

Online vibration monitoring system for rotating machinery based on 3-axis MEMS accelerometer

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Abstract. This article discusses the design of a rotating machine vibration monitoring system in real time by utilizing a 3-axis accelerometer MEMS sensor. The system consists of 2 main parts, namely, vibration data acquisition system and data analyse system with the principle of wireless data communication. The results of vibration measurements from each three MEMS accelerometer sensors will be forwarded by the Arduino Nano microcontroller to the data collection device, the Arduino Uno microcontroller. Also, the machine rotating speed data acquired by the TCRT5000 speed sensor will be forwarded by the Arduino Pro Mini microcontroller to the same collection device. Data that has been recorded by the collection device is then transmitted to the computer through wireless communication using the Node-MCU device. The Lab View software is used as a machine vibration data display that has previously been processed by the computer in accordance with parameters desired by the user. Testing stability of data transmission with a certain length of time and communication distance is carried out to ensure the measurement results are in accordance with the real-time vibration conditions. Test results show an average delay time of below 200ms for the farthest distance from the wireless device signal range.

1. Introduction

The development of data acquisition techniques, sensors and vibration analysis in the manufacturing industry today is demanded to be more reliable. The condition of the machine operating causes vibration will always be present in almost all types of rotating machines. The rotating machinery includes a gearbox, fan, shaft, motor, compressor, pump, mixer, dryer etc. Vibrations that occur on a rotating machine are generally caused by mechanical errors, e.g. mechanically loose, unbalance, wear and misalignment. Through vibration analysis techniques, the condition of the machine can be evaluated, so that precautions can be taken before the machine is fatally damaged. Take for example an industrial electric-motor, factors such as the level of viscosity of a lubricant, consideration of electric current, motor ventilation, alignment and motor load are various possibilities that can cause motor failure. These factors produce vibrations that tend to rise in electric motors or rise in motor temperatures to critical levels [1].

Vibration analysis is widely used in predictive maintenance in industries that use rotating machines. This method allows maintenance technicians to detect problems in the machine early. Appropriate vibration analysis can be used to identify damage to rotating machine components. Some component damage can be in the form of rotors or shafts unbalanced, bearing failures, shaft misalignment, shaft bending, gear wear, mechanical looseness, and so on. Vibration Analysis can provide relevant information about abnormal machine working conditions. Abnormal working conditions can cause failures that cause the factory to stop. So that maintenance and repair actions can be taken before failure occurs. By using vibration analysis techniques, one can find out the root causes of failure and ways to avoid successive failures.



Vibration analysis techniques can also be used to determine the decline in the function of machining components after a long period of use. Vibration analysis is only possible if the data used is sufficiently reliable and accurate, so the device used to collect data not only functions properly but must also be in accordance with the current machine conditions. There are three types of devices that can be used to measure and monitor vibrations, namely, displacement, velocity, and accelerometer. Each measuring device has certain usage limits and specifications depending on the conditions of measurement to be performed. An accelerometer is the best device for determining the force of a vibration source. In addition, the accelerometer has been widely used because of the development of low-cost Micro-Electro-Mechanical-System (MEMS) technology.

The main objective of this research is to design a real-time monitoring system of the vibration condition of a rotating machine using an accelerometer MEMS technology sensor with wireless communication. In the enforced system, ADXL345 3-Axis digital MEMS measuring device sensing element has been used as vibration sensing element. it's a little, thin, ultralow power, 3-axis measuring device with high resolution (13-bit) mensuration at up to ± 16 g. Digital output information is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I2C digital interface. Small, complete, and breadboard-friendly board supported the ATmega328P, Arduino Nano is used. Wireless transmission of information has been done by exploitation Node-MCU, ESP8266 Wi-Fi So-C from Espressif systems, and hardware that relies on the ESP-12 module. Interface is employed to interface sensing element information to LabVIEW computer code. Graphical interface, alarm indication and data-logging are going to be done exploitation LabVIEW computer code on the pc. Three continuous graphs shows vibration in unit of 'mm/s²'. An important aspect of this article is the results of the analysis of vibration data on the monitored system to display undesirable conditions that might occur and alert this to the maintenance team at work.

From the literature review it is known that the malfunction of rotating machine components can be detected through measurements of vibration levels [2]. This can be done through the use of sensor devices that record vibration data to be forwarded to the appropriate software. Several articles explain that the use of devices with capacitive type MEMS accelerometer as a vibration measuring device can be utilized [3–7]. The use of Arduino microcontroller boards in the development of low-cost machine vibration monitoring systems has also been studied in Papers [6–9]. In the development of cable-based vibration monitoring systems as data transmission media also presented in articles [4, 5]. However, cable-based technology is very far behind compared to the use of wireless communication technology in several aspects. The main advantage of utilizing wireless technology over transmission with cable is being able to reduce installation costs and obstacles by avoiding long cables from sensors to analysis devices. In addition, the use of wireless technology can improve aspects of mobility and easy reconfiguration. Several studies have developed a cordless machine vibration monitoring system using the Zig-Bee communication protocol [5, 10]. In terms of communication coverage and power consumption, wireless personal area network technology is superior to using the Zig-Bee protocol compared to the blue-tooth protocol [11]. Although Zig-Bee requires less power compared to Wi-Fi communication, device availability and ease of installation are superior to using Wi-Fi communication.

2. Experimental design

The experimental design shows on Figure 1. It displays the design of the overall machine vibration condition monitoring system. The system consists of two major parts, namely, the acquisition of vibration measurement results from the accelerometer MEMS sensor and the measurement data display section which is designed in accordance with initial planning to facilitate the user in monitoring the condition of the machine.

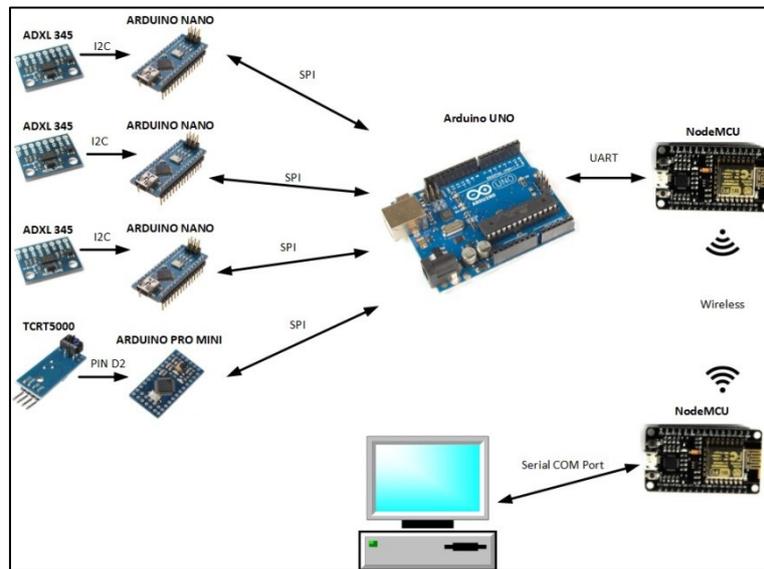


Figure 1. Design of vibration monitoring system.

2.1. Vibration data acquisition unit

The vibration data acquisition unit consist of several components as follows.

2.1.1. Vibration sensor. The ADXL345 is a complete 3-axis accelerations activity systems with selectable activity vary of ± 2 g, ± 4 g, ± 8 g, or ± 16 g. Figure 2 shows the functional block diagram of ADXL345 MEMS accelerometer sensor. It measures each dynamic acceleration ensuing from motion or shock and static acceleration, like gravity, that permits the device to be used as a tilt device. The device could be a polysilicon surface-micro-machined structure designed on prime of an element wafer. Polysilicon springs suspend the structure over the surface of the wafer and supply a resistance against forces thanks to applied acceleration. Deflection of the structure is measured victimisation differential capacitors that is accommodates freelance fastened plates and plates connected to the moving mass. Acceleration deflects the proof mass and unbalances the differential condenser, leading to a device output whose amplitude is proportional to acceleration. Phase-sensitive reception is employed to see the magnitude and polarity of the acceleration. Digital output measurement data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I2C digital interface.

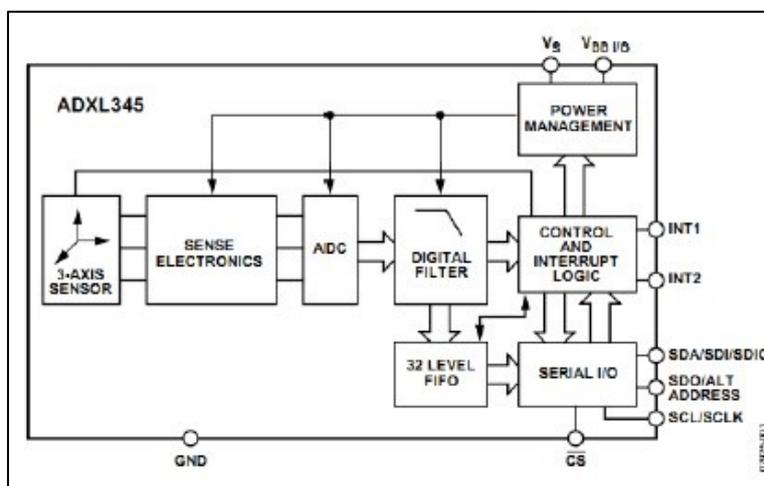


Figure 2. Functional block diagram of ADXL345.

2.1.2. Rotating speed sensor. The TCRT5000 is reflective sensors which include an infrared emitter and phototransistor in a leaded package which blocks visible light. It has peak operating distance about 2.5 mm and operating range within over 20 % relative collector current from 0.2 mm to 15 mm. Figure 3 shows the test circuit of TCRT5000. This device used to measure the speed of rotating equipment that will give the data as a reference for frequency of the vibration signal.

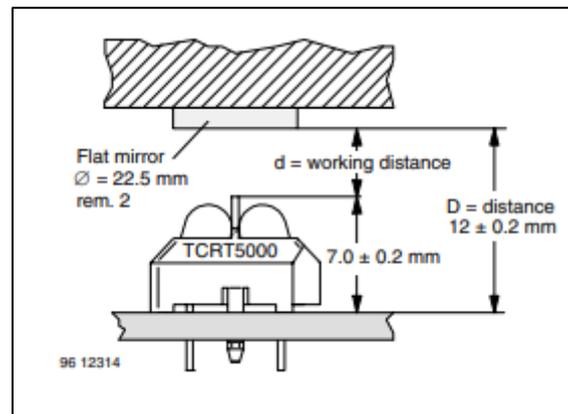


Figure 3. Test circuit of TCRT5000.

2.1.3. Microcontroller Arduino Nano and Arduino Pro-mini. Arduino Nano is a device that process digital signal from vibration sensor. It will write and read the data from the ADXL345 vibration sensor so it ready to transmit to the next device. In this research, three Arduino Nano were used to read data from three vibration sensors. On the other words, one microcontroller will read for one vibration sensor. Arduino Nano is small, complete, and breadboard-friendly board supported the ATmega328P. Arduino IDE software is used to write the program of this device. Furthermore, Arduino Pro Mini was used to get data from rotating speed sensor TCRT5000.

2.1.4. Microcontroller Arduino-Uno R3. Figure 4 shows the configuration of microcontroller device used. Arduino Uno R3 was used to collect all of measurement data from all other microcontrollers. It also gets power from power supply that generate from single 9 VDC battery and also generate power for other devices. Arduino is employed for building differing types of electronic circuits simply mistreatment of each a physical programmable printed circuit sometimes microcontroller and piece of code running on laptop with USB affiliation between the pc and Arduino. Programming language employed in Arduino is simply a simplified version of C++ that may simply replace thousands of wires with words. The most necessary part in Arduino Uno R3 is ATMEGA328P-PU is AN 8-bit Microcontroller with non-volatile storage reach to 32k bytes. Each of the fourteen digital pins on the Uno is often used as AN input or output, mistreatment Pin-Mode, digital-Write, and digital-Read functions. They operate at five volts. Every pin will offer or receive a most of forty mA and has an interior pull-up electrical device (disconnected by default) of 20-50 k Ohms. The Uno has six Analog inputs, labelled A0 through A5, every of which give ten bits of resolution (i.e.1024 completely different values). By default, they live from ground to five volts, although is it doable to alter the higher finish of their vary mistreatment the AREF pin and therefore the Analog-Reference operate.

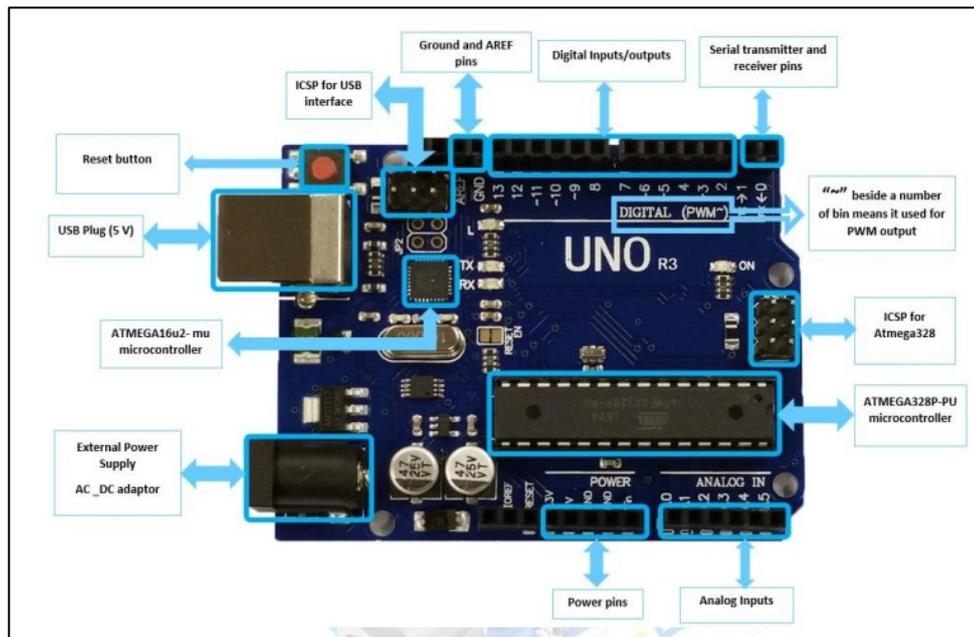


Figure 4. Arduino Uno R3 device configuration.

2.1.5. Node-MCU (ESP-01 Wi-Fi module). ESP-01 wireless fidelity module is developed by Ai-thinker Team, core processor ESP8266 in smaller sizes of the module encapsulated Tensilica L106 integrates industry-leading radical low power 32-bit MCU small, with the 16-bit short mode. Clock speed support 80 MHz, 160 MHz, supports the RTOS, integrated Wi-Fi MAC/BB/RF/PA/LNA, on-board antenna.

The module supports customary IEEE802.11 b/g/n agreement, complete TCP/IP protocol stack. Users will use the add modules to associate existing device networking, or building a separate network controller. ESP8266 is high integration wireless SOCs, designed for house and power forced mobile platform designers. It provides un-exceeded ability to imbed Wi-Fi capabilities inside different systems, or to operate as a standalone application, with the bottom price, and marginal house demand.

2.2. Vibration monitoring section

The vibration observation section receives information wirelessly and so displays the activity results mistreatment LabVIEW code on the computer. This section consists of the subsequent components:

2.2.1. AMICA Node-MCU module. A Node-MCU module core is an ESP8266 Wi-Fi Module based mostly development board. It is got a small USB slot that may be directly connected to the computer or alternative USB host devices. It is got 15x2 Header pins and a small USB slot, the headers may be mounted on a bread board and also the small USB slot is for association to a USB host device which will be a laptop. It is got a CP2102 USB to serial device. Within the vibration monitoring unit, the AMICA MCU Node Module is organized as an organiser mistreatment the Node MCU computer program code. The baud is ready as 9600. This device is connected to the computer via a USB Serial Port interface. This module is USB supercharged and incorporates a transformer of 3.3 volts. This module receives data transmitted by RF link and so serially transfers it to the computer.

2.2.2. Computers with display and input devices. For the system during this study, portable computers have been used. This fulfils the requirements needed to run LabVIEW software and the Arduino IDE 1.5.7 program. This computer has a USB communication as well as a serial port, for the Node MCU Module interface. The LabVIEW software has been installed on the computer for display development (GUI) for the machine vibration monitoring system. Vibration analysis can be performed on data obtained through features that have been embedded in this interface. An alarm indication feature has

been added as a safety control. The data recording feature has also been added to display reports that can be used for offline analysis.

3. Results and discussion

In vibration sensor unit, sensor ADXL345, TCRT5000, Arduino Nano, Arduino Pro Mini and ESP-01 Wi-Fi module are powered by Arduino Uno R3 microcontroller board. Small wheel grinding's machine is selected as source of vibrations for experimental vibration monitoring. Two Accelerometers are attached on top and right surface of motor case to measure on vertical and horizontal position, respectively. One Accelerometer is mounted on the face of rotor surface to measure vibration on axial position. The last one, rotating speed sensor is attached to base of machine to measure the speed of grinding wheel rotation. Sensor modules are attached on motor surface tightly using adhesive tape. Proper circuit connections were made and power supply was given to Arduino Uno R3 board. Coordinator Node-MCU AMICA module was interfaced to computer. Figure 5 Shows the final vibration sensor unit assembly.



Figure 5. Vibration sensor unit.

Figure 6 shows the flowchart of vibration sensor unit working principle. Initial condition when the engine is not turned on, the vibration in the monitoring system displays the results as shown in Figure 7. The three vibration sensors and rotation sensors on the display chart (X, Y, Z) show no significant vibration and rotation. Then, after the engine is turned on, vibration continues to rise and then stabilizes under certain conditions as shown in the graph Figure 8 and Figure 9. The display in the Lab-View application shows the engine vibration conditions in real-time. The highest allowable vibration limit is 9.8 mm/s^2 . When the vibration measurement value exceeds a predetermined threshold, the alarm indicator is ON with flashing. Recording of measurement data is still carried out as long as the STOP button on the application display has not been pressed and the measured text file is saved into the local computer's hard drive that has been predetermined.

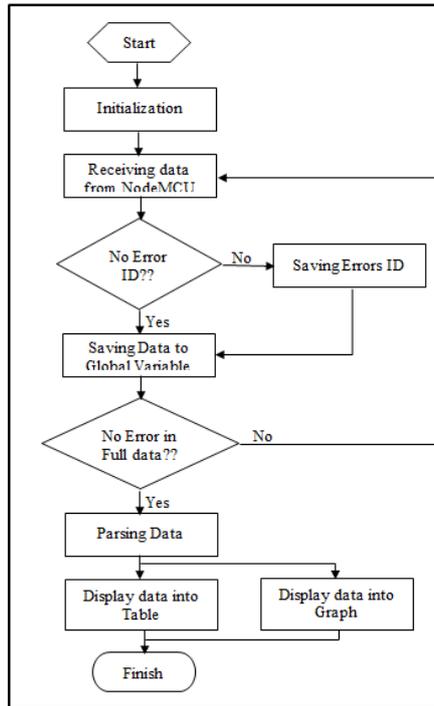


Figure 6. Flowchart of vibration sensor principle.

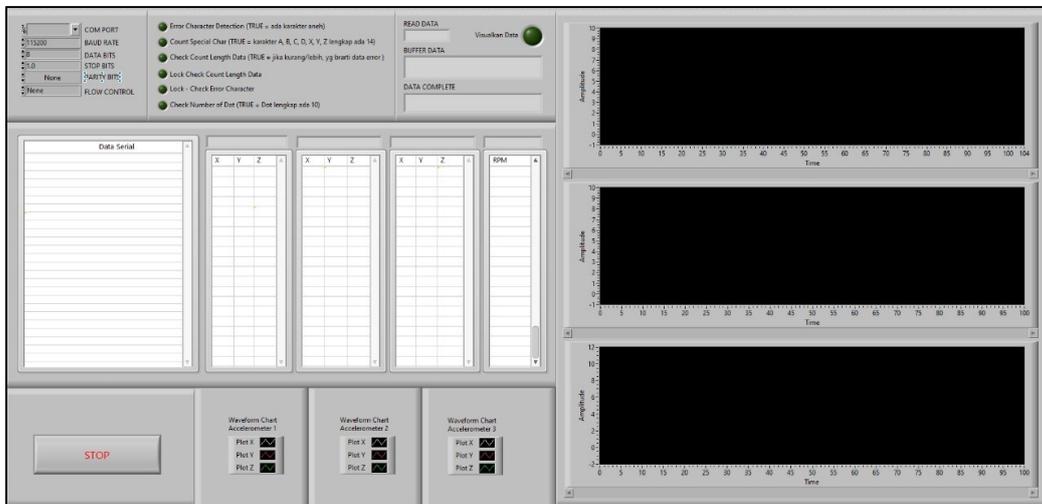


Figure 7. Vibration condition when machine OFF.

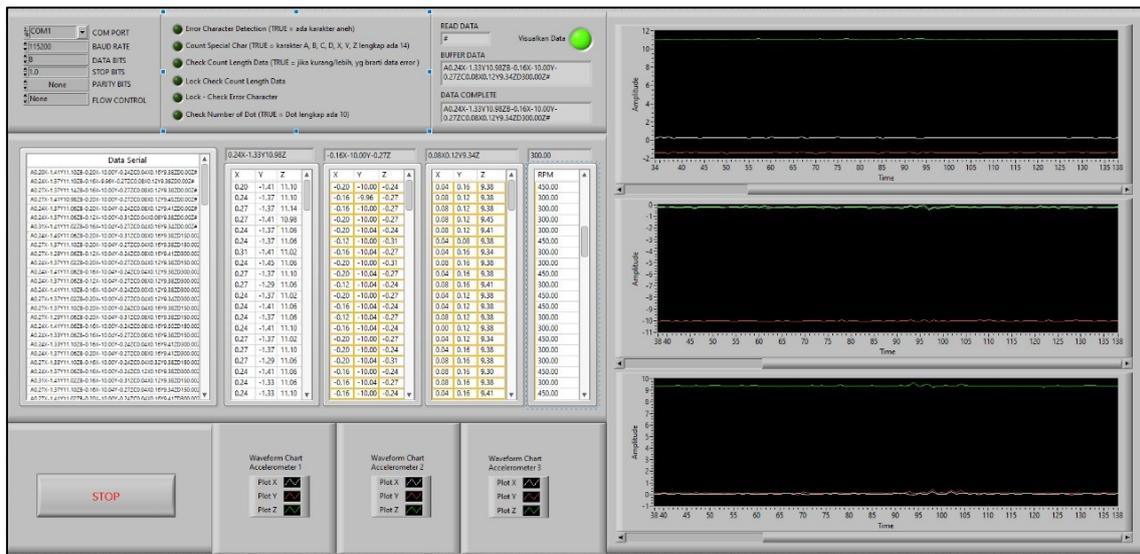


Figure 8. Vibration data when machine ON.

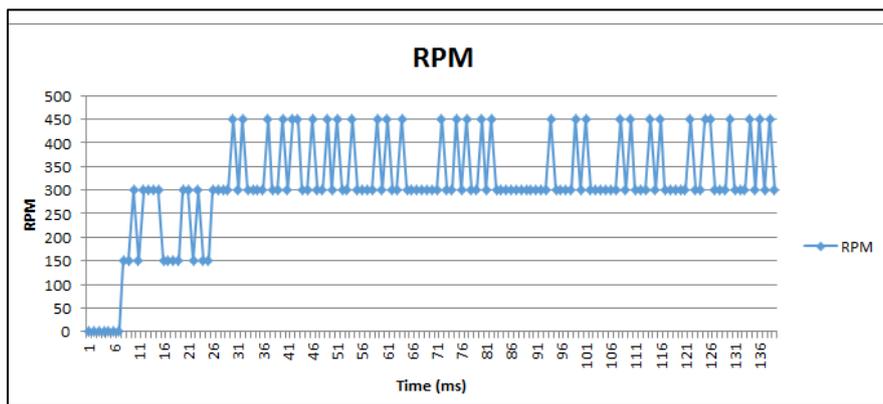


Figure 9. Speed rotation when machine ON.

4. Conclusion

In this paper, a real-time vibration monitoring system design has been implemented utilizing the ADXL345 MEMS accelerometer sensor with wireless data communication and making vibration monitoring displays using Lab-View software. The interface of the accelerometer sensor with a microcontroller board derived from Arduino has been explained. The implementation of wireless communication has been carried out using the MCU-Node module. The measurement results show the sensor can display four pieces of data, namely three engine vibration data in a vertical, horizontal and axial position on three axes (X, Y, Z), and one engine speed measurement data. Log data files stored on computer storage media can be used for vibration analysis and vibration data history at certain times.

5. References

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