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Anomaly Detection In Additively Manufactured Parts Using Laser Doppler Vibrometery

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Anomaly Detection in Additively Manufactured Parts using Laser Doppler Vibrometery

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***Abstract*—Additively manufactured parts are susceptible to non-uniform structure caused by the unique manufacturing process. This can lead to structural weakness or catastrophic failure. Using laser Doppler vibrometry and frequency response analysis, non-contact detection of anomalies in additively manufactured parts may be possible. Preliminary tests show promise for small scale detection, but more future work is necessary.**

I. Introduction

Selective laser sintering is a method of additive manufacturing where metal powder is layered and melted with a high powered laser in patterns to build up a metal part. Extrusion is a method of additive manufacturing where a layer of raw material is deposited in a pattern that builds up a part. Both methods of additive manufacturing are going through changes in build parameters. Testing parts made using these new parameters quickly and cheaply aids progress in additive manufacturing technology.

This fast paced development of additive manufacturing has allowed the integration of more and more additively manufactured parts to projects worldwide. The build quality of additively manufactured parts can be impacted by the additive manufacturing process. The detection of defects is important in helping determine the integrity of an additively manufactured part. Integrity of a part can be found using destructive methods, but these methods can render the part unusable. Current non-destructive techniques include methods such as X-ray analysis. While non-destructive, methods such as this can be costly in terms of both time and money. A laser vibrometer can be implemented as a non-destructive analysis tool that may be useful in determining integrity of additively manufactured parts. An acousto-mechanical frequency response transfer function acquired from an additively manufactured part using a laser Doppler vibrometer may be used as a tool to gather valuable information about the physical properties of that part.

II. Theory

It is known that when all other conditions remain the same, an identical waveform will propagate differently through an object with changing geometry or material [1]. This propagation change causes different resonances and attenuations in the object. Comparing a reference frequency response to the frequency response of a part containing an anomaly should reflect that the frequency response has changed.

A Wiener filter was used to estimate the frequency response transfer function of the object under test. The division of the input-output cross-spectral density by the input spectral density is used as the transfer function estimate. This operation is performed in Matlab [2].

The power spectral density of the time domain signals was derived using Welch's method. Welch's method converts a time domain signal to power spectrum using periodogram spectral estimation. A time domain signal is subdivided into overlapping segments. These overlapping segments are windowed. The windowing process mitigates discontinuities in the time domain, while the segment overlap is to reduce information lost during the windowing process. A discrete Fourier transform is applied to each of these segments. The frequency information of all segments are then averaged together. Welch's method is useful as it reduces the signal to noise ratio of the experiment data. This is desired as the noise power in laser vibrometer signals can be very high.

III. Method

An experiment was set up to achieve quickly repeatable and consistent tests on easily interchangeable objects.

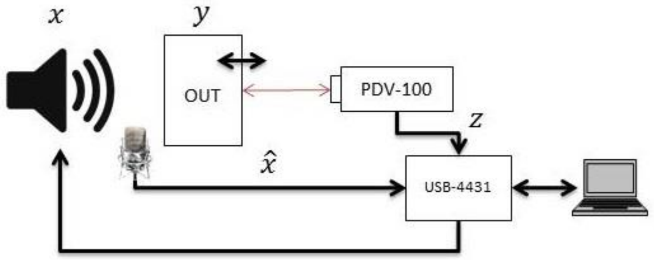


Fig. 1. A block diagram of the test procedure

An excitation signal is necessary to acquire the frequency response information about the Object Under Test (OUT). A swept sine signal was chosen as it has the highest signal to noise ratio while retaining useful frequency domain content.

LabVIEW code was written to acquire and save time domain information. The code gave flexibility in filename, test name, run type, signal samples/second, time length of the signal and total frequency range. LabVIEW then produced a swept sine using the parameters entered by the user. This swept sine wave was windowed with a Hamming window to prevent distortion of the sound wave. When testing is completed, the time domain data from the vibrometer and microphone is then saved as a Matlab structure for further processing.

A Yamaha HS7 studio speaker is used to create a swept sine signal across the chosen range of frequencies. This studio speaker was chosen as it has a flat frequency response across a broad range of frequencies. A Bruel & Kjaer flat frequency response microphone was used to measure a more accurate input signal. A microphone was used as an input to the system because the frequency response of the speaker would cause the acoustic signal created by the speaker to deviate from the original signal too much for accurate results. The microphone was placed in close proximity to the object to acquire an acoustic signal that closely resembled the input signal hitting the object under test. The flat frequency response of both the speaker and microphone are to help ensure that each frequency is accurately represented and no input is attenuated or magnified by non-flat device frequency responses.

The data acquisition device used in this experiment was a National Instruments USB-4431 high resolution data acquisition device (DAQ). This DAQ was chosen to increase ease of use as LabVIEW code was used to acquire data. This DAQ was also chosen as it has the ability to both send and receive signals. This was to help ensure the data was sent and gathered simultaneously. This DAQ also had the same analog to digital converter resolution as the vibrometer's digital to analog converter resolution.

A laser Doppler vibrometer measures the velocity of the object it is pointed at with high accuracy. The vibrometer analyzes a reference laser beam combined with a beam of reflected laser light which has been frequency shifted by the movement of the OUT. This new signal is processed and then recorded using a DAQ. The vibration velocity of the OUT caused by the acoustic energy from the speaker was measured using a Polytec PDV-100 vibrometer [3].

The OUT was tightly placed in a vise grip in front of the speaker. The OUT was placed in this manner because the vibrations caused by the acoustic signal shifted the OUT out of the vibrometer laser focus. Any data acquired when the vibrometer laser was out of focus had to be thrown out.

The transfer function of the object was estimated using the Matlab function tfestimate. Tfestimate uses Welch's method and an implementation of a Weiner filter to produce a transfer function estimation of the object under test. Tfestimate implements a Wiener filter to approximate the transfer function between the audio signal input and the vibration output.

Fig. 2. Final test setup. Left: speaker Right: microphone Bottom: Vibrometer Middle: OUT in vise

IV. Results

To first determine that the hypothesis is sound, objects of identical material and build were tested. When it was confirmed that the two identical objects shared the same frequency response, similar objects with large scale defects and material changes were tested. When it was confirmed that two objects were distinguishable in frequency response, parts with subtle defects were tested to determine if differences in frequency response were detectable.

Initial tests were performed on silicon pads that were manufactured using the same process and material type. Results from these initial tests showed that two objects with nearly identical structure have nearly indistinguishable frequency response transfer functions. That is, the peaks and valleys of the magnitude response match on the x-axis. Despite being nearly identical, the frequency response from the two objects showed an amplitude offset in the y-axis. Despite this small offset, the independent tests agree. Due to the structure of the silicon lattice, the reflection of the vibrometer laser became poor. This made data acquisition from the silicon pads a difficult process.

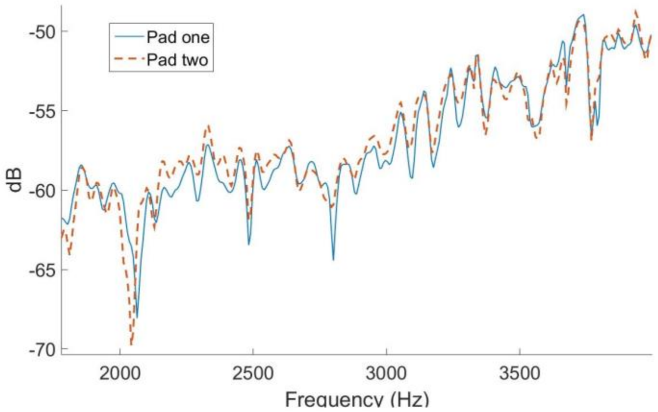
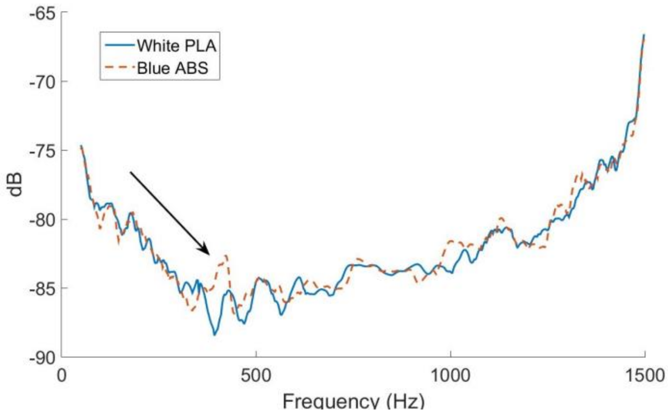


Fig. 3. Two identical objects share identical frequency response information

Three unmanned aerial vehicle booms printed using different materials and build qualities were tested. A boom made of Polylactic Acid (PLA) and two booms made of Acrylonitrile Butadiene Styrene (ABS). The purpose of these tests was to determine if large scale anomalies or differing composition are detectable. These objects were used for this particular test as they share nearly identical geometric properties. Of the two booms made of ABS, one had suffered a catastrophic structural defect. This test showed that despite similar geometric shape, the frequency responses vary far more with change in material than with similar material containing a large anomaly.



a.

Fig. 4. Frequency response of two structrualy sound UAV booms. One made of white PLA the other made of blue ABS. While similar in response, the boom made of blue ABS shows a large resonsance at 400Hz that is not present in the boom made of white PLA.

Test objects were printed in an attempt to determine what sized anomaly this method could detect. Multiple one inch length cubes were printed. Cubes of the same size were also printed with one quarter inch voids cut out of a corner. These cubes were tested using the same procedure outlined in this paper. The frequency responses of these cubes were all nearly identical. This indicates that the test objects are indistinguishable from each other in the frequency domain information gathered from the experiment setup outlined in this paper.

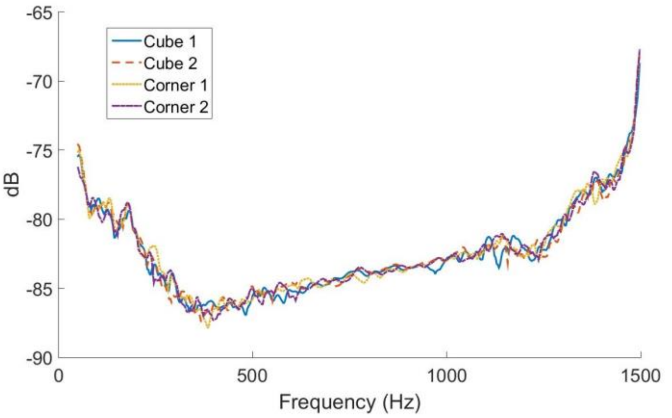


Fig. 5. Frequency response of two different sets of two identical cubes. Two full cubes and two cubes with corners cut out. The four cubes are nearly identical in frequency response information.

V. CONCLUSION

Laser Doppler vibrometry is capable of anomaly detection in additively manufactured parts. Detection capability is limited using this test procedure, as anomalies that are small in relative size to the reference object are not yet detectable.

The use of a vise grip may have caused the object to vibrate less than what is ideal for signal acquisition. While this may be conclusive, data gathered from an object that is allowed to freely vibrate could give more detailed frequency information. Similarly, the use of a more powerful excitation signal would lower the signal to noise ratio and may allow the defect to be revealed in the frequency domain information.

Laser Doppler vibrometry shows promise as a useful tool in anomaly detection. Research will be completed when it can be shown that the use of acousto-mechanical transfer functions can detect anomalies on a scale that cause defects in additively manufactured parts.

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