaluable in post test analyses.

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VSS DEMONSTRATION PROGRAM
PART 1

SYSTEM PERFORMANCE EVALUATION

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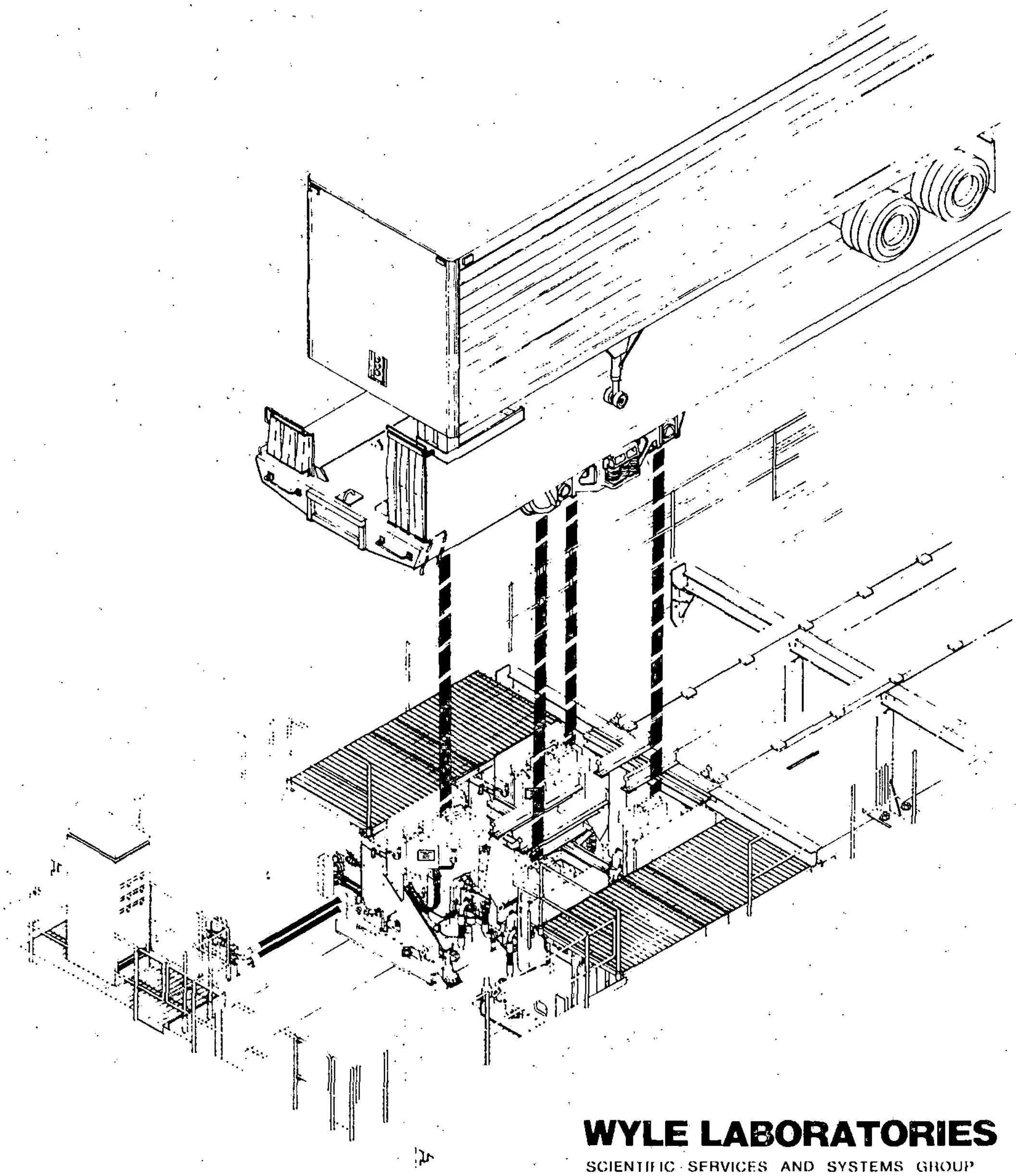

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1.0 INTRODUCTION

1.1 BACKGROUND

The Rail Dynamics Laboratory (RDL) at the Transportation Test Center (TTC) near Pueblo, Colorado has been designed and developed by the Federal Railroad Administration (FRA) to provide a laboratory in which basic studies in the areas of wheel/rail interaction, truck and suspension system design, vehicle body response, safety standards, etc., can be performed in a safe, controlled and economical environment. The Vertical Shaker System (VSS) is the first phase in the development of the RDL. The primary purpose of the VSS is the study of sinusoidal excitation of rail vehicles to determine their structural dynamic characteristics. The VSS consists of four vertical hydraulic shakers capable of driving two axle sets of a rail vehicle, having wheel loads up to 40,000 pounds, to a sinusoidal environment at magnitudes representative of vertical track profiles. Wyle Laboratories was responsible for the design, engineering, fabrication and system integration of the VSS and for the conduct of an acceptance and a performance demonstration test program.

1.2 SCOPE

The objectives of the VSS Demonstration Program were to demonstrate VSS performance and capabilities and to train the RDL operational personnel in its use. A test plan was developed that incorporated a trailer-on-flatcar (TOFC) as the test specimen designated for use during the test. Prior to testing, analytical models of the TOFC were developed to aid the structuring of definitive test procedures. Based on the results of response analyses performed using these analytical models, shaker force parameters, vehicle limit check requirements, and instrumentation types were identified.

A six week test and training program was performed using as the test specimens three configurations of the TOFC. During the conduct of the test program, data and information were obtained that allowed for the demonstration and evaluation of:

- Excitation system capabilities
- Range of allowable input regimes
- Control system performance
- Operating procedures
- Data acquisition system adequacies
- Data analysis capabilities
- Maintenance procedures.

Results of the VSS demonstration and evaluation are presented in this Part I of the Demonstration Program report. Part II will include a description of the analytical model development of the TOFC configurations, documentation of the associated time domain computer program, test data used to verify the analytical models of the TOFC configurations and a description of the process of verification.

2.0 TEST PROGRAM

2.1 OBJECTIVES

The objectives of the Demonstration Test Program (DTP) were to operate the VSS under various loading conditions in order to evaluate its capability, to train the RDL personnel in its use, and to obtain test specimen data for use in analytical model verification.

2.2 CONFIGURATION DESCRIPTION

Testing for the DTP was conducted on a Pullman Standard 89 foot 4 inch flatcar in three different load configurations. These configurations are shown in Figure 2.2-1. The flatcar was positioned on the shaker system such that vertical excitation was introduced into the B-end truck at the wheel/rail interface.

2.2.1 Configuration 1

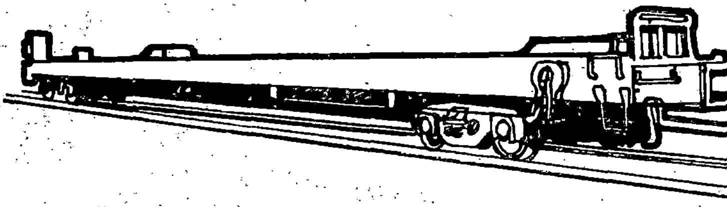
This configuration consisted of an unloaded Pullman Standard 89 foot 4 inch all purpose flatcar serial number TTAX973295. It was equipped with two ASF ride control trucks with 33 inch wheels and two Pullman Standard Model 5 trailer hitches. The weight breakdown for the flatcar is listed in Table 2.2-1. For configuration 1 the hitches were in the lowered positions and the truck ramps at each end were in a vertical or over the road position. The couplers at each end were not restrained from movement.

2.2.2 Configuration 2

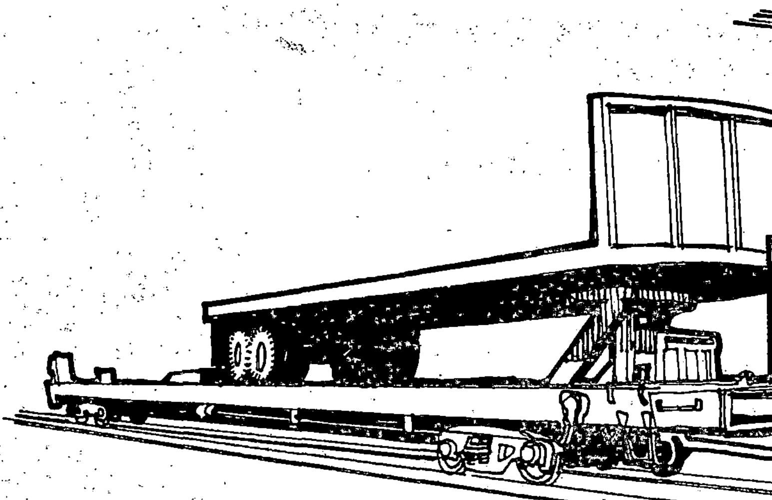
Configuration 2 was the fully loaded flatcar. It consisted of the flatcar defined in section 2.2.1 loaded with van and platform trailers as shown in Figure 2.2-2. The weight breakdown for configuration 2 is listed in Table 2.2-1.

2.2.2.1 Van Trailer

The van trailer was a Trailmobile Model A11A, Serial Number L32820. It was loaded with 49,825 pounds of sand bags on pallets as shown in Figure 2.2-3. The



CONFIGURATION 1



CONFIGURATION 3

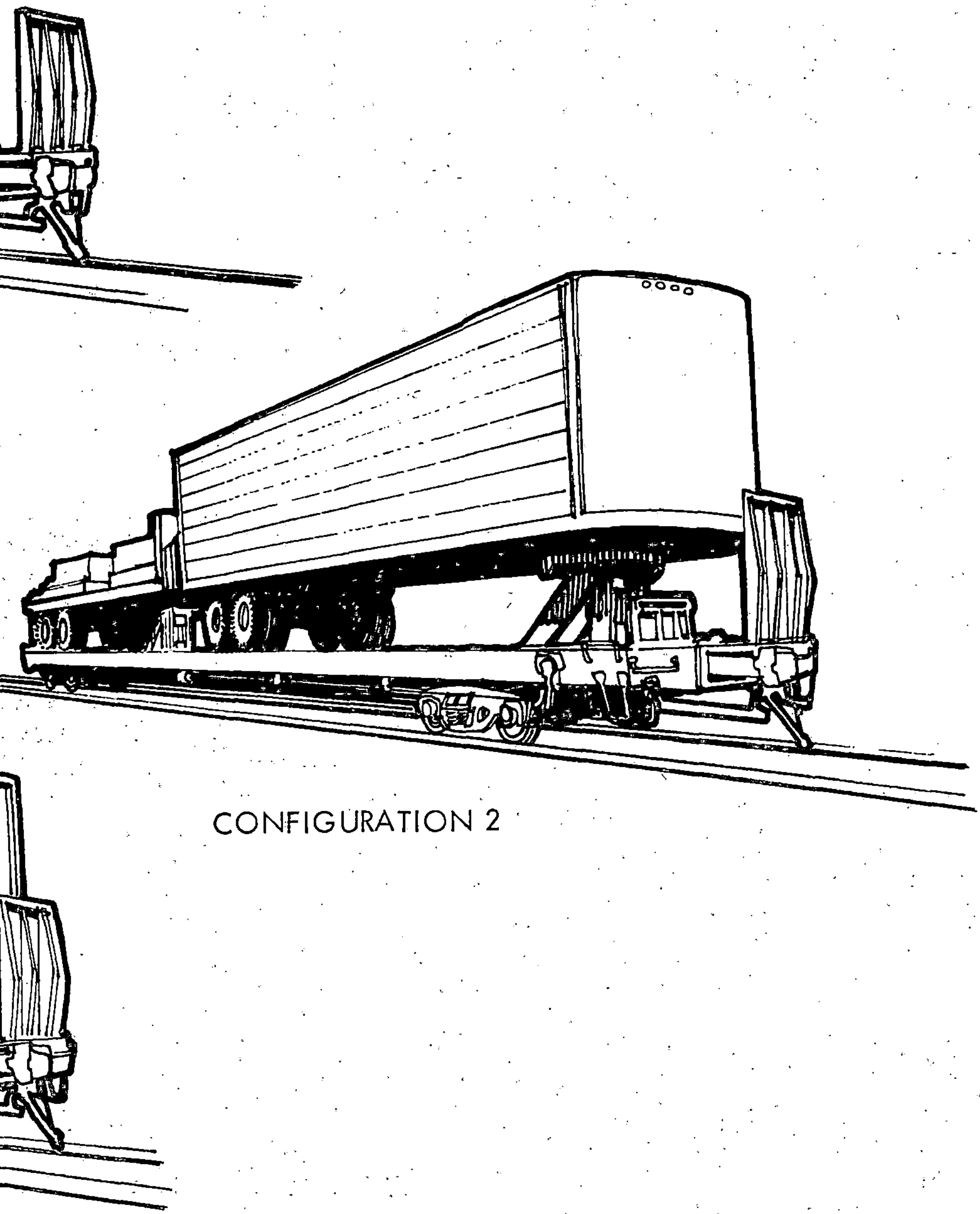


FIGURE 2.2-1 TEST CONFIGURATIONS

TABLE 2.2-1 WEIGHT SUMMARY

FULLY LOADED FLATCAR

FLATCAR STRUCTURE	52,561 lb	
FLATCAR TRUCKS	17,239 lb	
INSTRUMENTATION	100 lb	69,900 lb (Configuration 1)
VAN STRUCTURE	9,098 lb	
VAN TANDEMS	3,157 lb	
LADING (SAND BAGS)	49,825 lb	
		62,080 lb*
PLATFORM STRUCTURE	10,293 lb	
PLATFORM TANDEMS	2,707 lb	
LADING (LEAD WEIGHTS)	48,980 lb	
		61,980 lb*
	TOTAL	193,960 lb* (Configuration 2)
		82,900 lb (Configuration 3)

*Actual Weighed Values

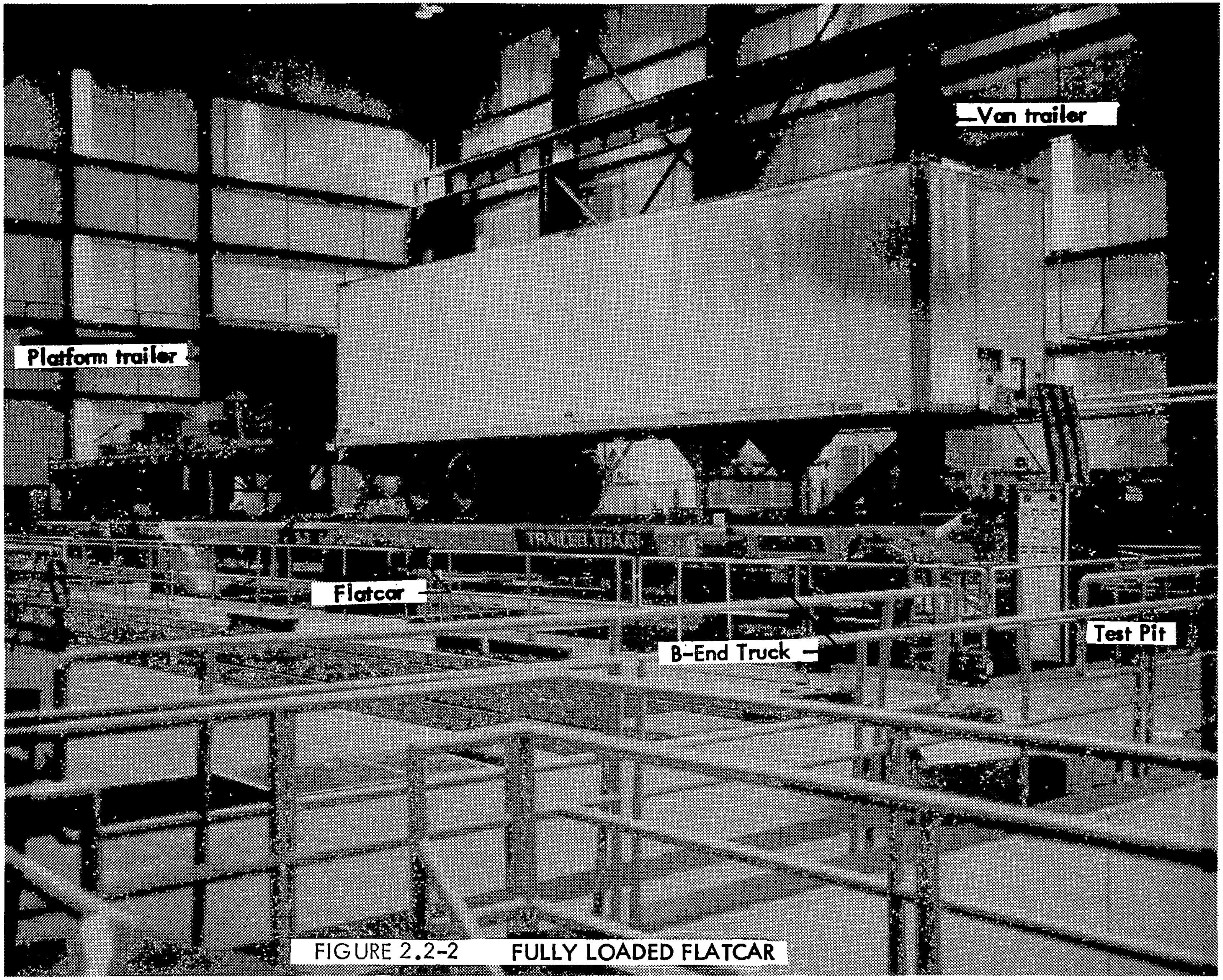
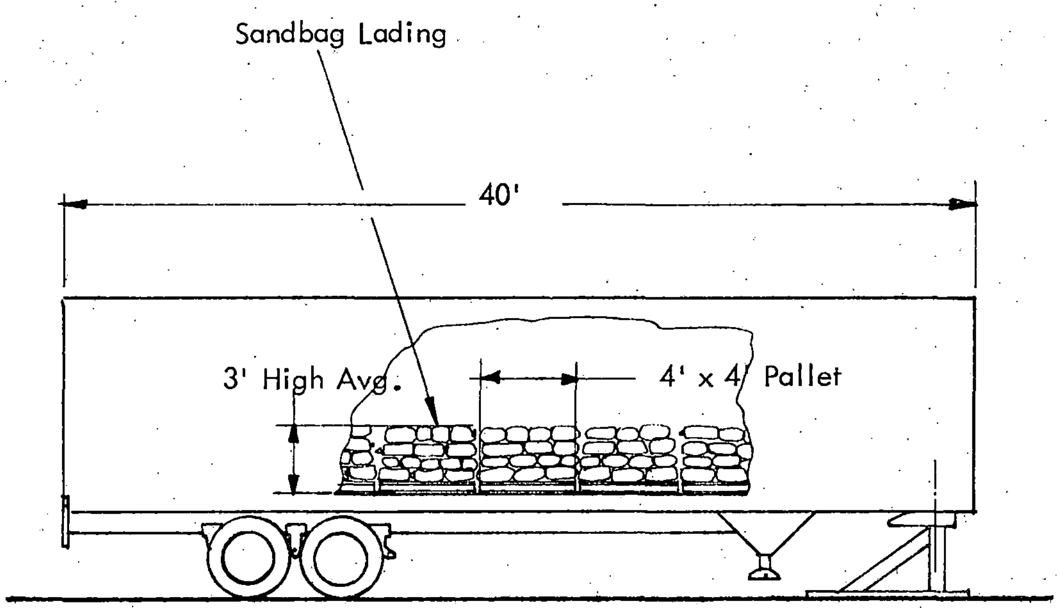
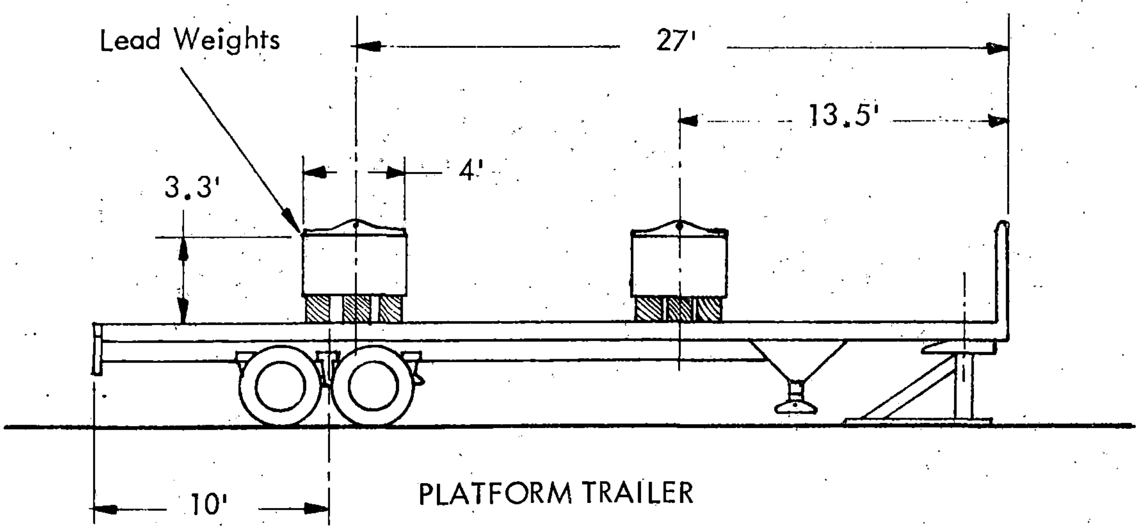


FIGURE 2.2-2 FULLY LOADED FLATCAR



VAN TRAILER



PLATFORM TRAILER

FIGURE 2.2-3 TRAILER CONFIGURATIONS

sand bags were loaded in the van on 17 pallets, two abreast with a single pallet at the rear. The sand bags were uniformly distributed on the pallets to a height of approximately three feet. The weight breakdown for the van trailer is listed in Table 2.2-1.

2.2.2.2 Platform Trailer

The platform trailer was a Trailmobile model P41T, serial number L32821. It was loaded with lead weights and cribbing weighing 48,980 pounds as shown in Figure 2.2-3. Two lead weights, weighing approximately 23,000 pounds each, were loaded on 12 by 12 inch cribbing and secured to the bed of the trailer by steel cables. The weight breakdown for the platform trailer is listed in Table 2.2-1.

2.2.3 Configuration 3

Configuration 3 consisted of the flatcar with an empty platform trailer loaded on the B-end as shown in Figure 2.2-1. The hitch at the A-end of the flatcar was in the retracted position. The weight breakdown for configuration 3 is listed in Table 2.2-1.

2.3 TEST SUMMARY

2.3.1 Component Tests

Several component tests were desired prior to starting the VSS testing of the flatcar. These tests were designed to measure spring constants, stiffnesses, and damping of the component parts of the flatcar, van trailer and platform trailer. The tests would have provided the RDL operational personnel an opportunity to run component tests and would have yielded more coefficients for use in the development of the analytical models. A series of tests were to determine the static deflection of both the van and platform trailers under load and are described in Appendix A.

2.3.2 TOFC Vibration Test

The TOFC configurations were subjected to sinusoidal sweep tests of various amplitudes with a controlled input based on displacement. Input motions were controlled with all shakers in phase for the excitation of the vertical modes of the test specimen. Torsional and roll modes were excited by controlling the right side shakers 180 degrees out of phase with the left side shakers. Discrete frequency dwell and decay tests were performed at specimen resonant and other selected frequencies with control at several input amplitudes. The input waveform was commanded to terminate at maximum or zero displacement thus allowing damping characteristics to be obtained through the analysis of vehicle response decay traces. A test log with a detailed listing of all the sweep tests performed including level, frequency range, and magnification factor (Q) values is contained in Appendix C. Also in Appendix C is a complete listing of all dwell and decays performed. The listing shows frequency, amplitude and type of test (dwell, high speed record, or decay).

2.3.3 Test Levels

The test procedure called for a minimum and a maximum sweep test level for each configuration. The minimum test level, a starting value, was increased to the maximum level or until the established specimen response limits were exceeded. In all cases the specimen limits would not permit the actuators to be exercised to the maximum test level. The maximum level attainable was different for each configuration and each is summarized in Appendix B. The solid lines in Figures B-1 through B-6 represent sweep levels and the circles represent dwell levels. The curves in Appendix B are presented as summary curves and in each case represent an envelope of the sinusoidal sweep tests performed over the frequency ranges identified. The time durations for the sweep tests were variable depending on magnification factor (Q). Since data is not acquired at every frequency during a digital sweep the number of frequency points is established based on system damping (magnification factor) to assure that the resonance frequencies are identified within 97 percent of the peak value.

2.3.4 Test Duration

An estimate of total test time was made by a post test analysis of the run log. The time for each sweep was based on the approximations in Table 2.3-1. The dwell test time was assumed to be one minute per dwell run. Table 2.3-2 summarizes the resultant estimate of total test time. An estimate was also made for the amount of test time spent at ± 0.5 Hz of the first flatcar bending resonance which varied with configuration and the total number of cycles accumulated at the first bending resonance. This data provided flatcar fatigue life information.

2.4 TRAINING

Another objective of the DTP was to train the RDL operational personnel in the operation of the VSS. During the testing of the first two configurations, RDL operating personnel worked directly with their Wyle functional counterparts and observed the operation of the VSS. After the successful completion of testing of the second configuration, the structural integrity of the VSS was demonstrated and hands-on training of the RDL operational personnel was initiated. RDL personnel accomplished all test operations during the final two weeks of testing with Wyle acting as only a requestor and monitor of activities. Daily meetings were held to evaluate performance and review operational procedures. During the hands-on training phase of the test program, the RDL operating personnel were exposed to the total system operation. The RDL operating personnel performed system maintenance, data reduction analysis and test setup and teardown of all three TOFC configurations. The data reduction analyses were performed with added classroom training given in the use of the updated features of the software described in Section 3.4.3. As a demonstration of proficiency in operating the VSS, RDL personnel were requested to perform a series of tests on the final test day. The request specified the test configuration and time constraints which were to be met. The inputs consisted of in-phase and out-of-phase sweeps with a given spectrum level, and a series of dwell and decay runs at specified amplitudes and frequencies. All the tests were satisfactorily performed as requested. Upon the completion of the test program the RDL operational personnel had demonstrated their ability to operate the VSS.

TABLE 2.3-1 APPROXIMATE SWEEP TIMES

APPRØXIMATE SWEEP TIME IN SECØNDS FRØM SELECTED FREQUENCIES TØ SELECTED FREQUENCIES AS A FUNCTIØN ØF Q

$$Q = \frac{1}{2\zeta}$$

TØ									
.50	68Q								
1.0	120Q	52Q							
2.0	155Q	97Q	45Q						
5.0	177Q	109Q	57Q	12Q					
10.	187Q	119Q	67Q	22Q	10Q				
20.	195Q	127Q	75Q	30Q	18Q	8Q			
50.	203Q	135Q	83Q	38Q	26Q	16Q	8Q		
100	210Q	142Q	90Q	45Q	33Q	23Q	15Q	7Q	
200	216Q	148Q	96Q	51Q	39Q	29Q	21Q	13Q	6Q
FRØM	.20	.50	1.0	2.0	5.0	10.	20.	50.	100

TABLE 2.3-2 ESTIMATED SPECIMEN TEST TIME

	TIME - HOURS			
	SWEEP		DWELL	
	Total	At 1st Resonance*	Total	At 1st Resonance*
Configuration 1	2.6	0.3	2.2	0.3
Configuration 2	4.6	1.1	2.7	0.8
Configuration 3	1.5	0.1	1.6	0.5

TOTAL HOURS TESTED	15.2
HOURS AT RESONANCE	3.1

*Resonance is defined as peak response frequency $\pm$ 0.5 Hz for both in and out of phase testing.

3.0 SYSTEM EVALUATION

3.1 OPERATIONS

3.1.1 Test Setup

3.1.1.1 Setup and Teardown

The vehicle setup procedure consisted of moving the vehicle from the service track to the test pit support track. Moving the unloaded flatcar was accomplished as shown in Figure 3.1-1 by utilizing the two overhead cranes at the RDL to lift the flatcar up and onto the test pit support track. The trucks at each end of the flatcar were chained to the flatcar body to keep them in place during this operation.

The loaded trailers were placed on the flatcar as shown in Figure 3.1-2. The trailers were positioned on the flatcar with each landing gear fully extended. Each hitch was then moved into place and tightened around the trailer kingpin. Both landing gears were raised about two inches off the flatcar deck. The A end of the flatcar secured in place by blocking each wheel of the truck as described in Section 3.1.1.2.

The setup procedure of the flatcar was performed once during the test program. The trailers were loaded and unloaded for configurations 2 and 3. At the end of the test program the flatcar was removed from the test pit track using the same procedure outlined above.

3.1.1.2 Vehicle Installation

The vehicle installation procedure was performed only on test days and consisted of moving the flatcar forward on the support track to the shaker heads and securing the flatcar prior to testing. In detail the bridge rails between the support track and actuators were moved into place, the A-end truck intermediate block was removed and the

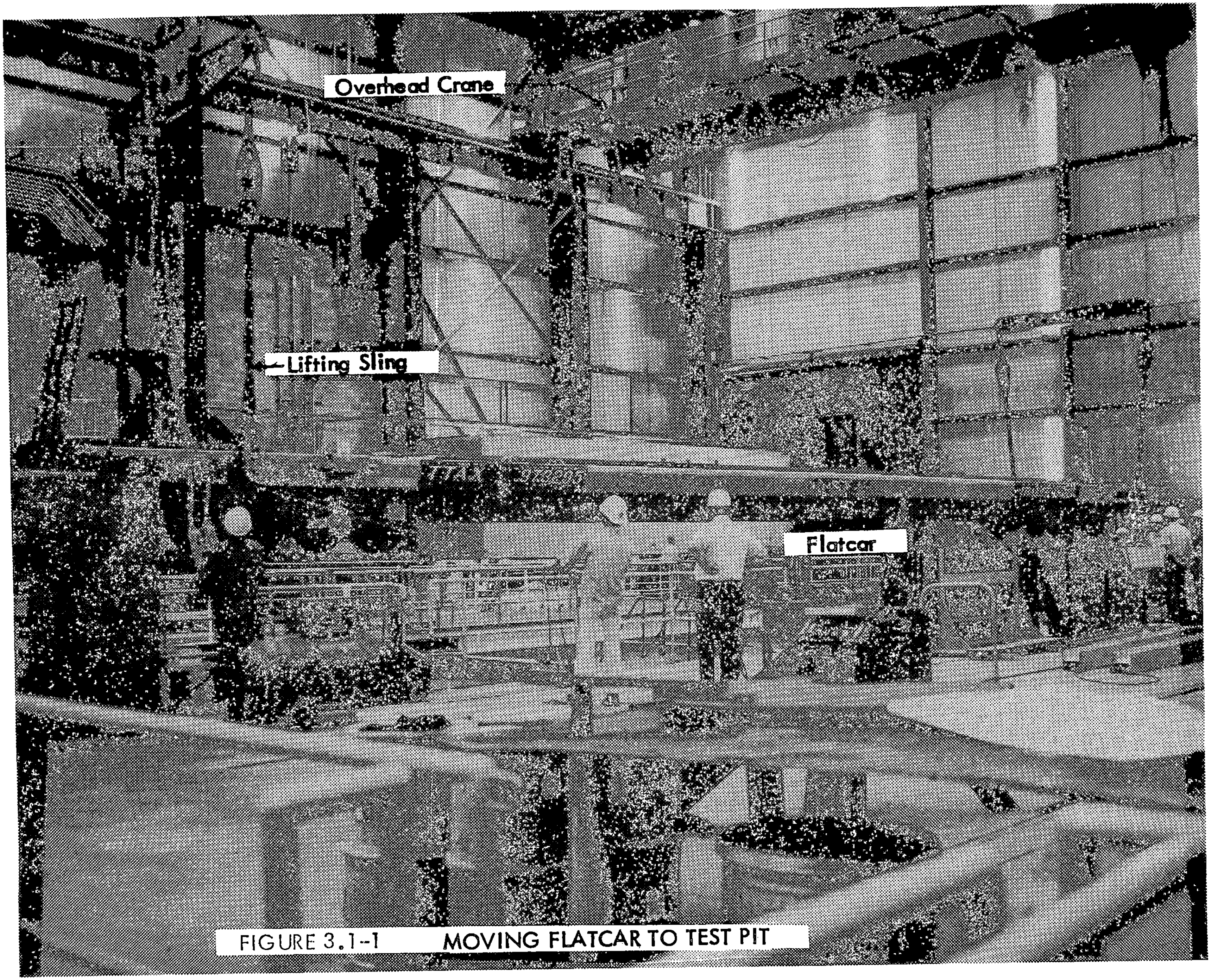


FIGURE 3.1-1 MOVING FLATCAR TO TEST PIT

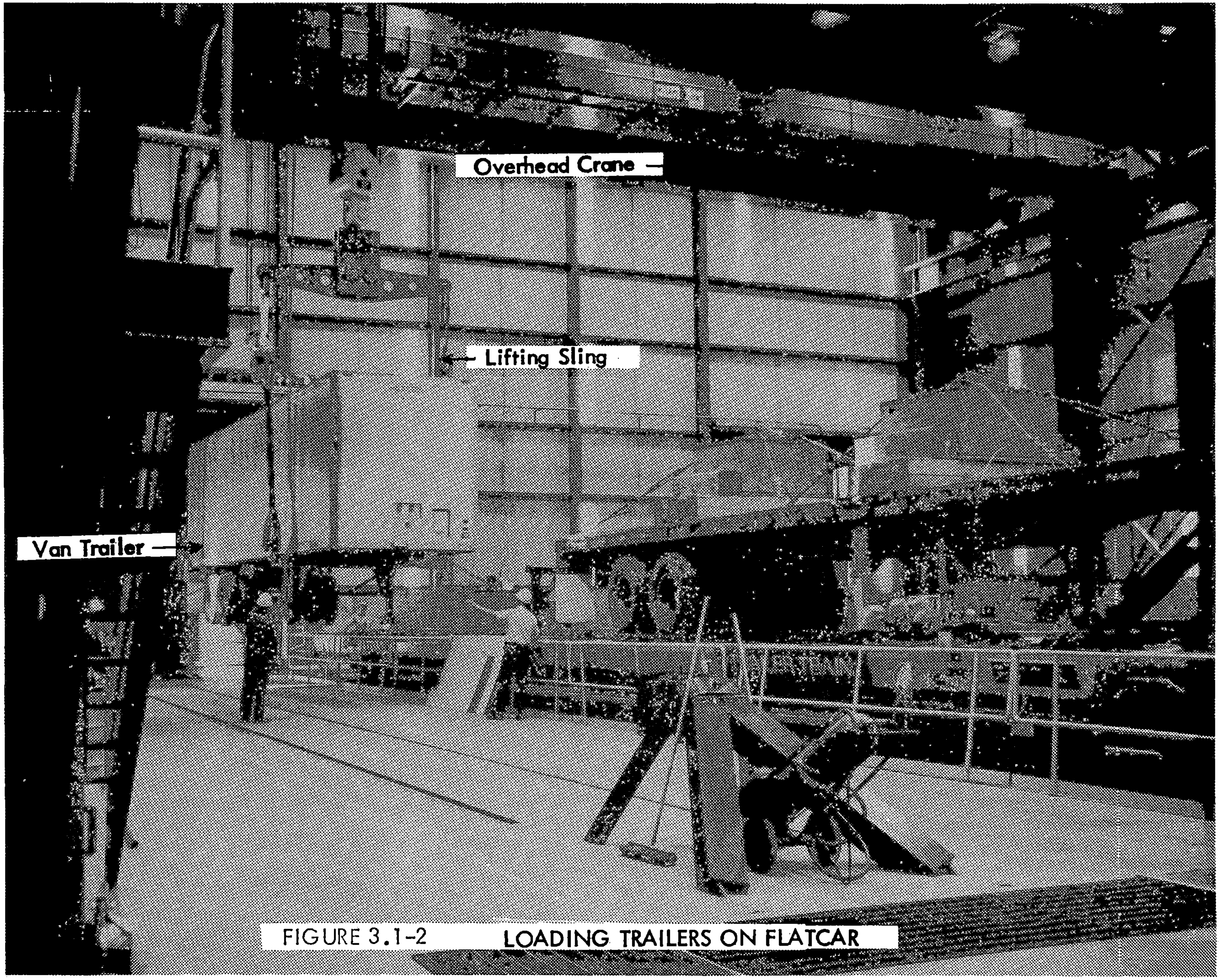


FIGURE 3.1-2 LOADING TRAILERS ON FLATCAR

flatcar moved to the forward permanent block. The flatcar was moved forward by forklift and once in place, the wheel liftoff switch was checked. The last step prior to testing was to remove the bridge rails. This process was reversed each day after completion of testing.

3.1.1.3 Vehicle Restraint

3.1.1.3.1 Flatcar - Once the flatcar was on the shaker heads as shown in Figure 3.1-4, the A-end truck was restrained in the longitudinal direction to keep the flatcar in position during testing. This was accomplished by placing a block at each wheel and wrapping chains between each axle and the vehicle support structure. The slack in the chains was removed. A schematic of this longitudinal restraint system is shown in Figure 3.1-3.

3.1.1.3.2 Trailer Restraint System - During the testing of configurations 2 and 3, a passive restraint system incorporating the overhead crane was used to prevent excessive rolling of the test specimen and to keep the trailer tandems in position on the flatcar. Before out of phase testing started on configuration 2, chains were wrapped around each trailer axle as in Figure 3.1-5 and tied to the flatcar body. The chains had about 2 inches of slack to allow for relative motion between the trailer tandems and the flatcar. For configuration 3 the overhead cranes were not used. The restraint systems were never activated during this test program.

3.1.1.4 Pre and Post Test Measurements

A series of pre and post test measurements were made on each trailer to document the diameter of the kingpins and the tire pressures. This data is contained in Appendix D. The trailer kingpin measurements showed no change. Tire pressures were initially set at 85 psi with the exception of the one flat tire. No significant variations appeared.

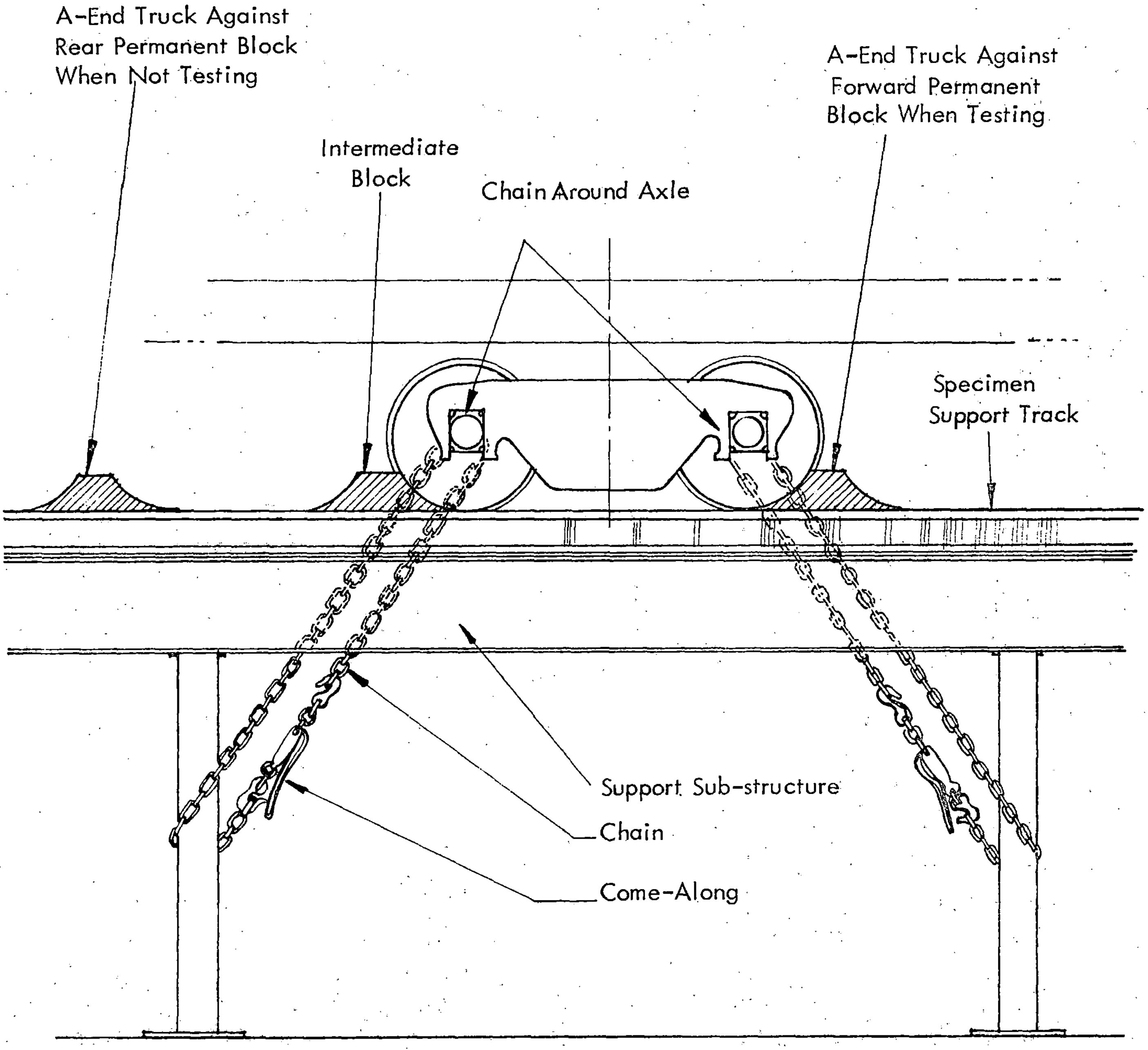


FIGURE 3.1-3 FLATCAR LONGITUDINAL RESTRAINT
A-END TRUCK

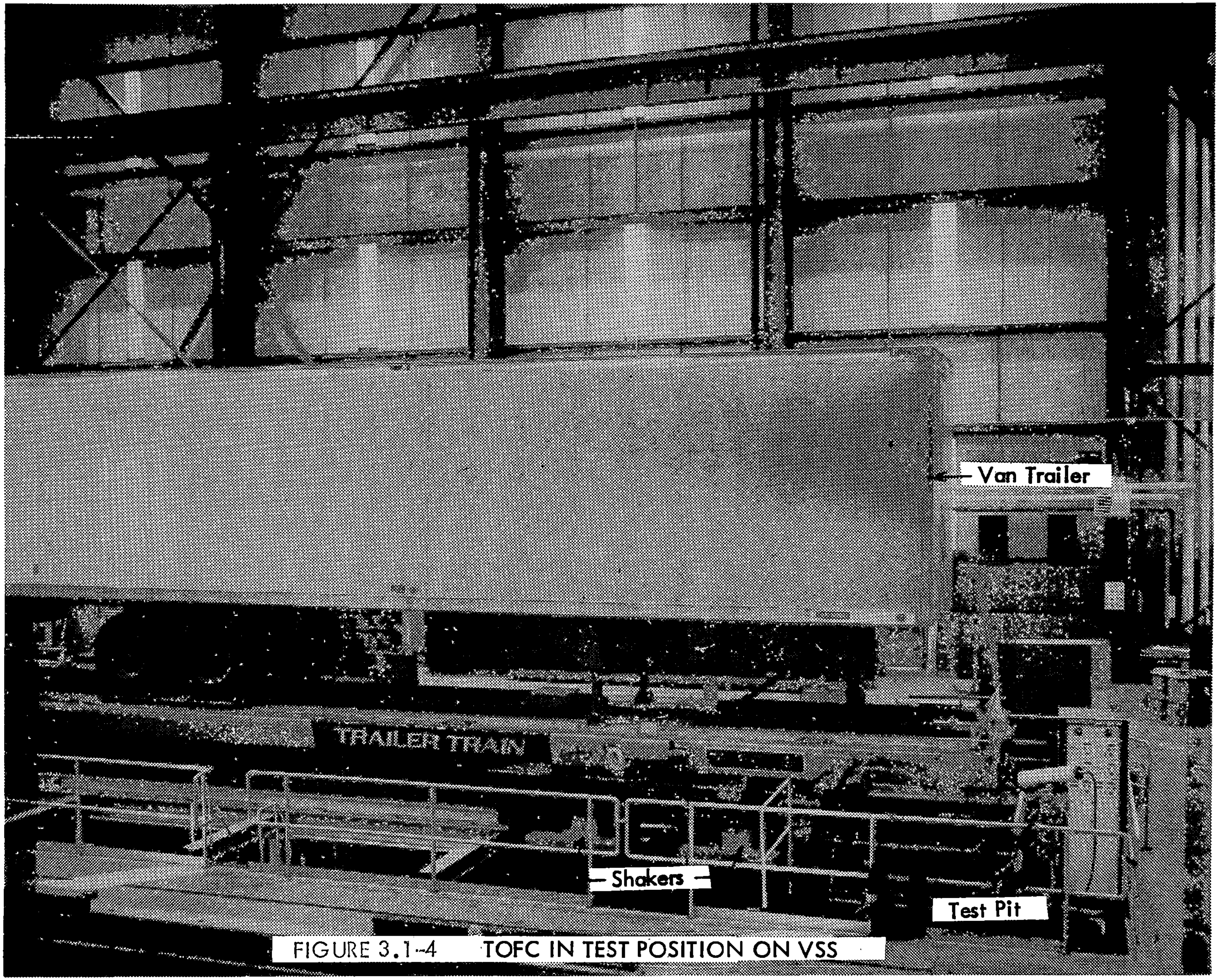


FIGURE 3.1-4 TOFC IN TEST POSITION ON VSS

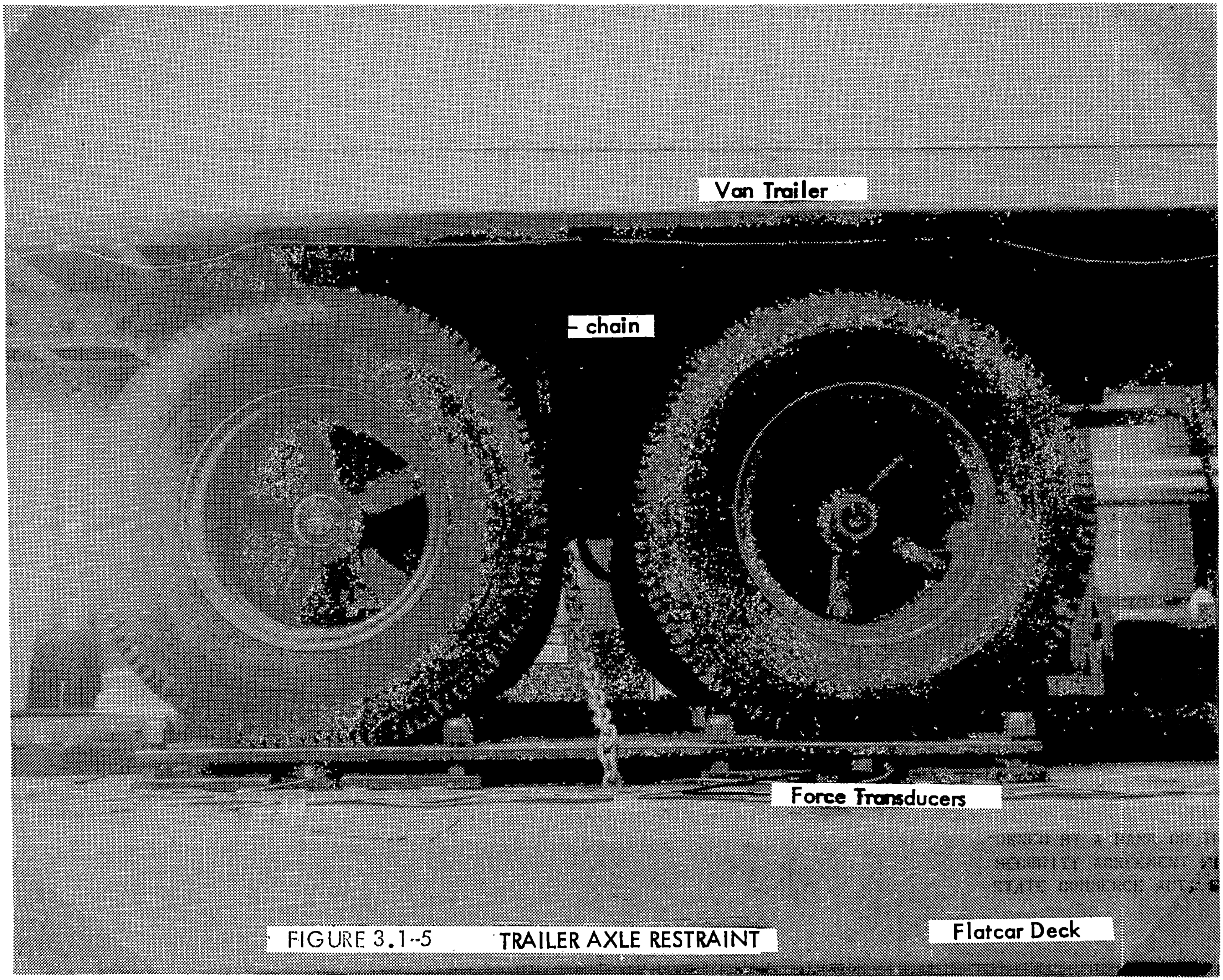


FIGURE 3.1-5 TRAILER AXLE RESTRAINT

3.1.2 Test Conduct Procedure

3.1.2.1 Test Schedule

The DTP was completed within the required six week time period as shown in Figure 3.1-6 with the accomplishment of all objectives. The testing of configuration 1 used the first three weeks of the program due to scheduled holidays, formal classroom training of RDL operators, and VSS problems. The second configuration was completed in two weeks and two days with much time again spent in classroom training and in solving system problems. The third and final configuration was completed with one day of test effort due to the experience gained by RDL personnel in planning, setting up, and running during the previous testing.

3.1.2.2 Test Procedures

A daily test procedure evolved during the course of the test program. The most efficient procedure consisted of starting hydraulic oil warm-up at 0700 hours, taking oil samples at 0800 hours then performing instrumentation calibration and unloaded shaker testing. A daily test review briefing, each morning, was found to be an effective means of communication among the cognizant personnel and provided the opportunity to discuss problems and/or requirements. Daily detailed test plans, including punched computer control cards for frequency sweeping and lists of dwell frequencies and amplitudes, proved to be conducive to timely testing.

The time required for setup, teardown and troubleshooting of the system provided the motivation to schedule a twelve hour day whenever testing was being conducted. Work continued until the objectives for that day had been accomplished. The trend toward greater VSS efficiency throughout the six weeks of the program is illustrated by the data given in Table 3.1-2.

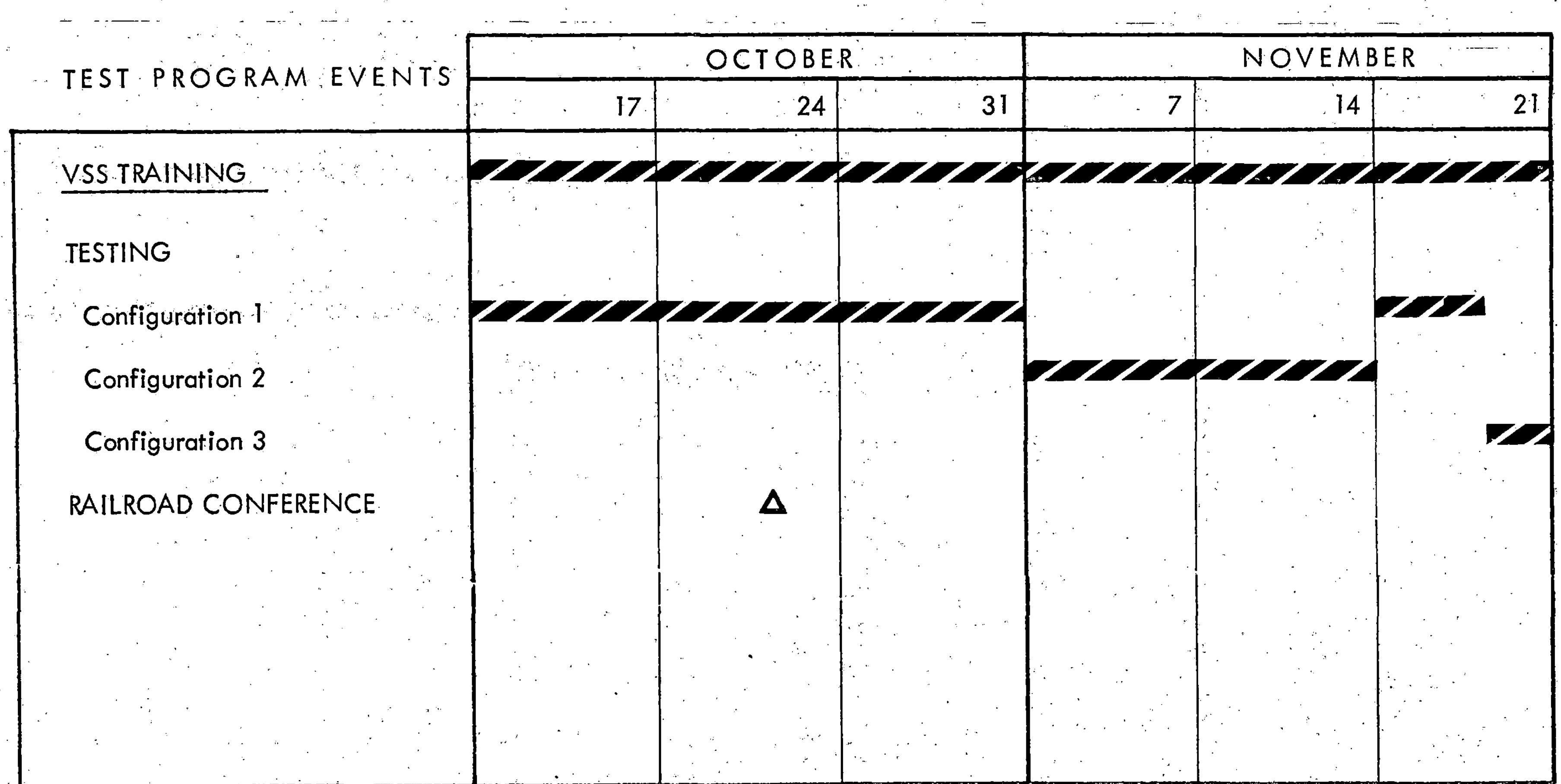


FIGURE 3.1-6 DEMONSTRATION TEST PROGRAM SCHEDULE

3.1.2.3 Limit Check Summary

Limiting the response of selected accelerometers on the test specimen is possible through the VSS limit check capability. The limit check is performed by the computer which automatically shuts down testing if a preset limit is exceeded more than the specified number of consecutive times. Limit checking is performed on the raw data signal, thus high frequency spikes may shut the system down. Because the limit check values were initially set too low, configuration 1 testing required as many as eight attempts before a successful run could be completed. Better selections for the limit check values were made for the later configurations and shutdowns were not as frequent. It was also found that by setting the number of consecutive occurrences at three the problem was significantly improved. A summary of the limit check values used is contained in Table 3.1-1. The table depicts only the maximum values used as in many cases much lower values were selected initially and had to be increased. Those channels specified as critical channels in Table 3.1-1 are those which were most sensitive in the TOFC system and which if lowered slightly would cause a system shutdown.

Channel 108 was a pressure switch which was used to shutdown the system should the flatcar wheels liftoff the shaker heads. During the entire test program this switch caused shutdown only once. This occurrence was intentionally repeated three times and, while not visually verifiable, established the validity of the pressure switch operation.

3.1.2.4 System Efficiency

One of the products of the Demonstration Test Program was to debug the VSS. As can be seen from Table 3.1-2, during the last week of testing a good percentage of the hours available for testing were spent in actual testing.

TABLE 3.1-1 LIMIT CHECK CHANNELS

Maximum Values

Channel No.	Configuration 1		Configuration 2		Configuration 3	
	In-Phase	Out-of-phase	In-Phase	Out-of-phase	In-Phase	Out-of-phase
57	5 g (1)	3 g (3)	3.0 g (3)*	2.5 g (3)	5 g (3)	3.0 g (3)
66	5 g (1)*		3.7 g (3)		3.7 g (3)	
71			1.2 g (3)	1.0 g (3)	1.2 g (3)	2.0 g (3)
73				1.0 g (3)		2.0 g (3)
81			3.7 g (3)			
89	3.6 g (1)	2.5 g (3)	2.5 g (3)	1.0 g (3)	2.5 g (3)	1.3 g (3)
102		25 rad/sec^2 (3)*		15 rad/sec^2 (3)*		
108	0.25 in (1)	0.25 in (1)	0.25 in (1)	0.25 in (1)	broken	broken
115	2 g (1)	2 g (3)*	1.5 g (3)	4.3 g (3)*	1.5 g (3)	2 g (3)
118	1.8 g (1)*				2.0 g (3)*	
119				2.0 g (3)		
126			1.3 g (3)*			
127					1.5 g (3)	2.5 g (3)*

*critical channels
( ) indicates number of consecutive occurrences

TABLE 3.1-2 SYSTEM EFFICIENCY

Week	Hours Scheduled For Testing	Hours Required For Setup and Teardown	Hours Available For Testing	Actual Hours Tested*
1	28	12	16	4
2	36	16	20	8
3	33	12	21	1.5
4	40	16	24	7.5
5	46	20	26	2.5
6	41	20	21	15.5

*These represent the hours the machine was up and ready to test. The hours the machine was running were less.

3.1.2.5 System Problems

System problems with the VSS occurred during the test program which resulted in the loss of several test days. Each problem was identified and corrected during that day and normal test operations were allowed to continue the next test day. In summary these problems included a broken accumulator bladder, a leaking "O" ring in the shaker hydraulics, and a leak in the pilot accumulator. Each repair required only a replacement part. In addition, the RDL facility hydraulic pump power supply went down for a day.

3.1.3 System Maintenance

Several of the more important of these maintenance procedures are included; in particular, as shown below, those relating to the daily operation of the system.

- Actuator and journal bearings are checked out by determining the resistance areas of the oil film in the bearing (no resistance indicates metal to metal contact and a problem).
- Hydraulic system line and flex hoses are visually inspected for evidence of leakage.
- Oil samples are taken from both hydraulic supply systems to verify oil cleanliness.
- Calibration checks are performed on the ADACS scanner and signal conditioners/data channels.
- Operational checks are made on the computer system to determine if various system components are capable of operations as expected. This check could be the performance of a computation from a magnetic tape copied from a sample program deck from the card reader.

If the VSS is not operated at least one day each week the hydraulic system should be powered up and the oil circulated through the modules until a temperature of 120°F is reached and maintained in circulation for one hour.

3.2 CONTROL SYSTEM

The VSS consists of four excitation hydraulic shakers with the associated control and monitor systems. This system is designed to provide vertical harmonic excitation to one end of a rail vehicle equipped with conventional two axle trucks.

Each of the four shakers consists of a high performance, electronically-controlled servo valve, a high force actuator and bias system assembly, a stationary structural assembly and the plumbing and components to support these items. The excitation modules are shown in Figure 3.2-1.

The electronic control and the dynamic shakers perform as a completely integrated electrohydraulic vibration system. The control system provides closed-loop displacement control of the wheel/rail interface at each shaker. A primary objective in designing the control system was to provide wide bandwidth control of the actuators while still maintaining adequate system stability. Wide bandwidth performance (3 db down at 40 Hz) has been achieved on the VSS. This performance significantly exceeds the Statement of Work (SOW) design requirements for the VSS and assures that the shakers will accurately respond to displacement commands with minimal harmonic distortion at the wheel/rail interface.

Figure 3.2-2 shows a schematic diagram of a control channel for one of the VSS shakers. The analog control subsystem consists basically of the analog controller and the associated instrumentation required to provide closed-loop displacement control and monitoring of the VSS electrohydraulic shakers.

The VSS is operated from the VSS test console located in the RDL control room. This console contains all necessary equipment required to perform the functions shown in Figure 3.2-3. In addition, closed-circuit television is included in this console for visual observation of the test area. The VSS control console is shown in Figure 3.2-4.

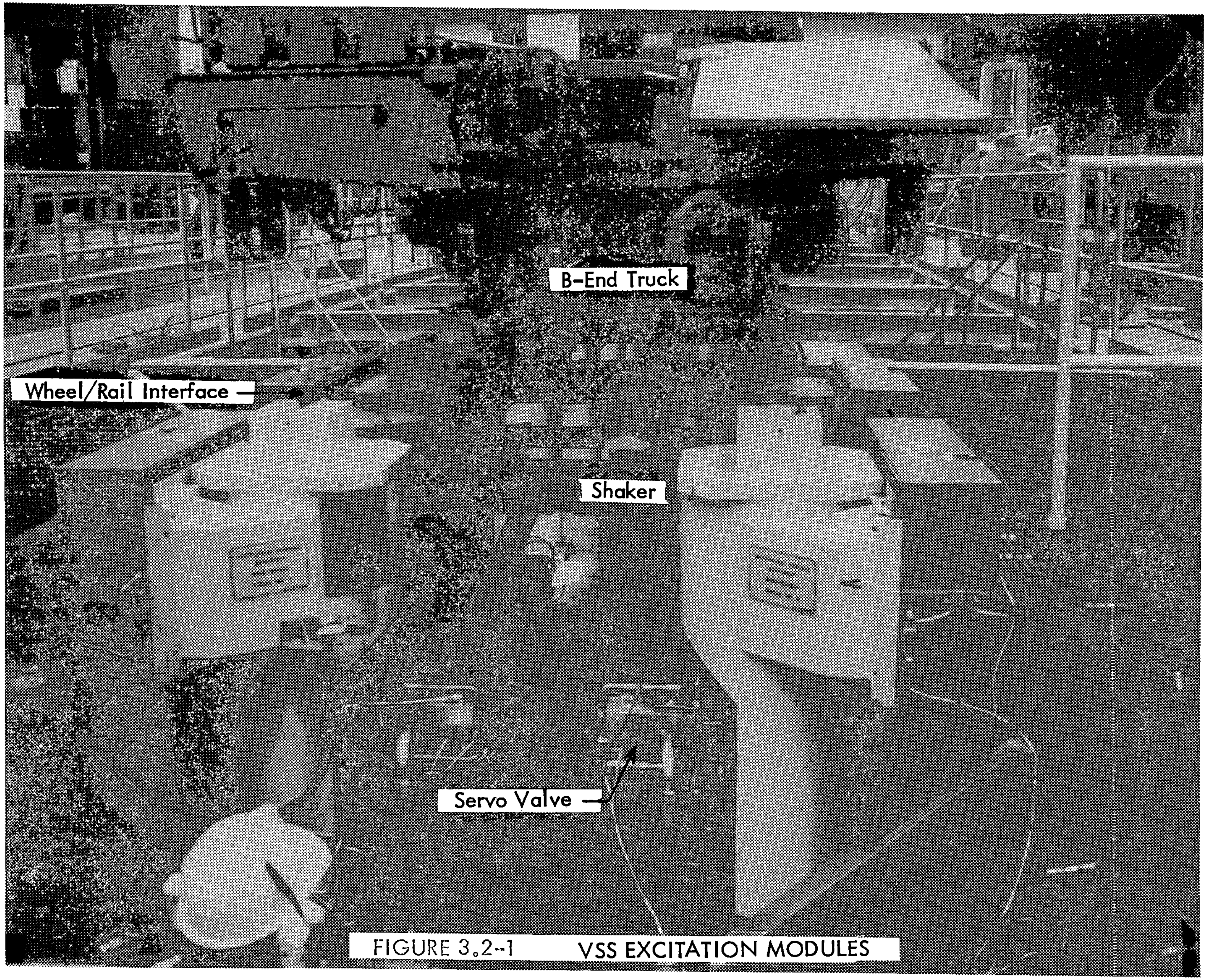


FIGURE 3.2-1 VSS EXCITATION MODULES

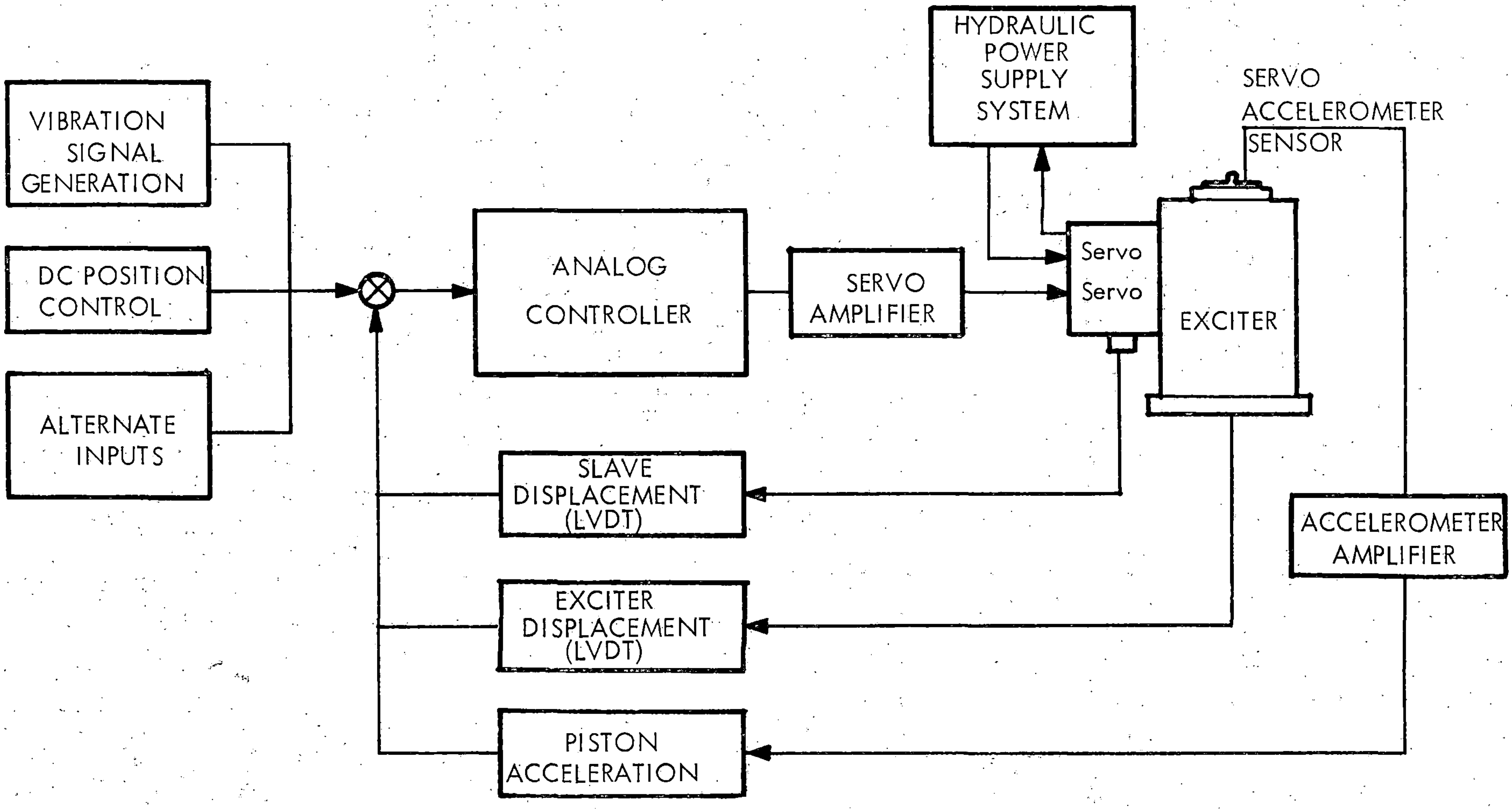


FIGURE 3.2-2 EXCITATION MODULE CONTROL SYSTEM SCHEMATIC

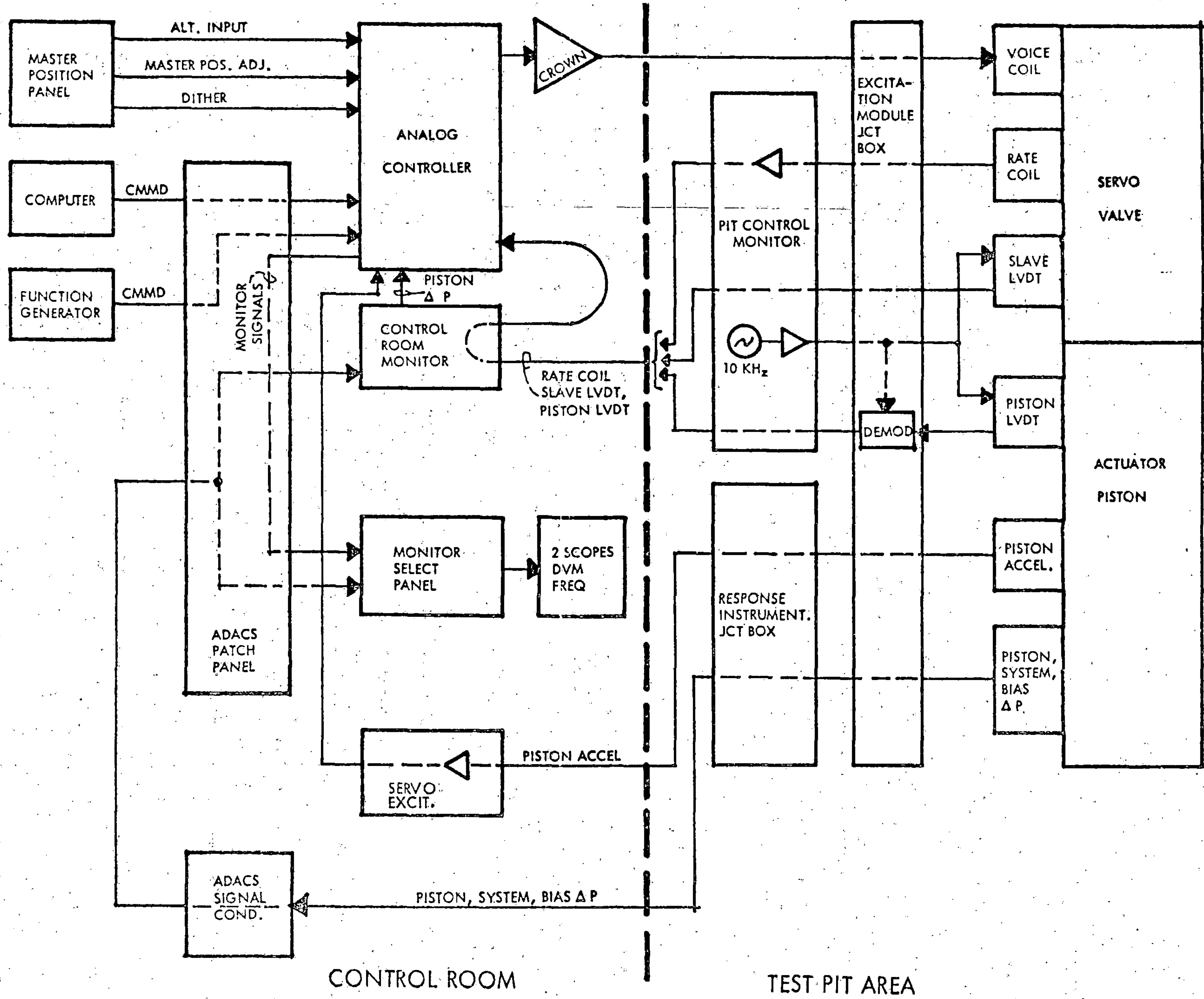


FIGURE 3.2-3 VSS CONTROL SYSTEM SCHEMATIC

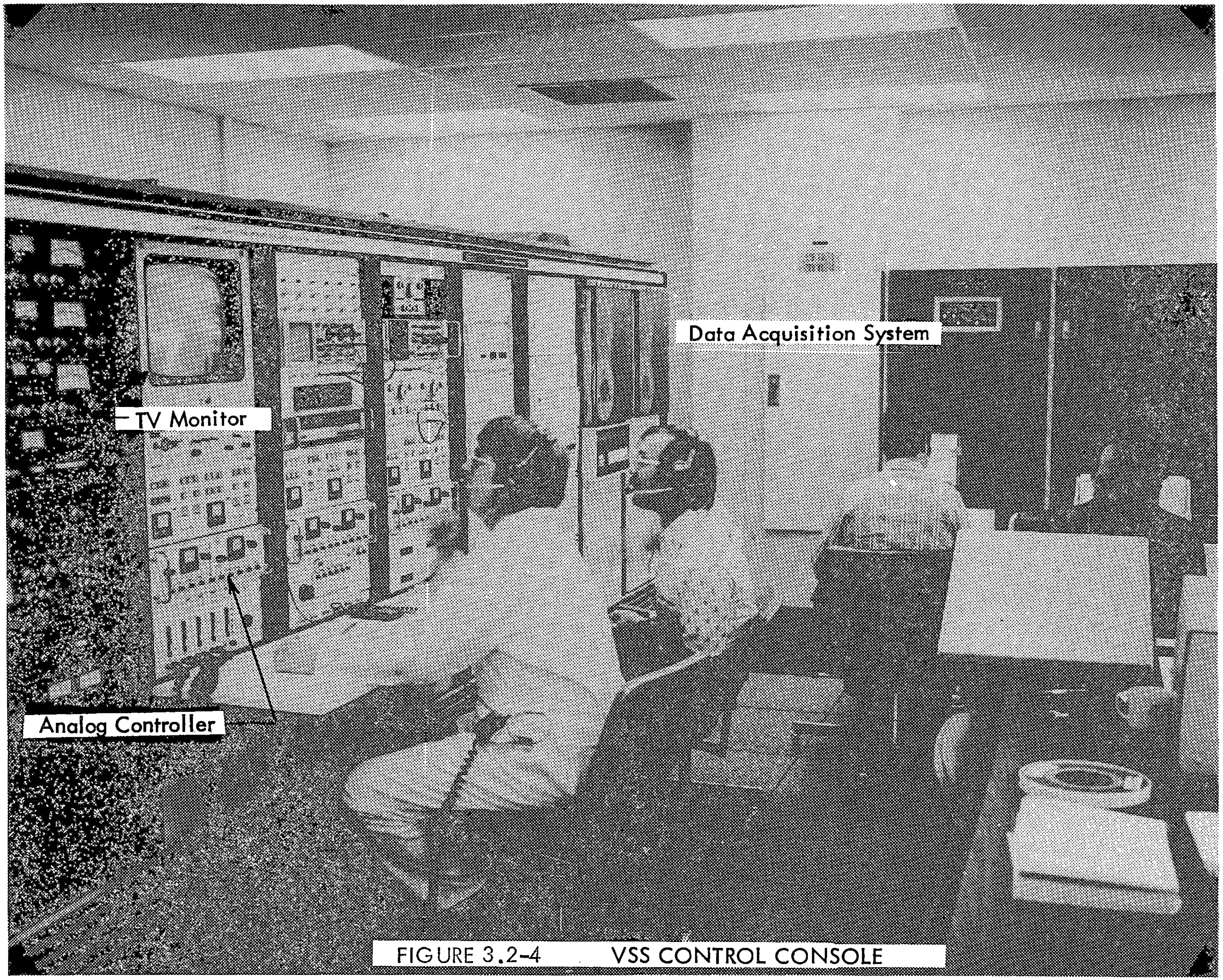


FIGURE 3.2-4 VSS CONTROL CONSOLE

3.2.1 Control System Design Objectives

As previously mentioned, a major design objective was to obtain wide bandwidth performance of the actuators. More specifically, it was required that the transfer function of each shaker be flat, within ± 2 db, to 20 Hz and 3 db down, within ± 2 db, to 30 Hz. In addition, the dynamic excitation capability requirements were:

- Displacement: greater than 1.9 in. up to 1.75 Hz
- Velocity: greater than 22 ips from 2 Hz to 20 Hz
- Acceleration: greater than 8.3 g's from 20 Hz to 30 Hz

Aside from the design objectives associated with meeting the basic performance requirements above, several other basic considerations entered into the control system design:

- The controls design should assure adequate system stability under all operating conditions.
- It should minimize system sensitivity to noise.
- The control system should provide damping of the piston/oil column resonance and structural resonance.

3.2.2 Control System Implementation

The VSS control system is designed to provide displacement control of the shakers, i.e. a given input voltage command provides a known piston displacement. To achieve wide bandwidth performance while still maintaining good shaker response fidelity with respect to the input commands, closed-loop feedback control is used. The feedback scheme utilizes a combination of slave displacement, shaker piston displacement, and shaker feedback acceleration as shown in Figure 3.2-2.

A brief description of the shaker servo-valve, is helpful when discussing implementation of the control system. The servo-valve is an integral two-stage hydraulic amplifier driven by a linear electro-magnetic signal transducer similar to an electro-dynamic vibration exciter or loud-speaker. The voice coil of the signal transducer is directly attached to the first stage or pilot stage of the hydraulic servo-valve. Axial motion of the pilot stage ports hydraulic fluid to drive the slave stage of the servo valve assembly.

The second stage slave valve is also a symmetrical, four-way, closed-center spool valve and is analogous to the actuator piston of the shaker. The slave, or power stage, is capable of instantaneously controlling 200 gpm hydraulic fluid flow to the actuator cylinder. The slave valve, unlike the pilot valve has no positioning springs and its position is proportional to the integral of the pilot valve position. The position of the slave spool is dynamically sensed by a position feedback transducer (LVDT) and this signal is used to form the "inner loop" feedback. Without this "inner-loop" around the pilot-slave stage, the simplified transfer function between the valve input and slave valve position would appear as an integrator and gain. The corresponding "open-loop" response for such a configuration is unacceptable since the response amplitude decreases with frequency. Providing slave valve position feedback around the pilot-slave stage effectively moves the slave pole (integrator) from the origin (zero frequency) out to some higher frequency thereby providing a constant amplitude versus frequency response out to some predetermined break frequency. This break frequency is dependent upon the feedback gain used in this loop. This linear response, however, is obtained at the expense of lowering the overall forward-loop-transfer function gain of the control system.

Similarly, piston displacement is utilized as an "outer-loop" feedback signal. Increasing the outer-loop piston displacement feedback gain increases the system bandwidth while decreasing system stability. The system stability is compromised because the lightly damped piston resonance poles cross over into the right half plane as the exciter displacement gain is increased. The no load piston hydraulic resonance for the VSS system has a natural frequency of $\approx$ 60 Hz with a damping ratio of 0.1 percent of critical.

To increase the system bandwidth and still maintain system stability, piston acceleration feedback was employed. The use of piston acceleration feedback increases the damping of the exciter oil column hydraulic resonance thereby allowing larger exciter position feedback gains to be used.

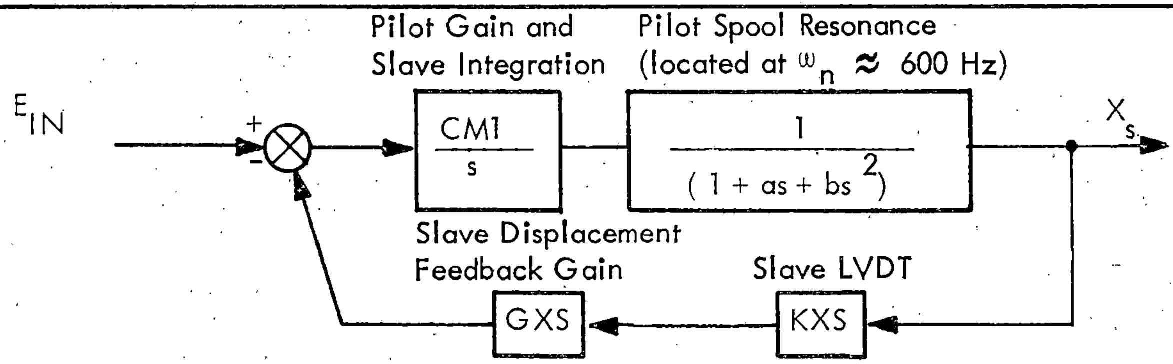
Figures 3.2-5 and 3.2-6 illustrate the system characteristic root movements as the slave (inner loop) and the acceleration feedback gains are adjusted. As the slave displacement feedback gain is increased, the bandwidth of the servo-valve (inner loop) increases as is indicated by the inner loop root locus. The nominal slave loop roll off frequency used is 80 Hz. For the control system configuration associated with the characteristic root locations shown in Figure 3.2-6, increasing the outer loop piston displacement feedback gain will increase the system bandwidth, however, the system stability margin will be decreased. Because of the interactive effects between feedback gain adjustments and the characteristic root movements of the control system, various simulation and stability studies were conducted to arrive at the basic control system configuration.

Figure 3.2-6 illustrates the acceleration feedback outer loop root locus for increasing acceleration feedback gains. The nominal pole locations associated with the controller gains used during the demonstration program are indicated in Figure 3.2-6.

These gains are a compromise between the need to decrease system sensitivity to instrumentation noise and the need to maintain system stability. The system was found to be sensitive to instrumentation noise at high acceleration feedback gains.

3.2.3 Control System Performance

VSS performance is discussed in terms of dynamic excitation capabilities and fidelity. The VSS performance capability measurements were performed and obtained during the DTP.



INNER LOOP FEEDBACK BLOCK DIAGRAM

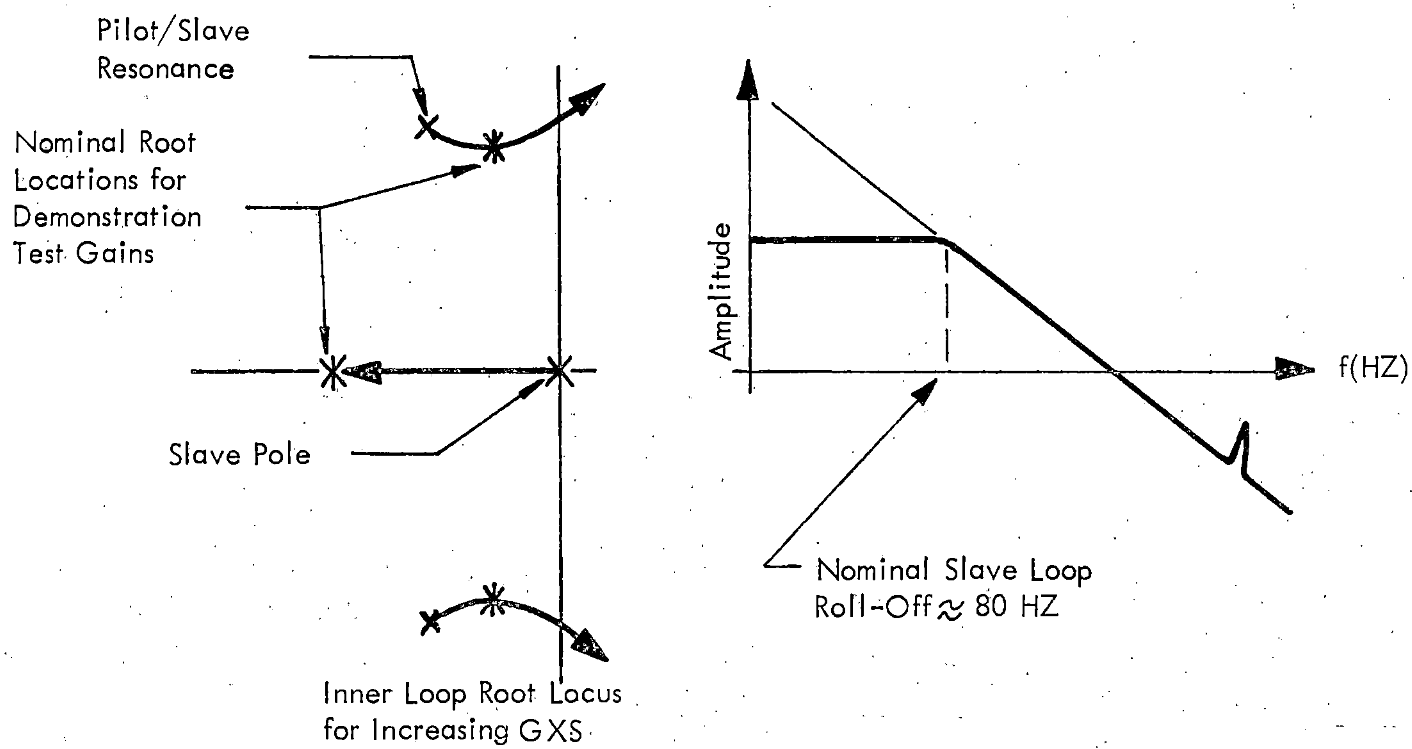


FIGURE 3.2-5 SLAVE (INNER) LOOP CHARACTERISTICS

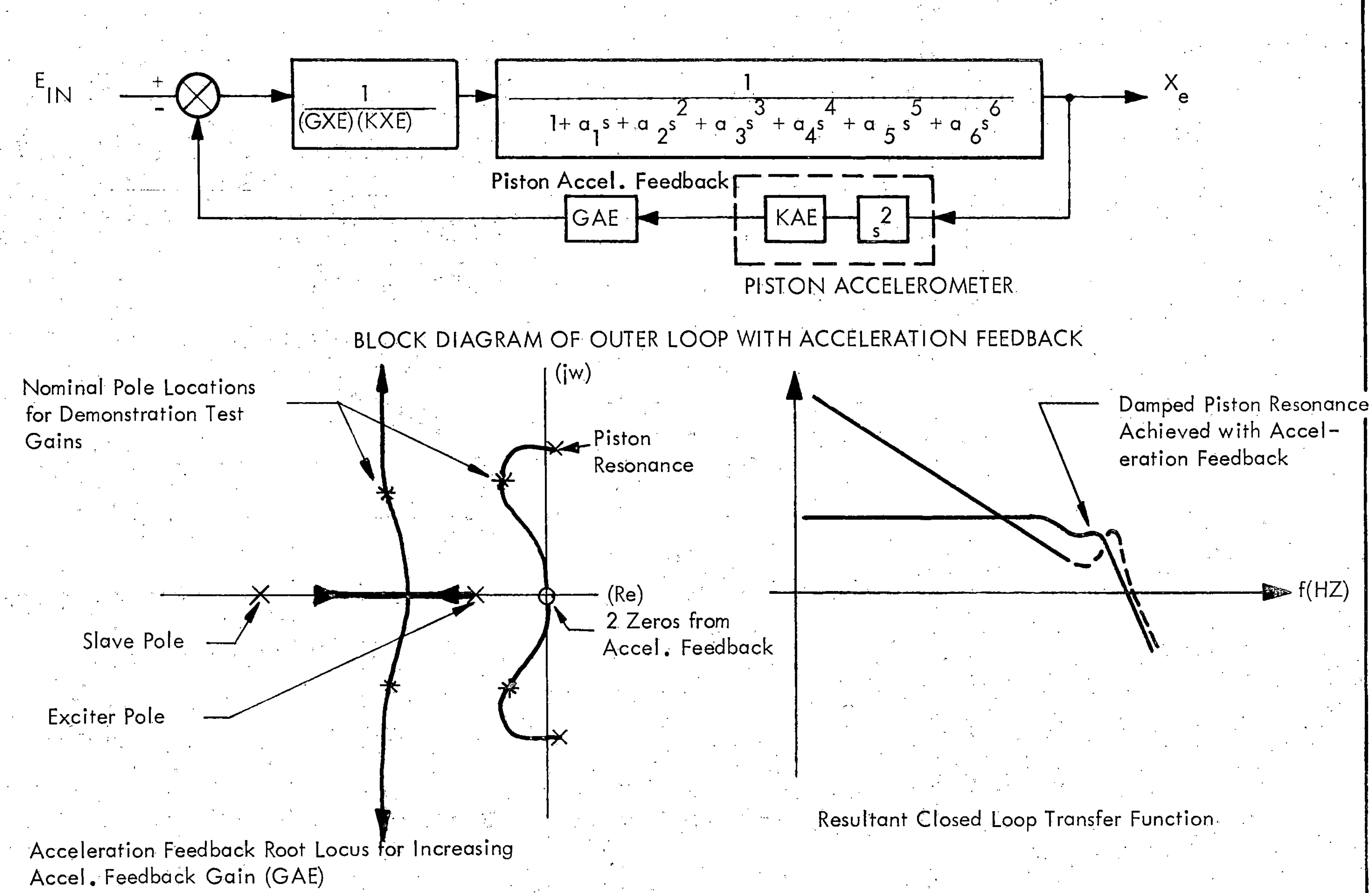


FIGURE 3.2-6 OUTER LOOP ACCELERATION FEEDBACK CHARACTERISTICS

3.2.3.1 Dynamic Excitation Capability

The sinusoidal dynamic excitation capability for all four unloaded shakers operating simultaneously exceeded the requirements below:

- Displacement: greater than 1.9 in. up to 1.75 Hz
- Velocity: greater than 22 ips from 2 Hz to 20 Hz
- Acceleration: greater than 8.3 g's from 20 Hz to 30 Hz

This dynamic motion capability envelope is shown in Figure 3.2-7. With the high bandwidth control system gains used during the DTP, the system transfer functions for each shaker exceeded the SOW requirements. The SOW required that the gain versus frequency be within ±2 db to 20 Hz and 3 db down, within ±2 db, at 30 Hz.

Figure 3.2-8 shows typical dynamic excitation capabilities measured for one of the shakers. A comparison of the transfer functions for all four shakers is shown in Figure 3.2-9 and 3.2-10. A comparison of the phase measurements between all shakers is summarized in Table 3.2-1.

3.2.3.2 System Distortion

Deviation of an output signal from the command signal waveform is a measure of system distortion. Minimization of system distortion in terms of control system design requires that the gain and phase be independent of frequency over the frequency band within which the signal energy lies. As shown in Figure 3.2-10, the gain and phase characteristics achieved with the control system design are compatible with minimum system distortion. This can be seen quantitatively in Figure 3.2-11 which compares a typical command sinusoidal input waveform and the output displacement waveform.

A more qualitative comparison of system distortion can be obtained by inspection of two statistical functions: (1) the probability density function as presented in the form of a histogram and (2) power spectral density (PSD). The following data was obtained for a typical test run during the DTP. Table 3.2-2 summarizes the basic statistical properties for the sample record of piston displacement shown in Figure 3.2-12.

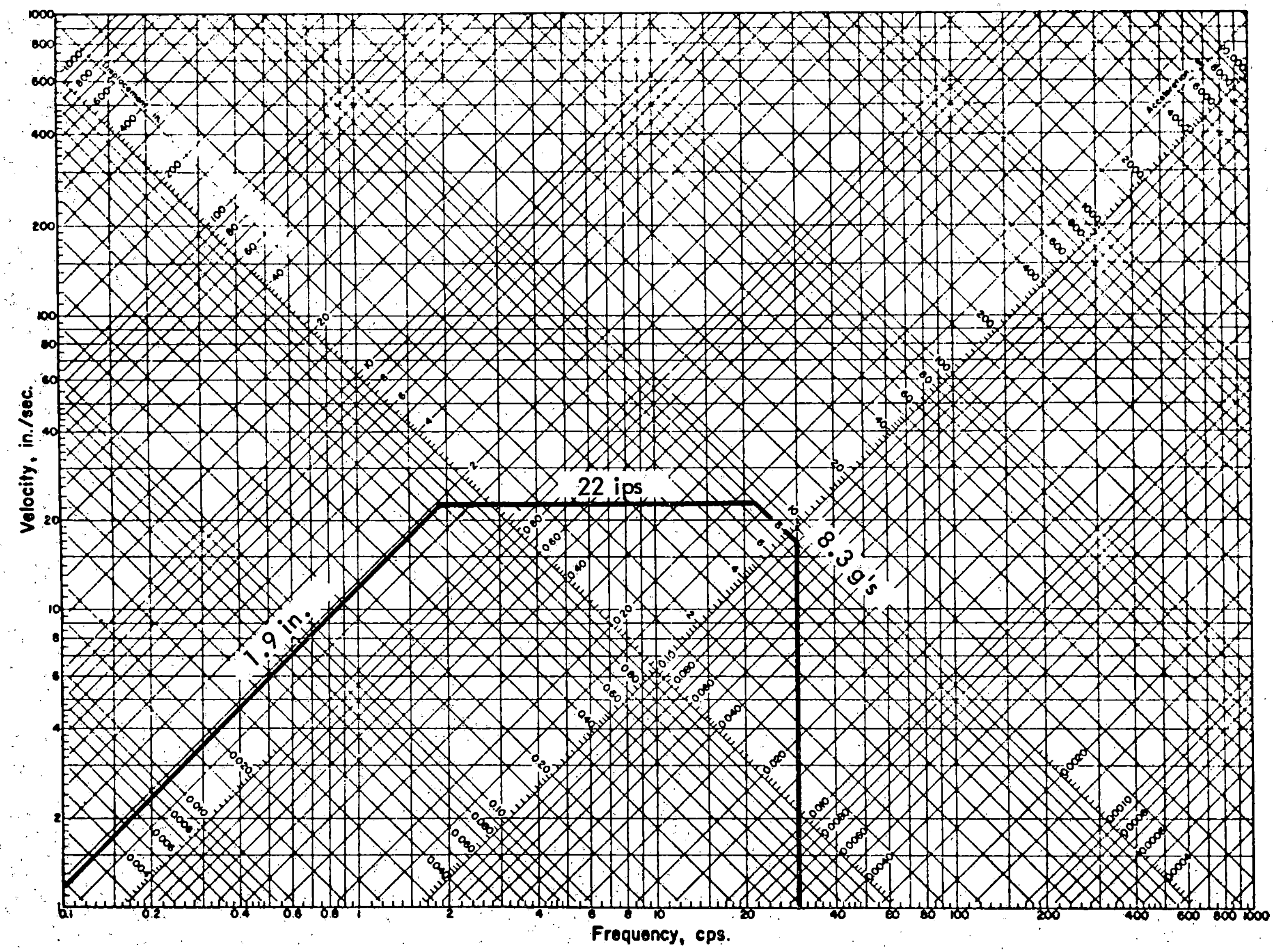
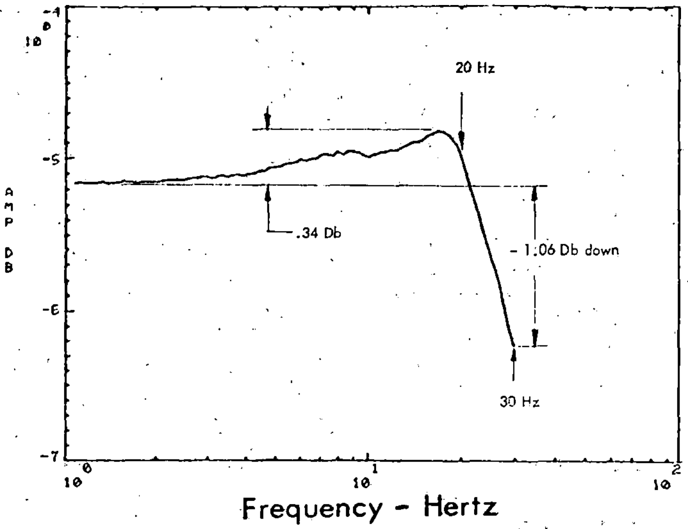
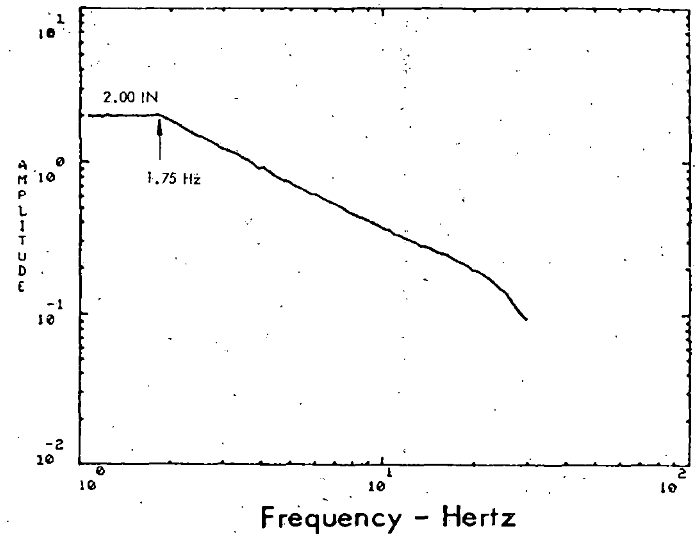


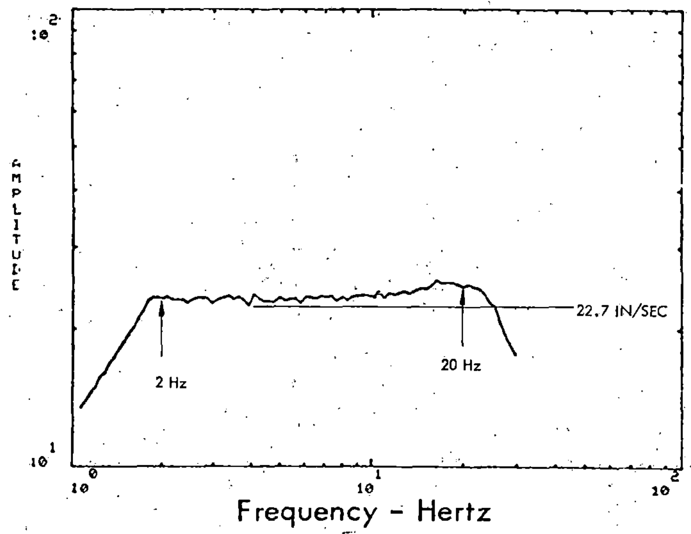
FIGURE 3.2-7 DYNAMIC MOTION CAPABILITY ENVELOPE
(Simultaneous Actuator Operation)



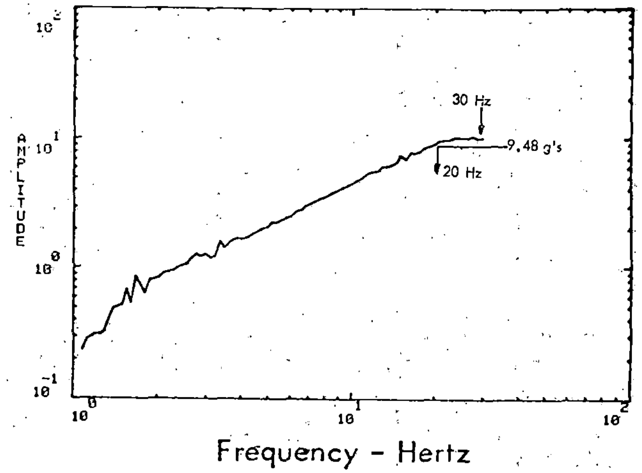
PISTON DISPLACEMENT PER DRIVE SIGNAL
(SHAKER 1)



PISTON DISPLACEMENT VS FREQUENCY
(SHAKER 1)



PISTON VELOCITY VS FREQUENCY
(SHAKER 1)



PISTON ACCELERATION VS FREQUENCY
(SHAKER 1)

FIGURE 3.2-8 TYPICAL DYNAMIC EXCITATION CAPABILITY

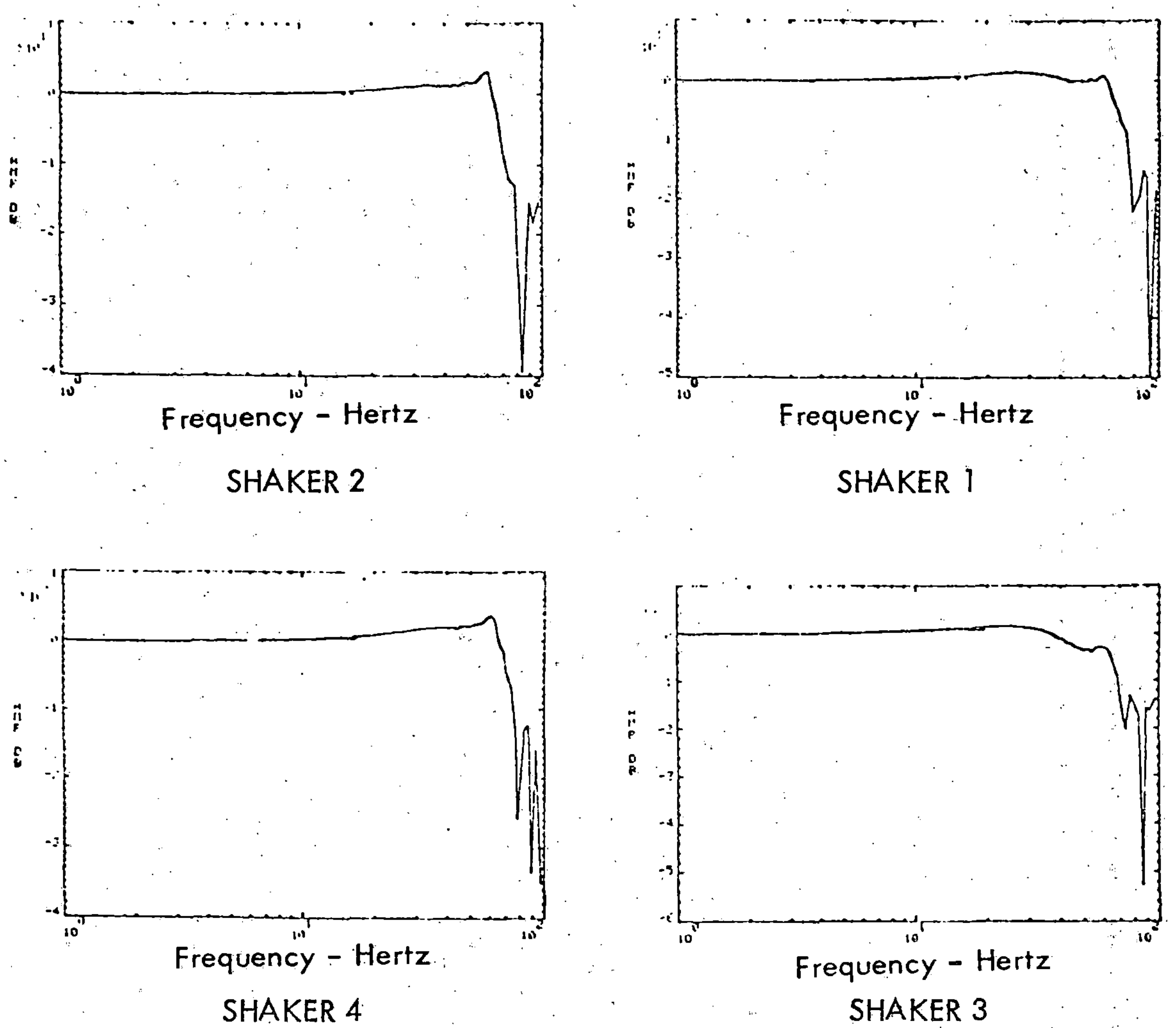


FIGURE 3.2-9 COMPARISON OF TRANSFER FUNCTIONS (20% FLOW)

NOTE: Controlled displacement equal to ± 0.5 inches.

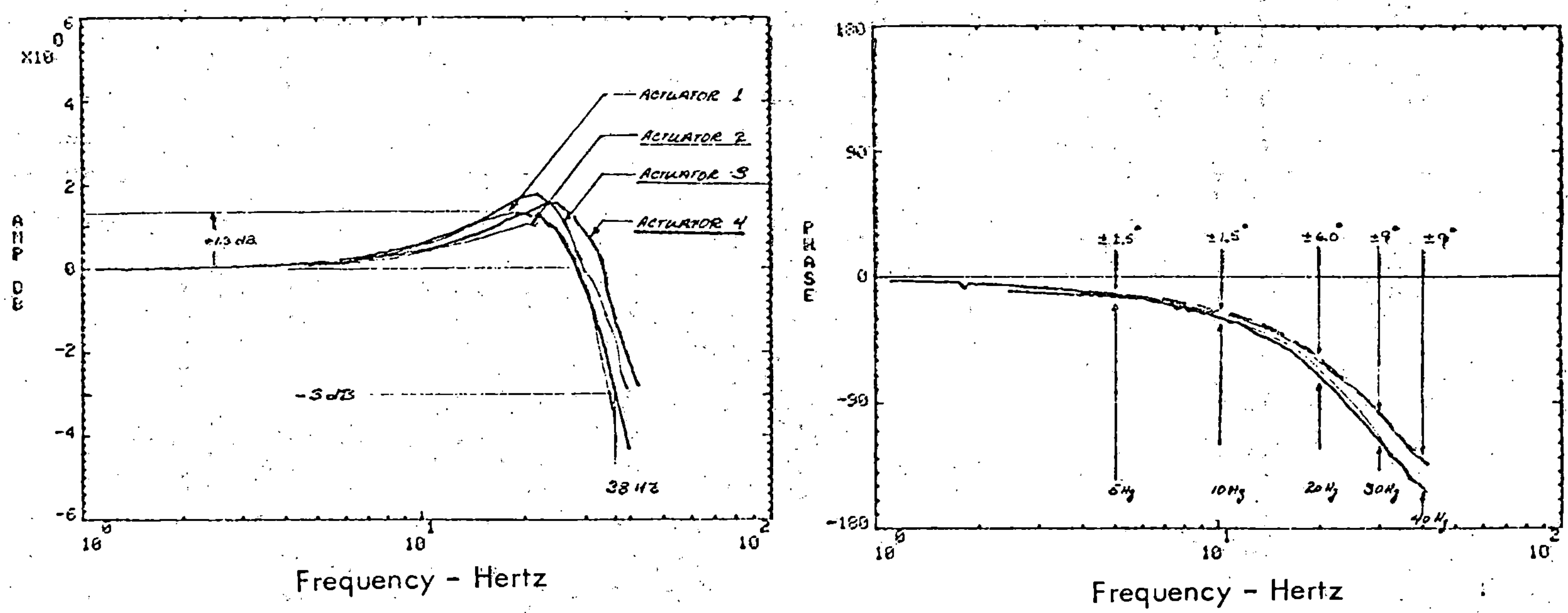


FIGURE 3.2-10 COMPARISON OF TRANSFER FUNCTIONS

TABLE 3.2-1 MEASURED ACTUATOR TF PHASE VERSUS FREQUENCY

The Loop was closed with the "Wide Bandwidth" gains.

EXCITATION FREQUENCY	CLTF PHASE* ACTUATOR 1	CLTF PHASE ACTUATOR 2	CLTF PHASE ACTUATOR 3	CLTF PHASE ACTUATOR 4	MEASURED DEVIATION ABOUT THE MEDIAN PHASE
5 Hz	-12°	-12°	-15°	-12.2°	$+1.5^\circ$
10 Hz	-29°	-27°	-28°	-26°	$+1.5^\circ$
20 Hz	-70°	-59°	-65°	-58°	$+6.0^\circ$
30 Hz	-117°	-99°	-116°	-99°	$+9^\circ$
40 Hz	-50°	-133°	-151°	-133°	$+9^\circ$

* CLTF = > Closed Loop Transfer Function

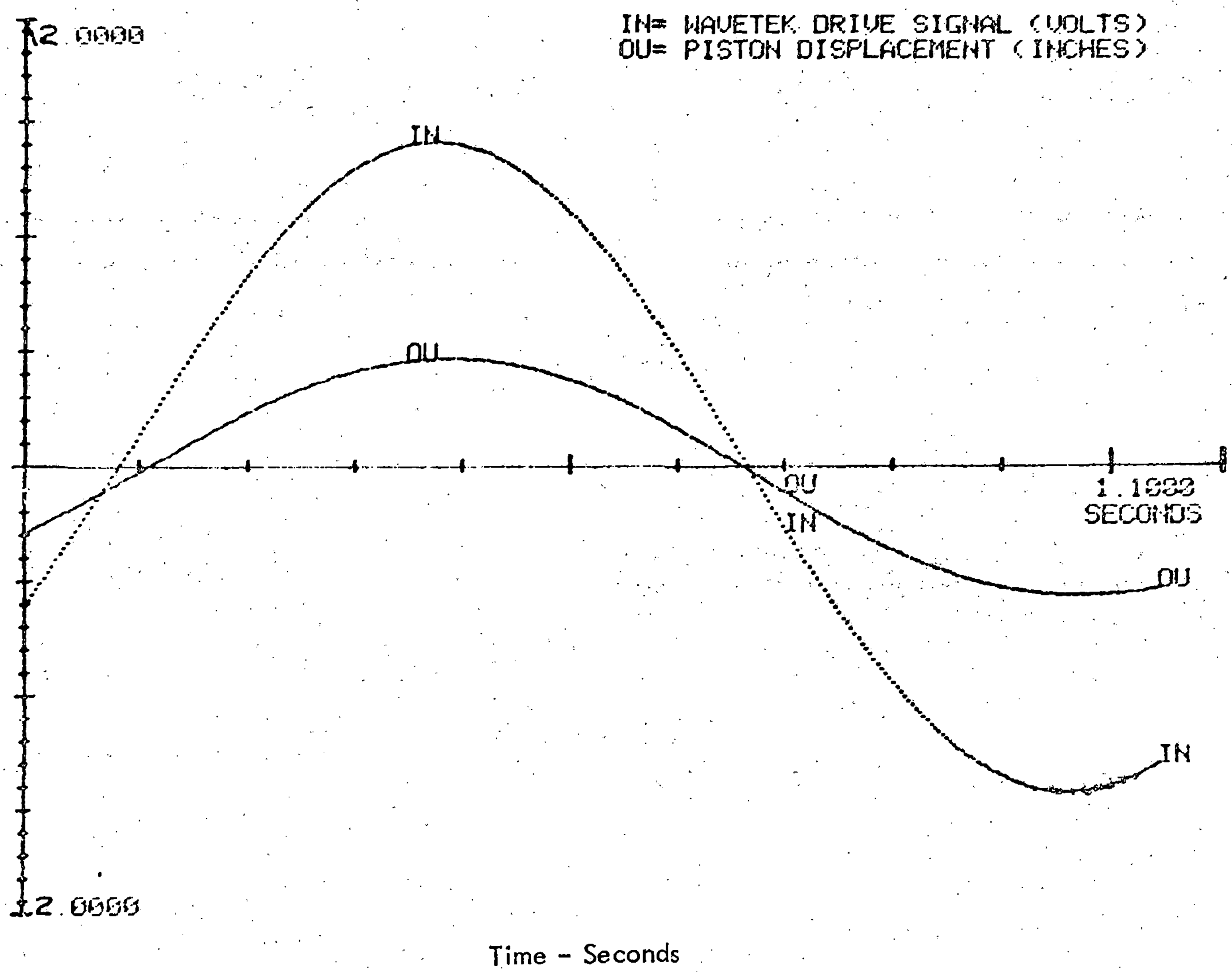


FIGURE 3.2-11 TYPICAL TIME HISTORY OF DRIVE SIGNAL VS SHAKER DISPLACEMENT

TABLE 3.2-2 VERTICAL SHAKER SYSTEM PERFORMANCE SUMMARY

ADJUSTED (NULLED) AMPLITUDE VALUES

Actuator	Minimum	Maximum
1	-.4582	.4598
2	-.4511	.4529
3	-.4596	.4615
4	-.4555	.4582

BASIC DATA

Actuator	Minimum	Maximum	Mean	Variance	Skewness	Kurtosis
1	-.4785	.4395	-.0203	.1055	-.0003	1.5091
2	-.4694	.4346	-.0183	.1029	.0027	1.4973
3	-.4517	.4694	.0079	.1057	.0046	1.4989
4	-.9828	.4309	-.0273	.1041	.0049	1.5004

NOTE: DATA WAS ACQUIRED AT 363 SAMPLES/SECOND, THE ABOVE RESULTS ARE FROM THE ANALYSIS OF APPROXIMATELY 1.5 SEC OF DATA

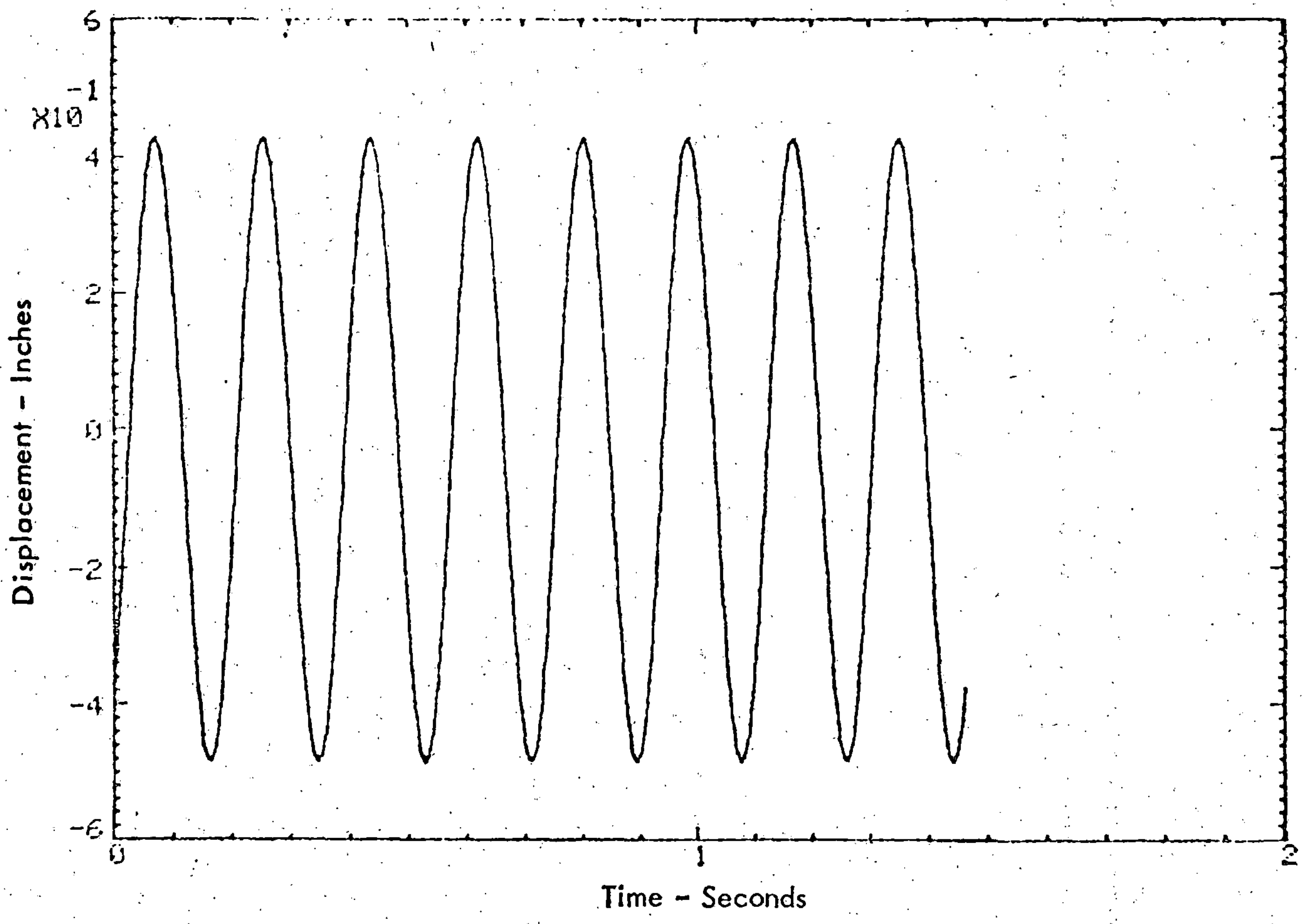


FIGURE 3.2-12 ACTUATOR 4 - PISTON DISPLACEMENT RAW DATA (5.467 Hz)

The probability density function can be used to distinguish between sinusoidal and random data. For a pure sinusoid, this function appears as a sharp edged, dish-shaped curve with a Kurtosis of 1.50. A typical histogram for actuator displacement is shown in Figure 3.2-13. As can be seen, the piston displacement histogram very nearly resembles that for a pure sinusoid indicating negligible distortion. The frequency composition of the piston displacement signal can be determined from it's PSD as shown in Figure 3.2-14. Only the fundamental drive signal appears at 5.5 Hz with no other measurable frequency components and therefore no distortion.

A statistical evaluation of the piston acceleration as shown in Figure 3.2-15 was also obtained from the same data as above. Since the shakers are displacement controlled rather than acceleration controlled, the piston accelerometer output is not as clean as the piston displacement signal. In addition, the piston accelerometers are sensitive to a 1200 Hz dither signal superimposed onto the servo-valve drive signals. The affects of this dither signal are discussed in the following paragraph.

The piston acceleration PSD is shown in Figure 3.2-16. As with the piston displacement PSD, the fundamental drive signal is quite apparent at 5.5 Hz. Up until 60 Hz which is well past the 30 Hz frequency range of basic interest, other apparent frequency components are at least two orders of magnitude less than the drive frequency. At 60 Hz, the lightly damped piston resonance shows up; however, it is still an order of magnitude less than the drive signal. Beyond 60 Hz, the most pronounced frequency component occurs at approximately 135 Hz. This component is attributed to aliasing of the servo-valve dither signal which is set nominally at 1200 Hz.

Aliasing or frequency folding occurs when a signal is sampled with fewer than two points per wavelength. Since the above data was sampled at a rate of 363 samples per second with no cut-off filter, the 1200 Hz servo-valve dither signal will cause

CHAN	MINIMUM	MAXIMUM	MEAN	VARIANCE	SKEWNESS	KURTOSIS
33	-.4828	.4309	-.0273	.1041	.0049	1.5004

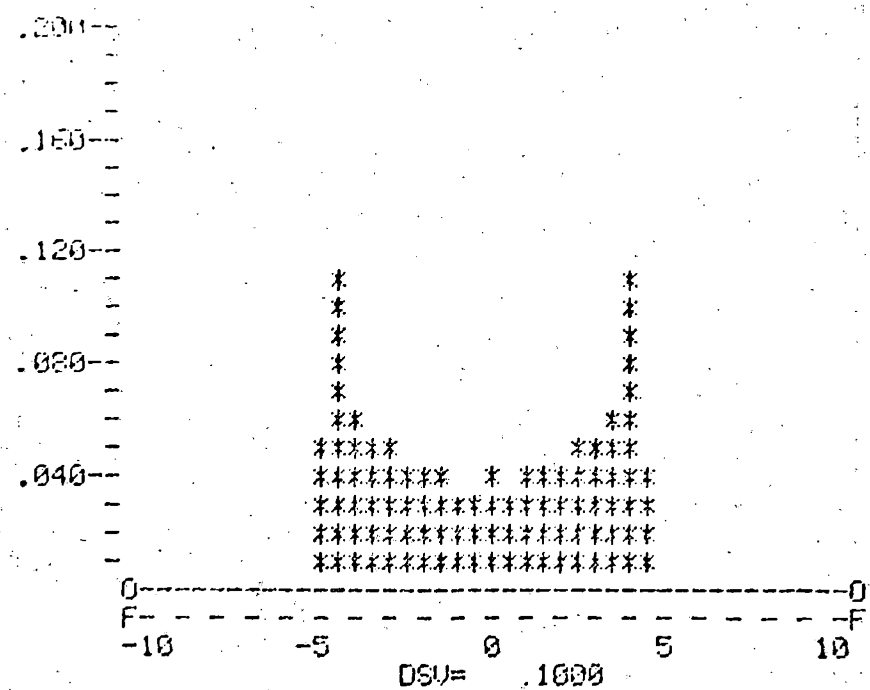


FIGURE 3.2-13 ACTUATOR 4 - PISTON DISPLACEMENT HISTOGRAM

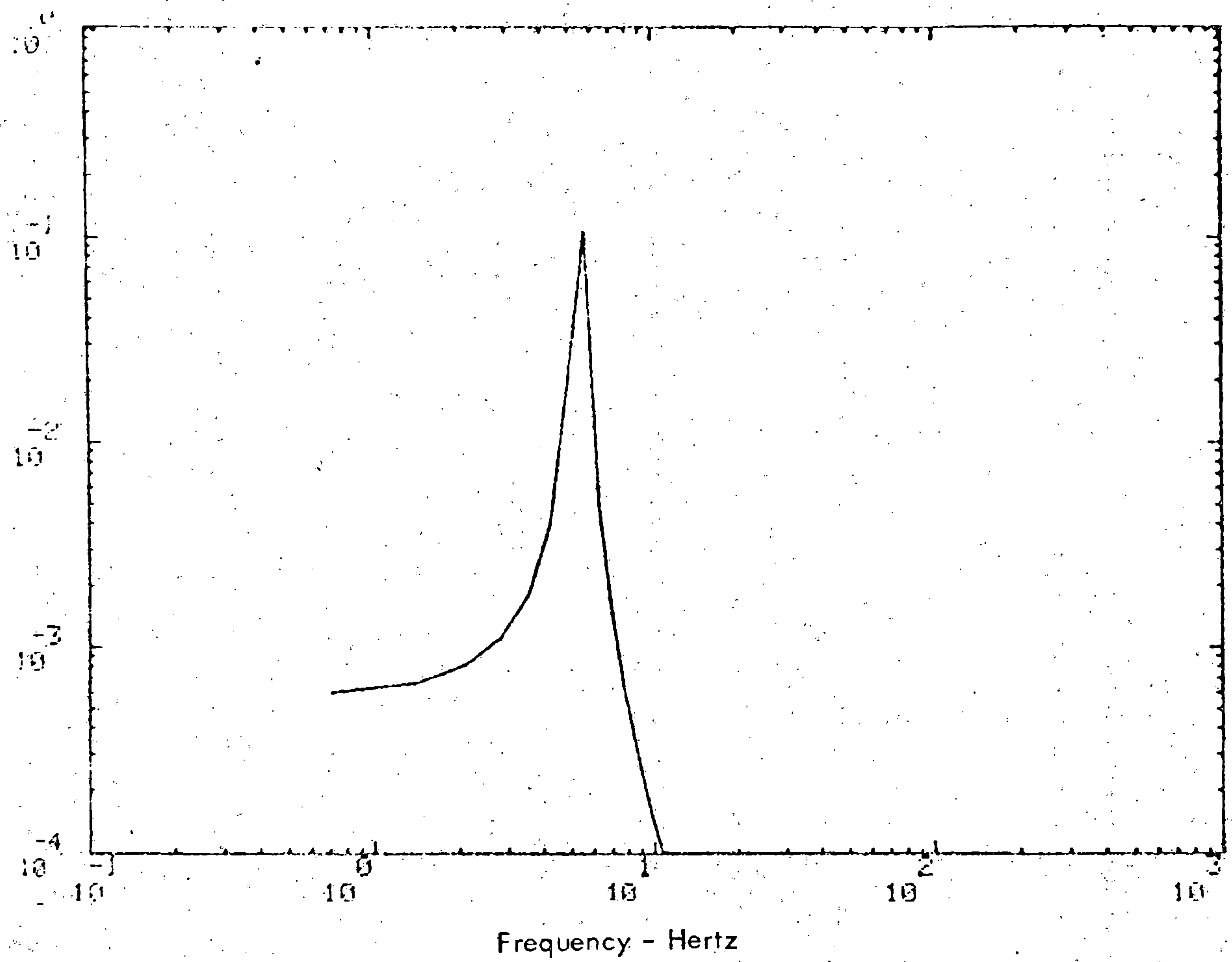


FIGURE 3.2-14 ACTUATOR 4 – PISTON DISPLACEMENT POWER SPECTRAL DENSITY

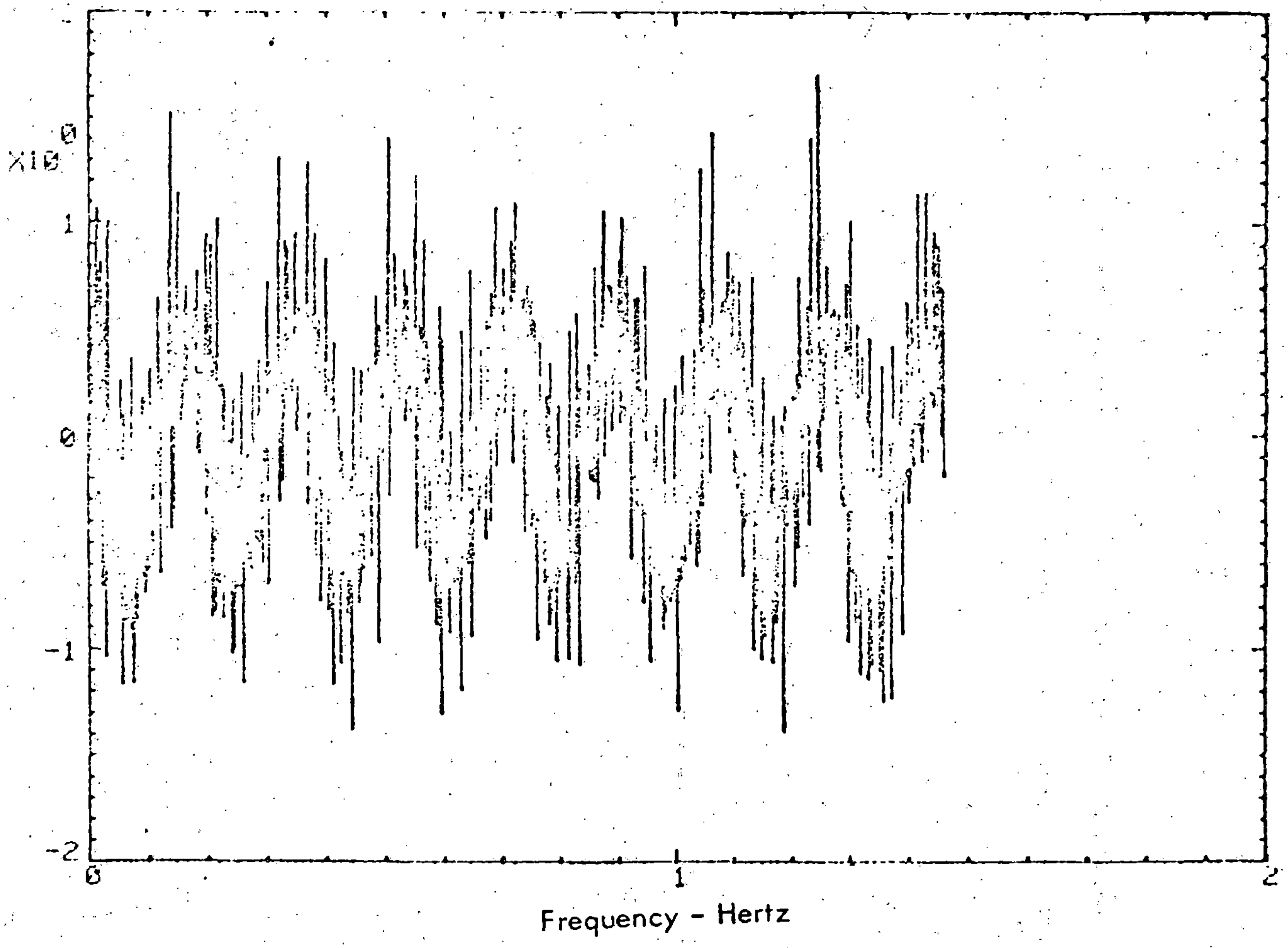


FIGURE 3.2-15 ACTUATOR 4 - PISTON ACCELERATION RAW DATA

aliasing problems. For a sampling interval h of (1/363) seconds, the folding frequency or cut-off frequency is:

$$f_c = \frac{1}{2h} = 181.5 \text{ Hz}$$

Then for $0 \leq f \leq f_c$, the frequencies above f_c which will be aliased with f are:

$$(2 f_c \pm f), (4 f_c \pm f) \ldots (2nf_c \pm f)$$

If the dither signal were set exactly at 1200 Hz, a strong frequency component would be expected at 111 Hz. In Figure 3.2-16, a strong accelerometer dither component occurs at approximately 135 Hz. This corresponds to a dither signal of 1224 Hz. Since the calculated dither signal is within 2 percent of the expected servo-valve dither, the strong frequency component at 135 Hz can be attributed to valve dither. Likewise the intermediate frequency component at approximately 83 Hz is most likely caused by aliasing of the pilot-slave valve resonance expected between 600 and 700 Hz.

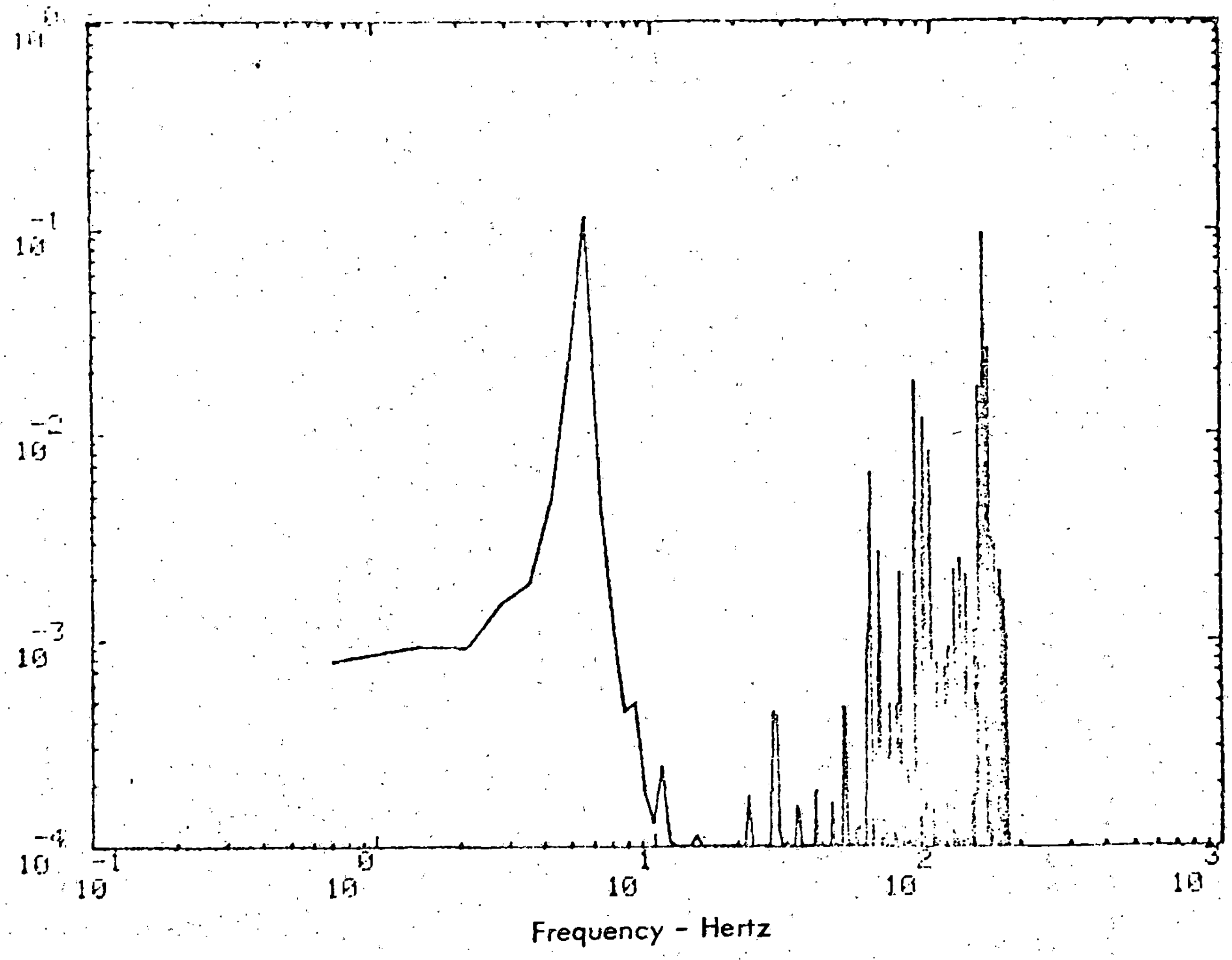
3.2.3.3 Shaker Cross-Coupling

During the DTP, a test was conducted for the purpose of evaluating actuator cross-coupling effects. This test was performed with configuration 2. Cross-coupling data was obtained by exciting two shakers while simultaneously commanding the other two to remain at null. Shaker cross-coupling is then proportional to the transfer function between the input displacement and the response at the null position.

The following command profile was used to drive shakers 1 and 2:

- Displacement: 0.2 in. from 1 to 4.8 Hz
- Velocity: 6 ips from 4.8 to 15 Hz
- Acceleration: 1.5 g's from 15 to 30 Hz

The achieved response for shakers 1 and 2 is shown in Figure 3.2-17,



NOTE: SAMPLING RATE WAS 363 SAMPLES/SECOND. ACCELEROMETER DITHER AT 1200 HZ WILL THUS ALIAS BACK INTO THE LOWER SPECTRUM.

FIGURE 3.2-16 ACTUATOR 4 - PISTON ACCELERATION POWER SPECTRAL DENSITY

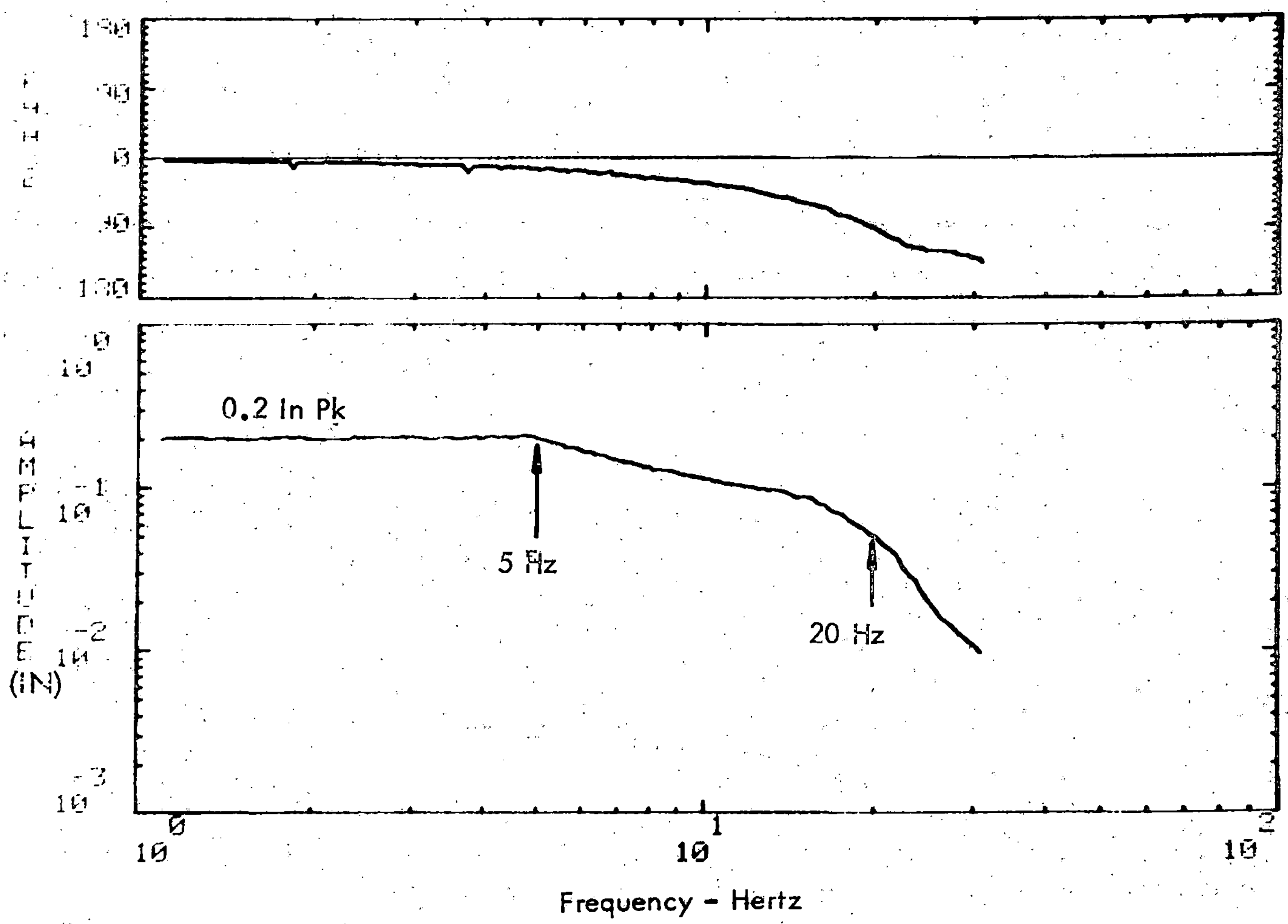


FIGURE 3.2-17 ACHIEVED RESPONSE OF ACTUATORS 1 AND 2

Shaker cross-coupling was evaluated in terms of the overall stiffness with which the undriven shakers were able to maintain while being commanded to null. The inverse of this stiffness is a measure of the external force cross-coupling coefficient. Shaker stiffness was calculated as shown below:

$$K = \frac{\lfloor (\text{piston } \Delta P)(\text{piston area}) \rfloor + \lfloor (\text{effective mass})(\text{piston acceleration}) \rfloor}{\text{piston displacement}} \ \frac{lb}{in.}$$

Piston displacements for the undriven shakers 3 and 4 are shown in Figures 3.2-18 and 3.2-19. The maximum piston displacement resulting from the external cross-coupling forces is .001 inch. The calculated shaker stiffness is shown in Figures 3.2-20 and 3.2-21. The minimum stiffness based upon these calculations is approximately 2.63×10^6 lb_f/in. The calculated hydraulic oil column stiffness based upon a measured bulk modulus of 131,783 psi is 1.79×10^6 lb/in. Since the maintained shaker stiffness exceeds the oil column stiffness, the cross-coupling effects are minimal.

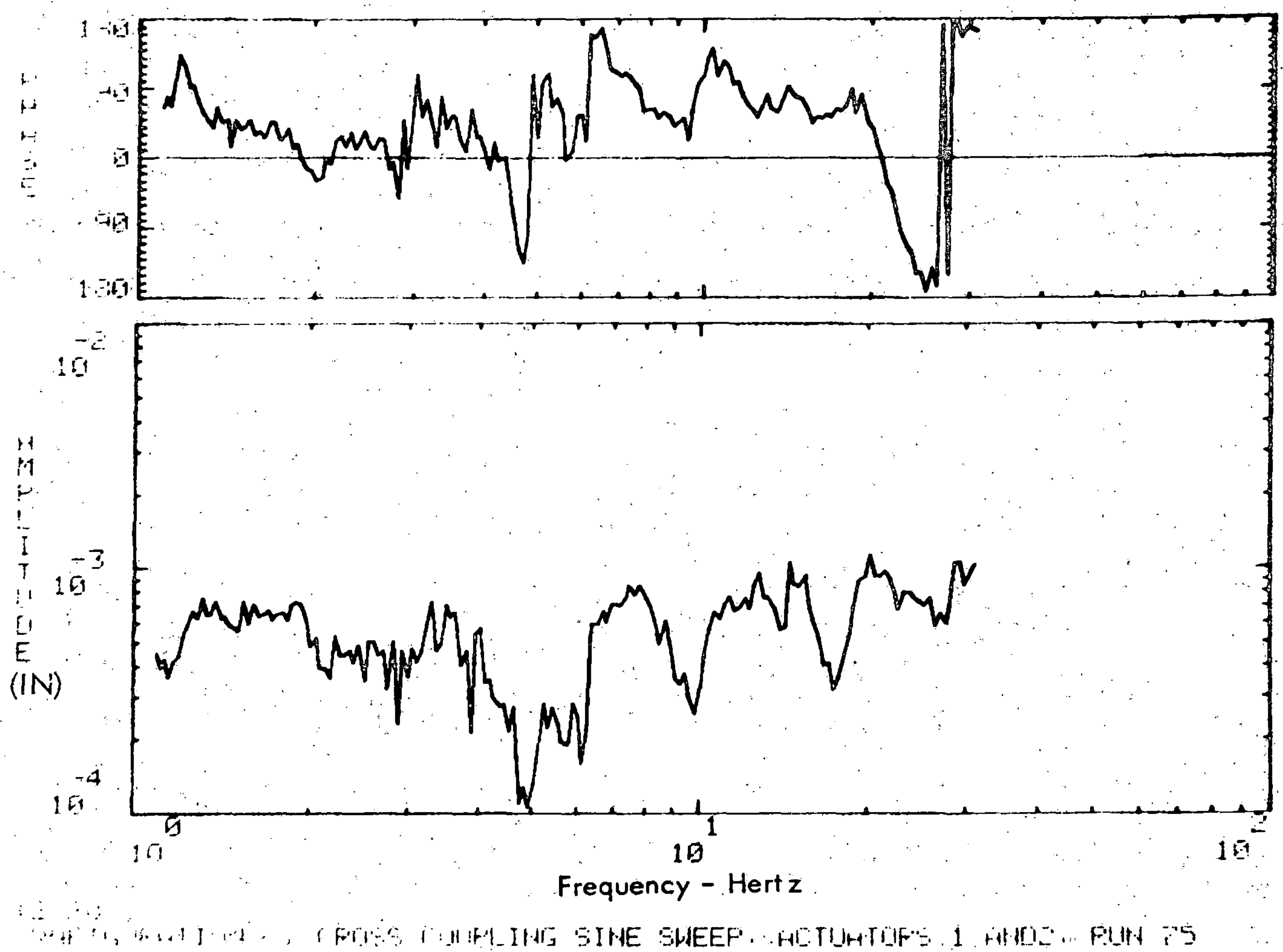
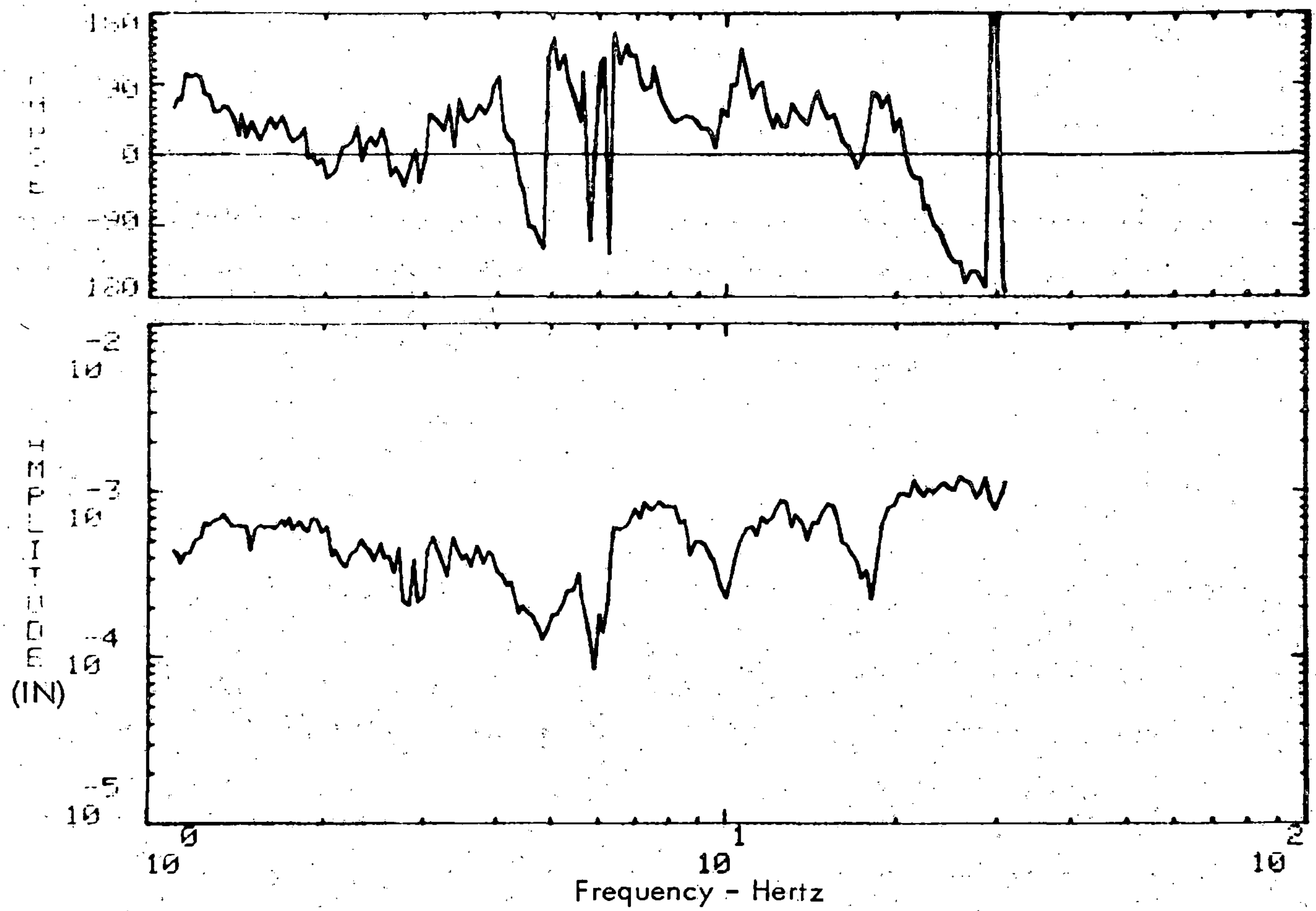


FIGURE 3.2-18 PISTON DISPLACEMENT FOR ACTUATOR 3



12/30/75
CONFIGURATION 2, CROSS COUPLING SINE SWEEP, ACTUATORS 1 AND2, RUN 75

FIGURE 3.2-19 PISTON DISPLACEMENT FOR ACTUATOR 4

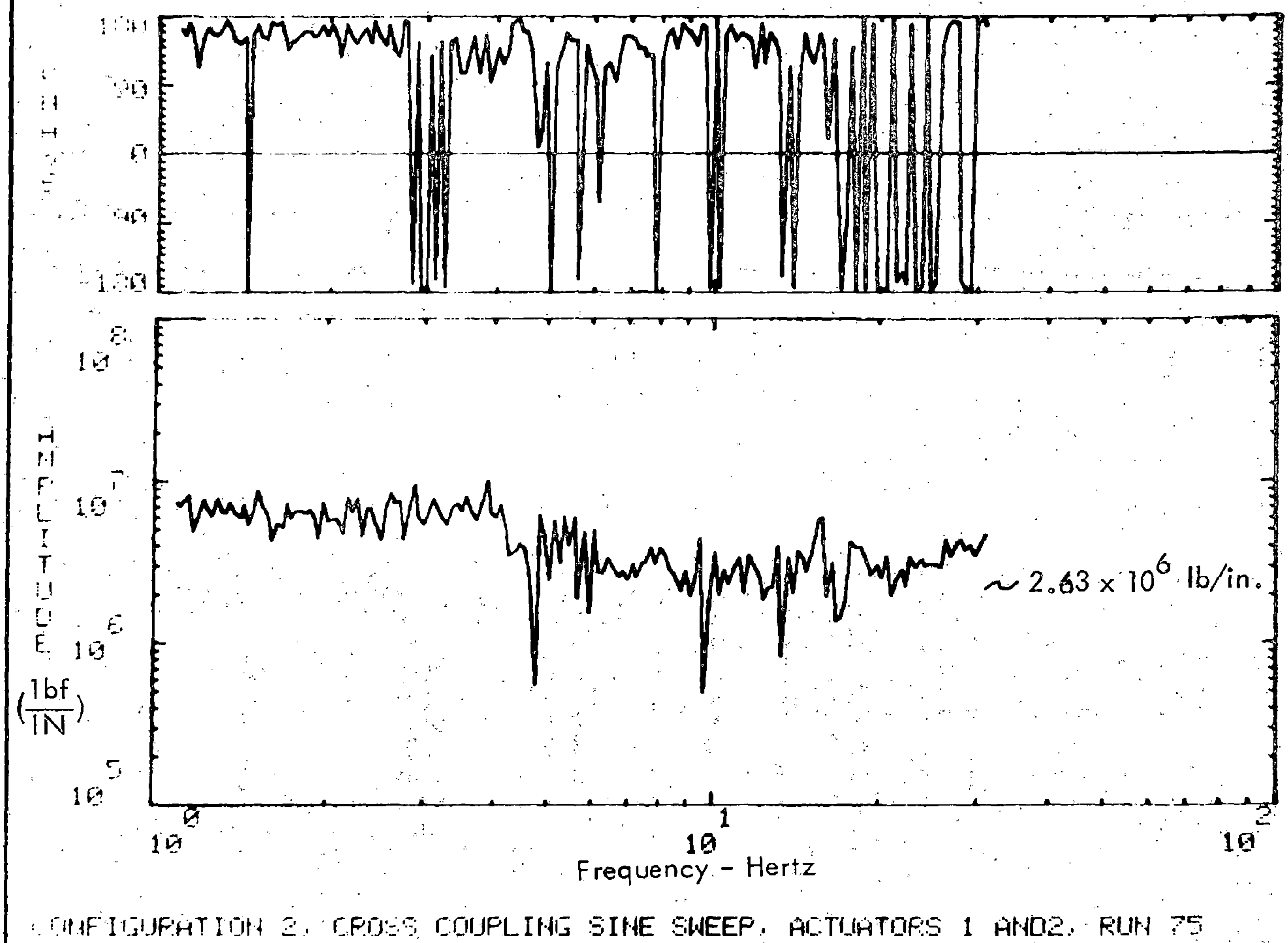
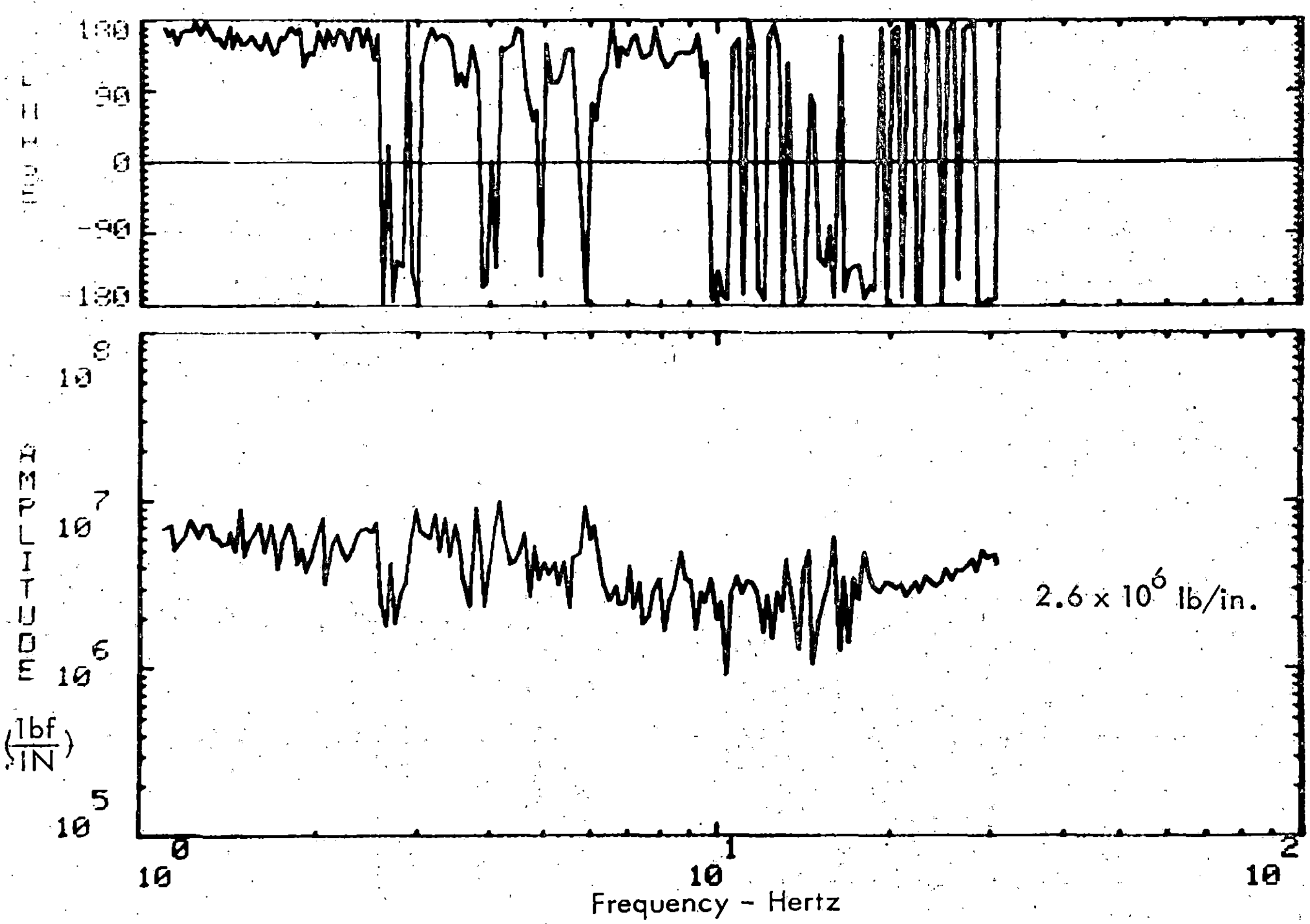


FIGURE 3.2-20 CONTROLLED ACTUATOR STIFFNESS FOR ACTUATOR 3



CONFIGURATION 2, CROSS COUPLING SINE SWEEP, ACTUATORS 1 AND2, RUN 75

FIGURE 3.2-21 CONTROLLED ACTUATOR STIFFNESS FOR ACTUATOR 4

3.3 INSTRUMENTATION

3.3.1 Requirements

Instrumentation was installed on the TOFC test specimen to measure acceleration, displacement, angular acceleration, strain, and force. The instrumentation was divided into three groups. The first group was VSS control instrumentation installed on the shakers for input control and monitoring functions. The second group was Ensco instrumentation which was installed on the specimen for the FRA TOFC program to follow the DTP. The third group was Wyle instrumentation installed on the test specimen to obtain additional data for use in analytical model verification. The run log in Appendix C contains a written description of those changes made to the instrumentation during the course of the test.

3.3.2 Description

A written description of the VSS control, Wyle and Ensco instrumentation is contained in Tables 3.3-1, 3.3-2, and 3.3-3 respectively. These tables include the measurement number, location/description, type, and range setting of all the transducers used on the DTP. The as tested instrumentation locations are illustrated in Figures 3.3-1 through 3.3-5. Figure 3.3-1 shows the instrumentation on the B-end truck which was driven by the shakers. Figures 3.3-6 through 3.3-8 are photographs of typical instrumentation locations on the trucks. Typical LVDT installations are shown in Figures 3.3-6 and 3.3-7. A typical accelerometer installation on the trucks is shown in Figure 3.3-8. The instrumentation locations on the A-end are shown in Figure 3.3-2. The instrumentation on the flatcar trucks was unchanged for all three configurations tested. The instrumentation on the flatcar and trailers varied depending on the configuration being tested. The instrumentation drawings for each of these configurations are shown in Figures 3.3-3 through 3.3-5. A photograph of typical instrumentation installations on the flatcar deck is shown in Figure 3.3-9. The strain gauge installations are shown in Figure 3.3-10 and the trailer tire force measurements installations are shown in Figure 3.1-5. All the accelerometers on the

TABLE 3.3-1 CONTROLS INSTRUMENTATION

MEASUREMENT NUMBER/ A-D INPUT	TYPE	LOCATION/DESCRIPTION	AXIS	RANGE
1	Pressure	CH 1/Piston ΔP		5000 psi
2	Pressure	CH 1/System ΔP		5000 psi
3	LVDT	CH 1/Piston LVDT	Vert	3-1/2 inches
4	LVDT	CH 1/Slave LVDT	Vert	1/6 inch
5		CH 1/WAVETEK		10 volts
6		CH 1/Crown Input		10 volts
7		CH 1/Rate Coil (Not hooked up)		10 volts
8	Accel	CH 1/Piston Accel	Vert	10 g's
9		CH 1/Control Input Sig		10 volts
10	Pressure	CH 1/Bias Pressure		5000 psi
11	Pressure	CH 2/Piston Δ P		5000 psi
12	Pressure	CH 2/System ΔP		5000 psi
13	LVDT	CH 2/Piston LVDT	Vert	3-1/2 inches
14	LVDT	CH 2/Slave LVDT	Vert	1/6 inch
15		CH 2/WAVETEK		10 volts
16		CH 2/Crown Input		10 volts
17		CH 2/Rate Coil (Not hooked up)		10 volts
18	Accel	CH 2/Piston Accel	Vert	10 g's
19		CH 2/Control Input Sig		10 volts
20	Pressure	CH 2/Bias Pressure		5000 psi
21	Pressure	CH 3/Piston Δ P		5000 psi
22	Pressure	CH 3/System Δ P		5000 psi
23	LVDT	CH 3/Piston LVDT	Vert	3-1/2 inches
24	LVDT	CH 3/Slave LVDT	Vert	1/6 inch
25		CH 3/WAVETEK		10 volts
26		CH 3/Crown Input		10 volts
27		CH 3/Rate Coil (Not hooked up)		10 volts
28	Accel	CH 3/Piston Accel	Vert	10 g's
29		CH 3/Control Input Sig		10 volts
30	Pressure	CH 3/Bias Pressure		5000 psi
31	Pressure	CH 4/Piston Δ P		5000 psi
32	Pressure	CH 4/System Δ P		5000 psi
33	LVDT	CH 4/Piston LVDT	Vert	3-1/3 inches
34	LVDT	CH 4/Slave LVDT	Vert	1/6 inch
35		CH 4/WAVETEK		10 volts
36		CH 4/Crown Input		10 volts
37		CH 4/Rate Coil (Not hooked up)		10 volts
38	Accel	CH 4/Piston Accel (Not hooked up)	Vert	10 g's
39		CH 4/Control Input Sig		10 volts
40	Pressure	CH 4/Bias Pressure		5000 psi
41		Log Conv In		
42		Log Conv Out to VCG		
43		CH 1X - Input (D/A)		
44		CH 2X - Input (D/A)		
45		CH 3X - Input (D/A)		
46		CH 4X - Input (D/A)		
47		Wavetek VCA		

TABLE 3.3-2 WYLE INSTRUMENTATION

A/D INPUT CHANNEL NO	TYPE	LOCATION/DESCRIPTION	AXIS	RANGE	TRANSDUCER
50	Strain gage	Center sill, sta 669		2000 microin/in	
51	Strain gage	Center sill, sta. 536, right		2000 microin/in	
52	Strain gage	Center sill, sta. 536, left		2000 microin/in	
53	Accel	B-end Stanchion	Long	± 5 G	CQ 55
101	Ang Accel	B-end Truck/King Pin, Flatcar	Yaw	± 100 rad/sec^2	
102	Ang Accel	B-end Truck/Bolster Center	Roll	± 100 rad/sec^2	
103	Ang Accel	Flatcar/Centerline-Sta. 690	Yaw	± 100 rad/sec^2	
104	LVDT	B-end Truck/Truck Springs, left	Vert.	±3 in.	
105		Drive Signal		± 10 volts	
106	LVDT	B-end Truck/Truck Spring, right	Vert.	± 3 in.	
107	Accel	B-end stanchion	Later.	± 5 G	CP 37
108	Switch	Wheel liftoff		± 1/4 in.	
109	LVDT	B-end Truck/Bolster-Car Body	Vert.	±3 in.	
110		Spare			
111	Accel	B-end Truck/Center Side Frame	Later.	±5 G	CQ 72
112	Accel	B-end Truck/Center Side Frame	Long.	± 5 G	CP 71
113	Accel	B-end Truck/Center Side Frame, left	Vert.	±5 G	CQ 43
114	Accel	B-end Truck/Center Side Frame, left	Later.	± 5 G	CR 01
115	Accel	Flatcar/Edge-B-End	Later.	±5 G	CQ 50
116	Accel	Flatcar/Centerline-Sta. 690	Later.	±5 G	CQ 06
117	Accel	Flatcar/Centerline-Sta. 690	Vert.	± 5 G	CQ 30
118	Accel	Flatcar/Outboard, Mid-span	Vert.	±5 G	CQ 40
119	Accel	Flatbed Trailer/Kingpin, Trailer	Later.	±5 G	CR 10
120	Accel	Van Trailer/Kingpin, Trailer	Later.	± 5 G	CP 39
121	Ang Accel	Van Trailer Center	Yaw	±100rad/sec^2	
122	Accel	B-end Truck/Center Side Frame	Vert.	±10 G	CQ 48
123	Accel	Flatcar/Edge-B-End	Vert.	±10 G	CQ 65
124	Accel	Flatbed Trailer/Kingpin, Trailer	Vert.	±10 G	CQ 72
125	Accel	B-end Stanchion	Vert.	±10 G	CQ 38
126	Accel	Flatbed Trailer/Suspension	Vert.	±10 G	CQ 82
127	Accel	Van Trailer/Kingpin, Trailer	Vert.	±10 G	CP 56
128	Accel	Van Trailer/Suspension	Vert.	±10 G	CQ 56

TABLE 3.3-3 ENSCO INSTRUMENTATION

Measurement No.	CABLE	LOCATION/DESCRIPTION	AXIS	RANGE	A/D CHANNEL
57	5	B-End Bolster Left	Vert	± 5 G	57
58	6	B-End Bolster Left	Long.	± 5 G	58
59	9	B-End Bolster Right	Vert.	± 5 G	59
60	10	B-End Bolster Right	Later.	±5 G	60
61	7	B-End Axial Left	Vert.	±50 G	61
62	11	B-End Axial Right	Vert.	±50 G	62
63	8	B-End Axial Left	Later.	± 20 G	63
64	12	B-End Axial Right	Later.	±20 G	64
65	19	Flatcar Body B-End Left	Vert.	±5 G	65
66	20	Flatcar Body B-End Center	Vert.	± 5 G	66
67	21	Flatcar Body B-End Center	Long.	± 5 G	67
68	23	Flatcar Body B-End Right	Vert.	±5 G	68
69	24	Flatcar Body B-End Right	Later.	± 5 G	69
70	44	Van Trailer Right Rear	Vert.	± 5 G	70
71	45	Van Trailer Right Rear	Later.	± 5 G	71
72	46	Van Trailer Front Center	Vert.	± 5 G	72
73	47	Van Trailer Front Center	Later.	± 5 G	73
74	48	Van Trailer Front Center	Long.	± 5 G	74
75	49	Van Trailer Left Rear	Vert.	± 5 G	75
76		Not used			76
77	1	A-End Bolster Left	Vert.	± 5 G	77
78	2	A-End Bolster Left	Later.	± 5 G	78
79	13	A-End Bolster Right	Vert.	± 5 G	79
80	14	A-End Bolster Right	Long.	± 5 G	80
81	3	Van Trailer Center	Vert.	± 5 G	81

TABLE 3.3-3 ENSCO INSTRUMENTATION

Measurement No.	CABLE	LOCATION/DESCRIPTION
82	15	A-End Axial Right
83	4	A-End Axial Left
84	16	A-End Axial Right
85	17	Flatcar Body A-End Left
86	18	Flatcar Body A-End Left
87	25	Flatcar Body A-End Right
88	27	Flatcar Body A-End Center
89	28	Flatcar Body Center
90	33	Platform Trailer Right Rear
91	34	Platform Trailer Right Rear
92	35	Platform Trailer Front Center
93	36	Platform Trailer Front Center
94	37	Platform Trailer Front Center
95	38	Platform Trailer Left Rear
96	39	Platform Trailer Center
97	30	Van Tire Pressure (right)
98	31	Van Tire Pressure (left)
99	29	Platform Tire Pressure (Right)
100	32	Platform Tire Pressure (Left)

(Continued)

AXIS	RANGE	A/D CHANNEL
Vert.	±50 G	82
Later.	± 20 G	83
Later.	± 20 G	84
Vert.	±5 G	85
Later.	± 5 G	86
Vert.	± 5 G	87
Vert.	± 5 G	88
Vert.	± 5 G	89
Vert.	±5 G	90
Later.	±5 G	91
Vert.	±5 G	92
Later.	± 5 G	93
Long.	± 5 G	94
Vert.	± 5 G	95
Vert.	± 5 G	96
Vert.	40,000 lbs	97
Vert.	40,000 lbs	98
Vert.	40,000 lbs	99
Vert.	40,000 lbs	100

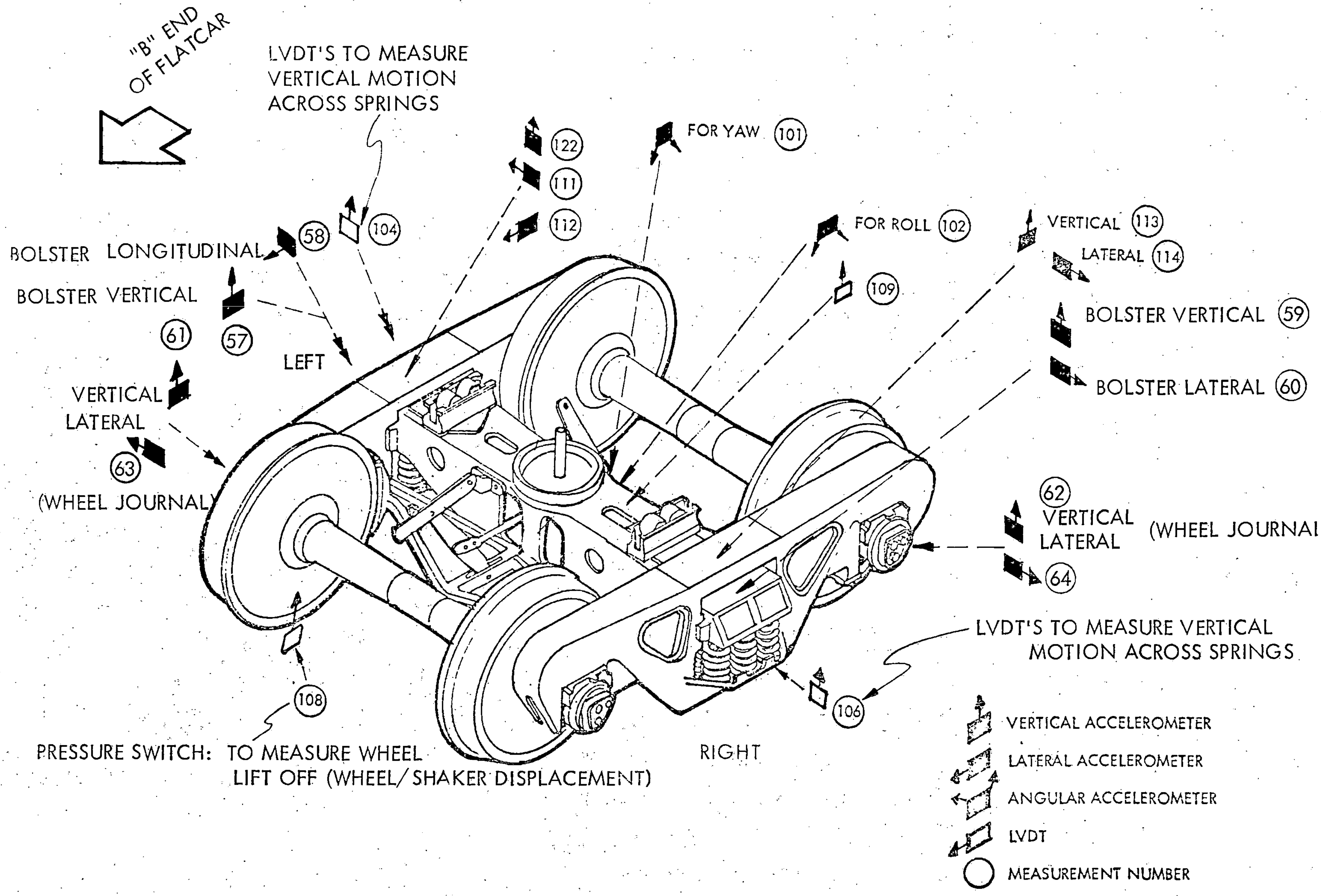


FIGURE 3.3-1 INSTRUMENTATION LOCATIONS B-END TRUCK

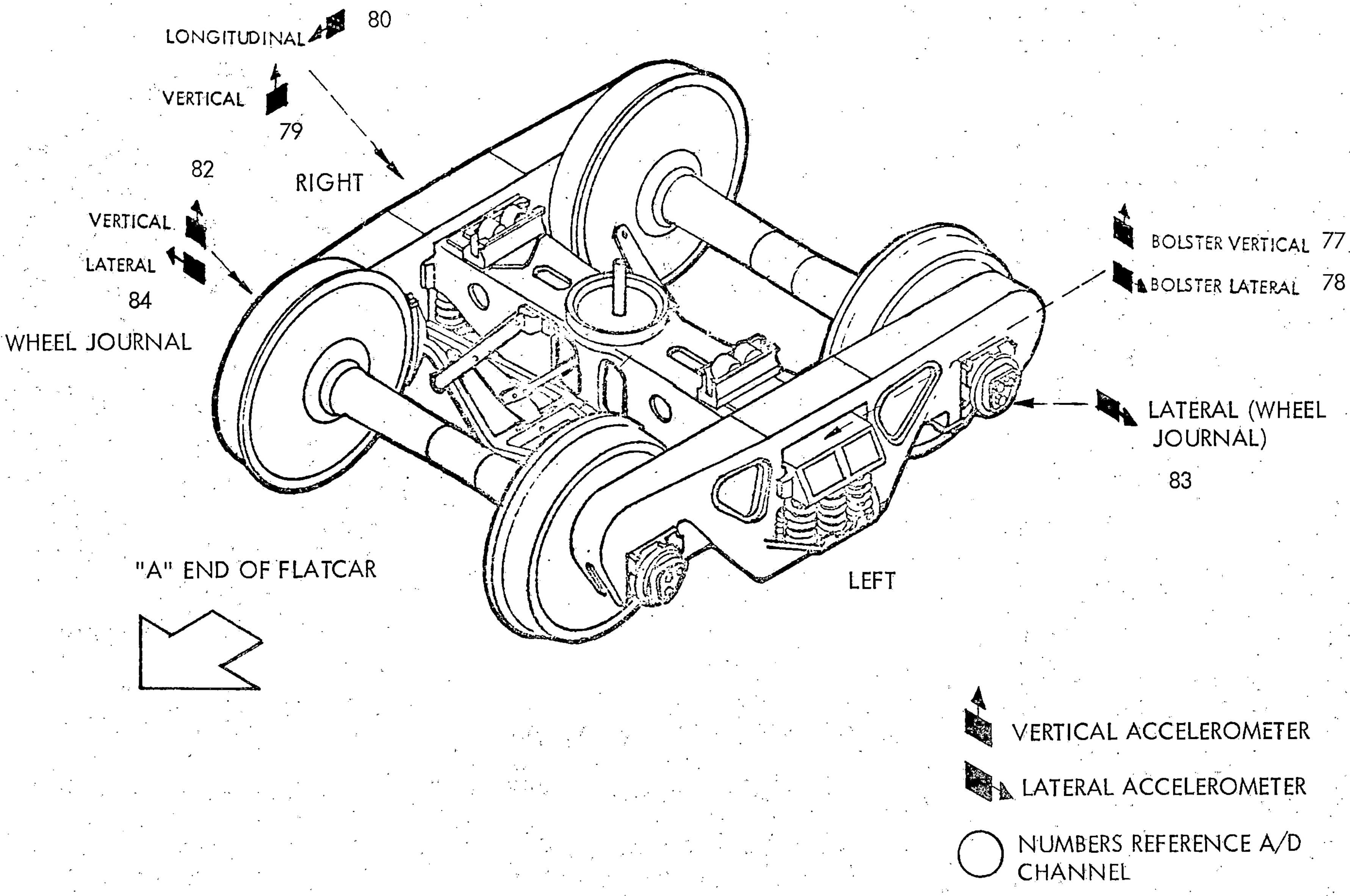


FIGURE 3.3-2 INSTRUMENTATION LOCATION A-END TRUCK

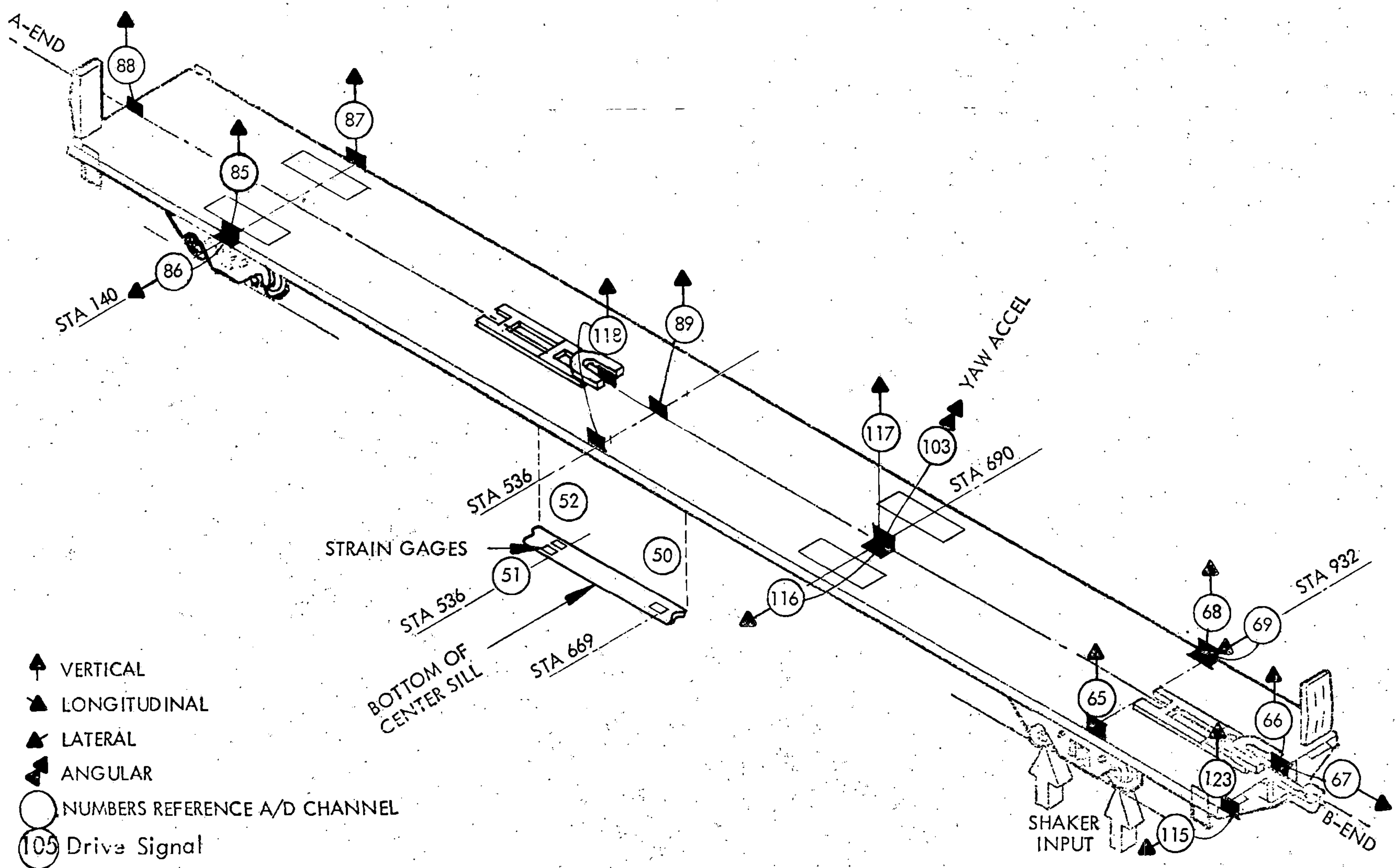


FIGURE 3.3-3 INSTRUMENTATION LOCATIONS - CONFIGURATION 1

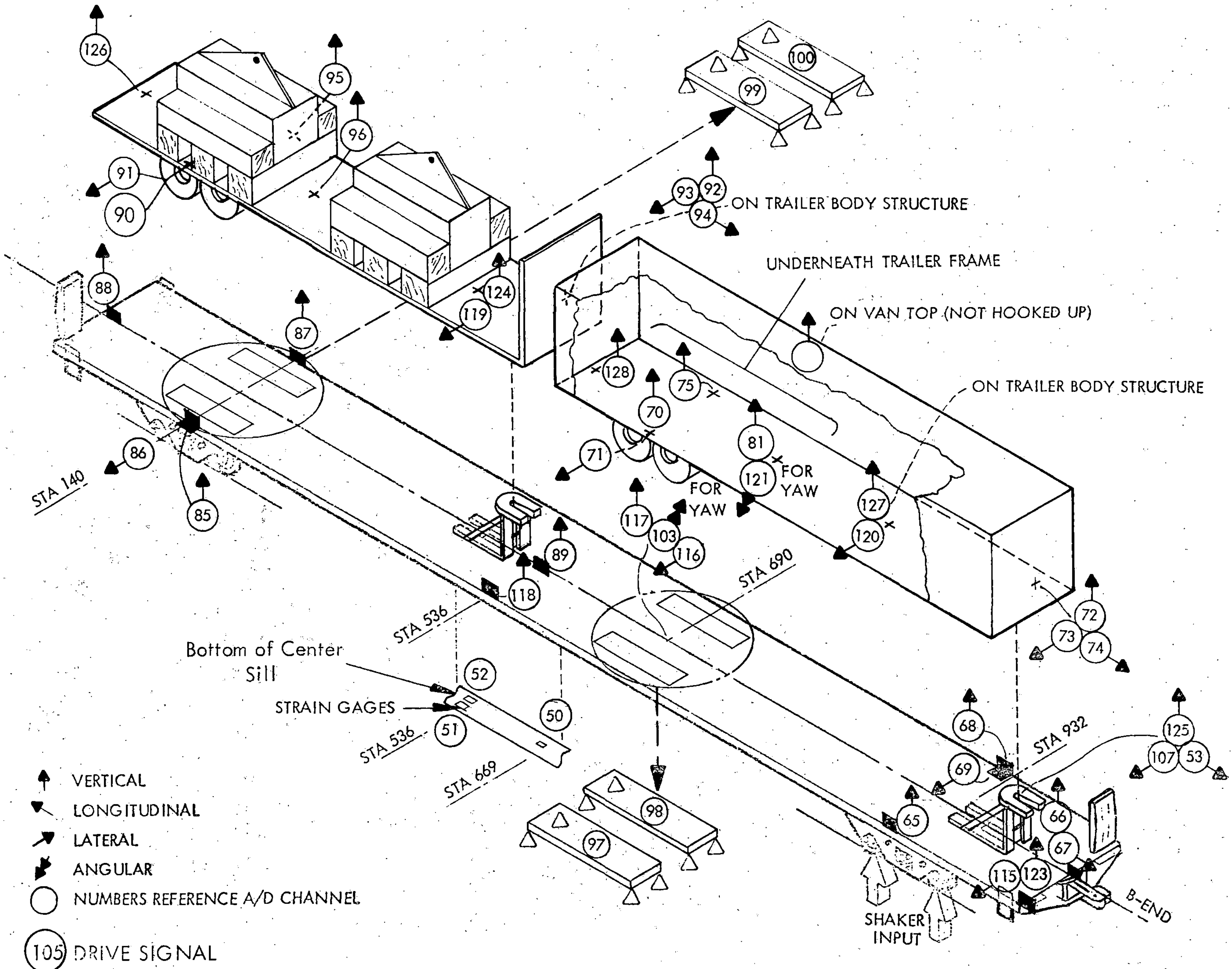


FIGURE 3.3-4 INSTRUMENTATION LOCATIONS - CONFIGURATION 2

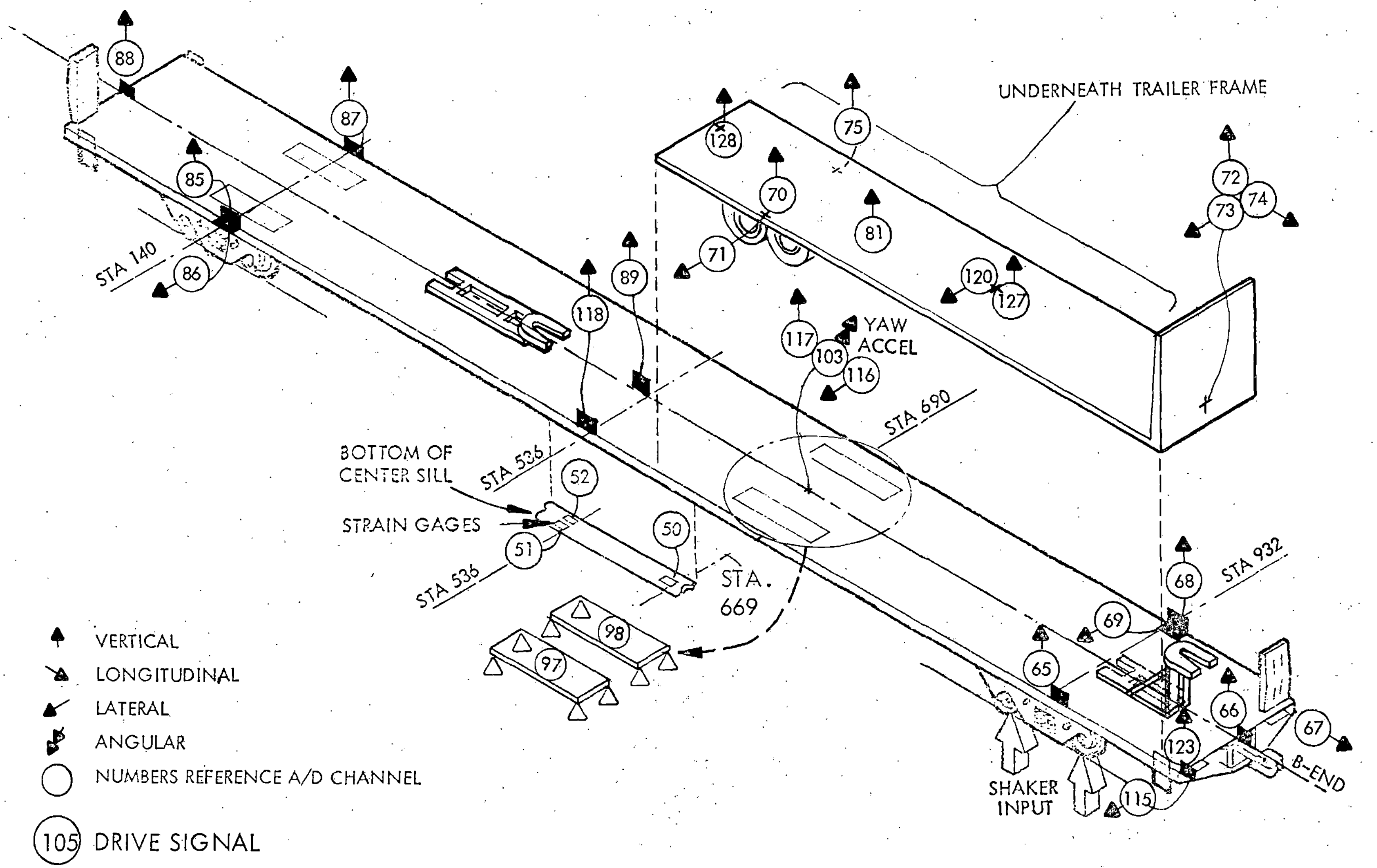
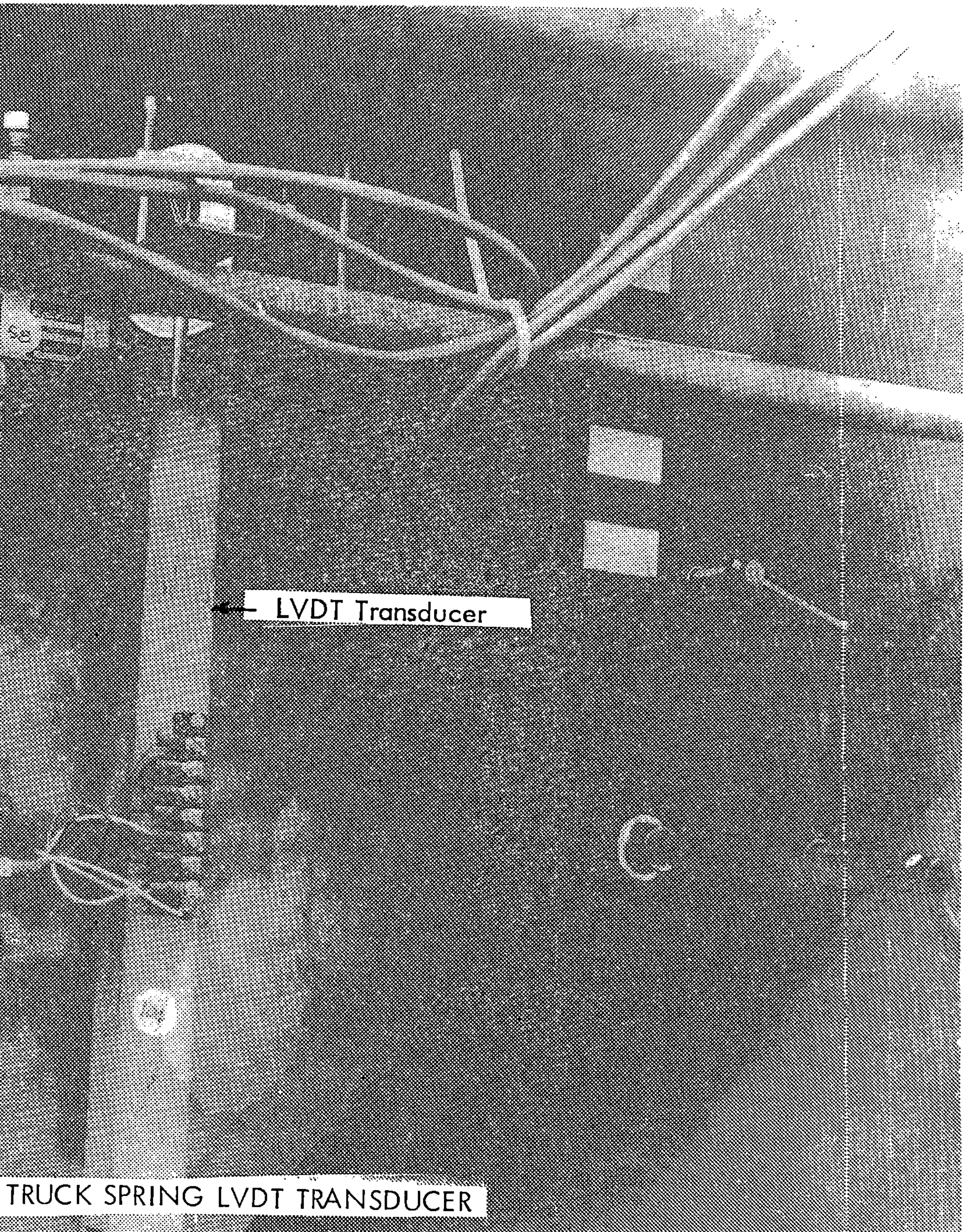


FIGURE 3.3-5 INSTRUMENTATION LOCATIONS - CONFIGURATION 3

FIGURE 3.3-6



TRUCK SPRING LVDT TRANSDUCER

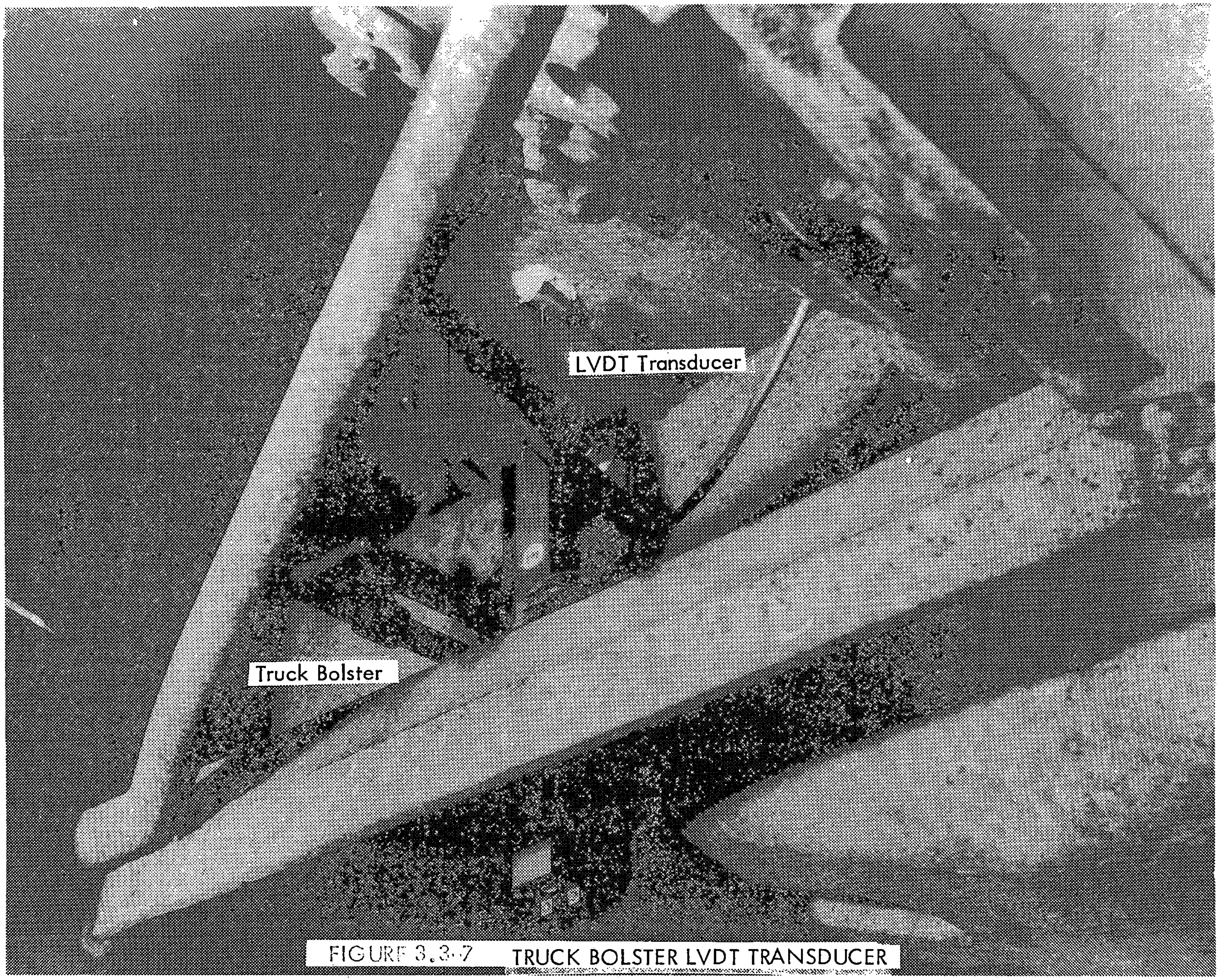


FIGURE 3.3-7 TRUCK BOLSTER LVDT TRANSDUCER

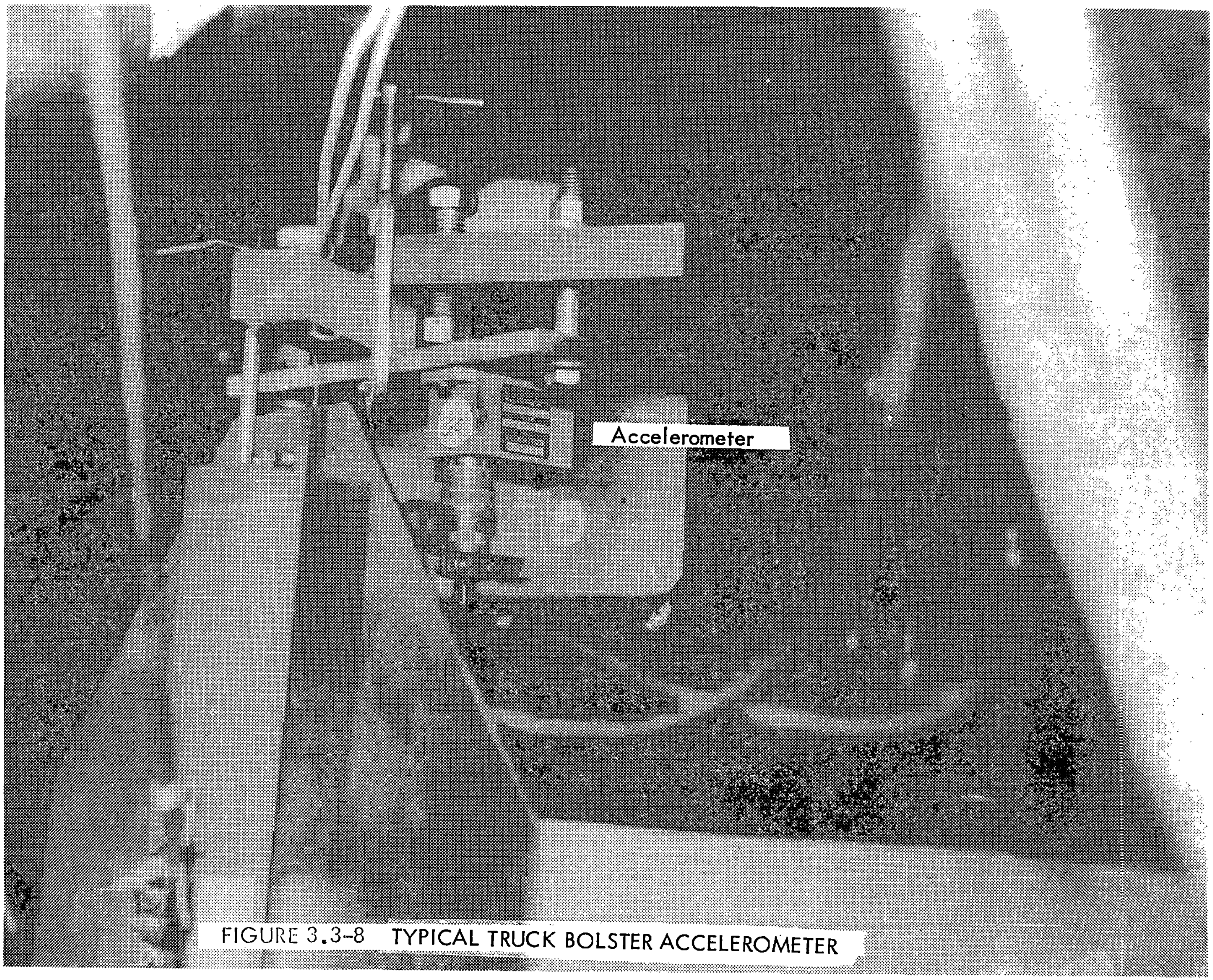


FIGURE 3.3-8 TYPICAL TRUCK BOLSTER ACCELEROMETER

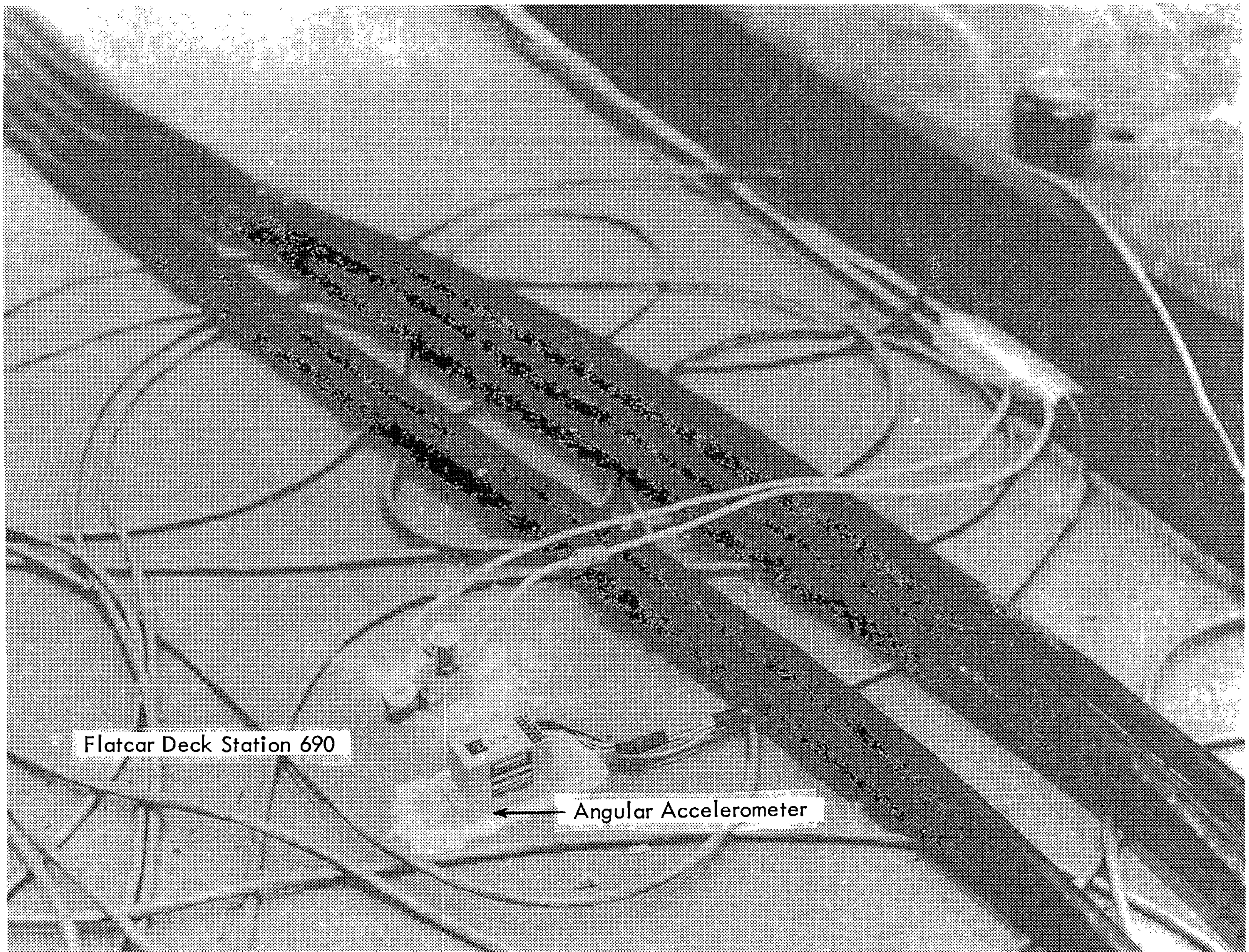


FIGURE 3.3-9 TYPICAL TRANSDUCER INSTALLATION ON FLATCAR

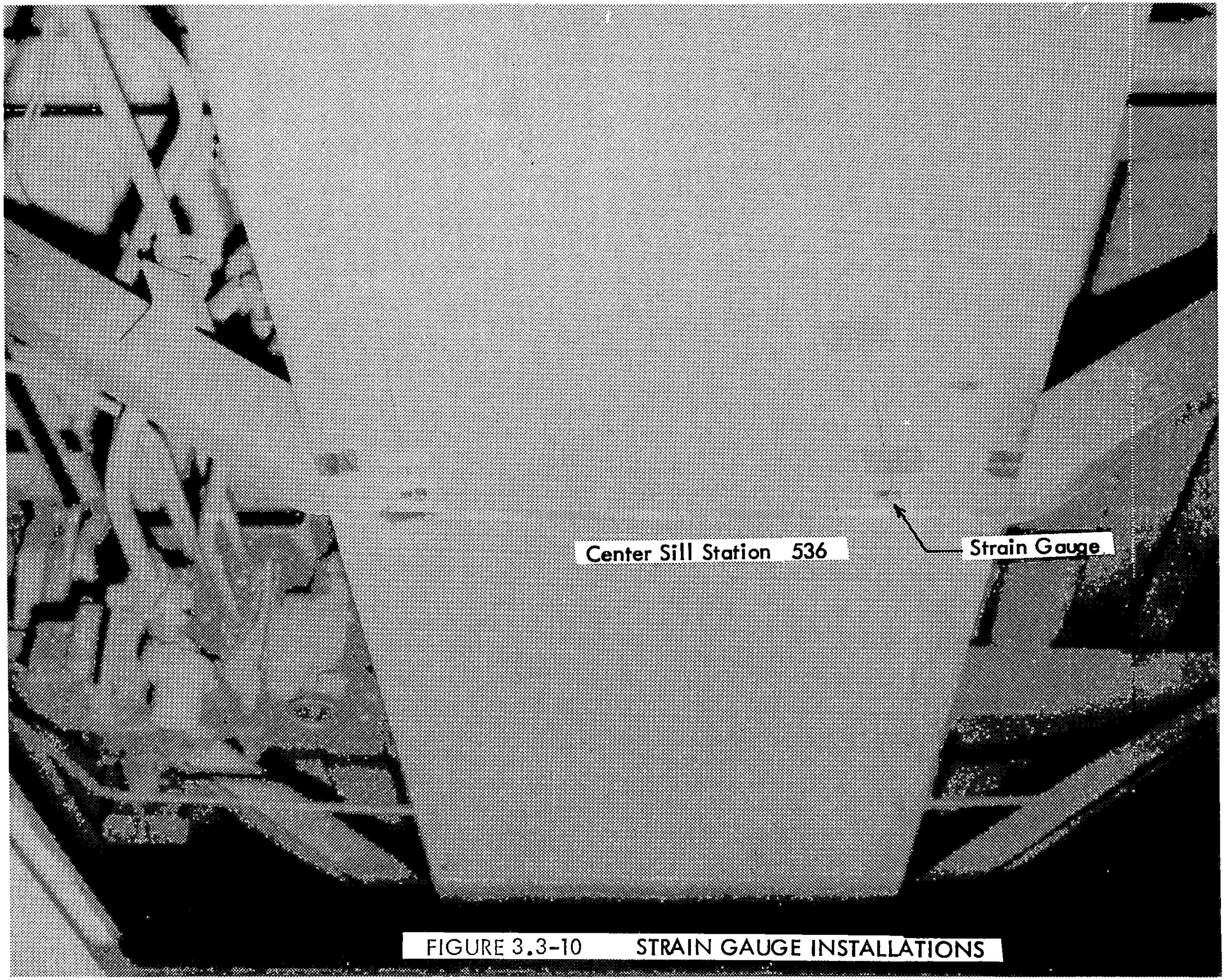


FIGURE 3.3-10 STRAIN GAUGE INSTALLATIONS

van trailer were mounted under the trailer body to the frame structure as shown in Figure 3.3-11, except for the triaxial accelerometers at the front end of the trailers which were mounted as shown in Figure 3.3-12. The pressure switch used to detect flatcar wheel liftoff is shown in Figure 3.3-13 along with one of the actuator piston accelerometers.

The instrumentation numbers on the platform trailer were changed between configurations 2 and 3. It was necessary to use the instrumentation cables at the B-end of the flatcar to connect the flatbed instrumentation when the platform trailer was moved from the A-end to the B-end. Thus configuration 3 has a new set of channel numbers for the platform trailer.

The data is analyzed by correlating a response channel to a reference channel and calculating an amplitude and phase angle, relative to reference, for the response channel. The reference channel used for the DTP was always channel 5, the control signal. Depending on the orientation of the accelerometers, any two accelerometers can be moving in the same direction and have a phase relationship of either zero or 180 degrees. Thus it is necessary to know how the accelerometers were mounted when analyzing the phase angle data. Using the piston head accelerometers as a reference, any vertical accelerometer moving in the same direction will have a phase relation as specified in Table 3.3-4. Also shown in Table 3.3-4 are the phase relationships of all the accelerometers mounted in the lateral and longitudinal directions.

The location of each transducer was measured and is summarized in Table 3.3-5. All distances have been referenced to the center of the flatcar deck.

3.3.3 Summary and Future Application

After the instrumentation had been set-up and checked out, the only problems that occurred during testing were associated with the LVDT rods bending and breaking. The

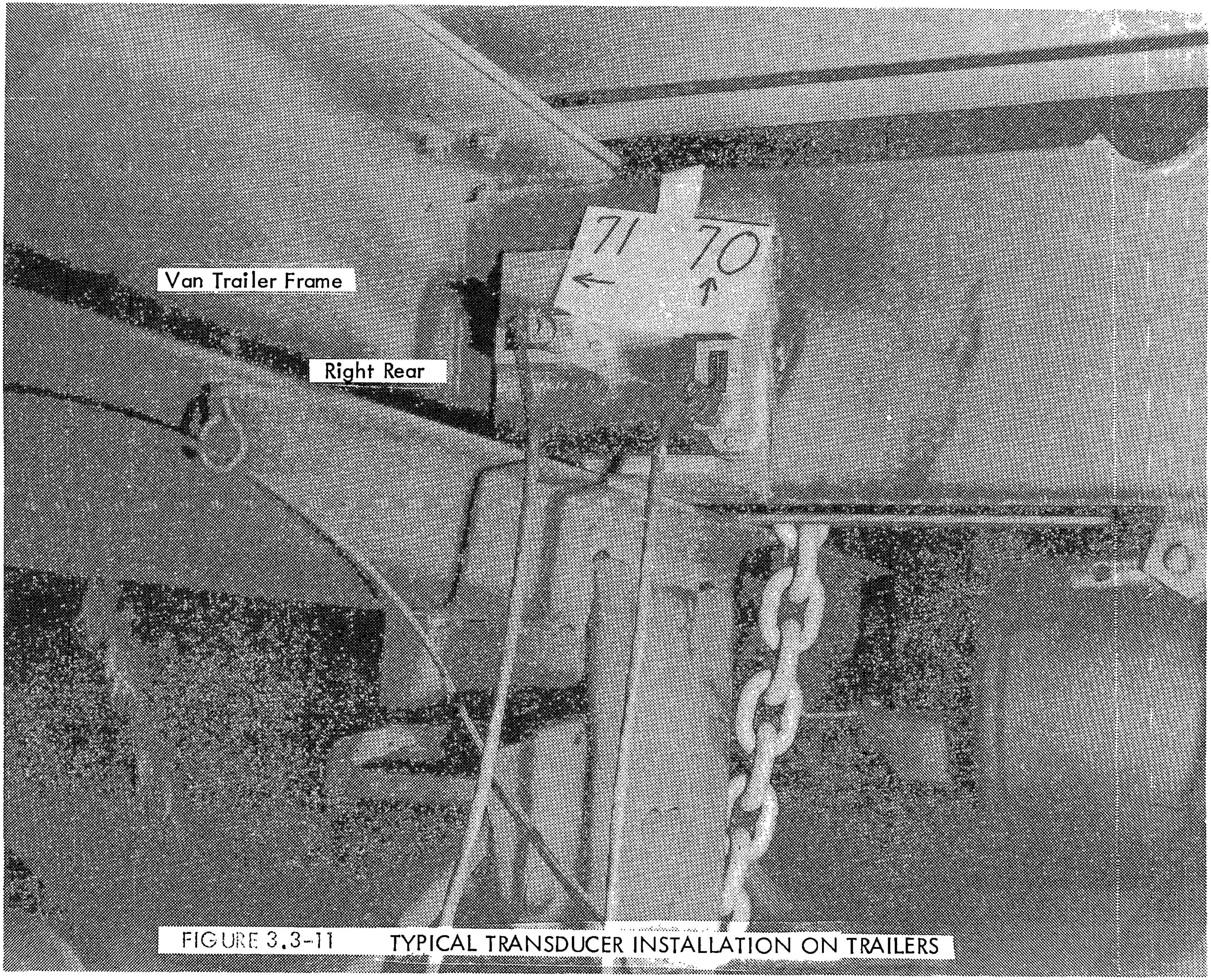


FIGURE 3.3-11 TYPICAL TRANSDUCER INSTALLATION ON TRAILERS

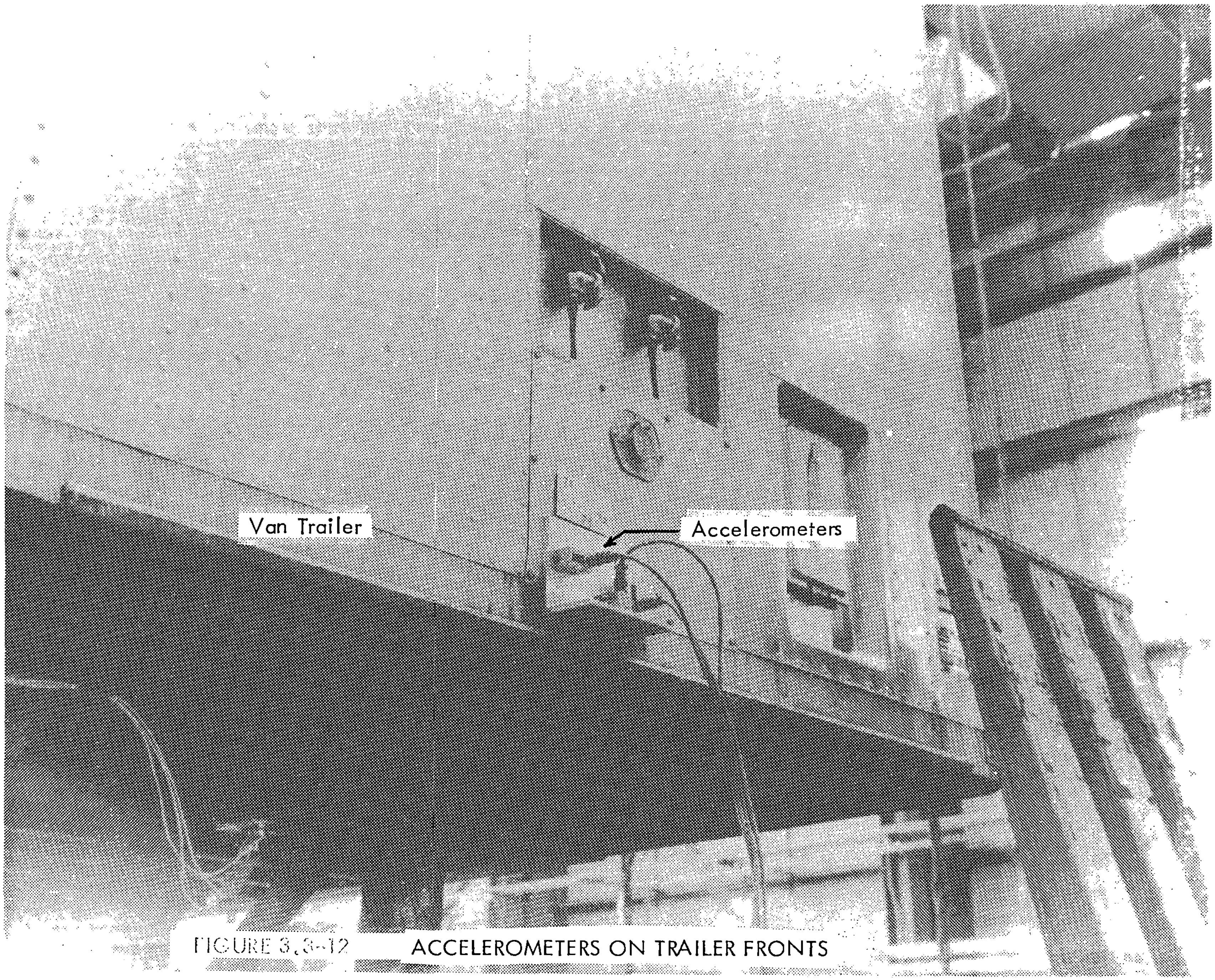


FIGURE 3.3-12 ACCELEROMETERS ON TRAILER FRONTS

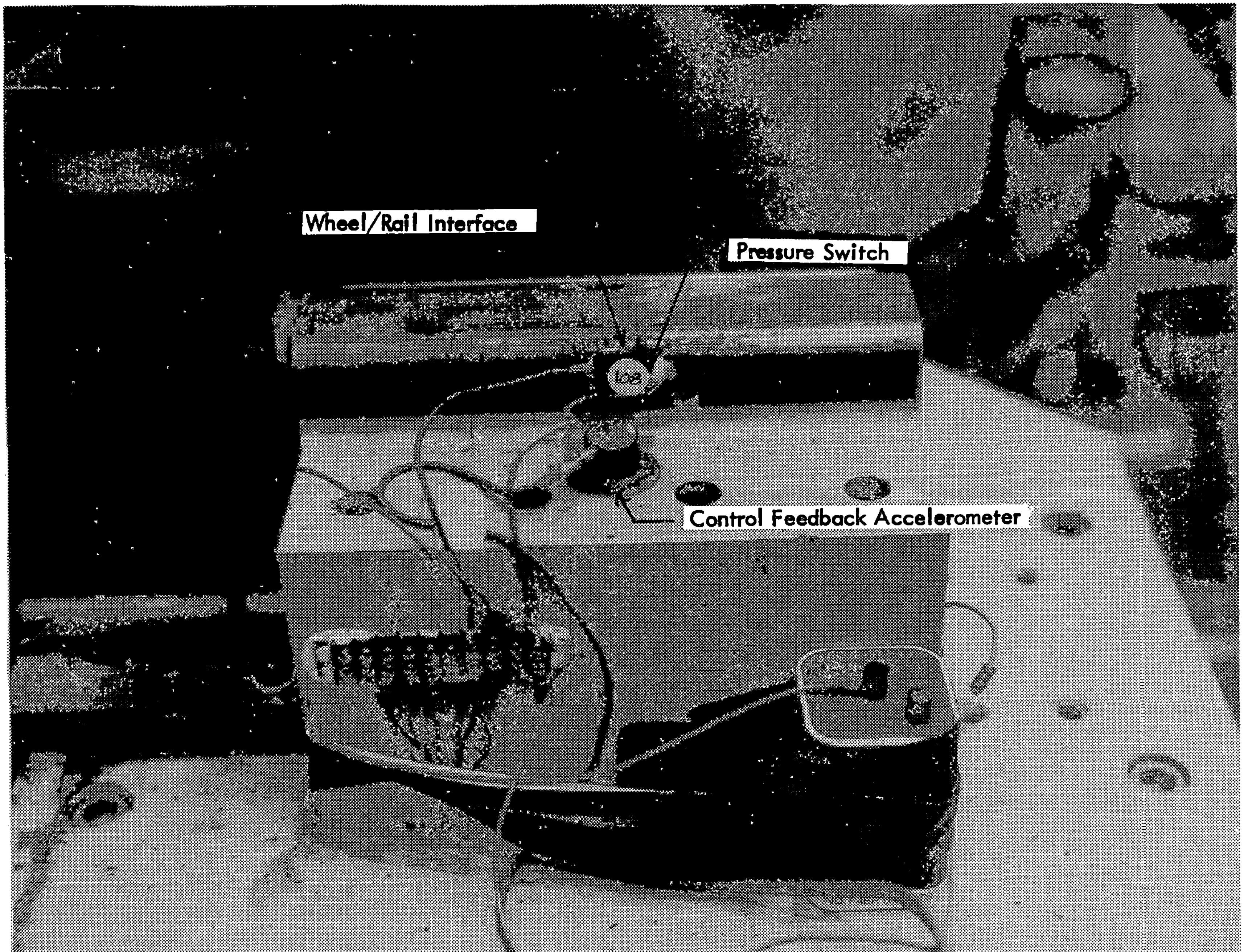


FIGURE 3.3-13 FLATCAR LIFTOFF PRESSURE SWITCH

TABLE 3.3-4 ACCELEROMETER PHASING *

VERTICAL ACCELEROMETERS

Accel. No.	Phase Relationship
Input	Reference
57	0°
59	0°
61	0°
62	0°
65	0°
66	0°
68	0°
70	0°
72	0°
75	0°
77	0°
79	0°
81	0°
82	0°
85	0°
87	0°
88	0°
89	0°
90	0°
92	0°
95	0°
96	0°
113	0°
117	0°
118	0°
122	0°
123	0°
124	180°
125	180°
126	180°
127	180°
128	180°

LATERAL ACCELEROMETERS

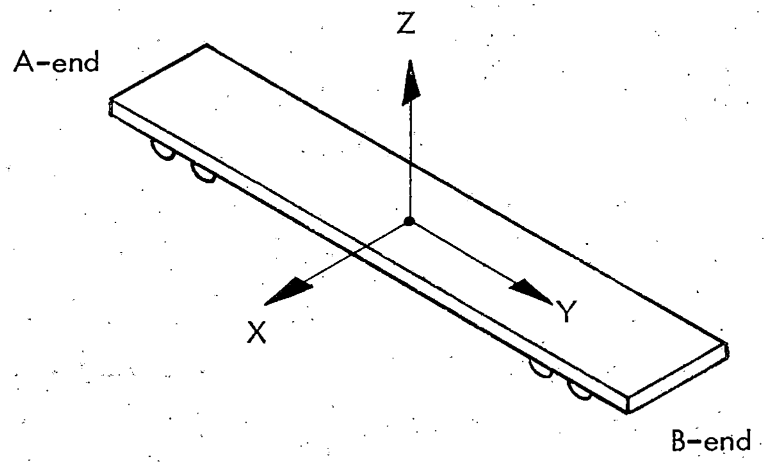
Accel No.	Phase Relationship
69	Reference
60	180°
63	0°
64	180°
71	180°
73	180°
78	180°
83	0°
84	180°
86	180°
91	180°
93	0°
107	0°
111	180°
114	0°
115	180°
116	0°
119	180°
120	0°

LONGITUDINAL ACCELEROMETERS

67	Reference
53	180°
58	0°
74	180°
80	180°
94	180°
112	0°

*For motion of given accelerometer moving in same direction as reference.

TABLE 3.3-5 TRANSDUCER COORDINATE LOCATIONS



TRANSDUCER NO.	COORDINATE LOCATION (INCH) X	Y	Z
Flatcar deck center	0.0	0.0	0.0
50	0.0	133.0	-30.0
51	-20.5	0.0	-30.0
52	20.5	0.0	-30.0
53	2.5	477.0	42.0
57	43.4	396.5	-20.0
58	43.4	395.0	-19.5
59	-43.4	396.5	-20.0
60	-43.4	395.0	-19.5
61	49.4	428.5	-21.0
62	-49.4	360.5	-21.0
63	49.3	434.0	-19.5
64	-49.9	366.0	-19.5
65	51.4	395.5	2.4
66	2.8	535.3	2.4
67	0	533.8	1.1
68	-51.4	399.7	2.4
69	-50.0	396.9	1.1
70	13.0	160.5	38.5
71	18.0	160.5	40.5
72	2.4	516.0	51.4
73	7.0	511.0	52.5
74	4.9	514.0	50.1
75	-18.3	160.5	38.5
77	43.4	-396.5	-20.0
78	43.4	-395.0	-19.5
79	-43.4	-396.5	-20.0
80	43.4	-395.0	-19.5
81	3.0	269.0	43.5
82	-49.4	428.5	-21.0

TABLE 3.3-5 TRANSDUCER COORDINATE LOCATIONS (Continued)

TRANSDUCER NO.	X	Y	Z
83	49.9	-366.0	-22.0
84	-49.9	-434.0	-19.5
85	51.4	-398.3	2.3
86	50.0	-395.5	1.1
87	-51.4	-534.8	2.4
88	-2.8	-534.8	2.4
89	2.8	1.5	2.4
90	14.3	-407.8	26.5
91	12.8	-404.8	26.5
92	5.5	-43.0	53.6
93	10.1	-43.0	54.8
94	8.3	-41.5	52.5
95	-14.3	-401.8	28.3
96	3.0	-282.5	45.5
97 (Plate Center)	35.8	154.0	2.5
98 (Plate Center)	-35.8	154.0	2.5
99 (Plate Center)	35.8	-407.0	2.5
100 (Plate Center)	-35.8	-407.0	2.5
101	0.0	396.0	-33.3
102	0.0	389.5	-24.5
103	0.0	151.5	-1.5
104	51.0	396.0	-20.75 to -33
106	-51.0	396.0	-20.75 to -33
107	2.5	477.0	42.0
108	29.0	464.0	-41.5
109	-19	389.5	-14 to -26.25
111	39.5	396.0	-13.5
112	39.5	396.0	-13.5
113	-39.5	396.0	-13.5
114	-39.5	396.0	-13.5
115	50.0	531.5	0.0
116	0.0	154.5	-1.5
117	0.0	154.5	-1.5
118	49.1	4.0	0.0
119	1.5	-128.0	49.5
120	0.0	326.0	44.5
121	0.0	271	44.5
122	39.5	396.0	-13.5
123	50.0	531.5	0.0
124	1.5	-128.0	49.5
125	2.5	477.0	42.0
126	0.0	-535.5	51.0
127	0.0	326.0	44.5
128	0.0	57.0	42.0

lateral measurement of the truck wheel motion was deleted due to the rod breaking problem and the long delivery time to obtain parts for a workable design. The proposed design change was a spring loaded core extension rod with a gauge roller tip as shown in Figure 3.3-14, however, delivery of this system did not support the DTP schedule. The two LVDT's used to measure truck spring displacement were operational but could have been improved by incorporating a ball joint attached to the fixed extension rod holder as shown in Figure 3.3-15. This change would have reduced the extension rod bending during out-of-phase testing.

The angular accelerometers on the flatcar and van trailer were installed in the yaw direction instead of the roll direction as planned. For future usage, these accelerometers should be remounted in the correct orientation.

For purposes of future usage, the following priority is placed on the DTP instrumentation as to the value of the data.

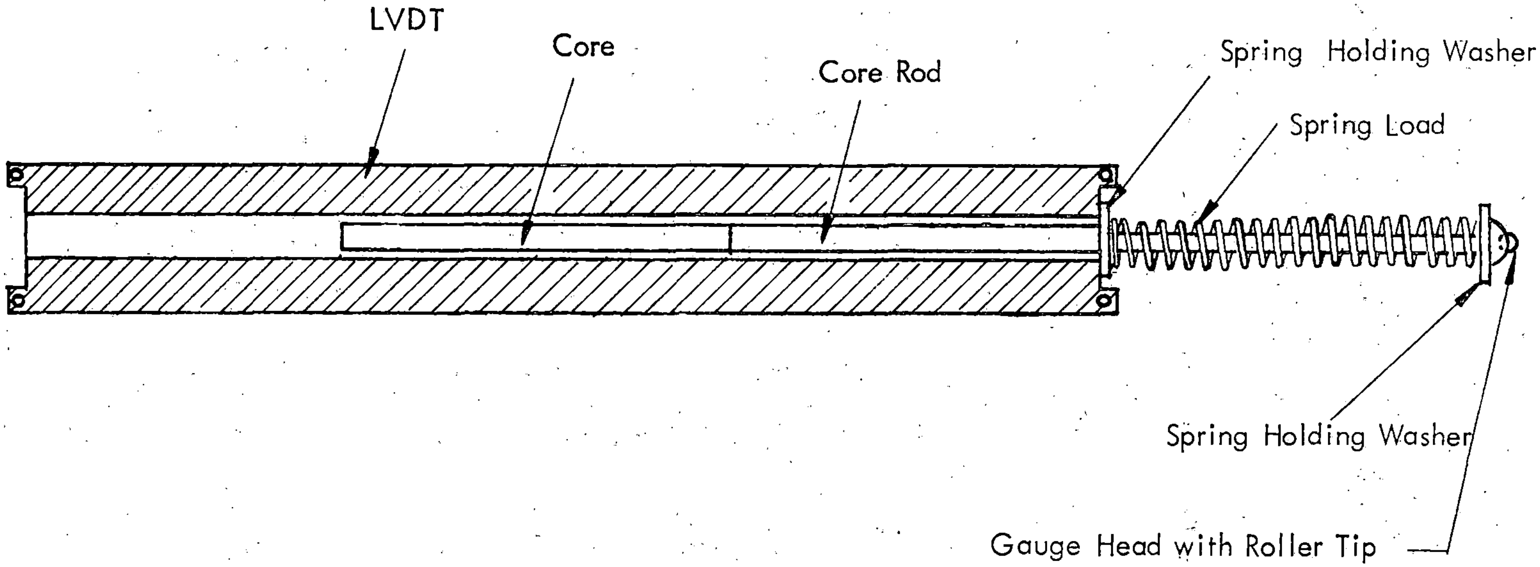
Channels of greatest value:
50, 103, 104, 106, 108, 109, 117, 118, 121, 123, 124, 125, 126, 127, 128.

Channels of secondary value:
51, 52, 53, 102, 105, 107, 115, 116, 119, 120, 122.

Channels of little value:
101, 111, 113.

Channels of no value:
112, 114

Should similar instrumentation be used on the flatcar, it is recommended that the above data be used for determining which channels can be deleted if additional instrumentation is required in later TOFC testing.



NOTE: Schaevitz Engineering will custom build extension rods with your choice of gauging head spring loaded with a means of adjusting for zero at your request.

FIGURE 3.3-14 LVDT - SPRING LOADED EXTENSION ROD

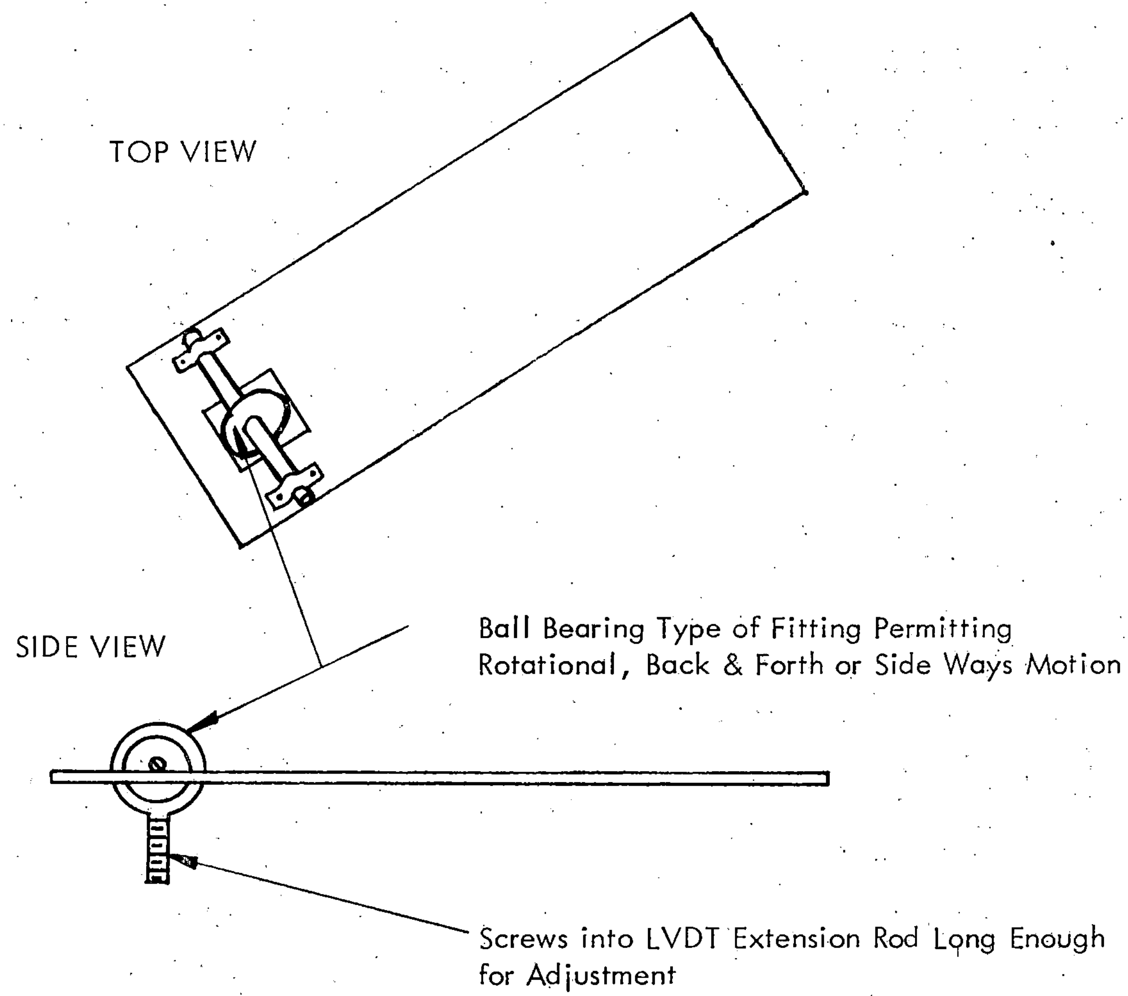


FIGURE 3.3-15 LVDT - BALL JOINT ATTACHMENT

3.4 DATA ACQUISITION AND REDUCTION

On-line data acquisition and shaker control are accomplished through the use of two programs: SINE SWEEP and DWELL REAL TIME. These programs control the excitation signal to the shakers and record the response data on magnetic tape.

Data reduction is accomplished through the use of two off-line programs: TRANSFER FUNCTION ANALYSIS and DWELL ANALYSIS. These programs accept as input the data recorded by the on-line programs. The operational software was developed by Wyle Laboratories for use on the Varian V-73 computer under the Varian Master Operating System (MOS).

3.4.1 System Description

The SINE SWEEP program generates a sine-wave signal whose frequency increases or decreases geometrically with time. The user specifies the beginning frequency, ending frequency, Q, and input amplitude. The frequency "sweep" is continuously interrupted at intervals to acquire data from the test specimen; and user determined limit checks are compared against the acquired data; and the sweep is terminated if these limits are exceeded.

The DWELL REAL TIME program commands the VSS and has the capability of making finite changes in frequency, amplitude and phase. On-line control of the driving signals is totally by input commands through the teletype. The user has control of the frequency, amplitude and phase, and the increment at which the requested frequency or amplitude is varied.

The TRANSFER FUNCTION ANALYSIS (TFA) program reduces and plots the tape output from the SINE SWEEP program.

The capabilities of the TFA program are:

- The exact frequency and amplitude of a reference channel can be determined at each response point.
- The exact amplitude and phase of up to 127 responses or system output channels relative to the reference channel can be determined.
- The amplitude and phase of each response channel can be plotted.
- The magnitude and phase of each response channel relative to the reference channel can be plotted for the transfer function determination.

The DWELL ANALYSIS (DAPR) program reduces and plots the tape output from the DWELL REAL TIME program.

The capabilities of the DAPR program are:

- Analysis of data can be performed as in the TFA
- The results of analysis can be plotted
- Raw data from the tape can be plotted
- Lissajous plots of any two data channels can be plotted.

3.4.2 Terminal Operation

The real-time terminal commands for SWEEP are limited to commands which commence the sweep, stop the sweep, and bring the MOS back into core.

DWELL REAL TIME, however, is at every stage controlled by real-time terminal commands. These commands are used to:

- Set conversion scale factors
- Set frequency
- Set Amplitudes and phases
- Set increments for frequency, amplitudes and phases
- Increment or decrement frequency, amplitudes or phases

- Specify channels for on-line analysis
- Request an analysis
- Cause data to be recorded at approximately 25.6 samples per wavelength
- Cause data to be recorded at a higher speed (up to 400 samples per second)
- Specify length of time for high speed recording
- Specify a "freeze" angle for instant stop of the output signals
- Cause the signal generation to stop
- Bring the MOS back into core.

3.4.3 Software Modifications

The following modifications were made to the software following the initial delivery. The modifications were implemented to facilitate accomplishing the aims of the DTP.

3.4.3.1 Sine Sweep

A reverse sweep capability was added to SINE SWEEP in order to be able to sweep from a high frequency to a lower frequency. This was necessary to allow an investigation of possible changes in resonant frequency depending on sweep direction caused by nonlinearities in the test specimen.

A command was added to the software to result in information being printed out about the frequency at which a limit check shutdown occurred. The number printed out was the frequency D/A count at shutdown. This can be converted to frequency using the curve or equation in Figure 3.4-1.

3.4.3.2 Dwell Real Time

The capability was added to the dwell program to enable the user to record data at a specified sample rate up to 400 samples/second. However, this capability is limited to 64 consecutive channels. The user specifies the starting channel and the next 63 channels are recorded. For starting channels above 65, the software will wrap-around from 128 to 1 and continue recording from there.

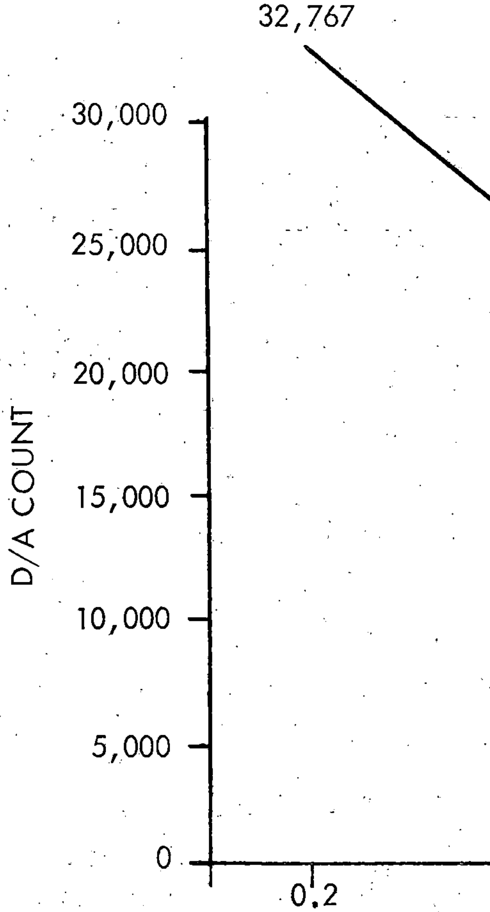
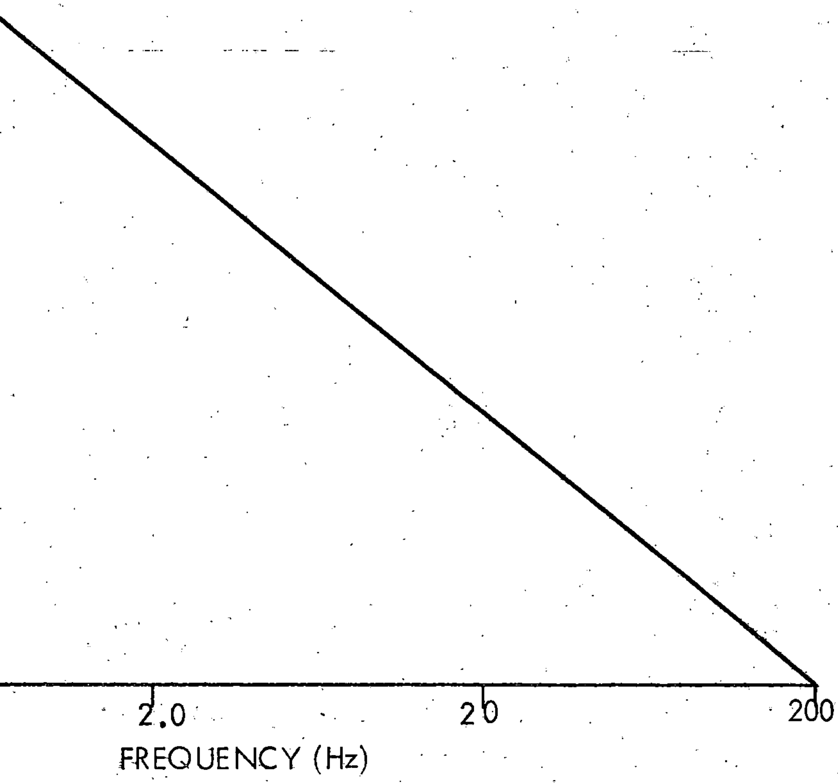


FIGURE 3.4-1

$$F_n = [10 ** (\text{Log } 200 - \frac{\text{Counts} * .3}{3276.8})]$$



SHUTDOWN FREQUENCY

A capability to perform decay tests was also added to dwell. In this mode the user specifies the angle from zero to 360 degrees of the input sine wave at which he wants the shakers to stop their motion. The shaker then stops at this position and the high speed recording capability of dwell is used to record the decay time histories of the response transducers.

3.4.3.3 Transfer Function Analysis

The TFA program was converted to the Varian VORTEX operating system for more efficient operation and shorter analysis time.

The arithmatic operation capability of TFA was also expanded so that any number of channels or constants could be added, subtracted, multiplied, divided, averaged, or summed in any or all combinations. This capability has enabled the operator to reduce the data in any form that he may require for data interpretation.

After the initial reanalysis of the sweep data, the TFA program can be restarted from tape or disk without reanalyzing the data. This means that after the measured data has been analyzed once, it is possible to go back and calculate desired transfer function at any time with a minimum of effort. Capability was also added to the sweep analysis to specify frequency and amplitude limits on the data to be plotted in order to expand a specified bandwidth for better resolution.

3.4.3.4 Dwell Analysis

The DAPR program was expanded to include the capability of analyzing the additional data acquired during dwell real time. The form of this reduction consisted of time history plots of the high speed recording. The starting record and number of records to be plotted are specified by the operator, so it is possible to look at the complete time history or any small portion of it. This capability is especially valuable when reducing decay traces because it is possible to look at only those cycles of the decay which are of interest. It is also possible to specify different scale factors when plotting the data to obtain a plot with greater definition. All of these capabilities are entered from the keyboard by the operator during reduction and can be changed until exactly the plot desired is obtained.

3.4.4 Examples of Data Output

All 128 channels of the ADACS System were recorded in digital form on magnetic tape for every run. This data was then reduced in several ways depending on the type of run being made. For the sweep runs the reductions consisted of printer listings of the analyzed values by frequency or by channel. An example of a sweep analysis by frequency is contained in Table 3.4-1 and one by channel is contained in Table 3.4-2. In addition the data can be plotted as shown in Figure 3.4-1. One of the valuable features of TFA is the ability to perform arithmatic operation between various channels and plot the data. An example of this is in Figure 3.4-2 which shows the ratio of the response at the middle of the flatcar to the average of the four input accelerations. For the dwell runs the data is reduced and tabulated as shown in Table 3.4-3. For the high speed recording, the data is displayed as plots of amplitude versus frequency as shown in Figure 3.4-3. The amount of data plotted could be varied to obtain a more detailed plot of the data as shown in Figure 3.4-4. The high speed record portion of dwell was used both for sinusoidal dwells (Figure 3.4-3) and for decay tests (Figure 3.4-4).

TABLE 3.4-1 SWEEP ANALYSIS LISTING BY FREQUENCY

TYPICAL DATA REDUCTION

CONFIGURATION 2, HIGH LEVEL SINE SWEEP, SHAKERS IN PHASE, RUN 54

REFERENCE NUM	FREQ.	AMPL.	CH.	RESPONSE AMPL.	PHASE	CH.	RESPONSE AMPL.	PHASE	CH.	RESPONSE AMPL.	PHASE
17	1.011	.980									
			3	.306	-4.65	13	.310	-4.65	23	.309	-4.54
			33	.305	-4.41	8	.051	176.06	18	.033	-170.46
			28	.032	170.82	38	.022	175.52	1	24.752	144.88
			11	66.795	170.93	21	16.298	176.17	31	5.054	-155.46
			4	.004	86.13	14	.004	85.89	24	.003	90.87
			34	.004	85.50	6	.017	62.77	16	.016	119.87
			26	.015	114.67	36	.021	111.31	9	.121	179.91
			19	.121	179.82	29	.121	179.86	39	.121	179.82
			50	203.231	-6.82	51	233.046	-7.00	52	217.907	-7.13
			53	.015	-64.57	57	.044	172.88	58	.002	-5.79
			59	.024	-144.91	60	.003	156.41	61	.044	162.62
			62	.021	165.47	63	.005	167.79	64	.002	-144.93
			65	.028	177.15	66	.042	170.66	67	.002	-23.57
			68	.040	173.12	69	.003	-27.25	70	.027	172.58
			71	.006	158.30	72	.038	171.52	73	.005	158.44
			74	.006	167.77	75	.029	171.75	77	.000	-159.56
			78	.000	72.65	79	.000	177.12	80	.001	163.49
			81	.031	173.59	82	.002	-83.98	83	.003	-52.04
			84	.003	-124.69	85	.001	-99.60	86	.001	143.09
			87	.001	115.50	88	.007	-2.17	89	.019	175.08
			90	.001	83.48	91	.004	145.65	92	.018	167.26
			93	.004	-31.04	94	.004	-16.68	95	.001	-48.21
			96	.006	167.90	97	280.367	-179.31	98	708.677	170.33
			99	175.258	-29.83	100	239.040	156.88	101	.017	119.21
			102	.043	-48.21	103	.066	-49.52	104	.000	-175.11
			105	.979	-.02	106	.001	155.19	107	.011	-10.86
			108	.002	15.77	109	.000	-113.83	110	.001	151.23
			111	.011	.86	112	.004	174.15	113	.025	176.58
			114	.008	122.51	115	.004	135.35	116	.002	-1.32
			117	.030	161.18	118	.020	173.60	119	.004	162.49
			120	.005	-18.71	121	.037	-145.11	122	.038	169.26
			123	.037	173.32	124	.014	-5.51	125	.036	-5.44
			126	.004	171.12	127	.033	-6.29	128	.026	-6.30

TABLE 3.4-2 SWEEP ANALYSIS LISTING BY CHANNEL

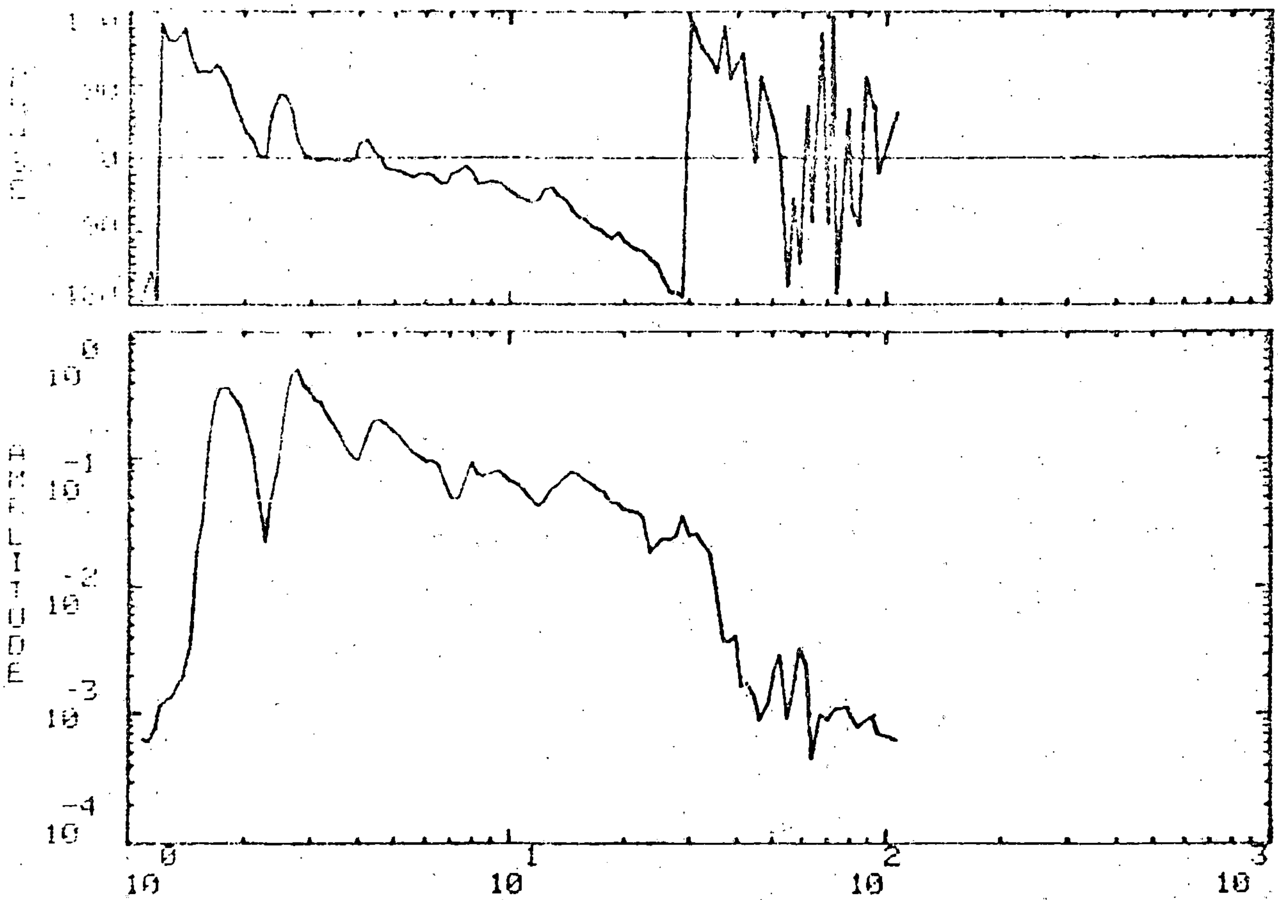
TYPICAL DATA REDUCTION

PAGE 95 11-06-75

CONFIGURATION 2, LOW LEVEL SINE SWEEP, SHAKERS IN PHASE, RUN 40

126,

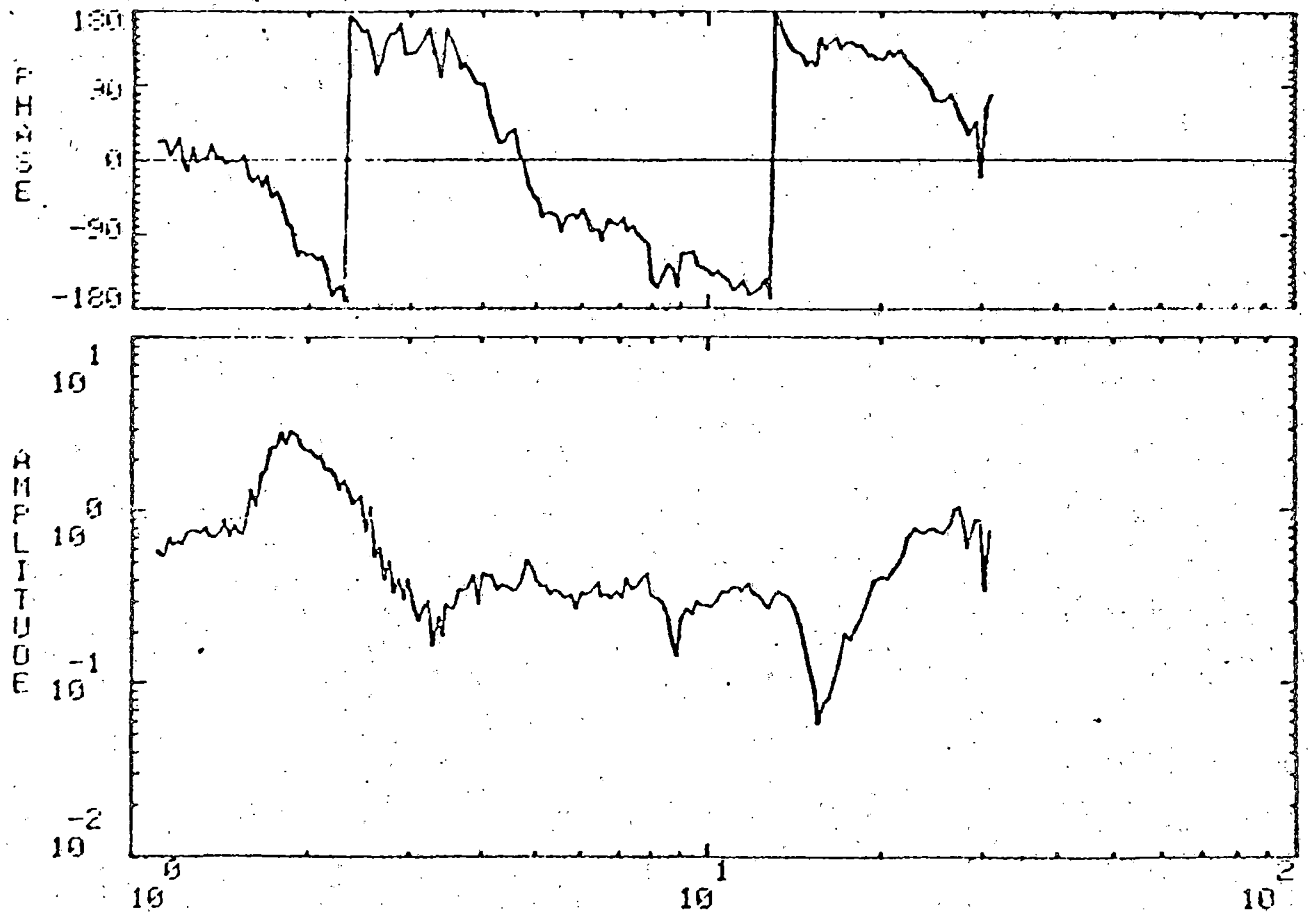
FREQUENCY	AMPLITUDE	PHASE	FREQUENCY	AMPLITUDE	LOG PHASE
3.561955	.094736	-49.007568	14.814667	.228919	-7.238281
3.627137	.082605	-33.826660	15.103600	.234508	-20.803223
3.689235	.085678	-30.255615	15.379433	.268875	-29.840332
3.768744	.072782	-68.508301	15.704811	.297313	-42.706787
3.852576	.066951	-68.033447	16.076797	.326846	-58.675293
3.928558	.062869	-89.874512	16.432205	.389615	-79.487549
4.000561	.067906	-101.516602	16.747139	.505851	-110.139160
4.095737	.068849	-85.684326	17.160156	.688895	-131.445557
4.154226	.072498	-145.913818	17.368126	.813713	176.161377
4.261551	.076706	-134.303223	17.843330	.687374	126.052490
4.349585	.080952	-147.310791	18.184898	.492937	94.973145
4.428154	.104296	173.595703	18.522041	.369326	69.014404
4.523479	.147625	154.745605	18.984161	.267475	51.997070
4.610317	.195842	128.092773	19.353396	.182826	36.125977
4.697901	.303076	114.798096	19.663467	.117299	31.466064
4.803877	.353875	102.848145	20.152092	.084168	23.093506
4.920704	.273915	88.665527	20.629250	.058494	16.081787
5.009813	.204103	70.814453	20.942039	.047429	6.154053
5.114250	.183523	55.019531	21.396103	.034561	1.748779
5.194405	.256129	57.745850	21.864670	.030550	-11.831299
5.363733	.270627	68.360107	22.324692	.021288	-13.148682
5.418413	.258309	30.369873	22.655312	.012994	-12.659912
5.543186	.270838	25.352051	23.369789	.009690	-4.650635
5.642666	.277257	3.065918	23.761177	.009235	10.823486
5.740696	.287313	9.915771	24.368301	.013579	36.528320
5.882376	.310999	2.668457	24.793091	.034646	44.537109
6.012720	.347953	-10.065918	25.266396	.070074	10.701416
6.098551	.341028	-22.418457	25.690857	.091146	-16.574219
6.256351	.361102	-33.639893	26.231331	.110758	-16.386963
6.427742	.408892	-50.351562	26.868263	.167086	-78.293701
6.510172	.477077	-56.955322	27.394501	.213573	-127.028564
6.663527	.600679	-86.471436	28.080902	.209549	-177.099609
6.777008	.497132	-112.075439	28.559105	.177370	143.943115
6.882822	.448287	-111.728027	29.308479	.155331	109.334473



CONFIGURATION 2, HIGH FREQUENCY SINE SWEEP, IN PHASE, RUN 70

FIGURE 3.4-1 SWEEP ANALYSIS PLOT

TYPICAL DATA REDUCTION



118, 8, 18, 28, 38,A4,/,

CONFIGURATION 2, HIGH LEVEL SINE SWEEP, SHAKERS IN PHASE, RUN 56

FIGURE 3.4-2 SWEEP ANALYSIS CALCULATIONS

TABLE 3.4-3 DWELL ANALYSIS LISTING

TYPICAL DATA REDUCTION

CONFIGURATION 2, DWELL TEST, SHAKERS IN-PHASE, RUN 56

REFERENCE				RESPONSE			RESPONSE			RESPONSE	
RUN	FREQ.	AMP.	CH.	AMP.	PHASE	CH.	AMP.	PHASE	CH.	AMP.	PHASE
12	2.197	.461									
			3	.145	-11.71	13	.146	-10.92	23	.148	-15.81
			33	.144	-10.10	8	.135	166.30	18	.107	-149.54
			28	.080	168.00	38	.115	80.16	1	122.734	93.57
			11	81.535	95.59	21	74.319	103.43	31	91.808	85.65
			50	2534.275	-154.07	51	2845.062	-154.28	52	2668.329	-154.14
			57	.088	-107.34	58	.067	160.38	59	.137	142.68
			60	.006	-104.65	61	.121	-129.34	62	.142	176.32
			63	.026	-68.11	64	.055	123.78	65	.065	134.44
			66	.268	-172.49	67	.046	150.94	68	.094	142.84
			69	.005	48.11	70	.215	36.35	71	.013	9.85
			72	.239	-170.63	73	.012	-158.00	74	.108	168.97
			75	.221	36.66	77	.018	-16.46	78	.003	161.17
			79	.030	7.94	80	.043	-34.45	81	.118	49.66
			82	.014	-64.58	83	.010	141.91	84	.018	5.75
			85	.015	13.20	86	.003	-17.03	87	.020	-18.65
			88	.086	-150.50	89	.184	30.84	90	.027	28.79
			91	.010	19.55	92	.181	28.10	93	.005	-67.15
			94	.086	176.21	95	.028	26.64	96	.106	27.11
			97	1491.687	41.53	98	1702.847	40.94	99	432.707	35.46
			100	593.160	35.62	101	.586	-72.95	102	.307	-139.09
			103	.127	41.30	104	.035	27.31	105	.463	-.40
			106	.012	5.13	107	.038	-1.47	108	.002	-18.68
			109	.001	-118.24	110	.004	37.24	111	.150	-10.48
			112	.055	-169.53	113	.104	98.98	114	.027	57.76
			115	.019	-85.08	116	.010	-89.27	117	.152	38.34
			118	.179	32.21	119	.006	150.57	120	.004	169.55
			121	6.646	-60.49	122	.120	153.70	123	.261	-174.45
			124	.169	-140.16	125	.189	-.93	126	.035	23.07
			127	.080	-86.39	128	.328	-148.68			

TYPICAL DATA REDUCTION

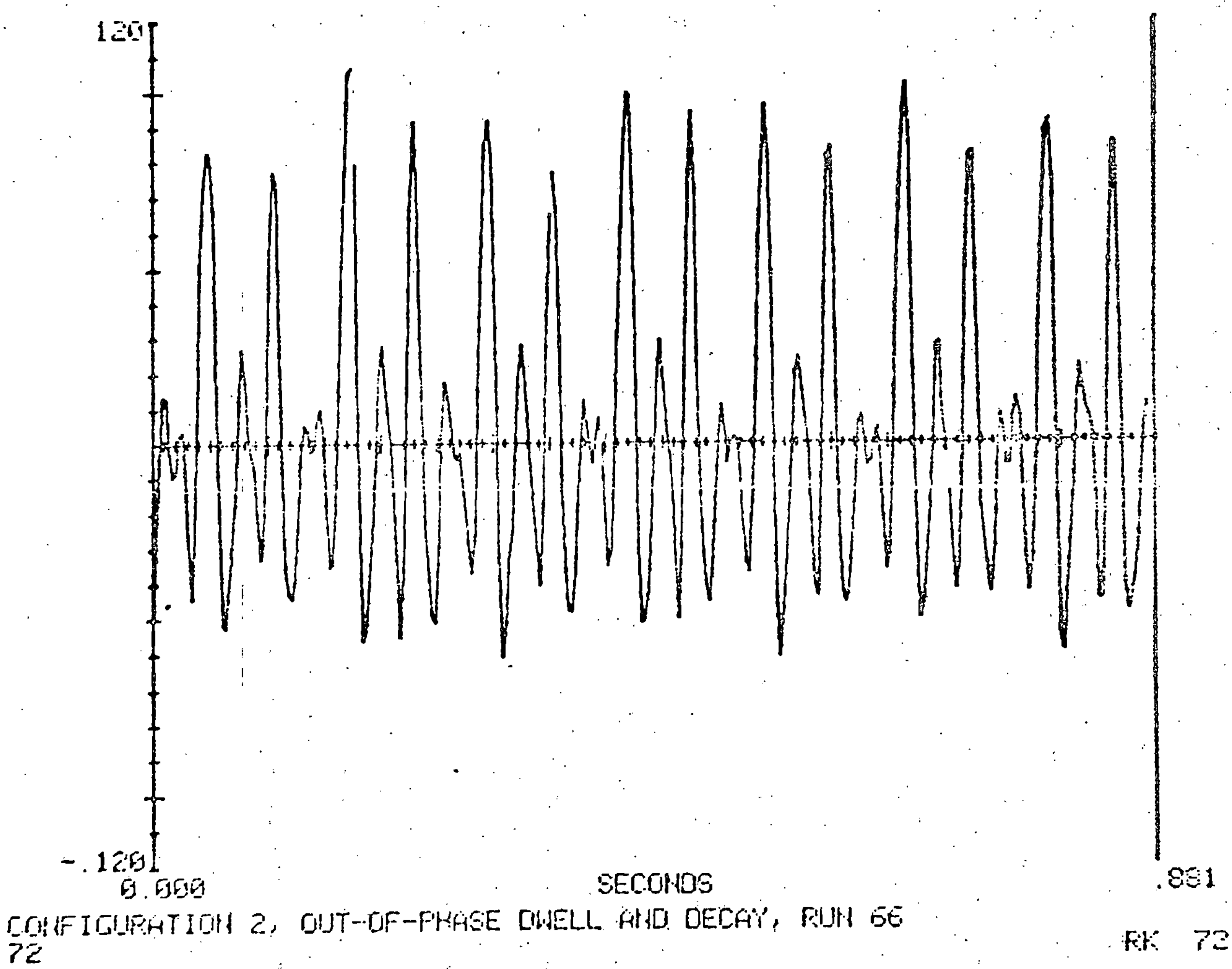
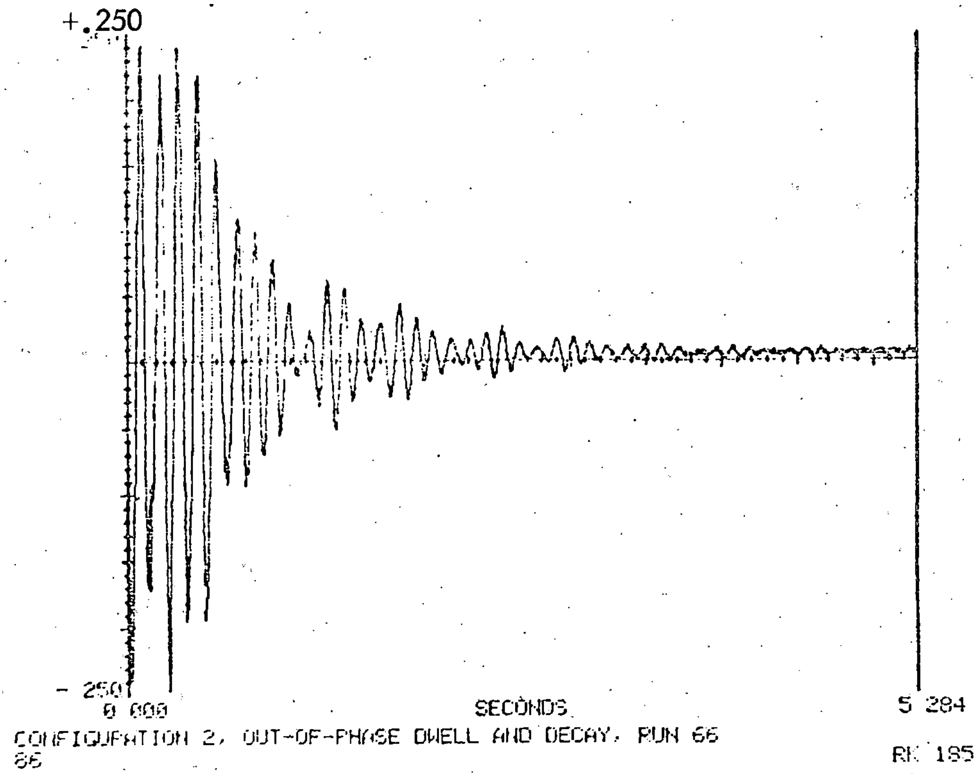


FIGURE 3.4-3 DWELL HIGH SPEED RECORD SINUSOIDAL TIME HISTORY



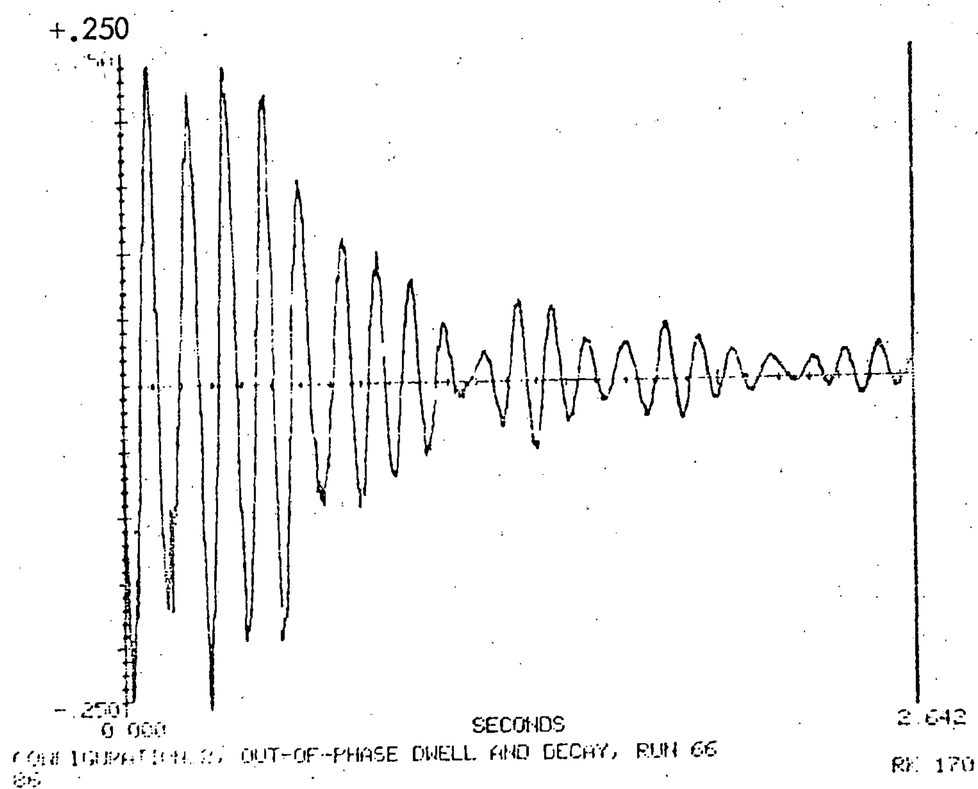


FIGURE 3.4-4 DWELL HIGH SPEED RECORD DECAY TIME HISTORY

3.4.5 Procedure for Quicklook Data Reduction

The sweep program has no provisions for real time data analysis and to get quicklook data reduction requires replacing the test program in the computer with the analysis program before the data can be reduced. This would have resulted in unacceptable delays in operation of the total system and so the DTP did not include any quicklook data reduction. The dwell program, however, has provisions for quicklook data on up to 15 channels. This enables real time decisions to be made based on actual data when running a dwell test. Data reduction of sweep test data can be available in a short amount of time if the frequency range and the number of channels reduced are limited. For example, if the frequency range of 1 through 30 Hertz is used with a Q of 10 and twenty-five channels are reduced and ploted the data would be available in one hour.

4.0 CONCLUSIONS

The VSS Demonstration Test Program was completed in the scheduled time with the accomplishment of all objectives. The VSS was operated at various levels of amplitude up to the response limit of the specimen for three different loading conditions of the TOFC. As a demonstration of VSS motion capabilities, each configuration was subjected to vertical (in-phase) and cross level (out-of-phase) input at the wheel/rail interface using the sweep, dwell and decay control software. RDL operational personnel assumed operation of the VSS during the last two weeks of the test program and successfully demonstrated their ability to maintain and operate the VSS for future programs.

Effective operation of the VSS requires pretest planning and the development of a test procedure that specifies the input levels and motion requirements for each test run in a days operation. Setup and pretest activities require a significant part of the test day and when the system is up and operating, the available test time must be effectively utilized. Three log books were maintained (one each by the test director, control station personnel and pit operations personnel) during the test program to record events, problems, and progress. These logs proved valuable and are still being used to reconstruct events that occurred during the test program.

Performance capabilities of the control system were demonstrated for the three loading conditions of the TOFC with no degradation. System distortion of the displacement drive control was minimal for the levels of test inputs and the wide bandwidth of the control system. The maintained actuator stiffness exceeded the oil column stiffness, thereby obtaining a minimal structural cross-coupling effect between actuators.

Analog data was acquired for all of the transducers for each test run. The sensor types and their sensitivities, together with the appropriate signal conditioning, provided an almost trouble-free instrumentation system.

Control, data reduction and analysis software were successfully used in all available modes of operation. Additional capabilities were added to the data analysis programs to allow for more user oriented capabilities. A reverse sweep capability was added to evaluate possible changes in resonant frequency due to sweep direction. The dwell program was expanded to enable the user to specify sampling rates up to 400 sps and to perform decay tests for the determination of damping characteristics. Display of response transfer functions was expanded to include several arithmatic operations for greater utility in data interpretation. These changes were incorporated and verified during the test program and the subsequent data reduction effort.

5.0 RECOMMENDATIONS

The VSS Demonstration Test Program provided Wyle and RDL operational personnel experience in total system operation in support of vibration test programs. Based on these experiences, the following recommendations for the conduct of future test programs are submitted.

- Establish with the requestor an understanding of the objectives for the proposed test.
- Develop a test plan that will attain the objectives with close attention given to VSS capabilities and limitations.
- Review test plan with the requestor for verification of approach.
- Prepare a test procedure that will maximize parallel setup and pretest activities. The procedure should be written with sufficient flexibility for the Test Director to make in-test changes to effectively utilize the system and test time available.
- Maintain a detailed log book of test program events, problems and system performance to assist in post test analysis.

APPENDIX A. COMPONENT TESTS

During the static deflection test three sets of data were obtained for each trailer; one set with the trailer loaded, one set unloaded, and a third with the trailer reloaded. The measurements were made at two foot intervals along the side of each trailer and referenced to a bench mark with an established elevation of 100. The trailers were positioned on their landing gear and tandems. The actual measured data is contained in pages A-4 through A-7 and summarized in Figures A-1 and A-2. The summarized data has been adjusted to zero deflection at the landing gear and tandem locations and then normalized with respect to the unloaded condition. This results in a straight line for the unloaded case. The trailer deflections for each side are shown for both the loaded and reloaded conditions.

The measured deflections were of small magnitudes making it difficult to get sufficient accuracy, therefore, the data is scattered. The measured data indicated that the trailers are quite rigid. Comparisons of the predicted platform trailer deflection with measured data (Figure A-2) shows the model predicted deflections in general agreement with measured test data.

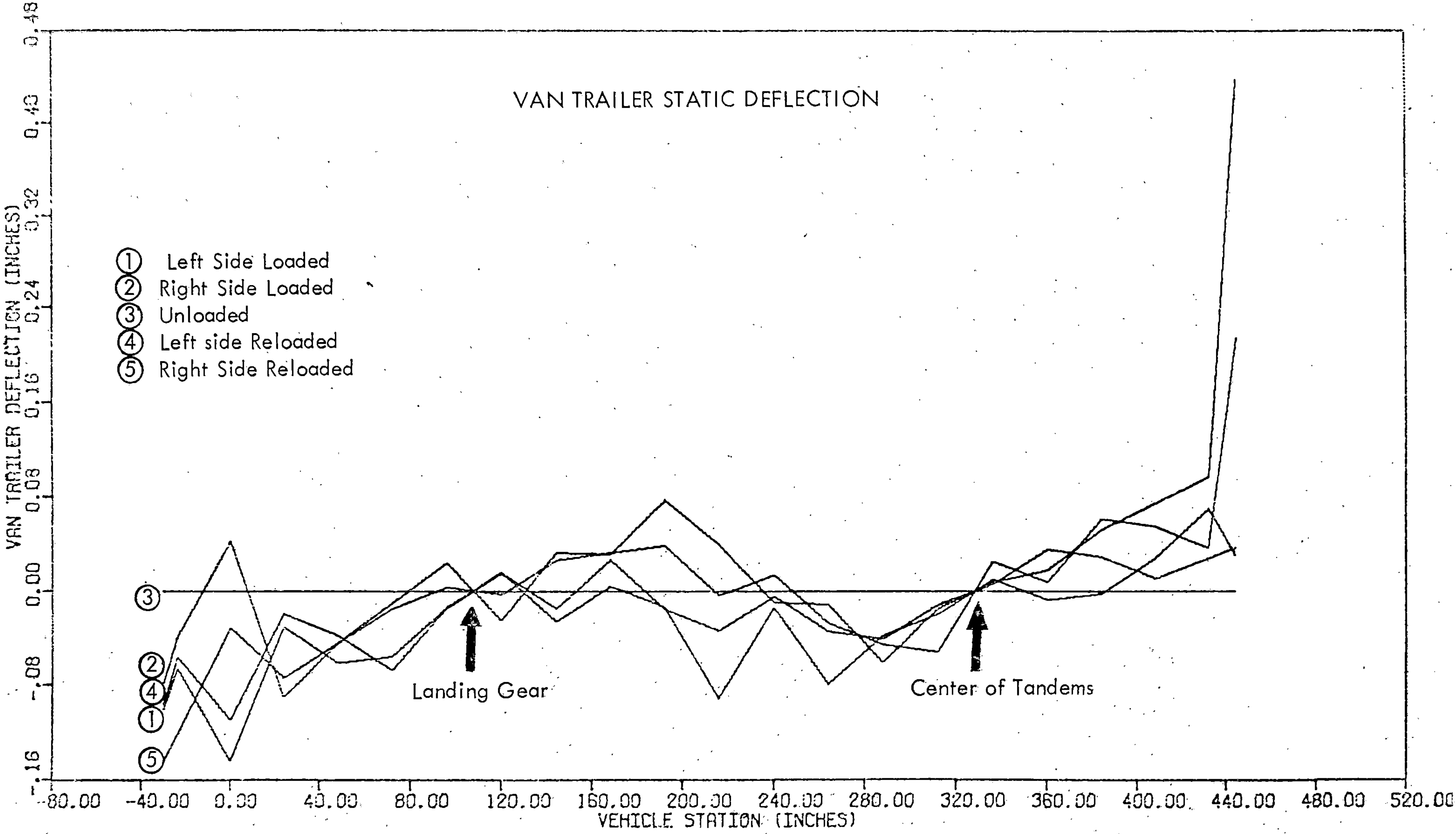


FIGURE A-1. VAN TRAILER STATIC DEFLECTION

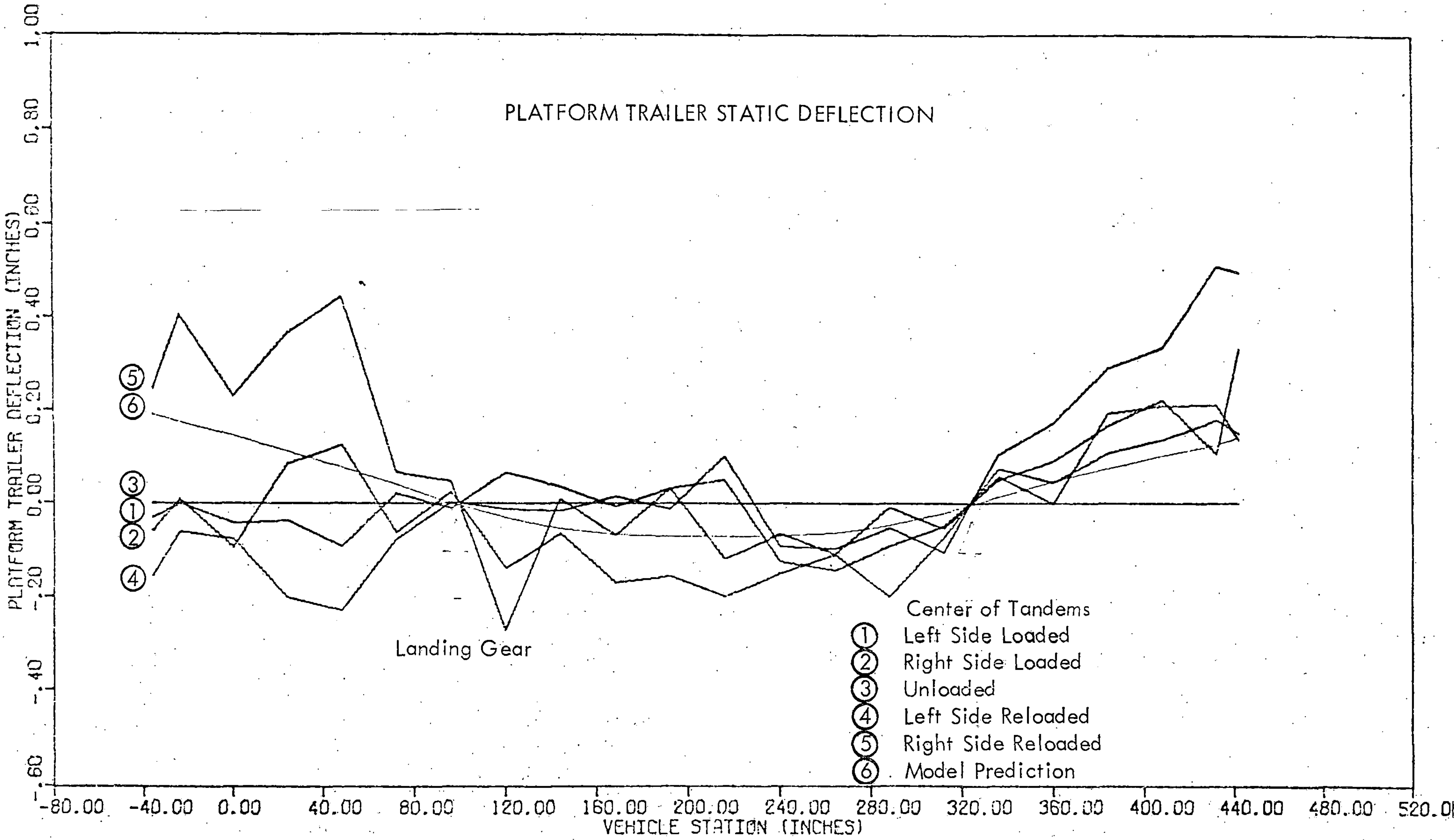


FIGURE A-2. PLATFORM TRAILER STATIC DEFLECTION

9-24-75
9-25-75

DEFLECTIONS - VAN

Refer - Field Book (Survey) Pg. 176 thru 183 - Engineering

Tele Ext. 265

LEFT SIDE

Point	Elev. (LOADED)	Elev. (UNLOADED)	Elev. (RELOADED)	1st Defl.	2nd Defl.
-2'6"	103^{822}	103^{796}	103^{795}	$+0^{026}$	-0^{001}
-2	103^{821}	103^{794}	103^{795}	$+0^{027}$	$+0^{001}$
0	103^{793}	103^{780}	103^{771}	$+0^{013}$	-0^{001}
2	103^{776}	103^{761}	103^{754}	$+0^{015}$	0^{007}
4	103^{760}	103^{755}	103^{741}	$+0^{005}$	0^{014}
6	103^{745}	103^{747}	103^{725}	-0^{002}	0^{022}
8	103^{727}	103^{733}	103^{710}	-0^{006}	0^{023}
10	103^{709}	103^{720}	103^{694}	0^{011}	0^{026}
12	103^{690}	103^{711}	103^{676}	0^{021}	0^{035}
14	103^{670}	103^{695}	103^{657}	0^{025}	0^{038}
16	103^{648}	103^{684}	103^{637}	0^{036}	0^{045}
18	103^{627}	103^{672}	103^{615}	0^{045}	0^{057}
20	103^{605}	103^{655}	103^{599}	0^{050}	0^{056}
22	103^{584}	103^{644}	103^{577}	0^{060}	0^{067}
24	103^{562}	103^{630}	103^{561}	0^{068}	0^{069}
26	103^{540}	103^{613}	103^{540}	0^{073}	0^{073}
28	103^{522}	103^{601}	103^{525}	0^{079}	0^{076}
30	103^{502}	103^{586}	103^{503}	0^{084}	0^{083}
32	103^{481}	103^{573}	103^{485}	0^{092}	0^{089}
34	103^{462}	103^{563}	103^{472}	0^{101}	0^{291}
36	103^{443}	103^{550}	103^{457}	0^{107}	0^{093}
37	103^{434}	103^{544}	103^{445}	0^{110}	0^{099}
F. Axle	100^{740}	100^{765}	100^{748}	0^{025}	0^{017}
R. Axle	100^{934}	100^{963}	100^{955}	0^{029}	0^{008}
O.K.B.M. 1	100^{000} (Assumed)				

9-24-75
9-25-75

DEFLECTIONS - VAN

Refer - Field Book (Survey) Pg. 176 thru 183 - Engineering

Tele Ext. 265

RIGHT SIDE

Point	Elev. LOADED	Elev. UNLOADED	Elev. RELOADED	1st Defl.	2nd Defl.
-2'6"	$103^{\underline{956}}$	$103^{\underline{935}}$	$103^{\underline{939}}$	$+0^{\underline{021}}$	$+0^{\underline{024}}$
-2	$103^{\underline{956}}$	$103^{\underline{934}}$	$103^{\underline{938}}$	$+0^{\underline{022}}$	$+0^{\underline{004}}$
0	$103^{\underline{936}}$	$103^{\underline{916}}$	$103^{\underline{920}}$	$+0^{\underline{020}}$	$+0^{\underline{004}}$
2	$103^{\underline{917}}$	$103^{\underline{917}}$	$103^{\underline{910}}$	$0^{\underline{000}}$	$-0^{\underline{007}}$
4	$103^{\underline{901}}$	$103^{\underline{906}}$	$103^{\underline{894}}$	$-0^{\underline{005}}$	$-0^{\underline{012}}$
6	$103^{\underline{884}}$	$103^{\underline{895}}$	$103^{\underline{878}}$	$0^{\underline{011}}$	$0^{\underline{017}}$
8	$103^{\underline{870}}$	$103^{\underline{887}}$	$103^{\underline{864}}$	$0^{\underline{017}}$	$0^{\underline{023}}$
10	$103^{\underline{850}}$	$103^{\underline{880}}$	$103^{\underline{849}}$	$0^{\underline{030}}$	$0^{\underline{031}}$
12	$103^{\underline{835}}$	$103^{\underline{869}}$	$103^{\underline{833}}$	$0^{\underline{034}}$	$0^{\underline{036}}$
14	$103^{\underline{815}}$	$103^{\underline{858}}$	$103^{\underline{815}}$	$0^{\underline{043}}$	$0^{\underline{043}}$
16	$103^{\underline{800}}$	$103^{\underline{848}}$	$103^{\underline{793}}$	$0^{\underline{048}}$	$0^{\underline{050}}$
18	$103^{\underline{781}}$	$103^{\underline{841}}$	$103^{\underline{780}}$	$0^{\underline{060}}$	$0^{\underline{061}}$
20	$103^{\underline{759}}$	$103^{\underline{832}}$	$103^{\underline{765}}$	$0^{\underline{073}}$	$0^{\underline{067}}$
22	$103^{\underline{738}}$	$103^{\underline{820}}$	$103^{\underline{742}}$	$0^{\underline{082}}$	$0^{\underline{078}}$
24	$103^{\underline{715}}$	$103^{\underline{810}}$	$103^{\underline{723}}$	$0^{\underline{095}}$	$0^{\underline{087}}$
26	$103^{\underline{697}}$	$103^{\underline{797}}$	$103^{\underline{702}}$	$0^{\underline{100}}$	$0^{\underline{095}}$
28	$103^{\underline{678}}$	$103^{\underline{785}}$	$103^{\underline{689}}$	$0^{\underline{107}}$	$0^{\underline{096}}$
30	$103^{\underline{660}}$	$103^{\underline{775}}$	$103^{\underline{670}}$	$0^{\underline{115}}$	$0^{\underline{105}}$
32	$103^{\underline{642}}$	$103^{\underline{763}}$	$103^{\underline{655}}$	$0^{\underline{121}}$	$0^{\underline{108}}$
34	$103^{\underline{626}}$	$103^{\underline{754}}$	$103^{\underline{638}}$	$0^{\underline{128}}$	$0^{\underline{116}}$
36	$103^{\underline{610}}$	$103^{\underline{745}}$	$103^{\underline{620}}$	$0^{\underline{135}}$	$0^{\underline{125}}$
37	$103^{\underline{683}}$	$103^{\underline{794}}$	$103^{\underline{630}}$	$0^{\underline{111}}$	$0^{\underline{114}}$
F. Axle	$101^{\underline{442}}$	$100^{\underline{959}}$	$100^{\underline{901}}$	$+0^{\underline{483}}$	$-0^{\underline{058}}$
R. Axle	$100^{\underline{961}}$	$101^{\underline{056}}$	$100^{\underline{982}}$	$+0^{\underline{875}}$	$+0^{\underline{916}}$
C.K.B.M.	$100^{\underline{000}}$	(assumed elev.)			

DEFLECTION ELEV. FLATBED TRAILER

Refer - Field Book (Survey) Pg. 168 thru 175 - Engineering

Tele. Ext. 265

LEFT SIDE

Point	Elev. (LOADED)	Elev. (UNLOADED)	Elev. (RELOADED)	1st Defl.	2nd Defl.
36-10	$103^{\underline{772}}$	$103^{\underline{937}}$	$103^{\underline{810}}$	$-0^{\underline{165}}$	$-0^{\underline{127}}$
36	$103^{\underline{773}}$	$103^{\underline{951}}$	$103^{\underline{830}}$	$0^{\underline{178}}$	$0^{\underline{121}}$
34	$103^{\underline{800}}$	$103^{\underline{955}}$	$103^{\underline{831}}$	$0^{\underline{155}}$	$0^{\underline{124}}$
32	$103^{\underline{815}}$	$103^{\underline{961}}$	$103^{\underline{845}}$	$0^{\underline{146}}$	$0^{\underline{116}}$
30	$103^{\underline{835}}$	$103^{\underline{974}}$	$103^{\underline{860}}$	$0^{\underline{139}}$	$0^{\underline{114}}$
28	$103^{\underline{853}}$	$103^{\underline{982}}$	$103^{\underline{874}}$	$0^{\underline{129}}$	$0^{\underline{100}}$
26	$103^{\underline{881}}$	$104^{\underline{005}}$	$103^{\underline{891}}$	$0^{\underline{124}}$	$0^{\underline{114}}$
24	$103^{\underline{895}}$	$104^{\underline{009}}$	$103^{\underline{911}}$	$0^{\underline{114}}$	$0^{\underline{098}}$
22	$103^{\underline{912}}$	$104^{\underline{017}}$	$103^{\underline{927}}$	$0^{\underline{105}}$	$0^{\underline{090}}$
20	$103^{\underline{940}}$	$104^{\underline{030}}$	$103^{\underline{952}}$	$0^{\underline{090}}$	$0^{\underline{076}}$
18	$103^{\underline{973}}$	$104^{\underline{035}}$	$103^{\underline{985}}$	$0^{\underline{062}}$	$0^{\underline{050}}$
16	$103^{\underline{985}}$	$104^{\underline{035}}$	$103^{\underline{987}}$	$0^{\underline{050}}$	$0^{\underline{049}}$
14	$104^{\underline{002}}$	$104^{\underline{042}}$	$104^{\underline{003}}$	$0^{\underline{040}}$	$0^{\underline{034}}$
12	$104^{\underline{020}}$	$104^{\underline{043}}$	$104^{\underline{018}}$	$0^{\underline{023}}$	$0^{\underline{025}}$
10	$104^{\underline{036}}$	$104^{\underline{043}}$	$104^{\underline{030}}$	$0^{\underline{007}}$	$0^{\underline{013}}$
8	$104^{\underline{045}}$	$104^{\underline{045}}$	$104^{\underline{045}}$	$0^{\underline{000}}$	$0^{\underline{000}}$
6	$104^{\underline{060}}$	$104^{\underline{044}}$	$104^{\underline{049}}$	$(+0^{\underline{016}})$	$(+0^{\underline{005}})$
4	$104^{\underline{067}}$	$104^{\underline{047}}$	$104^{\underline{051}}$	$+0^{\underline{020}}$	$+0^{\underline{004}}$
2	$104^{\underline{085}}$	$104^{\underline{047}}$	$104^{\underline{065}}$	$+0^{\underline{038}}$	$+0^{\underline{018}}$
0	$104^{\underline{101}}$	$104^{\underline{050}}$	$104^{\underline{090}}$	$+0^{\underline{051}}$	$+0^{\underline{040}}$
-2	$104^{\underline{120}}$	$104^{\underline{052}}$	$104^{\underline{105}}$	$+0^{\underline{068}}$	$+0^{\underline{053}}$
-2-10	$104^{\underline{125}}$	$104^{\underline{053}}$	$104^{\underline{104}}$	$+0^{\underline{072}}$	$+0^{\underline{051}}$
F. Axle	$101^{\underline{610}}$	$101^{\underline{671}}$	$101^{\underline{619}}$	$-0^{\underline{061}}$	$-0^{\underline{052}}$
R. Axle	$101^{\underline{612}}$	$101^{\underline{676}}$	$101^{\underline{598}}$	$-0^{\underline{064}}$	$-0^{\underline{078}}$

Assumed B.M. $100^{\underline{000}}$

DEFLECTION ELEV. FLATBED TRAILER

Refer – Field Book (Survey) Pg. 168 thru 175 – Engineering

RIGHT SIDE

Point	Elev. (LOADED)	Elev. (UNLOADED)	Elev. (RELOADED)	1st Defl.	2nd Defl.
36-10	103^{757}	103^{910}	103^{780}	-0^{153}	-0^{130}
36	103^{778}	103^{930}	103^{796}	-0^{142}	-0^{124}
34	103^{800}	103^{931}	103^{812}	-0^{131}	-0^{119}
32	103^{823}	103^{944}	103^{831}	-0^{121}	-0^{113}
30	103^{835}	103^{961}	103^{851}	0^{126}	0^{110}
28	103^{867}	103^{977}	103^{878}	0^{110}	0^{097}
26	103^{883}	103^{991}	103^{888}	0^{108}	0^{103}
24	103^{915}	104^{008}	103^{903}	0^{093}	0^{105}
22	103^{936}	104^{026}	103^{937}	0^{090}	0^{089}
20	103^{965}	104^{047}	103^{970}	0^{082}	0^{077}
18	103^{985}	104^{060}	103^{987}	0^{075}	0^{073}
16	104^{010}	104^{070}	104^{018}	0^{060}	0^{050}
14	104^{035}	104^{085}	104^{033}	0^{050}	0^{052}
12	104^{060}	104^{095}	104^{053}	0^{030}	0^{037}
10	104^{035}	104^{110}	104^{058}	0^{025}	0^{052}
8	104^{110}	104^{110}	104^{093}	0^{000}	0^{017}
6	104^{115}	104^{111}	104^{104}	(+0^{004})	-0^{007}
4	104^{140}	104^{109}	104^{142}	(+0^{031})	(+0^{033})
2	104^{157}	104^{118}	104^{153}	(+0^{039})	(+0^{035})
0	104^{165}	104^{130}	104^{162}	(+0^{035})	(+0^{032})
-2	104^{185}	104^{130}	104^{185}	(+0^{055})	(+0^{056})
-2-10	104^{195}	104^{140}	104^{186}	(+0^{055})	(+0^{046})
F. Axle	101^{625}	101^{678}	101^{602}	-0^{053}	-0^{076}
R. Axle	101^{596}	101^{671}	101^{572}	0^{075}	-0^{099}

Assumed B.N. 100^{000}

APPENDIX B

MAXIMUM TEST LEVELS

DEMONSTRATION TEST PROGRAM

CONFIGURATION 1, SHAKERS IN-PHASE

MAXIMUM TEST LEVELS

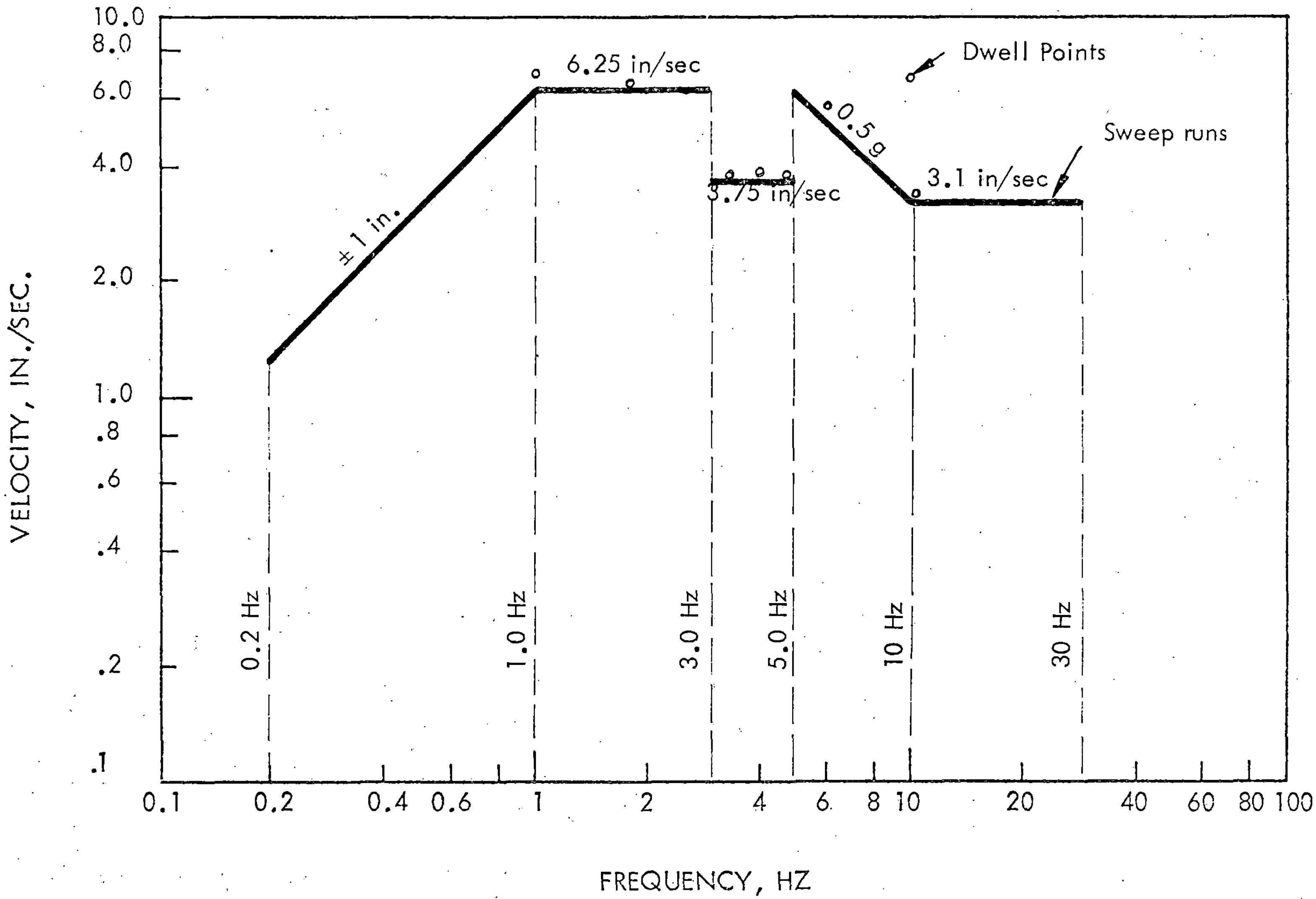


FIGURE B-1

DEMONSTRATION TEST PROGRAM

CONFIGURATION 1, SHAKERS OUT-OF-PHASE

MAXIMUM TEST LEVELS

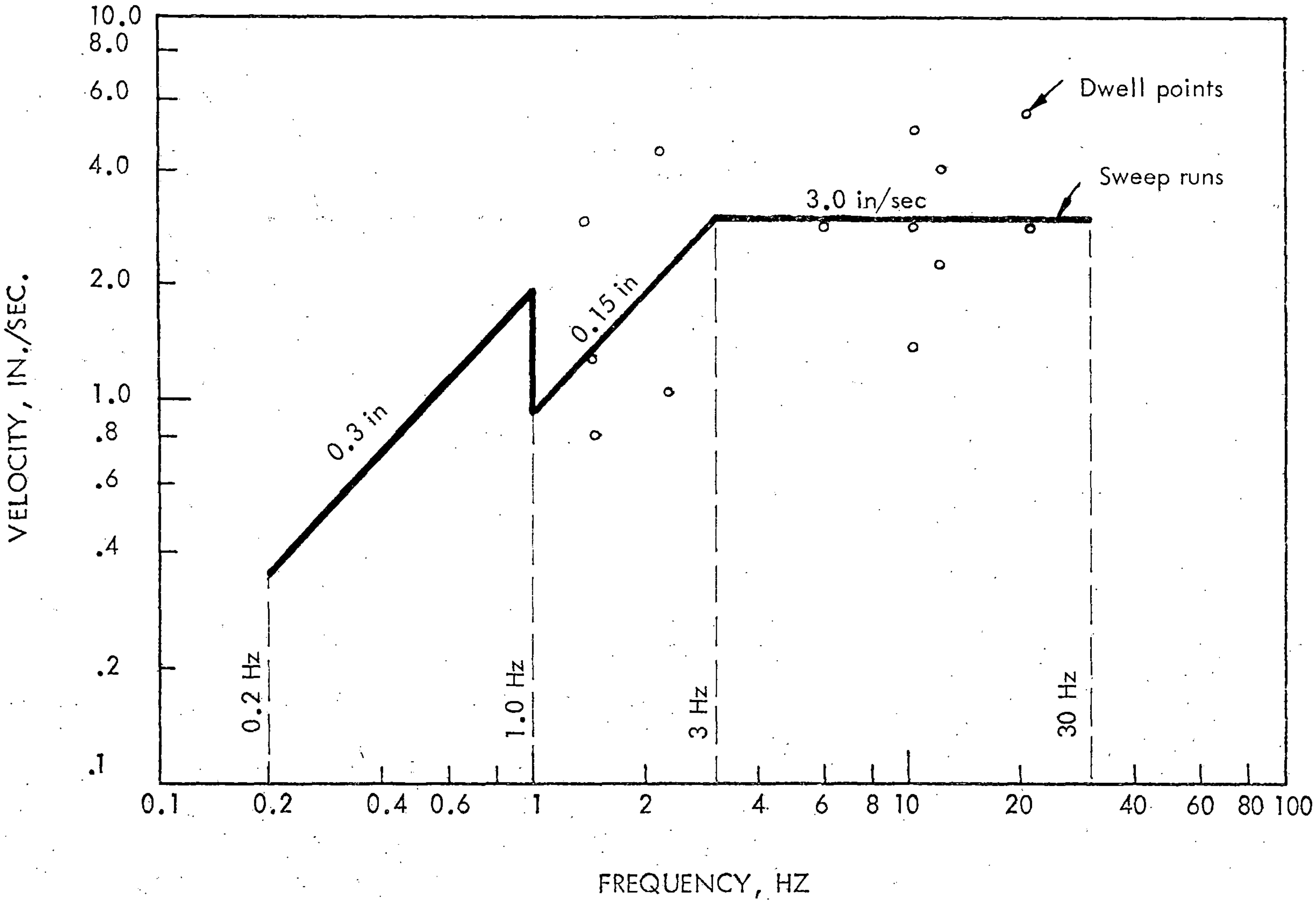


FIGURE B-2

DEMONSTRATION TEST PROGRAM

CONFIGURATION 2, SHAKERS IN-PHASE

MAXIMUM TEST LEVELS

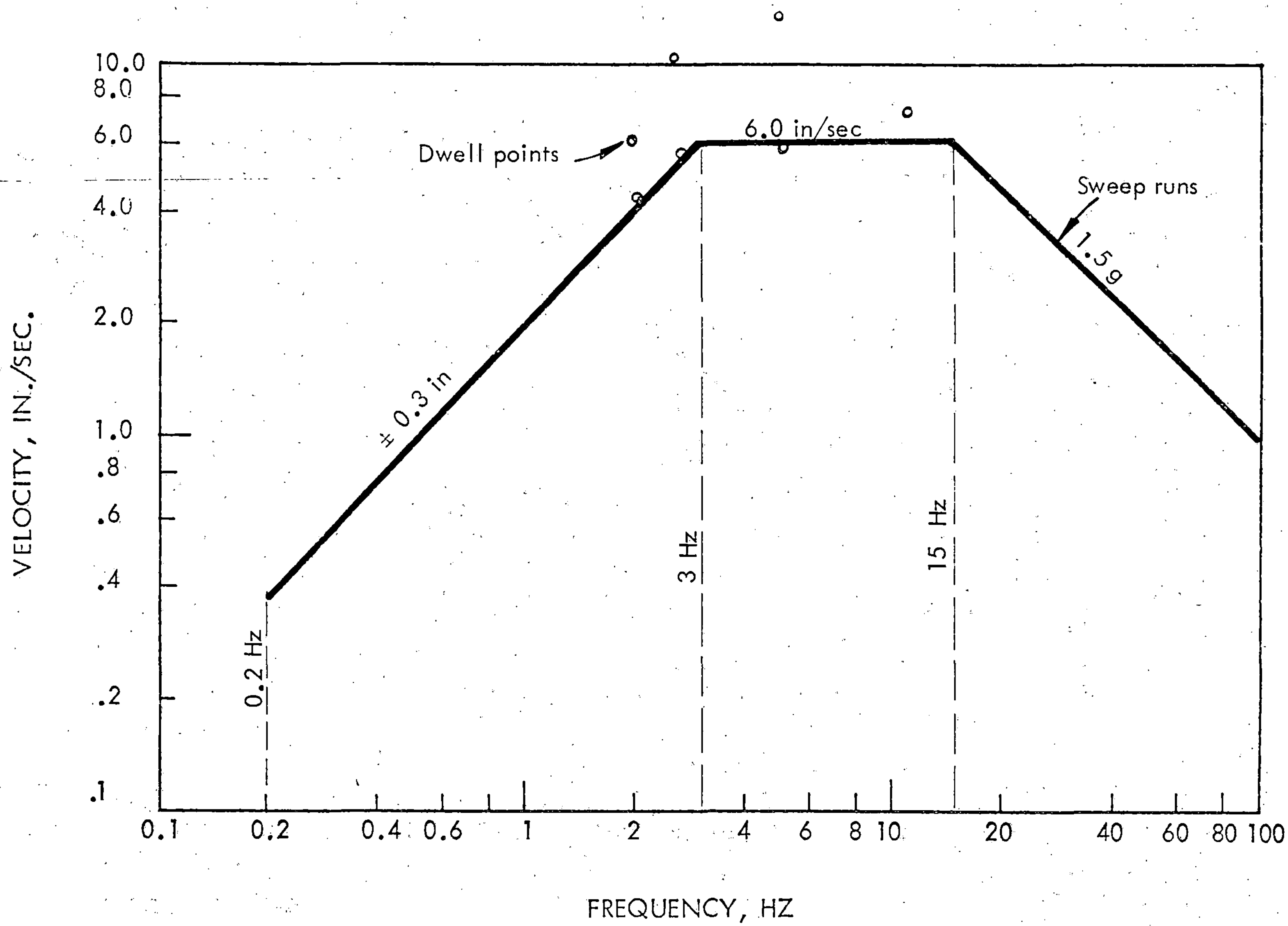


FIGURE B-3

DEMONSTRATION TEST PROGRAM
CONFIGURATION 2, SHAKERS OUT-OF-PHASE
MAXIMUM TEST LEVEL

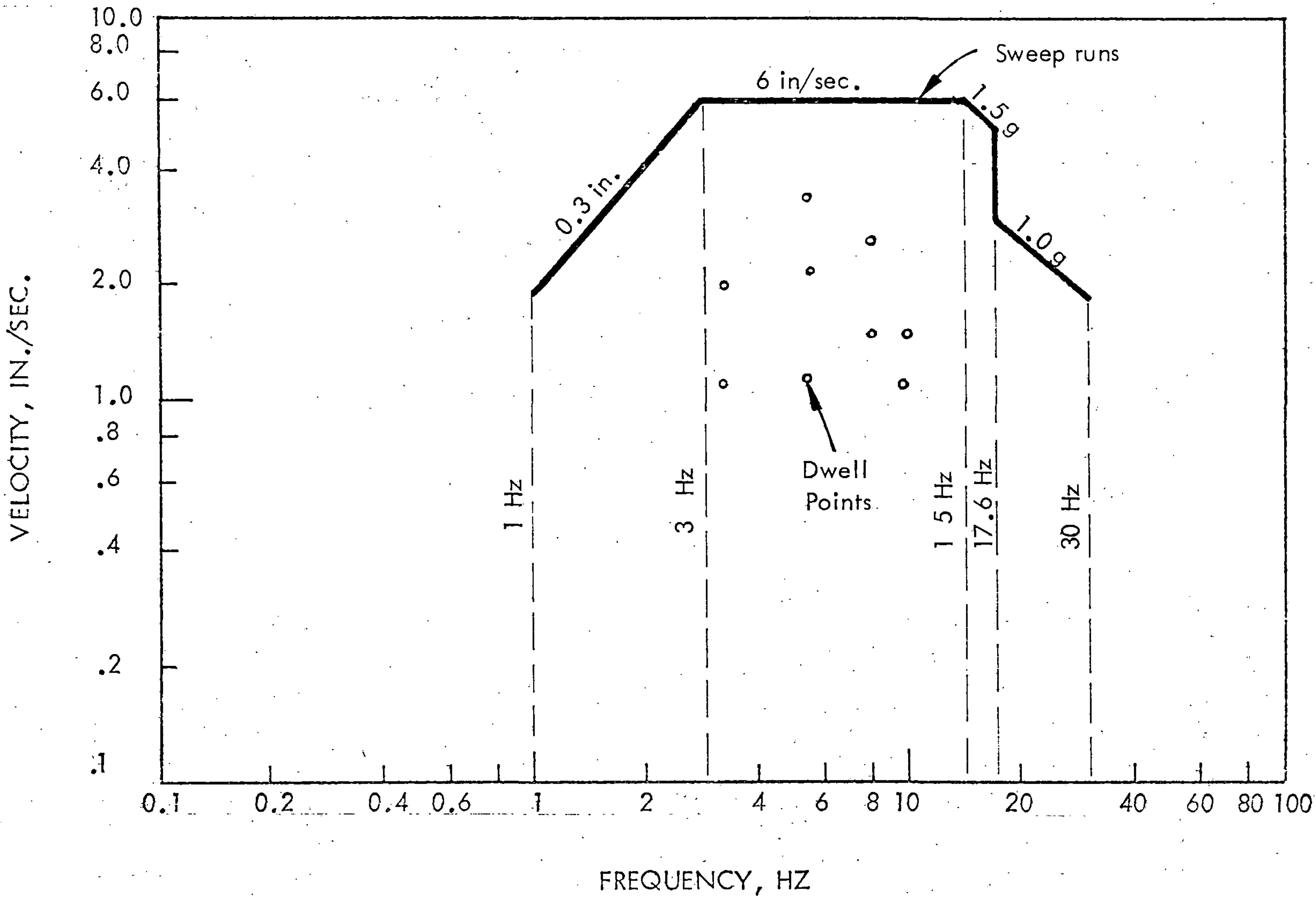


FIGURE B-4

DEMONSTRATION TEST PROGRAM
CONFIGURATION 3, SHAKERS IN-PHASE
MAXIMUM TEST LEVELS

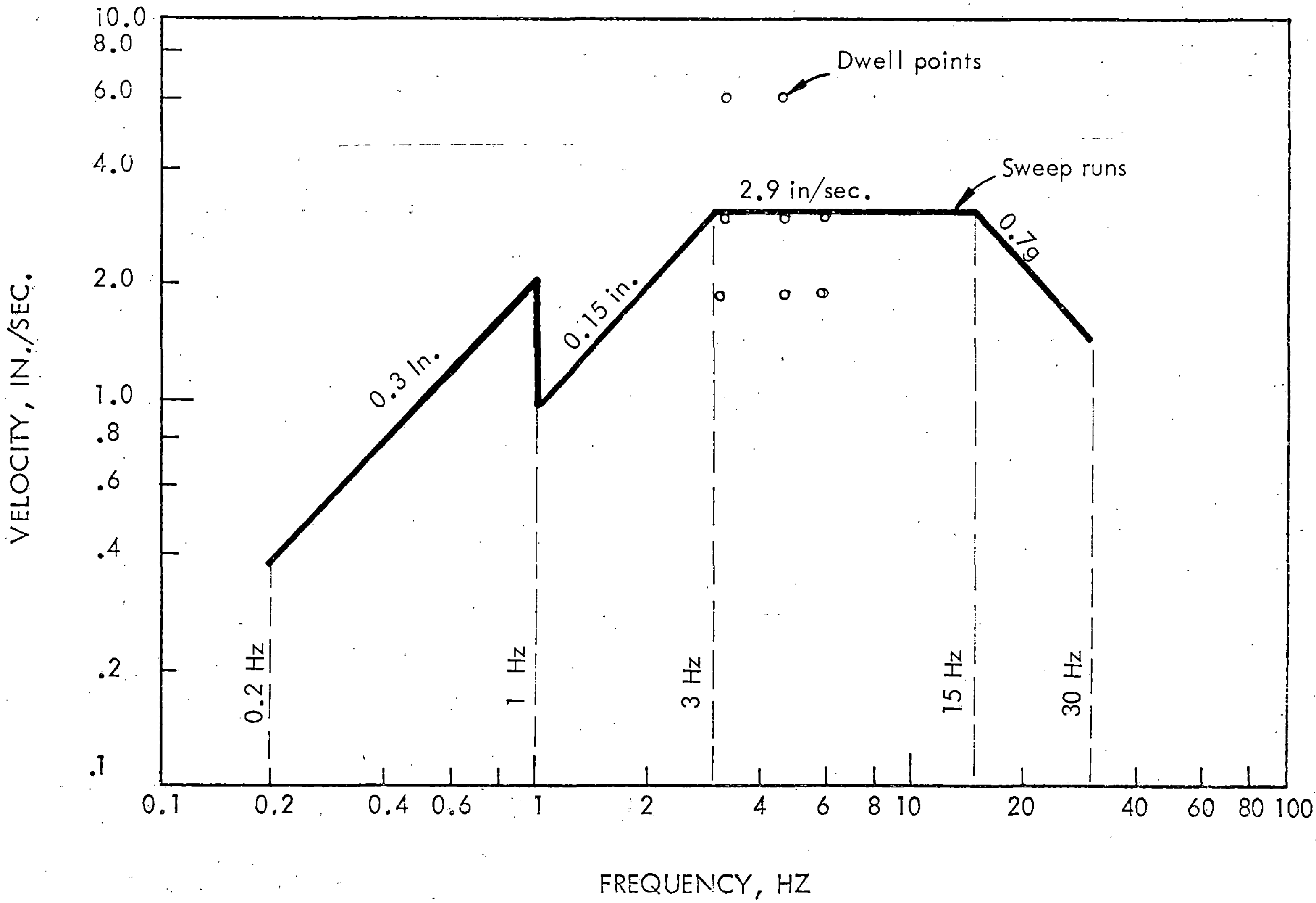


FIGURE B-5

DEMONSTRATION TEST PROGRAM

CONFIGURATION 3, SHAKERS OUT-OF-PHASE

MAXIMUM TEST LEVELS

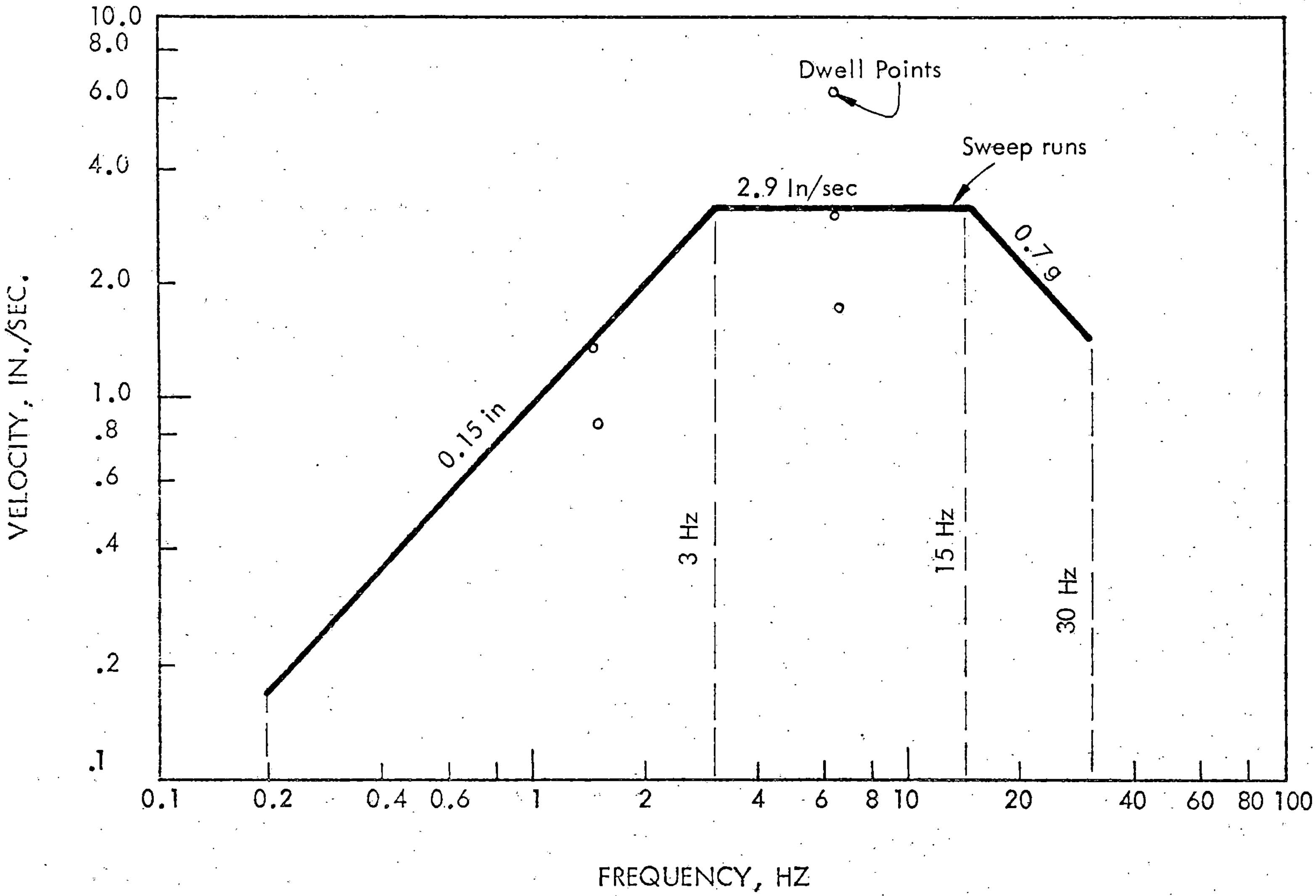


FIGURE B-6

APPENDIX C

DETAILED RUN SUMMARY

RUN NO.	CONFIGURATION	SHAKER PHASING
1	1	In
2	1	In
3	1	In
4	1	In
5	1	In
6	1	In
7	1	In
8	1	In
9	1	Out
10	1	Out
11	1	Out
12	1	Out
13	1	Out
14	1	Out
15	1	In
16	1	In
17	1	In

FINAL

DEMONSTRATION TEST PROGRAM

RUN SUMMARY

FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
0.2 to 1.0 Hz	0.1 inch	1	Normal	
1.0 to 3.0 Hz	0.1 inch	1	Normal	
3.0 to 4.2 Hz	0.1 inch	3.5	#118 @ 0.1 g's (1)	
1.0 to 4.7 Hz	0.1 inch	10	#57 @ 0.5's (1)	
1.0 to 5.3 Hz	0.05 inch	10	#57 @ 1.0 g's (1)	
1.0 to 8.9 Hz	0.05 inch	10	#66 @ 2.4 g's (1)	
8 to 9.6 Hz 9.6 to 16.2 Hz	0.05 inch 3 in/sec	10	#118 @ 1.2 g's (1)	
8 to 9.6 Hz 9.6 to 30 Hz	0.05 inch 3 in/sec	10	Normal	
0.2 to 1.3 Hz	0.1 inch	4	#115 @0.1 g's (1)	
1 to 2.1 Hz	0.1 inch	10	#115 @ 0.2 g's (1)	
2.0 to 3.2 Hz	0.1 inch	10	#102 @ 5 rad/sec^2 (1)	
2.0 to 5.1 Hz	0.1 inch	10	#115 @ 0.4 g (1)	
5.0 to 8.7 Hz	0.1 inch	10	#115 @ 0.75 g (1)	
8 to 9.6 Hz 9.6 to 12 Hz	0.1 inch 6 in/sec	10	#103 @ 10 rad/sec^2 (1)	
0.2 to 1. Hz 1 to 4 Hz	0.5 inch 3.1 in/sec	2	#57 @ 2.4 g (1)	
0.2 to 1 Hz 1 to 5 Hz	0.5 inch 3.1 in/sec	2	Normal	
0.2 to 1 Hz 1 to 3 Hz	1.0 inch 6.2 in/sec	2	#118 @ 1.8 g (1)	

RUN NO.	CONFIGURATION	SHAKER PHASING
18	1	In
19	1	In
20	1	In
21	1	In
22	1	In
23	1	In
24	1	In
25	1	Out
26	1	Out
27	1	Out
28	1	Out
29	1	Out
30	1	Out
31	1	In
32	1	In
33	1	In
34	1	In

FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
2 to 3.1 Hz	6.2 in/sec	15	#118 @ 1.8 g (1)	
2 to 3.2 Hz	5 in/sec	15	#118 @ 1.8 g (1)	
2 to 5 Hz 5 to 6 Hz	4 in/sec 0.3 g	15	Normal	
5 to 10 Hz 10 to 30 Hz	0.5 g 3.1 in/sec	20	Normal	
2 to 5 Hz 5 to 6 Hz	4 in/sec 0.3 g	10	Normal	
5 Hz	1 g		#102 @ 25 rad/sec^2 (1)	Immediate shutdown
2 to 5 Hz 5 to 6 Hz	4 in/sec 0.3 g	10	#66 @ 2.0 g (1)	
2 to 3 Hz	0.1 inch	15	#102 @ 15 rad/sec^2 (1)	
2 to 4.6 Hz	0.1 inch	15	#102 @ 25 rad/sec^2 (1)	
2 to 2.8 Hz	0.1 inch	15	#102 @ 37.5 rad/sec^2 (1)	
5 to 9.3 Hz	3 in/sec	15	#103 @ 10 rad/sec^2 (1)	
5 to 11.7 Hz	3 in/sec	15	#115 @ 1.3 g (1)	
5 to 30 Hz	3 in/sec	15	Normal	
2 to 4.2 Hz	4 in/sec	10	#66 @ 5 g's (1)	Wheel liftoff switch (108) added
Dwell 1.0 Hz/.1 in Decay 1.0 Hz/.1 in Dwell 1.6 Hz/.1 in Dwell 1.8 Hz/.1 in			# 57 @ 2.5 g (1)	Strain gages (50, 51, 52) added
Dwell 3.4 Hz/.16 in			#66 @ 2.5 g (1)	
Dwell 3.3 Hz/.16 in Decay 3.4 Hz/.16 in Dwell 4.0 Hz/.14 in Decay 4.0 Hz/.14 in				

RUN NO.	CONFIGURATION	SHAKER PHASING
35	2	In
36	2	In
37	2	In
38	2	In
39	2	In
40	2	In
41	2	In
42	2	Out
43	2	Out
44	2	Out
45	2	Out

FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
Dwell 4.1 Hz/.25 in			#66 @ 5.0 g (1)	
Dwell 5.0 Hz/.1 in				
Decay 5.0 Hz/.1 in				
Dwell 5.3 Hz/.06 in				
Dwell 5.3 Hz/.1 in			#66 @ 5.0 g (1)	
Decay 5.3 Hz/.1 in				
Dwell 10 Hz/.1 in				
0.2 to 1 Hz	0.1 in	2	Normal	Stantion vertical (125) and lateral (107) added. Drive signal (105) added. A end Axial left (81) deleted, van center (76) moved to 81.
3 to 3.1 Hz	0.1 in	10	#81 @ 0.25 g (2)	
1 to 2.8 Hz	0.1 in	10	#57 @ 0.5 g (2)	
1.8 to 3.6 Hz	0.1 in	10	#115 @ 0.1 g (2)	
1.8 to 3.7 Hz	0.1 in	10	#81 @ 0.5 g (2)	
1.8 to 4.8 Hz 4.8 to 6.9 Hz	0.1 in 3 in/sec	10	#115 @ 0.2 g (2)	
1.8 to 4.8 Hz 4.8 to 30 Hz	0.1 in 3 in/sec	10	Normal	
0.2 to 1 Hz	.05 in	2	Normal	
1 to 4.0 Hz	.05 in	10	#115 @ 0.1 g (2)	
3 to 4.8 Hz 4.8 to 5.2 Hz	.05 in 1.5 in/sec	10	#119 @ 0.15 g (2)	
1 to 4.8 Hz 4.8 to 5.2 Hz	.05 in 1.5 in/sec	10	#119 @ 0.3 g (2)	

RUN NO.	CONFIGURATION	SHAKER PHASING
46	2	Out
47	2	Out
48	2	Out
49	2	Out
50	2	Out
51	2	Out
52	2	Out
53	2	In
54	2	In
55	2	In
56	2	In
57	2	In

FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
3 to 4.8 Hz	.05 in	10	#115 @0.3 g (2)	
4.8 to 5.6 Hz	1.5 in/sec			
3 to 4.8 Hz	.05 in	10	#119 @ 0.5 g (2)	
4.8 to 7.8 Hz	1.5 in/sec			
3 to 4.8 Hz	.05 in	10	#119 @0 .75 g (3)	
4.8 to 7.9 Hz	1.5 in/sec			
3 to 4.8 Hz	.05 in	10	#115 @ 0.5 g (3)	
4.8 to 9.9 Hz	1.5 in/sec			
3 to 3.1 Hz	.05 in	10	#103 @ 5 rad/sec^2 (2)	
3 to 3.8 Hz	.05 in	10	#71 @ 0.6 g (1)	
3 to 4.8 Hz	.05 in	10	Normal	
4.8 to 30 Hz	1.5 in/sec			
				Error in Amplitude run shutdown
0.2 to 1 Hz	0.3 in	2	Normal	
1 to 2.6 Hz	0.3 in	10	#126 @ 1 g	
1 to 3 Hz	0.3 in	10	Normal	
3 to 15 Hz	6 in/sec			
15 to 30 Hz	1.5 g			
Dwell 1.9 Hz/.14 in				
Dwell 2.1 Hz/.14 in				
Dwell 2.1 Hz/.28 in				
Dwell 2.1 Hz/.48 in				
Decay 2.1 Hz/.48 in				

RUN NO.	CONFIGURATION	SHAKER PHASING
58	2	In
59	Bare	In
60	Bare	In
61	Bare	In
62	2	In
63	2	Out
64	2	In
65	2	Out

FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
Dwell 2.6 Hz/.15 in				
Decay 2.6 Hz/.15 in				
Dwell 2.6 Hz/.3 in				
Dwell 2.6 Hz/.5 in			#66 @ 3 g (3)	
Dwell 5.2 Hz/.1 in				
Decay 5.2 Hz/.1 in				
Dwell 5.2 Hz/.2 in				
Decay 5.2 Hz/.2 in				
Dwell 10 Hz/.05 in				
1 to 1.2 Hz	1 inch	4	Normal	No flatcar
1.2 to 11.9 Hz	7.5 in/sec			
11.9 to 100 Hz	1.5 g			
1 to 1.4 Hz	1.5 inch	1	Normal	No flatcar
1.4 to 27.3 Hz	13.5 in/sec			
27.3 to 30 Hz	6 g			
1 to 1.4 Hz	1.5 inch	1	Normal	No flatcar
1.4 to 27.3 Hz	13.5 in/sec			
27.3 to 30 Hz	6 g			
Dwell 2.0 Hz/.26 in				Stantion longitudinal
Dwell 2.0 Hz/.5 in				(53) added
Decay 2.0 Hz/.5 in				Paramount Picture
Dwell 2.1 Hz/.5 in				
Dwell 1.3 Hz/.1 in				Paramount Picture
Dwell 2.1 Hz/.5 in				Paramount Picture
Decay 2.1 Hz/.5 in				
Dwell 1.3 Hz/.03 in				
Dwell 1.3 Hz/.06 in				
Decay 1.3 Hz/.06 in				
Dwell 1.3 Hz/.1 in				
Decay 1.3 Hz/.1 in				
Dwell 3.1 Hz/.03 in				
Dwell 3.1 Hz/.06 in				
Dwell 3.1 Hz/.09 in				
Decay 3.1 Hz/.09 in				
Dwell 5.1 Hz/.03 in				
Decay 5.1 Hz/.03 in				
Dwell 5.1 Hz/.06 in				

RUN NO.	CONFIGURATION	SHAKER PHASING	FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
66	2	Out	Dwell 8.4 Hz/.015 in Dwell 8.4 Hz/.03 in Decay 8.4 Hz/.03 in Dwell 10 Hz/.015 in Dwell 10 Hz/.03 in				
67	2	In	1 to 3 Hz 3 to 15 Hz 15 to 100 Hz	0.3 in 6 in/sec 1.5 g	5	Normal	
68	2	In	1 to 3 Hz 3 to 15 Hz 15 to 100 Hz	0.1 in 2 in/sec 0.5 g	5	Normal	Level was 1/3 that called for in run cards.
69	2	In	30 to 15 Hz 15 to 3 Hz 3 to 1 Hz	0.5 g 2 in/sec 0.1 in	10	Normal	Reverse sweep same level problem as 68
70	2	In	1 to 3 Hz 3 to 15 Hz 15 to 100 Hz	0.3 in 6 in/sec 1.5 g	5	Normal	
71	2	In	30 to 15 Hz 15 to 3 Hz 3 to 2.54 Hz	1.5 g 6 in/sec 0.5 in	10	#108	Lift off switch fell off
72	2	In	30 to 15 Hz 15 to 3 Hz 3 to 1 Hz	1.5 g 6 in/sec 0.3 in	10	Normal	
73	2	In	30 to 15 Hz 15 to 3 Hz 3 to 1 Hz	1.5 g 6 in/sec 0.3 in	10	Normal	
74	2	Only 1 & 2 moving	1 to 4.8 Hz 4.8 to 12.6 Hz	0.2 in 6 in/sec		#115 @1.0 g (3)	Cross coupling test
75	2	Only 1 & 2 moving	1 to 4.8 Hz 4.8 to 15 Hz 15 to 30 Hz	0.2 in 6 in/sec 1.5 g	10	Normal	Cross coupling test
76	2	Only 3 & 4 moving	1 to 4.8 Hz 4.8 to 5.9 Hz	0.2 in 6 in/sec	10	#102 @ 10rad/sec^2 (3)	Cross coupling test

RUN NO.	CONFIGURATION	SHAKER PHASING
77	2	Only 3 & 4 moving
78	2	Out
79	2	Out
80	2	Out
81	2	Out
82	2	Out
83	2	Out
84	2	Out
85	2	Out
86	Bare	In
87	1	In
88	1	In

FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
1 to 4.8 Hz 4.8 to 15 Hz 15 to 30 Hz	0.2 in 6 in/sec 1.5 g	10	Normal	Cross coupling test
1 to 3 Hz 3 to 15 Hz 15 to 30 Hz	0.1 in 2 in/sec 0.5 g	10	Normal	
1 to 3 Hz 3 to 15 Hz 15 to 21 Hz	0.2 in 4 in/sec 1.0 g	10	#115 @ 1.5 g (3)	
3 to 15 Hz 15 to 30 Hz	4 in/sec 1.0 g	10	Normal	
30 to 15 Hz 15 to 3 Hz 3 to 1 Hz	1.0 g 4 in/sec 0.2 in	10	Normal	
30 to 15 Hz 15 to 3 Hz 3 to 1 Hz	1.0 g 4 in/sec 0.2 in	10	Normal	
2.0 to 6 Hz	0.3 in	2	Manual shutdown	error in Wavetek setting
1.0 to 1.4 Hz	0.3 in	10	Computer glitch caused shutdown	
1 to 3 Hz 3 to 15 Hz 15 to 17.6 Hz	0.3 in 6 in/sec 1.5 g	10	#102 @ 20 rad/sec^2 (3)	
Dwell 1.0 Hz/1.0 in				
1 to 3.05 Hz	6.25 in/sec	10	#57 @ 3.0 g (3)	
1 to 3.1 Hz	6.25 in/sec	10	#118 @ 1.3 g (3)	

RUN NO.	CONFIGURATION	SHAKER PHASING
89	1	Out
90	1	Out
91	1	Out
92	1	Out
93	1	Out
94	1	Out
95	3	In
96	3	Out
97	3	Out

FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
0.2 to 1 Hz	0.3 in	2	Normal	
1 to 2.3 Hz	0.15 in	10	#102 @ 15 rad/sec^2 (3)	
2 to 2.3 Hz	0.15 in	10	#102 @ 25 rad/sec^2 (3)	
2 to 3 Hz	0.15 in	10	Normal	
3 to 15 Hz	2.85 in/sec			
15 to 30 Hz	0.7 g's			
Dwell 1.0 Hz/.3 in				
Dwell 1.0 Hz/.5 in			#108 wheel liftoff	
Dwell 1.3 Hz/.1 in				
Dwell 1.3 Hz/.2 in				
Dwell 1.3 Hz/.3 in				
Decay 1.3 Hz/.3 in				
Dwell 2.2 Hz/.1 in				
Dwell 2.2 Hz/.2 in				
Dwell 3.0 Hz/.05 in				
Dwell 6 Hz/.05 in				
Decay 6 Hz/.05 in				
Dwell 9.5 Hz/.02 in				
Dwell 9.5 Hz/.03 in				
Dwell 9.5 Hz/.07 in				
Decay 9.5 Hz/.07 in				
Dwell 12 Hz/.03 in				
Dwell 12 Hz/.05 in				
Decay 12 Hz/.05 in				
Dwell 20 Hz/.01 in				
Dwell 20 Hz/.04 in				
1 to 3 Hz	0.15 in	5	Normal	Instrumentation changed to configuration 3 (see figure
3 to 15 Hz	2.85 in/sec			
15 to 30 Hz	0.7 g's			
1 to 3 Hz	0.15 in	5	#127 @ 2.5 g (3)	
3 to 4.7 Hz	2.85 in/sec			
1 to 3 Hz	0.15 in	5	Normal	
3 to 15 Hz	2.85 in/sec			
15 to 30 Hz	0.7 g's			

RUN NO.	CONFIGURATION	SHAKER PHASING
98	3	In
99	3	In
100	3	Out
101	3	In
102	3	In
103	3	In
104	3	In
105	3	Out

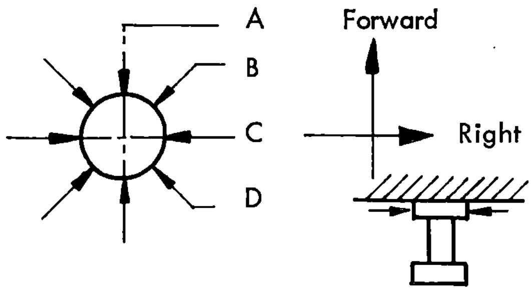
FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
Dwell 3.4 Hz/.07 in				
Dwell 3.4 Hz/.14 in				
Decay 3.4 Hz/.14 in				
Dwell 3.4 Hz/.25 in				
Decay 3.4 Hz/.25 in				
Dwell 4.1 Hz/.05 in				
Dwell 4 Hz/.11 in				
Decay 4 Hz/.11 in				
Dwell 4 Hz/.22 in				
Decay 4 Hz/.22 in				
Dwell 5.3 Hz/.04 in				
Dwell 5.3 Hz/.08 in				
Dwell 1.3 Hz/.08 in				
Dwell 1.3 Hz/.15 in				
Decay 1.3 Hz/.15 in				
Dwell 6 Hz/.04 in				
Dwell 6.3 Hz/.08 in				
Decay 6.3 Hz/.08 in				
Dwell 6.3 Hz/.15 in				
Decay 6.3 Hz/.15 in				
0.2 to 1.0 Hz	0.3 in	2	Normal	
1 to 3 Hz	0.225 in	10	#118 @ 1.25 g (3)	
3 to 15 Hz	4.28 in/sec			
15 to 22.6 Hz	1.05 g			
1 to 3 Hz	0.225 in	10	Normal	
3 to 15 Hz	4.28 in/sec			
15 to 30 Hz	1.05 g			
30 to 15 Hz	1.05 g	10	Normal	
15 to 3 Hz	4.28 in/sec			
3 to 1 Hz	0.225 in			
1 to 3 Hz	0.15 in	10	Normal	
3 to 15 Hz	2.85 in/sec			
15 to 30 Hz	0.7 g			

RUN NO.	CONFIGURATION	SHAKER PHASING
106	3	Out
107	3	Out

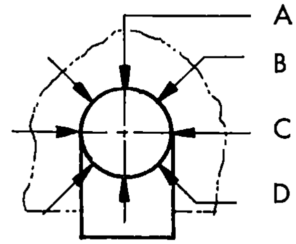
FREQUENCY/LEVEL		Q	SHUTDOWNS Channel/Level/Occurances	COMMENTS
0.2 to 1 Hz	0.15 in	2	Normal	
30 to 15 Hz 15 to 3 Hz 3 to 1 Hz	0.7 gls 2.85 in/sec 0.15 inch	10	Normal	

APPENDIX D

PRE AND POST TEST MEASUREMENTS



Trailer



Flatcar

1.0 Trailer

	Van		Platform	
	Pretest	Post test	Pretest	Post test
A	2.872	2.872	2.867	2,868
B	2.872	2.872	2.868	2.868
C	2.872	2.872	2.868	2.868
D	2.873	2.873	2.868	2.868

2.0 Flat Car

	A-End		B-End	
	Pretest	Post test	Pretest	Post test
A	2.975	2.940	3.004	2.797
B	2.749	2.931	3.012	3.005
C				
D	3.011	2.977	3.001	2.160

			TIRE PRESSURE (PSI)							
	Trailer		Front Axle				Rear Axle			
			Left		Right		Left		Right	
Date/Time	Van	Flat	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner
11/5/75 0845	X		85	85	85	85	85	85	85	85
11/5/75 0900		X	85	85	85	Flat	85	85	85	85
11/12/75 1310	X		85	85	85	85	85	85	85	85
1315		X	85	85	70	Flat	85	85	85	85
11/13/75	X		85	85	85	84	84	85	84	82
		X	85	85	85	Flat	85	85	83	84
11/17/75	X		83	83	82	84	81	83	83	82
		X	82	83	75	Flat	84	84	81	82
11/20/75	X		81	81	80	81	80	80	79	80
		X	80	80	79	Flat	80	62	79	80

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