Palestine Polytechnic University

College of Engineering and Technology

Mechanical Engineering Department

Graduation Project

Vibration Test Bench for Bearings

Done By:

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Submitted to the College of Engineering in partial fulfillment of the requirements for the bachelor's degree in Mechanics Engineering.

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Palestine Polytechnic University

College of Engineering

Mechanical Engineering Department

Hebron – Palestine

Bearing diagnostic device

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Abstract

Rolling contact bearings are used in almost every type of rotating machinery, but failures of it can be very critical because these lead to machinery damage, production losses and personnel injury.

So, there is a need to prevent these failures when they are in its initial stage. vibration analysis is the best tool for this purpose. The vibration analysis is a technique, which is being used to track machine operating conditions and trend deteriorations in order to reduce maintenance costs and downtime simultaneously.

The system consists of an accelerometer sensor mounted on Arduino powered by a computer. When the sensor is mounted on a bearing it starts to generate an acceleration in three axes measured in volt.

Using MATLAB this analog signal which represent the sensor reading will be plot in time domain, then by FFT converted to frequency domain. Taking the frequency graphs into consideration, a comparison is made between the ideal bearing and the tested one. Using the ideal bearing amplitude rang, we will be able to compare, for any bearing out of rang is unideal

الملخص

يتم استخدام المحامل (البيل) في كل نوع من أنواع الآلات الدوارة تقريبًا ، ولكن يمكن أن يكون فشلها حرجًا للغاية لأنها تؤدي إلى تلف الآلات وخسارة في الإنتاج وإصابة الأشخاص .

لذلك ، هناك حاجة لمنع الاعطال عندما تكون في مرحلتها الأولية. تحليل الاهتزاز هو أفضل أداة لهذا الغرض. تحليل الاهتزاز هو تقنية تستخدم لتتبع ظروف تشغيل الماكينة وتدهورها من أجل تقليل تكاليف الصيانة ووقت توقفها عن العمل في وقت واحد.

يتكون النظام من مستشعر تسارع مثبت على Arduino مدعوم من جهاز كمبيوتر. عندما يتم تركيب المستشعر على محمل ، فإنه يبدأ في توليد تسارع في ثلاثة محاور تقاس بالفولت.

باستخدام MATLAB هذه الإشارة التناظرية التي تمثل قراءة المستشعر سيتم رسمها في المجال الزمني ، ثم تحويل إلى مجال التردد بواسطة FFT . مع مراعاة الرسوم البيانية للتردد ، يتم إجراء مقارنة بين المحمل المثالي والمختبر. باستخدام السعة المثالية للمحمل السليم، سنكون قادرين على المقارنة .

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1.1 Introduction

Bearings are mechanical assemblies that consist of rolling elements and usually inner and outer races as show in figure 1, which are used for rotating or linear shaft applications, and there are several different types of bearings, including ball and roller bearings, linear bearings.

They provide a means of supporting rotating shafts and minimizing friction between shafts and stationary machine members. Therefore, any fault in the bearings can lead to losses on the level of production and equipment's as well as the creation of an unsafe working environment for humans. For that reason, the bearing fault diagnosis has received considerable attention from the research and engineering communities.

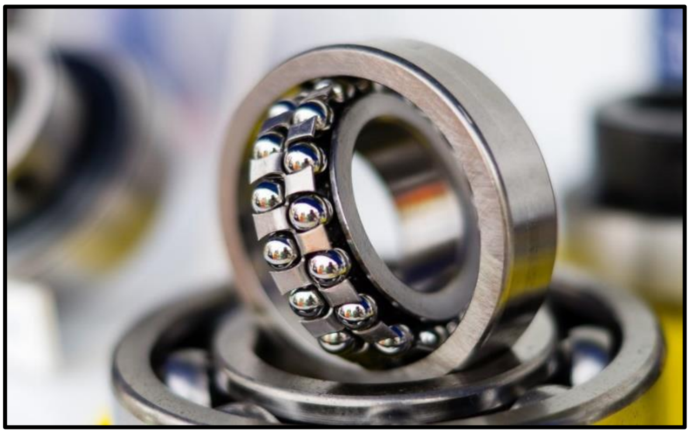

Figure 1Roll bearing

1.2 Problem definition

Today world more concerned with reducing the cost of failure and maintenance in any industry. Condition monitoring of these machine components like bearings was important to avoid failures. Several techniques were available and vibration monitoring was one of It is important for many reasons. It reduces the chance of a dangerous situation them. within your facility. Also, by locating problem areas within machinery ahead of time, you can repair the damage early on. Vibration analysis is also important as it helps you save money as you can repair minor problems now instead of dealing with major, more expensive issues later. You can also avoid production downtime, which may cost you clients and sales.

1.3 Project objectives

The main objectives that want to achieve in the project are the following:

1) Design and build a device that diagnose the rolling element bearing without need to disjoint it

2) Use vibration analysis techniques and explore their capabilities in monitoring rolling element bearings.

1.4 Conceptual Design

After defining needs and requirements and generate some solution by brain storming. Now we want to specify design concept that meet project requirement and functional specification to choose candidate design, to move forward to functional specifications in next section.

The purpose of the conceptual design is to define required parts and how it will work together, and the relationships between the components.

The system consists of an accelerometer sensor mounted on Arduino powered by a computer. When the sensor is mounted on a bearing it starts to generate an acceleration in three axes measured in volt.

Using MATLAB this analog signal which represent the sensor reading will be plot in time domain, then by FFT converted to frequency domain. Taking the frequency graphs into consideration, a comparison is made between the ideal bearing and the tested one. Using the ideal bearing amplitude rang, we will be able to compare, for any bearing out of rang is unideal.

1.5 Components

This system requires hardware and software components:

1.5.1 Hardware requirements:

- Arduino
- ADXL335 accelerometer
- Connecting wires
- USB cable for connecting Arduino with your Laptop
- Motor
- Roll bearing

1.5.2 Software requirements:

- Arduino Programming
- MATLAB
- AutoCAD

1.6 Project schedule and time plan

Table 1 Task description

	Task discerption
T1	Project selection
T2	Collecting references from libraries
T3	Collecting references from websites
T4	Writing proposal
T5	identify the method by which the bearing will be diagnosed
T6	Modify the previous design
T7	Select the device component and sensors
T8	Writing the text
T9	Prepare the 1st presentation
T10	Make the required adjustments on the introduction text
T11	Buy the mechanical and electronic parts
T12	Put the mechanical and electronic parts of the system
T13	Test the result
T14	Do some justification to make the system more efficient
T15	Try to correct the expected problems of the system
T16	Writing the text
T17	Prepare for the final presentation

Table 2First semester time table

Task/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
T1														
T2														
T3														
T4														
T5														
T6														
T7														
T8														
T9														

Table 3Second semester time table

Task/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
T10	■	■	■											
T11			■											
T12			■	■	■	■								
T13							■	■	■	■				
T14											■			
T15											■	■		
T16												■	■	
T17														■

1.7 Budget

When you going to make any project, you must take attention that your project will cost a certain amount of money. If you plan to make a development for your project, you must take attention more and more, to minimize the cost as possible as you can, to make a beautiful profit margin. Table 3 shows the budget of the device.

Table 4 Budget

Component	Cost
Arduino	10$
Accelerometer sensor	15$
Motor	100$
Bearings	10$
Wire	10$

1.8 Literature review

D.Ganeshkumar ,Dr. T. Manigandan and Dr. S. Palaniswamithey have developed a system for the analysis and diagnosis of bearing vibration and fault monitoring, where the most important features that it is low cost and effective, the design was done using the LAPVIEW program and DAQ (Data Acquisition) card PCI-6042E for testing the bearings, vibration analysis is carefully carried out using a piezo-electric sensor with advanced charge amplifier, their system convert the signal from time domain to frequency domain, and then compare reading signal with signals are stored in the system where they recorded five readings are as follows : a good rolling element bearing, a rolling element bearing with misalignment of the outer race, a rolling element bearing with a worn outer race and a rolling element bearing with an outer race crack.[1].

Duy-Tang Hoang a and Hee-Jun Kang they did work on a method for diagnosing faults of bearing that based on a deep structure of convolutional neural network. The method using vibration signals directly as input data. The target method is an automatic fault diagnosis system that does not need any feature extraction techniques and obtain robustness very and high accuracy under noisy environments. They did their study by using a motor, shaft and bearing. In results the suggest new approach based on CNN for diagnosing faults. By transforming 1-D vibration signals to 2-D images and exploiting the effectiveness of CNN in image classification, that method can achieve 100% accuracy in CWRU bearing data set. The main advantage of their methods it does not require the feature extraction step.[2]

Xinsheng Lou and Kenneth A. Loparo , they have done a study entitled" Bearing fault diagnosis based on wavelet transform and fuzzy inference" , they did new planner for the diagnosis of localized defects in ball bearings based on neuro-fuzzy and wavelet transform classification. They have acquired vibration signals for bearings with inner race faults, ball faults and normal bearings through using a motor-driven experimental system and shaft with load. The wavelet transform method was used to process the accelerometer signals and to generate feature vectors. In the results a new planner has been developed for the diagnosis of defects in bearings , the signals were normalized to (0,1) standard random variables, and then the wavelet transforms were completed using the Daubechies-2 wavelet , an ANFIS was trained as the pattern classifier, for comparison purposes [3].

Wojnar, Azarz and StanikItin "diagnoses of rolling bearing by vibration analysis ", the tests were carried out on cone rolling bearings of rear, non-driven wheels of a Seat Ibiza car – year of production 1993. Stand tests were carried out with the car lifted on a workshop lift. A car wheel balancer was used to velocity up one of the wheels. This allowed acceleration of the wheel up to the rotation velocity which corresponded to the car's velocity of maximum ca.150 km/h. The acceleration values of axial vibration of the bearing pivot were measured. Also, synchronous reference signals corresponding to the wheel revolutions were recorded. The vibration signal and the signal from the system of averaging synchronization were sampled with the frequency of 25,600 Hz and recorded on a computer hard disk. The car wheel whose rolling bearings were diagnosed, was balanced on a standard balancer. The recorded vibration signal was analyzed within ten intervals with a width corresponding to 25 revolutions of the wheel [4].

Shinji Utsumi,Zen-Ichioo ,Kenji Matso-Ura and Masatake Kawada in article of topic" Use of Wavelet Transform and Fuzzy System Theory to Distinguish Wear Particles in Lubricating Oil for Bearing Diagnosis" They did work Ferro graphic analysis in order to detect wear particles in lubricating oil automatically, because the customary approach takes a great deal of time. Has been proposed a new method to detect wear particles in lubricating oil in order to diagnose bearings, by means of local spatial frequency analysis using the wavelet transform. The Gabor function and cylindrical Gabor function are used as the mother functions of the wavelet transform. The Gabor function is effective in detecting particles which distribute along the lines of magnetic force on the ferro gram slide. The cylindrical Gabor function can detect circular particles. To discriminate the particles, we apply fuzzy system theory to the image transformed by two Gabor functions and show the effectiveness of this method [5].

2

Chapter two: Bearing failure and diagnoses

2.1 Bearing failure

2.2 Bearing diagnoses

2.3 Vibration method

2.4 Time-frequency domain approach

2.1 Bearing failure

Bearings can fail prematurely and unexpectedly even with planning and maintenance. The original equipment manager (OEM) selects bearings for each application in conjunction with the manufacturer's designed life expectancy based on a fatigued spall failure. For several reasons, few bearings reach their full designed life expectancy.

2.1.1 Bearing failure cases

1-Excessive Load:

This type of fatigue results from heavy ball bearings and the evidence for that high temperature and increased jamming; this can be minimized by reducing the load on it, excessive load bearing show in figure 2.

Figure 2Excessive load bearing

2-Overheating:

When increasing the temperature of 400 degrees Celsius lead to the cancellation of the ring around the bearing or can lead to deformation of rings. Too high temperature leads to the removal of lubricants and causes great damage, overheating bearing show in figure 3.

Figure 3Overheating bearing

3-Lubricant Failure

If the bearing colors (blue, brown) are evidence of the erosion of the bearing. The change in the temperature of the oil loses its properties and this causes problems in bearing, so we must choose the appropriate oil for bearing and lose oil from one period to another, lubricant failure bearing show in figure 4.

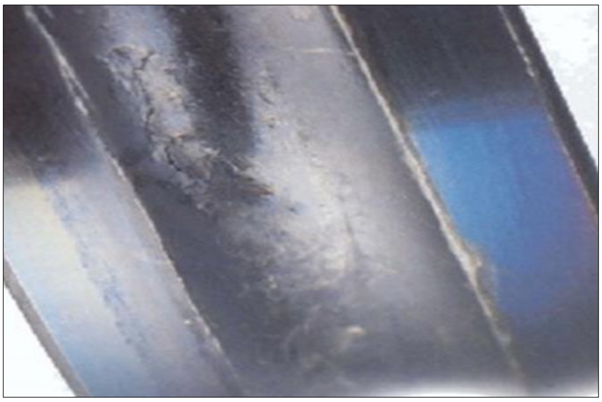

Figure 4Lubricant failure bearing

4-Misalignment:

Misalignment caused by installation forces the centerline of the inner bearing race (cone) to operate at a slight angle to the centerline of the outer race (cup). This causes the load to be unevenly distributed creating greater than expected stress at one end of the rolling surfaces, misalignment bearing show in figure 5.

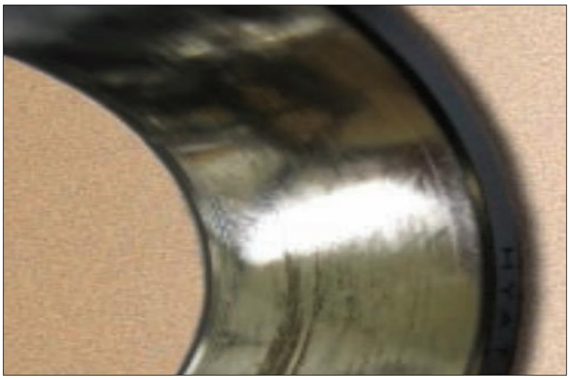

Figure 5Misalignment bearing

2.2 Bearing diagnosis

The accurate diagnosis of a bearing failure is imperative to prevent repeat failure and additional expense. Different methods are used for the diagnosis of wheel bearing; the methods are categorized as follows:

1- Vibration method.

2- Acoustic method.

3- Stator current method.

4- Temperature method.

5- Wear debris analysis.

2.3 Vibration methods

It is the mostly used method and several techniques have been applied. Vibration is most measured using accelerometer sensor. An accelerometer is a sensor that measures the dynamic acceleration of a physical device as a voltage.

There are several reasons for vibration as follow:

1. Varying compliance: The number of rolling elements and their position in the load zone change with bearing rotation, giving rise to a periodical variation.

2. Distributed defects: include surface roughness, waviness, misaligned races and off-size rolling elements.

3. Localized defects: include cracks, pits and spalls

In order to study vibration response of a defected bearing, it is very important to know in the beginning the defect, therefore, the researchers adopted two approaches to create a localized defects One is to run the bearing until failure and monitor the changes in their vibration response. Usually the failure is accelerated by either overloading, over speeding or starving the bearings of lubricants. The other approach is to intentionally introduce defects in the bearings by techniques such as acid etching, spark erosion, scratching or mechanical indentation, measure their vibration response and compare it with that of good bearings [6].

Several techniques have been applied to measure and analyze the vibration

The techniques are classified as

- Time-Domain approach
- Frequency- Domain approach
- Time-frequency domain approach
- Acoustic approach

2.4 Time-frequency domain approach

It is a widely used approach for bearing defect detection, and it is developed due the progress in signal processing techniques and Fourier transform.

This approach, whatever the method is, depends on taking the time vibration signal then converts it into frequency domain, and then study it. The conversion process is developed using FFT to give more accurate reading as show in the figure 6.

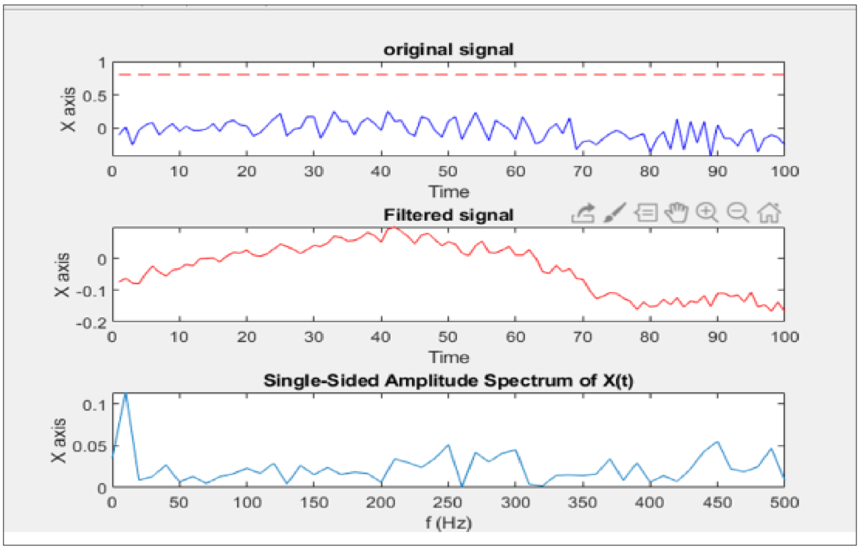

Figure 6 Time and frequency signal

Each bearing element has a characteristic rotational frequency. With a defect on a element, an increase in the vibrational energy at this element's rotational frequency occurs. These characteristic defect frequencies can be calculated from kinematic considerations, i.e., the geometry of the bearing and its rotational speed.

For simplicity to be used in the examples, the characteristics vibration frequencies, the outer ring frequency (fo) and the inner ring frequency (fi) for number of rollers (n) =6,…,12 are:

$F_o=0.4nf_{rm}$

$F_i=0.6nf_{rm}$

f_{rm}: the mechanical rotor speed

3

Chapter three: Components Selection and the design

3.1 Overview

3.2 Eclectic motor

3.3 Arduino

3.4 Accelerometer sensor

3.5 Screen

3.5 The design

3.1 Overview

This chapter explains the components of the system, principle of operation, specification and usage. All components should be well integrated into the system and design.

3.2 Electric Motor

To demonstrate the bearing motion inside the machine , a motor was used show in the figure , by mounting the bearing on the motor shaft, when the motor activates , the shaft turns the bearing, which simulates the bearing inside of a machine , after that the sensor is fixed in place to take the readings.

Figure 7 Motor

Specifications

- Nominal current = 2.9 Amp
- Voltage = 240 volt -50 Hz
- Speed = 2800 RPM
- Power = .5 hp or .37 KW
- Max work = 370 N.m
- Inductance= 10 mH
- Type: a synchronous motor

3.3 Arduino

Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, used to write and upload computer code to the physical board

Arduino board needs a way to be connected to a power source. The Arduino UNO can be powered from a USB cable coming from computer or a wall power supply, Arduino show in the figure

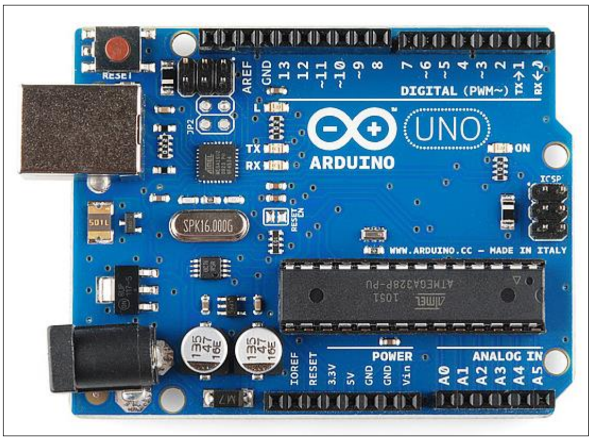

Figure 8 Arduino

Specifications

- Microcontroller: ATmega328
- Operating voltage :5 volt
- Digital I/O pins:14 (6 provide PWM)
- Analog input pins: 6
- DC current per I/O pins: 40 Ma
- Flash memory :32 KB
- SRAM :2 KB
- Clock speed: 16 MHz

3.4 ADXL335 accelerometer sensor

ADXL335 is accelerometer sensor which works on the principle of Piezoelectric effect. whenever we will tilt the sensor the ball is supposed to move in that direction because of Gravitational force. The walls are made of Piezoelectric elements. So, every time ball is touching the wall an electric current will be produced which will be interpreted in the form of values in any 3D space. ADXl335 is a triple axis accelerometer i.e. it will give 3 values in output. BW is adjustable as it has single capacitor per axis. Analog interfacing is done for communicating with other devices like Arduino

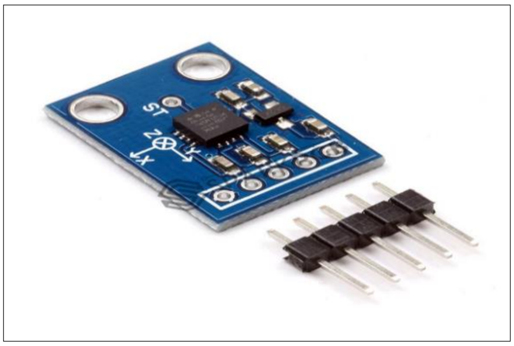

Figure 9 accelerometer sensor

3.5 The designs

The design as shown in figure 10 includes acceleration sensor connected with Arduino to measure vibrations. After the sensor is installed, a set of signals will be taken at time domain, then it will be converted to the frequency domain by fast furious transform (FFT)

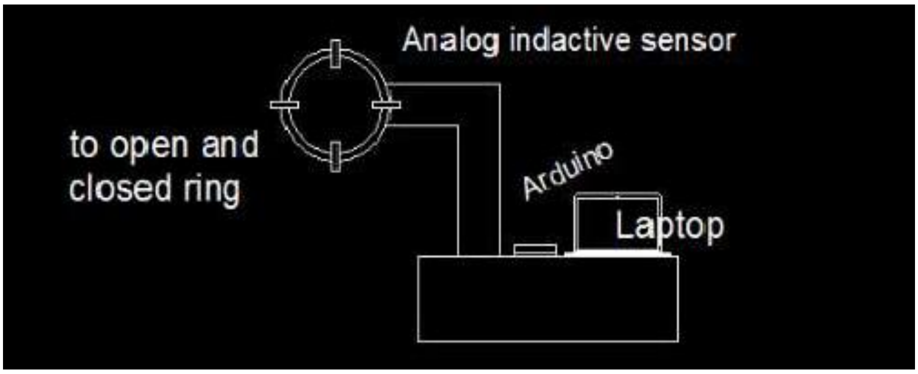

Figure 10 system design

A model was built, in which an ideal bearing and a faulty bearing were fixed to the model, as shown in the figure 11 , when the motor starts , the bearing starts rotating, then the sensor is added to take the readings , this model is built to ease studies and researches, instead of making this process inside the machine, where there is high vibration and noise.

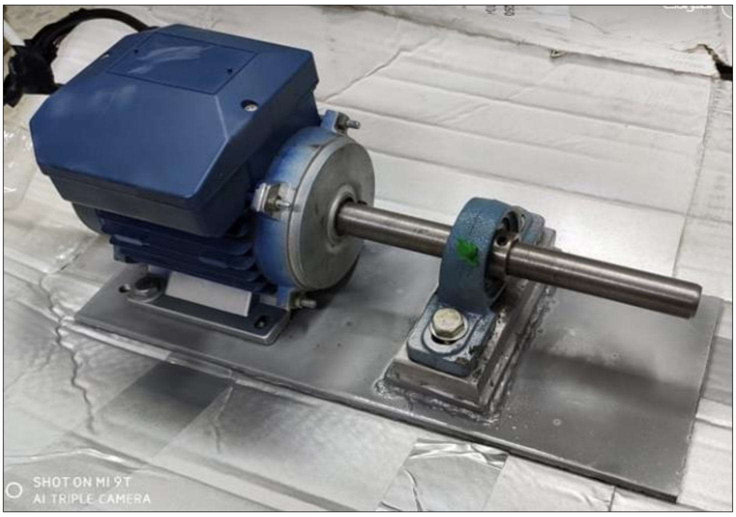

Figure 11 Motor with bearing

Then an Arduino was linked with the sensor, which will be mounted on the bearing afterwards, as shown in the figure 12, so the sensor starts to record the readings in three axes in volt.

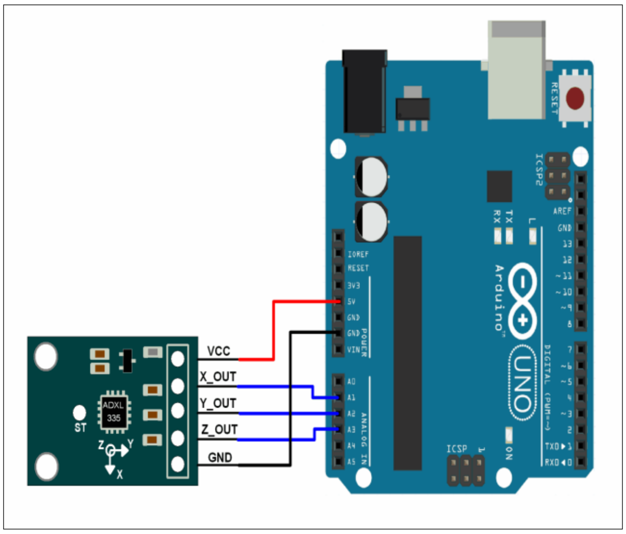

Figure 12 interference between Arduino and accelerometer sensor

Readings for every bearing will be saved, using the MATLAB, a time domain curve is graphed, using FFT it's converted to frequency domain.

After signal filtration a code is written to do the comparison, using this code as a reference, any bearing out of the curve's amplitude is faulty.

4

Chapter four: Result and conclusion

4.1 Result

4.2 conclusion

4.3 recommendation

4.1 Result

in this chapter , the signals will be shown for each of the ideal bearing and faulty bearing and it will be compared, according to the readings of the ideal bearing a code is written , in which the given data is checked , if it is out of range the bearing is faulty , if in range it's accepted.

At the start a bearing in good condition, signal as follow in figure 13 :

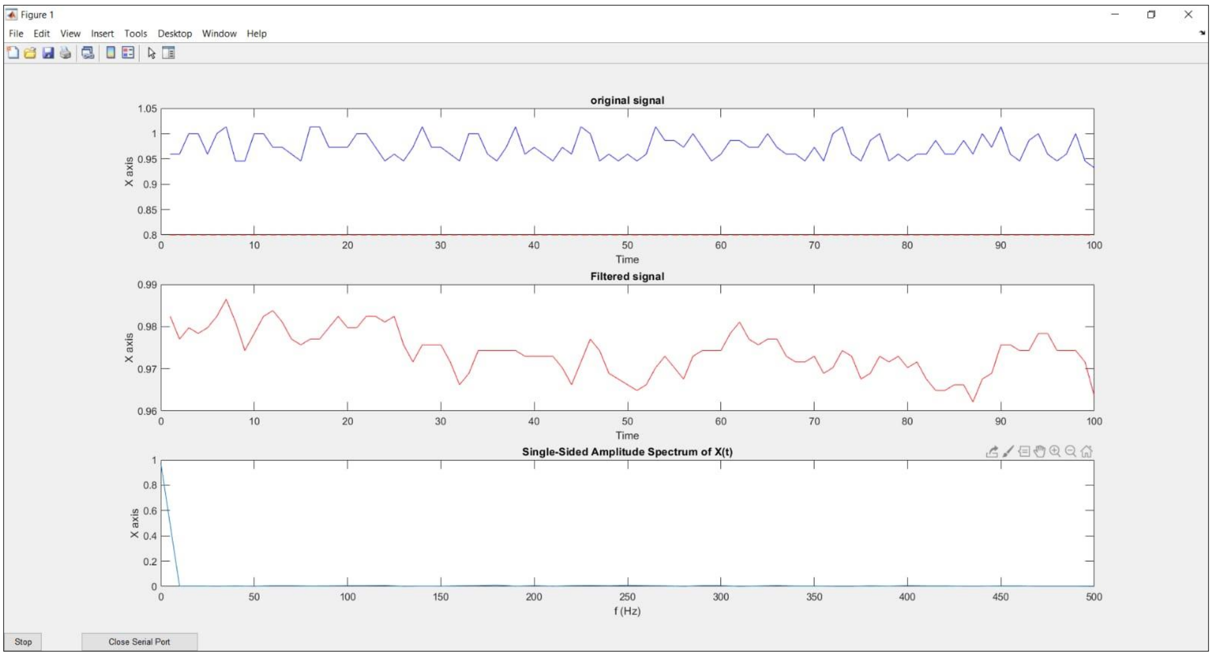

Figure 13Good condition bearing signals No.1

Through figure 13 ,we notice the peak-peak amplitude of the signal resulting from the good condition bearing almost equal .962 V to .986 V .

Another good condition bearing signal show in figure 14:

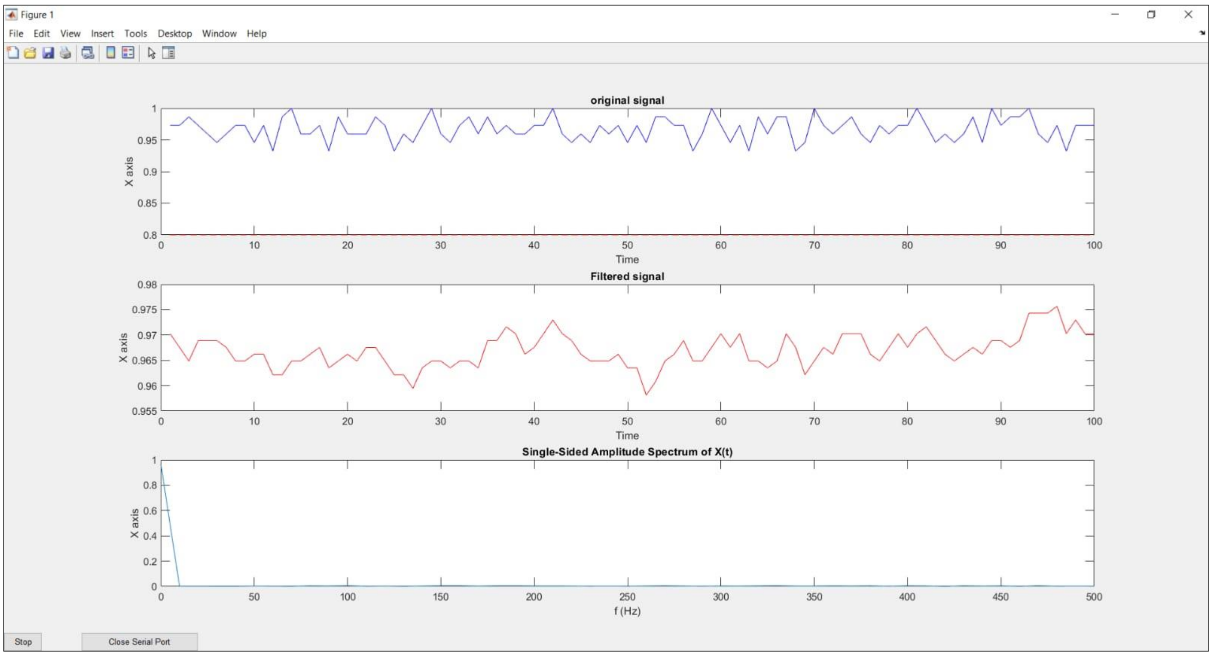

Figure 14Good condition bearing signals No.2

Through figure 14 ,we notice the peak-peak amplitude of the signal resulting from the good condition bearing almost equal .959 V to .974 V .

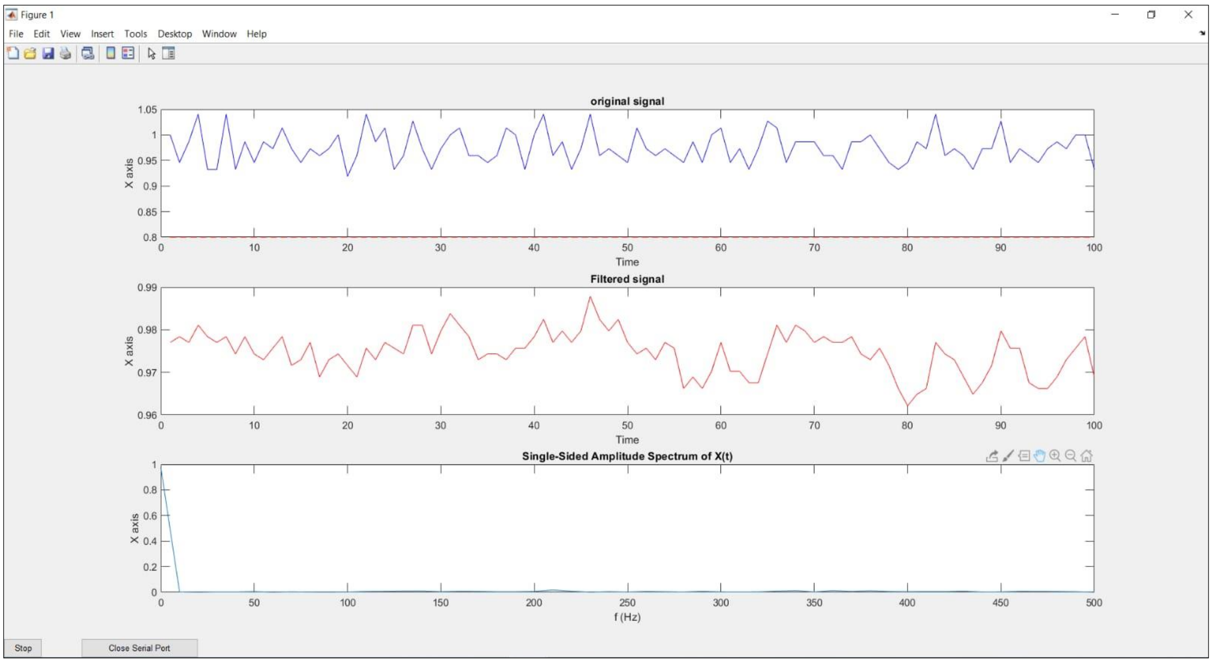

Figure 15 Faulty bearing signals

it's observed that the bearing amplitude is =.96 V to .99 V . , is out of range , so it's categorized as a faulty bearing

4.2 Conclusion

The vibrational methods are the mostly used one in its deferent branched approach. The signal processing techniques development has a great effect on the progress of the testing methods. Now many bearing testers have a signal analyzer to give the result about the bearing; This device is built depending on such a signal processing technique.

The system includes acceleration sensor connected with Arduino to measure vibrations. After the sensor is installed, a set of signals will be taken at time domain, then it will be converted to the frequency domain by fast furious transform (FFT) .

4.3 Recommendation

After completing our system design, there are many points of recommendations to improve the design going forward in the future. It recommended to Add an ultrasonic microphone and a temperature sensor to assess the defects of the roller bearings in different ways. It recommended to use Provide the headset with the device to listen to vibration and recording the voice comments for the sake of recalling the details.

Reference:

1. DIAGNOSTICS OF ROLLING BEARING BY VIBRATION ANALYSIS. Grzegorz WOJNAR, BogusáawàAZARZ, Zbigniew STANIK. s.l. : DIAGNOSTYKA’3 (39), 2006. ISSN.

2. Vibration Based Condition Monitoring and Fault Diagnosis Technologies For Bearing and Gear Components-A Review. S. Devendiran, Dr. K. Manivannan. India: International Journal of Applied Engineering, 2016, Vol. 11, pp. 3966-3975. pp 3966-3975.

3. K. R. FYFE, E.D.S. MUNCK.ANALYSIS OF COMPUTED ORDER TRACKING. Mechanical Systems and Signal Processing. 1997, pp. 167-205.

4. Tahsin Doguer, Jens Strackeljan. New Time Domain Method for the Detection of Roller Bearing Defects. Proceedings of International Conference on Condition Monitoring & Machinery Failure Prevention Technologies CM 2008. 2008.

5. Vibration Based Condition Monitoring and Fault Diagnosis Technologies For Bearing and Gear Components-A Review. S. Devendiran, Dr. K. Manivannan. India: International Journal of Applied Engineering, 2016, Vol. 11, pp. 3966-3975. pp 3966-3975.

6. An Intelligent Fault Diagnosis Method for Bogie Bearings of Metro Vehicles Based on Weighted Improved D-S Evidence Theory. Jianqiang Liu, Aifeng Chen * and Nan Zhao. China: http://www.mdpi.com/journal/energies, 18 January 2018.

Appendix

ADXL335 Datasheet

Parameter	Conditions	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range		±3	±3.6		*g*
Nonlinearity	% of full scale		±0.3		%
Package Alignment Error			±1		Degrees
Interaxis Alignment Error			±0.1		Degrees
Cross Axis Sensitivity[1]			±1		%
SENSITIVITY (RATIOMETRIC)[2]	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 3 V	270	300	330	mV/*g*
Sensitivity Change Due to Temperature[3]	V_S = 3 V		±0.01		%/°C
ZERO *g* BIAS LEVEL (RATIOMETRIC)					
0 *g* Voltage at X_{OUT}, Y_{OUT}	V_S = 3 V	1.35	1.5	1.65	V
0 *g* Voltage at Z_{OUT}	V_S = 3 V	1.2	1.5	1.8	V
0 *g* Offset vs. Temperature			±1		mg/°C
NOISE PERFORMANCE					
Noise Density X_{OUT}, Y_{OUT}			150		µg/√Hz rms
Noise Density Z_{OUT}			300		µg/√Hz rms
FREQUENCY RESPONSE[4]					
Bandwidth X_{OUT}, Y_{OUT}[5]	No external filter		1600		Hz
Bandwidth Z_{OUT}[5]	No external filter		550		Hz
R_{FILT} Tolerance			32 ± 15%		kΩ
Sensor Resonant Frequency			5.5		kHz
SELF TEST[6]					
Logic Input Low			+0.6		V
Logic Input High			+2.4		V
ST Actuation Current			+60		µA
Output Change at X_{OUT}	Self test 0 to 1		−300		mV
Output Change at Y_{OUT}	Self test 0 to 1		+300		mV
Output Change at Z_{OUT}	Self test 0 to 1		+550		mV
OUTPUT AMPLIFIER					
Output Swing Low	No load		0.1		V
Output Swing High	No load		2.8		V
POWER SUPPLY					
Operating Voltage Range		1.8		3.6	V
Supply Current	V_S = 3 V		350		µA
Turn-On Time[7]	No external filter		1		ms
TEMPERATURE					
Operating Temperature Range		−40		+85	°C