Modal Analysis of Replica Boss Hole During the Deburring Process in Aerospace Manufacturing Industry

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Abstract. The monitoring of surface finishing processes in aerospace manufacturing industry becomes one of key issues to maintain the overall quality of product or part. To date, the surface quality monitoring post machining processes such as deburring, use visual inspection, surface roughness test or laser gap gun. The whole manufacturing process then requires a considerable amount of time as the production line must be halted due to these measurements taking place. This study presents an online monitoring system to measure the chamfer quality of replica boss hole post-deburring process. Vibration signal was measured during the deburring process and the features that correlate to the deburring stages (passes) were extracted. This paper focuses on the validation of actual vibration signal with the modal analysis of work coupon (replica boss hole) to obtain the correlation between the vibration amplitude level on particular region and the mode shape of work coupon during the deburring process.

1 Introduction

Deburring and finishing are the treatment processes for burrs, sharp edges, and rough surfaces removal. They can often be treated as the step-child of a manufacturing process, but its importance is growing as tolerances get tighter and precision devices become the norm [1]. Deburring process was mostly used for safety in the past, however its significance in manufacturing process today has expanded. Other than removing burrs and reducing sharp edges, deburring process also increases robustness by eliminating stress concentrations.

As the automated detection of the machining process malfunctions is able to reduce the production costs and increase the quality of the machine parts, it has become a great interest among engineers and scientists. This use of process monitoring is aimed at eliminating surface anomalies by halting the production when manufacturing conditions indicate they are about to or have arisen. This approach might be of a real benefit for the reduction of the

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costs associated with part inspection after machining as well for the safety of the critical components such as turbine disks for the aero engines.

Acoustic emission refers to the transient elastic stress waves generated due to the rapid release of strain energy from a localized sources within a material. From the analyzed results of the experiment, it is shown that AE sensor feedback can be useful both for controlling metal removal and detecting/tracking the workpiece burr edge. Connected to the whole laser deburring system with a proper control scheme, this AE sensing technology could be a viable means for automating precision deburring operations [2].

Axinte, D. A. et al worked on research which attempts to correlate the quality of the machined surface after broaching and the output signals obtained from multiple sensors, namely acoustic emission, vibration, and cutting forces [3]. The results show that the cutting force signals are sensitive enough to detect the geometrical deviation of the machined profile, burr formation and to a lesser extent the chatter marks.

In another study, Shah, H. et all explored the use of embedded waveguides for monitoring delamination type defects in composites [4]. These waveguides confine the wave transmission in one dimension and waves leak only through the opening provided, which enhances the capability to inspect large composite structures with very low attenuation rate. Inaccessible areas can be inspected and inter-laminar delamination detection can be achieved. Live monitoring and assessment of discontinuities can be accomplished effectively by using this mechanism.

In this paper, an online monitoring system to measure the chamfer quality of replica boss hole post-deburring process will be studied. Vibration signal was measured during the deburring process and the features that correlate to the deburring stages (passes) were extracted. This paper focuses on the validation of actual vibration signal with the modal analysis of work coupon (replica boss hole) to obtain the correlation between the vibration amplitude level on particular region and the mode shape of work coupon during the deburring process.

2 Methods

2.1 Finite Element Method

The Finite Element Method (FEM) has developed into a key indispensable technology in the modelling and simulation of advanced engineering systems in various fields. Engineers and designers go through a sophisticated process of modelling, simulation, visualization, analysis, design, prototyping, testing, and lastly, fabrication. More often than not, much work is involved before the fabrication of the final product or system. This is to ensure the workability of the finished product, as well as for cost effectiveness in the manufacturing process. FEM is one of methods used for solving the natural frequencies and the mode shapes of oscillations.

2.2 Modal Analysis

Natural frequency of the boss hole will be analysed using ANSYS Workbench 17.1. The boss hole model was used to demostrate the vibrations using the parameters set. Natural frequency is found when the model oscillate with the highest amplitude vibration in the absence of damping force.

3 Material and experimental setup

The lab experiment were conducted on a work coupon which was designed to replicate the boss hole of Trent 700 combustor casing as presented in Figure 1. The diameter of the boss hole is 58.5mm, with the depth of 25mm. The deburring tool was able to cut the hole easily and also minimise the vibration caused by the machining torque as it was attached firmly to the T-slot table. The work coupon was attached to the base plate using M8 threaded screws and the base plate is firmly secured to the T-slot table below. The material used for fabrication is mild steel. Tri-axial accelerometer and three work coupons were used in the trials result in six vibration datasets. The machining setup comprised of an ABB IRB 6660 robot mounted with an electrically powered spindle (PDS Colombo RS 90). A standard aluminium oxide brush with a grid size of P80 is used as the deburring brush for removing sharp edges from the chamfer. The RPM of the spindle is controlled by a variable frequency drive set to 166.67 Hz which translates to 10000 RPM and the feed rate programmed to be 30 mm/sec.

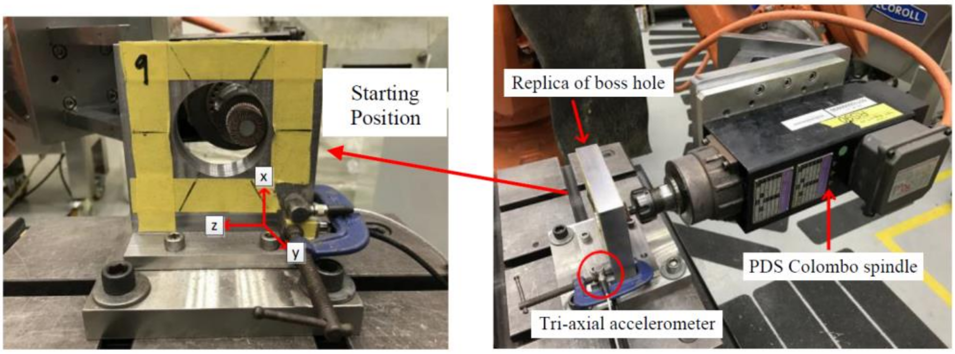
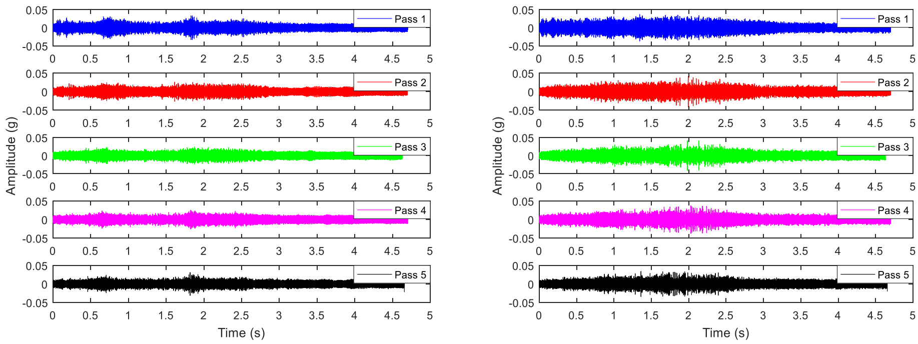


Fig. 1. Replica boss hole and machining setup.

4 Result and discussion

4.1 Vibration signal

The vibration signals were acquired from the following procedure: The DAQ and ABB robot controller were synced to acquire the accelerometer and AE sensor data. The ABB robot controller triggered (digital signal) the DAQ to start acquiring the accelerometer data when the brush first touched the boss hole surface at the start point (left side from the tool view). After the brush made a full circle around the boss hole and about to leave the surface, the ABB robot controller sent a stop signal to the DAQ to stop the sensor data acquisition. Therefore, the data from the accelerometer and AE sensor was acquired throughout actual deburring process. The vibration signals from y and z axis of accelerometer are presented in Figure 2.



(a) (b)

Fig. 2. The vibration signal in y-axis (a) and the vibration signal in z-axis (b).

The vibration signal in y-axis and z-axis is the highest from 1.5 seconds to 2.5 seconds. This corresponds to when the brush reached the top of the boss hole. Thus, highest amplitude was observed at the free-end of the boss hole.

4.2 Modal Analysis

For solutions of the modal analysis of the replica boss hole, ANSYS Workbench 17.1 was used with toolbox Modal. The replica boss hole in Figure 3 was created using SolidWorks based on the actual measurement of the work coupon used in the lab experiment. The model was then imported to ANSYS Workbench.

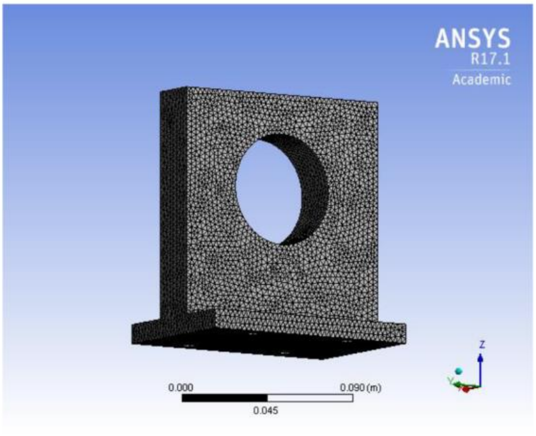


Fig. 3. Replica Boss Hole with Meshing

As a preliminary study, structural steel was chosen as the material used in this modal analysis, although mild steel was used in the lab experiment. Materials properties of the structural steel in the replica boss hole are shown in Table 1.

Table 1. Material Properties of Structural Steel.

Name	*Unit*	*Value*
Young’s Modulus	Pa	2×10^{11}
Poisson Ratio	-	0.3
Density	Kg/m^3	7850

Meshing sizing for relevance center was set to “fine”, as shown in Figure 4. The bottom of the boss hole work coupon was set as fixed, while the top was a free-end, to simulate the lab experiment performed. Figure 4 shows the boundary conditions, where four supports were fixed. Maximum modes to find was set to 10.

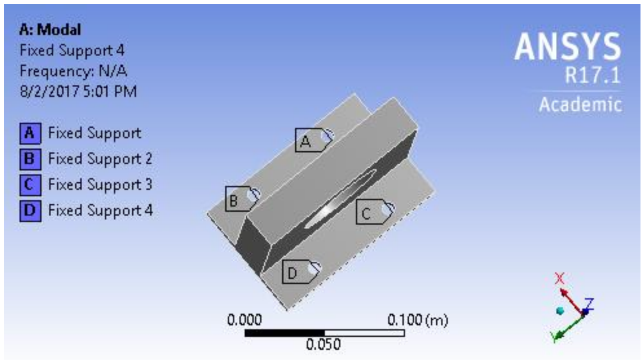


Fig. 4. Boundary Conditions

The first ten natural frequencies are given in Table 2.

Table 2. Natural Frequencies of Replica Boss Hole.

Mode	*Frequency [Hz]*	*Mode*	*Frequency [Hz]*
1.	950.48	6.	7334.
2.	1373.9	7.	7702.5
3.	2243.3	8.	8019.2
4.	3497.3	9.	8789.5
5.	5072.8	10.	8821.3

Next, two frequencies were chosen as they were deemed to suit the actual deformation during the lab experiment. The two frequencies are 950.48 Hz and 5072.8 Hz, correspond to Mode 1 and 5 respectively. The deformations are shown on Figure 5 below.

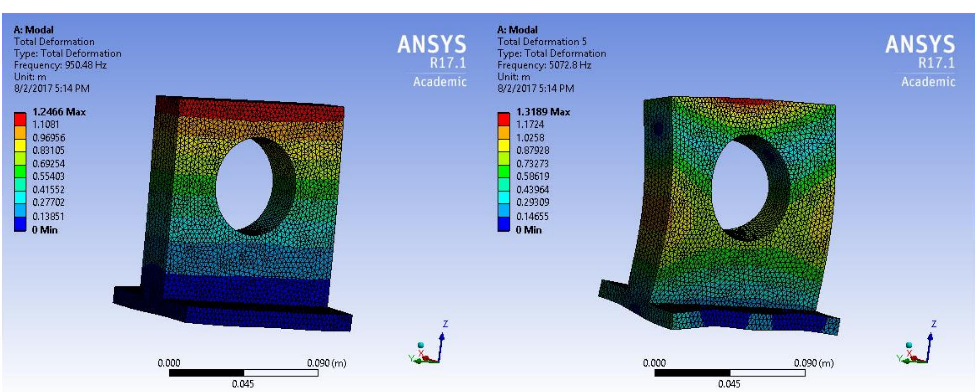


Fig. 5. Deformation of the Boss Hole Model under Natural Frequency 950.48 Hz (left) and 5072.8 Hz (right).

The most suitable model found had the largest deformation at the free-end, which was on the top of the boss hole work coupon. The top of the boss hole work coupon experienced the largest vibration when the boss hole was excited with the natural frequency.

It was found that the pattern of modal analysis of work coupon validated the actual vibration signal resulted from the lab experiment. It is implied that during the deburring process, the vibration amplitude level is related to the modal frequency. The work coupon (replica boss hole) will resonate with higher amplitude, especially at its free-end, when it is excited with its natural frequency. Hence, it is important to note the natural frequencies of the work coupon before deburring process so that it will not interfere with the sensor during data acquisition. However, this comparison holds based on the assumption that the frequency set for the brush in the lab experiment, 166.67 Hz (10,000 RPM), is also another natural frequency of the replica boss hole.

5 Conclusion

In conclusion, the actual vibration signal resulted from the lab experiment was validated by the modal analysis of the replica boss hole, as the vibration amplitude level corresponds to its mode shape. At the free-end of the replica boss hole, it resonated with higher amplitude at natural frequencies. Natural frequency is one important factor to be taken into account before deburring process to prevent it from interfering with the sensor in order to obtain a more reliable and accurate result. Further studies such as impact test and harmonic analysis with certain applied force will be conducted in the future to strengthen this preliminary study.

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