Vibration Monitoring for Hay Rotary Tedder

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Vibration monitoring provides a good-quality source of information about the health condition of machines, and it is often based on the use of accelerometers. Mechanical vibration transducers are used to receive a mechanical signal from a vibrating object and convert it into an electrical signal. This signal is properly processed. A measurement system includes a vibration transducer, for instance, a piezoelectric transducer, and an appropriate amplifier. Mechanical vibration measurement systems measure the vibrations produced by machines as well as the vibrations of buildings or bridges.

Keywords: accelerometer ; vibration monitoring ; machine health monitoring

1. Introduction

Manufacturers of agriculture and farming equipment are interested in machine monitoring systems, which check if a machine is productive, or in condition monitoring systems, which have the ability to assess the health of a machine over a period of time. This helps in minimizing wear and tear in parts such as bearings and gearboxes, reducing unplanned machine downtime and enabling automation based on real-time machine condition data [1]. A rotary tedder that includes multiple rotor gearboxes is an example of a machine incorporating a condition monitoring system.

Accelerometric sensors for measuring vibration parameters are divided into the piezoelectric [2] and MEMS (micro electro-mechanical systems) categories. The latter can be piezoresistive [3] or differential capacitive [4]. The choice of sensor depends on the application. Piezoelectric sensors are not suitable for static measurements, i.e., gravity g and overload tests, such as multiple-g accelerations caused by the thrust of a spacecraft taking off, or airplane maneuvers. Unlike capacitive and piezoresistive sensors, they are more suitable for seismic measurements where frequencies are less than 1 Hz (earthquakes, vibrations of buildings, bridges). The operating frequency range of these sensors is wide, and their use also includes measuring vibrations of electric machines, detecting faults in gears, and monitoring the operation of wind turbines. Piezoelectric sensors must be characterized by high sensitivity and a low level of transverse vibrations, and the operating frequency range should be lower than the resonance frequency [5].

2. High-Performance and Low-Cost Sensing

In the publication [6], it compares the parameters of the accelerometric sensors commonly found. These sensors range from the most expensive on the market (380–2070 €) to the cheapest (5.4–12 €). They often have similar ranges of ±2 g (3713B112G—triaxial MEMS DC response accelerometer, PCB Piezotronics) or ±3.6 g (ADXL335—triaxial low-power accelerometer, Analog Devices) and similar low operating frequencies of 0–250 Hz (3713B112G), 0.5–550 Hz (ADXL335). In contrast, cheaper differential capacitive sensors, such as ADXL335, usually have a higher spectral noise density of 300 µg/√Hz compared to the more expensive 3713B112G (22.9 µg/√Hz). Piezoelectric single-axis sensors KS48C (0.6 µg/√Hz) or KB12VD (0.06 µg/√Hz) are characterized by the lowest values of spectral noise density.

Other important parameters are the resolution (sensitivity) of the acceleration measurement, and the signal-to-noise ratio. The publication [7] measured the vibrations of wind turbines with a wireless system based on ADXL355 sensors (sensitivity 3.9 µg/LSB, noise spectral density 22.5 µg/√Hz) and compared the measurement results with the 3713B112G sensors in the registered stationary system (0.25 mg rms, 22.9 µg/√Hz). They observed that the sensor resolution of 1 mg may not be sufficient for the analysis of vibrations of wind turbine poles, and that it prevents analysis of higher frequencies with a good signal-to-noise ratio. The noise of the ADXL355 sensor depends on the sampling frequency. The measured mean standard deviation of the noise is 0.44 mg (1000 Hz), 0.19 mg (100 Hz) and 0.056 mg (15 Hz) [8].

A low-cost data-acquisition system based on Raspberry-Pi with a high sampling frequency (50 kHz) and a recording capacity of up to three channels, is proposed in publication [9]. It is designed for monitoring bearings and determining bearing faults where signals are processed by frequency methods (FFT, STFT, wavelets) [10]. Generally, the cost of equipment for registering vibrations is very high. It is 4000 EUR for the basic version of the AVM4000 (AMC VIBRO, Kraków, Poland) which is a multichannel device (4–24 channels). However, there are cheaper vibration monitoring devices available (one or two channels). The challenge for low-cost solutions is to use cheaper devices with an internal ADC of 10-bit or 12-bit, such as the ATmega 1280, PIC18F4550, USB NI-6008 with a sampling rate of 10–100 kHz and with an internal memory up to 512 bytes for buffering data [11]. If more functionalities of the DAQ unit are needed—for example, for wireless IoT condition monitoring—the use of an ESP32-WROVER SoC microcontroller unit with an integrated 2.4 GHz radio module, which enables Wi-Fi and Bluetooth connectivity, appears to be a good solution [12].

3. Vibration Calibration of Accelerometers

The instrument used to measure vibrations is a mechanical vibration calibrator. It is a standard source of vibrations consisting of a portable vibration exciter used to check the metrological properties of the measuring system. With this device, one can check whether the system correctly measures vibration parameters, such as amplitude (displacement), velocity or acceleration.

The standard vibration transducer used to transmit vibrations must have appropriate metrological properties and be very stable. The tested sensor and its wiring must be properly mounted to avoid erroneous results [13]. When calibrating, the ISO 16063-21 standard is used, in which the comparative method is described [14]. It consists in subjecting two transducers (the model transducer and the transducer of unknown sensitivity) to vibrations of the same values. The output signals from both transducers are measured. Knowing the sensitivity of the reference sensor, one can determine the parameters of the calibrated sensor.

The sensitivity of a transducer is defined as the ratio of the output signal, e.g., the voltage, to the input signal, e.g., the vibration acceleration to which the transducer is subjected. It provides a moderate accuracy (uncertainty) of measurement. The most accurate method is the absolute method, i.e., with reference to the basic SI units, such as meter, second, kilogram and electric current. This is considered the national standard. According to the ISO 16063-11 Standard, the absolute method is used to calibrate working standards or laboratory standards [15]. The sensitivity of such vibration transducers is determined over the entire operating frequency range (from 1 Hz to 10 kHz). A calibrated vibration transducer (sensor) is subjected to controlled sinusoidal vibrations, the values of which (amplitude and phase) are measured by the interferometric method. The laser beam is directed to the mounting surface and the voltage from the calibrated accelerometer is measured at the same time. Laser interferometers are very precise devices for measuring distance (displacement) with an accuracy of ± 100 nm in the range of 250 mm [4]. The measurement uncertainty is influenced by the instability of the frequency of the light source, as well as changes in environmental parameters, e.g., the temperature in the vicinity of the laser beam source.

4. Static and Dynamic Performance

Optical methods with the use of a QPD (four-quadrant photodetector) are also used to measure vibrations of low frequencies and low amplitudes. The optical accelerometer is characterized by high sensitivity (1.74 V/(ms^{-2}), a linear conversion function in the range of 0.4 to 12 Hz, the range of measured accelerations from 0.003 to 7.29 m/s^2 and a noise spectral density of 160 µms^{-2}/√Hz [16].

The calibration of accelerometric sensors is divided into static and dynamic categories. The method of static and dynamic calibration of low-cost 3D accelerometric sensors in the frequency range of 0–10 Hz is presented in the publication [17]. The transducer can be calibrated with a single frequency signal or a frequency sweep, or a random noise function can be used. The publication [18] discusses the methods of dynamic calibration for various types of amplifiers with bridge, charge and voltage output. The method of calibration of charge amplifiers using multisinusoidal input is presented here [19]. Seismic IEPE (Integrated Electronics Piezo-Electric) sensors with ultra-low noise operating in the frequency range from 0.003 Hz to 200 Hz cooperate with these types of amplifiers. The method of measuring sensor noise is presented in [20]. The publication [21] compares the parameters of the Meggitt model 731A, the PCB model 393B31, the Dytran model 3191A1 and the Colibrys model SF3000—all sensors used in earthquake prediction systems. The publication [22] presents three methods of calibration for piezoelectric sensors and MEMS, and [23] outlines a method for estimating the measurement uncertainty of accelerometer sensitivity.

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