HIGH SPEED PC BASED DATA ACQUISITION AND INSTRUMENTATION FOR MEASUREMENT OF SIMULATED LOW EARTH ORBIT THERMALLY INDUCED DISTURBANCES

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ABSTRACT

The Hubble Space Telescope (HST) Disturbance Verification Test (DVT) was conducted to characterize responses of the Observatory's new set of rigid solar array's (SA3) to thermally induced "creak" or stiction releases. The data acquired in the DVT were used in verification of the HST Pointing Control System on-orbit performance, post-Servicing Mission 3B (SM3B). The test simulated the on-orbit environment on a deployed SA3 flight wing. Instrumentation for this test required pretest simulations in order to select the correct sensitivities. Vacuum compatible, highly accurate accelerometers and force gages were used for this test. The complexity of the test, as well as a short planning schedule, required a data acquisition system that was easy to configure, highly flexible, and extremely robust. A PC Windows oriented data acquisition system meets these requirements, allowing the test engineers to minimize the time required to plan and perform complex environmental test.

The SA3 DVT provided a direct practical and complex demonstration of the versatility that PC based data acquisition systems provide. Two PC based data acquisition systems were assembled to acquire, process, distribute, and provide real time processing for several types of transducers used in the SA3 DVT. A high sample rate digital tape recorder was used to archive the sensor signals. The two systems provided multi-channel hardware and software architecture and were selected based on the test requirements. How these systems acquire and process multiple data rates from different transducer types is discussed, along with the system hardware and software architecture.

1. TEST SCOPE AND OBJECTIVES

The new rigid solar arrays (SA3) were designed to minimize their response to thermal inputs during each orbit. As part of the SA3 verification program, NASA/GSFC determined that a thermal vacuum/solar simulator test could measure the potential mechanical disturbances induced by on-orbit temperature fluctuations. The Disturbance Verification Test (DVT) was conducted at European Space Research and Technology Centre's (ESTEC) Large Space Simulator (LSS). The SA3 DVT campaign was conducted from 26 October through 30 October, 2000.

Eighteen orbit simulations were conducted over four days of testing with each orbit simulation lasting 90 to 120 minutes. Each orbit consisted of a one hour period with the sun simulator "ON", providing 1300 W/m^2 solar intensity, followed by one-half hour with the sun simulator "OFF". In order to stabilize the SA3 Panel Support Structure (PSS) temperatures after the first four orbit simulations, orbit nighttime was extended from one-half hour to one hour and the sun simulator intensity was raised to 1400 W/m^2 for the remaining orbits. Data were recorded at varied sample rates with transducer data converted to engineering data used for compliance assessment of Observatory Loss of Lock (LOL) requirements. All LOL measurement results were calculated over 60 second intervals.

2. OVERALL TEST CONFIGURATION

The overall test configuration illustrated in Figure 1, shows the SA3 placed inside the LSS chamber. The solar array is rotated 49 degrees away from the sun axis to fit within the beam of the sun simulator. The SA2 mast is secured to a stiff pyramid pedestal bolted to the seismic base of the LSS.

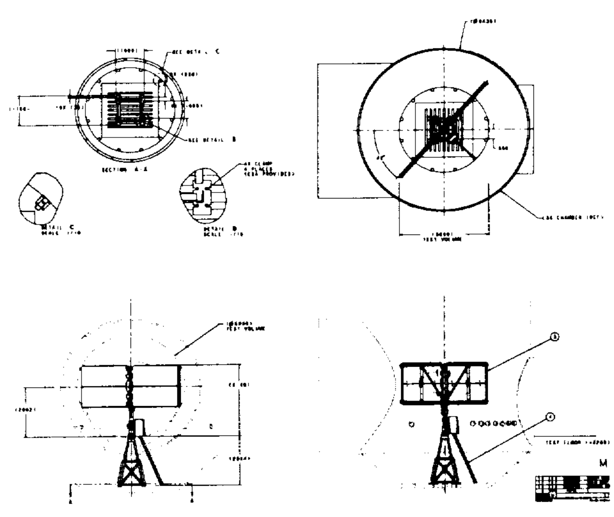


Figure 1. SA3 Installed in the LSS

3. INSTRUMENTATION

In preparation for the SA3 DVT, evaluations of several transducer types were performed to determine the suite of transducers to be used in the SA3 DVT. An analysis of the test configuration when the solar array is cantilevered from its base was performed using facility background noise provided for the LSS Chamber superimposed on transient creak functions, as in [1].

LSS noise measurements were recorded at the seismic base using Endevco 7707-1000 accelerometers, as in [2]. Measurements were taken during another project's campaign when the chamber was in LN2 mode at a vacuum pressure less than $5x10^{-5}$ milli-bars. During these measurements, the Sun Simulator (SUSI) was active and both the gimbal stand and spin box were rotating. All three directions of noise were assumed to be simultaneous random inputs to the base of the solar array in the analysis.

Thermal creaks are caused by sudden releases of stored strain energy and are unpredictable. For the pre-test analysis, the creaks are assumed to be at the limit of HST-FGS loss-of-lock. For the analysis, rectangular pulse with durations of 2, 5, and 25 milli-seconds were assumed.

Results from these pretest analyses show that for the thermal creak events peak transient responses are on the order of 10 to 15 lbs as measured at the base of the solar array when all three translational directions are vector summed. Acceleration vector summed responses at different locations of the solar array range in value from 50 to 1000 milli-g's. However, analysis of the background measurement alone shows acceleration and force levels of similar magnitude. Further analysis shows that a response from the thermal creak can be detected between 0 and 4 Hz. Accordingly, results indicate that accelerometers capable of having a dynamic range from sub milli-g to milli-g's will be sufficient for the test and that measurements should primarily focus on responses in the 0 to 10 Hz range.

The suite of instrumentation employed for this test to measure acceleration and interface forces included Endevco 7754-1000 Isotron accelerometers denoted as a6 and a7, Kistler 8628B accelerometers in triaxial configurations, denoted by a1 through a4, and Kistler 8628B accelerometers in a biaxial configuration, denoted as a5 in Figure 2. The Kistler Low Impedance PiezoBEAM Model 8628B accelerometers were selected since they are high sensitivity, lightweight accelerometers. This unit features 1 V/g sensitivity and is anodized for ground isolation and is vacuum compatible. However, this model is sensitive to temperature variations and will incur signal drift due to thermal variations. To minimize signal drift during the test, these accelerometers were mounted on blocks that were thermally conditioned by strip heaters. The Endevco 7754-1000 Isotron accelerometers were also selected since they are a piezoelectric accelerometer with integral electronics, designed specifically for measuring ultra-low level, low frequency vibration on structures and objects. The unit is hermetically sealed against environmental contamination, features 1 V/g sensitivity, state-of-the-art signal-to-noise ratio, and near-dc frequency response.

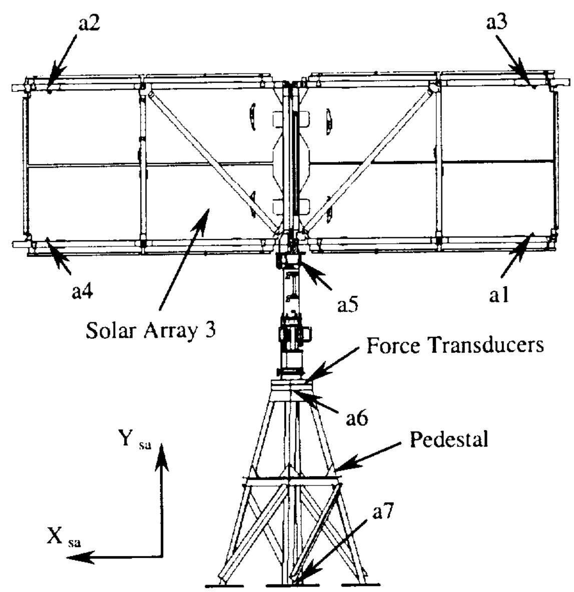


Figure 2. Accelerometer locations on SA3

Triaxial force gauges utilized in the test were Kistler type 9067 connected to a Kistler type 5017A charge amplifier. The Kistler 9067 force gage was selected based on its wide dynamic range (milli-lbs to lbs) and vacuum compatibility. Figure 3 illustrates the force gage configuration on the pedestal and denotes each as f11 through f14. Each force gage was oriented in the pedestal reference frame as opposed to the solar array reference frame. Due to the orientation of the force gages some channels were co-linear, therefore signals from the force gages were summed at the charge amplifier. This reduced the force gage channel count from 12 to 8. The force gages were placed in between the pedestal and an aluminum plate, Figure 3. Placing a bolt through its center and applying a torque preloaded each force gage. Each bolt was pre-loaded to 2000 lbs, which is below the recommended vendor value of 36,000 lbs. Pre-test demonstrations performed by NASA/GSFC determined the proper calibration factors for the test and verified that the calibrations achieved with lower pre-load are consistent with those achieved using higher pre-loads. This pre-test procedure consisted of applying a known vibration force in all three axes and measuring the resulting output.

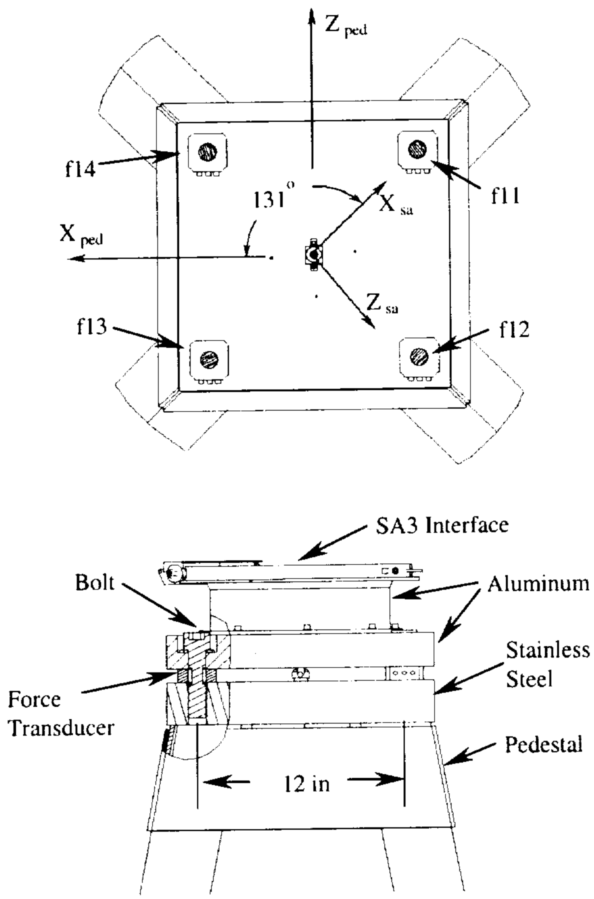


Figure 3. SA3 DVT Force Gage Configuration

Type T thermocouples were also employed for this test and placed in strategic locations to monitor the temperature change throughout the SA3. Twelve of them were designated "fast acting" and sampled at a rate of 1 sample every five seconds. Others were designated "slow acting" and sampled at a rate of 1 sample every 60 seconds. Thermocouples denoted as "fast acting" were coupled to the NASA supplied data acquisition systems and the remaining thermocouples were coupled to the ESA supplied systems.

4. DATA ACQUISITION SYSTEM OVERVIEW

For this test, three separate data acquisition systems were used. These systems include a Hewlett Packard (HP) VXI with HP E1413A A/D converter, a Pacific Instruments (PI) Data Acquisition System (DAS), and a Sony SR-1000 Digital Audio Tape (DAT) recorder. All three systems were used to acquire dynamic transducer data and to provide redundancy in the system should one system incur a catastrophic failure. Figure 4 illustrates the manner in which all three systems received conditioned transducer data. All transducers were secured to the test article and all data cables were passed through designated LSS feed through plates to both signal conditioners and data acquisition systems.

All data acquisition systems were time synchronized by setting all internal system clocks to local time. Local time clocks, furnished by ESTEC, were located nearby all data acquisition systems for the purpose of synchronizing the systems.

Since all systems provided similar functionality and satisfied SA DVT test requirements, further discussions will focus on the PI DAS and its implementation during the campaign.

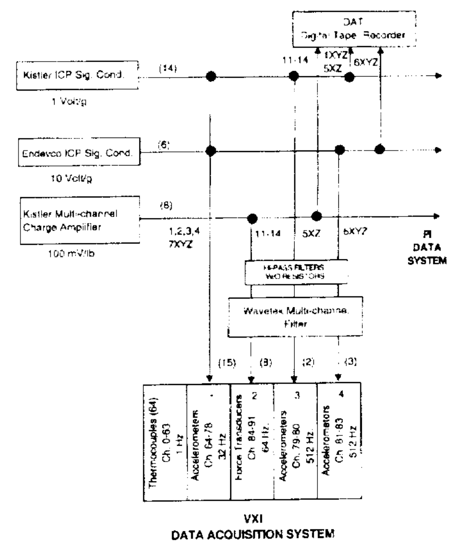


Figure 4. SA3 DVT Data Acquisition Overview

4.1 Pacific Instruments Data Acquisition Hardware

The Pacific Instruments (PI) 6000 Data Acquisition System (DAS), Figure 5, was deployed as one of three systems for measuring transducer data during the SA3 DVT. This system is a multi-channel transducer, digital input signal conditioning, and recording device providing DC coupled measurements using a 16 bit analog to digital converter.

The system interfaces with any Windows 98, 2000, or NT based Personal Computer (PC) through a National Instruments GPIB interface. The system requires that the GPIB automatic serial polling option be turned off. This is necessary since the 6000 system and PI660 use the serial poll response byte as a completion code for commands sent. Lastly, PI660 requires IEEE-488 High Speed (HS) 488 protocol for proper operation, thus the cable length for HS 488 between the PC and the bus must be specified. For the SA3 DVT, it was found that a 3 meter cable length was optimal and provided approximately 1M throughput.

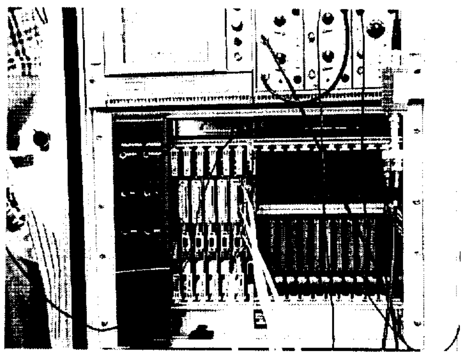


Figure 5. PI 6000 DAS bus

The PI 6000 DAS system was configured with three 6033 and five 6013 data acquisition cards. The 6033 card is an eight channel strain module. Each channel on the module has excitation voltage, programmable gain, filter, auto balance, auto zero, warnings, alarms, and general alarms. The 6013 card is an eight channel module that can be configured to accept voltage, thermocouple, or DC LVDT inputs. When the voltage input type is selected for the 6013 module the module closely emulates the 6033 capabilities.

4.2 <u>Pacific Instruments Data Acquisition Software</u>

PI660-6000 is the application software that operates the PI 6000 DAS and controls channel setup, acquisition of data, storage of data to disk, data conversion to engineering units, and export of data to common file types. The software operates under Microsoft Windows 98, 2000, and NT.

PI660 records data by emulating a tape recorder. The system allows for data to be previewed and data recording to be initiated manually or by a trigger. Acquired data can be placed in two either raw or single scan file types. Raw files contain binary Analog to Digital counts for the channels being scanned while single scan files contain glimpses of data coming into the system and are created as tab delimited text files. The software receives raw Analog to Digital converter counts from the PI 6000 DAS and stores the data in the same form as received. The data is subsequently converted to engineering units for display purposes.

PI660 will also convert data acquired into its raw data files into a number of different other formats for post-processing purposes. Formats employed for this test were Universal File Format 58 and D-Plot. In this conversion, the raw test data is converted from Analog to Digital converter counts to engineering units for use by other software applications.

The system contains multiple history type displays, e.g. oscilloscope, that display dynamic data, and current value type displays that are used for slower data. PI660 uses a multiple document interface (MDI) display architecture that allows for as many displays of the same or different types to be displayed simultaneously.

Acquisition parameters for each transducer are graphically entered using a Graphics User Interface (GUI) and allows for a description of the transducer, specification of the filter cutoff frequency, internal gain, and transducer sensitivities. These parameters are then downloaded into a scan list that allows for the specification of sample rates for each channel. Channels are added to the scan list using a multiple select tree view control. The PI660 software automatically adjusts the scan list structure to accommodate hardware requirements and requirements to sample different channels at different rates. In this case, PI660 ensures that the channels are added to the scan list in a periodic fashion so that the data for the channels are evenly spaced in time. An example of a scan list is shown in Figure 6.

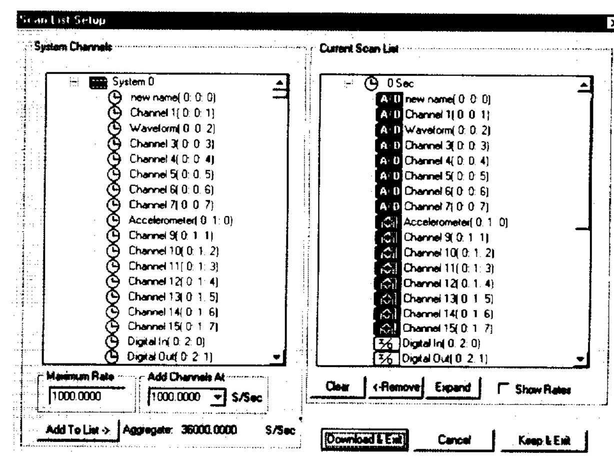


Figure 6. Scan List

5. PI DAS SA3 DVT TEST CONFIGURATION

For the SA3 DVT test, the PI DAS acquired only accelerometer and force gage data. No thermocouple data were acquired by this system; however, the system was capable of thermocouple data acquisition in the event of an anomaly with the primary thermocouple data acquisition systems. The system basic capabilities during the test were as follows:

Number of Channels Available: 64 (28 used)
Data Storage: Complete Time History

Bandwidth: 2000 Hz
Recording Duration per Test: 90 to 120 minutes
Run Display: Multiple Oscilloscopes and Spectra
Data Post Processing: Engineering data for D-Plot
Data Archiving: Raw files compressed written to CD

The PI 6000 DAS was connected to a Compaq Intel Pentium II 450 MHz PC. This PC was equipped with the Windows NT operating system and also had the PI660-6000 software resident on it. Additionally, the PC was equipped with a 40 GByte hard drive and a CD Read/Write system. The 40 GByte hard drive served as the throughput disk for all data collection.

The system was configured to acquire 28 channels on one 6033 and three 6013 cards. BNC pigtails were connected to the terminal boards that interface to each data acquisition card on one end with transducer cables connected to the remaining end. All Kistler 8628B accelerometers were directly patched to the PI DAS while the Kistler force gages and the Endevco accelerometers were passed through their respective signal conditioners and then patched to the PI DAS. The external gain applied to the Endevco accelerometers was 10.0 and the Kistler accelerometer and force gage external gain was 1.0.

Sampling rates and filter requirements were established in the test documentation [3]. These requirements are listed in Table 1.

Table 1. Data Acquisition Parameters

Label	Axis	Sample Rate (Hz)	Filter (Hz)	Label	Axis	Sample Rate (Hz)	Filter (Hz)
a1	$(X, Y, Z)_{sa}$	32	10	f11+f14	X_{ped}	64	32
a2	$(X, Y, Z)_{sa}$	32	10	f12+f13	X_{ped}	64	32
a3	$(X, Y, Z)_{sa}$	32	10	f11+f12	Z_{ped}	64	32
a4	$(X, Y, Z)_{sa}$	32	10	f13+f14	Z_{ped}	64	32
a5	$(X, Z)_{sa}$	512	256	f11	Y_{sa}	64	32
a6	$(X, Y, Z)_{sa}$	512	256	f12	Y_{sa}	64	32
a7	$(X, Y, Z)_{sa}$	32	10	f13	Y_{sa}	64	32
				f14	Y_{sa}	64	32

The PI system is capable of handling the multi-rate sampling frequencies, but could not support the requested filter cutoff frequency requirements. Each channel of the system utilizes a four pole Butterworth anti-aliasing filter that is compatible with plug-in filter frequency cutoffs of 10, 20, 50, 100, 200, 300, and 1000 Hz. The four pole Butterworth filter comes standard with the 6033 and 6013 cards and the filter frequency cutoffs are also standard options for the system. From previous testing using this system, it has been determined that 100% alias free data is not practical with 4-pole Butterworth filters. In order to achieve 100% alias-free data, a very large block size would be required. However, it was determined from previous testing that a frequency ratio of 8 between the sampling and filter cutoff frequency would produce only a 1.5% error in a Power Spectrum Density (PSD). Since this test afforded long durations for each orbital variation, the sample rate for all PI acquired signals was adjusted to 2400 Hz to minimize any anti-aliasing of data. This block rate was chosen by multiplying the highest filter cutoff frequency for a given channel by the aforementioned frequency ratio of 8. Table 2 denotes the final parameters used for the PI DAS during all aspects of the SA3 DVT test. Data acquired for 28 channels using a block rate of 2400 Hz resulted in 1 Gigabyte of raw test data for every orbit simulation.

For this test, the aggregate sample rate was 67200 samples per second with 28 channels being sampled at 2400 samples per second. Furthermore, the system was configured to acquire consecutive data sets for each orbit by specifying the duration of the acquisition period. Instructing the system to trigger upon termination of the previous data acquisition period and re-entering the preview mode made consecutive data acquisition periods possible. This autonomous data acquisition enabled the system to continue acquiring near continuous data throughout the campaign.

Table 2. PI Data Acquisition Final Parameters

Label	Axis	Sample Rate (Hz)	Filter (Hz)	Label	Axis	Sample Rate (Hz)	Filter (Hz)
a1	$(X, Y, Z)_{sa}$	2400	10	f11+f14	X_{ped}	2400	20
a2	$(X, Y, Z)_{sa}$	2400	10	f12+f13	X_{ped}	2400	20
a3	$(X, Y, Z)_{sa}$	2400	10	f11+f12	Z_{ped}	2400	20
a4	$(X, Y, Z)_{sa}$	2400	10	f13+f14	Z_{ped}	2400	20
a5	$(X, Z)_{sa}$	2400	300	f11	Y_{sa}	2400	20
a6	$(X, Y, Z)_{sa}$	2400	300	f12	Y_{sa}	2400	20
a7	$(X, Y, Z)_{sa}$	2400	10	f13	Y_{sa}	2400	20
				f14	Y_{sa}	2400	20

6. PI DAS POST-TEST DATA ANALYSIS

To assess data quality and to perform preliminary analyses of acquired data, the PI DAS system comes with the D-Plot program. D-Plot is an data analysis program written by the U.S. Dept of Waterways. The D-Plot format supported by the PI DAS is the Unformatted Binary format that contains a 1024 word header followed by time and data pairs for the rest of the file. The system converts the raw binary test data into the Unformatted Binary format required by D-plot and allows the user to specify individual channels, as well as, specific time intervals for each channel.

Throughout the test, the test team identified numerous potential thermal creak events. These instances were cross-correlated by examining the complete time histories for each channel using the D-plot utility. An example of one orbit's force gage time history is shown in Figure 7. Upon examination of the full orbit time history, specific instances are expanded by using a windowing function built into the D-plot program. An example of a windowed event is shown in Figure 8. This plot clearly shows the recorded response of the SA3 due to a thermal creak event at one of the force gage locations. The post processing of the data clearly shows that multiple thermal creaks were captured during testing and both the sample rate and selection of instrumentation chosen for this test were more than adequate.

Raw test data for the various identified thermal creak events were exported for all channels from the PI system by exporting it as converted binary data in Engineering Units (EUs) and converted into an ASCII compatible MATLAB file using a C subroutine supplied by PI. This allowed for the PCS group to perform spectral and time domain analyses of the data and to perform assessments regarding LOL due to these transient events.

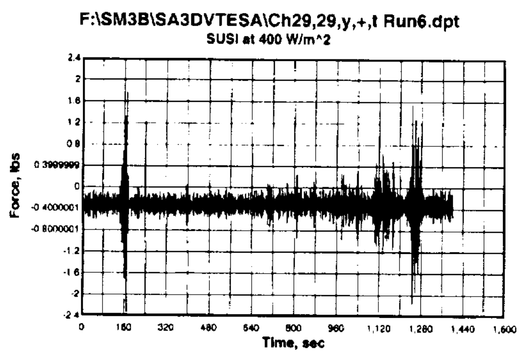
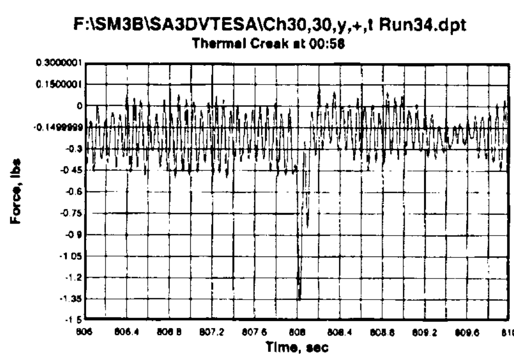


Figure 7. Force Gage Transient Plot Responses for



One Orbit

Figure 8. Force Gage Windowed Transient Plot of Thermal Creak Event

7. CONCLUSIONS

The PI 6000 DAS system performed well throughout the test campaign and provided flexibility to acquire data at multiple sample rates, interface to different types of transducers, provide redundancy for other systems, and to quickly post-process data to assess data quality and troubleshoot test set-up anomalies. The PI software proved flexible in its ability to allow for consecutive data acquisition periods using its trigger capabilities and its ability to provide multiple display formats for monitoring near real term data collection.

The SA3 DVT provided the opportunity to perform a complex thermal-structural test that presented both instrumentation and data acquisition challenges. The PI DAS, assembled using Commercial Off the Shelf products, demonstrated that it could be successfully tailored to meet any unique test requirements.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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