Variable Amplitude Control and Verification Methodology

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

ASTM May Committee Week
New Orleans, LA
Wednesday, November 12, 2014

Acknowledgement

- NAVAIR – Tim Fallon
- The Boeing Company – Eric S. Meyer Technical Fellow

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.

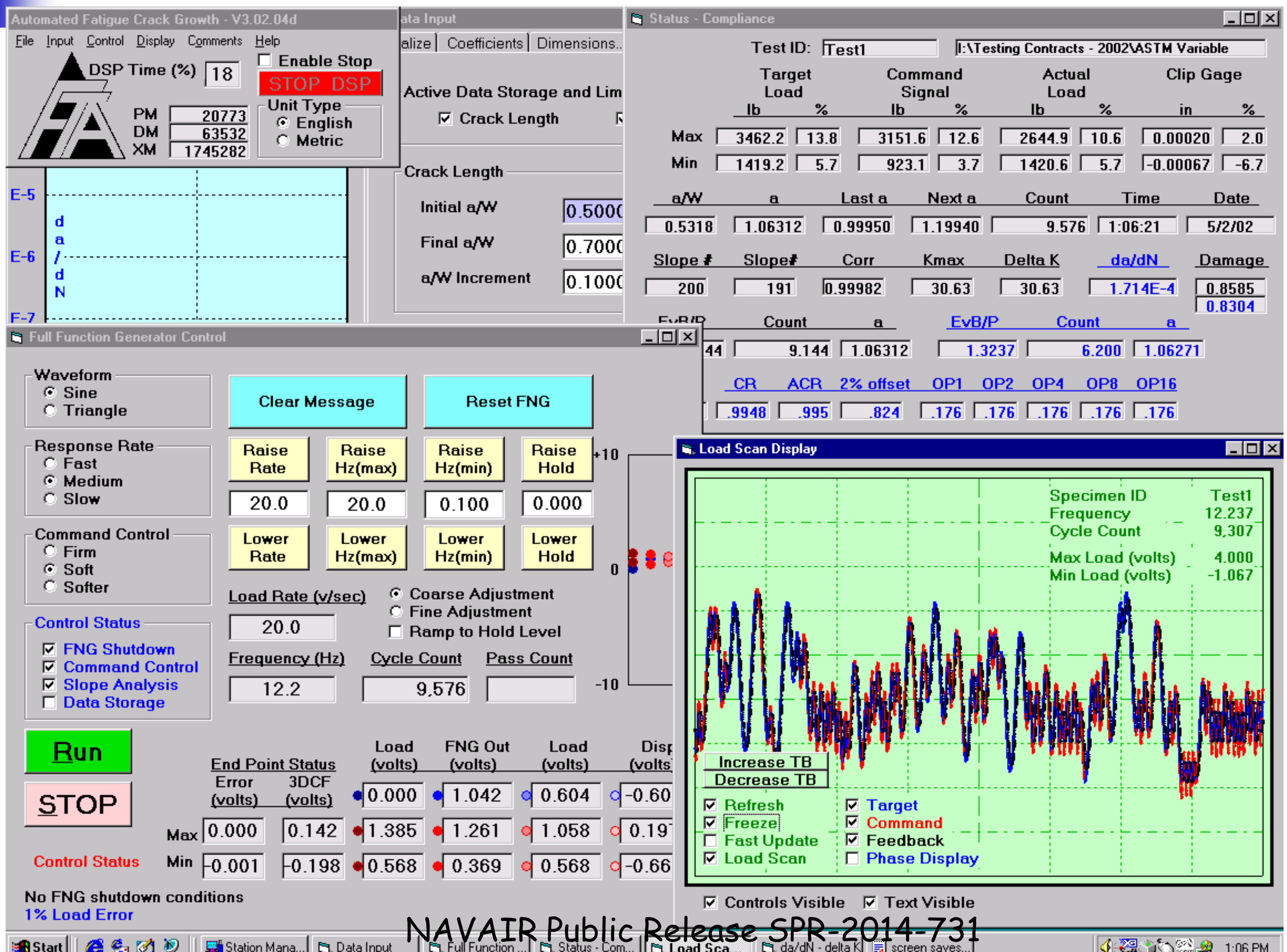
- ADBasic - Allows modular programming in high priority for time critical processes and low priority for background operations.

- 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.

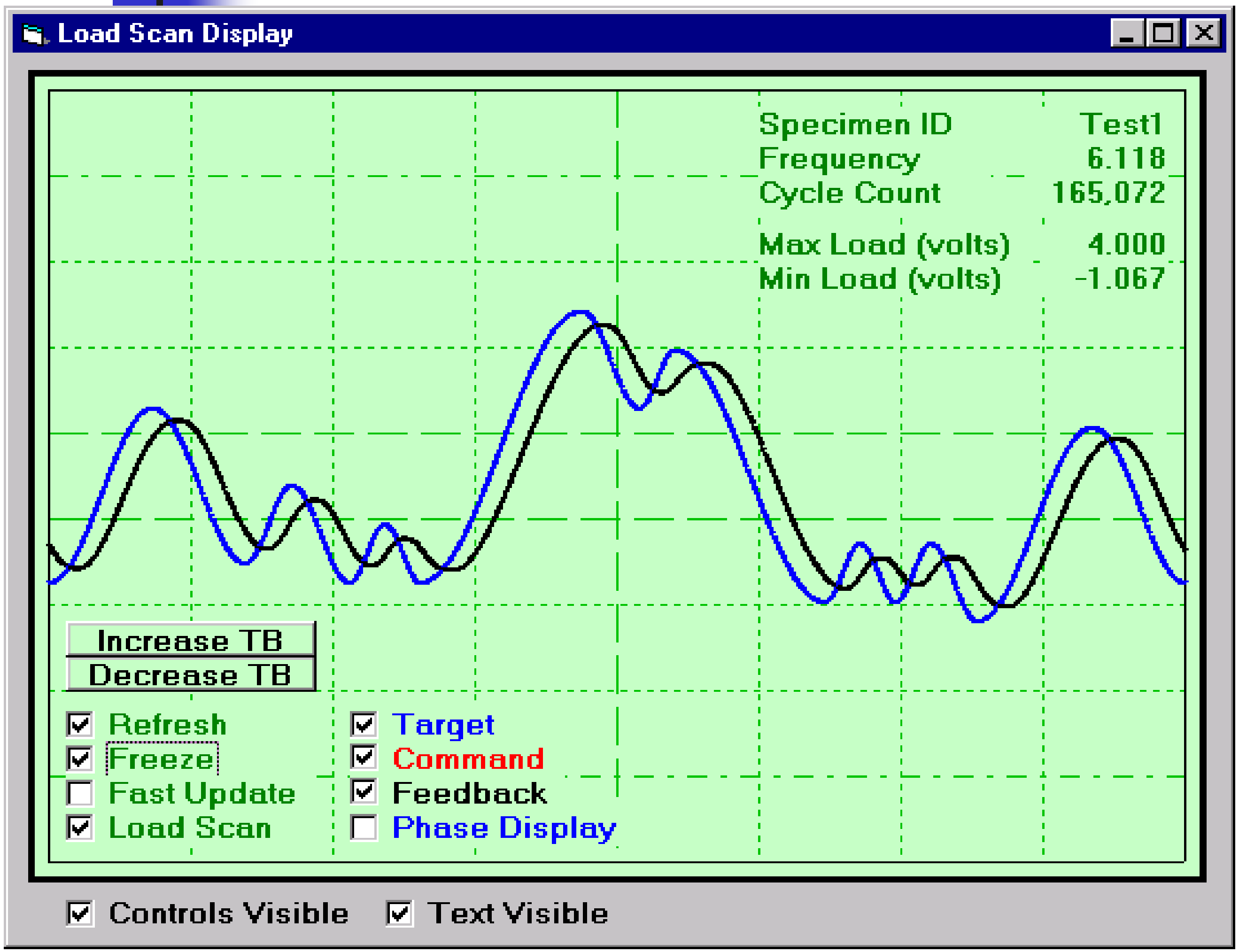
Features

- 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

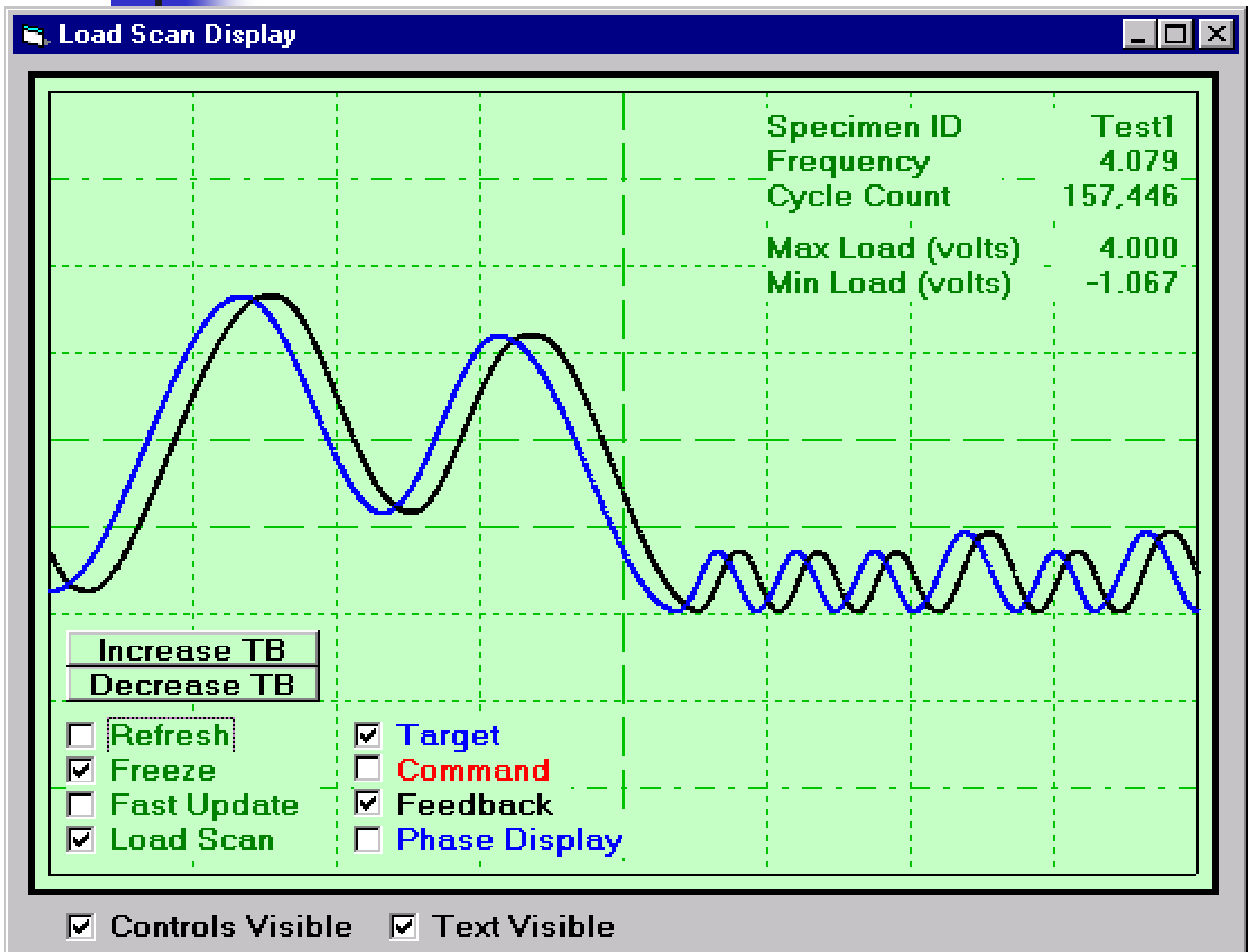


No Command Compensation



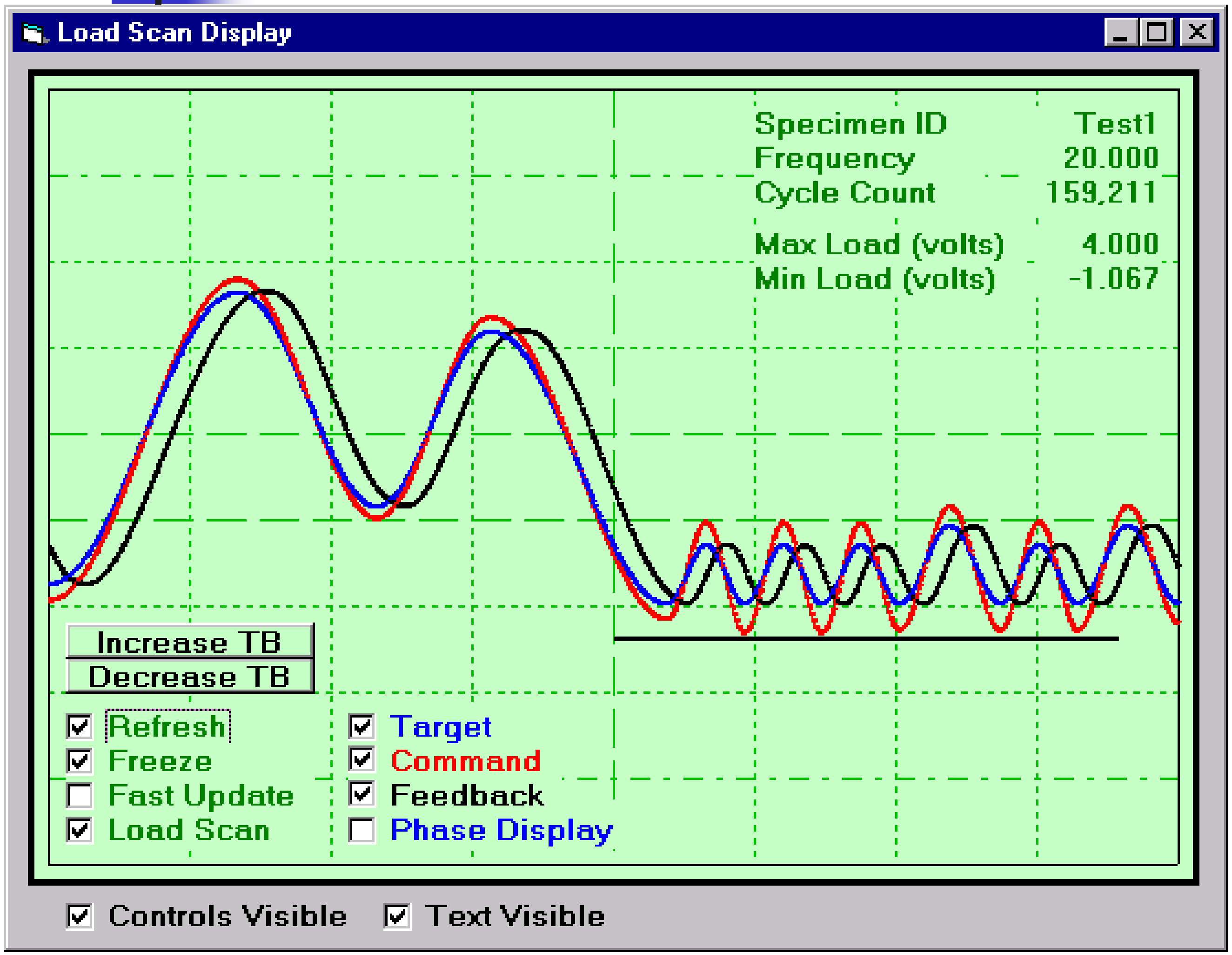
With no command compensation and poor PID tuning, the actual load peaks (in black) **do not** match the target load peaks (in blue).

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

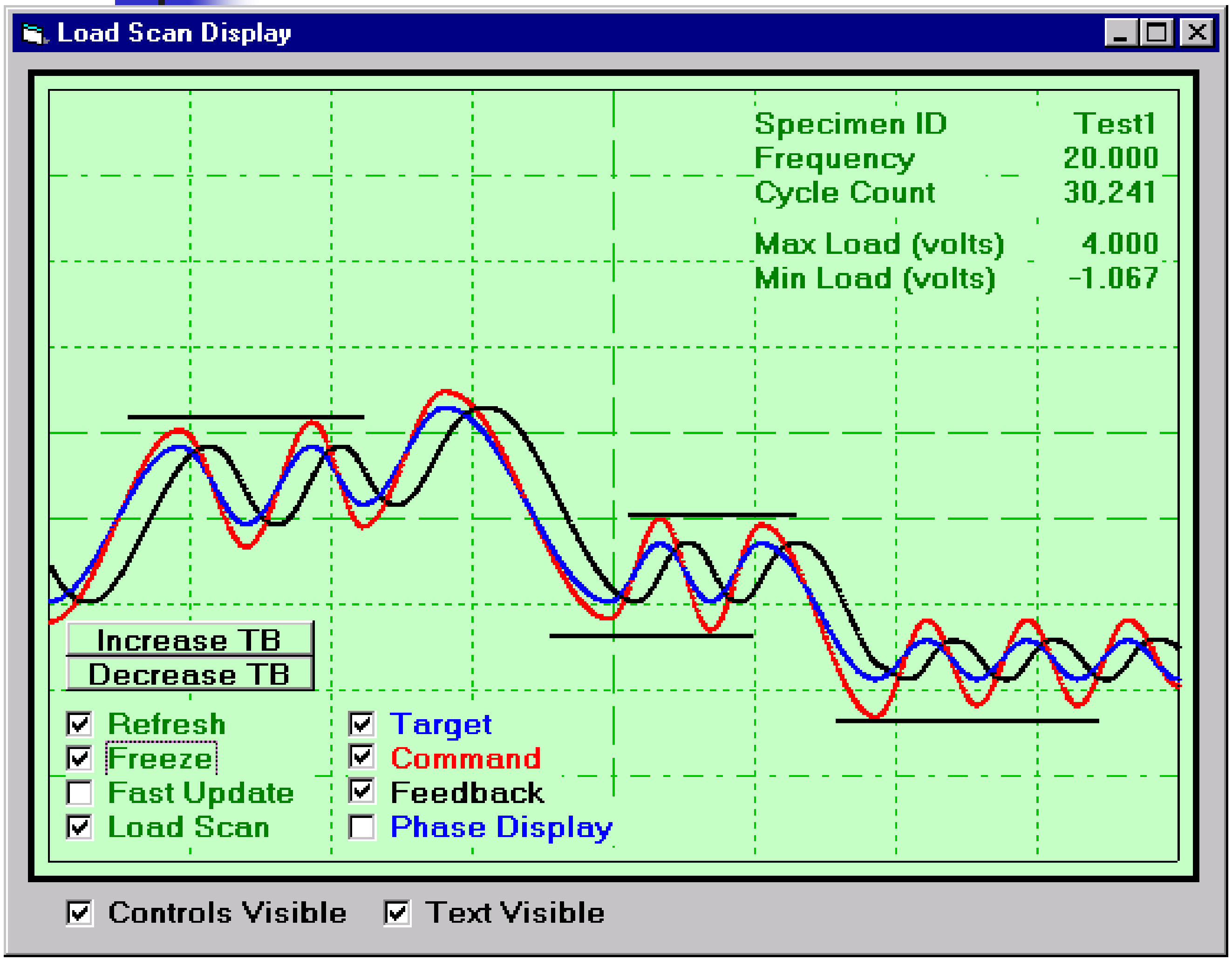
Command Compensation Enabled



Command signal is also shown (in red).

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

Command Compensation Enabled



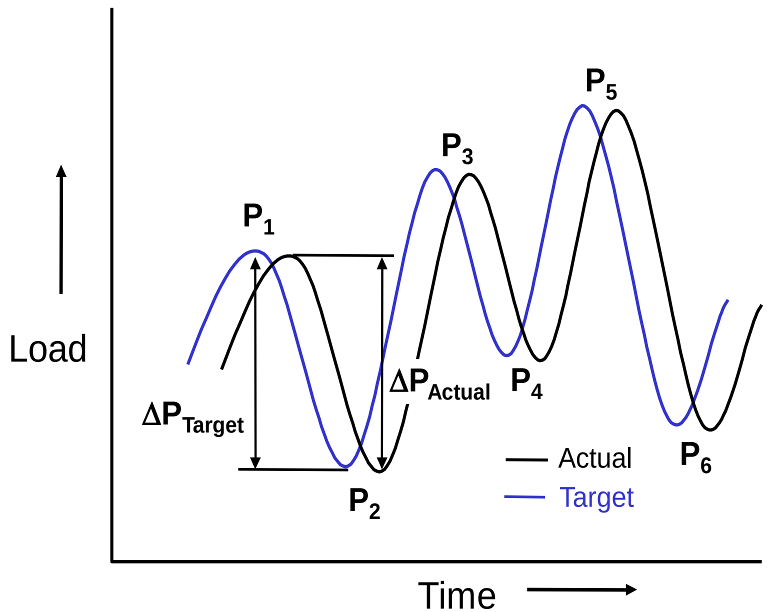
Command signal is also shown (in red).

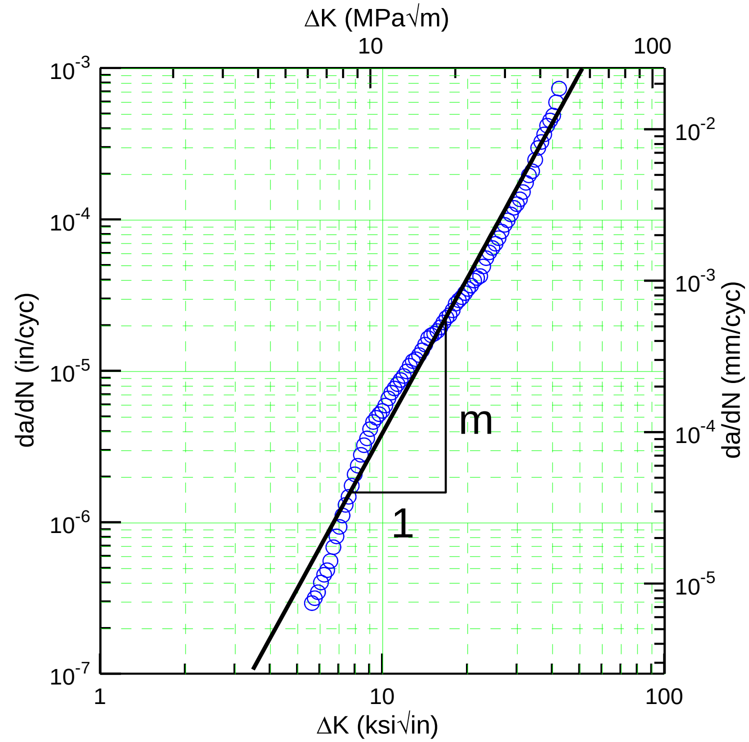
This shows four cases where identical endpoints have different command compensation.

Damage Parameter (McKeighan, et al)…

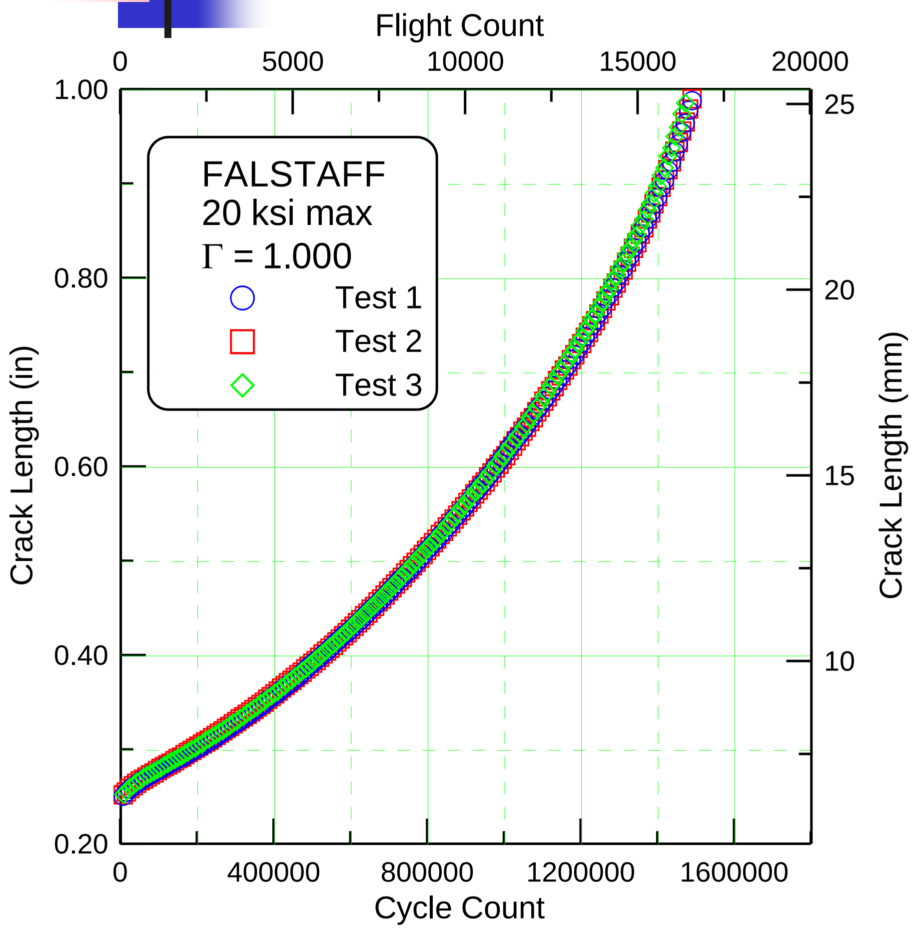
$$\Gamma = \frac{\sum (\Delta P_{Actual})^m}{\sum (\Delta P_{Target})^m}$$

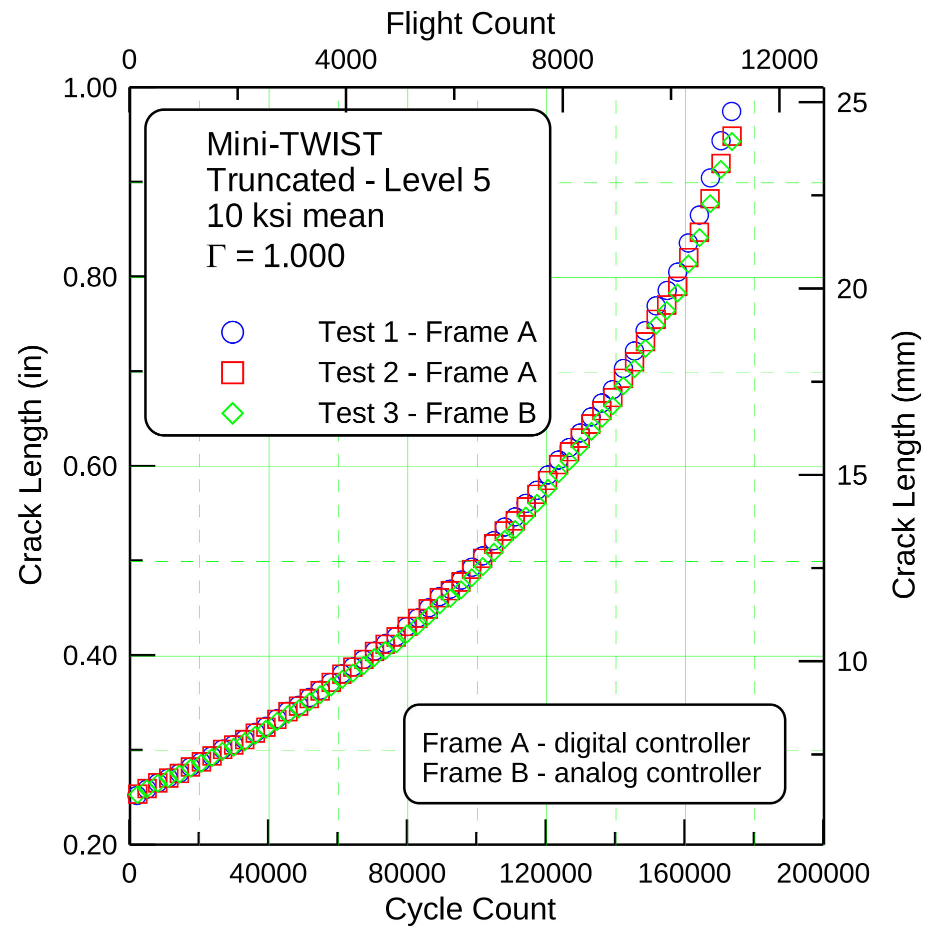
$$\frac{da}{dN} = C \cdot \Delta K^m$$





Triplicate Results with Γ = 1.000





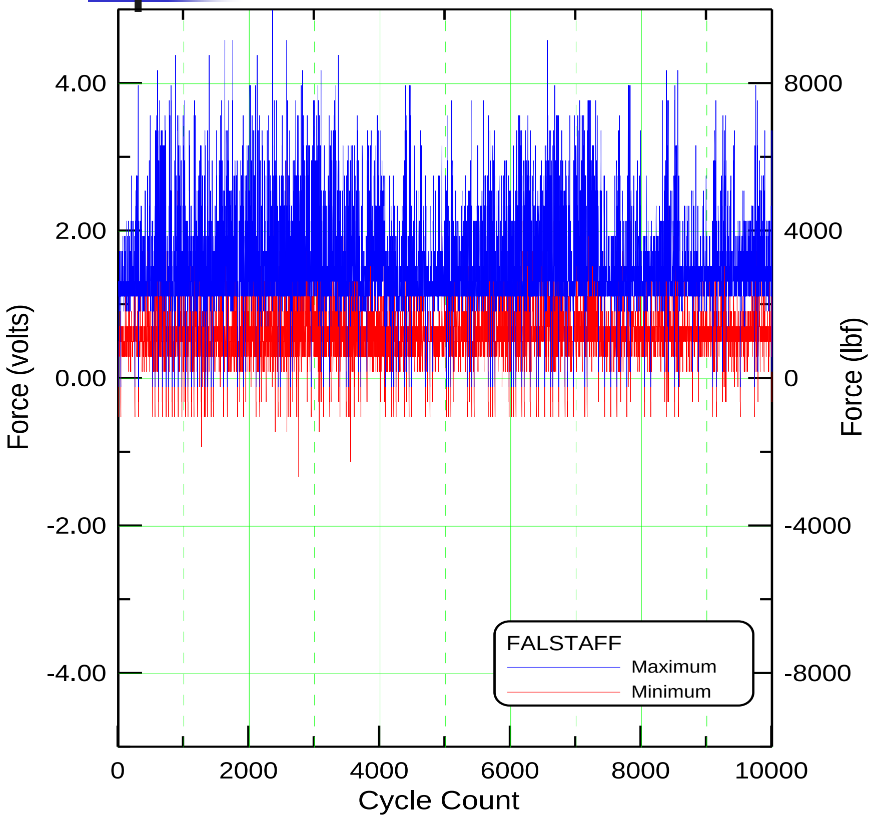
FALSTAFF

Mini-Twist (clipped)

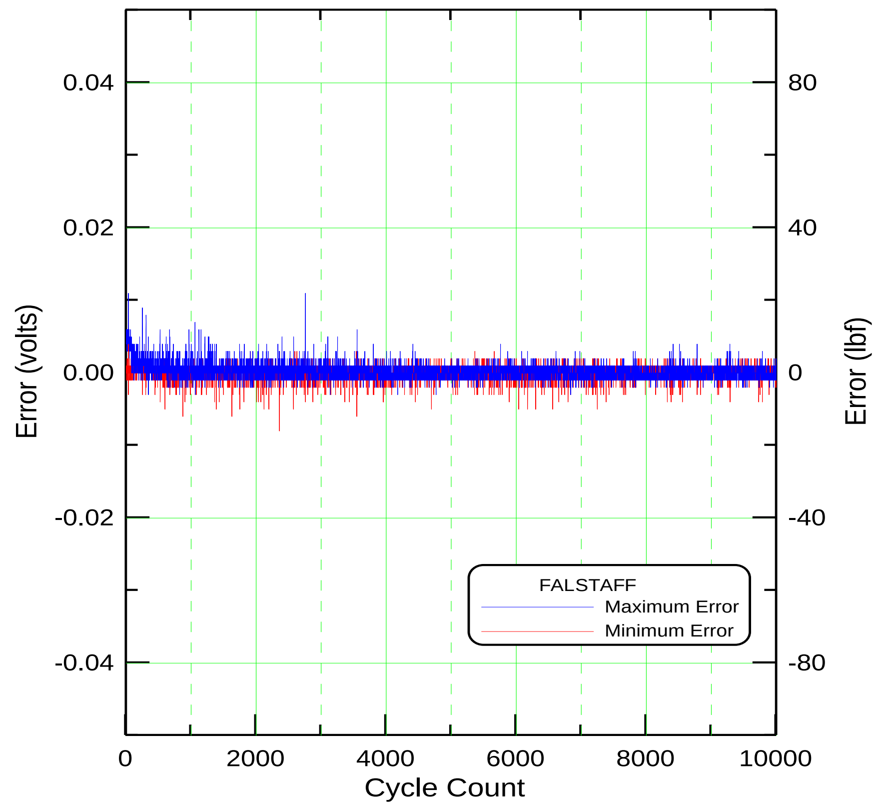
Limitations of Damage Parameter

- 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

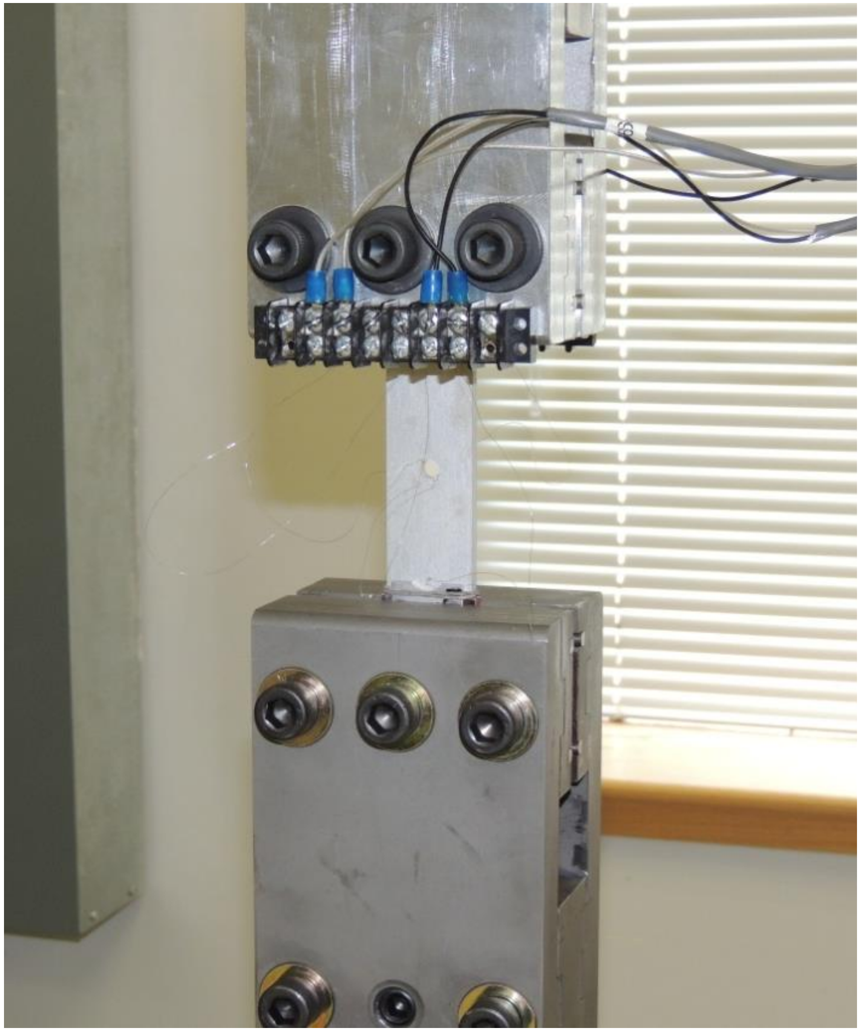
- Establish accuracy of life predictions
- Establish effect of cyclic test frequency

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 ± 2°F, RH = 40 ± 5%

Test Equipment

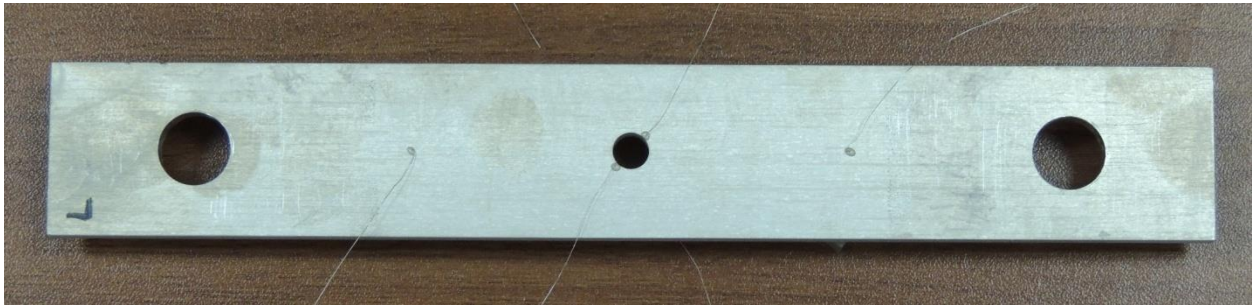
Test Equipment

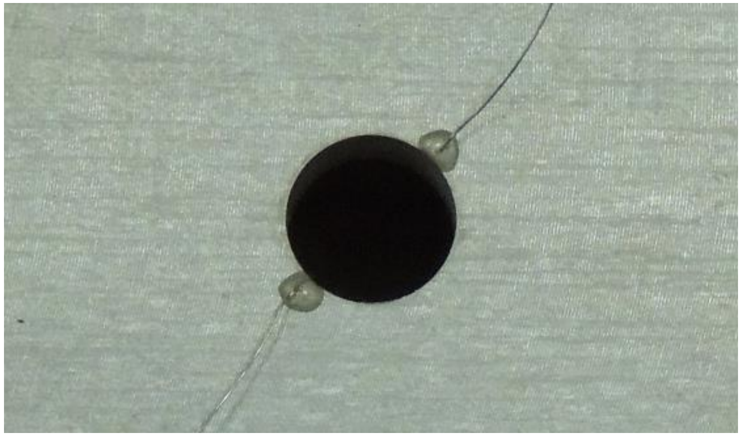


Note aluminum fixture on top.

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

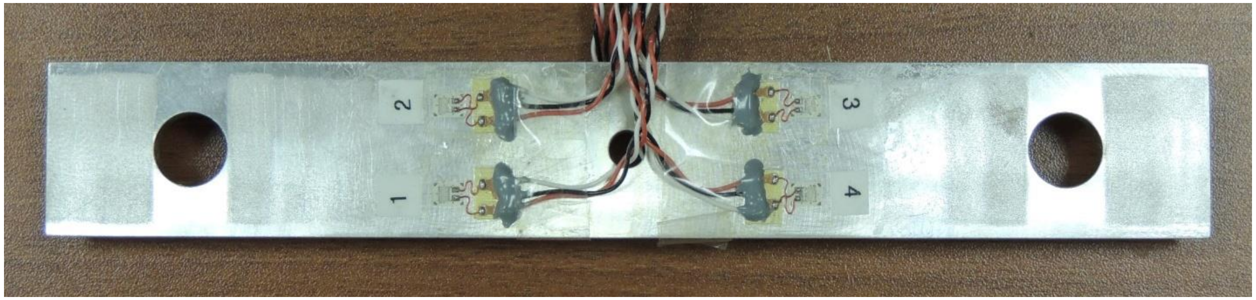
Test Sample

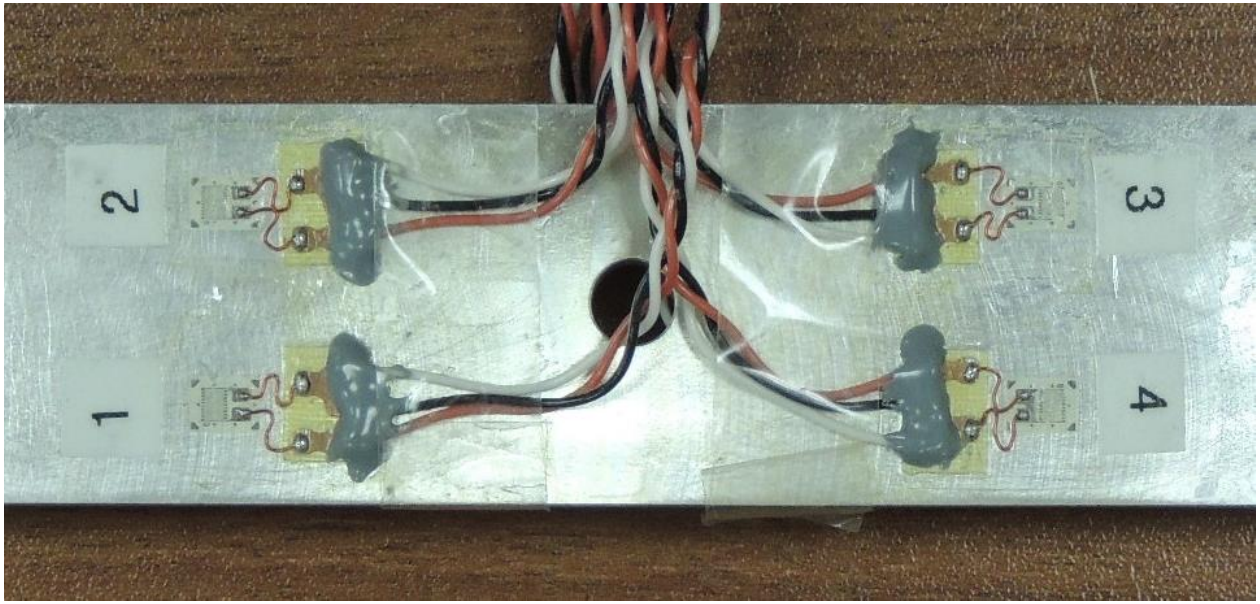




Bottom photo shows 0.25" diameter hole with 0.005" diameter platinum sensing leads

Alignment Verification Sample

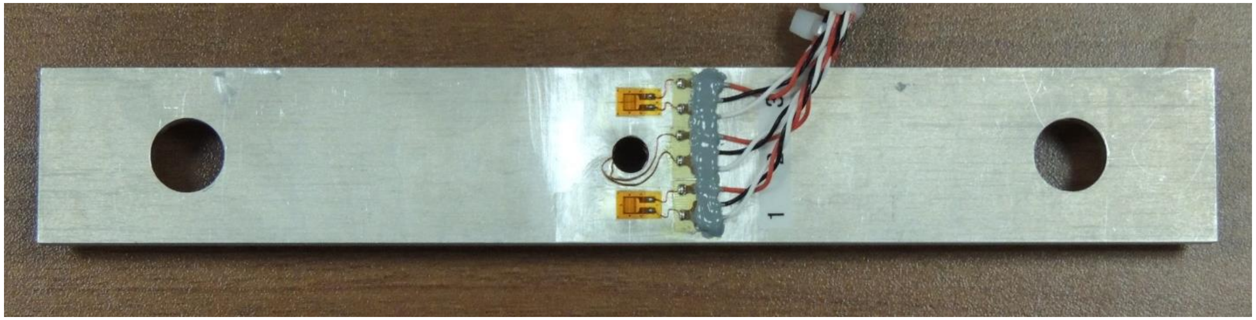


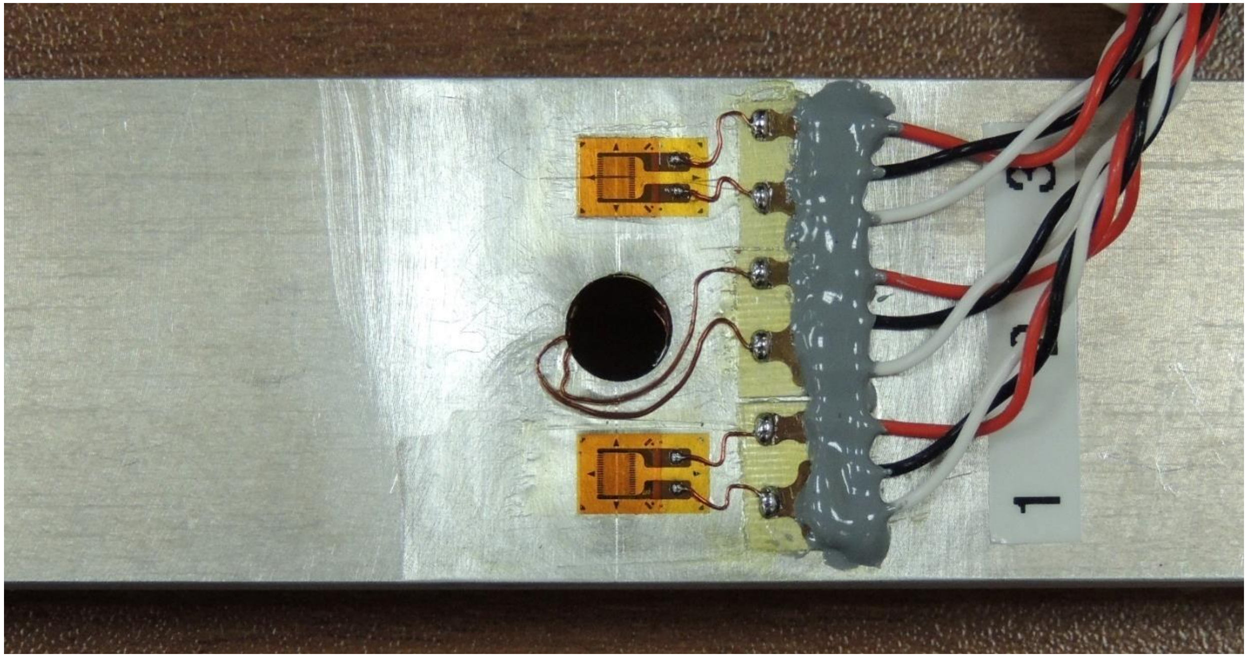


Alignment Verification Results

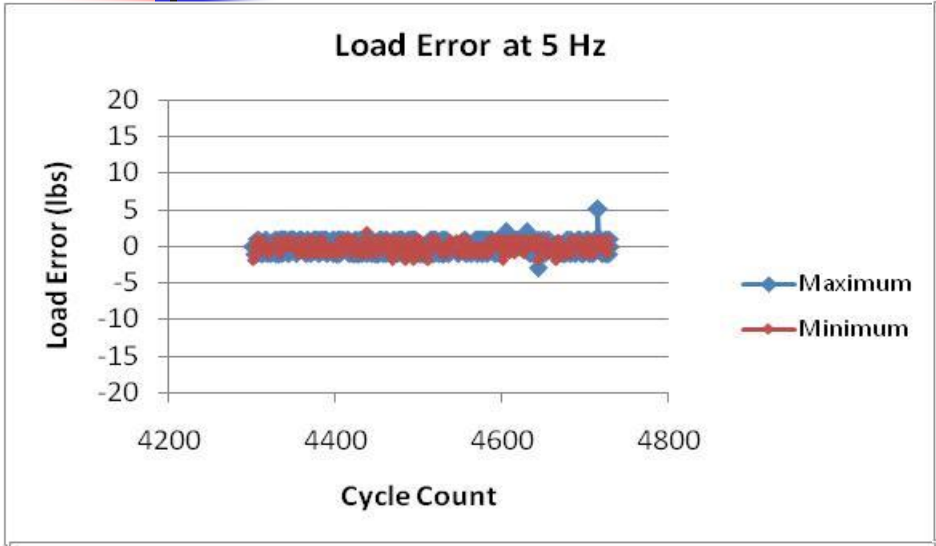
- Average bending strain was less than 0.5%.
- All cracks initiated as surface flaws in bore of hole. Initiation locations appeared random.

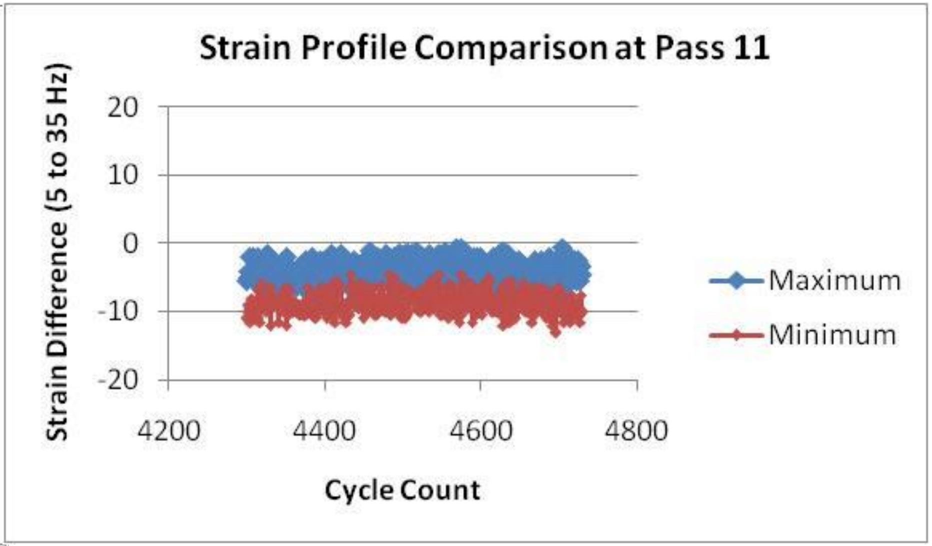
Dynamic Verification Sample

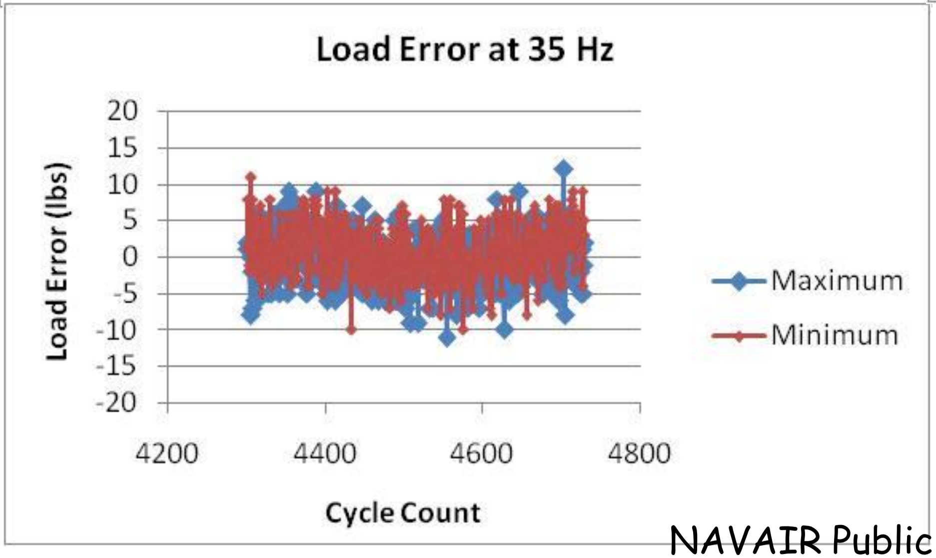




Dynamic Verification Results



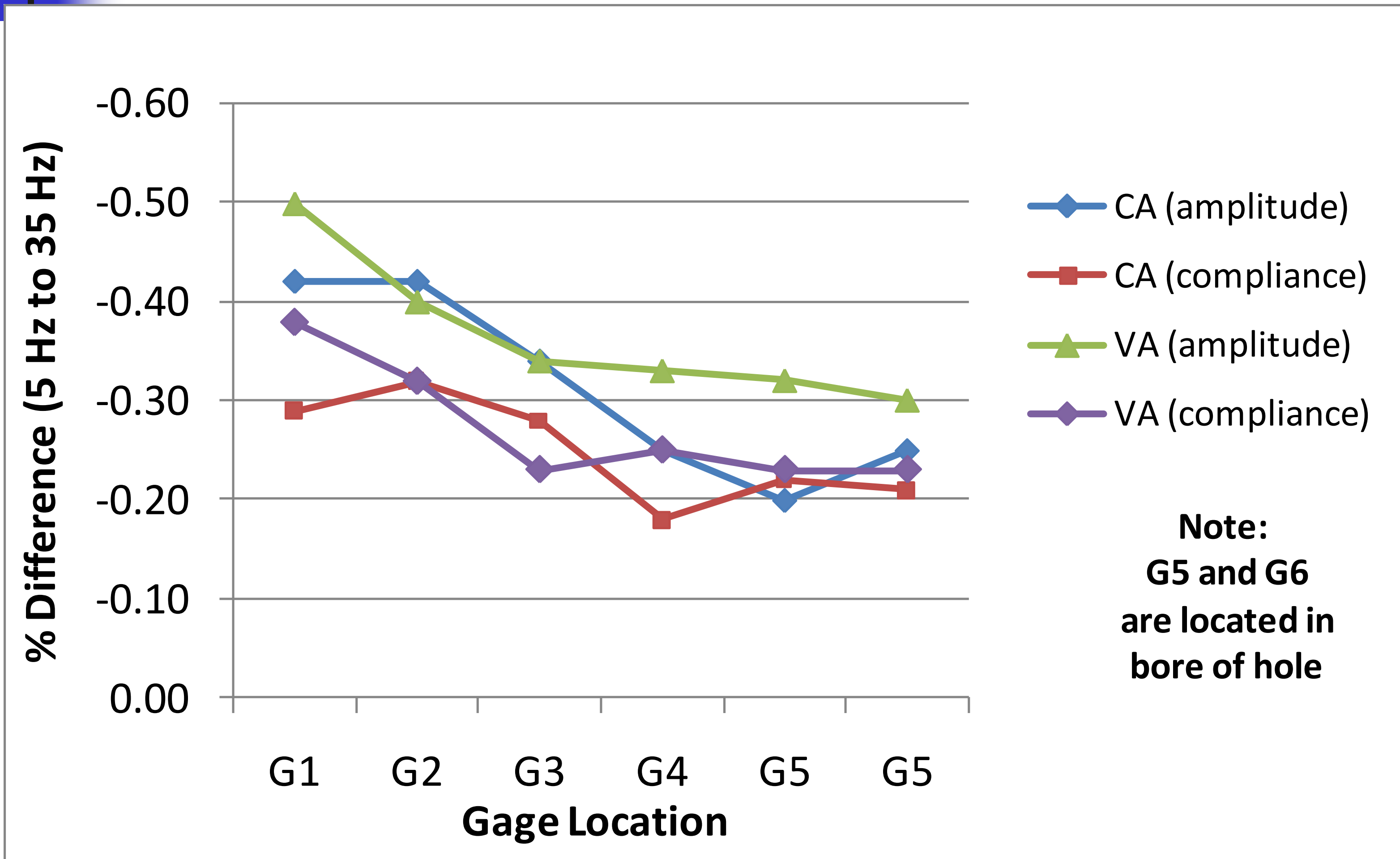




Left:
Load errors:
5 Hz ~0.1%
35 Hz ~0.3%

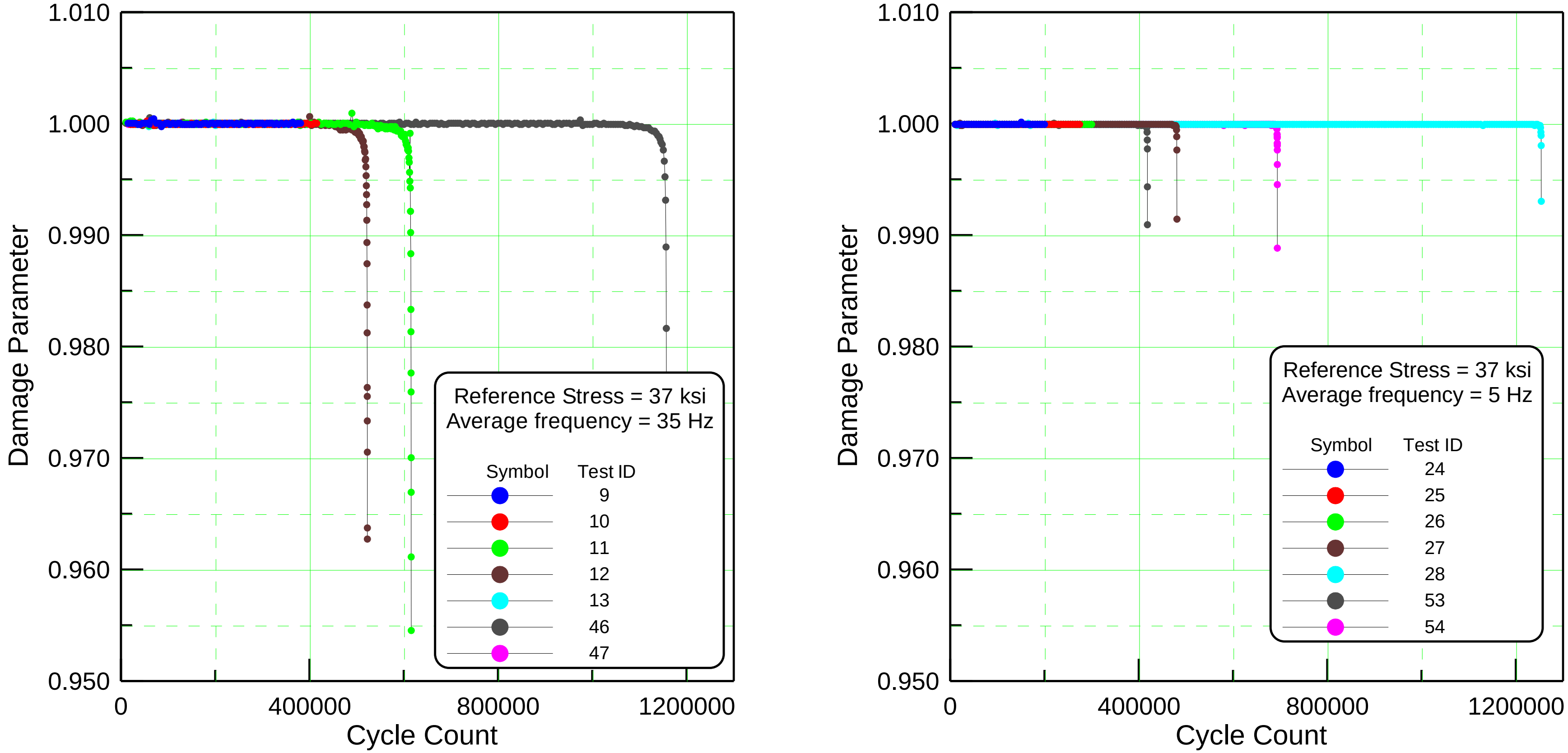
Above:
Dynamic strain comparison for Gage 1.

Dynamic Verification Results



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

Damage Parameter Verification

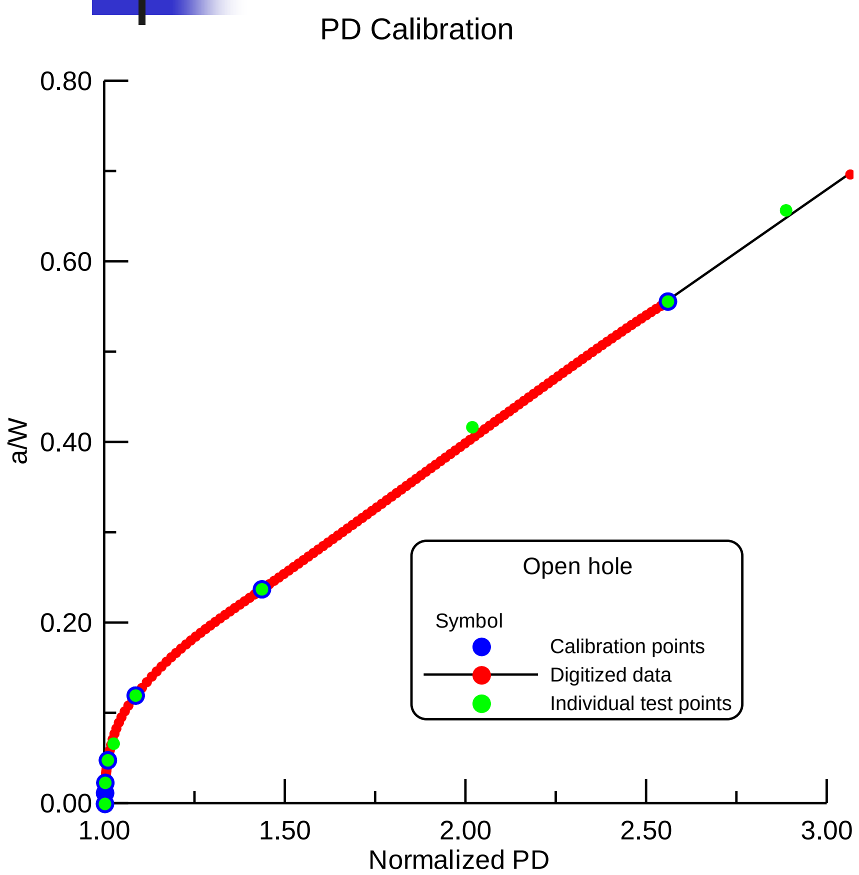


37 ksi, 35 Hz

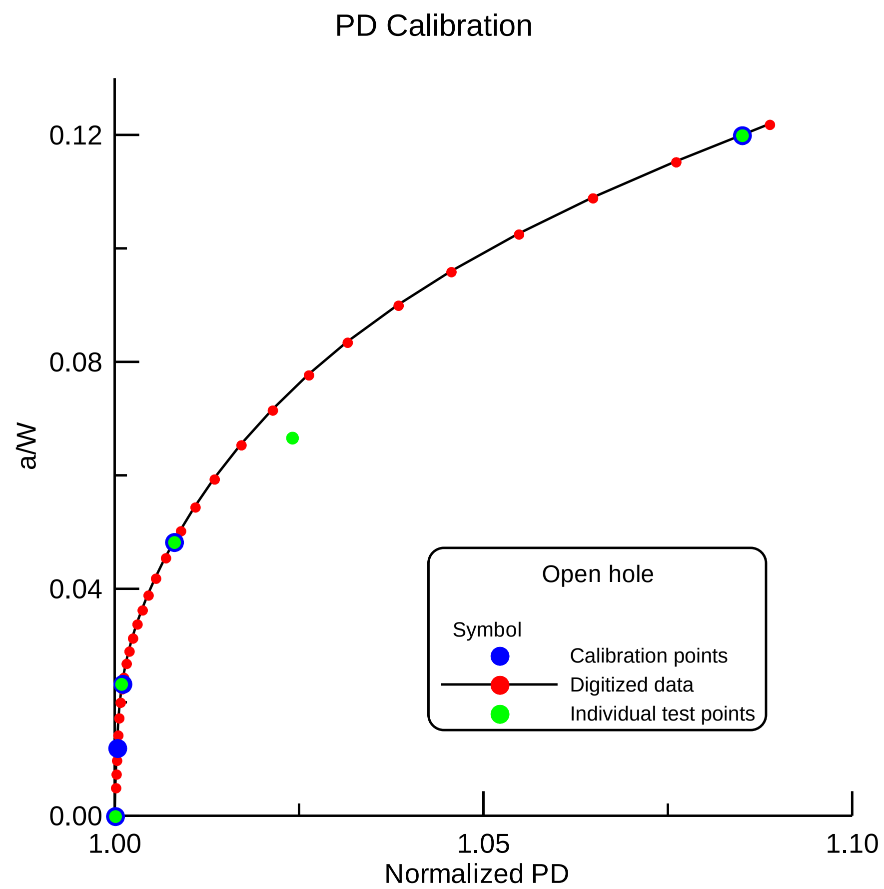
37 ksi, 5 Hz

Drop in damage parameter as sample approaches failure

DCPD Crack Size Calibration



Full Curve

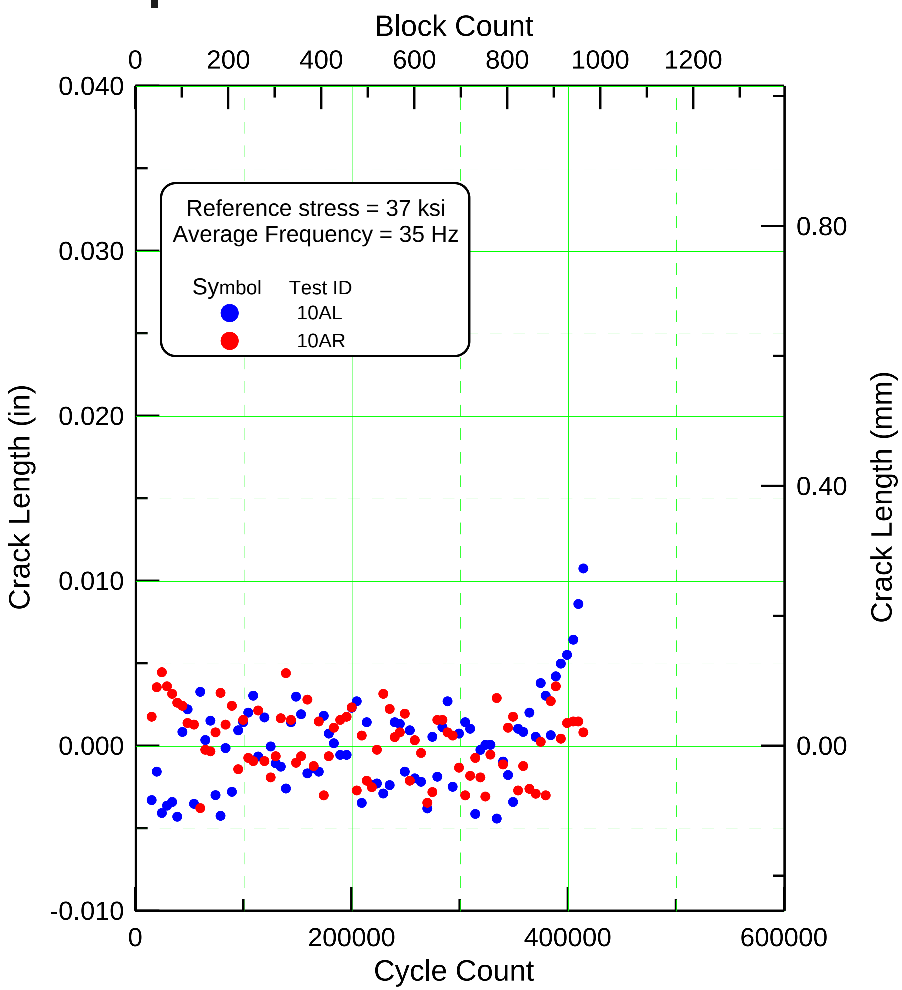


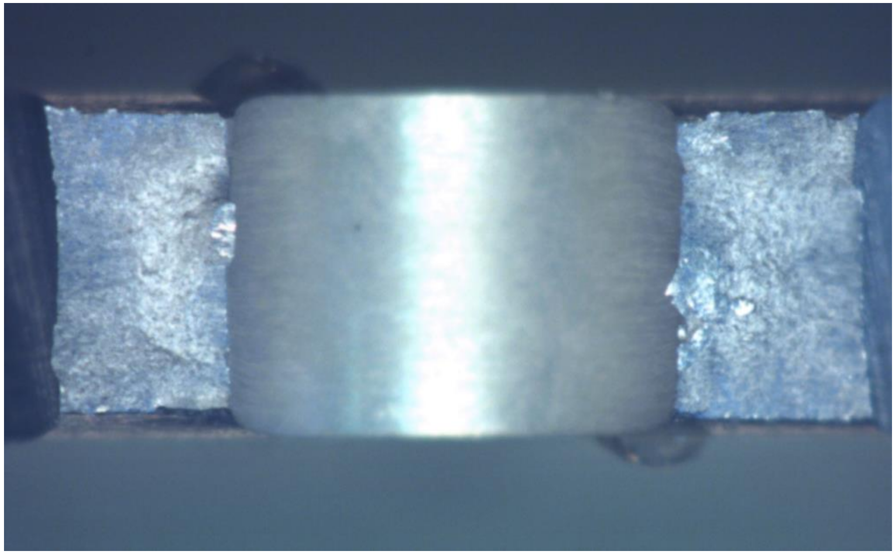
Out to Normalized PD of 1.10

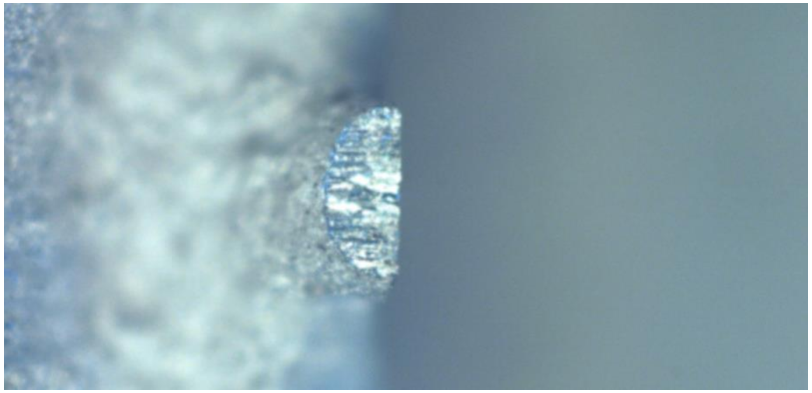
DCPD Crack Size Resolution

- 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



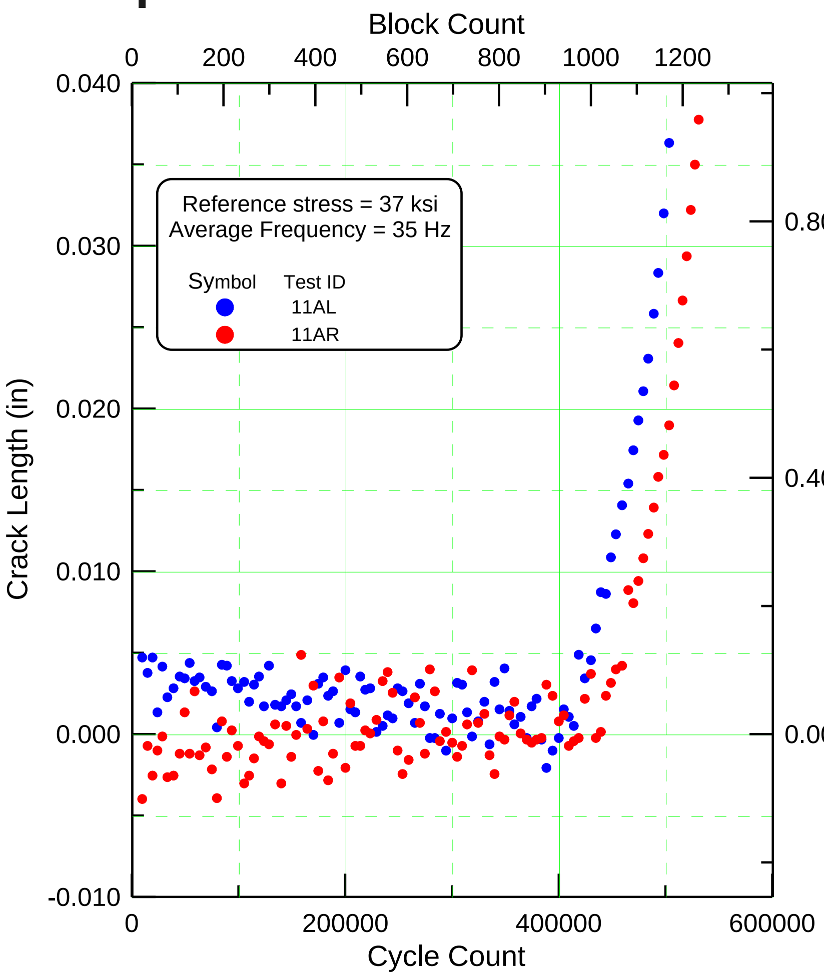


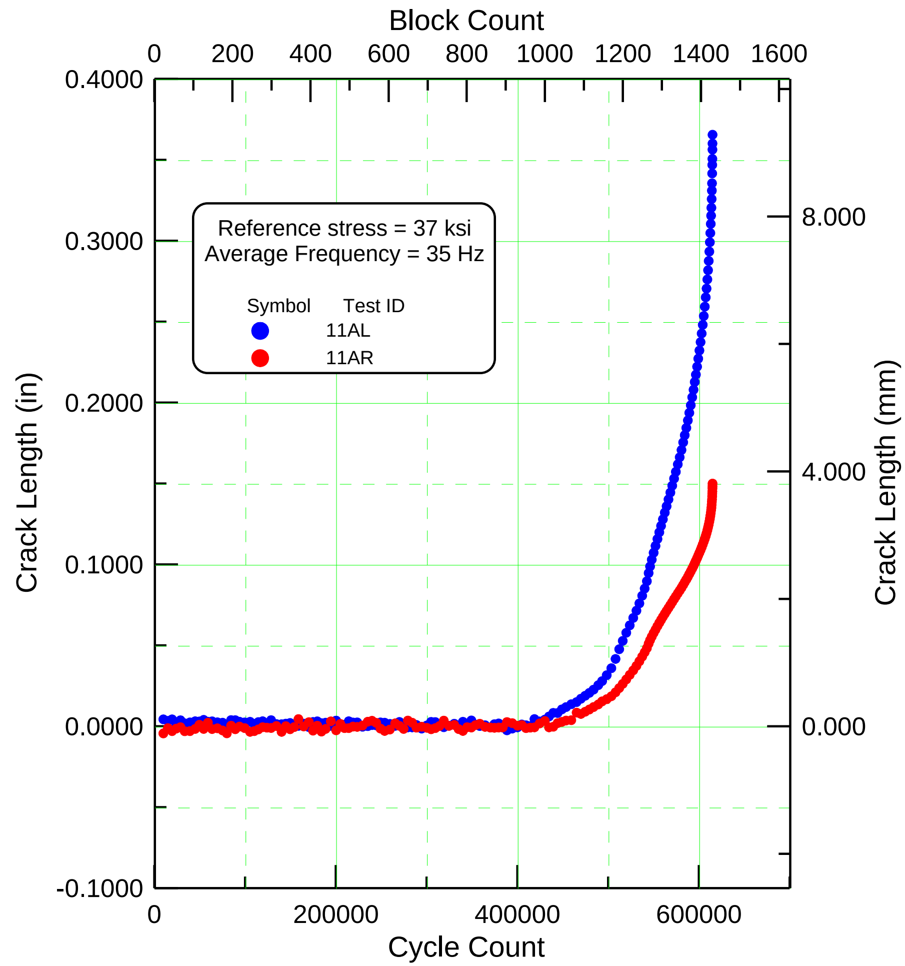


0.014 x 0.016" flaw

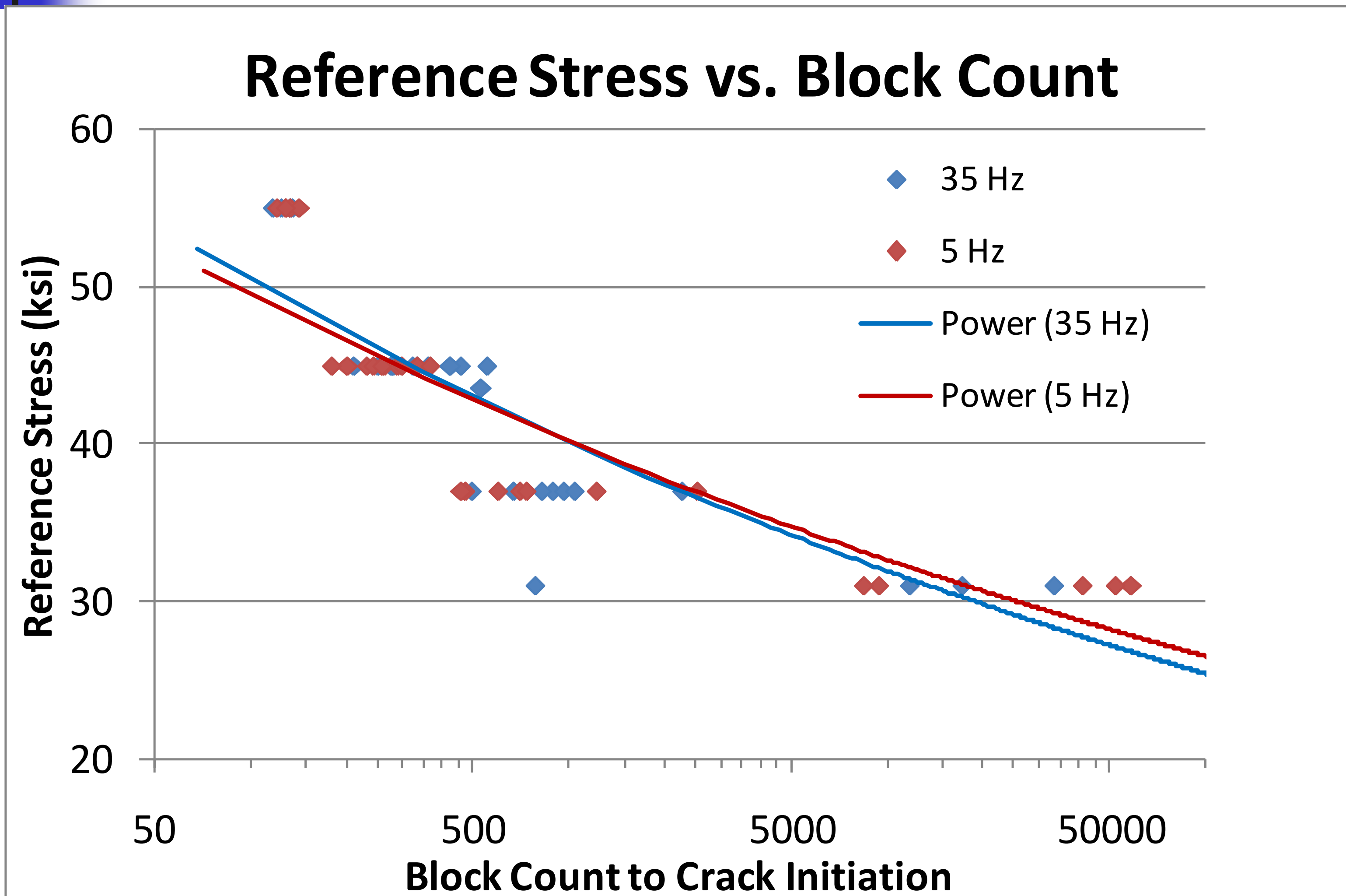
NAVAIR Public Release SPR-2014-731

Crack Size versus Cycle Count
Test Terminated at ~0.400"

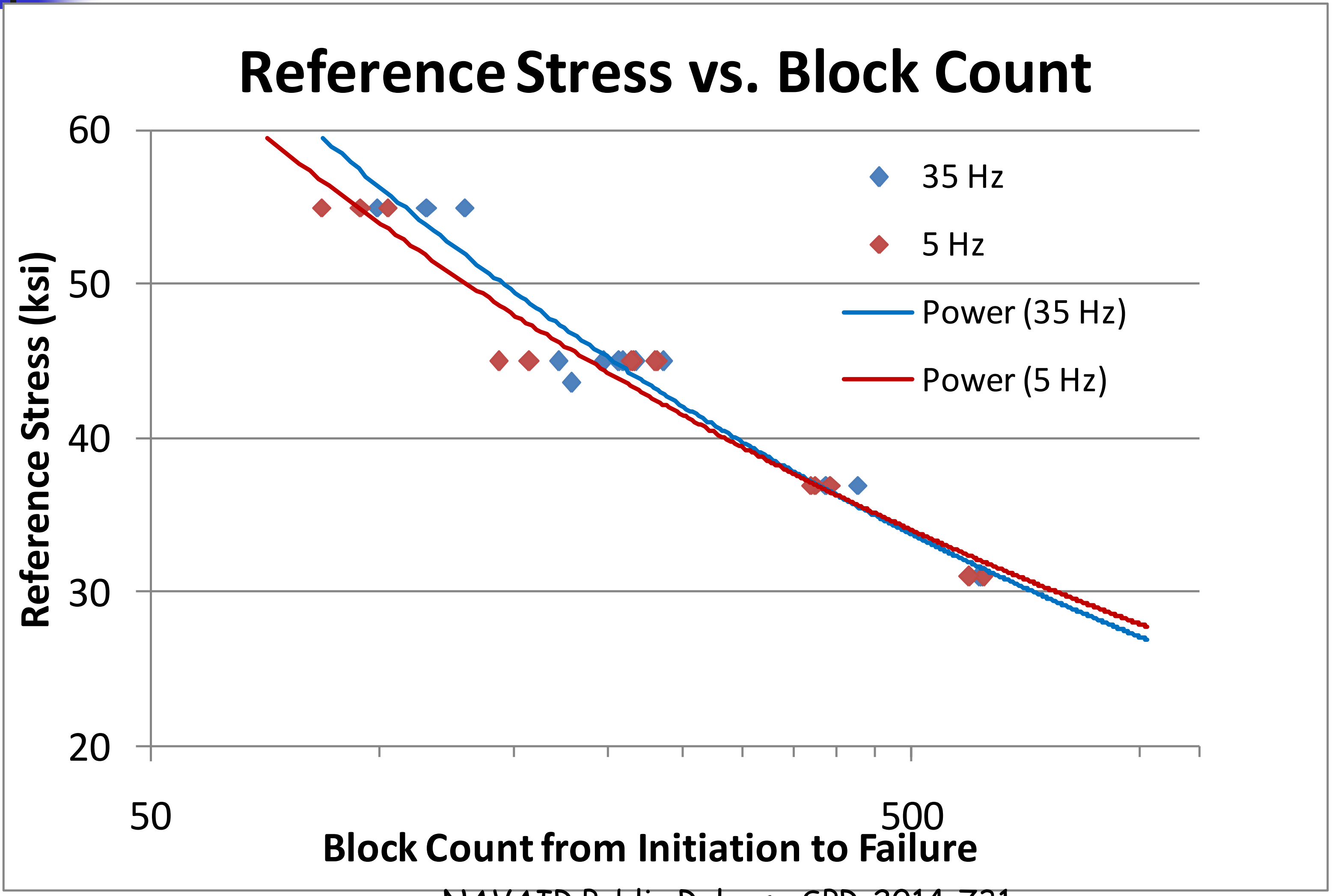




Block Count to Crack Initiation



Block Count from Initiation to Failure



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.