

USEFULNESS OF VIBRATION ANALYSIS TECHNIQUES AND SENSORS TO IMPROVE THE MONITORING OF INDUSTRIAL EQUIPMENT

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ABSTRACT

The food industry is constantly seeking advanced technologies to improve the efficiency and reliability of machinery, which is critical to improving product quality and manufacturing efficiency. This paper explores the applications of integrating vibration analysis techniques and sensors to improve machine monitoring in the food industry.

Vibration analysis is a well-established technique for mechanical fault detection, providing valuable insight into the condition of rotating equipment. By incorporating advanced sensors that can capture a wide range of vibration signals the aim of this research is to improve the accuracy and sensitivity of device health monitoring.

The review reviews existing literature on vibration analysis, sensor technology, and applications in the food industry. It explores how traditional vibration analysis methods can be incorporated into advanced sensor technologies such as accelerometers and other sensors. The integration of these technologies will provide a comprehensive understanding of machine behavior, leading to faster abnormal detection and predictive maintenance.

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1. INTRODUCTION

Vibration analysis is the study of mechanical vibration in a system, a non-invasive method of monitoring mechanical health and performance during use in industrial equipment. If necessary, equipped with sensors, this approach enables real-time data collection, analysis and interpretation. Characterized by complex and diverse machinery, the food industry presents unique challenges. From conveyor belts to mixing machines to packaging machines, each component plays an important role in the overall production process. Timely detection of anomalies or deviations in operation is essential to prevent unexpected damage, reduce maintenance costs, and ensure the safety of final products Here in lies the importance of vibration

research methods together, as they provide a comprehensive understanding of mechanical behavior.

2. LITERATURE REVIEW

Vibration analysis is a widely used technique in various industries to detect and diagnose faults in machinery and equipment (Khadersab & Shivakumar, 2018). In food machines, as in other machines, vibration analysis involves analyzing the vibration that occurs during operation. Figure 1 shows an example of a vibration analysis tool used in an engine.

This inspection is essential to ensure safe and long-lasting operation of the equipment, as excessive

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vibration can cause mechanical problems, reduced productivity and potential safety hazards.



Figure 1. Equipment used in vibration analysis (Source: V-Tech Engineering www.vtechengineer.com/)

Peter Brown's "Basics of Vibration Measurement and Analysis" examines the basic principles of vibration measurement and analysis. He begins by reviewing the transformational impact of microprocessors on data collection and analysis processes (Brown, 2010). Despite technological advances, the paper emphasizes the importance of ongoing specialized knowledge and experience in vibration analysis.

Basic concepts such as simple mechanical models with mass, stiffness, and damping are introduced (Brown, 2010). The discussion extends to vibration measurements and fast Fourier transform (FFT) analysis along with composite vibration standards (Brown, 2010).

The Fast Fourier Transform (FFT) is an important tool in vibration analysis, providing insight into the frequency characteristics of mechanical systems (Brown, 2010) and (Lin et al., 2016). Its applications range from fault diagnosis to condition monitoring and modal analysis, making it an important technique for engineers working in vibration and structural dynamics (Brown, 2010) and (Lin et al., 2016). Figure 2 shows vibration analysis using the Fourier transform (FFT) fast spectrum analysis is used.

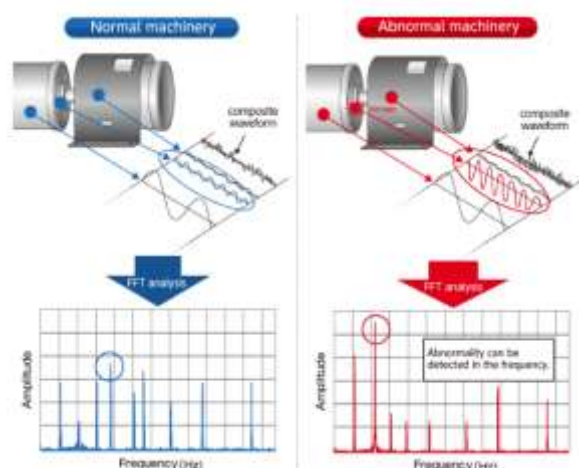


Figure 2. Vibration analysis using Fast Fourier transform (FFT) spectrum analysis (Source: Christiansen & Greenberg, 2008)

Overall, the text provides a comprehensive overview of vibration analysis, including theoretical foundations, measurement techniques, and resonance control techniques and ((Lin et al., 2016).). This emphasizes the importance of traditional knowledge and modern technology play a role in emphasizing the field of vibration analysis to enable effective fault diagnosis and corrective action planning.

The most common approach to vibration analysis is to use mathematical models and tools to describe and understand vibration. The behavior of vibrations in machines is usually described by equations for mechanical vibration energies.

The most important fundamental equations used in vibration analysis are natural frequency and damping ratio (Blevins, 2015).

The natural frequency (ω_n) of a vibrating system is related to the size and rigidity of the system (Blevins, 2015). It is expressed by the Eq.1:

$$\omega_n = \sqrt{\frac{k}{m}} \tag{1}$$

Where: ω_n is the natural frequency, k is the stiffness, and m is the mass.

In vibration analysis, the damping ratio is an important parameter, which describes the amount of damping or energy dissipation in a vibrating system. The damping ratio is determined by the equation shown as Eq.2.

$$\zeta = \frac{c}{2\sqrt{mk}} \tag{2}$$

where: ζ is the damping ratio, c is the damping coefficient, m is the mass, and k is the stiffness.

These equations provide a basis for analyzing the dynamics underlying high-collision systems in the food industry. By applying these equations to specific machines or equipment, engineers can gain insight into potential sources of vibration and implement appropriate mitigation strategies to ensure proper operation and they are reliable.

2.1. Advantages and disadvantages of vibration analysis

Some of the key benefits of using vibration analysis in food machines and equipment are as follows: According to Mohd Ghazali and Rahiman (2021) vibration analysis can detect mechanical faults at their earliest stages, thus enabling timely intervention and maintenance. This helps to prevent unexpected breakdowns and production losses. By regularly monitoring the vibrations of food machines and equipment, potential problems can be identified and addressed before they become major issues.

Vibrations in food machines and equipment can affect the quality of the final product, according to Taniwaki and Sakurai (2010). Manufacturers can use vibration analysis to identify and rectify any issues that may affect product quality. This ensures consistent production of high-quality food products, which leads to customer satisfaction and brand reputation.

However, there are several disadvantages when applying this technique to food machines and equipment in the food processing industry.

According to Mohd Ghazali and Rahiman (2021), the environments where food processing takes place are often filled with noise. This noise is a result of machines producing sounds and other background noises. The presence of this ambient noise can interfere with the accuracy of vibration analysis measurements, which in turn makes it harder to identify and fix faults in food machines and equipment. Additionally, the existence of other sources of vibration, like nearby equipment or production processes, can make the analysis even more complex and restrict its effectiveness.

According to Ghazali and Rahiman (2022), there might be some food machines and equipment that are not easily accessible for vibration analysis. These could include sealed processing systems or equipment located in hard-to-reach areas. As a result, gathering data for analysis can prove to be quite challenging, and in some cases, even impossible.

In food processing, equipment hygiene is of utmost importance. Vibrational analysis typically requires direct contact between the sensor and the machine, which introduces the risk of product contamination (Alsalaet, 2012). Using sensors that are not properly cleaned or sanitized can compromise food safety and violate industry regulations and standards.

3. SENSOR APPLICATIONS

The purpose of vibration sensors is to identify oscillations and vibrations in machinery (Goyal & Pabla 2016; Al-Badour et al., 2011). By analyzing the patterns of these vibrations, professionals in maintenance can detect mechanical imbalances, misalignments, and defects in bearings. This allows them to intervene promptly and prevent the failure of equipment (Immovilli et al., 2010).

In the realm of machine monitoring, we come across two distinct forms of vibration, as illustrated in Figure 3.

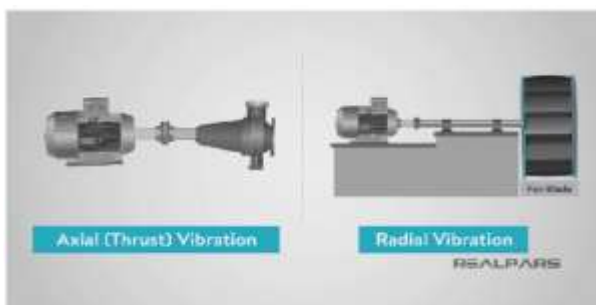


Figure 3. Two distinct types of vibration (Source: RealPars <https://www.realpars.com/>).

Axial (Thrust) Vibration: Axial vibration refers to vibration or oscillation along the axis of rotation (Sahebkar et al., 2011). For machine monitoring, axial

vibration is important for forces acting parallel to the axis, commonly referred to as thrust forces (Harun et al., 2017). Monitoring axial vibration helps identify cases of axial anomalies, imbalances, or trouble types of components affecting the axial direction of the machine.

Radial vibration: However, in radial vibration there is a motion perpendicular to the axis of rotation (Rahnejat & Gohar, 1985). It helps in analyzing the forces acting perpendicular to the axis, detecting possible problems such as imbalances, imbalances, faults in bearings and other rotational components (Kiral & Karagülle, 2006). Monitoring radial vibration provides insight into the health and performance of devices, helping to detect early faults and preventive maintenance.

Vibration detectors are used to accurately analyze such vibrations. Accelerometers, strain gauges, and eddy currents are specially used as vibration sensors.

An accelerometer is a special sensor designed to degree the acceleration of an object in three-dimensional area. In vibration evaluation, an accelerometer is a vital device for detecting and quantifying vibrations in machines and buildings.

The IEPE (*Integrated Electronics Piezoelectric*) accelerometer is a type of accelerometer that incorporates embedded electronics to facilitate velocity and vibration measurements. These accelerometers are widely used in industrial engineering due to their flexibility, robustness and include signal conditioning device and piezoelectric materials together therefore. Figure 4 shows an example of an accelerometer sensor for vibration analysis.

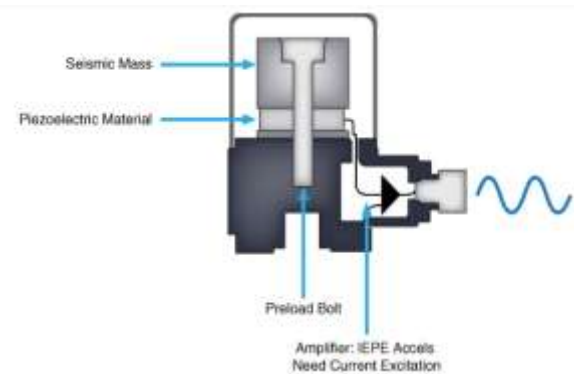


Figure 4. IEPE Accelerometers: Generating Voltage Signals Proportional to Vibration Force on Piezoelectric Crystals. (Source: Ni.com)

These devices convert mechanical motion, including vibrations or accelerations, into electric indicators that can be analyzed and interpreted.

In the examine conducted by Ng and Khor (2023), the focus lies on using accelerometer sensors for the dimension of vibrations within a gadget, aiming to enhance performance, make certain product fine, bolster safety measures, and extend the lifespan of the device. The vibrational indicators are subjected to evaluation thru Fast Fourier Transform (FFT), supplying valuable insights into the vibration tiers. Notably, as can be

visible in Figure 5, the natural frequency of the vibrating supply become decided to be 17 Hz, followed by a minimum overall harmonic distortion (THD) of 0.000177%. The analytical procedures had been accomplished utilising NI LabVIEW software (Odema et al., 2019).

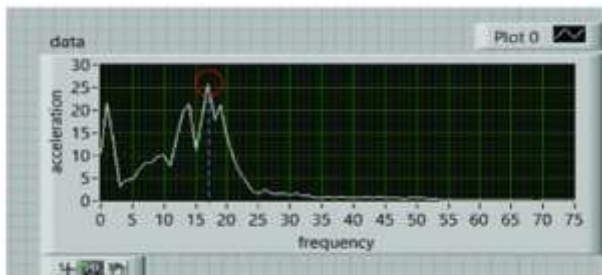


Figure 5. Vibration spectrum analysis involves the creation of a plot depicting frequency (measured in Hz) against acceleration (expressed in m/s^2) using NI LabVIEW software. software (Odema et al., 2019).

Scientists utilize strain gauge to assess vibrations within a system, aiming to enhance performance, ensure product quality, prioritize safety, and extend the lifespan of the system.

A strain gauge includes a strain-sensitive material and can be the active element in a transducer or attached directly to the device under test Figure 6 shows an example of such a sensor.



Figure 6. Vibrating wire strain gauge sensors. (Source: Spectotechnology.com)

The bonded metallic strain gauge shown in Figure 7 is a popular choice for vibration analysis because of its versatility. It is composed of metallic wire/foil in a grid pattern bonded to a carrier (Qu et al., 2013). A bonded strain gauge is commonly incorporated within a larger circuit configuration to precisely measure minute changes in resistance, as illustrated in Figure 7.

The research paper titled "Motion Induced Eddy Current Sensor for Non-Intrusive Vibration Measurement" introduces an innovative sensor designed for acquiring vibration signals from the surface of metal objects without intrusion (Yang et al., 2017).

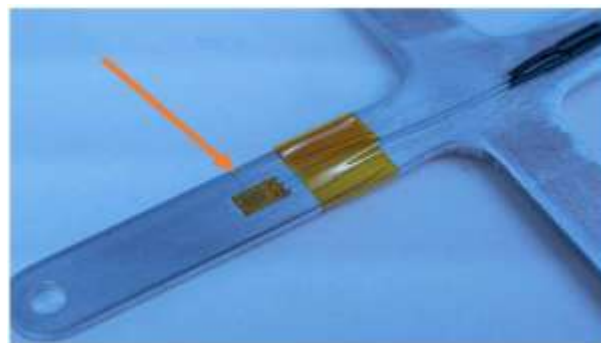


Figure 7. A bonded strain gauge. (Source: Cherie Stoll 2022)

The sensor configuration comprises a cylindrical permanent magnet and a pancake coil positioned coaxially beneath it. Its principle is shown in Figure 8.

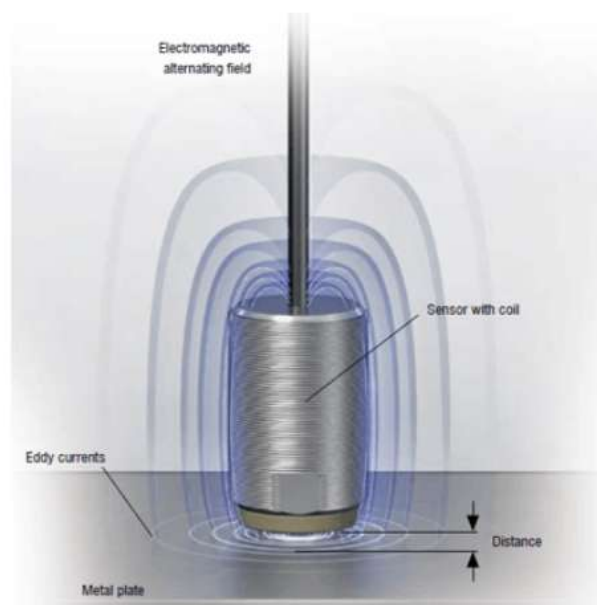


Figure 8. The operational principle of eddy current. (Source: Bestech.com)

The functioning of an eddy current sensor relies on the inductive eddy-current principle (Harms & Kern 2021). It gauges distance by harnessing energy from an oscillating circuit, essential for generating eddy currents in electrically conductive materials.

When an alternating current is applied to the sensing coil, it gives rise to a magnetic field surrounding the coil. If an electrically conductive material is introduced into this field, it induces an eddy current field in accordance with Faraday's induction law. As the object in question moves, it triggers a modification in the impedance of the coil, directly proportional to the alteration in distance between the sensor and the target. In a publication featured in the Sensors journal, researchers detailed the creation and examination of a compact eddy current displacement sensor. This sensor exhibits a sensitivity of around $3 \mu m$, operates within a

temperature range of 25–55°C, and boasts a remarkable linearity of $\pm 1.025\%$ (Wang et al., 2022).

Figure 9 displays a straightforward schematic depiction of the eddy current sensing process. When an alternating current (I_1) passes through the conducting coil, it gives rise to a dynamic magnetic field, denoted as H_1 . Proximity to the metal conductor leads to the induction of a counteractive magnetic field, H_2 , following Lenz's law. The alteration in magnetic flux within this opposing coil induces a time-varying current, I_2 .

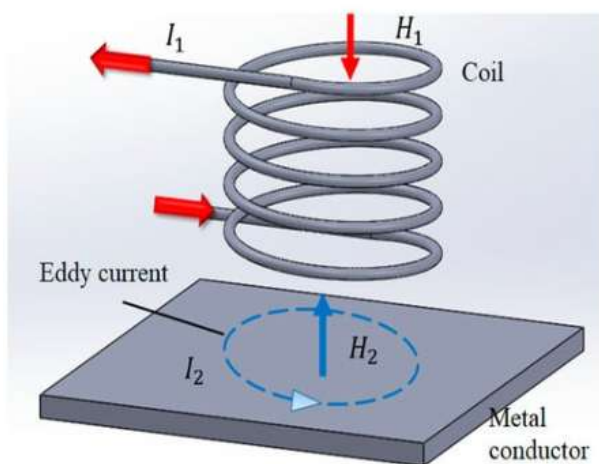


Figure 9. Diagram depicting the fundamental principles of eddy current sensing. (Source: Wang et al., 2022).

The magnitude of I_2 is intricately influenced by factors including the strength of the magnetic field, the surface area of the coil, the rate of flux change, and the resistivity of the conductor.

4. DISCUSSION

The usage of accelerometers and stress gauges for vibration evaluation has been considerably explored in the literature. Accelerometers, along with IEPE accelerometers, offer actual-time measurements with high sensitivity and are adept at shooting dynamic vibrations. Ng and Khor (2023) study exemplifies the efficacy of accelerometers, employing FFT analysis to determine the natural frequency of a vibrating source. In

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contrast, strain gauges provide an alternative means of measuring vibrations, offering precise assessments of minute changes in resistance due to mechanical strain. The choice between these sensor types depends on the specific requirements of the application, with accelerometers excelling in dynamic environments and strain gauges proving valuable for detailed strain analysis.

The creation of eddy modern-day sensors, in particular in non-intrusive vibration measurements, presents a singular approach to the sphere. The study Xue et al. (2019) demonstrates the capability of this generation. The ability to acquire vibration signals from the surface of metal objects without intrusion addresses a crucial need in industries where preserving the integrity of the target surface is paramount. The compact eddy current displacement sensor, detailed in the *Sensors journal*, showcases advancements in sensitivity, operating temperature range, and linearity. By evaluating this approach with conventional methods, it turns into obvious that eddy current sensors offer a promising solution for packages requiring non-intrusive and notably sensitive vibration measurements.

5. CONCLUSION

In conclusion, the discussion highlights various applications of sensors in the food industry, focusing on vibration sensors for machine health monitoring. The text also provides insights into specific sensor types and their role in vibration detection and analysis, plus the importance of using Fast Fourier Transform (FFT) and NI LabVIEW software to contribute to overall machine efficiency and service life in industrial settings. However, issues such as ambient noise and equipment unavailability are recognized as potential drawbacks in the application of vibration analysis techniques to food machinery. To improve vibration analysis in food machinery, it may be useful to consider combining bio-inspired noise cancellation algorithms that mimic the adaptive capacity of the human ear with innovative materials such as acoustically tuned composites to reduce vibrations and minimize noise.

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