Universal Library of Innovative Research and Studies
Short Communication

ISSN: 3065-0003 | Volume 1, Issue 2

Open Access | PP: 18-20

DOI: https://doi.org/10.70315/uloap.ulirs.2024.0102003

Using Non-stationary Time-Domain Statistical Measures for Predictive Maintenance of Large Centrifugal Compressors in the Absence of Component Faults

Kihong Shin

Department of Smart Mobility Engineering, Andong National University, Andong, South Korea.

Abstract

Time-domain statistical measures such as standard deviation, skewness, and kurtosis are simple yet effective tools for assessing the health of rotating machinery based on measured vibration signals. These statistical quantities are, therefore, widely used in industry when designing condition-based maintenance (CBM) systems, especially for rotating machinery. Despite the growing adoption of CBM systems, determining the overhaul schedule can still be challenging, particularly when the rotating machinery in question does not exhibit any fault symptoms. As a result, the overhaul schedule is often determined using the traditional time-based maintenance (TBM) approach. In this short communication, we examine the time-varying characteristics of statistical quantities immediately before and after the overhaul of a large centrifugal compressor. It was found that the non-stationarity of the standard deviation increases in cases where an overhaul is due, while the variability of skewness and kurtosis does not change significantly in the absence of specific fault components.

Keywords: *Non-Stationary, Vibration Signal, Condition Monitoring, Centrifugal Compressor, Rotating Machinery.*

INTRODUCTION

Measured vibration signals play a crucial role in designing condition-based maintenance (CBM) systems for rotating machinery in industry. Recent advancements in various signal analysis methods, such as time-frequency analysis and neural networks [1-5], enable a transition from traditional time-based maintenance (TBM) to CBM systems. However, in practice, field engineers often prefer time-domain statistical measures, such as standard deviation, skewness, and kurtosis, when assessing machine degradation, primarily due to the ease of physical interpretation.

Another practical concern relates to overhaul scheduling. For instance, in the case of large rotating machinery, such as a 1500 HP centrifugal compressor, overhauls are often conducted according to a predetermined time schedule due to safety policies, even when there are no symptoms of component faults. In such situations, a managing director may be concerned about whether to postpone the overhaul. This can be a challenging decision, as the risk of a sudden major fault may increase if the machine continues to operate.

In this short communication, we demonstrate the potential of using time-varying time-domain statistical measures to assist in deciding the overhaul schedule by comparing the conditions of a large centrifugal compressor immediately before and after the overhaul.

TIME-DOMAIN STATISTICAL MEASURES UNDER CONSIDERATION

Given a measured vibration signal $x(t)$ over a duration of T seconds, three statistical quantities - standard deviation, skewness, and kurtosis - can be expressed as follows, where $\overline{x}$ represents the mean value of the signal.

$$\sigma_x = \sqrt{\frac{1}{T}\int_0^T \left(x(t)-\overline{x}\right)^2 dt} \tag{1}$$

$$s_x = \frac{1}{T}\int_0^T \left(x(t)-\overline{x}\right)^3 dt \Big/ \sigma_x^3 \tag{2}$$

$$\gamma_x = \frac{1}{T}\int_0^T \left(x(t)-\overline{x}\right)^4 dt \Big/ \sigma_x^4 - 3 \tag{3}$$

It should be noted that the above equations are not mathematically rigorous but are intended to be more accessible to non-expert engineers in conveying the fundamental concepts. Therefore, we adopt these expressions for convenience.

If we define a moving window of length T_w, the three statistical quantities can be estimated within this window as it slides across the entire measured duration T. This process yields time-varying estimates of standard deviation, skewness, and kurtosis, i.e., $\sigma_x(t)$, $s_x(t)$ and $\gamma_x(t)$ respectively. These quantities can also be treated as time signals. Consequently, the standard deviations of these time-varying quantities can be estimated, resulting in time-varying standard deviations for each of them, i.e., $STD\left(\sigma_x(t)\right)$, $STD\left(s_x(t)\right)$ and $STD\left(\gamma_x(t)\right)$.

APPLICATION EXAMPLE FOR A LARGE CENTRIFUGAL COMPRESSOR

In this section, the three previously discussed time-varying statistical measures are applied to vibration signals from two cases (Case A and Case B) involving 1500 HP centrifugal compressors. Both compressors are free of component faults; however, Case A has recently undergone a major overhaul, while Case B is approaching its scheduled overhaul.

Vibration signals were measured using an industrial accelerometer attached to one of the compressor's bearings. The sampling rate was set to 4 kHz, with a total signal duration of $T = 600$ seconds. To investigate the non-stationary behavior of the statistical measures, the moving window length was set to $T_w = 5$ seconds. The estimated time-varying standard deviation, skewness, and kurtosis are presented in Figs 1–3, respectively,with the standard deviation of each quantity also displayed in the corresponding figures.

From the figures, it is evident that the variability in the time-varying standard deviation for Case B has increased significantly compared to Case A, whereas the changes in the time-varying skewness and kurtosis are less pronounced, though still noticeable to some extent.

This characteristic can be further highlighted by presenting the standard deviation (*STD*) values of Case B relative to those of Case A, as shown in Fig. 4. It can be observed that $STD(\sigma(t))$ of Case B is 78% greater than that of Case A, while the changes in $STD(s(t))$ and $STD(\gamma(t))$ are far less pronounced.

This characteristic can be explained as follows. Since neither compressor has faulty components, the temporal changes in skewness and kurtosis are not great over the 600-second measurement period. However, in Case B, the amplitude of vibration signals fluctuates significantly, possibly due to changes in clearances and the accumulation of sludge between components during prolonged operation. These fluctuations are particularly noticeable when the oil characteristics and compressed air flow vary over the measurement period. As a result, the variability in the time-varying standard deviation of Case B is much greater than that of Case A.

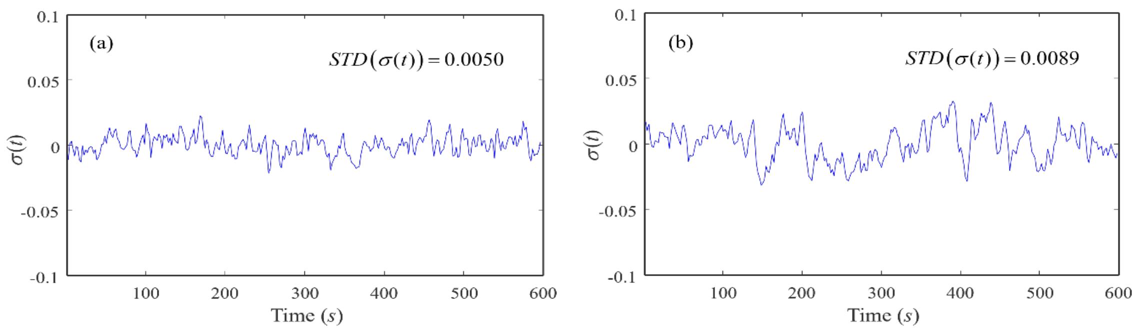

Fig. 1. Time-varying standard deviation (a) Case A, (b) Case B

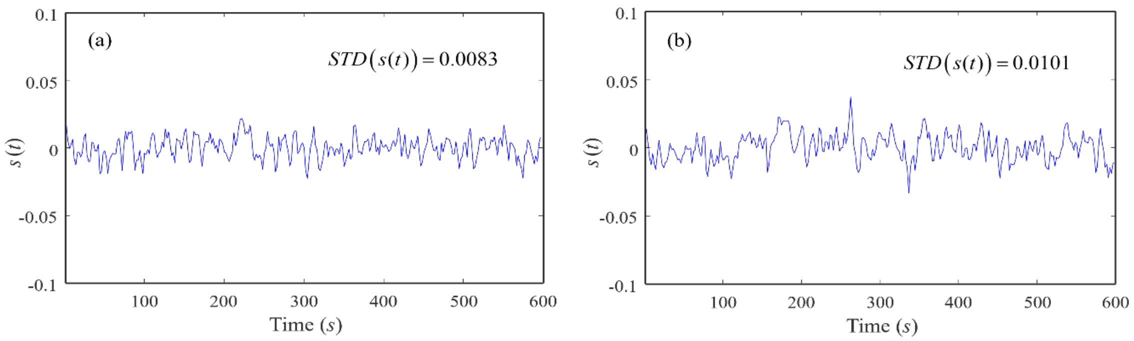

Fig. 2. Time-varying skewness (a) Case A, (b) Case B

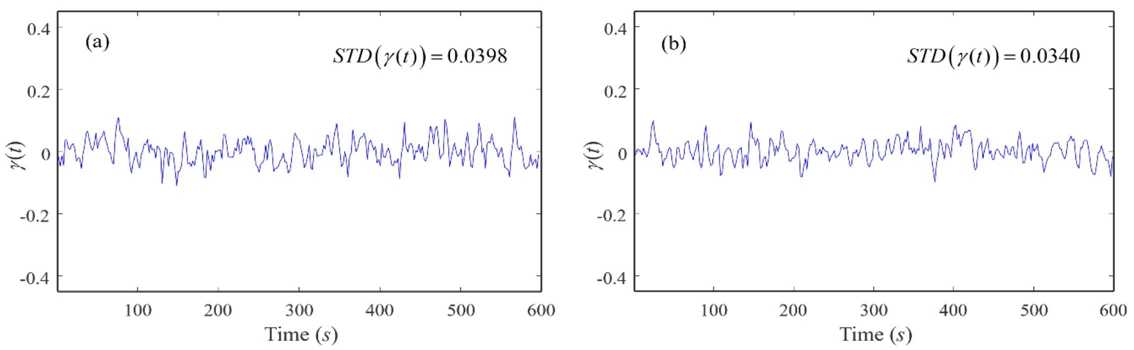

Fig. 3. Time-varying kurtosis (a) Case A, (b) Case B

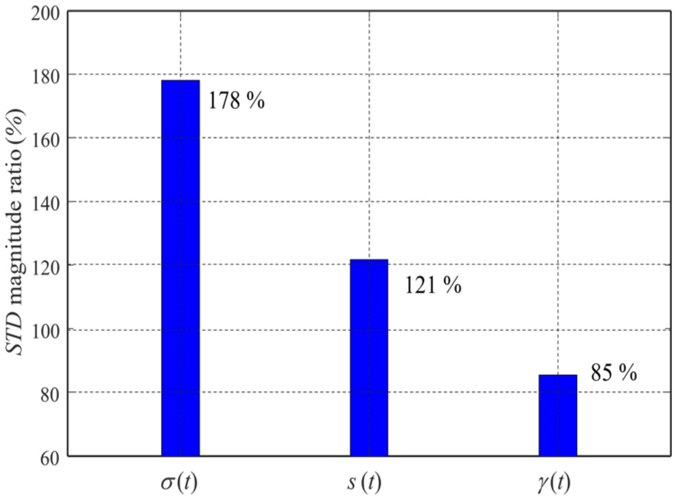

Fig. 4. *STD* values of Case B relative to Case A

CONCLUSIONS

In this research, the non-stationary characteristics of three time-domain statistical quantities from measured vibration signals were examined for two cases of rotating machinery. Case A represents a healthy machine immediately following a major overhaul, while Case B, although free of faulty components, exhibits significant degradation after prolonged operation. It was found that the non-stationarity of the time-varying standard deviation in Case B is much greater than in Case A, whereas the non-stationarities of the time-varying skewness and kurtosis are less pronounced.

Although this result does not definitively determine whether an overhaul is necessary, it suggests the potential of using time-varying statistical measures as one of the criteria for decision-making, once more data is accumulated for similar rotating machinery. Consequently, a simple yet effective criterion could be established within the CBM system to assess the overall degradation of a rotating machine.

Acknowledgements

This work was supported by a Research Grant of Andong National University.

REFERENCES

1. Jardine, A. K. S., Lin, D. &Banjevic, D. (2006)"A review on machinery diagnostics and prognostics implementing condition-based maintenance."*Mechanical Systems and Signal Processing*, 20(7), 1483~1510.
2. Jayaswal, P., Wadhwani, A. K. & Mulchandani, K. B. (2008)"Machine Fault Signature Analysis."*International Journal of Rotating Machinery*, Article ID 583982.
3. Peng, Y., Dong, M. & Zuo, M. J. (2010)"Current status of machine prognostics in condition-based maintenance: a review."*The International Journal of Advanced Manufacturing Technology*, 50(1-4), 297~313.
4. Ahmad, R. & Kamaruddin, S. (2012)"An overview of time-based and condition-based maintenance in industrial application."*Computers and Industrial Engineering*, 63(1), 135~149.
5. Lei, Y., He Z. & Zi, Y. (2008) "A New Approach to Intelligent Fault Diagnosis of Rotating Machinery." *Expert Systems with Applications*, 35(4), 1593-1600.

Citation: Kihong Shin, "Using Non-stationary Time-Domain Statistical Measures for Predictive Maintenance of Large Centrifugal Compressors in the Absence of Component Faults", Universal Library of Innovative Research and Studies, 2024; 1(2): 18-20. DOI: https://doi.org/10.70315/uloap.ulirs.2024.0102003.