VALIDATION OF MICROPHONE PLACEMENT FOR ACOUSTIC EMISSION FOR ONLINE DETECTION OF POROSITY FORMING PHENOMENA DURING METAL LASER POWDER BED FUSION

D. Kouprianoff[1*], N, Luwes[2], I. Yadroitsava[1] and I. Yadroitsev[1]

ABSTRACT

Some concerns which arise during the metal laser-based powder bed fusion (LPBF) process are lack of fusion between tracks following non-optimal input process parameters; scanning and building strategies and/or inhomogeneity in delivered powder layer. The problem is that unstable geometrical characteristics of single tracks cause porosity in 3D parts. Non-contact acoustic emission is one of the methods for online monitoring of LPBF. The purpose of this paper is to validate the placement of the non-contact acoustic emission sensor. This was done by means of mathematical evaluation of the data for symmetrical fusion at different distances from the sensor. Excludible small variants in time domain root mean square values and good correlation of the power spectrum transformations show that the current placement of the sensor was acceptable for acoustic emission and can be used for online detection of porosity forming phenomena during metal LPBF.

[1] Department Mechanical and Mechatronic Engineering, Central University of Technology, Free State, South Africa
[2] Department Electrical Engineering, Central University of Technology, Free State, South Africa

1. INTRODUCTION

Laser powder bed fusion (LPBF) is an additive manufacturing (AM) process which uses energy from a laser beam to fuse selected regions of a powder bed [1]. Online and early detection of unstable geometrical characteristics of single tracks is the most important to prevent porosity in 3D parts. Sensing defects and control during the process is one of the main ways for ensuring repeatability and consistency of LPBF manufacturing. Key process parameters in LPBF are laser and scanning parameters; powder material properties; powder bed properties, recoating parameters and build environment. Process signatures emanating from the melt pools in LPBF are molten/solidified pool, plasma emission/absorption, radiation, reflected light, etc. These parameters need to be controlled and are the basis for stability and repeatability of the LPBF process [2].

Some non-destructive testing (NDT) techniques that can be used for quality control in AM are visual, ultrasonic, Eddy current, radiographic, magnetic methods, liquid penetrant test, shearography, acoustic and thermography [3, 4]. Thermography and acoustic emission testing are applied as inspection methods for in-situ monitoring of AM processes, but the spatial and temporal resolution of in-process monitoring with feedback depends on scanning parameters. LPBF is a rapid process that makes on-line NDT and feedback control extremely difficult. For spatial capability, minimum defect size also have to be determined in order to qualify parts [5, 6]. Available commercial LPBF monitoring systems consists of photodiode melt pool monitoring, CMOS camera for powder bed imaging systems and others that make use of infrared and ultraviolet photo sensors and pyrometers [2].

Yusof et al. [7] investigated the feasibility of using acoustic monitoring of laser power and pulse width during Pulse Mode Laser Welding to indicate depth of penetration. One of the conclusions drawn is that some post processing is needed to eliminate the influence of noise. For metal LPBF, Fisher et al. [8] showed that when attaching a sensor to the substrate a clear difference could be obtained from the acoustic signatures when using different laser powers. It was found that there was a clear shift and missing peaks in spectral analysis at different laser powers. As showed in previous work, a non-contact AE can be used for online monitoring during metal LPBF [9]. Authors have shown that the quality of AE results is dependent on noise; Horvat et al. [10] proposed a new algorithm that eliminates reverberation and background noise during AE monitoring of Gas Metal Arc Welding (GMAW). Similarly Alfaro and Cayo [11] showed that the quality of online AE monitoring was effected more by environmental conditions when compared to online infrared monitoring during GMAW. Thus, factors like the effect of sound reflections, machine environment, noise and the location of the recording device therefore need to be considered as a basis of qualification. This paper shows the analysis of the results of AE sensor placement as sampled in the actual metal LPBF machine. These results include all the environmental factors as well.

2. METHODOLOGY AND RESULTS

2.1 Materials and methods

Maraging steel MS1 from EOS with the chemical composition being Ni 17.6%, Co 8.88%, Mo 4.85, Ti 1.06% was used. Samples were produced by an EOSINT M280 system on the substrate with similar chemical composition. Powder layer thickness was 50 µm. The building chamber was filled with nitrogen atmosphere. Single tracks were 200 mm in length and were scanned at a laser power of 305 W with a scanning speed of 1.01 m/s. AE was measured using an ICP microphone having an optimal frequency range of 3.75-20 000 Hz (±2dB). The microphone was placed inside the building chamber (Fig. 1).

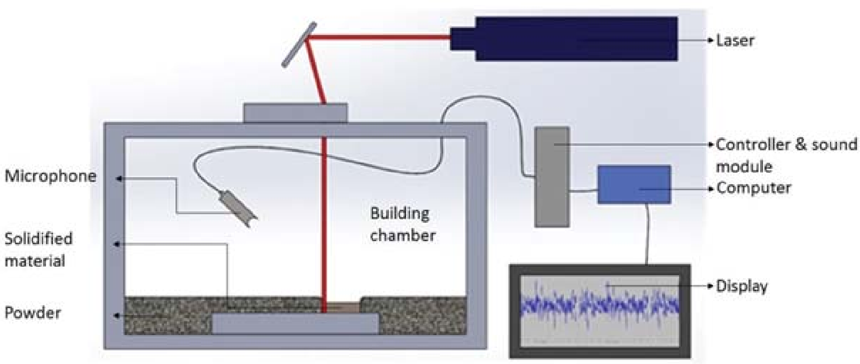

Fig. 1. Experimental scheme.

To determine if AE differs with respect to the distance from the microphone, the microphone was fixed above the substrate and the laser scanned at 5 different positions, 40 mm apart. Each set containing 3 tracks. Tracks were scanned consecutively from Position 1; Track 1 (P1; T1) on the right, to the left end at Position 5; Track 3 (P5; T3) (Fig. 2).

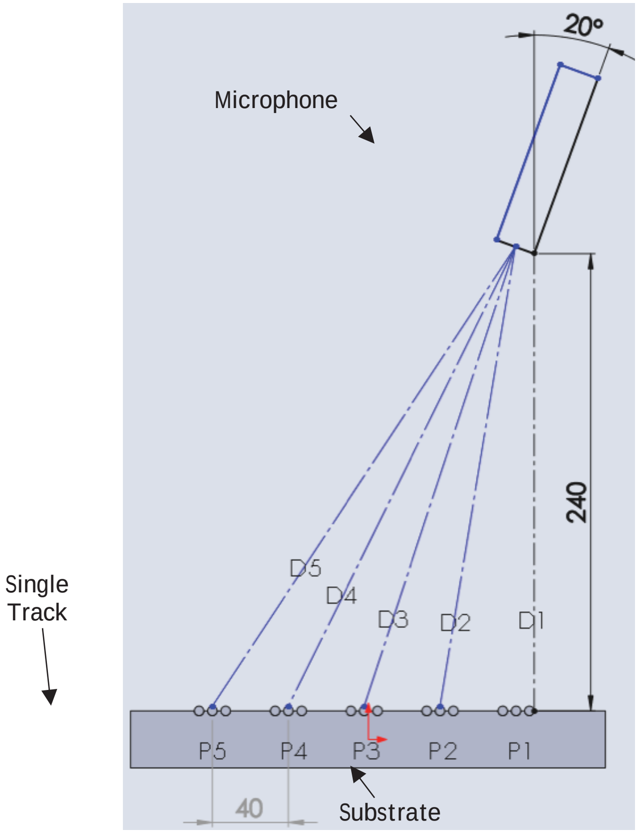

Fig. 2. Correctional view of system layout.

In Figure 2 the distance from the microphone edge to the midpoint of each position is indicated and their corresponding values are shown in Table 1.

Table 1: Distance from microphone to different scanning position.

	D1	D2	D3	D4	D5
Distance (mm)	240	243.31	252.982	268.328	288.444

The data were acquired at a sampling frequency of 102.4 kHz. Code for post-processing of data was written using LabView and its signal processing algorithm libraries. It was seen experimentally that a 1500 Hz high pass filter could remove the effect of ambient operating noise that does not pertain to the actual laser scanning. Each individual scan track was extracted from the total data scan to ease analysis. The average sound pressure at individual scans was calculated using root mean square (RMS) value. Thereafter evaluation of frequencies at each position were analysed to determine whether certain positions might amplify or absorb some frequencies due to its position in the system. The individual frequency content was analysed using power spectrum and doing correlation with one another. Since all the process parameters are physically the same with the only difference being distance from sensor, good correlation results would indicate the optimal sensor placement (*>0.99)*.

2.2 Results

The tracks were visually analysed, and no major irregularities were present. A section of the tracks at Position 1 is shown in Fig 3.

Fig. 3. Track 1 to 3 of Maraging steel on substrate.

After applying the 1500 Hz high pass filter, the tracks were clearly distinguishable in the time domain. The scanning time of each track is equal to the time that it would take to scan a track at a speed of 1.01 m/s for 200 mm length as shown in Fig **4.**

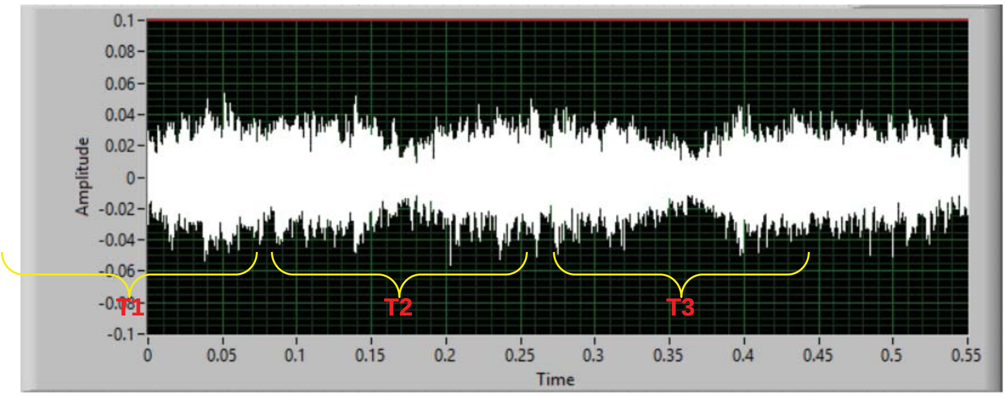

Fig. 4. Signal of first three tracks after applying signal filtering.

The individual RMS values sound pressure level (SPL) showed no large variations in relation to the distance from the microphone. Variations could be attributed to slight differences in powder layer thickness over the platform. Table 2 shows the SPL of each scan. The maximum fluctuations in sound pressure during the process was calculated by taking the max and min value of Track 1, 2 and 3 as shown in Table 3.

Table 2: SPL at each position (dB).

	P1	P2	P3	P4	P5
Average	83.24898	83.11877	83.16945	82.8472	83.39392
Standard deviation	0.656737	0.350508	0.760288	0.471983	0.197635

Table 3: Max and Min track SPL value and corresponding SPL difference.

	Max	Min	Δ SPL
T1	83.52422	82.35053	1.17369
T2	84.00713	83.28985	0.717278
T3	83.59498	82.4994	1.095574

These results show that the sound levels reaching the sensor is relatively close to each other, but one needs also to indicate if any frequency distortion could have taken place. The induvial frequency content for each track was calculated with power spectrum and results correlated with Track 1.Table 4 shows that all the samples showed good correlation.

Table 4: Power spectrum correlation value of Track 1 with other tracks.

P1			P2			P3		
T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0.993	0.999	0.994	0.991	0.993	0.988	0.991	0.994

P4			P5		
T1	T2	T3	T1	T2	T3
0.997	0.994	0.991	0.9995	0.992	0.993

Thus, with good correlation and similar RMS values, one can conclude that the current sensor position in this setup is not influenced by the environment or scanning position.

3. CONCLUSION

The purpose of this paper was to validate the microphone placement during acoustic emission for online detection of porosity forming phenomena during metal laser powder bed fusion. Analysis was done inside the EOSINT M280 machine using Maraging steel; placement with chosen distances seem to be adequate, but care should be taken if any variable such as machine, sensor or material is changed. Similar SPL levels and good frequency correlation *of the tracks* for this environment with this sensor placement indicate that measures and data can be trusted for non-contact acoustic emission during online detection of porosity forming phenomena during metal LPBF. This would pave the way for a reliable AE detection system for early detection of unstable geometrical characteristics of single tracks or powder layers which can cause porosity in 3D parts.

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