

Palestine Polytechnic University
College of Engineering
Mechanical Engineering Department



Demonstration Of Resonance Phenomena Using A Shaking Table

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Submitted to the College of Engineering
in partial fulfillment of the requirements for the
Bachelor degree in Mechanics Engineering

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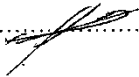
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Supervisor Signature

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Chair of the Department Signature

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Abstract

An educational model (shaking table) designed and implemented to simulate the effect of the harmonic motion on structural and mechanical systems, where various frequencies can be applied on different structures whence weight, the properties or material type, and in our study the structures located above the shaking plate, a structure consists three mass equal on weight and type of material but each mass the height from table is different

The shaking table will be provide to PPU laboratories to enhanced the understanding of the effect of vibration on structures and demonstrate the resonance phenomena and pre- and post-resonance phenomena and comparison between theoretical and experimental result .

The harmonic motion of the shaking table will be generated by stepper motor which moves a mechanism (slider with two gear and timing belt) and the system controlled by an Arduino Uno and Arduino Nano, the various frequencies generated by three Potentiometers.

الملخص

تم تصميم وتنفيذ نموذج تعليمي لمحاكاة تأثير الحركة التوافقية على الابنية و الأنظمة الميكانيكية ،و سوف سيتم في نظامنا تطبيق ترددات مختلفة القيمة على صفيحة, التي تحمل مجموعة من الهياكل التي قد تكون مختلفة عن بعضها من حيث الوزن او نوع المادة او عن مدى ارتفاعها عن القاعدة ,لكن دراستنا اقتصرت على حالة وحدة هي ثلاثة كتل متساوية الوزن و النوع المادة ولكن ارتفاع كل كتلة عن القاعدة مختلف .

سيزود هذا النموذج التعليمي لمختبرات جامعة بوليتكنك فلسطين لتعزيز فهم ظواهر متعلقة بالاهتزازات وبالتحديد ظاهرة الرنين. القدرة على ملاحظة ثلاثة حالات في نفس الوقت عند نفس التردد بحيث كل جسم يسلك طريقة مختلفة بحيث في بعض الحالات يكون جسم ما قبل الرنين و جسم اخر في مرحلة الرنين و الجسم الثالث لعدى المرحلة ,ايضا يتم استخدامه لمقارنة النتائج النظرية التي تيم التوصل لها عن طريق قوانين الاهتزازات مع النتائج العملية للجهاز .

الحركة التوافقية المؤثرة على الصفيحة يمكن الحصول عليها بعدة آليات ميكانيكية , يكمن وظيفتها بعملية تحويل الحركة الدورانية المتولدة من المحرك الى حركة توافقية تقوم بتحريك الصفيحة بنفس الحركة ,وبذلك تتأثر الهياكل الموضوعة على الصفيحة بتلك الحركة وبذلك نقوم بدراسة تأثير تلك القوى المختلفة وملاحظة ظاهرة الرنين.

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Chapter One Overview

- 1.1 Introduction
- 1.2 Problem definition
- 1.3 Solving the problem
- 1.4 Motivation of study
- 1.5 Objective and output of the project
- 1.6 Project Schedule and Time Plan
- 1.7 Budget

1.1 Introduction

Today, more than ever, the role of educational technology in teaching is of great importance because of the opportunity given to the student trying to analyze, design, develop, implement, and evaluate process and tools to enhance learning in ways that are easier, faster and more accurate.

This project aims to clarification the resonance phenomenon, this phenomenon is very important in our life especially at architecture and industry because it's dangerous, so the Engineers and designers careful to be far away from this phenomenon, wherefore it have been designed an educational device to demonstrate this phenomenon to understand it .

This project consists of two essential parts ,the first part is a shaking plate ,and it's considered as a base of the second part ,the shaking plate connect between mechanism and structure ,the second part is the structure , and it consists of three systems each system consists of block ,the three block are equal in weight and each block drawn above a shaking plate with different height.

The motion of the shaking plate could be produced using special mechanism such as cam and follower, ball screw, scotch yoke, crank slider or combination between them. The mechanism has been chosen in this project combination between slider with timing pelt and two gears ,because this mechanism produces harmonic motion and it is available.

1.2 Problem definition

In PPU vibration laboratories there is no enough educational devices and this causes more effort to understand the basic concepts of resonance phenomena, to overcome this problem we will design and implement an educational device

1.3 Solving the problem

Design and implement an educational device to enhanced the understanding of the resonance phenomena.

1.4 Motivation of study

The lack of adequate educational tools in the Palestinian educational institutions that can explain the effect of vibration and frequency on structure also the importance of resonance phenomena so, this thing motive us to design and implement this project to be supplied to institutions.

1.5 Objective and output of the project

The main objectives of this project is:

- 1) To design and implement an educational device to enhance the understanding of the vibration phenomena and specially resonance .
- 2) Design a three models with different natural frequencies to examine the response behavior of structures in order to note the effect of specific frequency on the three structures at the same time.

Shaking table can be used in many ways:

- 1) An educational model that used in educational institutions.
- 2) Model used to study the effect of vibration and frequency on different structures.
- 3) The shaking table consider as an earthquake simulator.
- 4) Using the shaking table in scientific researches.

1.6 Project Schedule and Time Plan

The followings are the distribution of the work for the first semester summarized in table (1.1), and the second semester summarized in table (1.2):

Task 1: Selection of project Idea

At this stage, the determination of the concept and the main idea of the project.

Task2: Collecting the Data

Collecting information about the components and previous studies.

Task 3: Conceptual Design

Conceptual design that describes the system main concept and parameters.

Task 4: Components selection

In this step, selecting the hardware and software components and costs.

Task 5: Documentation

Writing and documenting the projects text.

Task 6: Print documentation

In this step, print documentation.

Task 7: Order the components

Start to order all the components needed to build the shaking table.

Task8: Assemble the machine

Start building project, and then assemble parts of the shaking table.

Task 9: installing, testing and calibration

For each module individually, then for the whole system.

Task 10: implementation and validation

Implementation and making sure there is no problem in the system operations.

Task 11: Documentation of graduation final report

Writing notes and making any necessary additions and modifications on the project documentation.

Table1.1: Time plan for the first semester.

Week Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Task1	█	█	█	█											
Task2			█	█	█										
Task3				█	█	█	█								
Task4							█	█	█	█	█				
Task5										█	█	█	█	█	█

1.8 Budget

The following table (1.3) shows the parts and total costs of the projects prototype:

Table1.3: Budget for Parts and Prices

Item	quantity	price (JD)
Stepper motor	1	38.5
Driver for stepper motor	1	44
Mechanical part(mechanism)	1	108
Nano Arduino	1	14
Power supply	1	22
The structure	1	36
Converter and LCD	2	16
Uno Arduino	1	16
Potentiometer and switches	5	13
Photomicrosensor	1	22
Total		330

2

Chapter Two Concept of vibration

- 2.1 Introduction.**
- 2.2 Classification the project.**
 - 2.2.1 Undamped forced single degree of freedom vibration system.**
 - 2.2.2 Number of degrees of freedom.**
- 2.3 Modeling**
 - 2.3.1 Vibration Analysis Procedure**
- 2.4 Literature Review**

2.1 Introduction

Most human activities involve vibration in one form or other. For example, we hear because our eardrums vibrate and see because light waves undergo vibration. Breathing is associated with the vibration of lungs and walking involves (periodic) oscillatory motion of legs and hands.

Human speech requires the oscillatory motion of larynges. Any motion that repeats itself after an interval of time is called vibration or oscillation. The swinging of a pendulum and the motion of a plucked string are typical examples of vibration. The theory of vibration deals with the study of oscillatory motions of bodies and the forces associated with them.

Vibration could be used to create amazing useful application in our daily life such as musical instrument to produce a special kind of sound that is pleasant to listen by making something vibrate .For example, guitars make sound when their strings vibrate.

Shakers are another example of the application that help to form a homogenous mixture from more than one ingredient. Used in many types of industry, such as food and beverage, cosmetic, pharmaceutical, and electronics, as well as labs that deal with life sciences, wastewater treatment, and biotech, laboratory mixers and shakers are an important part of many labs.

On the another hand vibration could have harmful effect by producing undesirable noise or excessive stresses that can element machine life , so engineers should control the vibration by set the frequency of the machine member and use of some vibrating absorbing material and increase the maximum transmit the load of vibration.

To reduce some predetermined level resonance that can destroy of all systems of machine or any devices. It is the most crucial stage while designing the machine member.

What are resonant frequencies?

Resonance is the phenomenon that occurs when a physical system is periodically disturbed at the same period of one of its natural frequencies.

Resonance is the tendency of a system to oscillate at maximum amplitude at certain frequencies, known as the system's resonance frequencies.

At these frequencies, even small periodic driving forces can produce large amplitude vibrations, because the system stores vibrational energy, as shown in Figure (2.1).

Resonant frequency continue, until the energy loss in the physical system due to non-elastic motion equals the energy supplied by the disturbing force. In extreme cases, the system will exceed its limits and self-destruct before equilibrium occurs.

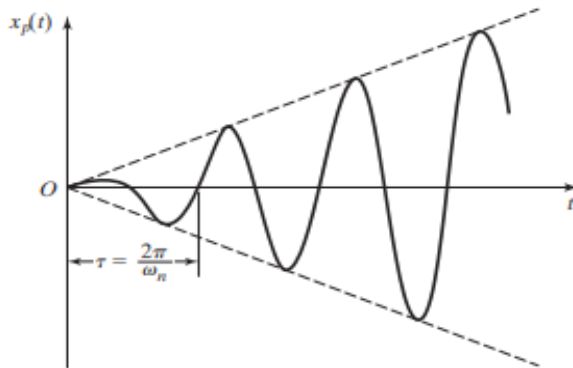


Figure 2.1: Response when $\omega/\omega_n = 1$

When two different waves overlap, a phenomenon known as interference happens. There is positive interference, in which the amplitude of the wave is intensified, and there is destructive interference, when it is diminished or completely destroyed.

Resonance is the phenomenon in which positive interference keeps happening and the wave builds up to an ever-increasing magnitude. A good example of this is a child on a swing. If you time it just right, you can make them go higher without pushing it stronger.

That is exactly what happened with Tacoma's bridge shown in figure (2.2). It was a phenomenon that had been previously noted, so much so that the bridge got nicknamed "Galloping Gertie" for it. Attempts were made to strengthen it, but also, they failed.



Figure 2.2: Tacoma Narrows Bridge

2.2 Classification the project

There are many types of vibration system that can be classified based on the existence of an external forces, damping and number of degree of freedom. Shaking plate is considered as undamped forced single degree of freedom.

2.2.1 Undamped forced single degree of freedom vibration system

What is the undamped forced vibration system?

1) Forced Vibration:

If a system is subjected to an external force (often, a repeating type of force), the resulting vibration is known as forced vibration. The oscillation that arises in machines such as diesel engines is an example of forced vibration. If the frequency of the external force coincides with one of the natural frequencies of the system, a condition known as resonance occurs, and the system undergoes dangerously large oscillations. Failures of such structures as buildings, bridges, turbines, and airplane wings have been associated with the occurrence of resonance.

2) Undamped vibration:

If the energy is not lost or dissipated in friction or other resistance during oscillation, the vibration known as undamped vibration.

2.2.2 Number of degrees of freedom

The minimum number of independent coordinates required to determine completely the positions of all parts of a system at any instant of time defines the number of degrees of freedom of the system.

Single degree of freedom is selected to design shaking plate for these reasons:

1. to be easy to understand the effects of vibration.
2. Less components.
3. Reliable.

2.3 Modeling

The vibration of a system involves the transfer of its potential energy to kinetic energy and of kinetic energy to potential energy, alternately. If the system is damped, some energy is dissipated in each cycle of vibration and must be replaced by an external source if a state of steady vibration is to be maintained.

Whenever the natural frequency of vibration of a machine or structure coincides with the frequency of the external excitation, there occurs a phenomenon known as resonance, which leads to excessive deflections and failure. The literature is full of accounts of system failures brought about by resonance and excessive vibration of components and systems. Because of the devastating effects that vibrations can have on machines and structures; vibration testing has become a standard procedure in the design and development of most engineering systems.

2.3.1 Vibration Analysis Procedure

A vibratory system is a dynamic one for which the variables such as the excitations (inputs) and responses (outputs) are time dependent. The response of a vibrating system generally depends on the initial conditions as well as the external excitations. Most practical vibrating systems are very complex, and it is impossible to consider all the details for a mathematical analysis. Only the most important features considered in the analysis to predict the behavior of the system under specified input conditions. Often the overall behavior of the system can be determined by considering even a simple model of the complex physical system. Thus, the analysis of a vibrating system usually

involves mathematical modeling, derivation of the governing equations, solution of the equations, and interpretation of the results.

2.4 Literature Review

The subject of vibration effects has many studying and research; most of these studies are focused on earthquakes and its influences on structures, so that the researcher on their practical experiments made a vibrating system to work as a natural vibration and observation the resonance frequency influences on these structures.

This project addresses are includes random vibration which has some phenomenon like resonance state and has the equations which is important to explain the motion of the shaking table(equation of motion) and what the relation between input force and output force in any parts in this project.[4][3]

This project talk about the design for any mechanical component like shaking plate, frame table and the columns which need to support the masses (cantilever beam) and the book contain all equation can help to make a design.[2]

Materials science and engineering give the types of materials which used in this project and what the characteristics of there. Also talk about the internal structure for the materials and the deal with stress, strain, stiffness, bending and hardness.[6]

3

Chapter Three

Mechatronics design and Implementation

3.1 Introduction

3.2 Conceptual design

3.3 Mechatronics design

3.3.2 Mechanical components

3.3.2 Electrical components

3.3.3 Control

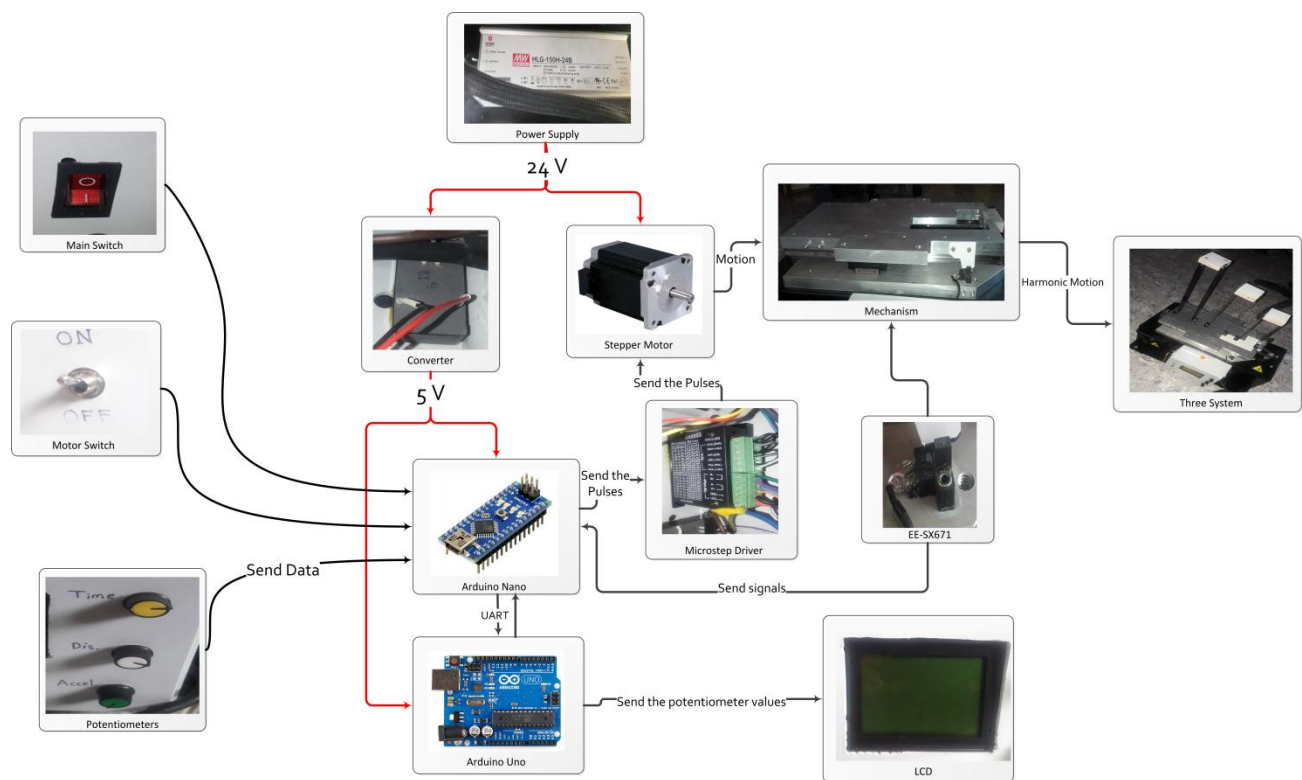
3.3.4 Deflection of the beam

3.1 Introduction

This chapter will contain the conceptual design of the system, the mathematical model for the three systems (structure), and the main connections for the system including the project components. Moreover, the sensing and controlling units will be described with details.

3.2 Conceptual design

The conceptual design describes the whole system, how it will work, and how the main components interface with each other. In addition how is the project and this thing shown in Figure (3.1).



Figure(3.1): Conceptual Design

The basic system units:

1) Control unit: the main purpose of the control unit is to operate the stepper motor on the desired frequency indirect way based on the input signal from the potentiometers

2) Mechanical unit: (the mechanism) convert the rotational motion from the stepper motor to reciprocating motion to the shaking plate, to generate the harmonic motion

3) Electrical unit: stepper motor controlled by driver of the motor, and fasten with the mechanism .

4) Sensing unit: in order to return the plate to home position .

3.3 Mechatronics design.

This section show all components that use in project, and how it was implemented .

3.3.1 Mechanical compounents.

The mechanical components used in the project and the design of them as follow :

1) Shaking plate.

As we explained before the shaking plate. as shown in Figure(3.2) , it is very important part in the project, which has the mission to carry the structure on its surface, and transfer the harmonic motion from mechanism to structure ,but in this state the structure can make some type of forces on this plate like bending moment and shear force which cause a deflection, so to solve this problem the plate need some supporters and in this project was chosen two sliders to do this mission via help the plate to carry the structures so to reduce of occurrence the deflection, the design of the plate, we can notice gap in the plate, we have been drilling the gap intention to see the mechanism.



Figure(3.2):shaking plate with systems

We designed the shaking table with the dimensions shown in Figure (3.3), and the shaking table made of aluminum, it has been chosen this material because it's lightweight and aluminum rustproof, the weight of shaking table 10kg .

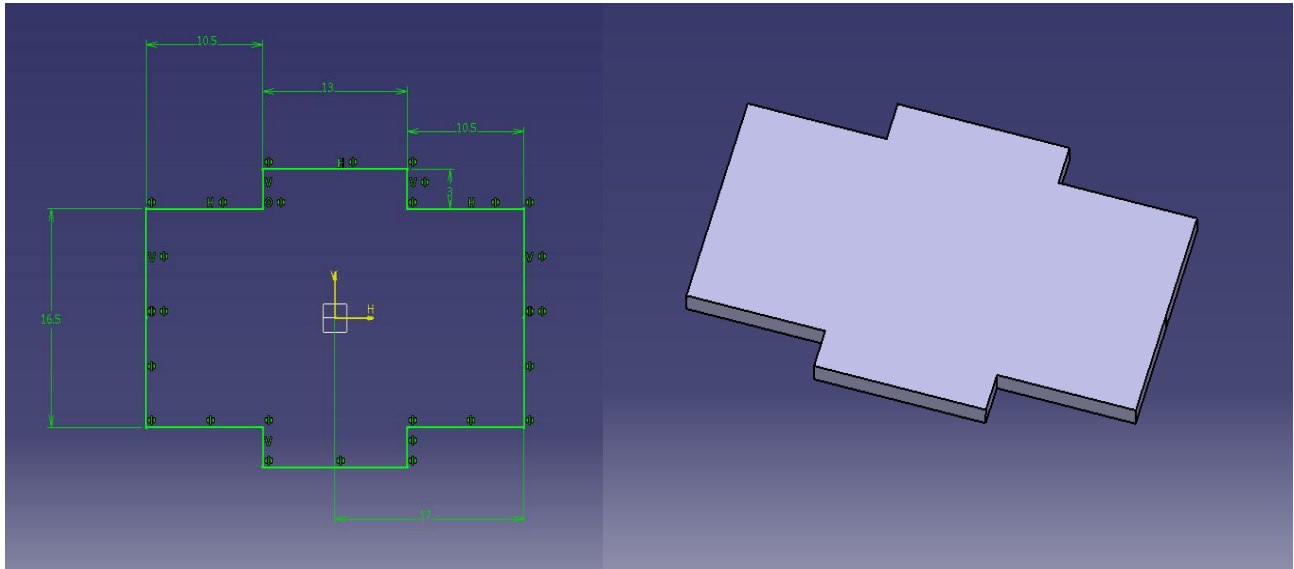


Figure 3.3: the design of shaking table

2) Mechanism.

The mission of the mechanism is to generate harmonic motion to plate this thing by convert the rotational motion from the stepper motor to reciprocating motion to the shaking plate. There are many mechanisms to realize this mission such as cam and follower, ball screw, scotch yoke, crank slider or combination between them. The mechanism has been chosen on the project combination between slider with timing belt and two gears, the mechanism shown in Figure(3.4) and Figure(3.5), the first gear connect with shaft of stepper motor and the second gear existing to connect the timing belt then is done transfer the motion to the slider, we chose this mechanism because it's available, cheap, generate harmonic motion, and the maintenance of system it easy don't need experience.



Figure3.4:Slider mechanism



Figure3.5: Timing belt and two gear mechanism.

3.2.2 Electrical component :

The electrical components that used in the project ,it as follow :

1)Power Supply

A power supply shown in Figure(3.6),is an electrical device that supplies electric power to an electrical load. The primary function in the system is to power supply 24 volt to stepper motor and driver .But, the control unit need 5 volt ,so we used a converter shown in Figure(3.7)to convert 24volt (from power supply) to 5 volt (to supply the control unit).



Figure3.6: Power supply.



Figure3.7: Converter.

2) Potentiometers and switches:

Three potentiometers as shown in Figure (3.8) connect with the analog pins in the Arduino Nano, the first potentiometer (dis.) is used to adjust the moving distance of the table, the second potentiometer (time) is used to set and adjust the time delay between the pulses of the stepper motor and the third potentiometer (accl.) is used to set and adjust the motor's acceleration, so we have three variables can be used to control the motion of plate and the range of frequency.



Figure3.8: Potentiometers.

We have two switch in the system the first switch (main switch) is shown in Figure (3.9),it extends power to all component ,and the second switch(motor switch) is shown in Figure (3.10),it control the status of motor (on or off).



Figure3.9: main switch.



Figure3.10: motor switch.

3) Stepper motor:

A stepper motor shown in Figure (3.11) is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence, and The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

We have chosen this motor because it operates on high torque and high speed and the speed of motor is proportional to the frequency of the input pulses, we use this thing to found the frequency for plate .

This motor has two problems, the first one ,the stepper motor open loop operation so the motor doesn't know where its location ,we solve this problem by using Photomicrosensor (**EE-SX671**), the second problem ,the stepper motor operates on 24 volts , if the motor connect with Arduino ,the Arduino will burn , wherefore we use microstep driver shown in Figure(3.12).

Microstep driver allows a motor to make far finer steps , protection the stepper motor and the system , and it transfer the data (pulse)from Arduino to stepper motor.

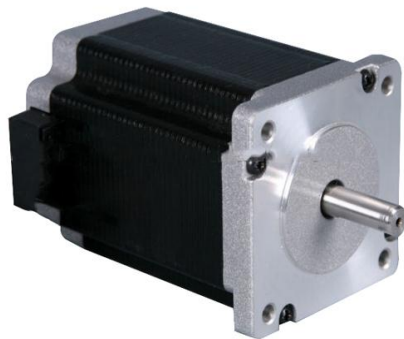


Figure3.11: Stepper motor.

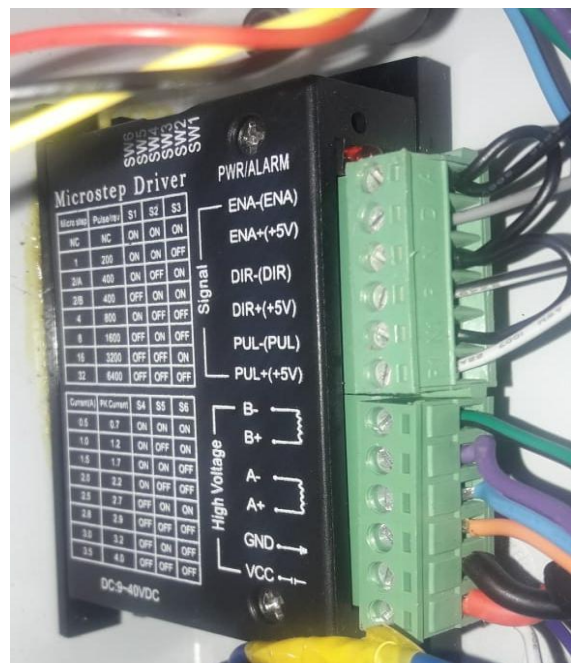


Figure3.12: Microstep driver.

4) Photomicrosensor(**EE-SX671**) :

Photomicrosensor is a compact optical sensor that senses objects or object positions with an optical beam ,it shown in Figure (3.13),the aim for use photomicrosensor, the stepper motor open loop operation ,so we use photomicrosensor to return the plat to home position at the beginning operation the system and control the distance the motor moves, by preventing the engine from coming out after sensor.



Figure3.13: Photomicrosensor.

5) Liquid crystal display(LCD):

LCD used to display the value of the three potentiometers, and it help to know the status of system and it will help to calculation the frequency of system, the LCD show in Figure(3.14).



Figure3.14: LCD.

3.3.3 Controller

The controller unit consists of the Arduino Uno and Arduino Nano ,connect together by using universal asynchronous receiver-transmitter(UART).

Arduino Uno shown in Figure (3.15) is a single-board microcontroller meant to make the application more accessible which are interactive objects and its surroundings. The hardware features with an open-source hardware board designed around an 8-bit Atmel AVR microcontroller.[7]

The Arduino Uno receives the data from Arduino Nano then will be process then show the value of potentiometers on the LCD.the code shown in **APPENDX A**

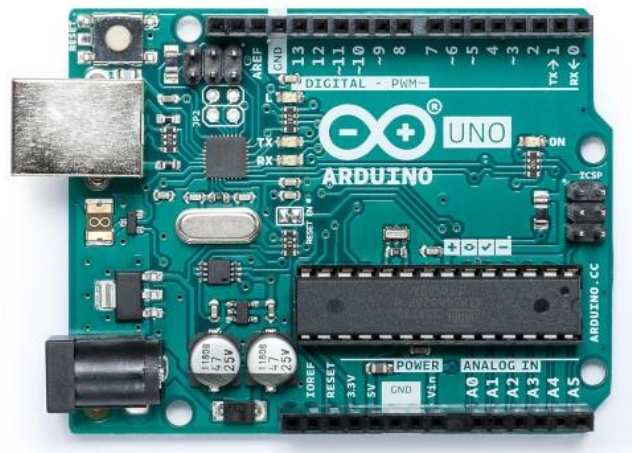


Figure3.15: Arduino Uno

The Arduino Nano shown in figure(3.16) is a small, complete, and breadboard-friendly board based on the ATmega328P; offers the same connectivity and specs of the UNO board in a smaller form factor .we chose Arduino Nano because it is smaller than Uno and a tooling box don't have space to put two Arduino Uno so we chose the Arduino Nano and the second reason for chosen Arduino Nano the number of analog pins is more than Uno .[8]



Figure3.16 : Arduino Nano

The Arduino Nano receives the data from potentiometers then will be process and send the data to the driver of stepper motor to control the motion of stepper motor then send the value of potentiometers to Arduino Uno, and Arduino Nano control the main and motor switches ,the code shown in **APPENDX B**

Why arduino?

- 1) Inexpensive - Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than \$50
- 2) Cross-platform - The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows.
- 3) Simple, clear programming environment - The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well.
- 4) Open source and extensible software - The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based.

5) Open source and extensible hardware - The plans of the Arduino boards are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

Table3.1: The specification of Arduino Uno[7]

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Table3.2: The specification of Arduino Nano[8].

Microcontroller	ATmega328
Architecture	AVR
Operating Voltage	5 V
Flash Memory	32 KB of which 2 KB used by boot loader
SRAM	2 KB
Clock Speed	16 MHz
Analog IN Pins	8
EEPROM	1 KB
DC Current per I/O Pins	40 mA (I/O Pins)
Input Voltage	7-12 V
Digital I/O Pins	22 (6 of which are PWM)
PWM Output	6
Power Consumption	19 mA
PCB Size	18 x 45 mm
Weight	7 g

3.3.4 Deflection of the beam

Above the shaking plate consist three systems , each system consist two beam and mass as shown in Figure(3.17) , We have tested beam made from different materials ,to choose the best material for beam ,the test of beam shown in Figure(3.18),we choose the iron because the deflection of beam clear .



Figure3.17:Three systems .

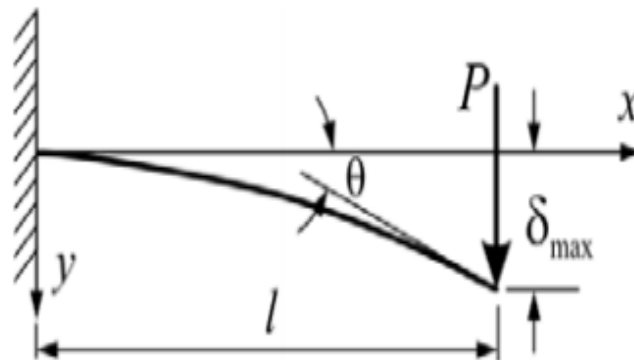


Figure 3.18:Test of material.

But we don't find the modulus of elasticity for the material of beam we chose ,so we did experiments as shown in Figure (3.19) applied a load on beam then find the deflection of beam in applied force ,and by using the data is shown in table(3.3) and using the design equations[2] to find the modulus of elasticity.

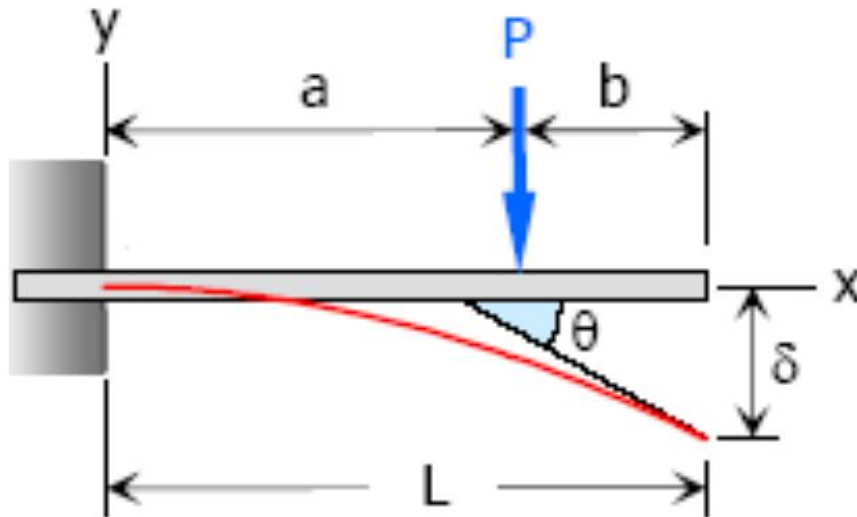


Figure3.19: The deflection of beam

our experience on the first system ,and the applied force =1kg and distance of force (L)=8.5cm,the cross section of beam rectangular so the second moment of inertia for all beams the same ,show in equ(3.1).

$$I = \frac{1}{12}bh^3 \quad (3.1)$$

$$I = \frac{1}{12} \times 30 \times 10^{-2} \times (3.2 \times 10^{-2})^3$$

$$I = \frac{1}{12} \times 3.2 \times 10^{-2} \times (2 \times 10^{-3})^3$$

$$I = 2.13 \times 10^{-11} \text{ m}^4$$

By using the properties of beam and the we find the modulus of elasticity as shown in equ (3.2).

$$E = \frac{Pa^2}{3\delta I} \quad (3.2)$$

$$E = \frac{1 \times 9.81 \times (8.5 \times 10^{-2})^2}{1 \times 10^{-2} \times 3 \times 2.13 \times 10^{-11}} = 111 \text{Gpa}$$

We found the modulus of elasticity to use it to find the spring constant(k) for each system.

1. spring constant for first system .

$$K_1 = \frac{3EI}{L^3} = \frac{3 \times 111 \times 10^9 \times 2.13 \times 10^{-11}}{(30 \times 10^{-2})^3} = 262.7N / m \quad (3.3)$$

The system have two beam parallel so

2. spring constant for second system .

$$K_2 = \frac{3EI}{L^3} = \frac{3 \times 111 \times 10^9 \times 2.13 \times 10^{-11}}{(25 \times 10^{-2})^3} = 453.94N / m$$

The system have two beam parallel so

$$K_{2total} = K_2 + K_2 = 907.89N / m$$

3. spring constant for third system .

$$K_3 = \frac{3EI}{L^3} = \frac{3 \times 111 \times 10^9 \times 2.13 \times 10^{-11}}{(20 \times 10^{-2})^3} = 886.61N / m$$

The system have two beam parallel so

$$K_{3total} = K_3 + K_3 = 1773.225N / m$$

Table 4.1: Information about three system

	First system	Second system	Third system
Dimension (cm)	30x3.2x2	25x3.2x2	20x3.2x2
Wight (kg)	0.062	0.052	0.042

4

Chapter Four

Results and recommendations

- 4.1 Theoretical results.
- 4.2 Experimental results.
- 4.3 Problems that encountered the project & Future work of the project.
- 4.4 Conclusions.

4.1 Theoretical results.

In this section it has been used the spring constant which calculated it in chapter three, to determine the natural frequency for each system ,each system contain two beam with mass between the beam ,three system is shown in Figure (4.1),the weight of each mass =1kg and ,the material of mass is iron and the dimensions=6x6x3.5, it has been choose this dimensions because proportion with the dimensions of shaking plate .

The natural frequency for each systems:

1. First system :

$$W_{n1} = \sqrt{\frac{k_{total1}}{m}} = \sqrt{\frac{525.4}{1}}$$
$$W_{n1} = 22.92 \text{ rad / sec}$$

And

$$f_1 = \frac{W_{n1}}{2\pi} = \frac{22.92}{2\pi} = 3.6 \text{ Hz}$$

2. Second system :

$$W_{n2} = \sqrt{\frac{K_{total 2}}{m}} = \sqrt{\frac{907.89}{1}}$$
$$W_{n2} = 30.13 \text{ rad / sec}$$

And

$$f_2 = \frac{W_{n2}}{2\pi} = \frac{30.13}{2\pi} = 4.79 \text{ Hz}$$

3. Third system :

$$W_{n3} = \sqrt{\frac{K_{total3}}{m}} = \sqrt{\frac{1773.225}{1}}$$

$$W_{n3} = 42.11 \text{ rad / sec}$$

And

$$f_3 = \frac{W_{n3}}{2\pi} = \frac{42.11}{2\pi} = 6.705 \text{ Hz}$$

Where:

Ktotal: spring stiffness (N/m).

m: weight mass (Kg).

f: natural frequency(Hz).

Wn: natural frequency(rad/sec).

4.2 Experimental results.

The data of three potentiometer has been used which shown in LCD to evaluate the experimental results ,by using the main meaning of frequency ,the frequency is the number of occurrences of a repeating event per unit of time.

In the system has been used stepper motor , the stepper motor moves with send number of pulses from the controller to motor ,and it's already known the number of pulses by knowing the distance that shaking table moves .

$$\#of\ pulses = distance \times 85.7$$

Where :

85.7: the calibration value of stepper motor.

Destine: (the value of second potentiometer)

And to evaluate the frequency it's required to know the time of all pulse ,the first potentiometer give the time of one pulse .

$$T_{total} = T \times \#of\ pulses$$

Where

Ttotal: total time of all pulses

T:the time of one pulse (the value of first potentiometer)

1) First system:

(Dis. = 5 mm , Time = 130 msec)

$$\#pulses = 5 \times 85.6 = 428 \text{ pulses.}$$

$$T_{total} = 428 \times 130 \times 10^{-3} = 55.64 \text{ sec}$$

$$f = \frac{428}{2 \times 55.64} = 3.9 \text{ Hz}$$

2) Second system:

(Dis. = 5 mm , Time = 84 msec)

$$\#pulses = 5 \times 85.6 = 428 \text{ pulses.}$$

$$T_{total} = 428 \times 84 \times 10^{-3} = 35.952 \text{ sec}$$

$$f = \frac{428}{35.952 \times 2} = 5.95 \text{ Hz}$$

3) Third system:

(Dis. = 5 mm , Time = 71 msec)

$$\# \text{ pulses} = 5 \times 85.6 = 428 \text{ pulses.}$$

$$T_{\text{total}} = 428 \times 71 \times 10^{-3} = 30.5 \text{ sec}$$

$$f = \frac{428}{2 \times 30.5} = 7 \text{ Hz}$$

now it ready to evaluate the frequency of each system at any time , this process used to find the frequency because the project is consider as an educational model and this proses works to help student to understand how stepper motor work and how can evaluate the frequency.

	Theoretical frequency results.(Hz)	Experimental frequency results.(Hz)	%Error
First system	3.6	3.9	8.3%
Second system	4.79	5.95	24.2%
Third system	6.705	7	4.39%

The system have the percentage of error because the base of the theoretical results, experimental value (the value of modules of elasticity) so it have the some error in the theoretical result.

It has been suppose that each system didn't effect to another system, but the in fact each system effect to another system so this make error in the experimental results.

4.3 Problems that encountered the project & Future work of the project.

We encountered a lot of problems in the project:

1. The delay in implementation of producing the system structures do to the lack of cooperation from some local companies
2. The slow communication process between stepper motor and the Arduino , the problem solved the by coding
3. An ability to run the system on specific frequency due to the undesirable effect on the system input (potentiometer)
4. The stepper motor ,open loop operation ,so it makes problem to find the distance that shaking plat move ,so a photomicrosensor has been used to return the motor to home position .
5. The system at high frequency, it was effect on the system and it moved the system, so a rubber has been used under the system to intake the effect of frequency.

It has been expected that the system will be developed, to be as follow:

1. Using the shaking table as a tester for another system and find out the effect of the frequency produced of the system.
2. Convert the system from single degree of freedom to multi degree of freedom and studying the mod shop of the system.
3. Using the shaking plate to make an earthquake simulator and scientific researches of material and how the frequency effect on material

4.4 Conclusions:

1-The un agreement in the results refer to:

- a) The damping factor is considered zero through the study, but there is a small damping in the system structures.
- b) The three structures are studied as a three discrete system, that's mean each system is studied separately.
- c) The friction and losses found in the mechanisms in this system (Shaking Table).

2-Eash system (structure) does not damage at the calculation natural frequency, because the solution which used is not the exact solution of the any system.

3-The deflection for each layer (the column that holds the mass) increase by the force amplitude.

4-The high natural frequencies haven't large effect on the structures.

5-When increasing the natural frequency we will observe the change of resonance, first in the long structure, then to the middle structure, finally to the shorter structure.

References

- [1] Y. Tagawa and K. Kajiwara, "Controller development for the E-Defense shaking table," *Proceedings of the institution of mechanical engineers, Part I: Journal of Systems and Control Engineering*, vol. 221, pp. 171-181, 2007.
- [2] R. G. Budynas and J. K. Nisbett, *Shigley's mechanical engineering design* vol. 8: McGraw-Hill New York, 2008.
- [3] S. S. Rao and F. F. Yap, *Mechanical vibrations* vol. 4: Prentice Hall Upper Saddle River, 2011.
- [4] P. Koval'chuk and T. Krasnopol'skaya, "Resonance phenomena in nonlinear vibrations of cylindrical shells with initial imperfections," *Soviet Applied Mechanics*, vol. 15, pp. 867-872, 1979.
- [5] N. J. Inamdar, "Educational shaking table modules for earthquake engineering," 2010.
- [6] W. D. Callister and D. G. Rethwisch, *Materials science and engineering: an introduction* vol. 7: John Wiley & Sons New York, 2007.
- [7] <https://components101.com/microcontrollers/arduino-uno>
- [8] <https://components101.com/microcontrollers/arduino-nano>

APPENDIX A

```
#define FASTADC 1

// defines for setting and clearing register bits
#ifndef cbi
#define cbi(sfr, bit) (_SFR_BYTE(sfr) &= ~_BV(bit))
#endif

#ifndef sbi
#define sbi(sfr, bit) (_SFR_BYTE(sfr) |= _BV(bit))
#endif

const uint8_t bufferSize = 6; //unsigned char(0-255)
uint8_t buffer[bufferSize];

int runSwitch = 1;
boolean limitSwitch = false;

int x = 0;

#define max_dis 50
#define max_delay 1000
#define max_accel 1000

#define min_dis 1
#define min_delay 5
#define min_accel 70
```

```

#define calibration 85.71428571428571;

int _delay = min_delay ; // time
int _dis = min_dis;
int accel = min_accel ;
int _steps = 0; //distance
int homingSteps = 0;
int flag1 = 0 , flag2 = 0 , flag3 = 0;;

unsigned long t1 , t2 = 0;

void setup()
{
  while (!Serial);
  Serial.begin(9600);
  buffer[0] = 0x7E;

  //these lines speed up the ADC. no loss of quality
#ifdef FASTADC//fast analog read
  // set prescale to 16=100
  sbi(ADCSRA, ADPS2) ;
  cbi(ADCSRA, ADPS1) ;
  cbi(ADCSRA, ADPS0) ;
#endif
}

```

```

//DDRB=PORTB(DDRB IS the data direction recister
DDRB |= (1 << DDB4); //pin 12 is in output mode (PULSE) the output =1
DDRB |= (1 << DDB3); //pin 11 is in output mode (DIR)
DDRB |= (1 << DDB2); //pin 10 is in output mode (ENABLE)

DDRD &= ~(1 << DDD7); //pin 7 as input (Homing Limit Switch)the out put =0
DDRD &= ~(1 << DDD6); //pin 6 as input (RUN)
while (1)
{

runSwitch = (PIND & B01000000);
if (runSwitch == 0) {
    if (flag3 == 0) {
        PORTB &= ~(1 << PORTB2); //pin #2b=0
        flag3 = 1;
    }
    _steps = _dis * calibration;
    runProccess();
    /*-----> */
    for (int i = 0; i < _steps;)
    {
        limitSwitch = (PIND & B10000000);//read only
        if (limitSwitch) {
            break;
        }
    }
}

```

```

if (limitSwitch == 0 && i == _steps - 1) {
    i--;
}

if (flag1 == 0) {
    flag1 = 1;
    PORTB &= ~(1 << PORTB3);
}

if (accel > _delay) {
    if (i <= _steps / 2) {
        x = map(i, 0, _steps / 2, accel, _delay);
    }

    if (i > _steps / 2) {
        x = map(i, _steps, _steps / 2, accel, _delay);
    }
} else {
    x = _delay;
}

t1 = micros();
if (t1 - t2 >= x) {
    i++;
    t2 = t1;
}

```

```

    PORTB &= ~ (1 << PORTB4);
} else {
    PORTB |= (1 << PORTB4);
}
}
/*<-----*/
runProcess();
for (int i = 0; i < _steps;) //Backward 5000 steps
{

    if (flag1 == 1) {
        flag1 = 0;
        PORTB |= (1 << PORTB3);
    }
    if (accel > _delay) {
        if (i <= _steps / 2) {
            x = map(i, 0, _steps / 2, accel, _delay);
        }

        if (i > _steps / 2) {
            x = map(i, _steps, _steps / 2, accel, _delay);
        }
    } else {
        x = _delay;
    }
}

```

```

t1 = micros();
if (t1 - t2 >= x) {
    i++;
    t2 = t1;
    PORTB &= ~ (1 << PORTB4);
} else {
    PORTB |= (1 << PORTB4);
}
}

}

else {
    PORTB |= (1 << PORTB2);
    flag3 = 0 ;
    runProccess();
}
}
}

void runProccess() {
    runSwitch = (PIND & B01000000);

    _delay = analogRead(A0);

```

```
_dis = analogRead(A1);
accel = analogRead(A2);

_delay = map(_delay , 0 , 1023 , min_delay , max_delay);
_dis = map(_dis , 0 , 1023 , min_dis , max_dis);
accel = map(accel , 0 , 1023 , min_accel , max_accel);
```

```
buffer[1] = _delay / 4;
buffer[2] = _dis;
buffer[3] = accel / 4;
buffer[4] = runSwitch;
buffer[5] = checksum();
```

```
//We send all bytes stored in the buffer
Serial.write(buffer, bufferSize);
}
```

```
uint8_t checksum() {
    uint8_t result = 0;
    uint16_t sum = 0;

    for (uint8_t i = 0; i < (bufferSize - 1); i++) {
        sum += buffer[i];
    }
}
```



```
result = sum & 0xFF; //??
```

```
return result;
```

```
}
```

APPENDIX B

```
#include <openGLCD.h>
#include <bitmaps/Logo_64x64.h>
#define DELAY 1500 // ms delay between examples

#define FASTADC 1
// defines for setting and clearing register bits
#ifndef cbi
#define cbi(sfr, bit) (_SFR_BYTE(sfr) &= ~_BV(bit))
#endif
#ifndef sbi
#define sbi(sfr, bit) (_SFR_BYTE(sfr) |= _BV(bit))
#endif

////////////////////////////////////
const uint8_t header = 0x7E;
const uint8_t bufferSize = 6;

uint8_t buffer[bufferSize];
uint8_t readCounter;
uint8_t isHeader;

//Flag that helps us restart counter when we first find header byte
uint8_t firstTimeHeader;
////////////////////////////////////

String sta; //Status
```

```

int _delay = 0 ; // time
int _dis = 0;
int accel = 0 ;
int _steps = 0; //distance

unsigned long t1 , t2 = 0;

unsigned long timer0 , timer1 , timer2, i0 = 70, i1 = 70 ;

int sig_v[113];
void setup()
{

    //these lines speed up the ADC. no loss of quality
#ifdef FASTADC
    // set prescale to 16
    sbi(ADCSRA, ADPS2) ;
    cbi(ADCSRA, ADPS1) ;
    cbi(ADCSRA, ADPS0) ;
#endif

    //////////////////////////////////////
    while (!Serial);
    Serial.begin(9600);

    readCounter = 0;
    isHeader = 0;
    firstTimeHeader = 0;

```

```
////////////////////////////////////
```

```
pinMode(19, INPUT);
```

```
GLCD.Init();
```

```
GLCD.SelectFont(System5x7);
```

```
GLCD.DrawBitmap(Logo_64x64, GLCD.Width / 2 - 32, 0);
```

```
delay(DELAY);
```

```
GLCD.ClearScreen();
```

```
GLCD.DrawString(F("System Starting!"), gTextfmt_center, gTextfmt_center);
```

```
delay(1000);
```

```
GLCD.ClearScreen();
```

```
GLCD.Init();
```

```
GLCD.ClearScreen();
```

```
GLCD.SelectFont(System5x7, BLACK);
```

```
GLCD.CursorToXY( 0, 2);
```

```
GLCD.print("5V");
```

```
GLCD.CursorToXY(0, 36);
```

```
GLCD.print("0V");
```

```
GLCD.DrawVLine(14, 0, 44, BLACK); //DrawVLine(x, y, height, [color]);
```

```
GLCD.DrawHLine(0, 44, 127, BLACK); //DrawHLine(x, y, width, [color]);
```

```
GLCD.DrawHLine(11, 43, 3, BLACK);
```

```
GLCD.DrawHLine(11, 22, 3, BLACK);
```

```
GLCD.DrawHLine(11, 0, 3, BLACK);
```

```
GLCD.CursorToXY(0, 57);
GLCD.print("Ti/Div:");

GLCD.DrawVLine(78, 55, 8, BLACK);
GLCD.CursorToXY(82, 57);
GLCD.print("A:");
```

```
while (1)
{
    getValues();
    // int sig = analogRead(0);
    int test_up, test_down;
    int time_div;
    int min_amp = 43, max_amp = 0;

    for (int i = 0; i < 113; i++)
    {
        getValues();
        //sig= analogRead(0);
        //delayMicroseconds(10);

        sig_v[i] = map(analogRead(5), 0, 1023, 0, 43);
        time_div = 700;
        delayMicroseconds(time_div);
    }
    //GLCD.ClearScreen() ;
```

```

GLCD.FillRect( 15, 0, 112, 43, WHITE);
GLCD.DrawVLine(70, 0, 43, BLACK);
GLCD.DrawHLine(14, 22, 113, BLACK);
for (int i = 0; i < 113; i++)
{
  getValues();
  test_up = (43 - sig_v[i + 1]) - (43 - sig_v[i]);
  test_down = (43 - sig_v[i]) - (43 - sig_v[i + 1]);
  if (test_up > 0 && i != 112)
  {
    GLCD.DrawLine( i + 15, 43 - sig_v[i], i + 15, 43 - sig_v[i + 1], BLACK);
  }
  else if (test_down > 0 && i != 112)
    GLCD.DrawLine( i + 15, 43 - sig_v[i + 1], i + 15, 43 - sig_v[i], BLACK);
  else
    GLCD.SetDot(i + 15, 43 - sig_v[i], BLACK);
  //Serial.println(sig_v[i]);
  min_amp = min(min_amp, sig_v[i]);
  max_amp = max(max_amp, sig_v[i]);
}

GLCD.CursorToXY(40, 57);
GLCD.print(time_div);
GLCD.print("uS");
GLCD.CursorToXY(94, 57);
GLCD.print((max_amp - min_amp) / 10.6);

```

```

    GLCD.print("V");
}

}

uint8_t verifyChecksum(uint8_t originalResult) {
    uint8_t result = 0;
    uint16_t sum = 0;

    for (uint8_t i = 0; i < (bufferSize - 1); i++) {
        sum += buffer[i];
    }
    result = sum & 0xFF;

    if (originalResult == result) {
        return 1;
    } else {
        return 0;
    }
}

void padding( int number, byte width ) {
    int currentMax = 10;
    for (byte i = 1; i < width; i++) {
        if (number < currentMax) {
            GLCD.print("0");

```

```
    }  
    currentMax *= 10;  
  }  
  GLCD.print(number);  
}
```

```
void getValues() {
```

```
  if (Serial.available() > 0) {  
    //read only one byte at a time  
    uint8_t c = Serial.read();
```

```
    //Check if header is found
```

```
    if (c == header) {  
      if (!firstTimeHeader) {  
        isHeader = 1;  
        readCounter = 0;  
        firstTimeHeader = 1;  
      }  
    }  
  }
```

```
  //store received byte, increase readCounter
```

```
  buffer[readCounter] = c;  
  readCounter++;
```

```
  //prior overflow, we have to restart readCounter
```

```
  if (readCounter >= bufferSize) {
```



```

readCounter = 0;

//if header was found
if (isHeader) {
    //get checksum value from buffer's last value, according to defined protocol
    uint8_t checksumValue = buffer[5];

    //perform checksum validation, it's optional but really suggested
    if (verifyChecksum(checksumValue)) {
        //We'll employ PWM to control each RGB Component in the Led
        if (buffer[4] == 0) {
            sta = "1";
        } else {
            sta = "0";
        }
        GLCD.CursorToXY(0, 47);
        GLCD.print("T");
        padding( buffer[1] , 3);
        GLCD.print(" ");
        GLCD.print("D");
        padding( buffer[2] , 3);
        GLCD.print(" ");
        GLCD.print("AL");
        padding( buffer[3] , 3);
        GLCD.print(" ");
        GLCD.print("ST");
        GLCD.print(sta);
    }
}

```

```
}  
  
//restart header flag  
isHeader = 0;  
firstTimeHeader = 0;  
}  
}  
}  
}
```