An Approach Towards an Integrated Process Control for Vibropeening

Abhay Gopinath[1,2], A. Senthil Kumar[1#]

1 Department of Mechanical Engineering, National University of Singapore, 21 Lower Kent Ridge Rd, Singapore
2 Rolls-Royce Singapore Pte Ltd, 1 Seletar Aerospace Crescent, Singapore
Corresponding Author / Email: asenthil@nus.edu.sg, TEL: +65 65166800

KEYWORDS: Vibropeening, Almen strips, Process control

Vibropeening, a surface conditioning technology, has been proven to enhance the fatigue life of complex components like blisk airfoils. However, the current research on Vibropeening is significantly constrained by time-consuming Almen peening used for process control, traditionally executed both before and after the Vibropeening process. This paper introduces a step change method integrating Almen peening directly into the Vibropeening of components, with the objective of improving efficiency. Through several experiments, a specialized fixture is designed and validated. The results suggest that this integrated process control method could potentially decrease process time. Further experiments using IN718 and Ti64 strips demonstrate the feasibility of employing actual component material strips for process control. This advancement paves way for a broader adoption of Vibropeening in the aerospace sector and underscores the necessity for further exploration in this area.

1. Introduction

Fatigue enhancement for aerospace parts is achieved conventionally through a process called Shot Peening[1]. Shot Peening imparts compressive residual stress into an aerospace part resulting in an improvement in fatigue life. According to AS9100, Shot Peening can be classified as a special process where it is not possible to measure the outcome of the process on the part non-destructively[2]. Hence, the aerospace parts produced by Shot Peening need special attention during manufacture to guarantee that they have required quality. This is achieved through an appropriate process monitoring and control method called Almen strip peening.

Almen strip peening was invented by J. O. Almen of General Motors Corporation in 1942. Almen strips, made of spring steel, have been the most established process control for Shot Peening in aerospace[3]. 3 types of strips are commonly used based on the requirement: N, A, and C strips. N is the thinnest, and C is the thickest strip as shown in Fig.1. Media is peened over the strip at a desired pressure and mass flow rate, resulting in bending of the strip[4]. This bending increases with an increase in peening time, due to more impacts until it reaches a saturation point. This is measured by an Almen gauge for different peening exposure times to plot a saturation curve as shown in Fig.1[5–8]. “Almen Intensity is defined as the first point of the curve that, if the exposure time is doubled, the arc height increases by 10%”.

The objective of the process monitoring and control is to regulate the energy and number of impacts of the shot stream that produce plastic deformation[9]. An effective Almen peening on a representative fixture before and after the actual part peening can make sure the Shot Peening process is controlled[10]. Almen intensity is highly correlated to depth of compressive stress layer[11].

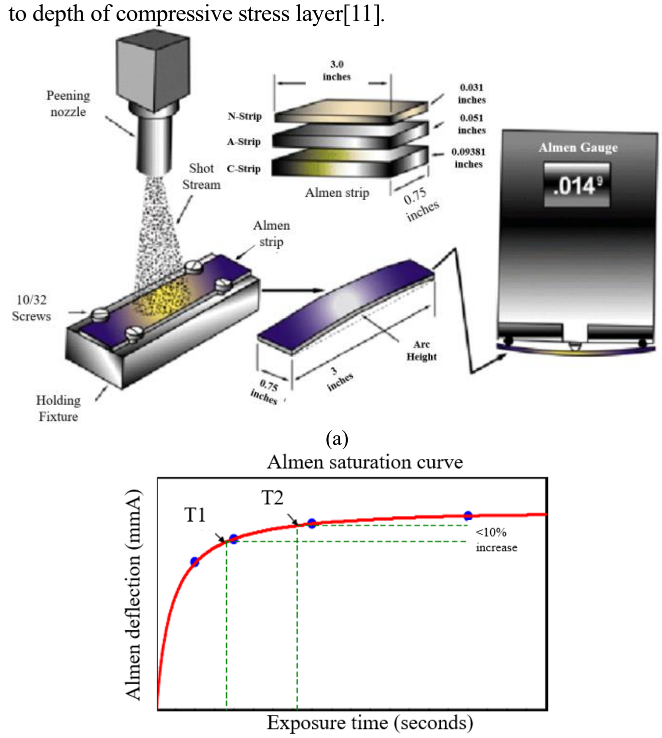

Fig. 1 (a) Almen strip application in Shot Peening (b) Almen saturation curve to calculate intensity[10]

However, Shot Peening often results in increased surface roughness (especially on smoother parts), thereby necessitating an additional step of Vibropolishing to restore/recover the surface roughness[12]. Rough surfaces can result in reduced aerodynamic efficiency[13]. Vibropeening is a relatively new area of research in surface conditioning of Aerospace parts. Vibropeening achieves residual stress and reduces surface roughness in a single process and hence is a very attractive technology to reduce process time of manufacturing complex parts like blisk airfoils as shown in Fig.2[14]. Following from Shot Peening, Almen strips are also reported in literature for process control for Vibropeening. Volker et al. used Almen to demonstrate the change in residual stress using an Almen system for Vibratory polishing[15]. Canals also reported Almen strips to be capable for process control for Vibropeening[16].

Fig. 2 Vibropeening of blisk drum setup with Almen blocks for process control (courtesy: Rolls-Royce)

Despite its benefits, the application of Vibropeening technology in industry is hindered by the time-consuming Almen peening process control method before and after Vibropeening. This results in lower manufacturing efficiency, representing a critical gap in current practices and research. Thus, this paper primarily addresses the gap by proposing a step change approach that incorporates Almen peening into the Vibropeening process itself, targeting a substantial reduction in process time and improved overall efficiency in the manufacturing process. Further to this different material strips are also tried as process control method. Coverage related topics are out of the scope of the paper but using different material strips could open the possibility for coverage related research for the future.

2. Methodology

A TFM 58/32 machine from Walther Trowal is used as per setup shown in Fig. 3[17]. At each motor RPM (1000 to 1500) and specific amplitude (4mm), experimental trials were completed and Almen deflections were documented. Standard stainless steel 4mm media from Walther Trowal is used as media. A saturation curve was obtained, using saturation curve solver from Electronics Inc, USA from various Almen heights at different timing which was used to calculate the Almen intensity. Once desired Almen intensity is obtained, trials have been repeated two more times and an average with variance is reported. Almen deflection is measured in millimeters of N type strip denoted by mmN.

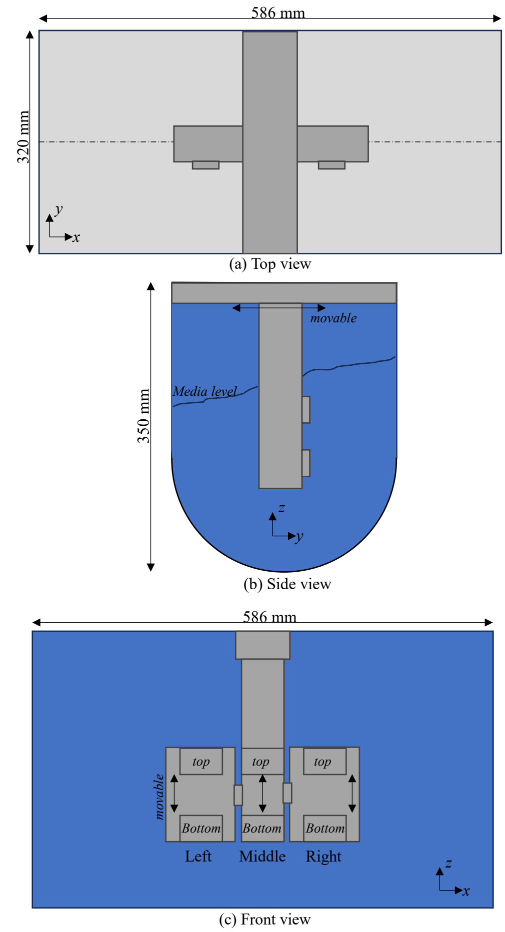

Fig. 3 Illustration of an integrated process control experimental setup

3. Results and discussions

3.1 Almen saturation curves

As seen in Fig.4 Vibropeening exhibits a lower energy transfer rate to an Almen strip when compared to Shot Peening. This results in a more extended duration for Vibropeening to achieve the same Almen deflection. Vibropeening requires approximately 80 minutes to reach the same Almen deflection that Shot Peening achieves in just one minute. Consequently, this underlines the necessity for an integrated process control mechanism in Vibropeening to optimize the process efficiency.

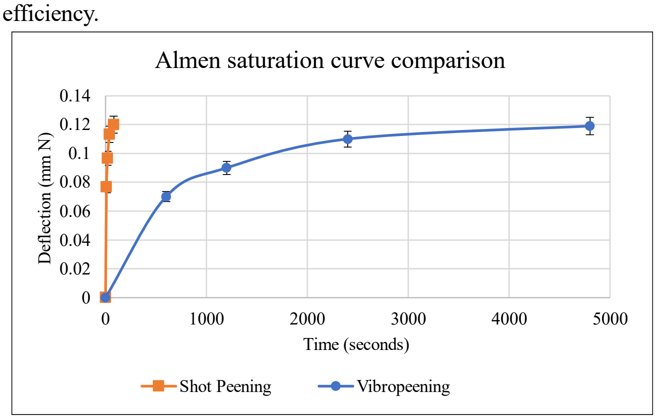

Fig. 4 Saturation curve comparison between Shot Peening and Vibropeening

3.2 Integrated process control

Fig. 5 illustrates the concept of an integrated Almen fixture, facilitating Almen control at various depths. The integrated control is positioned on both sides of the fixture, with the center location initially used for correlation development, then intended for actual coupons. This design ensures corresponding Almen deflection data is obtained from each experiment, providing increased confidence through reliable in-process data, as opposed to pre- and post-experiment data only.

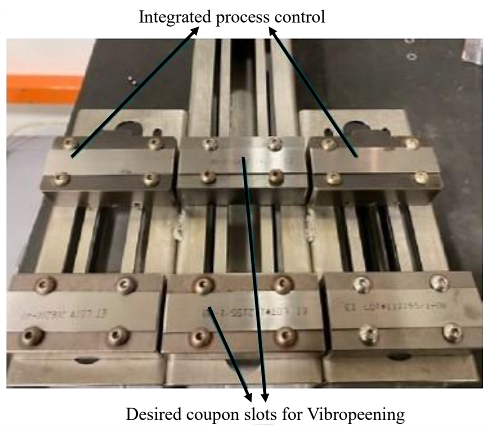

Fig. 5 Integrated Almen fixture for Almen based process control

Fig. 6 demonstrates a correlation between Almen intensity and motor RPM with a clear ascending trend observed from right position to left, with left location having highest intensity. This asymmetry implies slight irregularities in the experimental setup. These are likely due to machine vibrations and cross direction (*x* axis) media flow. Despite this, high data repeatability is observed which suggests potential for an effective, integrated Vibropeening control mechanism. Such a mechanism can reduce process time by eliminating the need for pre and post Almen peening. Also, as RPM increases, the left-to-right intensity differential amplifies indicating heightened asymmetric vibrations. However, the central area retains a more stable and intermediate intensity.

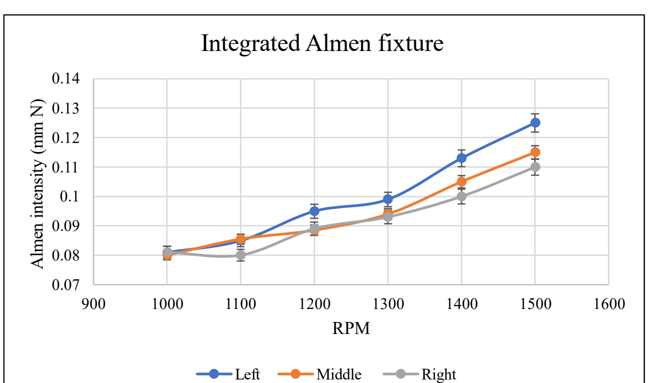

Fig. 6 Almen results from the integrated process control fixture for various RPM.

3.3 Titanium and Inconel strips

Specific aerospace grade Titanium 64 and Inconel 718 strips with proprietary heat treatment were cut off from engine components and made into flat strips with special attention. Fig. 7 indicates the magnitude of strip flatness measured prior to experiments. For the same Vibropeening process variables, responses across different materials were examined. As shown in Fig. 8, Almen, Titanium64, and Inconel 718 strips demonstrated progressive increases in deflection. At each given time point, Inconel718 exhibited the highest deflection, followed by Titanium 64, while Almen strips recorded the least deflection. Interestingly, while Almen and Titanium strips continuously demonstrated an increase, Inconel 718 deflection began to decline after 80 minutes showing potential stress relaxation. However, the magnitude of reduction is low and hence more work could be done to study larger process time in the future.

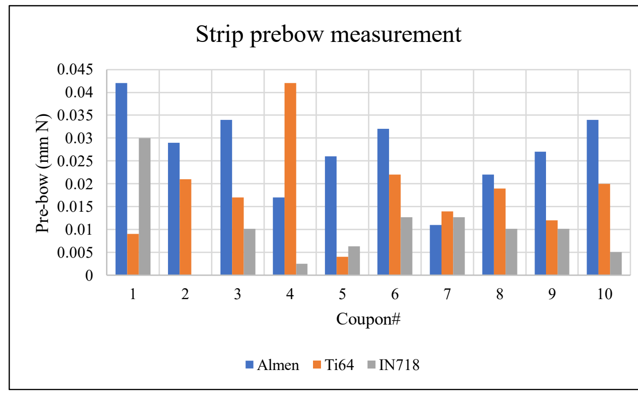

Fig. 7 Prebow magnitude of Almen, Ti64 and IN718 strips before Vibropeening

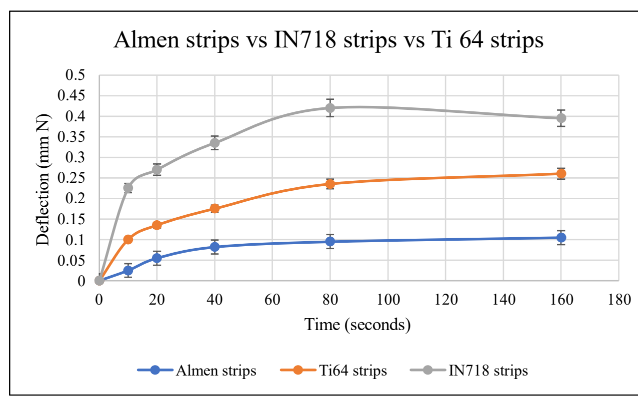

Fig. 8 Deflection data for Almen, IN718 and Ti 64 strips for a specific machine setting

These observations suggest that the choice of material can significantly influence the peening process and should be considered when planning and optimizing Vibropeening parameters.

4. Conclusions

The study presents a study towards a step change to Vibropeening process control by integrating Almen peening directly into the process. This has demonstrated potential in reducing process time up to 60% which is a step change to Vibropeening research. Moreover, investigations revealed the feasibility of employing actual component material strip for process control, paving the way for further research. As such, future studies should aim at improving this integrated process control mechanism by assessing the impact of asymmetrical vibrations, and extensively examining the effect of Vibropeening variables on intensity, coverage, and roughness on different materials.

ACKNOWLEDGEMENT

Authors thank National University of Singapore for providing resources for measurement and analysis. Authors thank Dr. Thomas Haubold and Dr. Goetz Feldmann from Rolls-Royce Deutschland for technical guidance.

REFERENCES

1. Kirk, D.: Shot peening. Aircr. Eng. Aerosp. Technol. 71, 349–361 (1999). https://doi.org/10.1108/00022669910270727.
2. SAE International: Quality management systems - Requirements for aviation, space, and defense organizations AS9100D. AS 9100D. (2009).
3. Almen, J.O.: No Title, (1942).
4. Dr. David Kirk: Quantification of shot peening intensity rating, https://www.shotpeener.com/library/pdf/2015007.pdf, (2015).
5. Champaigne, J.: Almen gage accuracy and repeatability. In: Proceedings of Fifth International Conference on Shot Peening. pp. 16–27. , Oxford, England (1993).
6. Champaigne, J.: Calibration apparatus and method for shot blast intensity measurements, (1998).
7. Champaigne, J.: Method of calibrating gages used for measuring intensity of shot blasting, (2001).
8. Champaigne, J.: Almen gage calibration. , Mishawaka, USA.
9. Dr. David Kirk: Back to basics: Peening intensity, https://www.shotpeener.com/library/pdf/2021017.pdf, (2021).
10. Curtiss-Wright Surface Technologies: Shot peening applications.
11. Champaigne, J.: Shot peening intensity measurement, https://www.shotpeener.com/library/pdf/1992082.pdf.
12. Wu, J., Liu, H., Wei, P., Lin, Q., Zhou, S.: Effect of shot peening coverage on residual stress and surface roughness of 18CrNiMo7-6 steel. Int. J. Mech. Sci. 183, (2020). https://doi.org/10.1016/j.ijmecsci.2020.105785.
13. Bai, T., Liu, J., Zhang, W., Zou, Z.: Effect of surface roughness on the aerodynamic performance of turbine blade cascade. Propuls. Power Res. 3, 82–89 (2014). https://doi.org/10.1016/j.jppr.2014.05.001.
14. Feldmann, G., Wong, C.C., Wei, W., Haubold, T.: Application of vibropeening on aero-engine component. In: Procedia CIRP. pp. 423–428 (2014). https://doi.org/10.1016/j.procir.2014.04.072.
15. Schulze, V., Gibmeier, J., Kacaras, A.: Qualification of the stream finishing process for surface modification. CIRP Ann. - Manuf. Technol. 66, 523–526 (2017). https://doi.org/10.1016/j.cirp.2017.04.079.
16. Canals, L.: Preliminary assessment of the Vibro-Peening process for improving the fatigue life of aerospace components, (2018).
17. Gopinath, A., Chan, W.L., Kumar, A.S.: Data driven optimization of vibropeening. In: Procedia CIRP (2020). https://doi.org/10.1016/j.procir.2020.02.036.