



# RPPR Final Report

## as of 05-Dec-2022

Agency Code: 21XD

Proposal Number: 77363TERIP

Agreement Number: W911NF-21-1-0035

### INVESTIGATOR(S):

**Name:** Ph.D. Brian Wisner  
**Email:** bwisner@ohio.edu  
**Phone Number:** 7405660136  
**Principal:** Y

Organization: **University of Ohio @ Athens**

Address: 184 Stocker Center, Athens, OH 457016817

Country: USA

DUNS Number: 041077983

EIN: 316402113

**Report Date:** 10-Mar-2022

Date Received: 02-Dec-2022

**Final Report** for Period Beginning 11-Dec-2020 and Ending 10-Dec-2021

**Title:** Fiber Optic Laser Vibrometer for Research on Material Damage Evolution

**Begin Performance Period:** 11-Dec-2020

**End Performance Period:** 10-Dec-2021

**Report Term:** 0-Other

Submitted By: Ph.D. Brian Wisner

Email: bwisner@ohio.edu

Phone: (740) 566-0136

**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

### STEM Degrees:

### STEM Participants:

**Major Goals:** There were two major goals of this work. Goal one was to develop a non contact Nondestructive method to detect and track damage evolution in dynamic systems. Goal two involves developing a Multiphysics approach to monitor additive manufacturing processes for Digital Twin.

**Accomplishments:** Objective 1: Develop a noncontact Nondestructive Method to detect and track damage evolution in dynamic systems.

A noncontact laser vibrometer is proposed to perform NDE on materials during the additive process to improve material quality and to monitor the damage evolution of material systems subjected to use loads. This proposal introduces the required technology and discusses the implementation of the laser vibrometer based AE system both into existing projects the PI is working on along with two future research directions that will be made possible.

The laser vibrometer device, shown in Figure 3, capable of measuring displacement, velocity, and acceleration changes on the surface of a mechanical system with no contact was acquired. The system is highly versatile, capable of measuring up to 25m/s velocities with a 24MHz bandwidth and a high sensitivity of 1.7 nm/s resolution in velocity. Additionally, it can measure picometer displacement changes making it ideal for Acoustic Emission applications that cause very small surface vibrations. The system can output the recorded displacement, velocity, and acceleration data as either an analog signal for syncing with other NDE data systems or as a digitized signal with a sampling rate of 160 million samples per second far exceeding the current standard for traditional AE data acquisition boards and eliminating sensor transfer functions making direct comparison to physical models possible. A single Multipurpose head was purchased for this work.

Calibration of the Laser system against PZT

A combination of ASTM Standard pencil lead break tests (PLBT) Coin Tap and Monotonic fracture experiments were conducted to compare the Laser acoustic Emission (AE) results to the traditional PZT data. Both methods were shown to detect the PLBT and Coin Tap tests with some differences in wave duration, amplitude and frequency. When performing monotonic tests, the Laser data is collected as a continuous wave shown in Figure 2a while the PZT data is generally collected as individual hits making it difficult to compare the results directly. An attempt to collect the PZT data as a continuous wave was made, however the file was too large to open. A method to examine the continuous wave and extract traditional features was developed using a window approach. The results are shown in figure 2b where The AE data from the laser (green) and PZT sensors (red) are overlaid with the load curve. The general trend in both data sets is the same, though there are some variations in the onset of damage as indicated by each method.

# RPPR Final Report

## as of 05-Dec-2022

Noncontact Laser Based AE has been performed on Compact tension and middle tension samples. An example of this type of data was provided in figure 2. Additional testing on fatigue samples has been conducted and data has been extracted. The fatigue data shows less consistent AE than the monotonic tests. As a result, analysis is still ongoing to understand the reason. A combination of small-scale testing to understand the damage mechanisms along with fractography is being developed to explain the variation.

The laser vibrometer was used through a protective acrylic layer to detect the penetration of a ballistic impact. It was shown that an penetration shows significantly higher amplitude than a non penetration.

Objective 2: Develop a Multiphysics approach to monitor Additive Manufacturing Processes for Digital Twin.

Modeling of the fatigue response of Krouse geometry fatigue bending samples was conducted. Figure 3 shows the FEA geometry and fatigue set up. The Green dot represents the Laser vibrometer position used to monitor both damage and the resonance response of the sample. This same location was used to extract the displacement of the sample for comparison between the Model and the Experimental Data. Both the model and experiment produced almost identical responses to the loading with additional noise showing up in the

Additive Manufacturing Build Plate Monitoring

A method of altering the microstructure of AM materials during build was developed in a DLA Phase 1 SBIR grant. This method relies on ultrasonic vibration to enter the melt pool and modify the solidification front. To achieve this sufficient amplitude at the target frequency is required. To validate the system was supplying the target frequency and amplitude the laser vibrometer was implemented to measure the build plate vibration. The results showed that the target frequency was hit, but not at the intended amplitude. This data was used to develop the theory that a smaller amplitude vibration can alter the sub grain structure while the larger amplitude vibrations can alter the grain structure. A publication is under preparation on this topic. Figure 4 shows the configuration of the Transducer and the results from the laser vibrometer. This vibrometer is used to monitor the vibration of the build plate prior to beginning the build. It was found that an incorrect tightness resulted in a lower frequency entering the build plate than intended but at a higher velocity. By using the laser vibrometer the optimum tightness can be achieved to generate quality builds.

**Training Opportunities:** Nothing to Report

**Results Dissemination:** Results of the work in Additive Manufacturing and in Damage detection were reported at the Acoustic Emission Working Group and at the Society for Experimental Mechanics Conferences.

**Honors and Awards:** Nothing to Report

**Protocol Activity Status:**

**Technology Transfer:** Nothing to Report

### **PARTICIPANTS:**

**Participant Type:** PD/PI

**Participant:** Brian Wisner

**Person Months Worked:** 12.00

Project Contribution:

National Academy Member: N

**Funding Support:**

**RPPR Final Report**  
as of 05-Dec-2022

**Partners**

,

I certify that the information in the report is complete and accurate:

Signature: Brian Wisner

Signature Date: 12/2/22 4:37PM

## **Fiber Optic Laser Vibrometer for Research on Material Damage Initiation and Evolution**

### **Project Summary (for Public Release)**

The identification of defects produced during manufacturing and use of a material system rely on the ability to collect data. Nondestructive Evaluation (NDE) methods are often used to obtain the data in a way that is not detrimental to the material to ensure safe component use after inspection. Where possible, the use of these techniques during the manufacturing process or during service use of components is preferred as it minimizes downtime. Currently, limitations exist for such techniques when monitoring components used in extreme environments such as elevated temperatures as many sensor systems are not designed for these conditions. Additionally, dynamic systems such as engine turbines subjected to high velocity rotation, vibrations, and temperatures are impossible to directly instrument with sensors as direct contact can alter the response of the system and make it difficult to accurately assess the material. Application of NDE methods in manufacturing processes is similarly challenge as a result of high temperatures, moving parts, and minimal access space that exist in some form in all manufacturing methods. A Fiber Optic Laser Vibrometer was acquired that allows for the NDE monitoring of such systems with the Acoustic Emission (AE) NDE technique to detect defects and damage during material use. This technique is based on the concept that a material will release energy as it fails resulting in surface vibrations which can be detected by a sensor. This method is a passive technique that uses low energy consumption to detect damage and traditionally requires the sensor to be in contact with the sample. The implementation of the Laser system (LAE) has expanded the material systems and loading methods that can be monitored. The system is still being implemented to detect defects that are produced during additive manufacturing (AM) to allow for feedback to alter the build parameters to correct for the defect detected or to halt the build and begin again reducing material waste and manufacturing time while ensuring quality. The benefit of the LAE system is that it can be used to monitor for defects in metal, polymer, or even composite manufacturing including additive manufacturing processes. In addition, the LAE system was be used to probe material response to external loads in the form of monotonic and fatigue loading along with ballistic impacts to gain understanding of how a material will initiate and grow damage and determine what leads to catastrophic failure.

**Objective 1: Develop a noncontact Nondestructive Method to detect and track damage evolution in dynamic systems.**

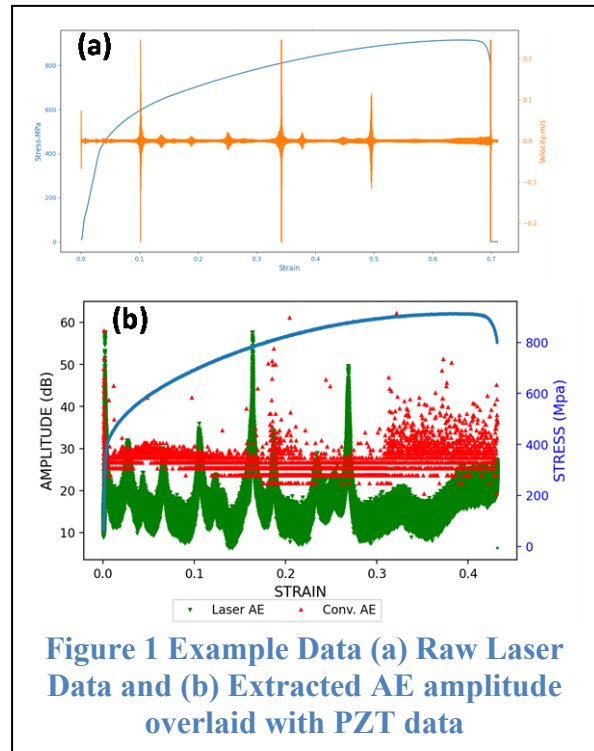
A noncontact laser vibrometer is proposed to perform NDE on materials during the additive process to improve material quality and to monitor the damage evolution of material systems subjected to use loads. This proposal introduces the required technology and discusses the implementation of the laser vibrometer based AE system both into existing projects the PI is working on along with two future research directions that will be made possible.

Acquired Laser Vibrometer

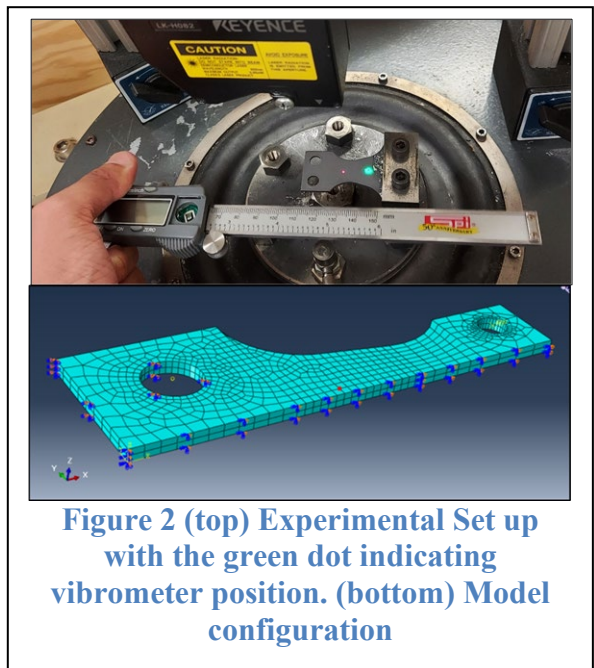
The laser vibrometer device, shown in Figure 3, capable of measuring displacement, velocity, and acceleration changes on the surface of a mechanical system with no contact was acquired. The system is highly versatile, capable of measuring up to 25m/s velocities with a 24MHz bandwidth and a high sensitivity of 1.7 nm/s resolution in velocity. Additionally, it can measure picometer displacement changes making it ideal for Acoustic Emission applications that cause very small surface vibrations. The system can output the recorded displacement, velocity, and acceleration data as either an analog signal for syncing with other NDE data systems or as a digitized signal with a sampling rate of 160 million samples per second far exceeding the current standard for traditional AE data acquisition boards and eliminating sensor transfer functions making direct comparison to physical models possible. A single Multipurpose head was purchased for this work.

Calibration of the Laser system against PZT

A combination of ASTM Standard pencil lead break tests (PLBT) Coin Tap and Monotonic fracture experiments were conducted to compare the Laser acoustic Emission (AE) results to the traditional PZT data. Both methods were shown to detect the PLBT and Coin Tap tests with some



**Figure 1 Example Data (a) Raw Laser Data and (b) Extracted AE amplitude overlaid with PZT data**



**Figure 2 (top) Experimental Set up with the green dot indicating vibrometer position. (bottom) Model configuration**

differences in wave duration, amplitude and frequency. When performing monotonic tests, the Laser data is collected as a continuous wave shown in Figure 2a while the PZT data is generally collected as individual hits making it difficult to compare the results directly. An attempt to collect the PZT data as a continuous wave was made, however the file was too large to open. A method to examine the continuous wave and extract traditional features was developed using a window approach. The results are shown in figure 2b where The AE data from the laser (green) and PZT sensors (red) are overlaid with the load curve. The general trend in both data sets is the same, though there are some variations in the onset of damage as indicated by each method.

Damage Detection using Laser Vibrometry

Noncontact Laser Based AE has been performed on Compact tension and middle tension samples. An example of this type of data was provided in figure 2. Additional testing on fatigue samples has been conducted and data has been extracted. The fatigue data shows less consistent AE than the monotonic tests. As a result, analysis is still ongoing to understand the reason. A combination of small-scale testing to understand the damage mechanisms along with fractography is being developed to explain the variation.

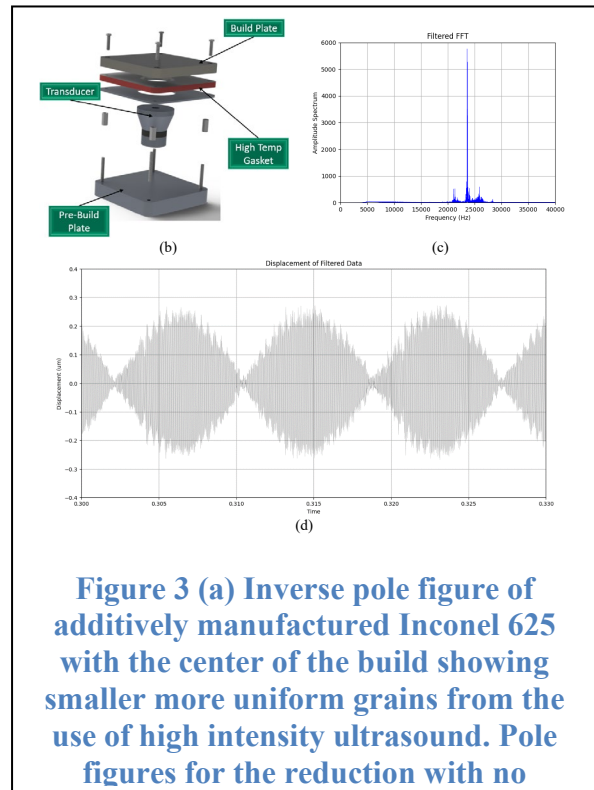
Ballistic Impact Detection

The laser vibrometer was used though a protective acrylic layer to detect the penetration of a ballistic impact. It was shown that an penetration shows significantly higher amplitude than a non penetration.

**Objective 2: Develop a Multiphysics approach to monitor Additive Manufacturing Processes for Digital Twin.**

Vibration Response for FEA validation  
 Modeling of the fatigue response of Krouse geometry fatigue bending samples was conducted. Figure 3 shows the FEA geometry and fatigue set up. The Green dot represents the Laser vibrometer position used to monitor both damage and the resonance response of the sample. This same location was used to extract the displacement of the sample for comparison between the Model and the Experimental Data. Both the model and experiment produced almost identical responses to the loading with additional noise showing up in the

Additive Manufacturing Build Plate Monitoring  
 A method of altering the microstructure of AM materials during build was developed in a DLA Phase 1 SBIR grant. This method relies on ultrasonic vibration to enter the melt pool and modify the solidification front. To achieve this sufficient amplitude at the target frequency is required. To validate the system was supplying the target frequency and amplitude the laser vibrometer was implemented to measure the



build plate vibration. The results showed that the target frequency was hit, but not at the intended amplitude. This data was used to develop the theory that a smaller amplitude vibration can alter the sub grain structure while the larger amplitude vibrations can alter the grain structure. A publication is under preparation on this topic. Figure 4 shows the configuration of the Transducer and the results from the laser vibrometer. This vibrometer is used to monitor the vibration of the build plate prior to beginning the build. It was found that an incorrect tightness resulted in a lower frequency entering the build plate than intended but at a higher velocity. By using the laser vibrometer the optimum tightness can be achieved to generate quality builds.