

Variable Amplitude Control and Verification Methodology

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Workshop on User's Experience with Variable Amplitude
Testing and Analysis

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Introduction

- Reliable fatigue crack growth data under variable amplitude loading requires sophisticated control and verification to assure targeted peak and valley loads have been achieved.
- A damage parameter (Γ , McKeighan, et al) has been incorporated to quantify the magnitude and effect of loading errors.
- A load amplitude validation log of “missed endpoints” can also provide valuable information on the reliability of the test data.
- An application example will be presented highlighting the importance of high resolution data acquisition, precise command control and verification to enhance confidence in the test results.

System Description



- Dedicated DSP processor, local memory and high speed (100k Hz max) 16 bit resolution analog input and output.
- Complete process, including crack length calculations, runs independently of the PC operating system.



Software

- ADBasic - Provides waveform generation, data acquisition and data processing required for command-feedback verification, crack length determination and K-control.
- ADBasic - Allows modular programming in high priority for time critical processes and low priority for background operations.
- Visual Basic - Provides the communication link for data input, test status and graphical display of force and displacement as well as crack growth rates as a function of K.



Features

- A waveform output with a constant loading rate and upper and lower frequency limits.
- A command correction compensation based on the unique signature of the previous, current and next endpoint error.
- A real time damage parameter used to estimate the success in attaining peak loads in a spectrum test.
- The storage of the command correction factors unique to each spectrum so that the optimum response can be "pre-tuned".
- A validation log for cataloguing "missed endpoints" beyond a user specified error threshold.

Example of Graphical Display

Automated Fatigue Crack Growth - V3.02.04d

File Input Control Display Comments Help

DSP Time (%) Enable Stop
STOP DSP

PM 20773
 DM 63532
 XM 1745282

Unit Type
 English
 Metric

E-5
d
a
/
E-6
d
N
E-7

Data Input

Calibrate Coefficients Dimensions...

Active Data Storage and Lim
 Crack Length

Crack Length

Initial a/W

Final a/W

a/W Increment

Status - Compliance

Test ID: I:\Testing Contracts - 2002\ASTM Variable

	Target Load		Command Signal		Actual Load		Clip Gage	
	lb	%	lb	%	lb	%	in	%
Max	3462.2	13.8	3151.6	12.6	2644.9	10.6	0.00020	2.0
Min	1419.2	5.7	923.1	3.7	1420.6	5.7	-0.00067	-6.7

a/W	a	Last a	Next a	Count	Time	Date
0.5318	1.06312	0.99950	1.19940	9.576	1:06:21	5/2/02

Slope #	Slope#	Corr	Kmax	Delta K	da/dN	Damage
200	191	0.99982	30.63	30.63	1.714E-4	0.8585
						0.8304

EvB/P	Count	a	EvB/P	Count	a
44	9.144	1.06312	1.3237	6.200	1.06271

CR ACR 2% offset OP1 OP2 OP4 OP8 OP16

.9948	.995	.824	.176	.176	.176	.176	.176
-------	------	------	------	------	------	------	------

Full Function Generator Control

Waveform
 Sine
 Triangle

Response Rate
 Fast
 Medium
 Slow

Command Control
 Firm
 Soft
 Softer

Control Status
 FNG Shutdown
 Command Control
 Slope Analysis
 Data Storage

Run STOP

Clear Message Reset FNG

Raise Rate Raise Hz(max) Raise Hz(min) Raise Hold

Lower Rate Lower Hz(max) Lower Hz(min) Lower Hold

Load Rate (v/sec) Coarse Adjustment
 Fine Adjustment
 Ramp to Hold Level

Frequency (Hz) Cycle Count Pass Count

End Point Status	Load (volts)	FNG Out (volts)	Load (volts)	Disp (volts)
Error 3DCF (volts)	0.000	1.042	0.604	-0.60
Max	0.000	1.385	1.261	1.058
Min	-0.001	-0.198	0.568	0.369

Control Status

No FNG shutdown conditions
 1% Load Error

Load Scan Display

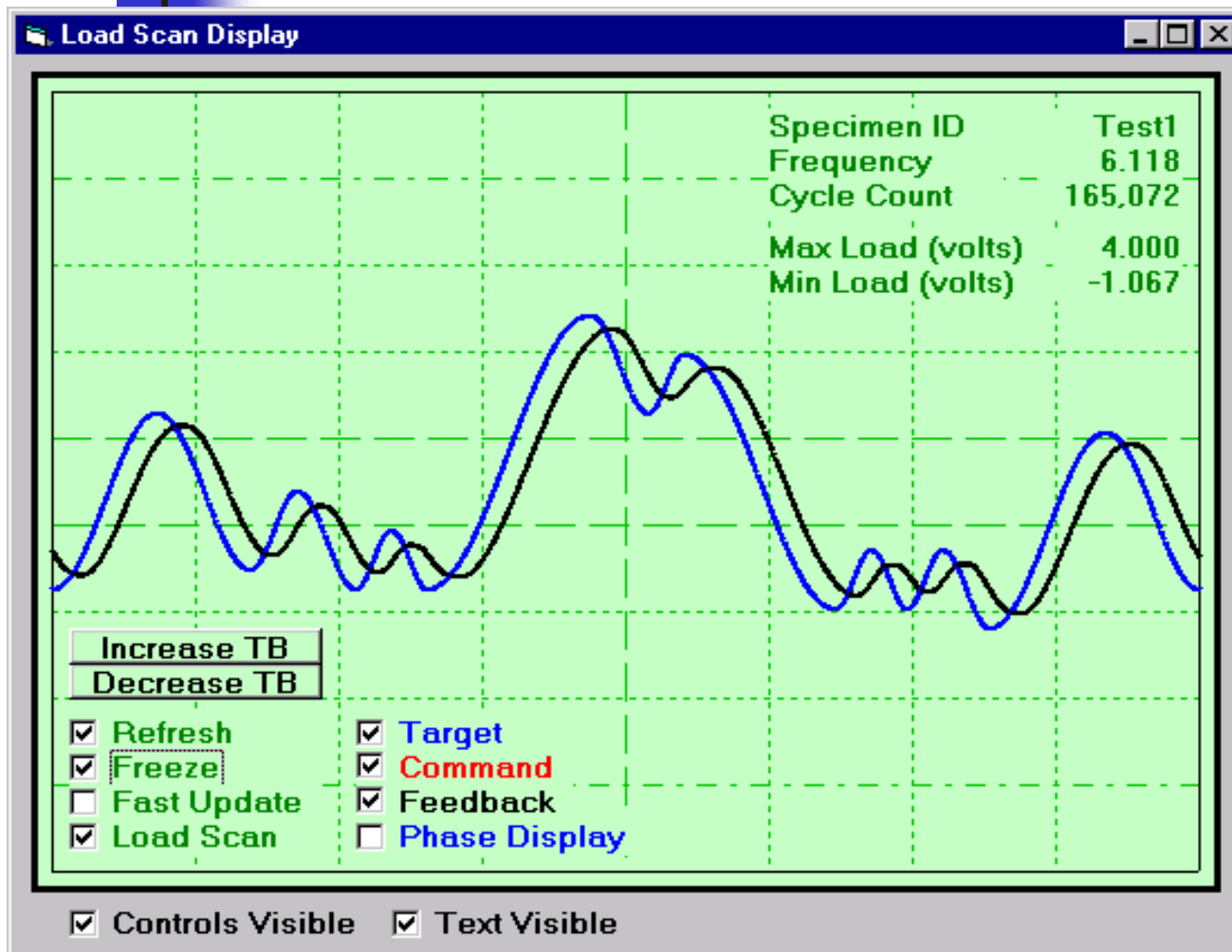
Specimen ID	Test1
Frequency	12.237
Cycle Count	9.307
Max Load (volts)	4.000
Min Load (volts)	-1.067

Increase TB Decrease TB

Refresh Target
 Freeze Command
 Fast Update Feedback
 Load Scan Phase Display

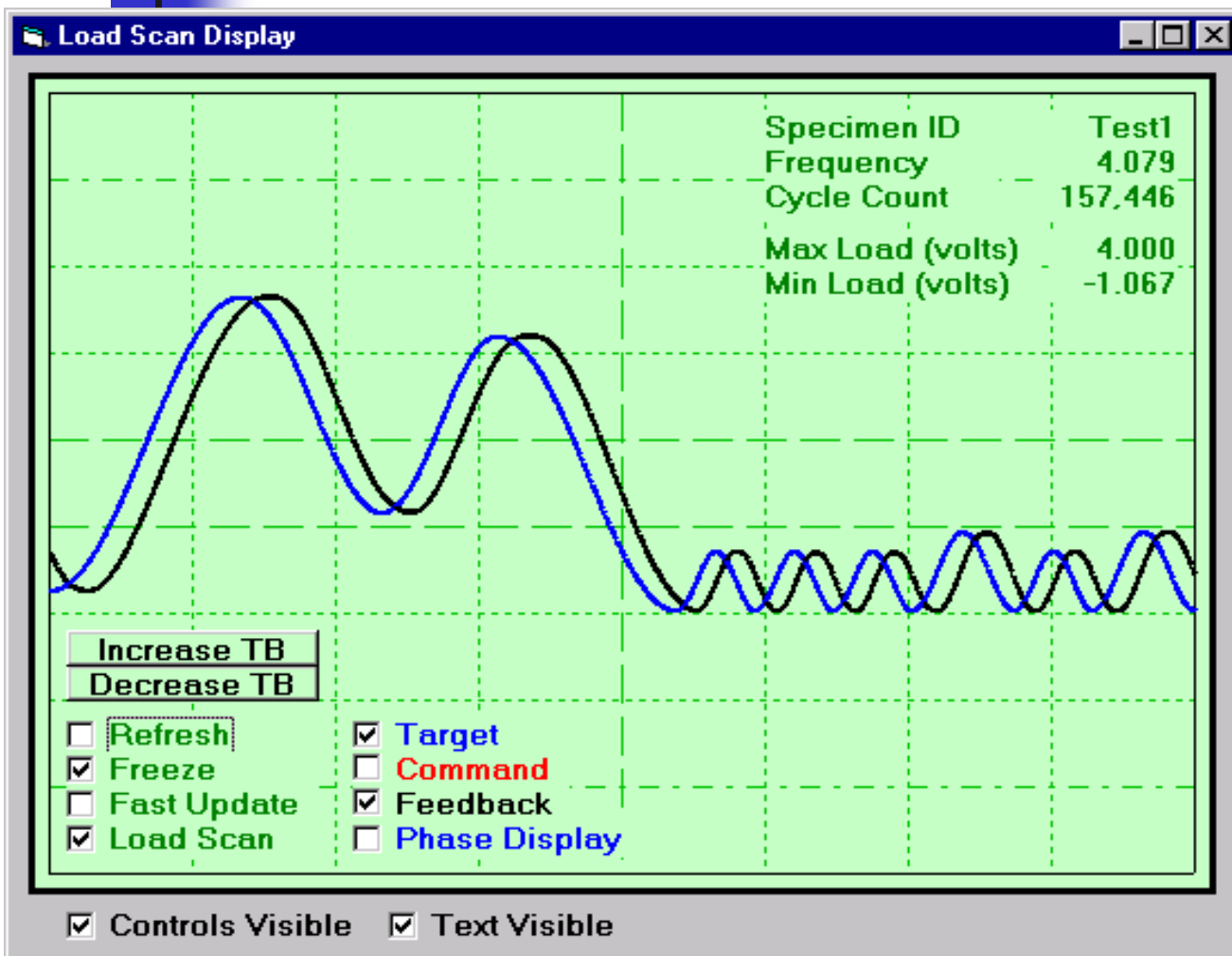
Controls Visible Text Visible

No Command Compensation



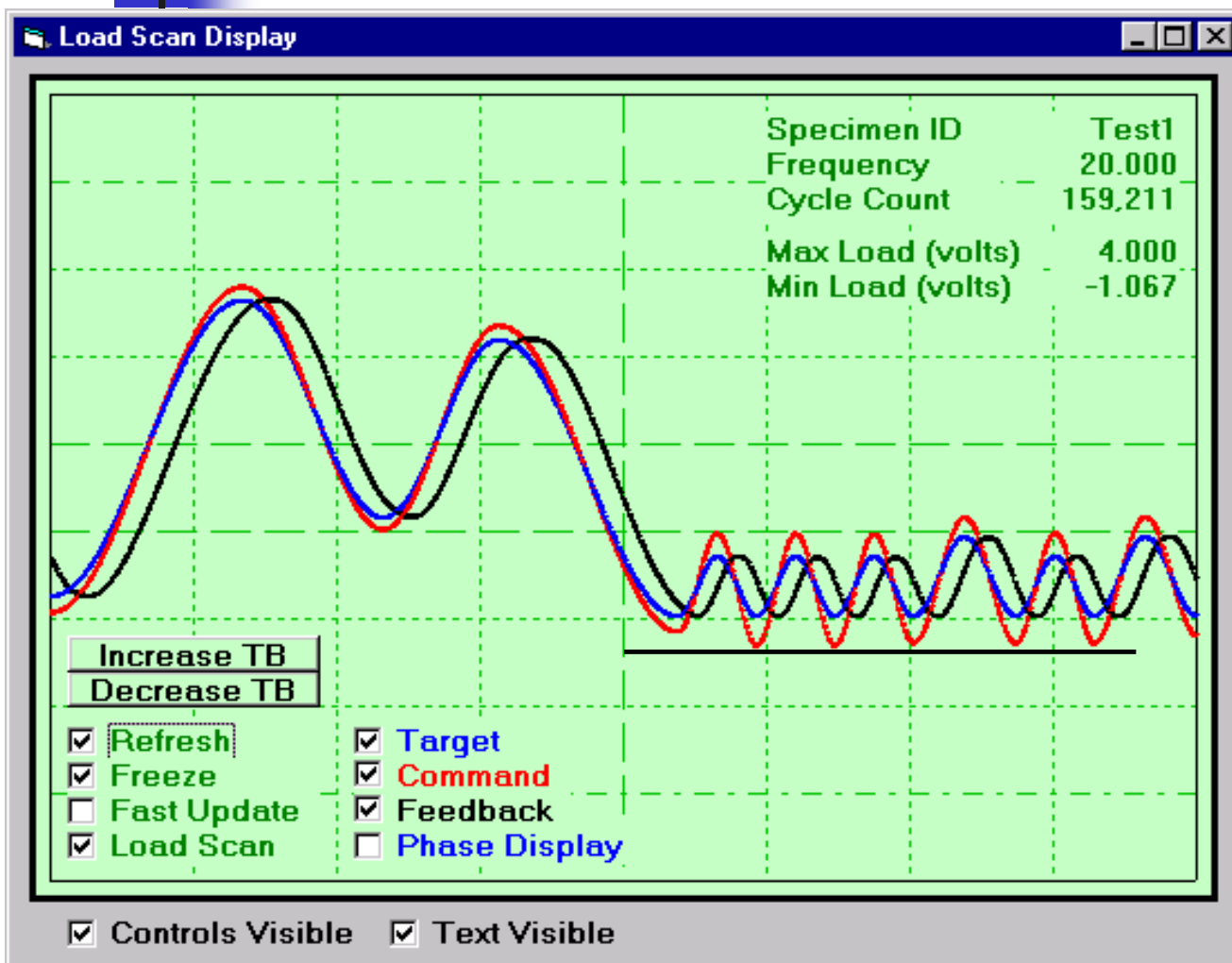
With no command compensation and poor PID tuning, the actual load peaks (in black) **do not** match the target load peaks (in blue).

Command Compensation Enabled



With command compensation enabled, the actual load peaks (in black) do match the target load peaks (in blue), despite poor PID tuning

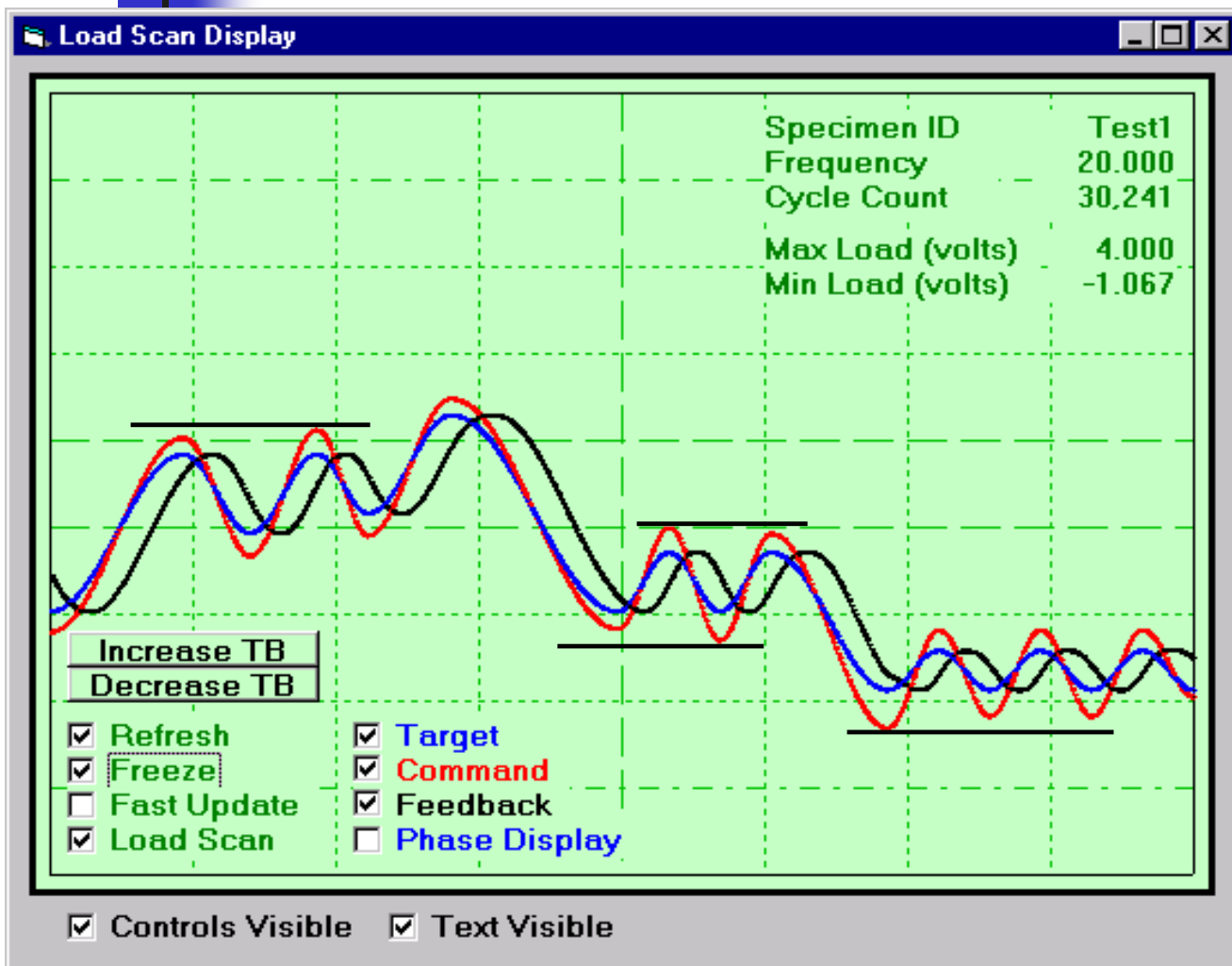
Command Compensation Enabled



Command signal is also shown (in red).

Note that command compensation is not necessarily the same for equivalent endpoints.

Command Compensation Enabled



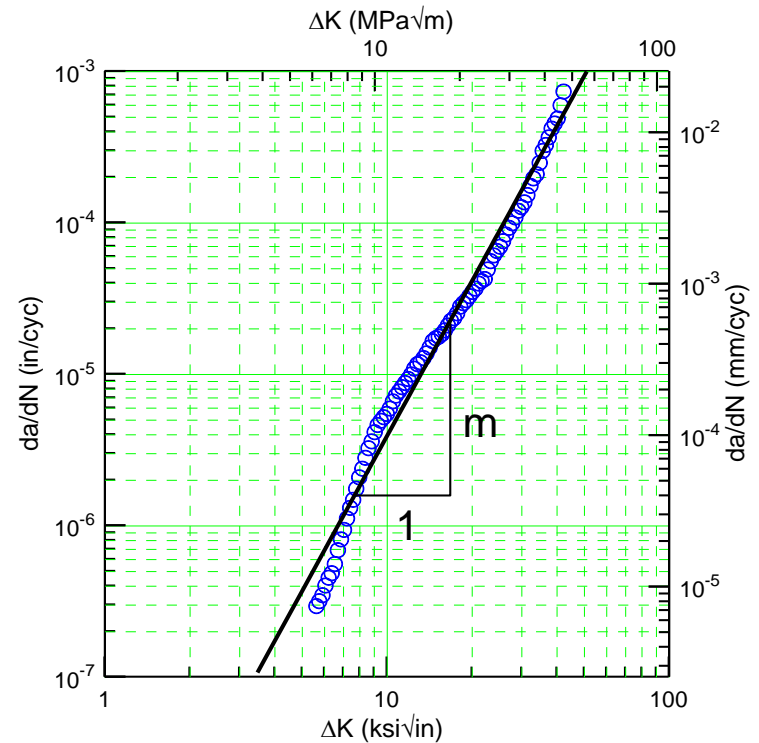
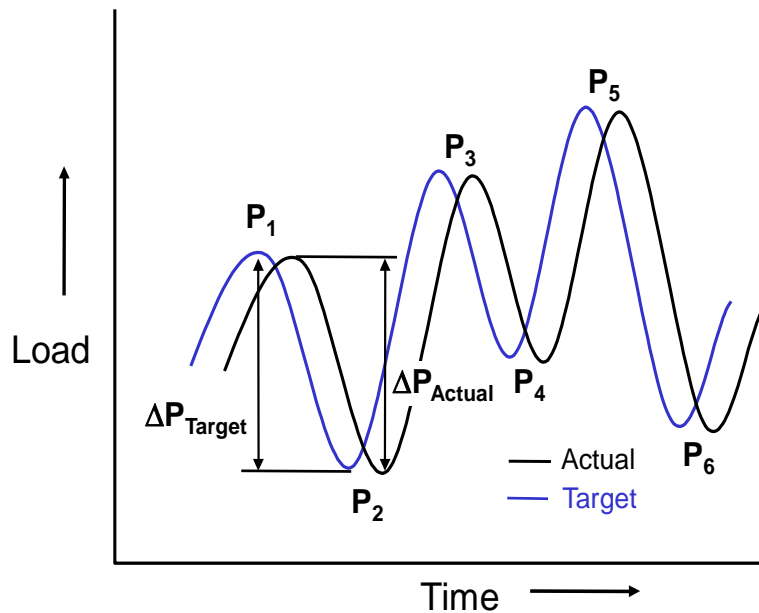
Command signal is also shown (in red).

This shows four cases where identical endpoints have different command compensation.

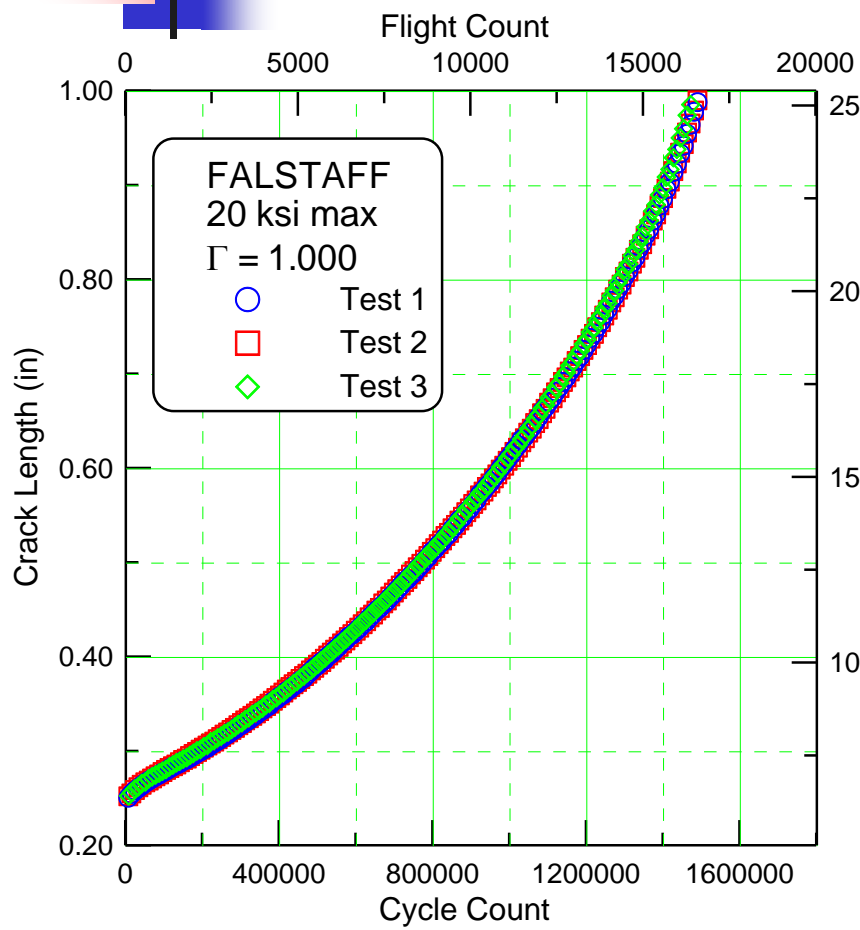
Damage Parameter (McKeighan, et al)...

$$\Gamma = \frac{\sum (\Delta P_{Actual})^m}{\sum (\Delta P_{Target})^m}$$

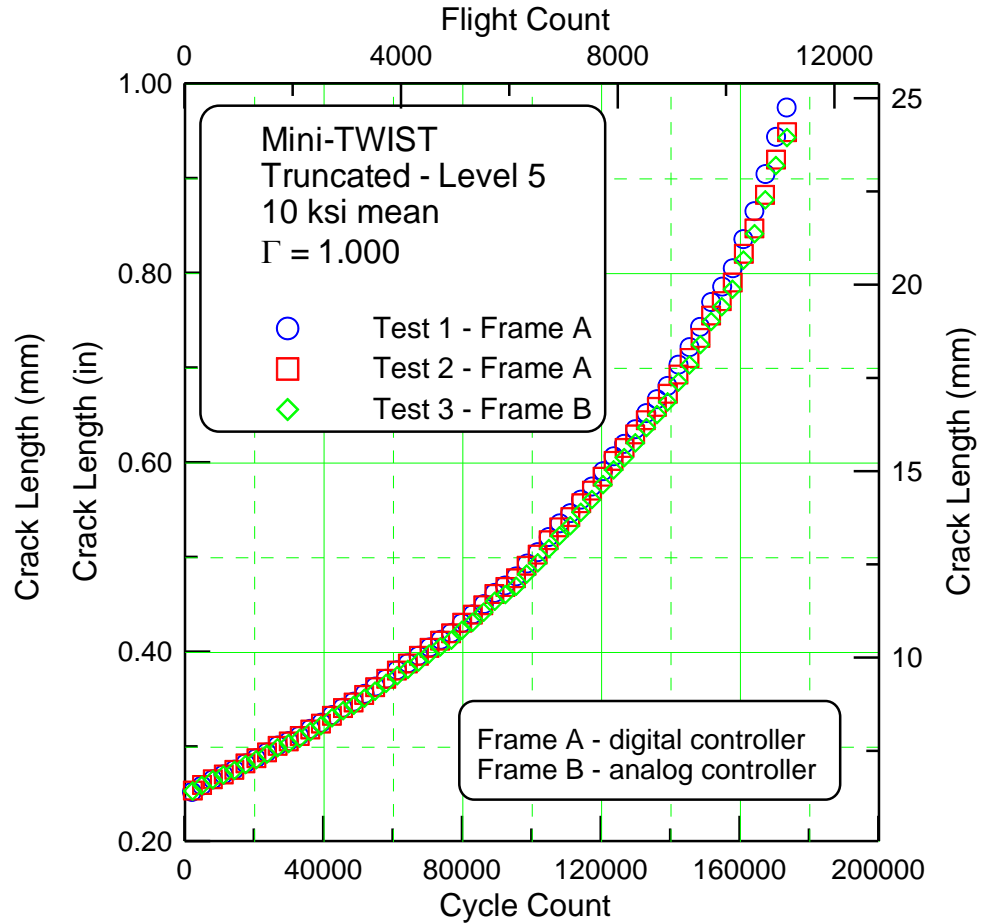
$$\frac{da}{dN} = C \cdot \Delta K^m$$



Triplicate Results with $\Gamma = 1.000$



FALSTAFF



Mini-Twist (clipped)

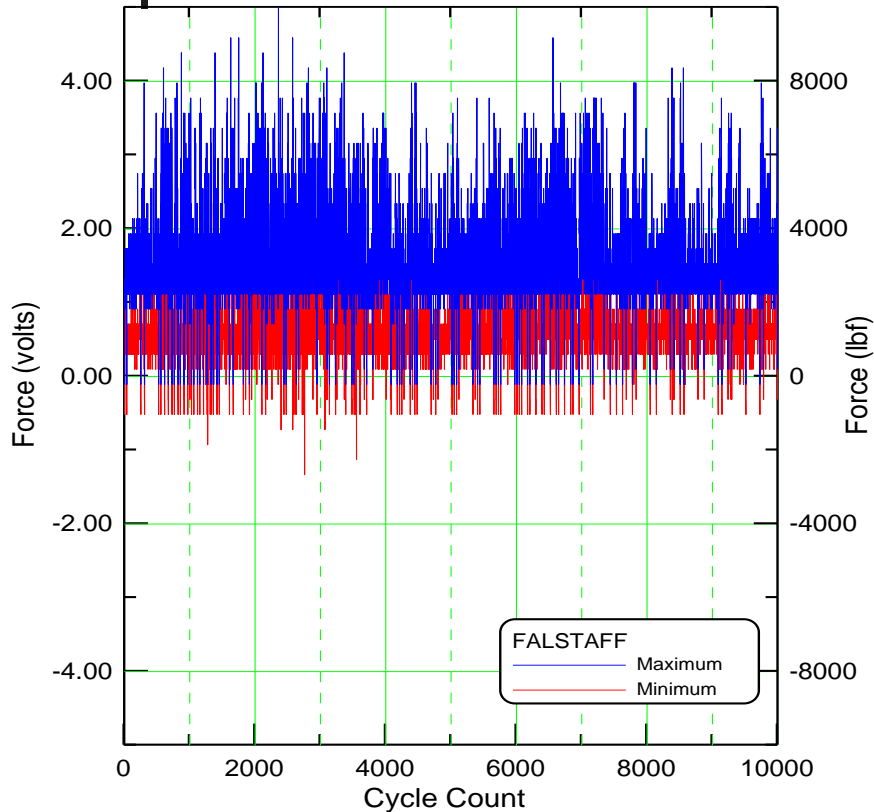


Limitations of Damage Parameter

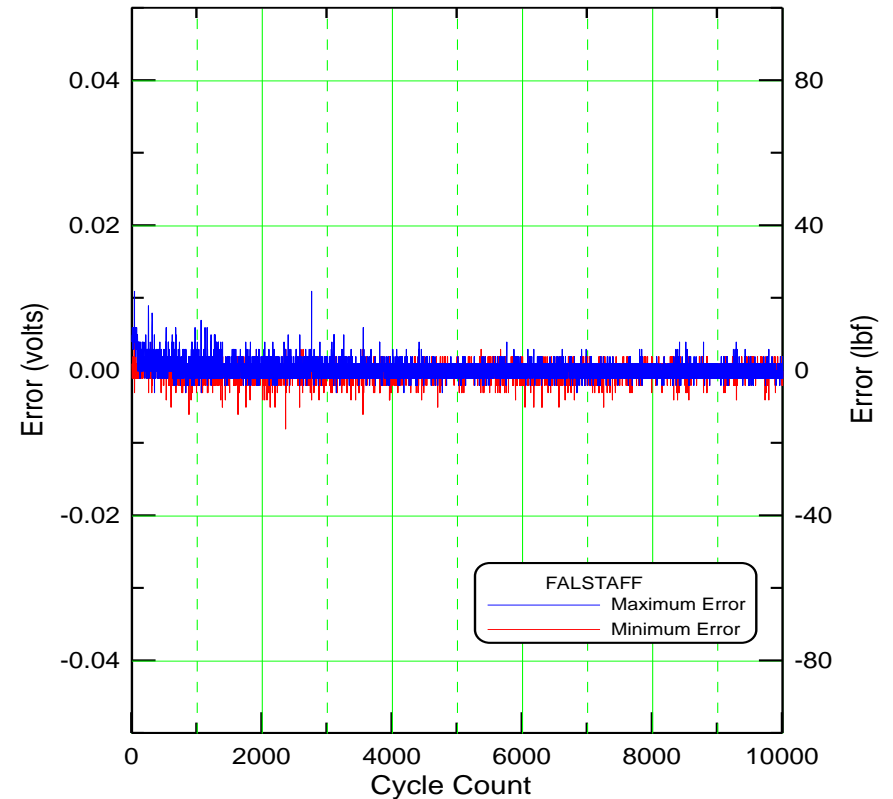
- A damage parameter gives average response but fails to adequately address consequence of “missed” endpoints.

- A validation log provides documentation of missed endpoints by providing for each cycle:
 - a) Cycle count
 - b) Desired Peak
 - c) Desired valley
 - d) Actual Peak
 - e) Actual valley

Validation Log Results



Actual Endpoints



Endpoint Errors

Typical errors less than 0.1% of full range



Element Test Program

Outline

- 7075-T7451 aluminum plate (0.250 " thick)
- Variable amplitude spectrum - 430 cycles/block
- Reference stress - 31 to 55 ksi
- Average cyclic frequency - 5 Hz and 35 Hz
- Crack initiation and crack growth from 0.25" diameter holes
- DCPD used to detect 0.012" surface crack in bore of hole
- DCPD used to monitor crack growth
- 56 samples tested at four stress levels and two frequencies



Element Test Program

Program Objectives

- Establish accuracy of life predictions
- Establish effect of cyclic test frequency

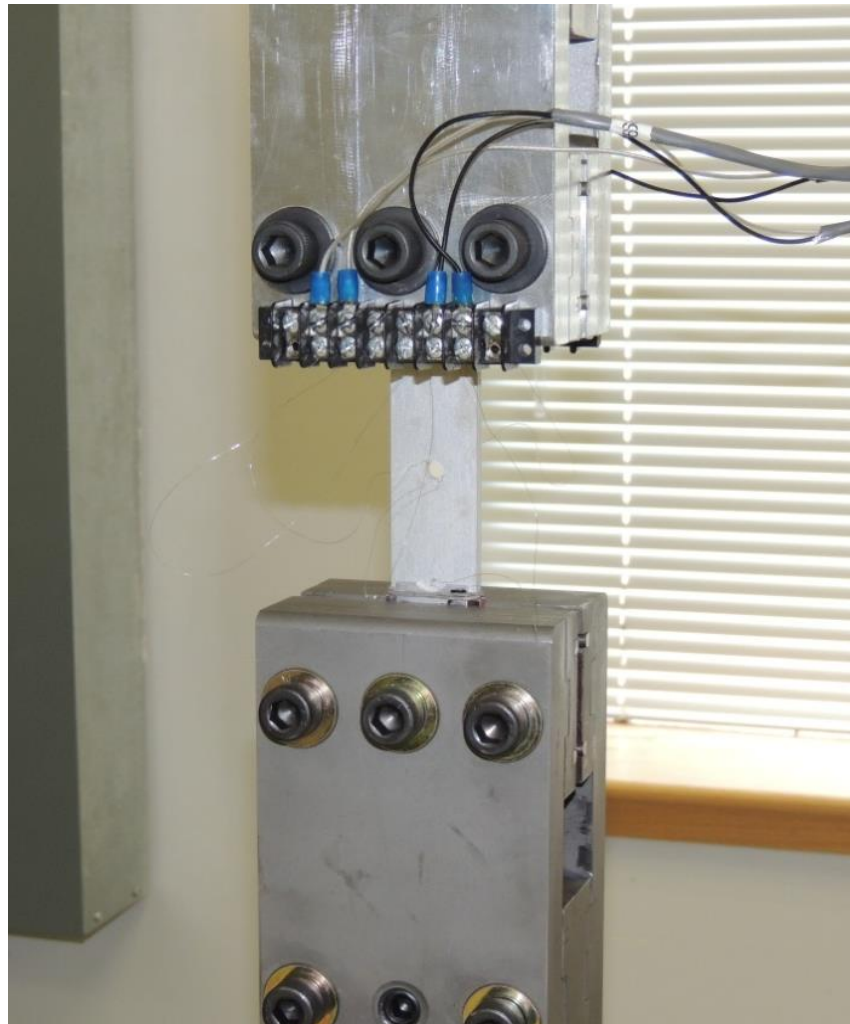
Considerations Critical to Program Objectives

- Sample preparation
- Alignment verification
- Dynamic loading verification
- Endpoint accuracy verification
- DCDP crack size calibration
- DCPD resolution necessary to detect 0.012" flaw size
- Environmental control: Temperature = $75 \pm 2^{\circ}\text{F}$, RH = $40 \pm 5\%$

Test Equipment



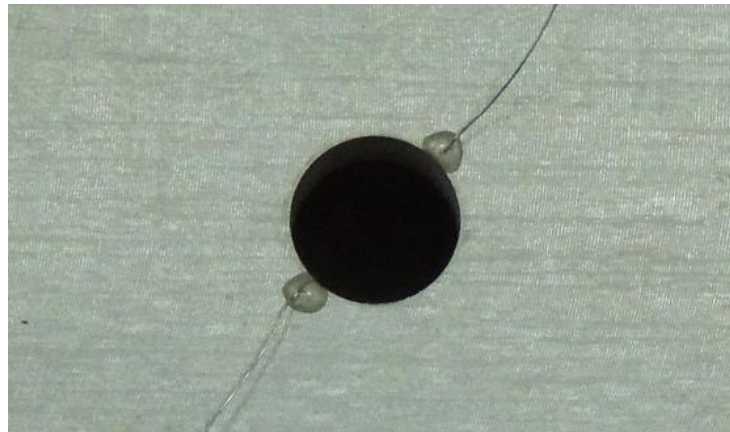
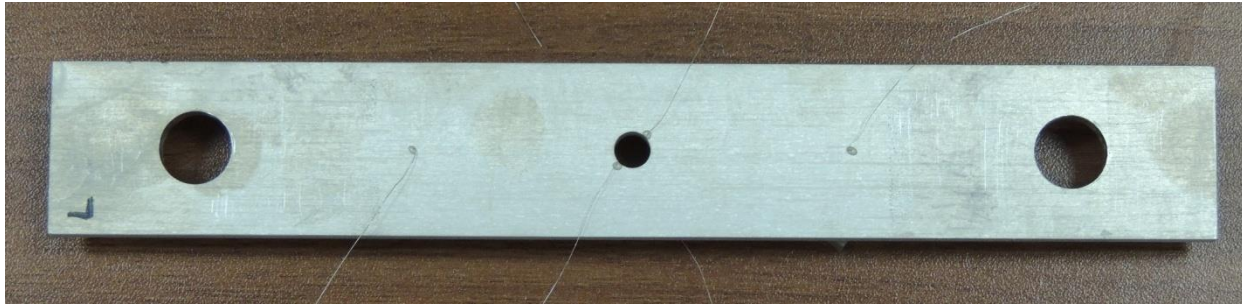
Test Equipment



Note aluminum fixture on top.

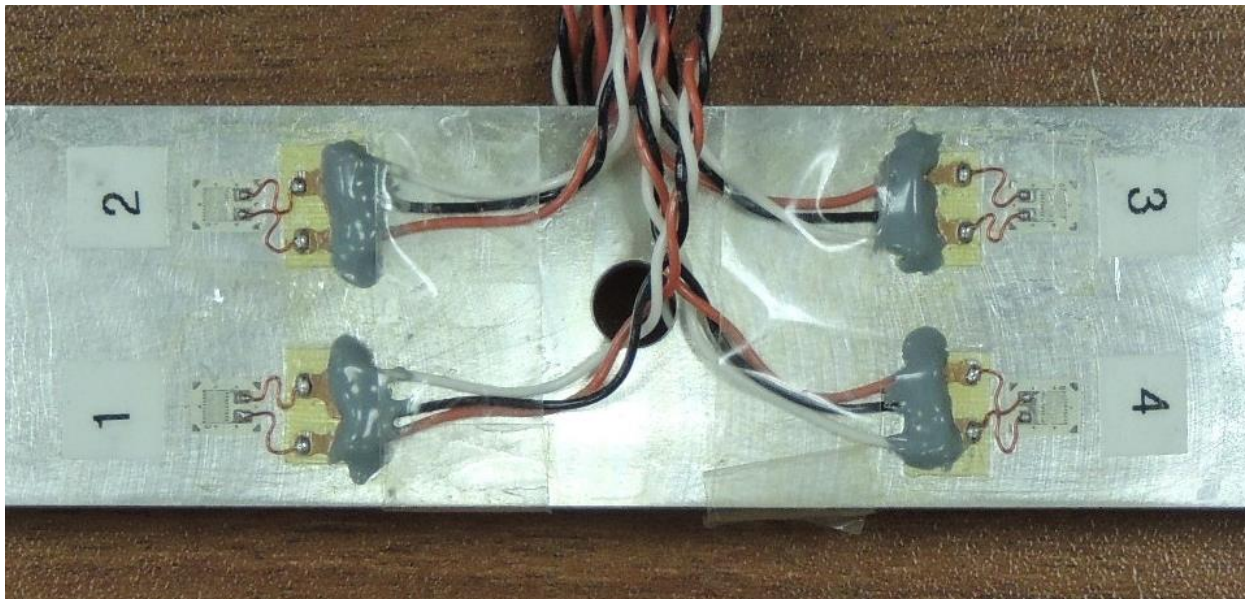
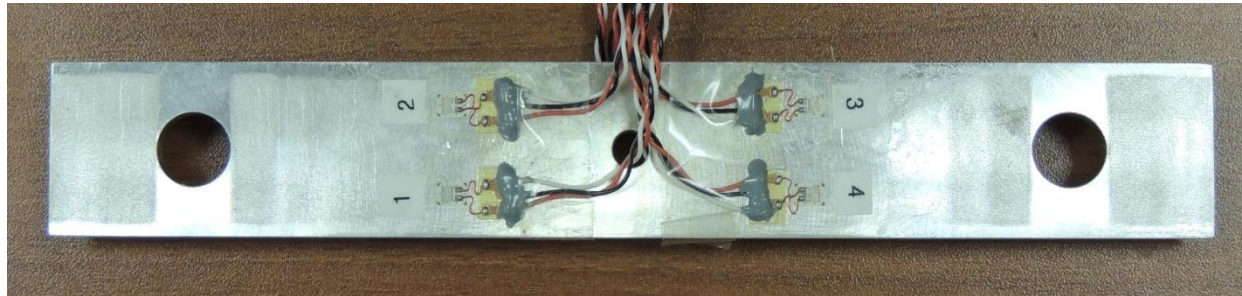
Aluminum was used instead of steel between sample and load cell to reduce dynamic loading errors.

Test Sample



Bottom photo shows 0.25" diameter hole with
0.005" diameter platinum sensing leads

Alignment Verification Sample



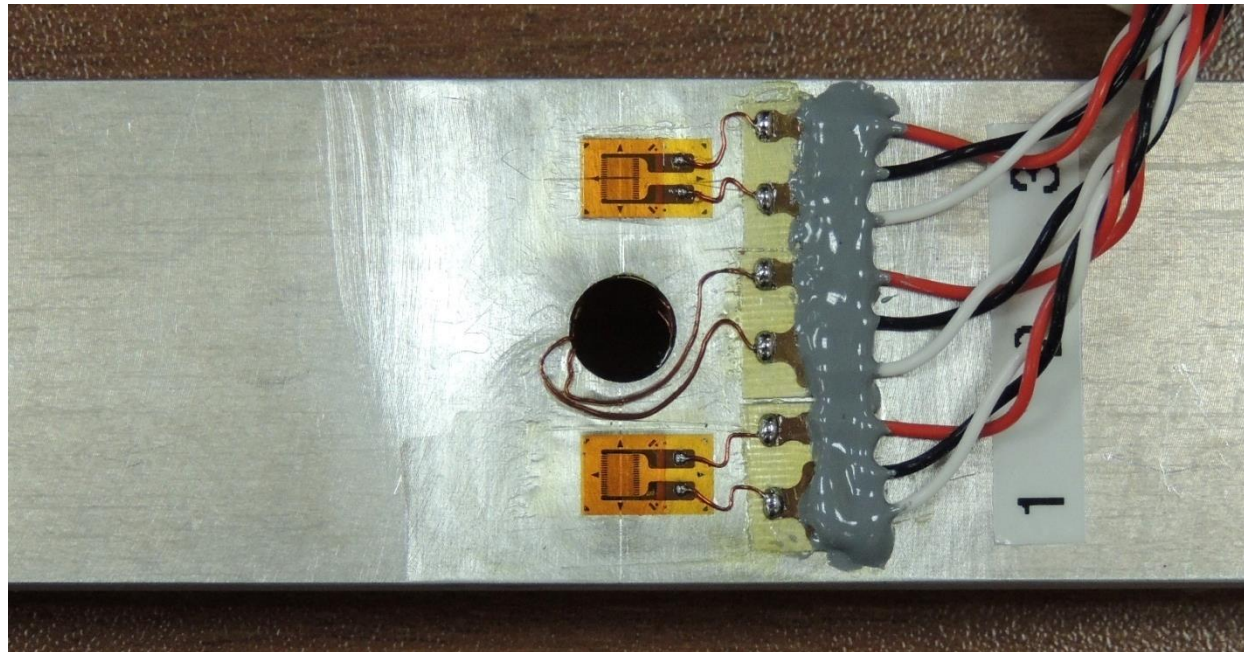
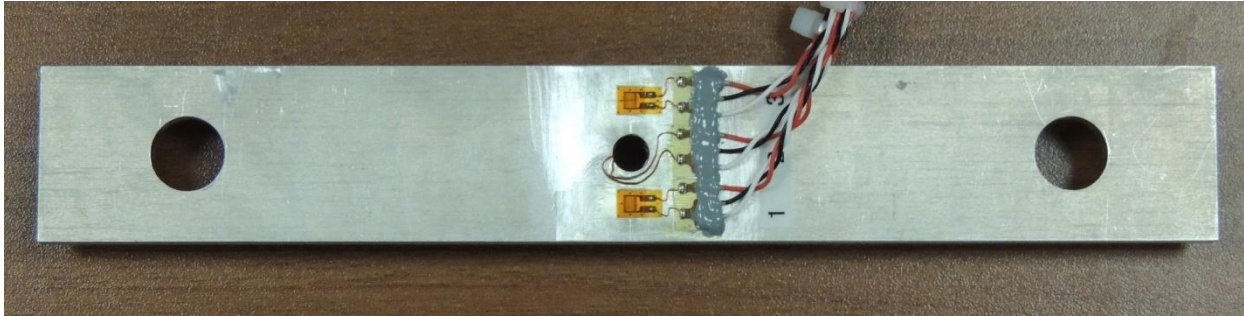


Alignment Verification Results

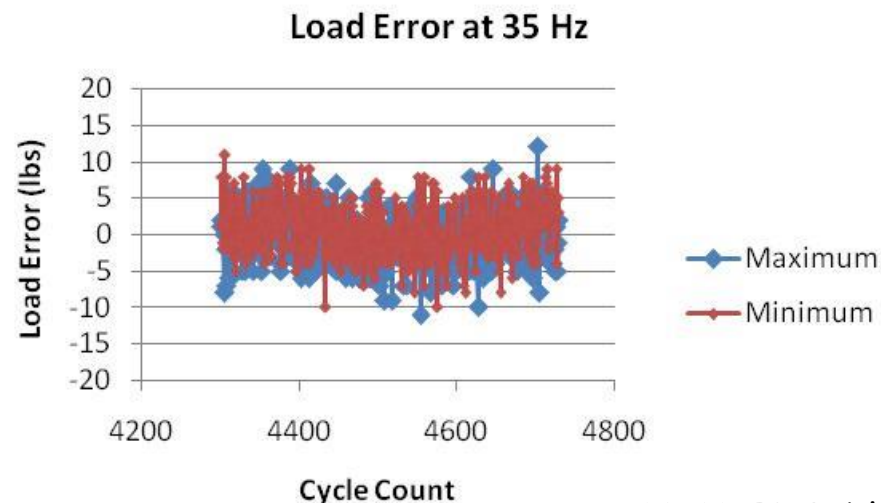
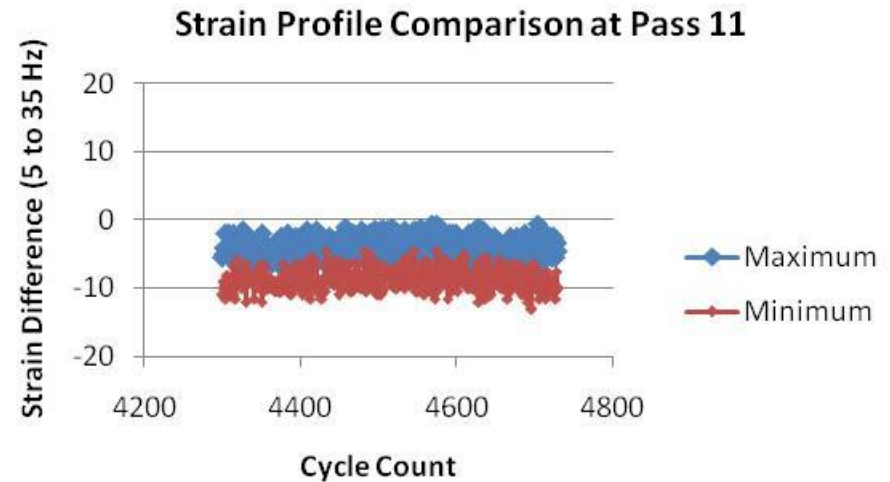
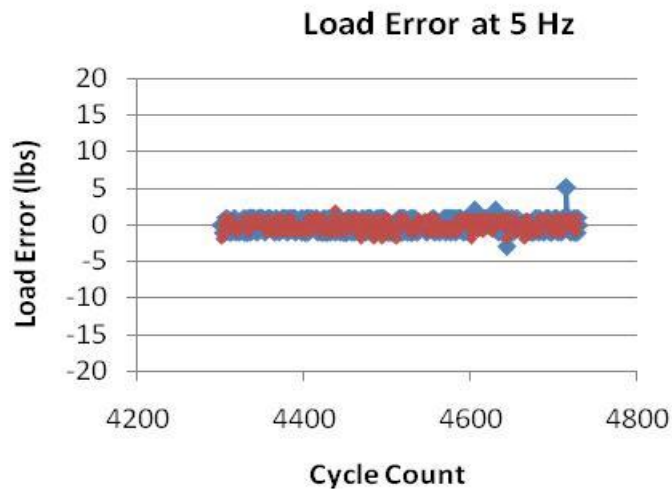
- Average bending strain was less than 0.5%.
- All cracks initiated as surface flaws in bore of hole. Initiation locations appeared random.



Dynamic Verification Sample



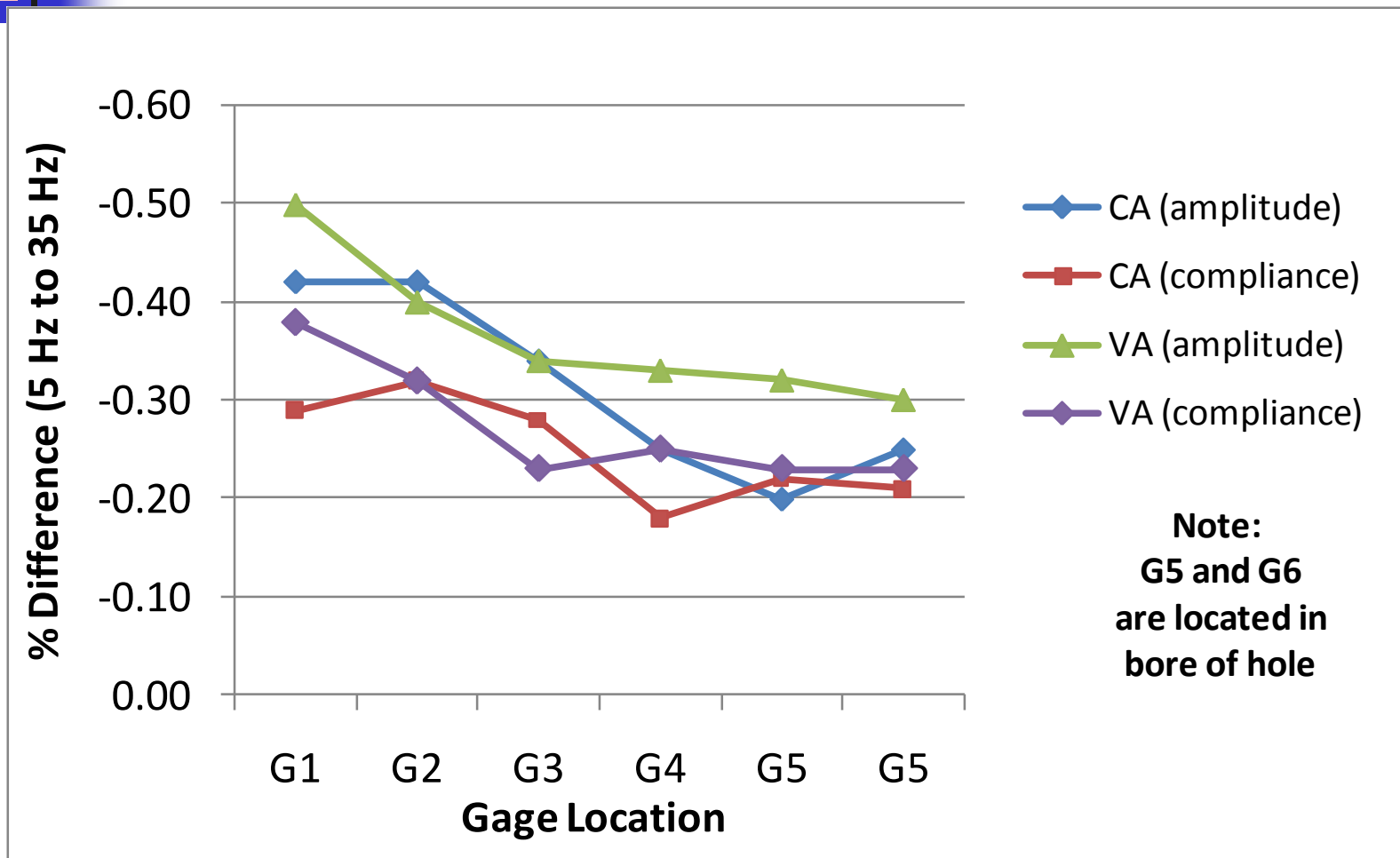
Dynamic Verification Results



Left:
Load errors:
5 Hz ~0.1%
35 Hz ~0.3%

Above:
Dynamic strain comparison for
Gage 1.

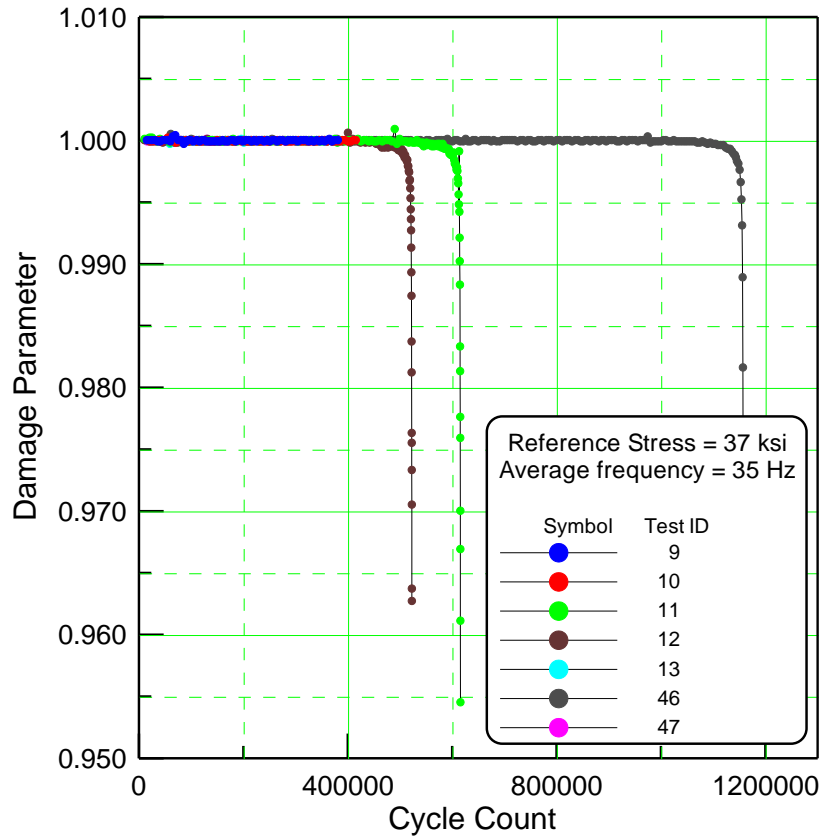
Dynamic Verification Results



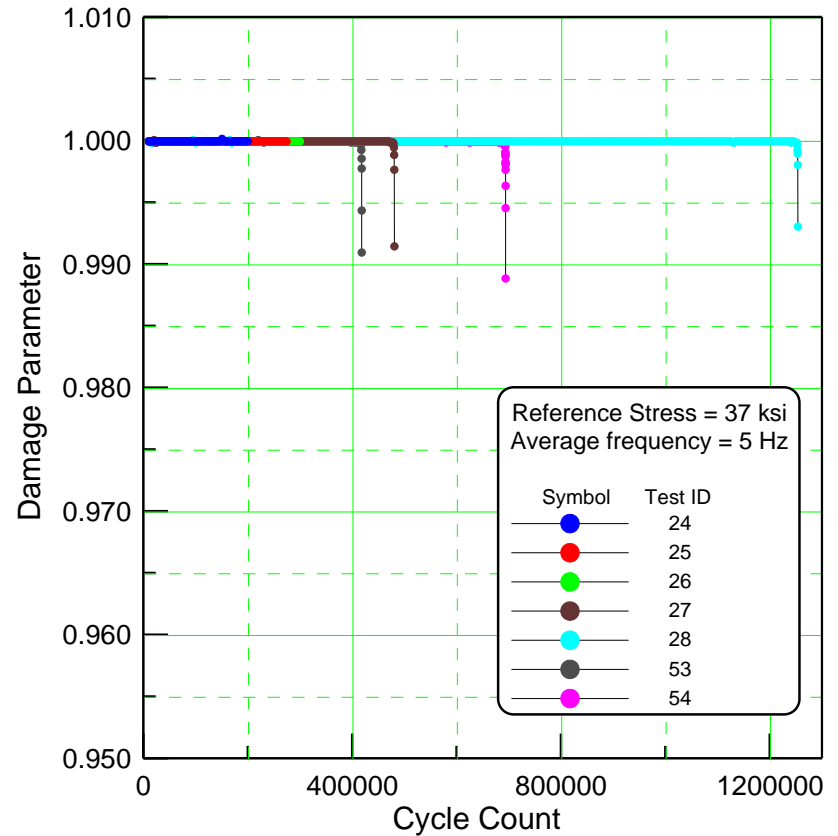
Note:
G5 and G6
are located in
bore of hole

Dynamic loading error in bore of hole is -0.2% to -0.3% at 35 Hz

Damage Parameter Verification



37 ksi, 35 Hz

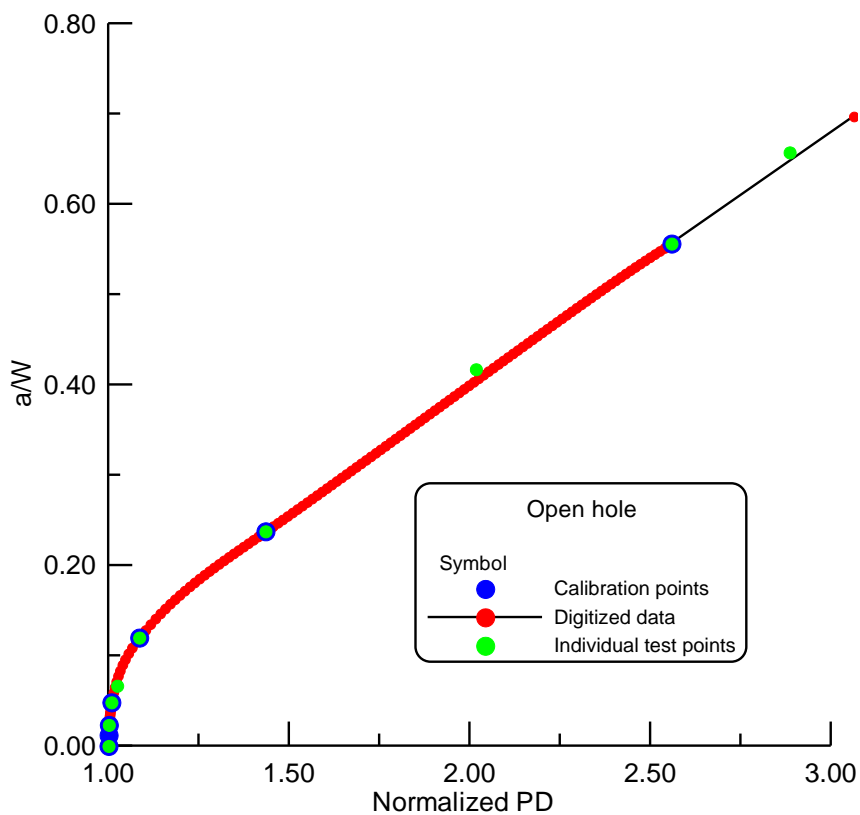


37 ksi, 5 Hz

Drop in damage parameter as sample approaches failure

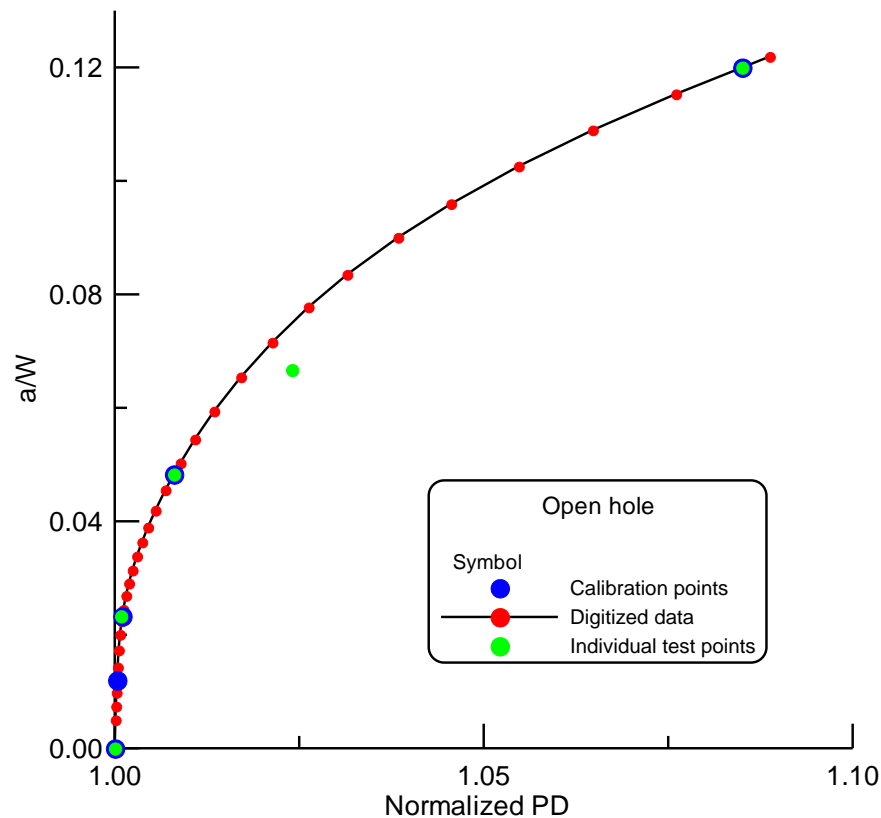
DCPD Crack Size Calibration

PD Calibration



Full Curve

PD Calibration



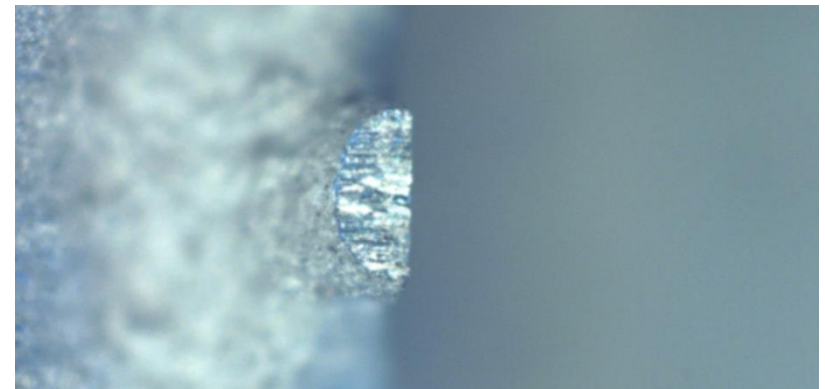
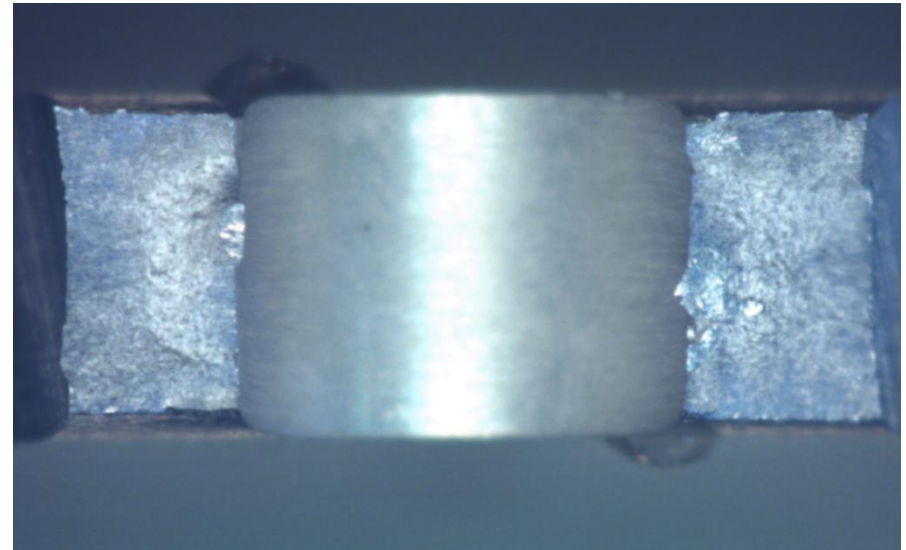
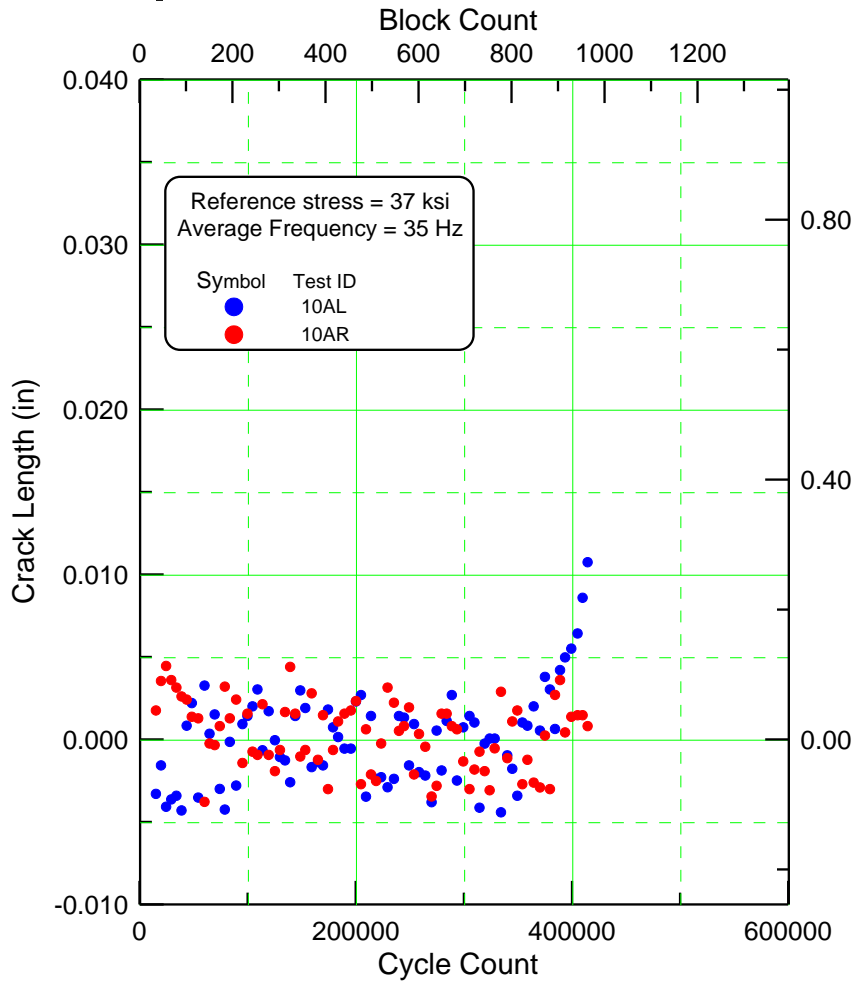
Out to Normalized PD of 1.10



DCPD Crack Size Resolution

- Current magnitude was 15 amps
- Active probe magnitude was ~38 micro-volts
- Reference probe magnitude was ~320 micro-volts
- Detection of 0.012" to 0.015" flaw size required 30 nano-volt resolution

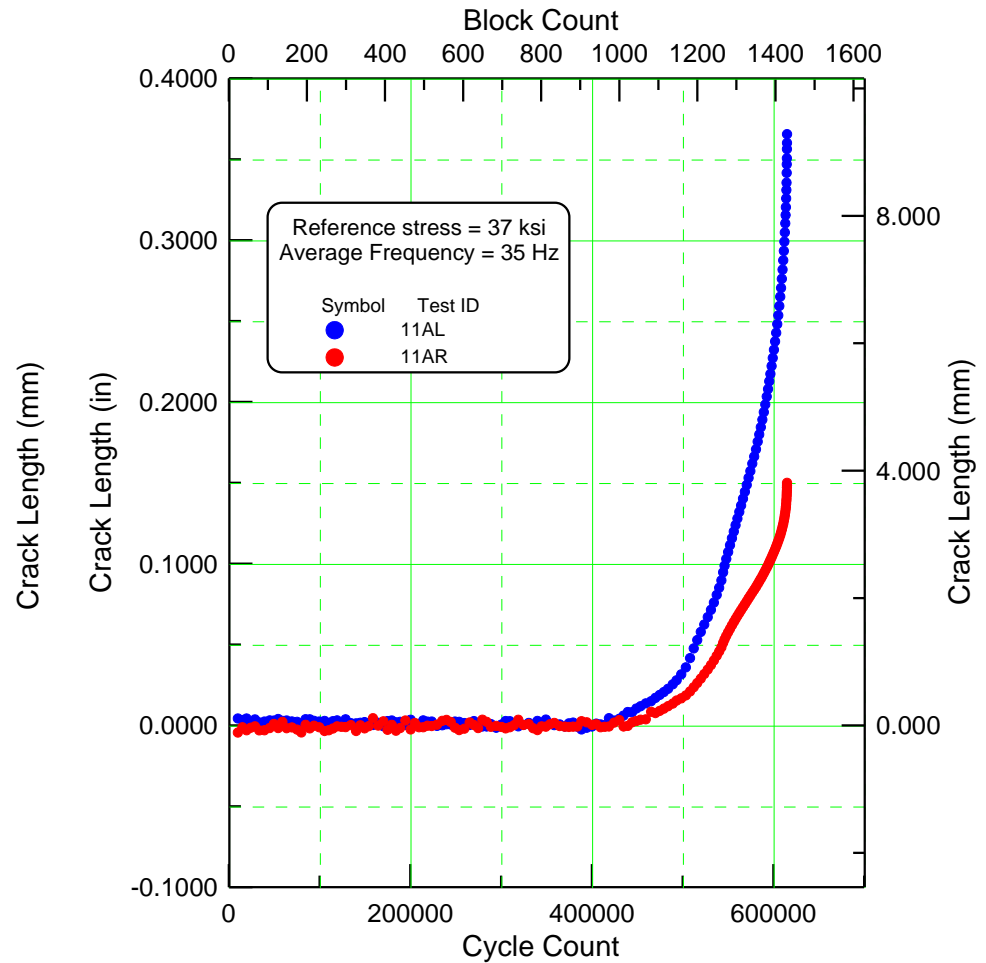
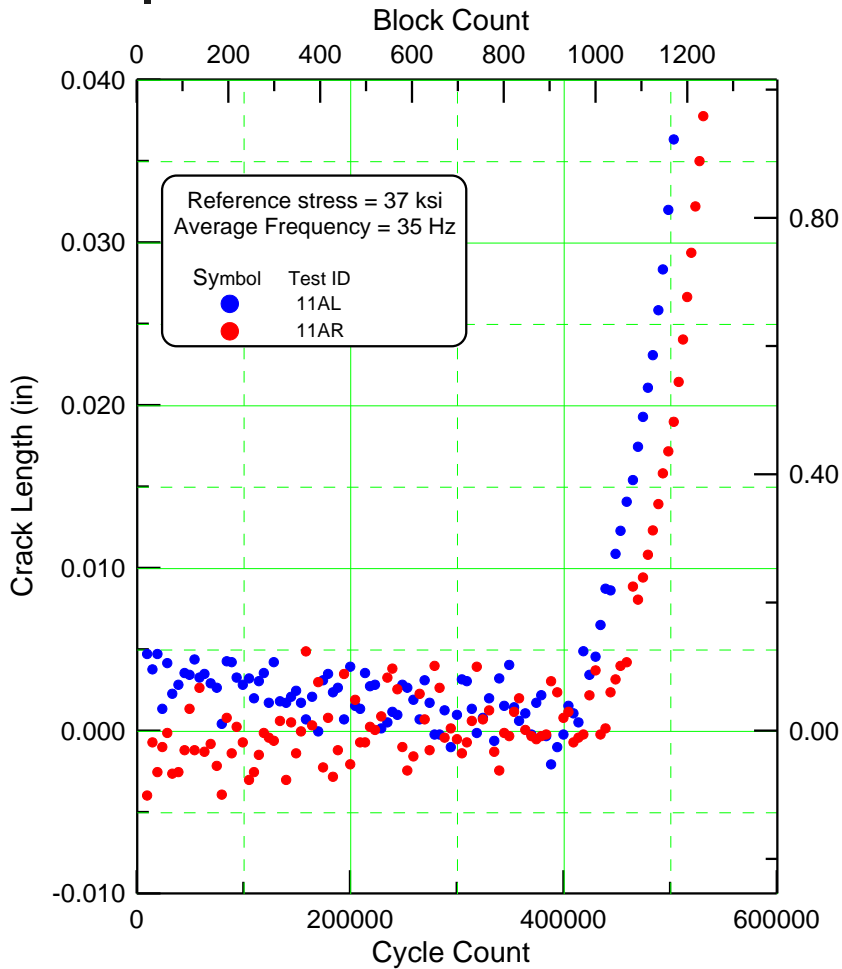
Crack Size versus Cycle Count Test Terminated After Initiation



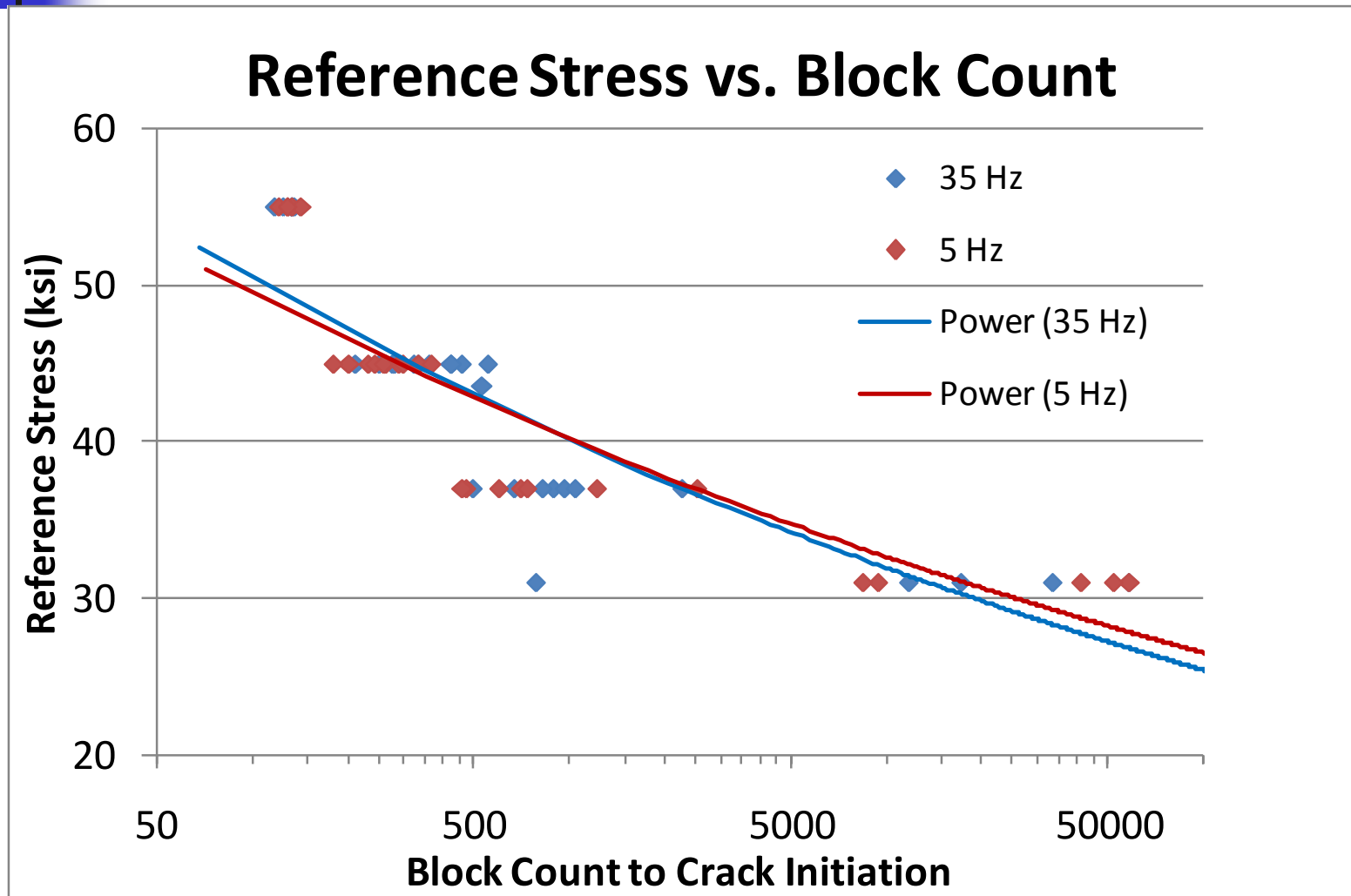
0.014 x 0.016" flaw

Crack Size versus Cycle Count

Test Terminated at ~0.400"

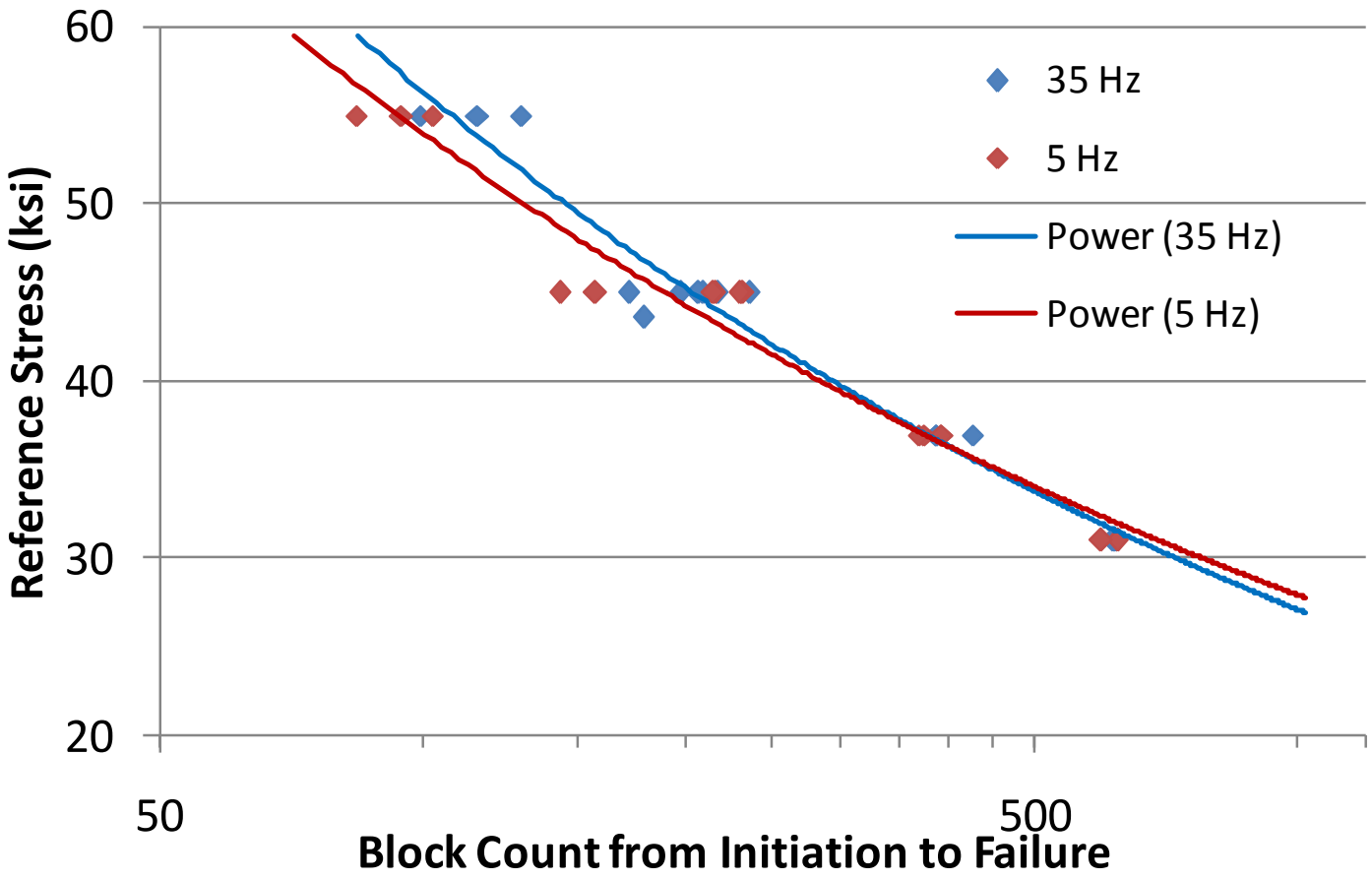


Block Count to Crack Initiation



Block Count from Initiation to Failure

Reference Stress vs. Block Count





Summary and Conclusions

- A damage parameter may be a useful tool for real time evaluation of tuning and compensation.
- A load amplitude validation log provides greater confidence that expected performance has been achieved.
- A precision DCPD calibration and resolution provides high confidence in detection of crack initiation.
- Careful consideration to dynamic verification confirms no appreciable impact of test frequency.