SAND2015-9920C

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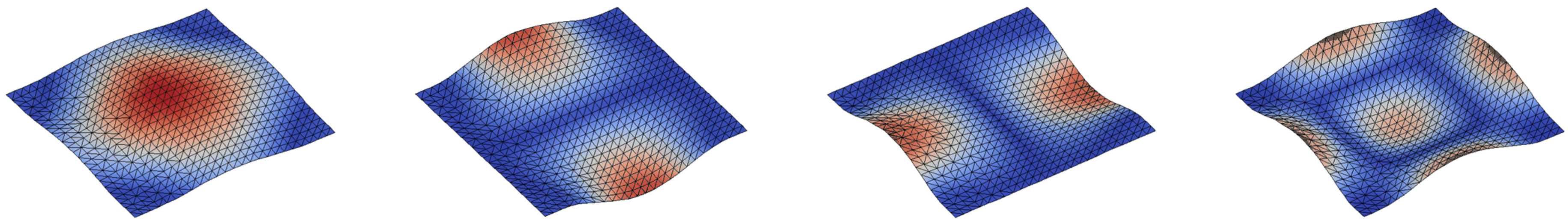

524.283203125 Hz   874.781677246 Hz   883.254394531 Hz   1405.89904785 Hz

Stereo-DIC vs 3D Scanning LDV for Modal Testing

Which one do I choose?

Phillip L. Reu, Daniel Rohe, Laura Jacobs and Dan Turner

1st Annual International DIC Society Meeting
November 3-5, 2015, Columbia, SC

U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration

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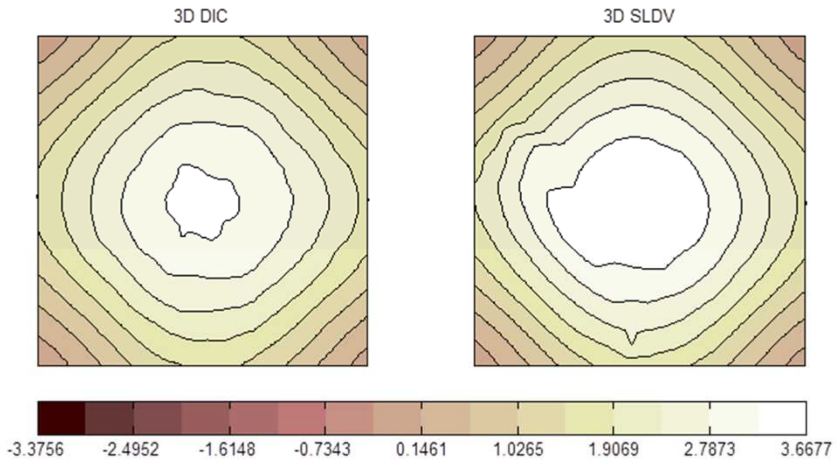
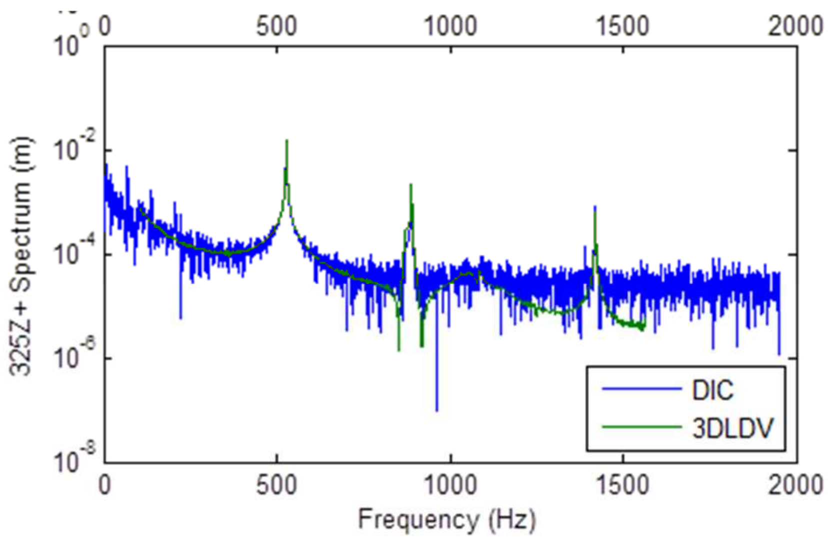
The goals of modal testing are determining the mode shape, frequency and damping.



Mode Shape
Modal Frequency = 529Hz



Damping = 0.0004

Modal Testing Reveals

- Frequencies that the object will vibrate (resonance) at and are to be avoided.
- The damping of the structure – how quickly vibrations die out.
- Needed for design of systems and structures.
- Can be used for FE model validation.
- Strain hot-spots or places for failure in the system.

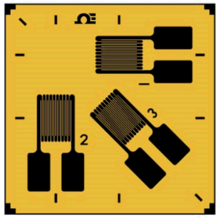
There are a number of technologies that can be used for modal testing.

www.modalshop.com

www.pcb.com

Excitation Methods

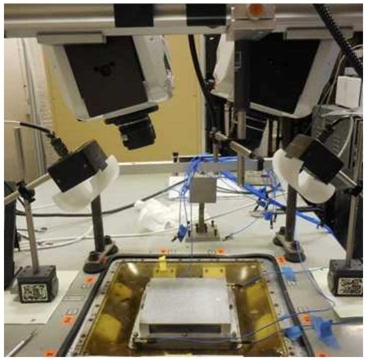
www.pcb.com



SGD-1/120-RYT21

www.omega.com

Single point measurement methods

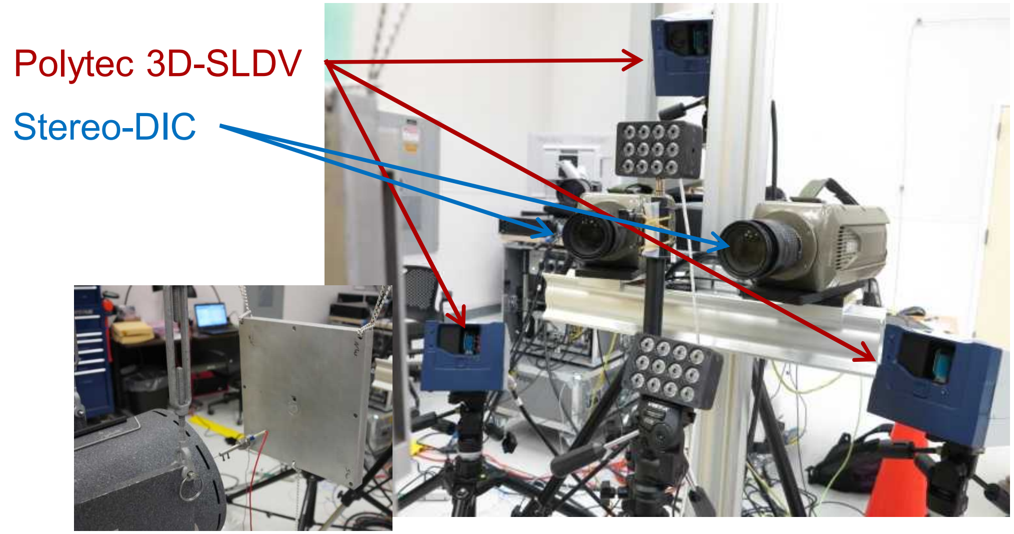


Non-contact and full-field methods

Pros and Cons

- Strain gages are typically cheap and easily used.
- Accelerometers may load light structures.
- Single point measurements may miss the peak location.
- Full-field methods are expensive in cost and time (maybe).

For many experiments full-field methods are preferable (if you have the money).

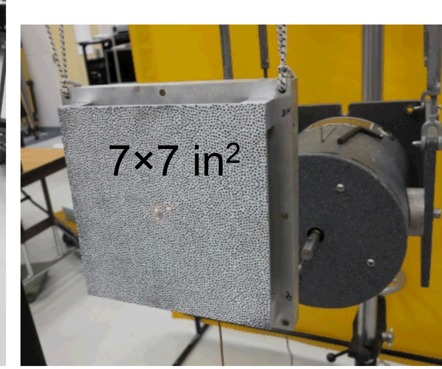


Why full-field?

- Captures peak location.
- Allows visualization of the entire mode shape.
- Does not mass-load the structure.

Experimental Setup

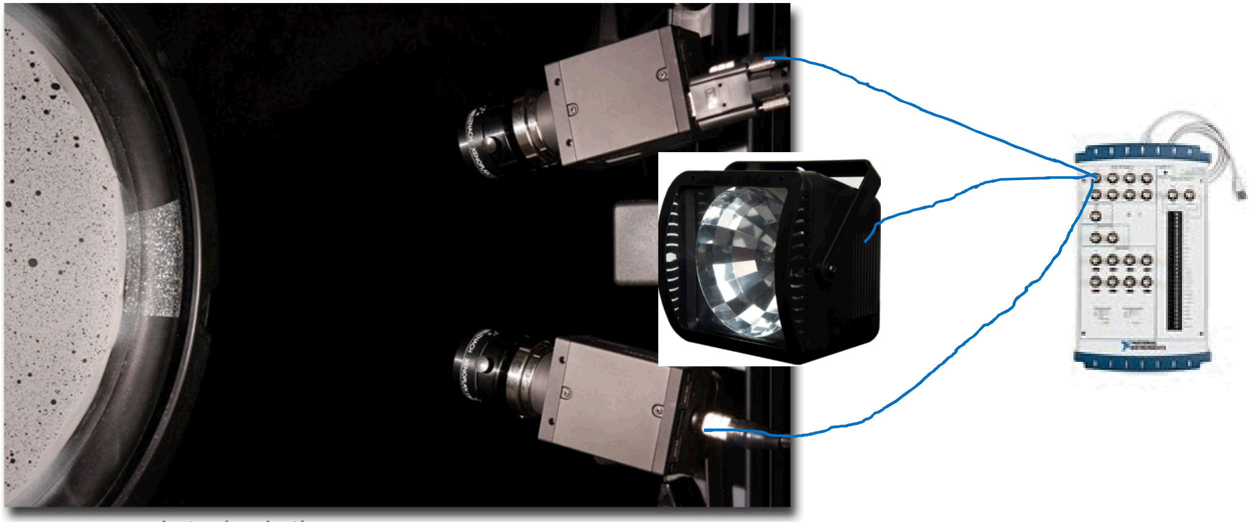
- Polytec PSV-500 3D-Scanning LDV system.
- Vic3D and Phantom 611 Cameras (800×800)
- 3906.25 Hz (200 μs exposure) to match LDV
- MB-50 Shaker on a shaker stand (Pseudo-Random)
- Speckle painted surface (not ideal for LDV)
- Retro surface (not possible for DIC)



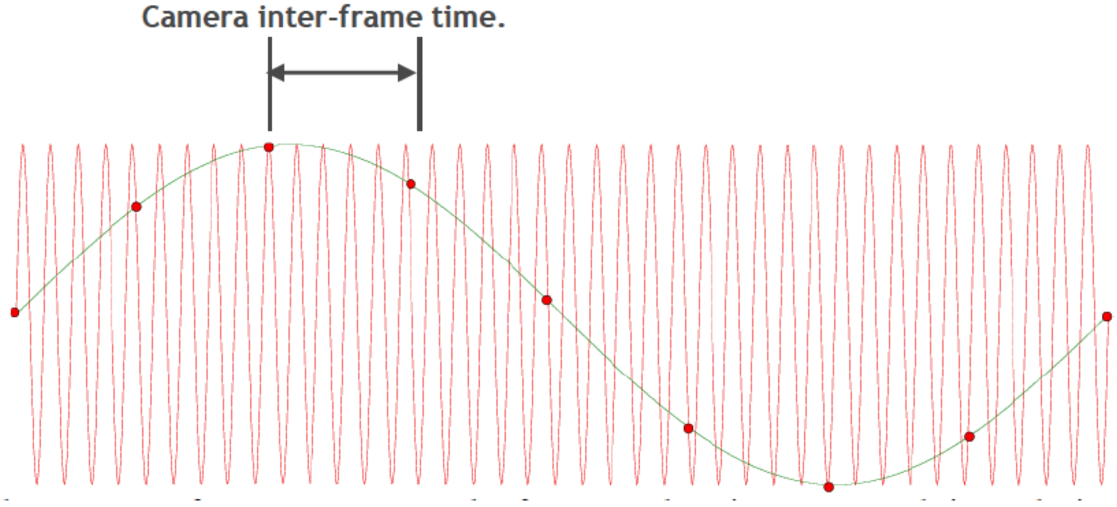
What we investigated

- Time to measurement (setup)
- Cost (not really)
- Measurement time
- Analysis time/data point
- Noise floor/resolution
- Ease of use (subjective)

Other possibilities for harmonic motion. But not for random or impact results.



www.correlatedsolutions.com



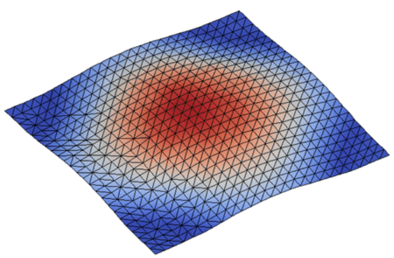
Strobe Applications

- Harmonic motion only
- Sine drive
- Allows high-resolution cameras
- Exposure controlled by strobe
- Slip-sync with DAQ hardware

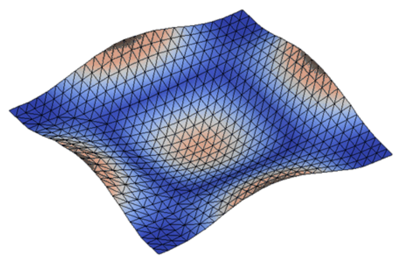
Time to solution: When do you want to wait? During the test or after.

LDV solution time

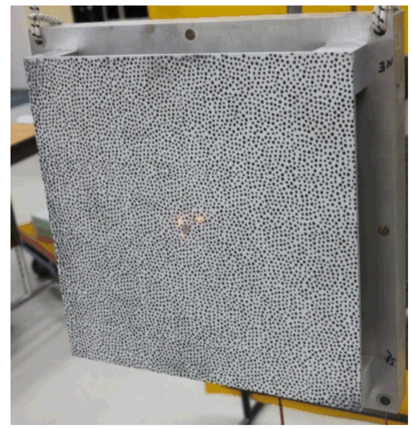
- Scanning for **545** points took 45 minutes
- For 715 points (to match DIC) it would be 60 minutes.
- Data storage is minimal if only the frequency data maintained.

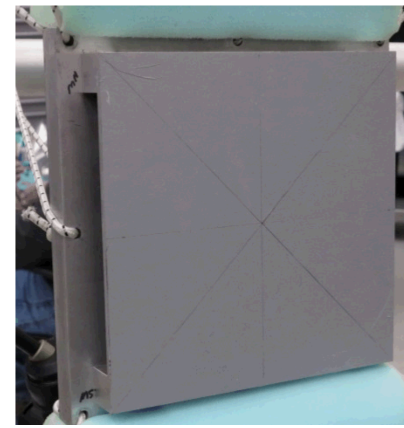


524.283203125 Hz



1405.89904785 Hz

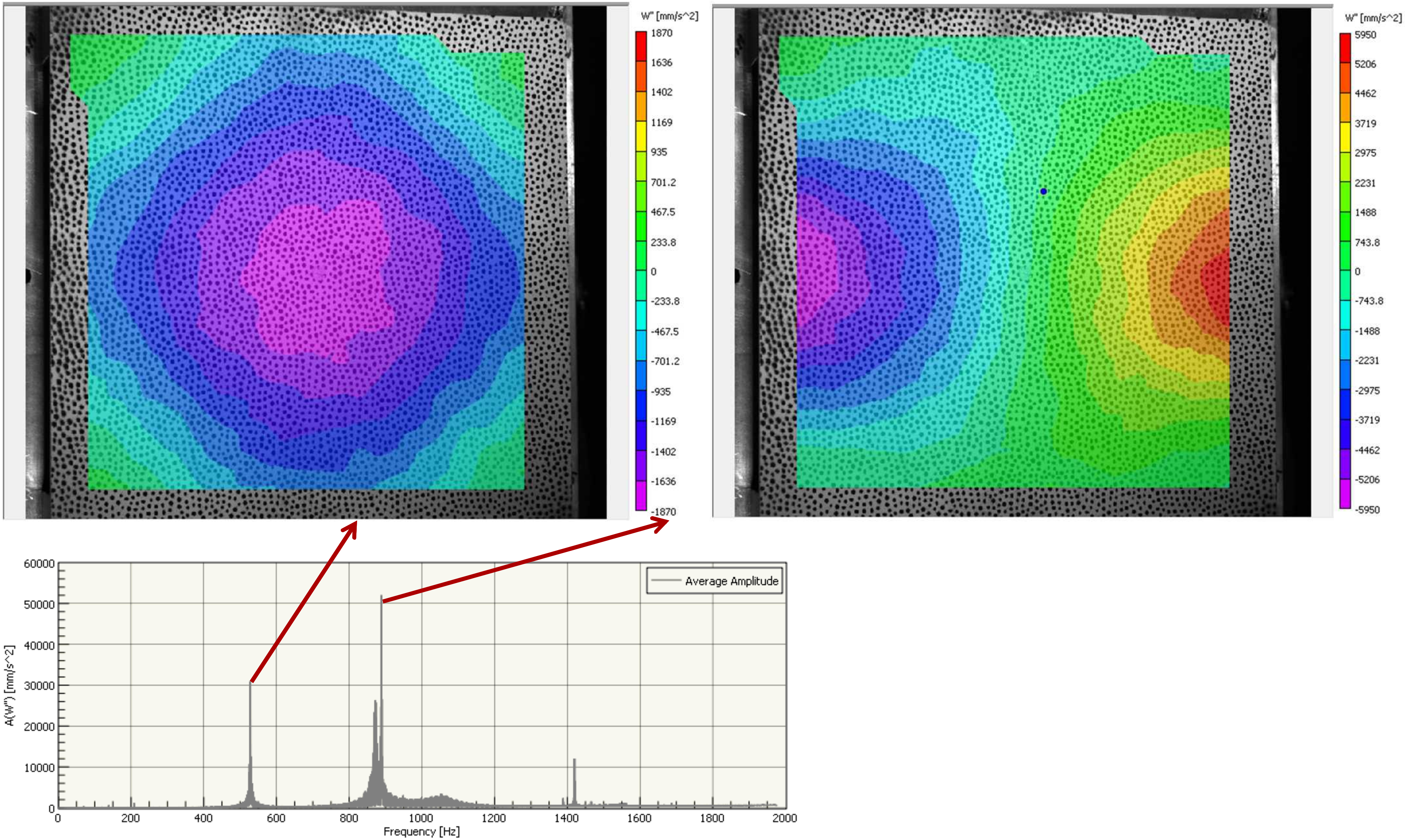




DIC solution time

- Data collection is 6 seconds (800×800 pixels^2 or 640,000 points)
- Download: 23,723 8-bit images from two cameras ≈20 minutes
- Data Storage is 16-Gbytes of data (×2)
- **715** Data points solved in 1.5 hours
- Subset = 51, Step = 25, Strain Window = 15, NSSD, 4-Tap, No filtering

Native FFT analysis in Vic3D



Modal fitting analysis approach.

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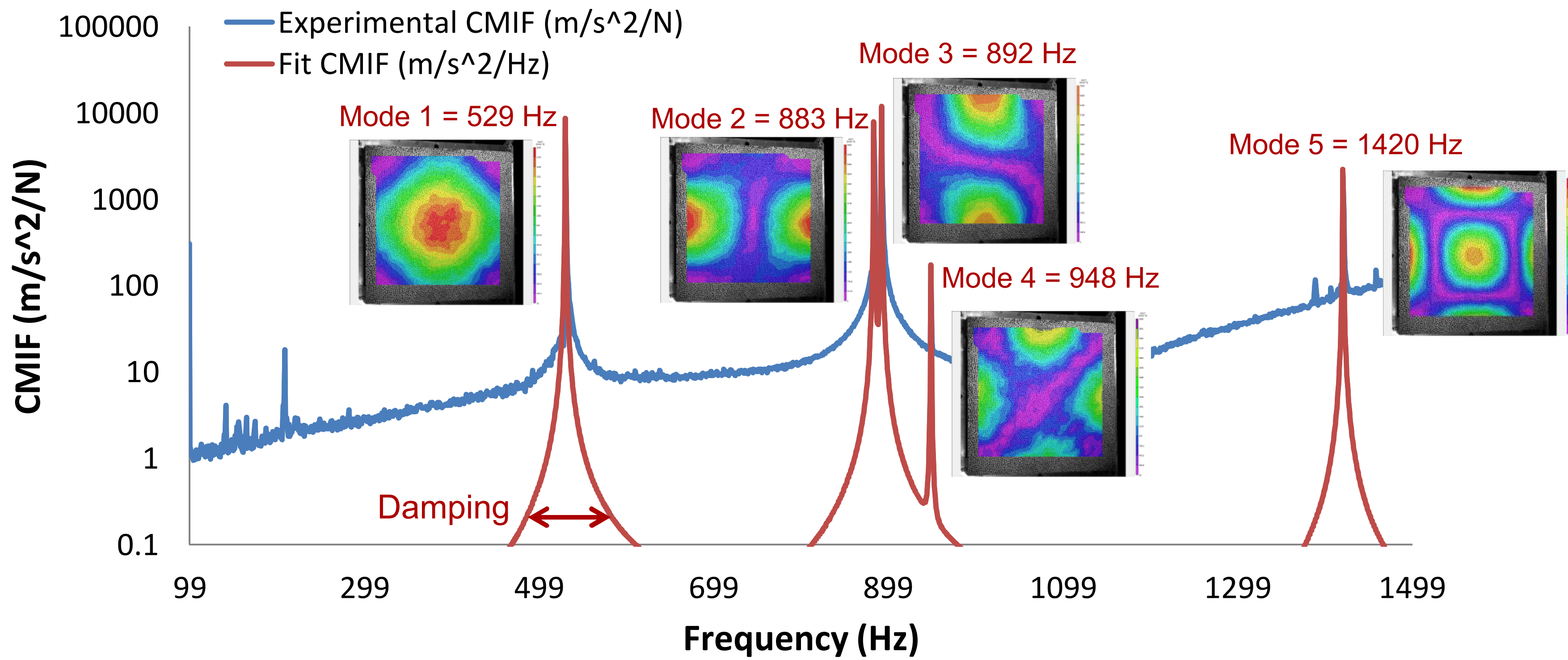

Modal Fitting Software

- SMAC† – Sandia's modal identification software
- There was some challenge with the large number of data points from the DIC software.
- CMIF is the Complex Mode Indicator Function.

†"Extending SMAC to Multiple Reference FRFs" by Daniel P. Hensley and Randy L. Mayes, Proceedings of the 24th International Modal Analysis Conference, January, 2006, St. Louis, Missouri.

Fitting results and comparisons. Show some mode shapes, damping and frequencies.

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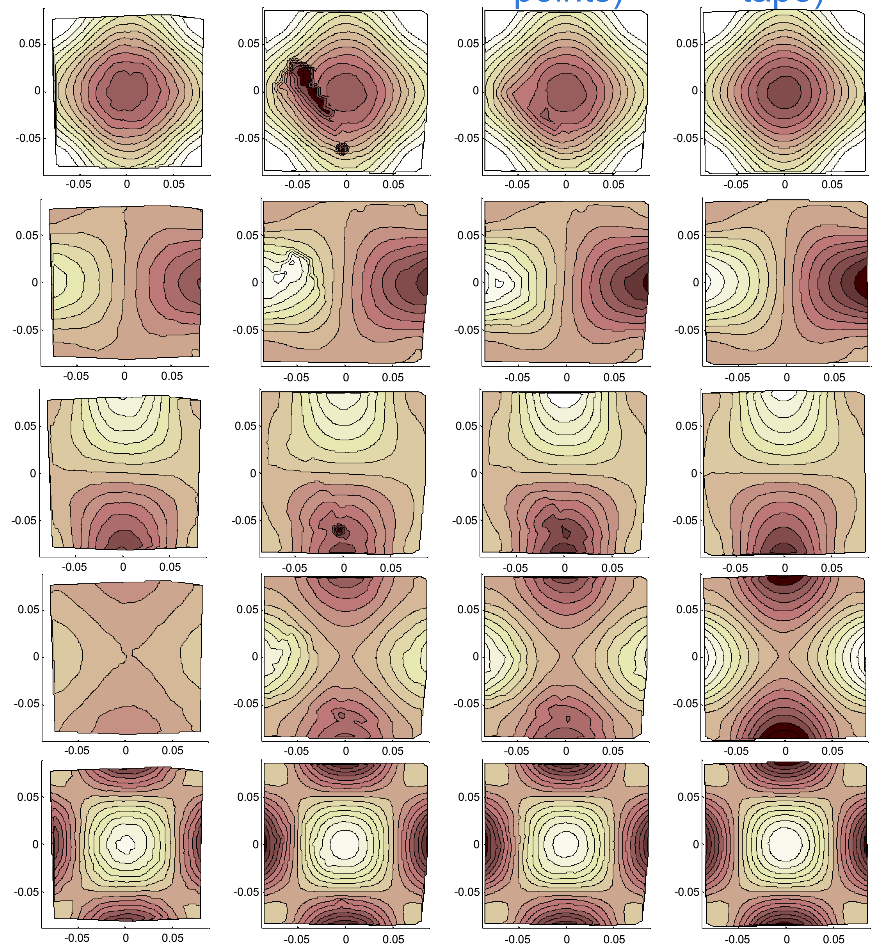
Mode	Frequency		Damping	
	DIC	LDV	DIC	LDV
1	529.4	529.5	0.042	0.042
2	883.0	883.1	0.022	0.024
3	891.7	891.7	0.015	0.026
4	948.3	948.4	0.019	0.019
5	1420.1	1420.4	0.015	0.020

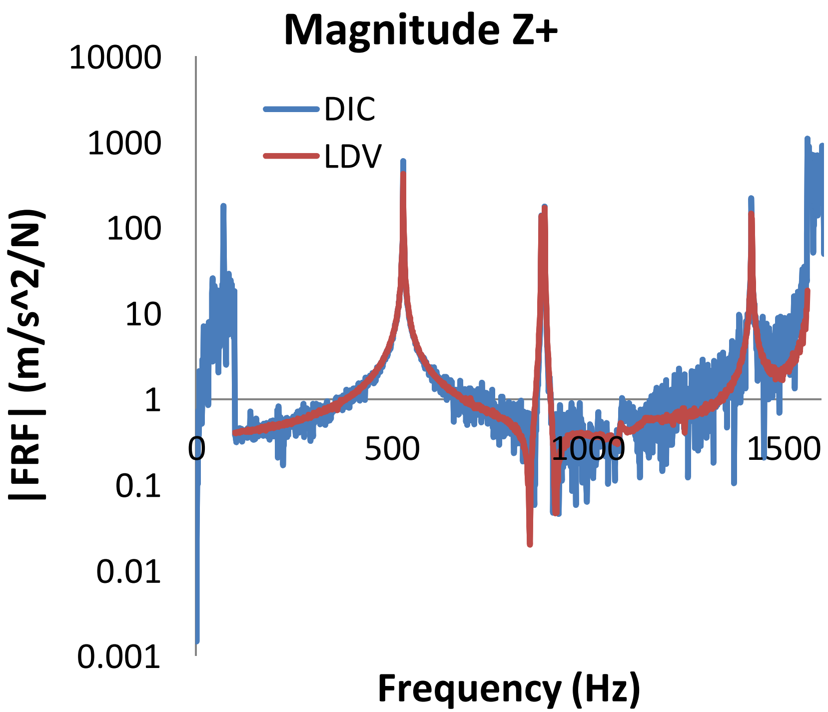
DIC | 3D-SLDV | 3D-SLDV (invalidate points) | 3D-SLDV (Retro-tape)

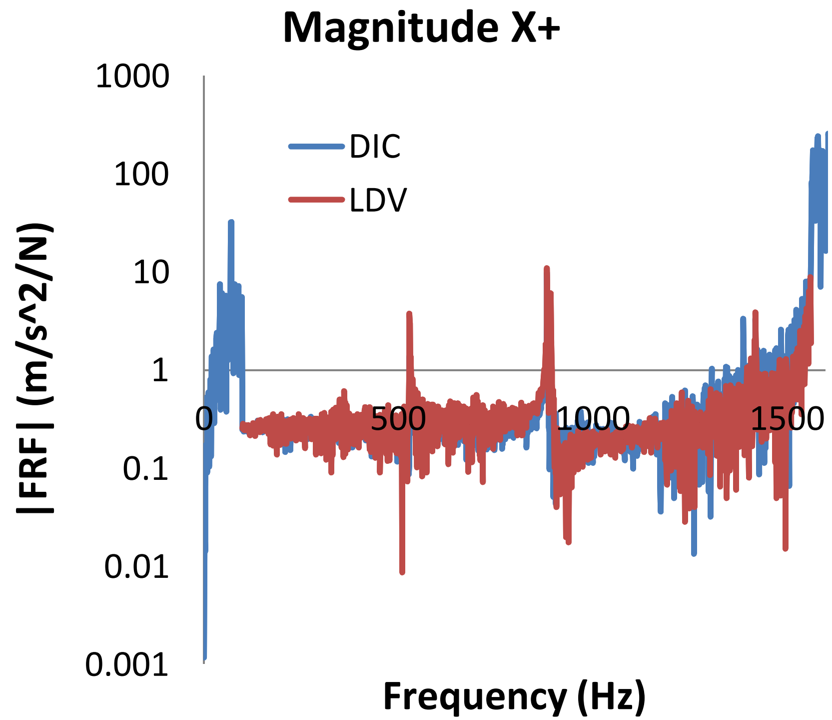


Notes on the Results

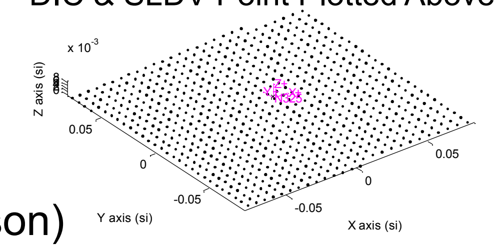
- DIC = 715 Points, LDV = 545 Points
- Scale identical for each group of results
- DIC plots are from the speckled surface.
- 3D-SLDV are taken on the speckle surface.
- 3D-SLDV (invalidate points) removes “bad” data points from the analysis.
- 3D-SLDV (retro-tape) covered the speckle pattern with a retro tape to improve signal quality.

LDV has a better noise floor than DIC in Z and comparable in X and Y.





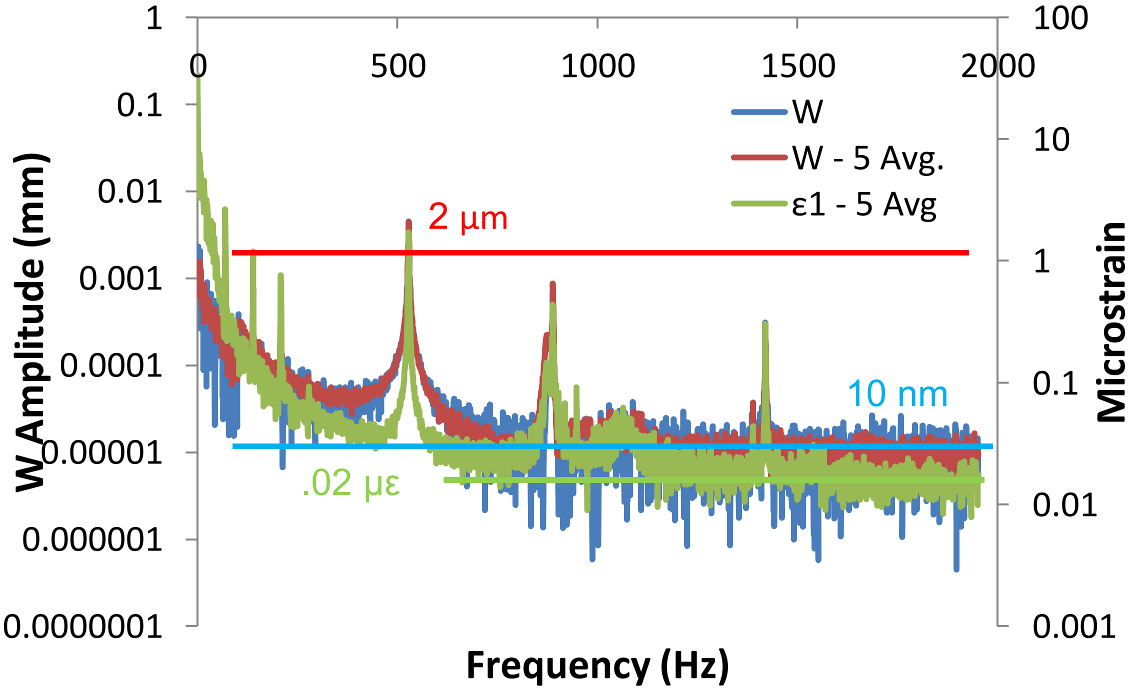
DIC & SLDV Point Plotted Above

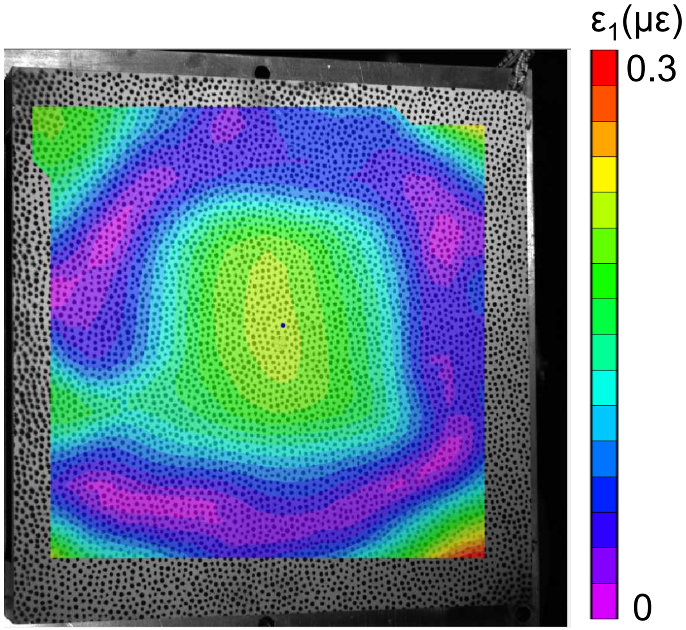


Notes on the comparison

- Data at point near the middle of the plate.
- LDV is more sensitive out-of-plane, DIC is less sensitive.
- Not much in-plane motion at center (not important for this comparison)

The DIC noise floor is significantly better in the frequency domain than the time domain.





Notes on Resolution

- Typical DIC resolution for a 7 inch FOV would be 2 µm or 200 µε.
- The noise is distributed across all the frequencies – therefore lower at any given frequency band.
- Displacement resolution in the frequency domain is much better than that in the time domain.
- FFT averaging improves the noise even further (i.e. more images are better!), i.e. you can trade frequency resolution for noise reduction (i.e. more averaging).

Strain calculations: Should we do this in the modal fit space? Is it the same?

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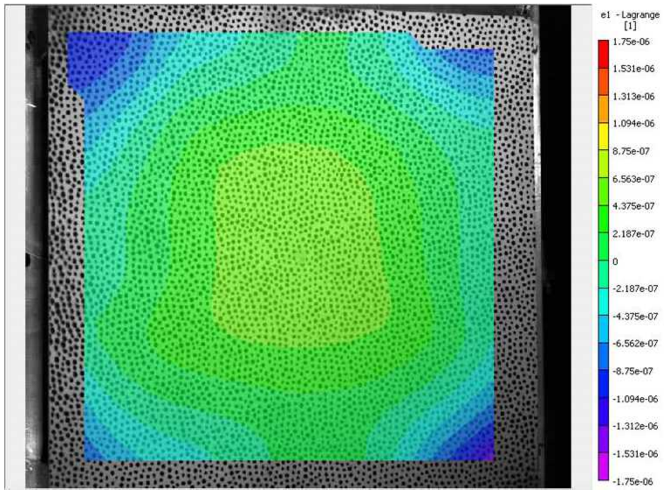
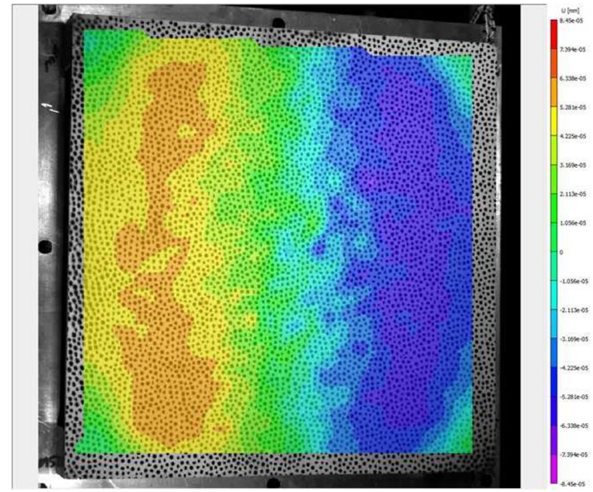
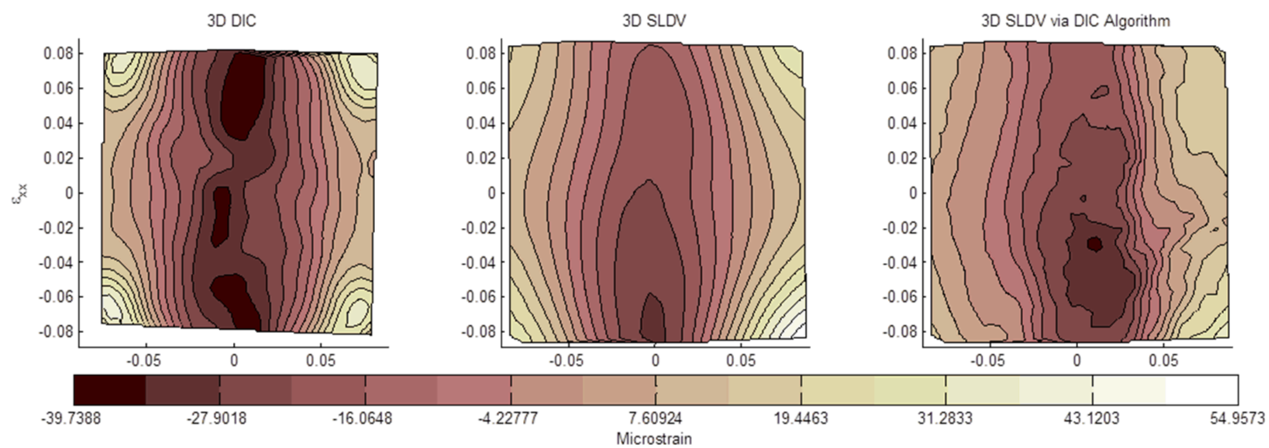
$\varepsilon_1 = \pm 1.75\ \mu\varepsilon$



$U = \pm\ 84.5\ \text{nm}$





Temporal† anti-aliasing. It can be a big deal.

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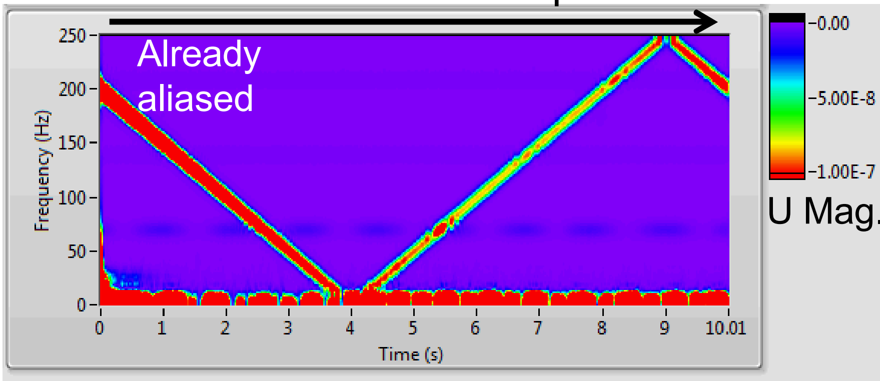
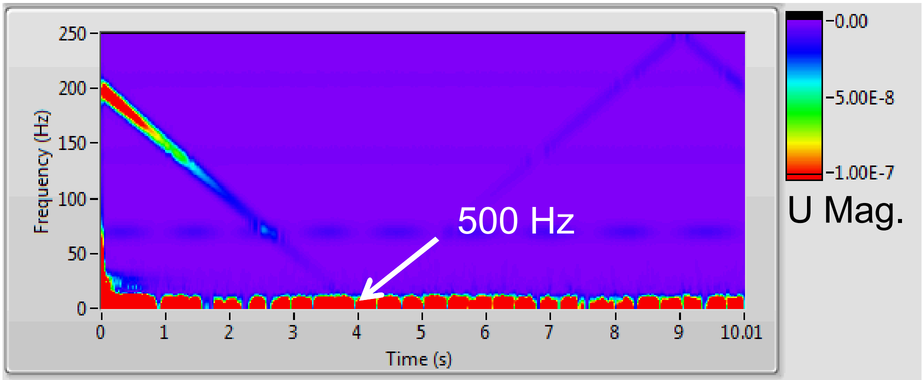
†Spatial aliasing is another completely different and important topic.

Frame Rate = 500 Hz: Nyquist = 250 Hz

300 – 800 Hz Sweep





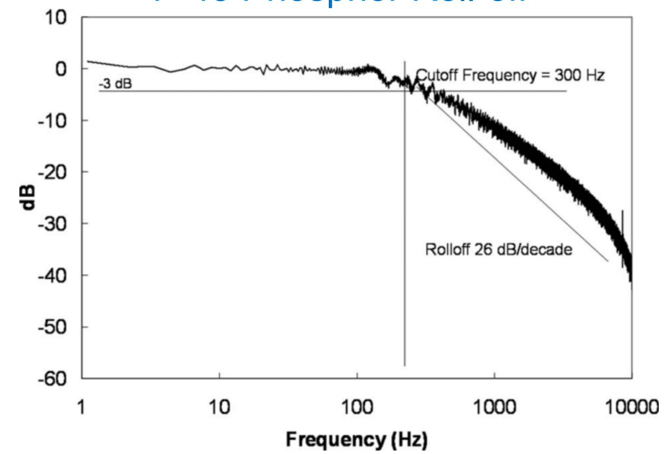
Exposure = 200 μs or 5000 Hz

Exposure = 1900 μs or 526 Hz

Notes on aliasing

- With cameras – there are no good antialiasing filters. (Ideas do exist †)
- Long exposures provide some aliasing protection.
- Best solution: have a single point measurement (with antialiasing) to ensure the frequency content of the signal.
- With impact testing – the force profile rolls off gradually with frequency and will lead to aliasing issues.

P-43 Phosphor Roll-off



†Reu, P. L. and B. D. Hansche (2008). "Optical temporal frequency low-pass filtering and heterodyning with a microchannel plate." Optical Engineering **47(7).**

What are the pros and cons of the two methods. When do we use one or the other.

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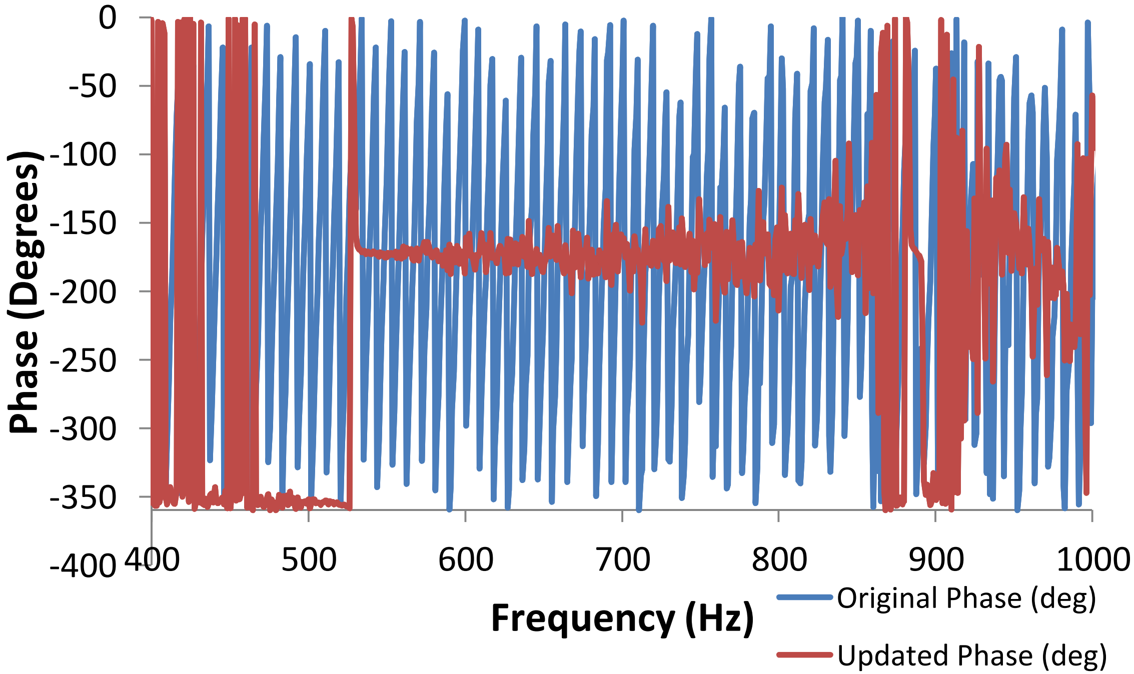
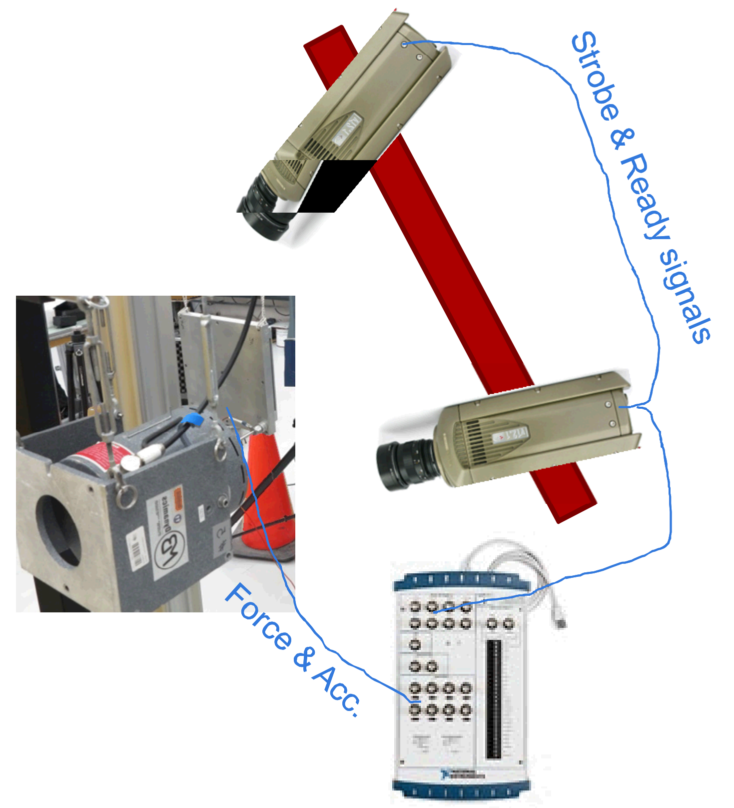
Comparison Metric†	LDV	DIC
Cost	≈$650k	≈$350k ✓
Setup time	2 hours	2 hours
Acquisition Time	Hours	Seconds ✓
Analysis Time	Seconds ✓	Hours
Disp. Resolution	≈ picometers ✓	≈ nanometers
Strain resolution	?	5 microstrain ✓
Strain Calculation	Integrated – but researchy	Seamlessly Integrated ✓
Anti-aliasing	Included ✓	Not possible at the moment
Data volume	Small (Mbytes) includes only frequency data	Large (Gbytes) but includes time history
Software	Designed for modal analysis. ✓	In its infancy.

Questions

†The comparison is for this test setup – but should be broadly accurate in many other situations.

The drive signal must be acquired synchronously with the images.





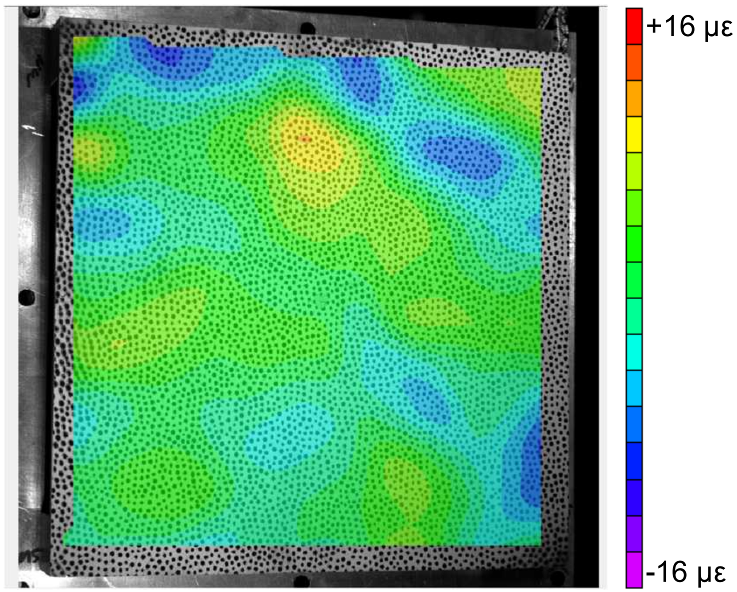
High-Speed Camera Setup

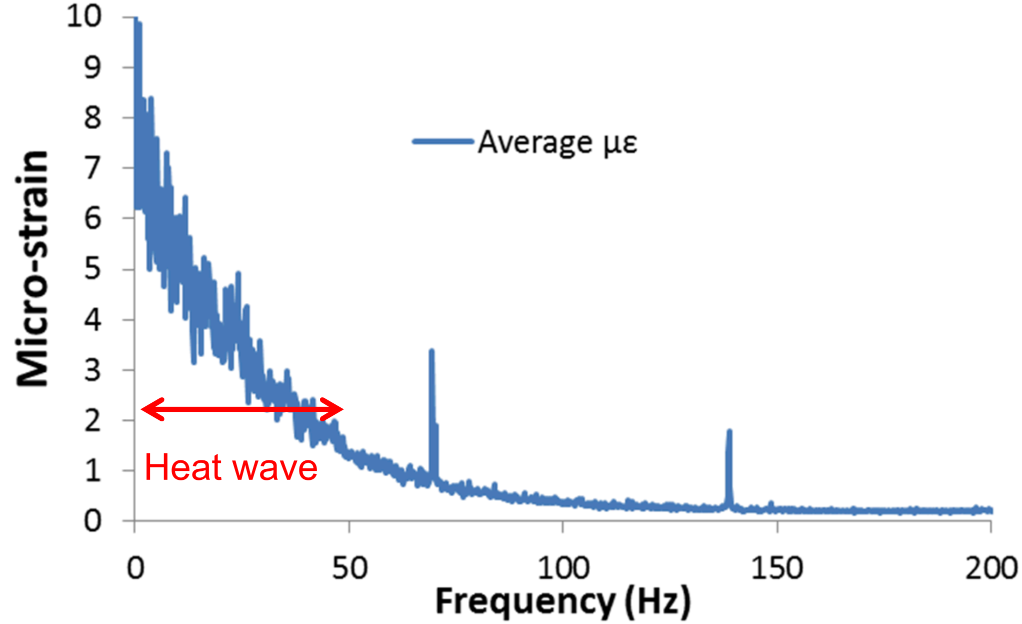
- Must synchronize cameras with DAQ
- Measure input signals to system
- Shaker input control (sine or pseudorandom)

Phase shift in the camera DAQ was discovered and fixed by a simple linear phase shift. Not sure where this came from in our experiment.

The influence of heat waves is in a specific frequency band.

ε_1 at 8 Hz



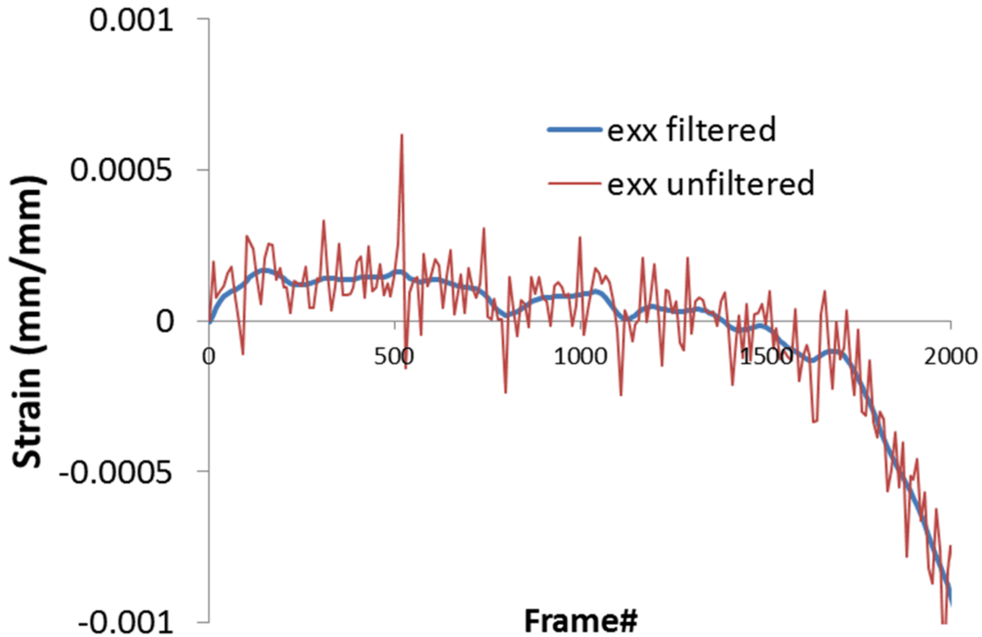


Notes on heat waves

- The heat causes index of refraction changes and therefore "optical distortions"
- Contained in the 5 – 70 Hz band (for this experiment)
- For quasi-static testing – low pass filter the results using extra images (next slide)
- For dynamic testing – Use the frequency domain

For quasi-static testing – temporal averaging (filtering) can remove heat waves.

Strain Measurement on a Heated Sample



Notes

- At 5 frames/second the heat waves are highly aliased.
- A 0.1 Hz cut-off (Recursive 3rd order filter) was used
- Noise is greatly reduced.