Noncontact Laser Sensing Technology for Structural Health Monitoring and Nondestructive Testing

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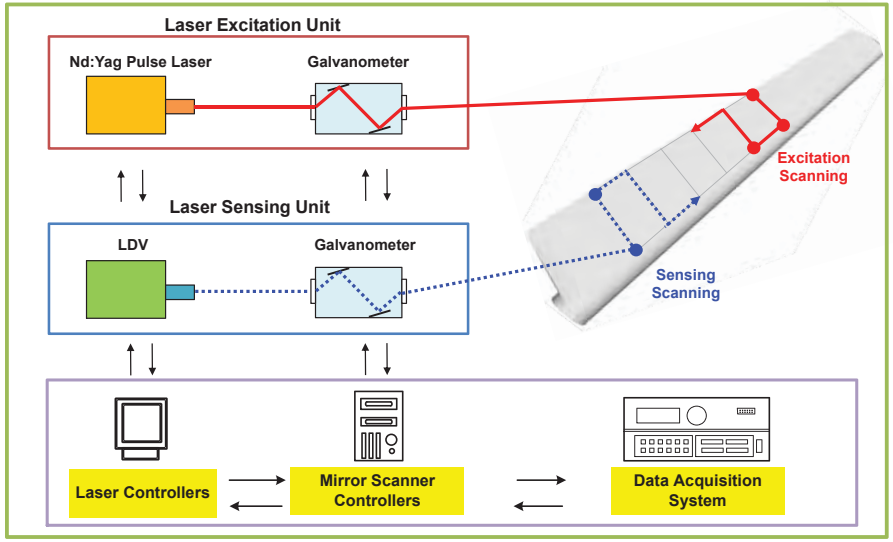
Presentation Outline

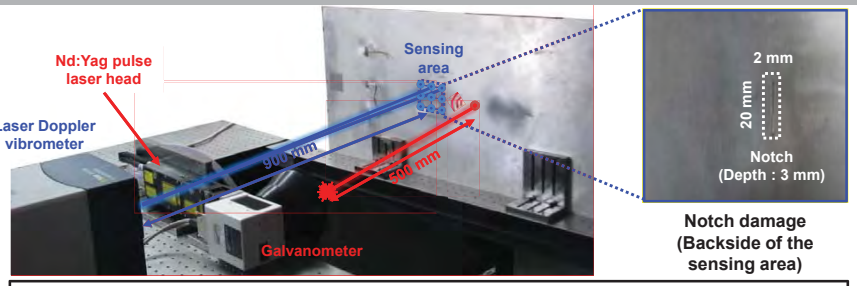
1. **Noncontact Laser Ultrasonics**
   - Notch detection for metallic structures
   - Delamination detection for composite & wind turbine structures
   - Fiber guided laser ultrasonic system for nuclear power plant monitoring
2. **Contact/Noncontact Nonlinear Ultrasonic Wave Modulation**
   - PZT based crack detection for an aircraft fitting lug
   - ACT based crack detection for a rotating shaft
   - Laser based nonlinear ultrasonics wave modulation
3. **Laser Lock-in Thermography**
   - Surface crack detection for high-speed train bogies
   - Micro crack detection for semiconductor chips
4. **LiDAR/LADAR**
   - Noncontact dynamic displacement estimation
   - Dimension estimation for precast concrete slabs
   - Surface defect detection for concrete panels
5. **Laser based Power/Data Transmission**

Noncontact Laser Ultrasonic Scanning System

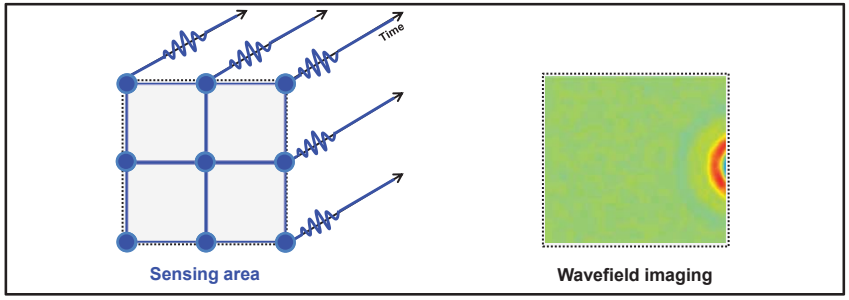


* Y.K. An, B.J. Park, H. Sohn, *Smart Materials and Structures*, Vol. 22, 025022. 2013

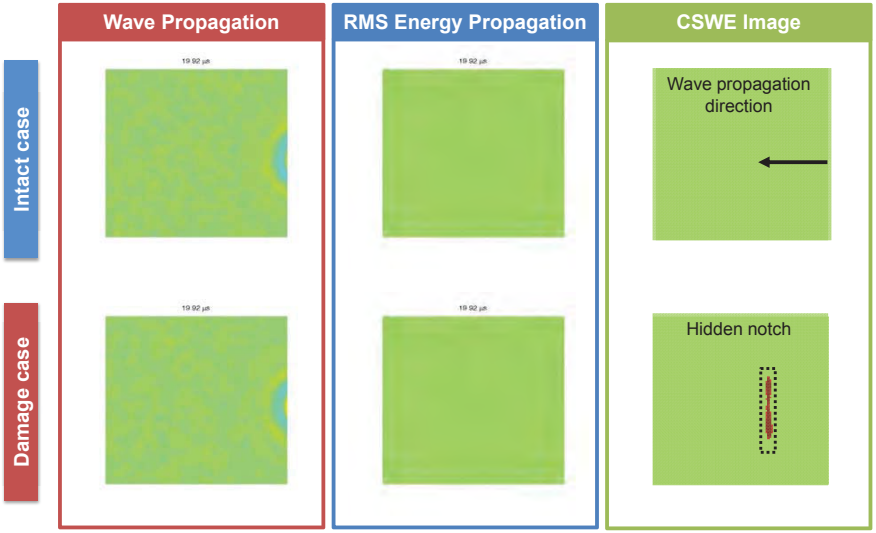
Hidden Notch Detection for an Aluminum Plate
(Sponsored by National Research Foundation of Korea)



Notch damage (Backside of the sensing area)

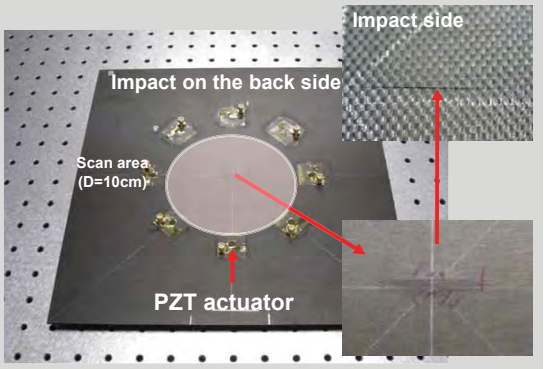


Wave Propagation Images for Intact & Damage Cases

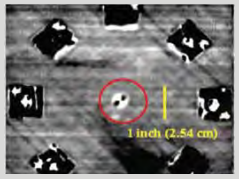


Delamination Detection in a Composite Plate
(Sponsored by US Air Force Research Laboratory)

A 275 mm × 275 mm square plate with the thickness of 1.8 mm



Thermography Images

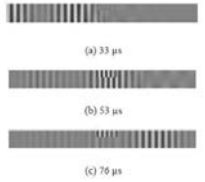


(a) Impact side

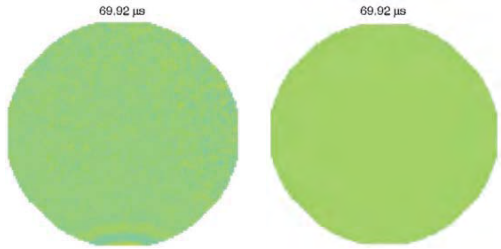
(b) Back side

* H. Sohn, D. Dutta, J.Y. Yang, et al., *Composites Science and Technology*, Vol. 71, PP. 1250–1256, 2011

Wave Propagation Imaging and Application of Laplacian Filtering



Lamb wave propagation
through delamination [Hayashi, 2002]

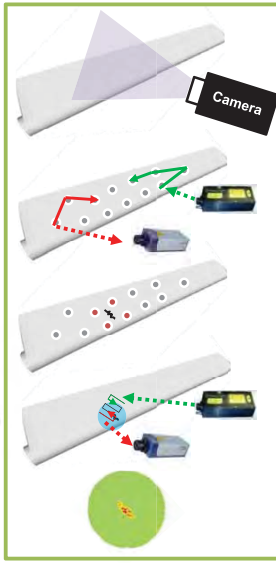


Wave propagation | RMS + Laplacian propagation

$$A\cos(\omega t - kx) + B\cos(\omega t + kx + \varphi)$$
$$= B\cos(k\bar{x})\cos(\omega t + \frac{\varphi}{2}) + (A - B)\cos(\omega t - k\bar{x} + \frac{\varphi}{2})$$

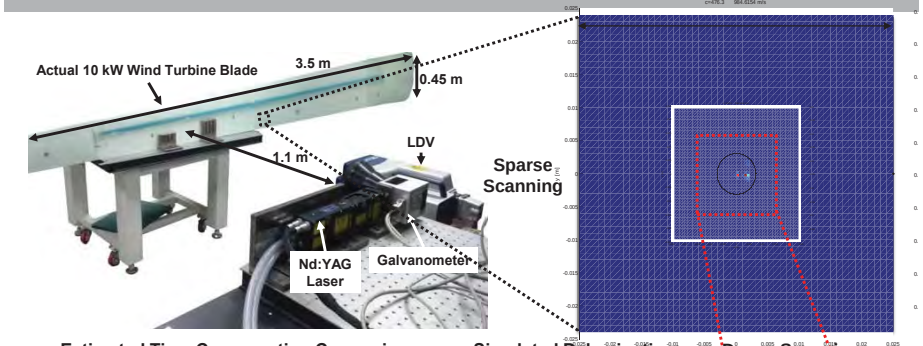
Standing wave | Propagating wave

Wind Turbine Blade Monitoring using Laser Ultrasonic System
(Sponsored by Korea Institute of Energy Technology Evaluation and Planning)



1. Vision-based laser position control
2. Laser scanning with coarse resolution
3. Rough damage area estimation
4. Laser scanning with dense resolution
5. Automated damage visualization

Faster Inspection using Two-Level Laser Scanning

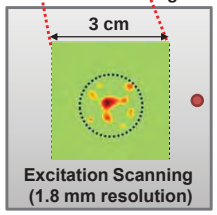


Estimated Time Consumption Comparison

Only Dense Scanning (2 mm Resolution)	Two-level Scanning (10 cm Resolution & 2 mm Resolution)
~7000 minutes	~25 minutes (15 min for sparse / 10 min for dense)

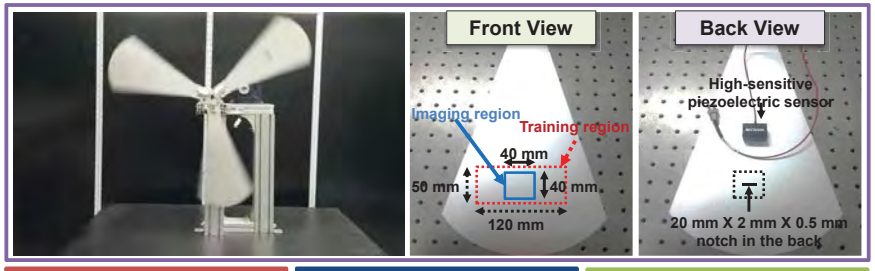
Simulated Delamination

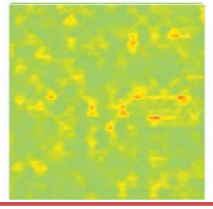
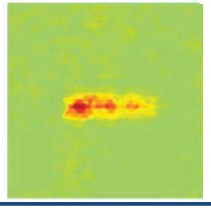
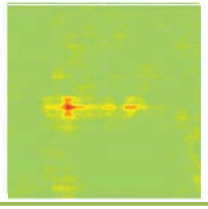
Dense Scanning



* B. Park, Y.K. An, H. Sohn, *Composites Science and Technology*, submitted, 2013

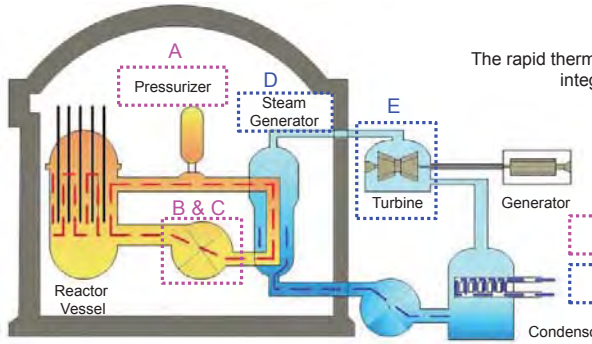
Hidden Damage Detection in a Rotating Blade



Raw Images with 20 rpm Rotating Speed	Stationary Condition	Improved Images using the Proposed Technique
		

* B. Park, H. Sohn, C.M. Yeum, et al., *Structural Health Monitoring An International Journal*, Vol. 12, pp. 494-506, 2013

Monitoring of Pipelines inside Nuclear Power Plants
(Sponsored by KAIST Initiative on Energy, Environment, Water & Sustainability)

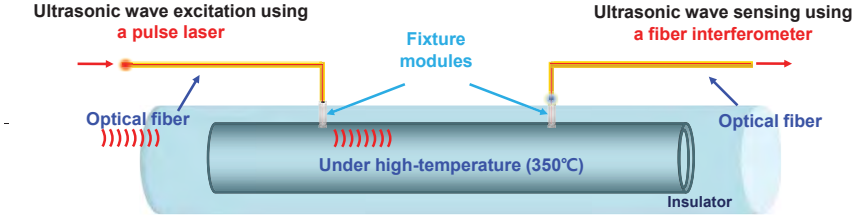


The rapid thermal gradient is critical for structural integrity of NPP structures

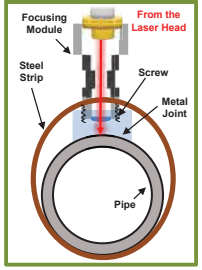
PWR type nuclear reactor

- **Primary coolant system (PCS)**
  - A. Pressurizer: Surge line between pressurize and hot legs in the PCS
  - B. Reactor coolant system (RCS): Injection line between accumulator and cold-leg of RCS
  - C. Reactor auxiliary cooling system (RACS): Heat exchangers in residual heat removal system (RHRS) and chemical volume control system (CVCS)
- **Secondary coolant system (SCS)**
  - D. Steam generator (SG): Connection part between SG and main water feed system
  - E. Turbine: Connection part between turbine and condenser

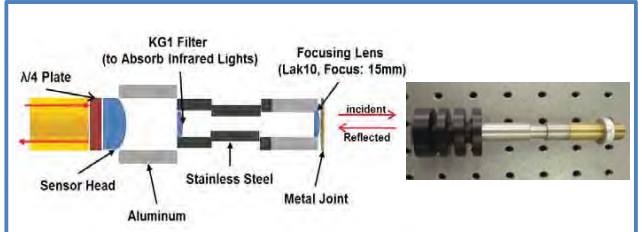
Optical Fiber Guided Ultrasonic Excitation and Sensing



Connection b/t Fiber and Pipe

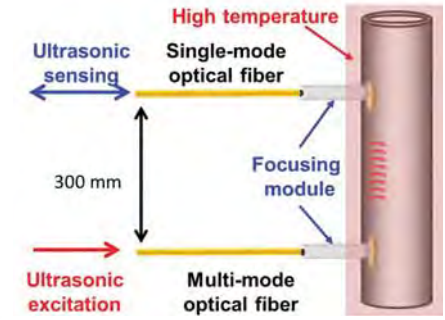


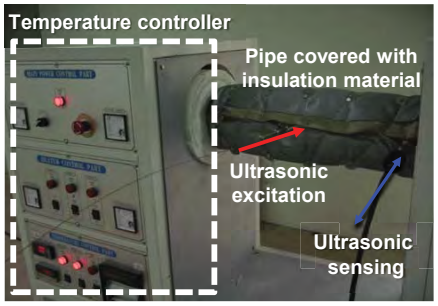
Sensing Part



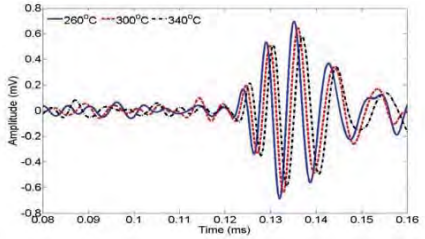
* H.S. Lee, J.Y. Yang, H. Sohn, *Structural Health Monitoring An International Journal*, Vol. 11, PP. 684-695, 2012

Test under High Temperature Environment



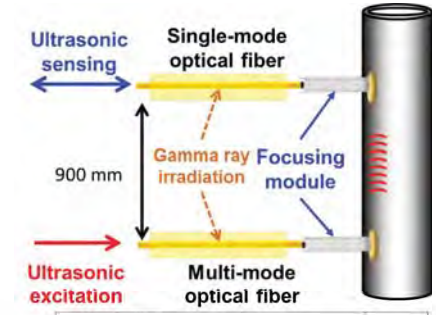


Courtesy of SKI Co. Ltd.

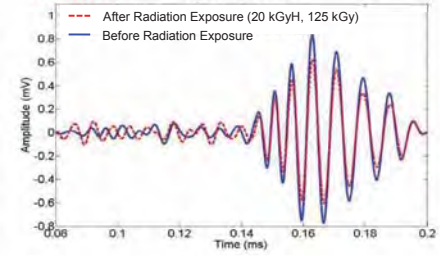


- **Temperature ranges:**
  - 260℃, 300℃, 340℃
- **Signal changes at high temperature**
  - Reduction in signal amplitude
  - Slower wave speed

Test Under High Radiation Environment



Radiation facility (KAERI)



- **Gamma ray irradiation dose:**
  - 125 kGy for 10 years
  - 20 kGy/h (NPP: 1 kGy/h~10 MGy/h
- **Signal changes after high radiation**
  - Amplitude reduction observed

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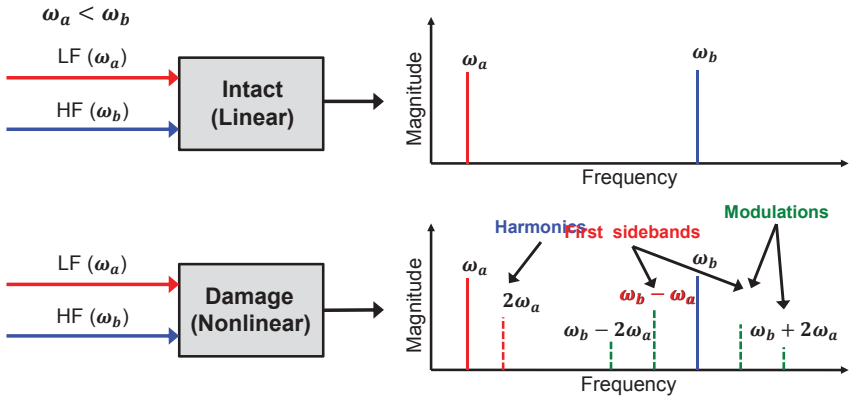
5. **Laser based Power/Data Transmission**

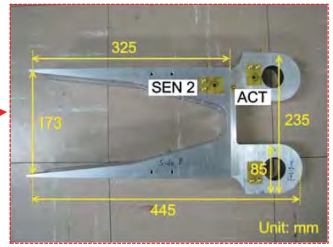
Working Principle of Nonlinear Wave Modulation

Nonlinear wave modulation uses the modulation between a low frequency (LF) signal and a high frequency (HF) signal that occurs in the presence of structural nonlinearity such as fatigue cracks [de Lima and Hamilton (2003)]

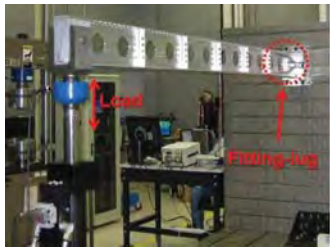


PZT based Nonlinear Modulation for Aircraft Fitting Lug
(Supported by US Air Force Research Laboratory)

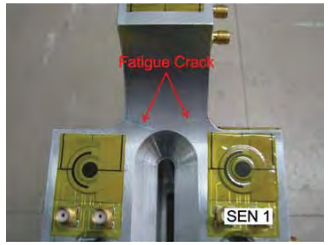
F-15 Aircraft



Fitting-lug mock up specimen

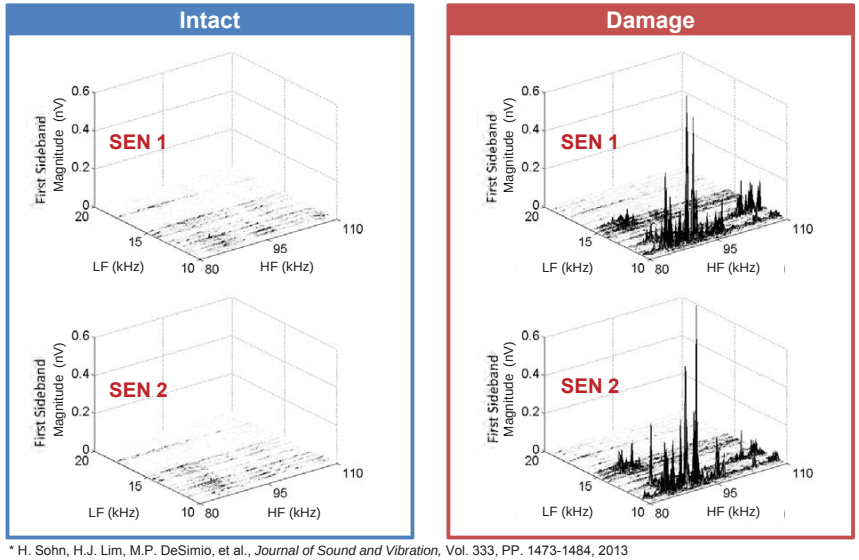


Fatigue test



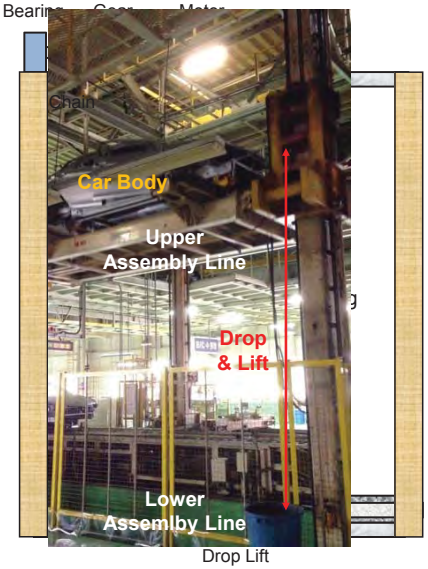
Fatigue crack on the specimen

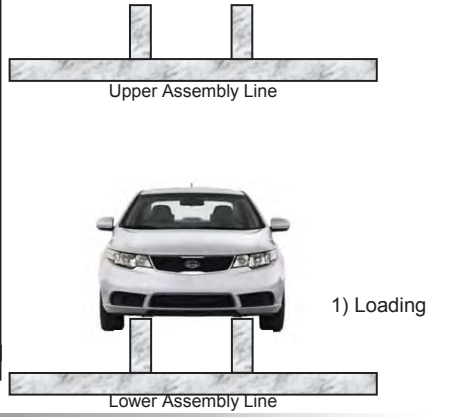
First Sideband Spectrum for Fatigue Crack Detection



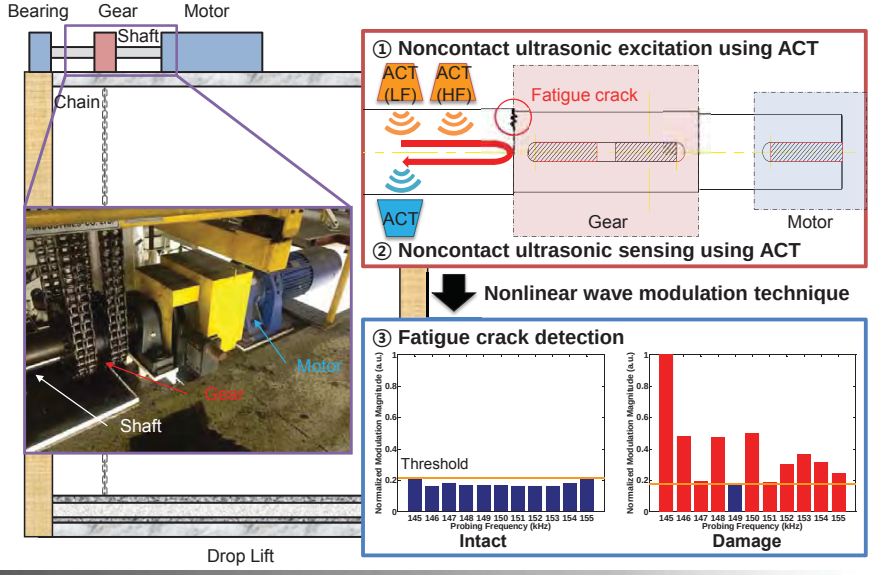
* H. Sohn, H.J. Lim, M.P. DeSimio, et al., *Journal of Sound and Vibration*, Vol. 333, PP. 1473-1484, 2013

Monitoring of a Drop Lift in Automobile Assembly Lines
(Sponsored by Hyundai/KIA Motors)

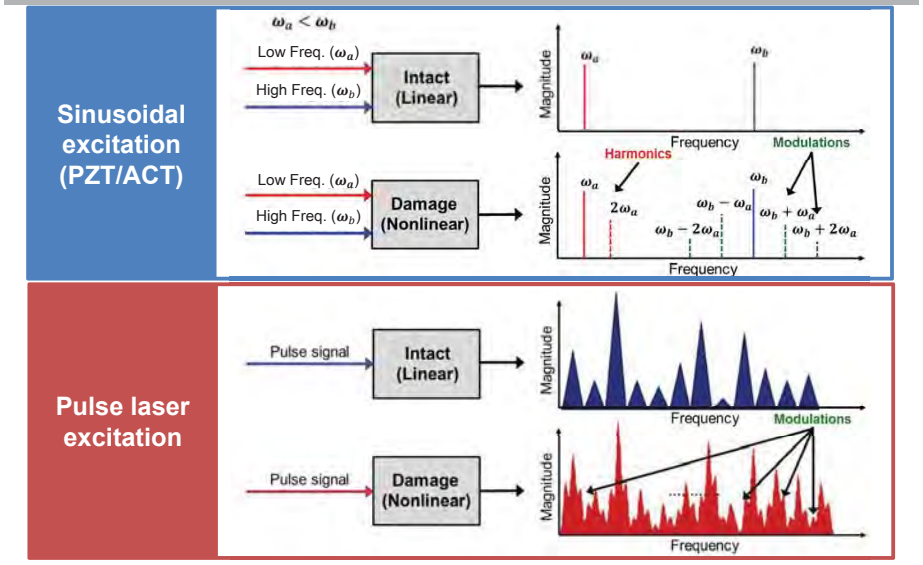




ACT based Nonlinear Modulation for Rotating Shaft
(Sponsored by KIA Motors)



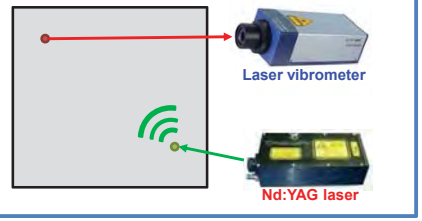
Laser based Nonlinear Ultrasonic Modulation
(In collaboration with Prof. T. Kundu from Univ. of Arizona, Brain Pool Program)



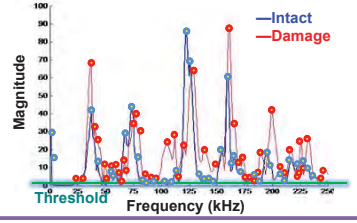
* Eiras et al., Journal of Nondestructive Evaluation, Vol. 32(3), pp. 300-314, 2013.

Overview of Laser based Nonlinear Ultrasonic Modulation

(1) Laser excitation and laser sensing

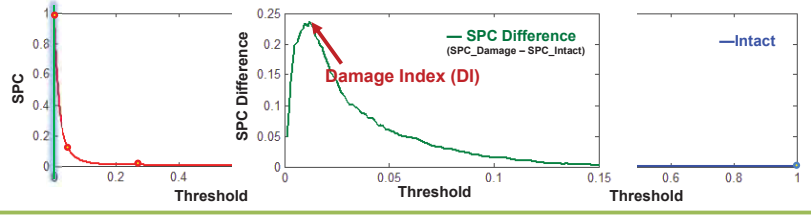


(2) Frequency spectrum construction

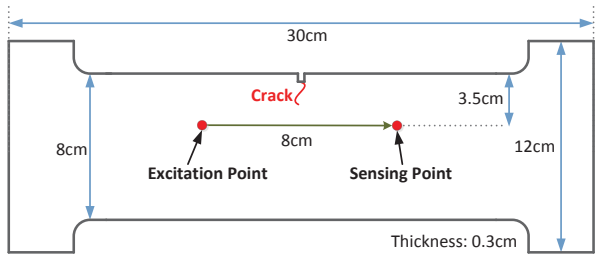


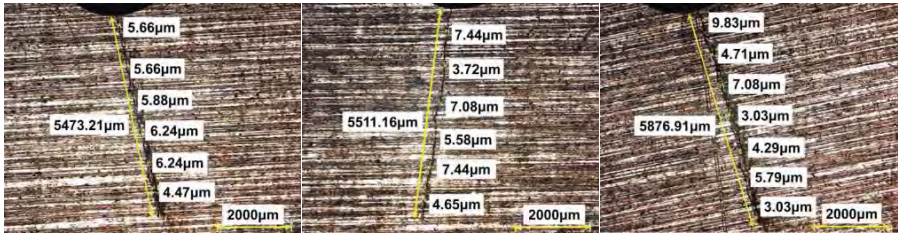
(3) Sideband Peak Counting (SPC) and Damage Index (DI) obtaining

$$SPC = \frac{Num(Peak\ value > Threshold)}{Total\_Peak\_Num}$$



Fatigue Crack Detection using Laser based Nonlinear Ultrasonic Modulation



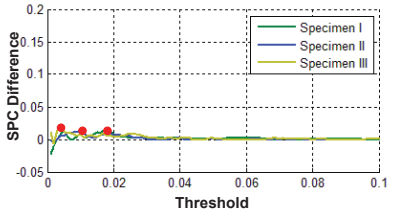


Specimen I Specimen II Specimen III

Sideband Peak Counting (SPC) Results

Intact

SPC Difference (Intact – Reference)

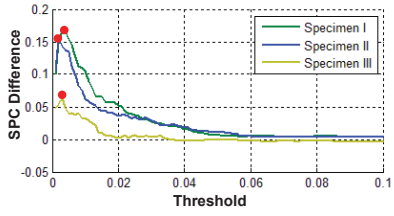


Damage Index (*Max*(SPC Difference))

Specimen	Damage Index (DI)
I	0.018
II	0.017
III	0.022

Damage

SPC Difference (Damage – Reference)



Damage Index (*Max*(SPC Difference))

Specimen	Damage Index (DI)
I	0.173
II	0.158
III	0.072

* All the reference data is collected before the cracks are introduced

* P.P. Liu, H. Sohn, T. Kundu, *The 166th Meeting of the Acoustical Society of America*, 2013