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Prototype of small-scale test machine for vibration measurement on bearings

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Abstract

Repetitive movements of shaft in bearings over time intervals generate vibrations. The aim of this research is to build the prototype of small scale of machine to measure the vibration values of bearing due to spinning shaft using an accelerometer and Arduino sensor device. The method used is to build a device of miniature rotating machines which was used to simulate machine vibrations. The ADXL345 accelerometer measured the magnitudes of vibration that occurs on the rotating shaft. Arduino Uno analyzed data from ADXL345. The amplitude, speed, acceleration and frequency values were measured according to rotation values. It was found the largest amplitude, speed, acceleration and frequency values were obtained at the radial point Y1 position.

Keywords: Bearings; Vibration; Arduino; Accelerometer

1. Introduction

The shaft and bearing assembly are a rotating part attached to elements such as gears, pulleys, flywheels, cranks, and other power transmission elements. The shaft can receive bending, tensile, compressive, or torsional loads, which work individually or together. When these loads work together, static stress, alternating stress, and repetitive stress will work simultaneously [1].

The rotating shaft is not actually in a straight position, but rotates in a curved position. At a certain point of rotation, the curvature of the shaft reaches its maximum value. The rotation that causes the curvature of the shaft to reach its maximum value is called the critical rotation. This condition is called the rotating shaft effect [2].

In the rotating bearing and shaft parts, there is usually movement on both a small and large scale due to the load on the shaft. If this movement is repeated at certain time intervals, then the movement is called vibration [3]. As a result of vibrations that occur on the shaft, it can damage machine components and cause unwanted forces. In addition to vibrations caused by loading, there is also shaft deflection that will be measured from the amount of deflection that occurs and also the shaft rotation due to variations in the length and weight of the disk load mass [4].

Vibration measurement is one of the most common measurements carried out in monitoring the condition of rotating machines. The higher the measured vibration value indicates that the disturbance is likely to cause damage to the machine [5]. The selection of vibration parameters to be measured determines the type of sensor used. This is due to the differences in the objects being measured and for ease of use. Eddy current sensors are sensors that are commonly used for displacement parameters, generally used to measure shaft displacement relative to the bearing housing [6]. The swing coil speed sensor is a sensor that is commonly used for speed parameters. While for acceleration parameters, piezoelectric accelerometer sensors are usually used. The last two sensors are usually used to measure vibrations in the bearing housing [7].

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Research on vibration measurement is still wide open considering the many components in moving machines. In addition, the effect of vibration on machine performance also still requires in-depth research, especially the many determining factors involved, including the type of material, type of damper, and so on [8]. Therefore, in this study a prototype of a machine vibration measuring instrument was developed using the MEMS ADXL345 accelerometer sensor. By using Arduino-based measurements, the measurement results are processed and displayed on the LCD and PC. On the PC, Megunolink software is used to plot the measurement data. A miniature rotating machine is also made to simulate the effect of engine rotation on the measurement results.

2. Material and methods

2.1 Measurement Instrument

The design of the measurement system is illustrated through a block diagram of the design, which serves as an important component in the manufacturing and production process of the vibration measurement instrument (Figure 1). A mini rotary machine is used to replicate vibrations that may occur under standard and atypical conditions. The ADXL345 accelerometer detects the intensity of vibrations present in this mini rotary machine. Arduino Uno serves as a signal processor, facilitating data acquisition from ADXL345 [9]. An LCD is integrated with Arduino to function as a display, while Megunolink is used as software for data visualization on a computer.

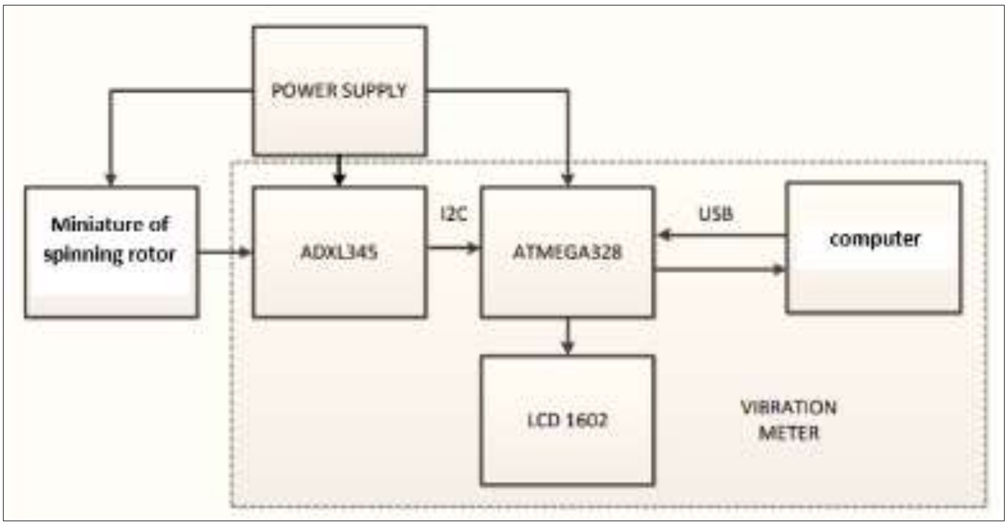

Figure 1 Design of vibration measurement system.

When vibration meters are used for measuring machine vibrations, a suitable accelerometer must be selected depending on the type of mechanical. Accelerometers designed for low frequencies measure low acceleration levels and thus, are highly sensitive. However, their larger size and mass result in low resonance frequency when mounted. Accelerometers for high frequency measure high acceleration levels and are normally compact and lightweight with low sensitivity. The design of vibration measurement system in this work is a selection of piezoelectric accelerometers, covering a wide frequency range. By combining an accelerometer with a vibration meter that is designed to make the best use of its characteristics, a wide range of measurements can be performed with optimum efficiency.

Piezoelectric accelerometers are normally used for measuring vibrations with a frequency of more than 1 Hz. This type of accelerometer has good high-frequency characteristics and is especially suited for measuring vibrations in the upper frequency range. Major applications are vibration monitoring and diagnostic checks of mechanical installations in industrial plants. Piezoelectric accelerometers generate a certain amount of low-frequency noise when ambient temperatures change (so-called pyronoise). Depending on the application, the accelerometers must therefore be protected from temperature changes. When velocity and displacement to be used for evaluation are obtained by integrating acceleration, pyronoise will to be evaluated as integral products, pyronoise will be amplified and must therefore be given special consideration. With the exception of types containing, piezoelectric accelerometers require a charge amplifier.

2.2 Tools and materials

Accelerometers are mounted on rotating machines to detect vibration amplitude based on acceleration parameters. The data obtained from this sensing process is then analyzed by a microcontroller, which then presents the measurement results in the form of computer graphics.

The main tools and materials used in this study consist of:

- Hardware includes ADXL345 accelerometer sensor, Arduino Uno R3, 2x16 LCD character display, transformer, and other components.
- Software includes Arduino Integrated Development Environment (IDE), Megunolink, and PCB Wizard.

2.3 Vibration formulas

There are three vibration parameters which can be used to express the magnitude of vibration: displacement, velocity, and acceleration. To find the amplitude from a simple harmonic motion equation, identify the coefficient of the cosine function in the simple harmonic motion equation. The absolute value of this coefficient is the amplitude. The total distance travelled in one complete cycle as it oscillates, multiply the amplitude. In the sense of simple harmonic motion, an object that moves back and forth over the same path is in a periodic motion. This is caused by a restoring force that acts to bring the moving object to its equilibrium position. A simple harmonic motion occurs when the restoring force is proportional to the displacement of an object. A simple harmonic motion is given by the following equations. With x is amplitude, A is displacement, ω is the angular speed, t is time and a is the acceleration, the calculation formulas for vibration parameters are shown in the following equations.

$$x = A \sin \omega t \quad (1)$$

$$v = \omega \text{ A} \cos \ \omega t \quad (2)$$

$$a = -\ \omega^2 A \sin \omega t \quad (3)$$

2.4 Mechanical Design

The mechanical design process involved the development of a small-scale rotating machine, which was then used to replicate the vibrations of the machine (see Figure 2).

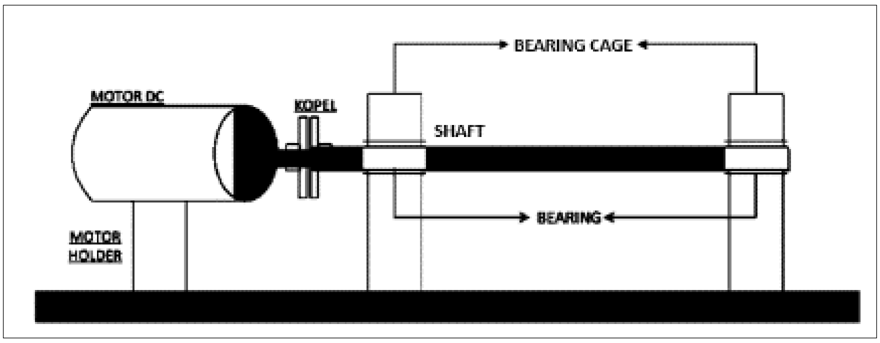

Figure 2 Miniature engine design.

The construction of a mini rotary machine involves several main components, including a DC motor, bearings, bearing housing, motor mount, disturbing pendulum, clutch, and base or coaster. Specifically, a 12V DC motor is used, accompanied by bearings that have an outer diameter of 22 mm and an inner diameter of 10 mm.

The tools used in this study are as follows:

- 12-volt DC motor, 32 watts, 6000 rpm.
- Shaft made of ST 52 steel.
- Motor rotation controller (PID) to regulate the motor rotation speed.
- Tachometer to measure the rotation speed of the drive rotor.
- Infrared sensor.
- Camera for documentation purposes.
- Ruler to measure the length of the shaft and the distance of the given load.
- Grinder to cut the shaft, solid iron, and other materials.
- Wrench to open and adjust the bearing support shaft to match the length of the shaft.

3 Results and discussion

This study tested the performance of rotating shafts on two ball bearings supporting a 40 cm long shaft. Arduino was fixedly installed at both points on the side of the bearing housing. Vibration data collection was carried out for 25 seconds covering 100 acceleration values, meaning that the device recorded vibration values every 0.25 seconds. However, the table only displays data up to 37 because this is considered sufficient to represent the phenomenon to be analyzed.

The vibration values in Table 1 were obtained from the two spots, displaying acceleration value data from the results of vibration value tests on bearings supporting a rotating shaft at a motor speed of 1400 rpm. The acceleration variation range is 0 to 0.3 mm/s^2. This is included in the stable category. Acceleration values are susceptible to fluctuations, except for rotations exceeding 1500 rpm. Acceleration values are measured in three directions of the axis, namely x, y and z. In Figure 3, the y-axis is represented by the color orange and also shows the largest acceleration value from unstable shaft rotation. While the lowest acceleration value is obtained on the x-axis which is represented by the color yellow, namely 0.1 mm/s^2.

The vibration acceleration values for all x, y and z axis tend to increase as the motor rotation increases. The largest acceleration is obtained at 1500 rpm of 1.27 m/s^2 (Figure 4).

Table 1 Acceleration values at two points of the bearing housing in the x, y and z axis directions.

Time (s)	Axis directions					
	x1	y1	z1	x2	y2	z2
1	0.1	-0.0	0.0	0.0	0.1	0.0
2	0.1	-0.0	0.0	0.0	0.1	0.0
3	0.1	0.0	0.0	0.0	0.1	0.0
4	0.1	0.0	0.0	-0.0	0.1	0.0
5	0.1	0.0	0.0	-0.0	0.1	0.0
6	0.2	0.2	0.0	-0.0	0.1	-0.0
7	0.2	0.2	0.0	-0.0	0.1	-0.0
8	0.0	0.0	0.0	-0.0	0.0	-0.0
9	0.0	0.0	0.0	-0.0	0.0	-0.0
10	0.0	-0.3	-0.0	-0.0	-0.1	-0.0
11	0.0	-0.3	-0.0	-0.0	-0.1	-0.0
12	0.1	-0.3	0.0	-0.0	-0.2	-0.0
13	0.1	-0.3	0.0	-0.0	-0.2	-0.0
14	0.2	-0.2	-0.1	-0.0	0.1	0.0
15	0.2	-0.2	-0.1	-0.0	0.1	0.0
16	0.2	0.2	0.1	-0.1	0.1	-0.0
17	0.2	0.2	0.1	-0.1	0.1	-0.0
18	0.2	0.2	0.1	-0.1	0.1	-0.0
19	0.2	0.1	-0.0	-0.0	0.1	0.0
20	0.2	0.1	-0.0	-0.0	0.1	0.0
21	0.3	-0.0	0.0	-0.1	0.1	-0.1
22	0.3	-0.0	0.0	-0.1	0.1	-0.1

23	0.1	-0.0	-0.0	0.1	0.1	0.0
24	0.1	-0.0	-0.0	0.1	0.1	0.0
25	-0.1	0.1	0.0	-0.1	-0.1	-0.0
26	-0.1	0.1	0.0	-0.1	-0.1	-0.0
27	0.1	0.2	0.0	-0.0	-0.1	0.0
28	0.1	0.2	0.0	-0.0	-0.1	0.0
29	0.1	0.3	0.1	-0.0	-0.0	-0.0
30	0.1	0.3	0.1	-0.0	-0.0	-0.0
31	0.1	0.1	-0.0	-0.0	0.1	-0.0
32	0.1	0.1	-0.0	-0.0	0.1	-0.0
33	0.0	-0.0	0.0	-0.0	0.1	0.0
34	0.0	-0.0	0.0	-0.0	0.1	0.0
35	0.0	-0.0	0.0	-0.0	0.1	0.0
36	0.0	0.0	0.0	-0.0	0.1	-0.0
37	0.0	0.0	0.0	-0.0	0.1	-0.0

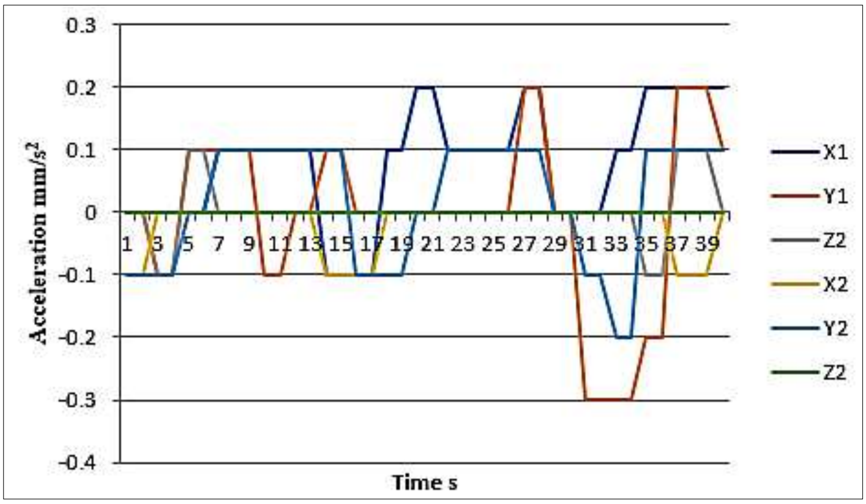

Figure 3 Relationship between acceleration and time on two bearing housings at the x, y, and z axis positions with a motor speed of 1400 rpm.

Meanwhile, the comparison of vibration velocity values is only taken at one spot of the bearing housing. The shaft is subjected to varying motor rotations from 600, 740, 800 to 1500 rpm. Observations were made over a period of 15 seconds. From the results of vibration velocity measurements, an increase in speed is seen as the rotation increases. The lowest average speed at 600 rpm is 0.13 m/s while the highest average speed at 1500 rpm is 1.27 m/s (Figure 5).

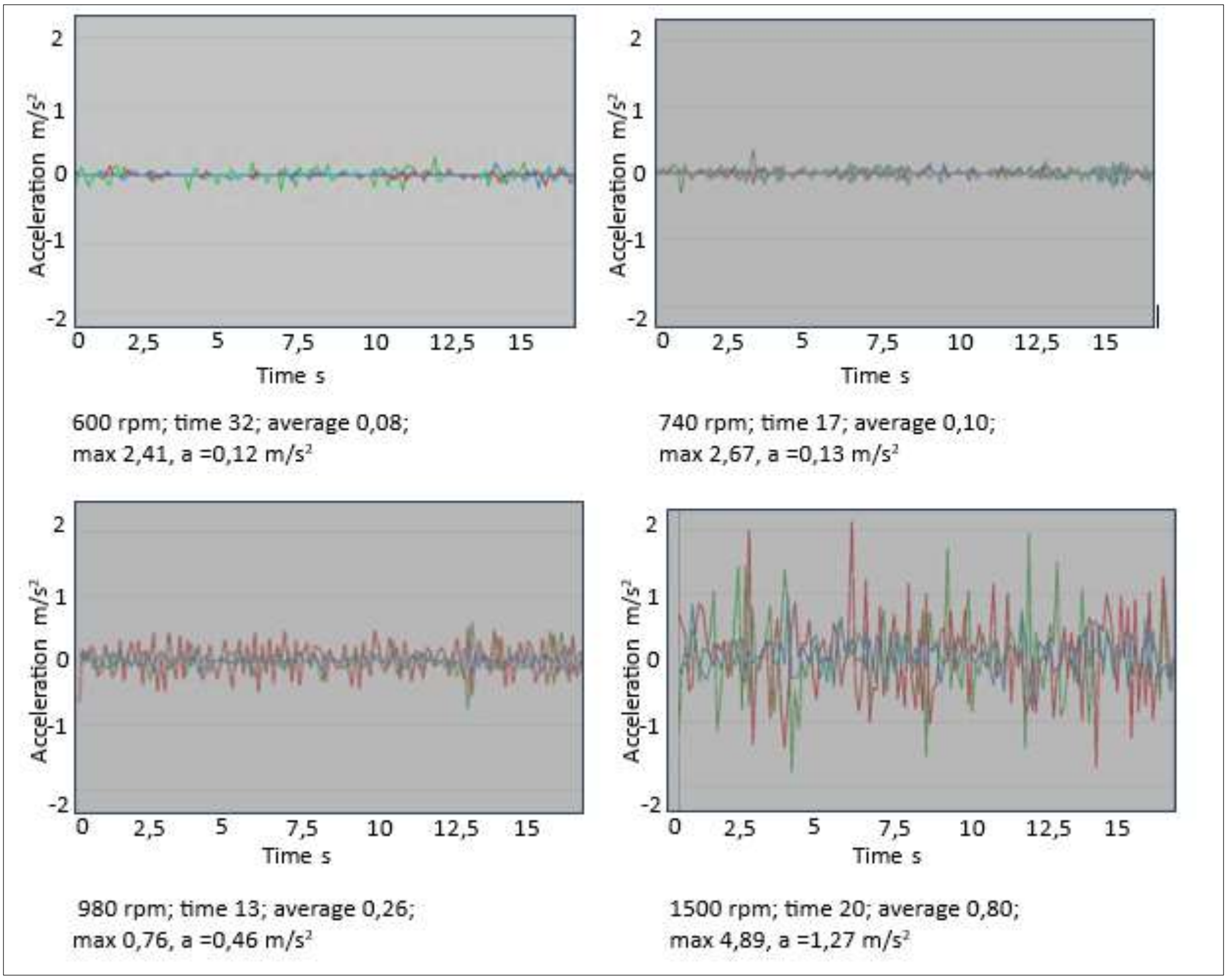

Figure 4 Vibration acceleration value based on motor rotation.

While the amplitude value is shown in Figure 6 according to the vibration frequency. Vibration amplitude is the distance of wave movement from its initial position or equilibrium position. However, in this test, the amplitude value is measured in g units expressed in metric units (m/s2) or gravitational constant units g, where 1 g = 9.81 m/s2. Amplitude shows the characteristics of the vibration strength that occurs. The higher the amplitude, the stronger the vibration that occurs. One of the quantification methods includes the vibration frequency value. The amplitude value is shown at each varying motor rotation. The greater the motor rotation, the greater the amplitude value. The largest amplitude value is obtained at 1500 rpm, which is 0.67 g. The frequency value shows fluctuating symptoms. The lowest frequency value is obtained at 600 rpm, the frequency value is 33.43 Hz, while the largest is at 1500 rpm, the frequency value is 49.75 Hz. So that experimentally the average values of speed, acceleration, amplitude, and frequency tend to increase as the motor rotation increases (Table 2).

Table 2 Vibration parameter values based on motor rotation.

Rotation (rpm)	***v* (m/s)**	***a* (m/s²)**	***X* (g)**	***f* (Hz)**
600	3,31	0,12	0,325	33,43
740	3,30	0,13	0,350	34,59
980	3,31	0,46	0,400	37,31
1500	3,36	1,27	0,67	49,75

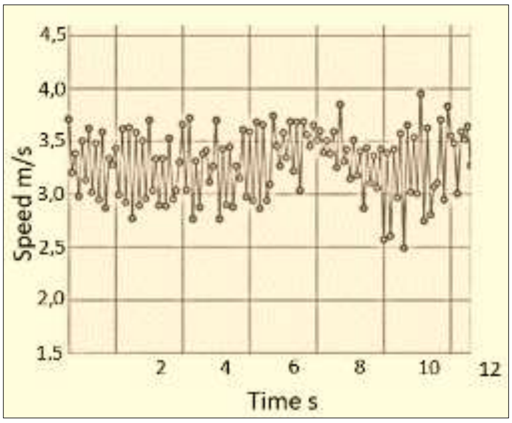

Figure 5 The speed of vibration at rotation of 1500 rpm

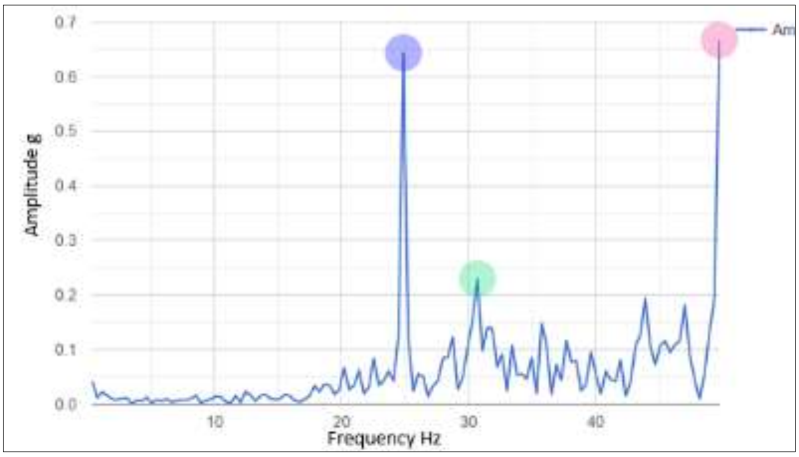

Figure 6 Amplitude value against vibration frequency at 1500 rpm.

4 Conclusion

A small-scale machine for measuring vibration parameters on bearings has been successfully created. From the performance test of rotating shafts on two ball bearings supporting a 40 cm long shaft at a motor speed of 1400 rpm, the acceleration variation range is 0 to 0.3 mm/s2. The acceleration value is measured in three axis directions, namely x, y and z. The largest acceleration value is shown in the y-axis direction, which is 0.3 mm/s^2. While the lowest acceleration value is obtained on the x-axis which is represented by the yellow color, which is 0.1 mm/s^2.

In the measurement of vibration speed, an increase in speed is seen as the rotation increases. The lowest average speed at 600 rpm is 0.13 m/s while the highest average speed is obtained at 1500 rpm is 1.27 m/s.

The amplitude value is shown at each varying motor rotation. The greater the motor rotation, the greater the amplitude value. The largest amplitude value is obtained at 1500 rpm, which is 0.67 g. The lowest amplitude value is shown at 600 rpm, which is 0.25 g. The lowest frequency value was obtained at 600 rpm of 33.43 Hz while the highest frequency was obtained at 1500 rpm of 49.75 Hz. So experimentally the average values of speed, acceleration, amplitude, and vibration frequency tend to increase as the motor rotation increases.

Compliance with ethical standards

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Disclosure of Conflict of interest

There is no conflict of interest.

Statement of ethical approval

There is no need any statement of ethical approval.

Statement of informed consent

There is no statement of informed from any individual participants included in the study.

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