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A VIBRATION BASED HEALTH MONITORING SYSTEM FOR AN AUTOMATIC PACKAGING MACHINE

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ABSTRACT

This study focuses on the design and development of a condition monitoring system for automatic packaging machines using accelerometer-based measurements. The purpose is to detect defects on the rotating components to enhance machine reliability and operational efficiency. A critical aspect of the study involved determining the optimal placement of accelerometers to maximize sensitivity to wheel defects. The investigation involved extensive testing under controlled conditions with several combinations of working conditions, various artificially induced defects and sensor locations. Data collected from the accelerometers were processed and analyzed using multiple statistical indicators, including bearing-related techniques and cyclostationary approaches. These analyses enabled the identification of key patterns and thresholds indicative of wheel defects. Preliminary results demonstrate the feasibility of detecting early-stage anomalies through accelerometer data and highlight the relevance of sensor positioning in capturing meaningful signals. The ongoing phase of the project focuses on refining the system's accuracy and robustness through additional testing and refining of the data processing procedure. Future developments aim to integrate the system into machine control units for automated defect detection and alerts.

Keywords: *Condition monitoring, NVH, industrial machinery, wheel fault.*

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1. INTRODUCTION

In modern industrial environments, ensuring the reliability and efficiency of machinery is critical for maintaining productivity and reducing operational costs. Predictive maintenance, driven by advanced diagnostic techniques, plays a key role in detecting potential failures before they lead to costly downtime. Among various approaches, as also shown by Jardine A. et al. in [1], vibration-based health monitoring has proven to be effective in assessing rotating and mechanical components.

The effectiveness of accelerometers in condition monitoring is well-documented in several books, including the work by Wu et al. [2] that discusses the application of vibration-based condition monitoring in hydraulic machinery. The authors emphasize the role of accelerometers in measuring the absolute vibration of machine components. In this context, it is crucial to underline that acceleration measurements are used to assess the health conditions of the most critical components of automatic machines, e.g. rolling element bearings [3,4] and gears [5,6]. In this context, it is mandatory to underline that acceleration measurements have become the reference approach, also thanks to a vast community of research groups that have continuously developed a variety of signal processing techniques with the purpose to maximize the extraction of information. Their use is currently so widespread that acceleration signals represent a reference source of information also in physics-based diagnostic and prognostic protocols, since they are used for tuning and validation of digital twins of faulty mechanical components [7–9].

As a matter of fact, signal processing techniques play a pivotal role in vibration-based condition monitoring. Feature extraction methods, such as time-frequency analysis, enhance the detection of faults in machinery components such as rolling bearings. A study by Zhang et al. [10] provides a review of these techniques, emphasizing their application in estimating degradation trends in low-speed slew bearings. This context is particularly proficient in the case of mechanical rotating machines, which have been largely proven to behave as cyclo-stationary systems [11]. Based on this observation, several techniques have been developed with the purpose to define diagnostic indicators from acceleration signals by taking advantage of the cyclo-stationary behavior of the system. In this framework, works such as the one reported in [12] propose approaches to detect the appearance of pitting phenomena in gears, while others such as the one in [13] are devoted to define specific techniques for rolling element bearings.

The described scenario clarifies as the specialized literature may currently provide a relevant variety of case studies, open-source datasets with experimental results and innovative research project outcomes regarding the diagnostics of rotating mechanical components, however their application on actual machines and production lines is certainly less common. Within this context, the present work has the purpose to provide insights regarding the use of well-established indicators, commonly adopted for the diagnostics of single mechanical components, in real machines adopted in an industrial environment. In particular, the study focuses the attention on automatic packaging machines, which are widely used in packaging industries and are commonly subject to wear and mechanical degradation over time. Implementing a vibration-based monitoring system can enhance their operational efficiency by identifying early signs of malfunction, enabling timely maintenance interventions.

The following section is devoted to the description of the mechanical system under study and the experimental tests carried out to characterize the vibration behavior of the machine. Section 3 reports the results of the analysis applied to the experimental results. Eventually, the last section is devoted to concluding remarks.

2. MECHANICAL SYSTEM DESCRIPTION

The study focuses on a automated packaging machine with rotative mechanical subsystems, which are supported by groups of wheels located in circle. Each group is constituted by three polymer wheels, two of them with axes of rotation disposed along the ring radial direction and the remaining one with axis of rotation disposed along the ring axial direction.

The experimental study has been carried out with the purpose to fully characterize the behavior of a complete wheel group through the entire available working conditions of the machine. In this context, three triaxial accelerometers have been placed on top of the bearings of the three wheels constituting a wheel group, while other three triaxial accelerometers have been placed on the ring frame. An optical tachometer is used to assess the wheel position and the instantaneous rotational speed of the machine. Tests have been conducted at four different workin conditions, with speed varied from 25% to 100% of the maximum available value, with each acquisition lasting for 60 s and the sampling frequency set to 25600 Hz. The test campaign involved the baseline condition, i.e. the machine in nominal condition, and eight different artificial faults.

3. RESULTS AND DISCUSSION

The present section reports the results of the different signal processing techniques applied on the data obtained from the experimental study described in section 2. Figure 1 reports Root Mean Square (RMS) and Kurtosis values referring to the data acquired from the two accelerometers placed on the radial axes wheels of a wheel group. Data are expressed as the difference with respect to the analogous value computed from the baseline condition. As it may be observed, both statistical indicators are capable to recognize the presence of defects located on the wheels of the same wheel group where the accelerometers are mounted, while their sensitivity to faults located on other wheel groups is almost negligible. Moreover, both RMS and Kurtosis appears to be highly sensitive to faults involving faceted wheels, while other modifications do not seems to produce significant modifications in the values of the indicators.

The analysis is then repeated for the data acquired with the accelerometers located on the ring frame, as reported in Fig. 2. As it may be observed, the presence or absence of the film does not alter the results significantly, with the x direction, which coincides with the radial one, being the most sensitive. Again, artificial faults involving the faceted wheel appear to have a more significant effect on both indicators, while other modifications, such as displacing the gear along the ring center, lead to RMS and Kurtosis values almost superimposed to the baseline condition.

In order to deepen the analysis and define a wider set of indicators with significant sensitivity to all the simu-

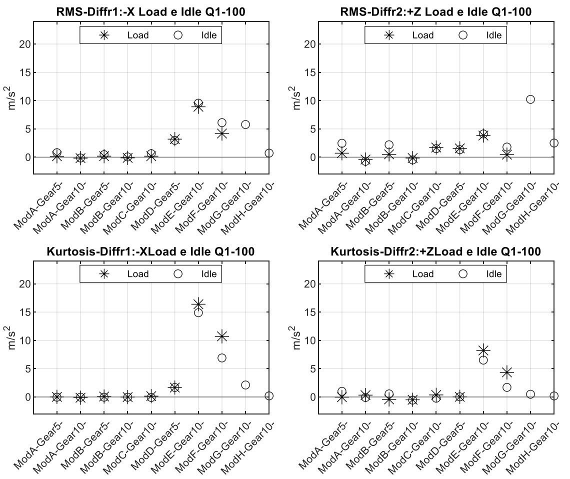

Figure 1. RMS and Kurtosis values for the two accelerometers placed on the radial axis wheels of a wheel group, expressed as difference with respect to the values computed from baseline conditions.

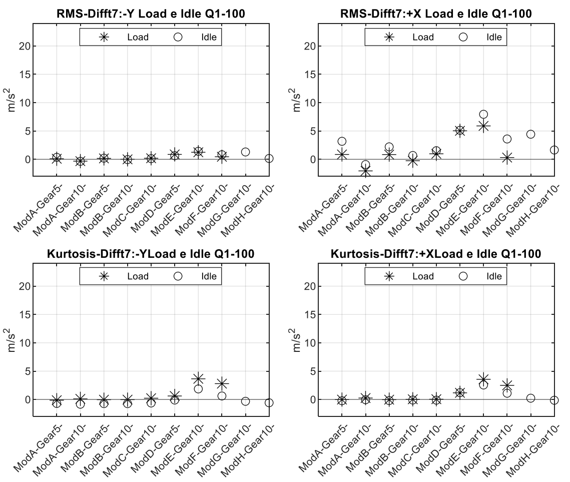

Figure 2. RMS and Kurtosis values for one of the accelerometers placed on the ring frame, expressed as difference with respect to the values computed from baseline conditions.

lated faults, the acquired data have been further processed by using five additional indicators: skewness, Teager-Kaiser Energetic Operator (TKEO), Power Spectral En-

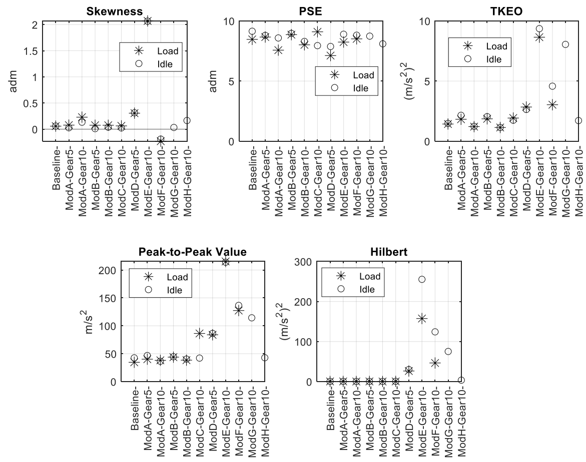

Figure 3. Computation of additional indicators on the data obtained from the same accelerometer adopted in Fig. 1.

tropy (PSE), Peak-to-Peak value and the Hillbert indicator. Figure 3 reports the results of this analysis applied to the same accelerometer observed in Fig. 1. The results show that most of the indicators demonstrate a relevant sensitivity to the proposed modifications, with the Hillbert indicator that certainly achieve the highest sensitivity while PSE seems almost not-influenced by the considered faults. Moreover, it is worth underlining that similar results have been obtained from the signals collected by all the involved accelerometers, both located on the wheel group and the ring frame.

4. CONCLUDING REMARKS

This study focused on the design and development of a condition monitoring system for automatic packaging machines using accelerometer-based measurements. The purpose was to detect defects on the wheels to enhance machine reliability and operational efficiency. The study is based on an extensive experimental analysis, involving six triaxial accelerometers, 16 different working conditions and 8 artificial faults, from wheel displacement to wheel faceting.

The acquired signals have been post-processed with different techniques: the first analysis is focused on statistical indicators, such as RMS and Kurtosis, showing that faults involving faceted wheels have significant effects on them. On the other hand, artificial faults involving wheel displacements are less observable. The analysis has been further deepened by including additional indicators such as skewness, Teager-Kaiser Energetic Operator (TKEO), Power Spectral Entropy (PSE), Peak-to-Peak value and the Hillbert indicator. The outcomes of this second round of post-processing demonstrated that faceted wheel faults produce significant effects on several indicators, on all the applied accelerometers. Conversely, wheel displacement faults probably do not alter the energy content of the phenomenon and therefore are less prone to be observed with these indicators. In addition, as a whole consideration, the analysis has demonstrated that the diagnostic protocol could be applied during both load and idle conditions. Further works will be focused on defining an artificial intelligence approach capable to take into account all the defined indicators in order to classify faults according to their nature.

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