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PERFORMANCE EVALUATION OF AN ON-BOARD DATA ACQUISITION SYSTEM

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

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16. Abstract

This report contains the results of a test performed to evaluate an on-board data acquisition system in a crash test environment. The test was performed at the Federal Outdoor Impact Laboratory (FOIL) located in McLean, Virginia. The data acquisition system was manufactured by DSP Technologies, Incorporated. Data collected by the on-board system was compared to data collected by the current FOIL system. The on-board data acquisition system posed no physical barriers for use at the FOIL. The data from the on-board data acquisition system compared well with the data collected by the current FOIL system.

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Introduction

This document is an extension of a document entitled "Evaluation of Alternative Data Acquisition Systems,"[1] and contains the results from a single full scale vehicle crash test at 20 mi/h (9.84 m/s) into a slip base mounted luminaire support. The test was conducted at the Federal Outdoor Impact Laboratory (FOIL) in McLean, Virginia. The purpose of this test was to further evaluate the performance of an on-board data acquisition system in an actual crash test environment. Both the hardware and software of the system were under evaluation during the crash test. The data acquisition system was manufactured by DSP Technologies, Inc. The data collected by the on-board system was compared to the data collected by the current data collection system used at the FOIL. Comparisons were made between vehicle change in velocity, peak acceleration, impact event duration time, and the overall shape of the acceleration versus time data trace to determine the adequacy of the system. The FOIL system is considered the reference system due to the repeatability and reliability of previous crash test data.

Data Acquisition Systems Description

1. FOIL System

Currently at the FOIL, an umbilical cable stretches between the test vehicle and the FOIL's instrumentation enclosure. Inside the instrumentation enclosure, the transducer signals are conditioned and amplified by a Vishay 2300 signal conditioning amplifier. The signals are then recorded on analog tape using a Honeywell 5600 E tape recorder. The recording capacity of the tape recorder limits the amount of data collected to 14 channels. After the

[1] Brown, Christopher, "Evaluation of Alternative Data Acquisition Systems," Federal Highway Administration, Report No. FHWA-RD-89-160, May 1989.

tests, the tape is played back through a low pass anti-aliasing Butterworth filter with a cut-off frequency of 350 Hz, then through a Keithley-Das series 500 digitizer connected to an IBM PC-AT. The sampling rate of the A/D converter is 1250 Hz. The digital data files are then scaled and converted to engineering units using an array of FORTRAN algorithms. Included in the FORTRAN algorithms is a digital Butterworth low pass filter with a cut-off frequency of 100 Hz. The new converted and filtered files are then imported into a Lotus 123 worksheet, where the data are graphed and analyzed.

2. DSP ODAS III

The DSP system consists of two separate units. The first unit is the ODAS III unit. The ODAS III is capable of recording 8 channels of data (other configurations are available). The transducers are supplied excitation voltage from the ODAS unit. The transducer signals are also amplified, filtered and digitized within the ODAS unit. The ODAS III parameters are factory set at a 12.5 kHz sampling rate, 4000 Hz anti-aliasing filter, and transducer excitation voltage of 10 volts. The ODAS III box used in this test had a memory capacity of 4k bytes.

The second ODAS unit is the communication and power distribution box (CPD box). The function of the CPD box is to distribute 12 volts DC power to each ODAS III unit connected to the CPD. The CPD box is supplied 12 volts DC from a gell cell battery not provided by DSP Technologies. The CPD unit can accommodate up to six ODAS III units. In this test, only one ODAS III was used. The CPD box also links each ODAS III unit to a host computer during system configuration and data retrieval. Another function of the CPD box is to distribute a trigger signal to each ODAS III unit simultaneously, once the CPD itself has been triggered.

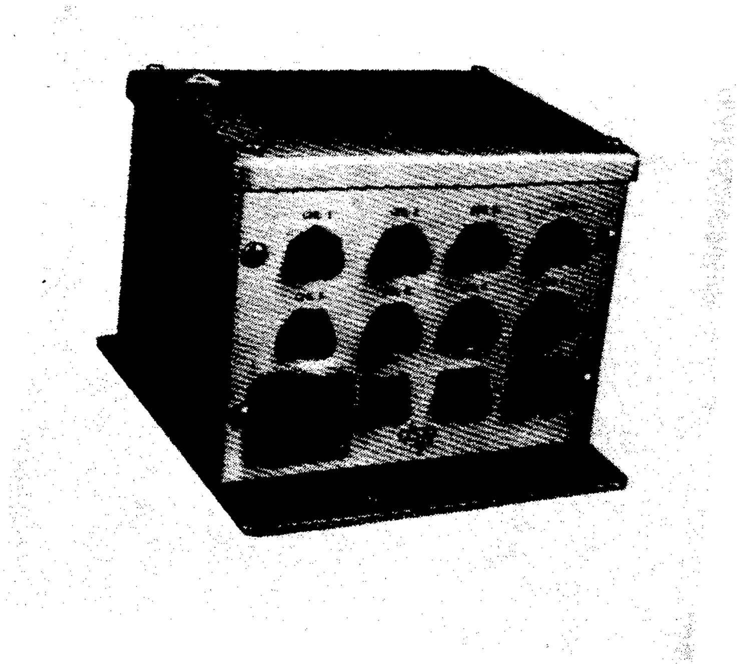
After data have been collected and downloaded to the host computer, the data are converted to engineering units and displayed graphically within the DSP system. In addition, the digital data files are converted to ASCII format using a routine within the DSP system software for analysis in a Lotus 123 worksheet. Before the data files are imported into the Lotus spreadsheet, the data files are run through a digital Butterworth low pass filter with a cut-off frequency of 100 Hz (to match the FOIL systems' final cut-off frequency). The DSP ODAS III system is shown in figure 1. Further system capabilities and specifications are listed in Appendix A.

Test Vehicle

The automobile used in the crash test was a 1979 VW Rabbit two door sedan. The test automobile had the gas tank, battery, and back seat removed. The vehicle weighed 1805 lb (820 kg) completely instrumented (including both the transducer data package and the on-board data system). A remote brake system was also installed in the test vehicle, and consisted of an air tank and a cylinder with a remotely triggered electronic valve. The cylinder was attached to the brake pedal. This test vehicle was previously used as part of a separate research project at the FOIL. The purpose of this test was to evaluate an on-board data acquisition system, not the automobile or the luminaire support it struck. Therefore, reuse of the vehicle was not a concern.

Test Article

The test article was a breakaway luminaire support consisting of a 32 ft (9.8 m) steel pole with a three bolt slip base welded to its bottom. No mast arms were attached to the pole. Prior to the test, the pole was weighed and the center of gravity was determined. The pole weighed 485 lb (220 kg). The pole was mounted to the slip base (type CA-31) using 1 in (25.4 mm) galvanized hardware torqued to 400 ft-lb (536 N-m).



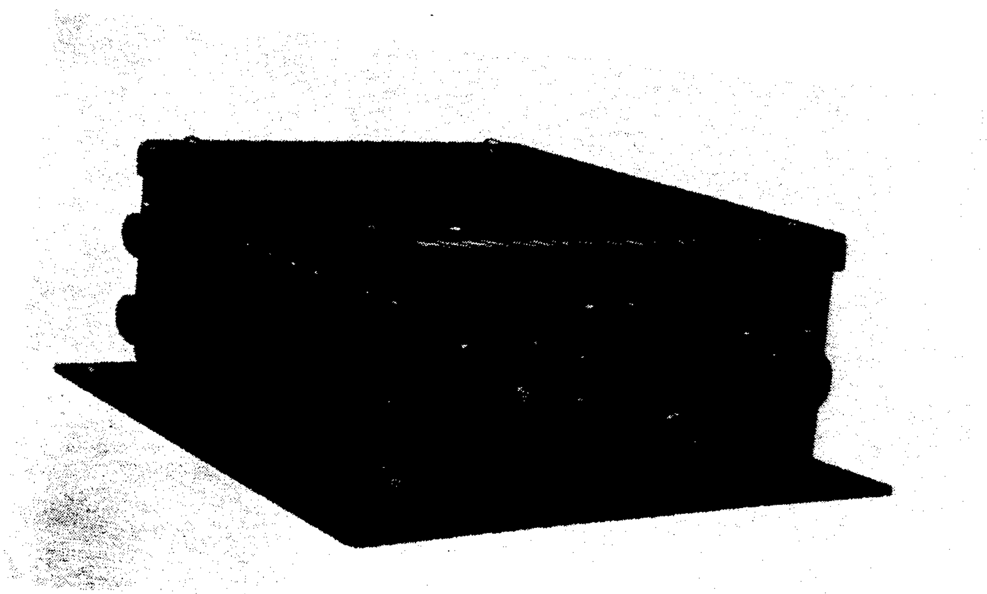


Figure 1. DSP Technologies Inc., ODAS III, (above) and the Communication and Power Distribution box (CPD box).

Instrumentation and Data Acquisition Systems Installation

1. Transducer Data Package

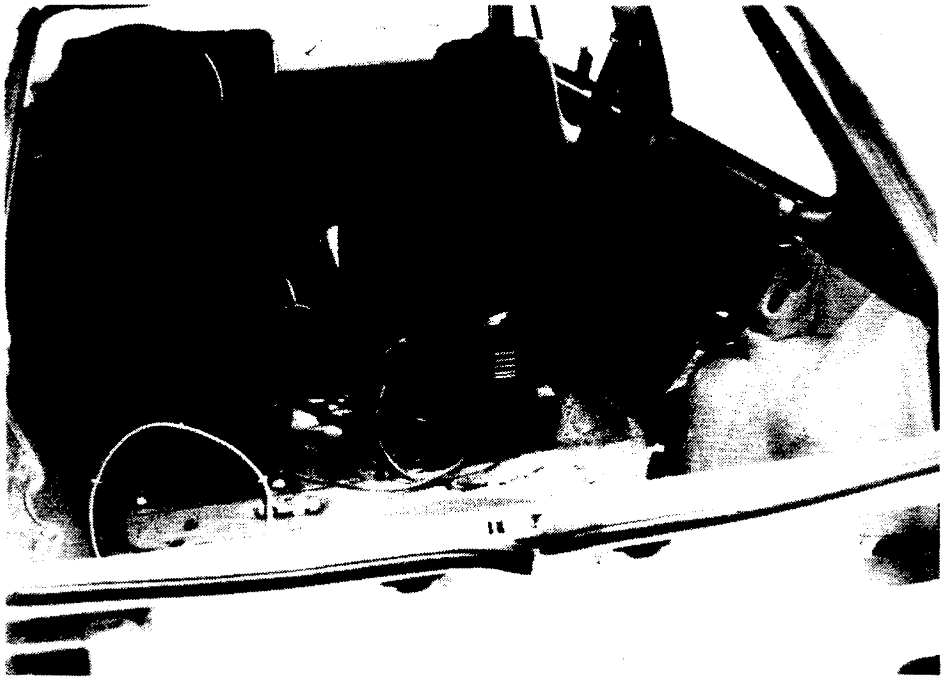
The test vehicle was instrumented with four accelerometers. The data package containing the accelerometers was mounted approximately at the vehicle's center of gravity. Each system recorded data from two accelerometers. All four accelerometers measured acceleration along the vehicle's X-axis (longitudinal direction). The FOIL system recorded acceleration using two Gould 50 g accelerometers. The DSP ODAS III system used 2 Endevco 25 g accelerometers. In addition to the accelerometers, each system was connected to an impact switch. The switches consisted of pressure-sensitive contact strips mounted to the front of the vehicle, and were used to determine the instant of impact.

2. Data Acquisition System

The DSP ODAS III is an on-board system and was mounted directly to the test vehicle's chassis. As shown in figure 2, the DSP ODAS III was mounted in front and to the right (passenger side) of the vehicle's spare tire well. The DSP system CPD box was mounted in front and to the left (driver side) of the spare tire well. The DSP system was powered by a 12 volt gell cell battery mounted inside the spare tire well. While installing the DSP system, a ground loop was discovered between the DSP ODAS III unit and the test vehicle. Isolation of the ODAS III unit, by mounting the unit to a block of wood and then mounting the wood to the vehicle, solved the ground loop problem.

3. Film

The crash test was photographed using three high speed cameras and one real-time camera. All high speed cameras used Kodak 7251 color film, while the real-time camera used Kodak 7239 color film. Black and white 35 mm prints and color slides were also taken. The camera configuration and placements are summarized in table 1.



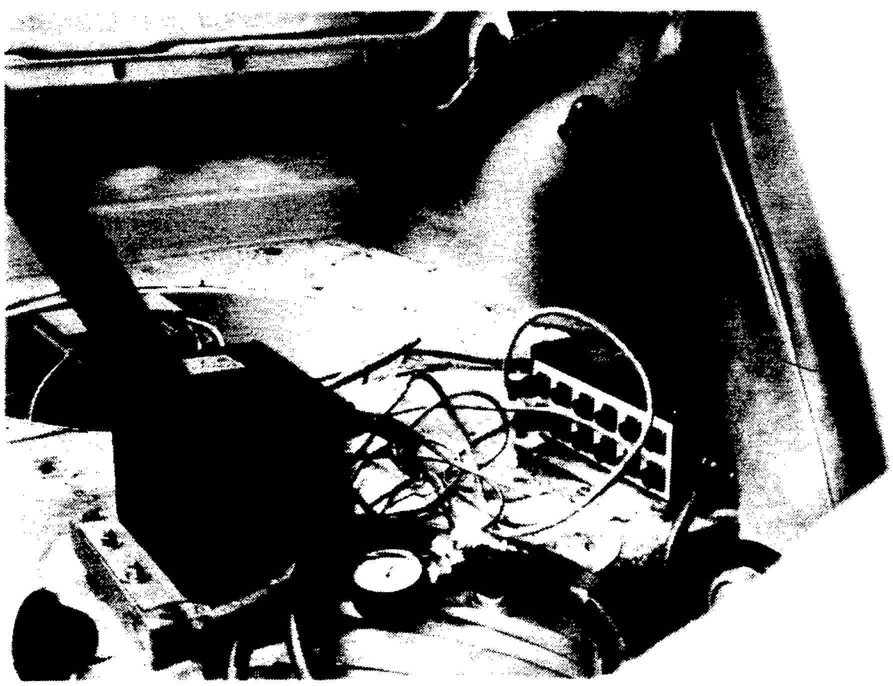


Figure 2. DSP Technologies data acquisition system installation.

Table 1. Camera configuration and placement.

Camera no.	Type	Film speed (frames/s)	Lens (mm)	Location
1	Locam	500	100	right side close
2	Locam	500	75	right side close
3	Locam	500	9	right side overall
4	Bolex	24	zoom	documentary
5	Canon A-1	still	zoom	documentary (prints)
6	Canon A-1	still	zoom	documentary (slides)

Cameras 1 and 2 obtained close-up views of the impact zone, which were used to determine impact and exit speeds. Camera 3 provided an overall view of the impact event. Camera 4 provided pre- and post-test panning shots of the crash tests in addition to a real-time view of the impact event. Finally, cameras 5 and 6 were used to provide still black and white prints and color slides of the pre- and post-test environment.

4. Speed Traps

Speed traps, consisting of multiple pressure-sensitive contact switches placed a known distance apart, were used to measure vehicular speed just prior to impact and after impact. Signals from the traps were recorded by the FOIL system on analog tape using a Honeywell tape recorder, model 5600 E. The tape was played back through an oscillograph, and the time was measured from the first pulse to each of the subsequent four remaining pulses. The time-displacement data were then input into a computer spreadsheet, and a regression analysis was performed to determine pre- and post-impact velocities.

Results

1. Test 89F022

The test vehicle was accelerated to an impact velocity of 20.9 mi/h (9.3 m/s). The vehicle broke the pole away from the foundation, and pushed the pole until the pole fell to the driver's side of the test vehicle. The average vehicular change in velocity determined from accelerometer data was 9.4 ft/s (2.9 m/s) by the FOIL system and 9.3 ft/s (2.8 m/s) by the DSP ODAS III system. The average peak acceleration measured by the FOIL system was 21.6 g's. The average peak acceleration measured by the DSP system was 20.2 g's. The impact duration times compared well between the FOIL system and the DSP system. The FOIL system measured a 40 msec duration, while the DSP system measured a 39 msec duration. Acceleration versus time graphs for each individual system are shown in figures 3 and 4. These graphs include each accelerometer used in the particular system, and are shown as a comparison within each of the systems. Table 2 summarizes the data collected in test 89F022. Pre- and post-test photographs are shown in figures 5 and 6.

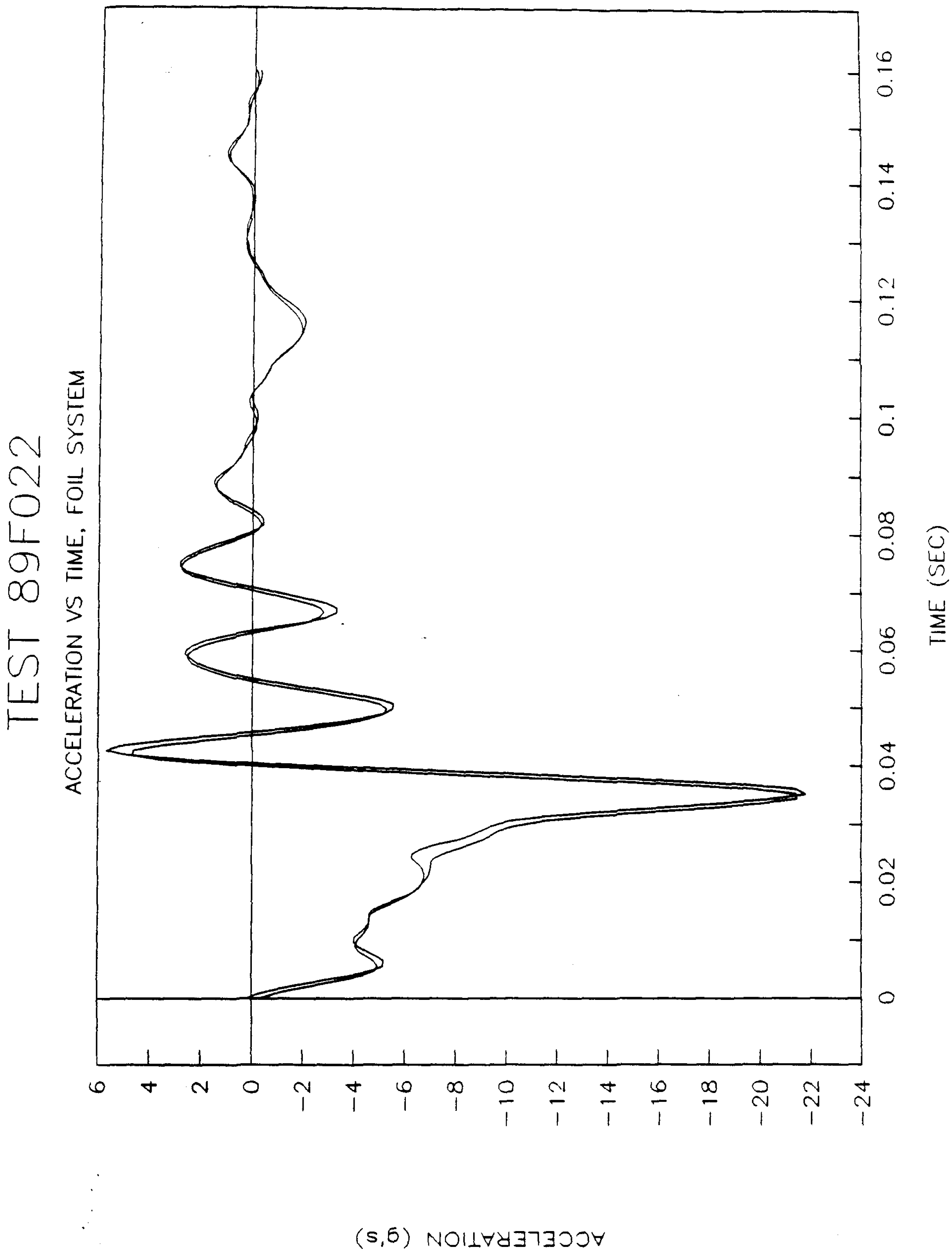


Figure 3. FOIL system acceleration vs. time trace, test 89F022.

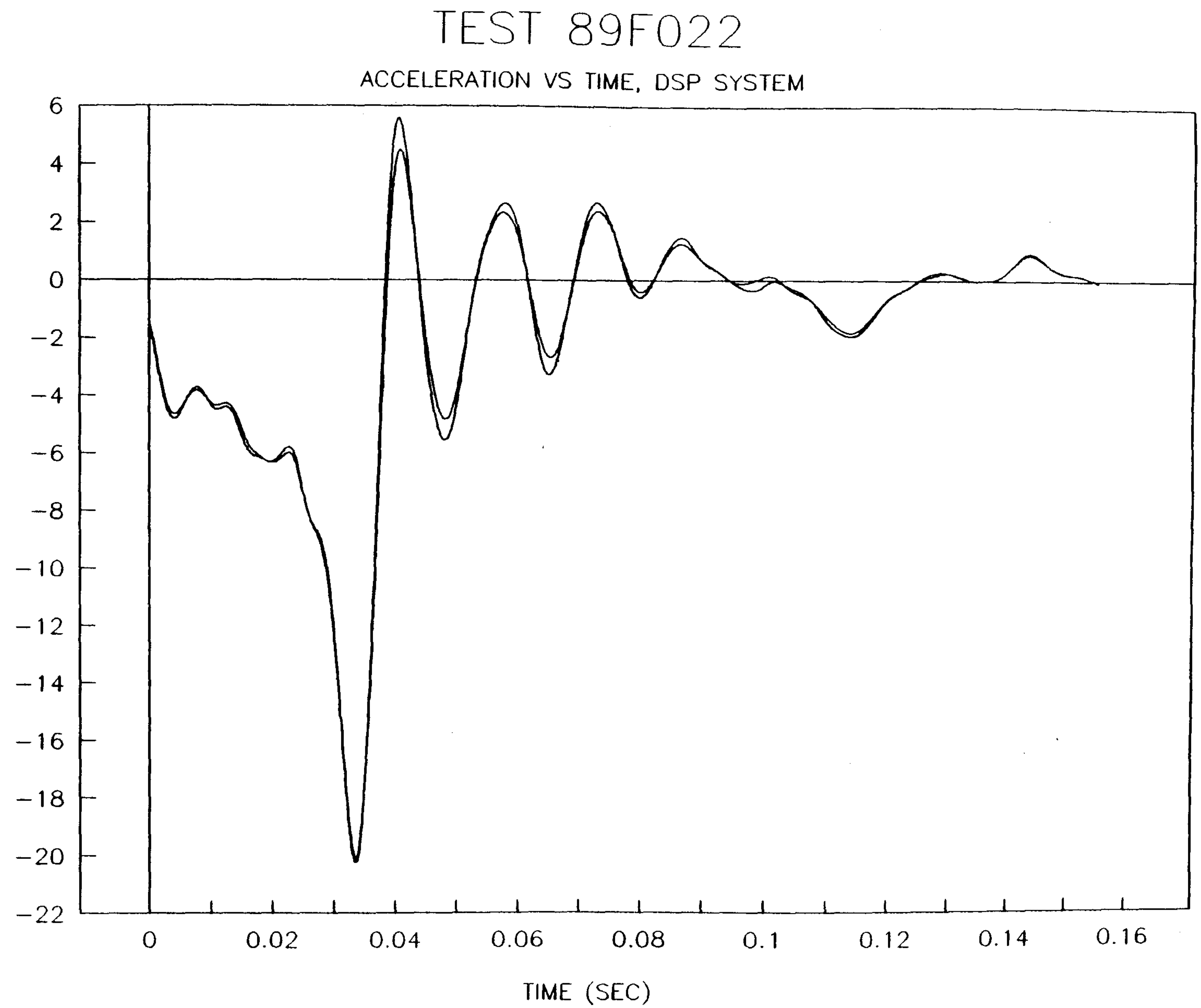


Figure 4. DSP system acceleration vs. time trace, test 89F022.

Table 2. Summary sheet for test 89F022.

TEST NUMBER	89F022	VEHICLE WEIGHT	1805 LBS.
TEST DATE	9/11/89	TEST VEHICLE	1979 VW RABBIT
IMPACT SPEED	29.9 FT/S (9.1 M/S)	TEST ARTICLE	SLIP BASE POLE

	DELTA V (FT/S)	PEAK ACCEL (g's)	IMPACT DURATION (MSEC)
FOIL SYSTEM			
GOULD 50 g	9.6	21.5	40
GOULD 50 g	9.3	21.8	40
AVERAGE	9.4	21.6	40
DSP ODAS III			
ENDEVCO 25 g	9.3	20.2	39
ENDEVCO 25 g	9.3	20.1	39
AVERAGE	9.3	20.2	39

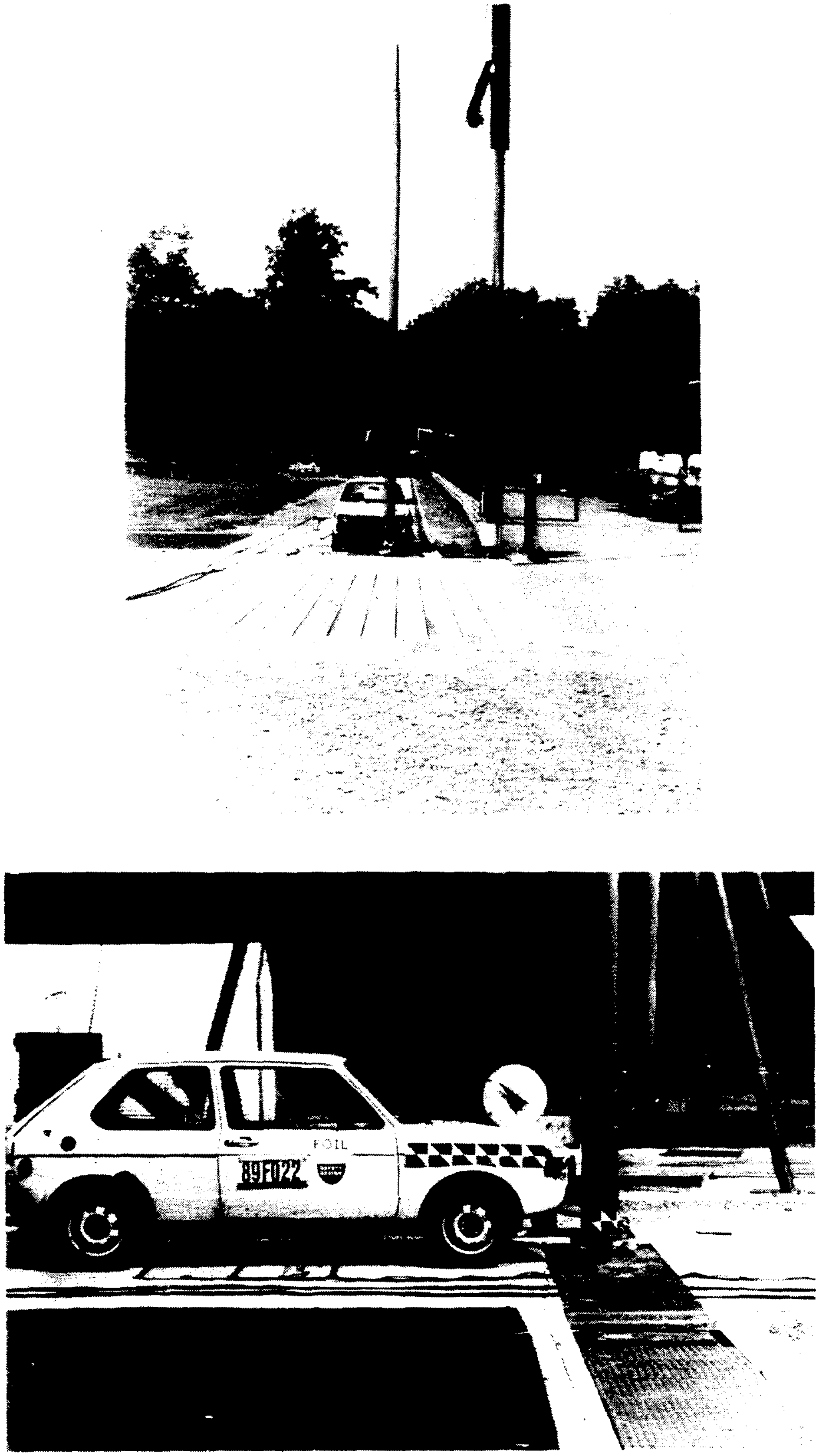


Figure 5. Pre-test photographs, test 89F022.

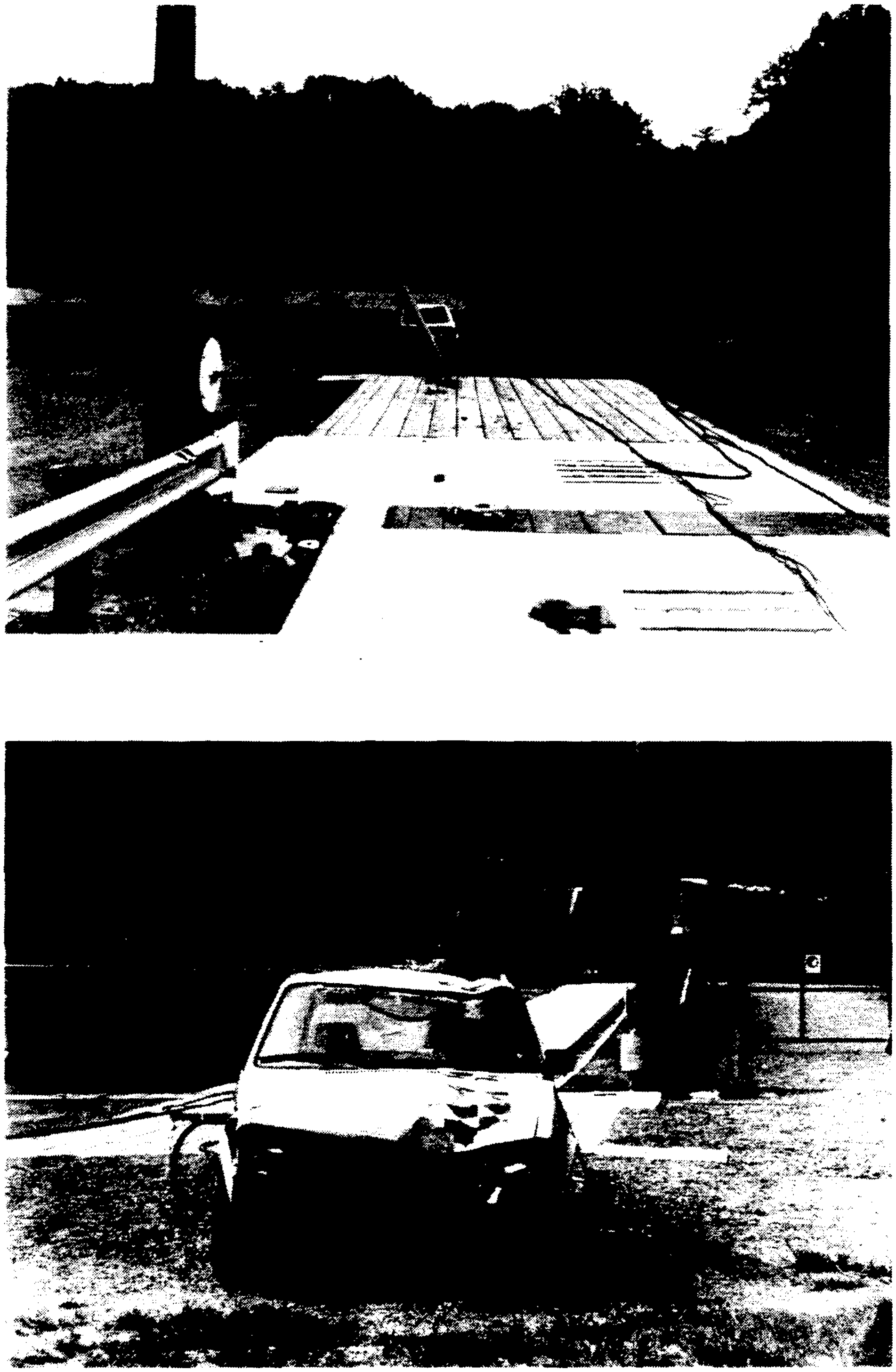


Figure 6. Post-test photographs, test 89F022.

Discussion

The on-board data acquisition system described in this report was subjected to a series of environmental tests, benchtop tests, and the aforementioned in-situ test. These three segments of testing together make up an overall acceptance testing program. This document only reports on the in-situ testing portion of the acceptance program. The conclusions deal only with the data collection ability and practicality of the system, and are not the sole basis for acceptance or failure. Other in-situ crash test results utilizing the DSP ODAS III system are documented in the report "Evaluation of Alternative Data Acquisition Systems."[1]

In general, the data collected by the on-board system compared well with that collected by the current FOIL system. The good correlation between the DSP system and the current FOIL system can be shown by overlaying an acceleration versus time trace from each system. Figure 7 consists of one transducer from each system (a Gould 50 g accelerometer from the FOIL system and an Endevco 25 g accelerometer from the DSP system) plotted together for comparison.

Conclusions

The DSP ODAS III on-board data acquisition system posed no physical or procedural barriers for current applications at the FOIL. Installation and setup of the system (both hardware and software) did not incur any major time delays or distractions. The system proved to be practical and reliable in a crash test environment. The data collected by the DSP ODAS III system compared well with that collected by the current FOIL system. Based solely on this test, the DSP ODAS III system would serve as an adequate replacement for the current FOIL system.

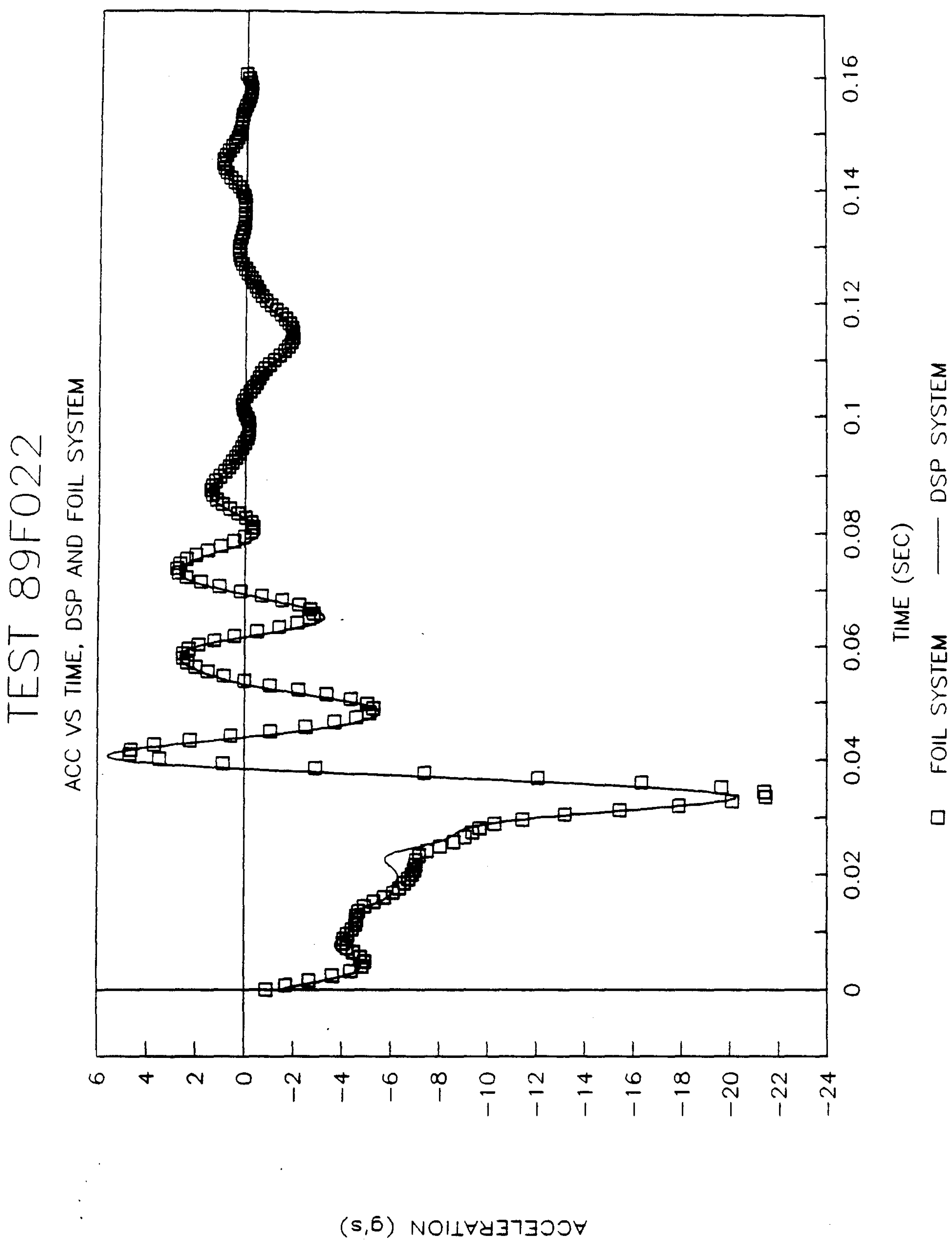


Figure 7. Comparison of accelerometer data from each system, test 89F022.

Appendix A

DSP ODAS III Capabilities and Specifications

ODAS III
On-board Data Acquisition System

FEATURES

- On-board multichannel (8 to 192) ADC data recording system for high accuracy and data integrity.
- On-board 16 channel switch state sensor with time resolved state recorder
- Lightweight, ruggedized, high density for in-vehicle barrier safety testing, sled testing, road testing and aerospace applications.
- Minimum drag cable requirements via on-board recording and on-board power and communication line fan-out.
- Field application proven.
- Meets SAE/ISO J211 specifications.
- Complete system accuracy and error budget analysis by Martin Marietta Measurement Systems (Document Number MSOC -87-067).
- Auto balance and auto calibration for transducers.
- High current drive for transducers.
- Record lengths of 8k or 64k data samples per channel with 12 bit (0.025%) resolution per sample.
- Pre & post trigger recording.
- 48 hour Ni-Cad battery backup of recording memory for data integrity.
- User programmable with on-board intelligence.
- Downloadable diagnostics with auto-calibration.
- Two high speed serial interface ports.
  One floppy disk interface port .
- Powered by 12 V dc.

ODAS III/8 and ODAS III/32 ANALOG CHANNEL DESCRIPTION

SIGNAL CONDITIONING:
The signal conditioning design supports the wide variety of transducers and sensors used for barrier, road, and sled testing. It also reduces the associated labor costs for calibration and zeroing. Each transducer channel can be auto-zeroed and auto-calibrated by the on-board processor which programs offset and gain DACs (digital-to-analog converters). The calibration method uses a "Digital Transducer Calibrator"™, a unique implementation of the bridge shunt method allowing high resolution, multi-point calibration. Rather than employing a series of shunt resistors which would be switched across the transducer bridge completion resistors, one precision (0.005%) ten thousand ohm resistor is connected to the center point between the two completion resistors and driven by a twelve bit digital to analog converter.

Each transducer channel has a programmable amplifier with eleven binary gain steps from 1 to 1024 and an eight pole Butterworth anti-aliasing filter. The filter cutoff frequency is set to 4 kHz (other frequencies available). Transducer excitation is supplied through a protected current amplifier with a 120 milliampere cutoff. Current limiting provides for an orderly shutdown without current surges or voltage spikes which might affect other data channels should a short occur. There is one dc-dc power converter for every two signal channels to provide isolation and reliability.

SIGNAL CONVERSION:
The signals for all channels are sampled simultaneously at a 12.5 kHz rate (other rates available). Each bank of eight signals is then multiplexed to a CMOS, 12 bit analog-to-digital (0.025% resolution) converter. The outputs of the converters are stored in battery-backed memory (Ni-Cad battery, 48 hour data retention capacity) which can be read out to a host computer after completion of testing. Each data channel is allocated 8192 memory locations (64536 optional). Pretrigger information is recorded by allocating 1024 samples of each channel's data memory for storage of information that occurred before triggering. The maximum channel to channel time skew and overall aperture delay is less than 100 nanoseconds consistent with the required 12 bit resolution for SAE class 1000 data.

CONTROL:
The ODAS system, using a Rockwell 65F11 Forth based microcomputer, RS-232 test port, and Forth development read only memory (ROM), provide a powerful tool for customized software development. The processor can access up to 256 individual sixteen kilobyte banks of memory. By utilizing battery backed memory, software written in Forth can be executed without resorting to EEROMS or EPROMS. Customization of the package software can be accomplished without the aid of a development system. A disk controller board provides access to advanced diagnostic software routines.

COMMUNICATIONS:
Data can be bidirectionally transferred via a serial port at rates up to 38k baud. Alternate interfaces and/or software support for most personal computers and mainframe CPUs are feasible. Our technical staff is available to discuss your requirements and to provide complete hardware and software solutions.

PACKAGING:
Both instruments are packaged in an anodized aluminum container with an internal steel support structure. ODAS III/32 measures 6" X 12" X 16" and weighs 32 pounds. ODAS III/8 is 6" X 8" X 6" and weighs 10 pounds. Both are specified to withstand shocks up to 100G. Mil Spec circular connectors are standard.

ODAS III/8 and ODAS III/32 SPECIFICATIONS Part I

PHYSICAL SPECIFICATIONS:

INPUT (each channel)
Configuration: 2 wire plus shield
Accommodates 1, 2 or 4 active Arm Bridges.

EXCITATION (each channel)
Output: 10.000 V
Output Current: 120 mA, max.

AMPLIFIER (each channel)
Input Impedance: 20 Megohms shunted by 10 pf (does not include 10 kohm shunt calibration resistor or 25 kohm auto-zero resistor).
Input Protection: ± 30 V without damage.
Gain: Eleven binary gains from 1 to 1024.
Bandwidth: 10 kHz, 3 dB, Gain = 1024.
Common Mode Rejection:
> 130 db @ gain of 1024
> 80 db @ gain of 1
dc to 60 Hz.
Common Mode Voltage: ± 10.5 V

FILTER (each channel)
Characteristic: 8-pole Butterworth, 48 dB/octave roll-off.
Cutoff Frequency: 4 kHz (other frequencies available)

ANALOG-TO-DIGITAL CONVERTER
Resolution: 12 bits, binary output.
Sample Rate: 12.5 kHz (other rates available).

MEMORY
Size (Words): 8k samples per channel.
64k samples per channel (optional).
Type: CMOS with 48 hour battery (Ni-Cad) backup.

CONTROL
Post-Trigger: 1/8 of memory is pretrigger data, 7/8 is post-trigger data.
Trigger: High noise immunity, differential input.
Calibration: One sample/channel of pretest data is stored for offset calibration.

CALIBRATION
Auto-zero and auto-calibrate routines are executed by the internal microprocessor upon receipt of an external command.

PROCESSOR
Rockwell 65F11 FORTH based Microcomputer. RS-232 port. FORTH ROM allows direct development of control code. A plug-in disk controller board allows development of advanced diagnostics. (32 channel unit)

INTERFACE
a) Serial port, for data and command communication, 38k Baud maximum transmission rate.
b) RS232 interface for processor code development.
c) Disk controller, supports up to four 5 1/4" drives (ODAS III/32 only).

POWER
100 Watts typical (ODAS III/32)
30 Watts typical (ODAS III/8)
11.6 – 13.8 Volts dc input.

MECHANICAL
6" X 12" X 16", 32 lbs (ODAS III/32)
6" X 8" X 6", 10 lbs (ODAS III/8)

SHOCK
Maximum of 100 G's with 20 msec load pulse (peak at 160 G's).

CONNECTORS
Burndy, circular Mil Spec type connectors.

COOLING
Fan cooled, 8 CFM (ODAS III/8), 16 CFM (ODAS III/32).

OPERATING TEMPERATURE
Operates in an environment of 0° C to 50° C. All components are rated at a minimum of 0° C to 70° C. Consult factory for -20° C to 85° C operation.