Sudan University of Science and Technology

College of Engineering

Electrical Engineering Department

Design and Implementation of Magnetic levitation Train System

تصميم وتنفيذ نظام قطار التعليق المغناطيسي

A Project Submitted In Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering

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الآية

قال تعالى :

" الله لا إله إلا هو الحي القيوم لا تأخذه سنة ولا نوم له ما في السماوات وما في الأرض من ذا الذي يشفع عنده إلا بإذنه يعلم ما بين أيديهم وما خلفهم ولا يحيطون بشيء من علمه إلا بما شاء وسع كرسيه السماوات والأرض ولا يئوده حفظهما وهو العلي العظيم "

صدق الله العظيم

البقرة (255)

DEDICATION

Every challenging work needs self-efforts as well as guidance of elders especially from who are very close to our hearts. Our humble effort is dedicated to our sweet and loving parents, our brothers, sisters, friends and their affection and encouragement that led us to be honored to be able to get such success. This project would have never been possible without their support and love.

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First and foremost, we would like to thank our God who bestowed his blessings upon us. We would like to express our sincere gratitude to our advisor **Ust.Galal Abdalrahman Mohammed** for his instructions, excellent guidance and support to complete the work in his fair way.

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Lastly, we need to thank our teachers in electrical and nuclear engineering school for their support.

Abstract

Classical trains are a series of vehicles moving on a specific track called"railways". This type of train depends on the friction between the areas and rods in its path, which limits its speed and increases the need to maintain it continuously.

In this research, the hybrid electromagnetic suspension system has been studied, which is based on magnetic force, where the train is used with electric and permanent magnets, the magnetic field lift the train of the rail, helping to move easily without frication.

A Maglev train had been designed depending on repulsive magnetic force to levitate and aerodynamic force to move. After studying the system's components such as: DC motor, Neodymium magnets, microprocessors and Bluetooth. An Arduino C programming language had been used to write codes to remotely control the train. The microcontroller receives control signals from a Smartphone through electromagnetic waves and then interprets it and function accordingly.

State space equations had been concluded for the electromagnetic of the magnetic levitation system. Matlab had been used to study the system's response and designing a controller to improve the system's stability. The new system's characteristics were seen to be very appealing because of the high stability range that had been produced.

المستخلص

القطارات التقليدية عبارة عن سلسلة متصلة من العربات تتحرك في مسار محدد يسمى خطوط السكة الحديدية وهذا النوع من القطارات يعتمد على الأحتكاك بين المجالات والقضبان في سيره مما يحد من سرعته و يزيد من الحوجة لصيانته بصورة مستمرة.

في هذا البحث تم دراسة نظام التعليق المغناطيسي الهجين الذي يعتمد على القوة المغناطيسية، حيث يتم استخدام القطار مع مغناطيسيات كهربية ودائمة فتقوم المجالات المغناطيسية برفع القطار عن السكة مما يساعد على الحركة بسهولة من غير احتكاك.

تم تصميم نموذج قطار طفو مغنطيسي يعتمد في طفوه على قوة التنافر المغنطيسي وفي حركته على قوة الدفع الهوائية وذلك بعد دراسة مكونات المنظومة من مغنطيسات مثل محرك التيار المستمر والمغنطيسات الدائمة والمتحكم الدقيق والبلوتوث، تم استخدام لغة برمجة (Arduino C) لكتابة أوامر التحكم في القطار عن بعد حيث يستقبل المتحكم اشارات التحكم من هاتف ذكي عن طريق الموجات الكهرومغنطيسية ويقوم بتفسيرها وتوليد اشارات التحكم.

تم ايضا استنباط المعادلات الوصفية للتعليق المغنطيسي عن طريق المغناطيس الكهربي وتم استخدام الماتلاب لدراسة استجابة النظام وتصميم متحكم يؤدي الى الاتزان، وقد اعطى النظام الجديد مدى اتزان عالي. تم اختبار النظام عمليا وملاحظة استجابته الطبيعية.

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LIST OF ABBREVIATIONS

PID	Proportional Integral Derivative
DC	Direct Current
PWM	Pulse Width Modulation
AC	Alternative Current
CPU	Central processing unit
RAM	Random Access Memory
ROM	Read Only Memory
LED	Light Emitting Diode
LCD	Liquid crystal display
MOSFET	metal-oxide semiconductor field-effect transistor
MAGLEV	Magnetic levitation
SPP	Serial Port Protocol
IC	Integrated circuit
IDE	Integrated Development Environment
USB	Universal Serial Bus
VIN	Input voltage
GND	Ground pins
SISO	Serial input serial output

LIST OF SYMBOLS

l	electro magnet coillength, m
A	electro magnetcore sectional area, m^2
m	Mass of the steel ball, kg
f_g	Steel ball weight, N
g	Gravity acceleration, m/sec^2
f_m	electro magnet force, N
N	electro magnet coil turns, turns
L	electro magnet coil inductance, Henry
R	electro magnet coil resistance, Ohm
x	Distance between electromagnet and the ball,m
x_0	Equilibrium pointdistance,m
i_0	Equilibrium point current,Amp
k	electro magnet force constant,$N.A^2/m^2$
$i(t)$	electro magnet coilcurrent,Amp
$v(t)$	electro magnet coil terminal voltage,V

CHAPTER ONE

INTRODUCTION

1.1 General Concepts

Overcoming the grip of the earth's gravity has been a major challenge for years. However, the work of scientists and engineers who have found many ways to levitate a variety of objects is being applied in the field of transportation in several countries.

A long with the increase of population and expansion in living zones, automobiles and air services cannot afford mass transit anyone. Accordingly, demands for innovative means of public transportation have increased. In order to appropriately serve the public, such a new-generation transportation system must meet certain requirements.

Maglev (derived from magnetic levitation) uses magnetic levitation to propel vehicles. With maglev, a vehicle is levitated a short distance away from a "guide way" using magnets to create both lift and thrust. High-speed maglev trains promise dramatic improvement for human travel.

The Magnetic Levitation (Maglev) train is one of the best candidates to satisfy: rapidity, reliability and safety. While conventional train drives forward by using friction between wheels and rails, the maglev train replaces wheels by electromagnets and levitates on the guide way, producing propulsion force electromechanically, without any contacts.

The Maglev train looks to be very promising solution for the near future, many researchers have developed technologies such as modeling and analysis of linear electric machinery superconductivity, permanent magnets.

1.2 Problem Statement

The Wheel-on-rail systems suffers from numerous problems mostly is caused by the friction because of the weight that the train applies to the rail which cause loss in energy. The wheel-on-rail systems can't reach high speeds. The wheel-on-rail systems are environmentally unfriendly; it can be represented as the conventional train.

Conventional train drives forward by using friction between wheels and rails. This friction causes many problems such as noise, vibration, reduces acceleration and needs periodical maintenance.

The maglev train replaces wheels by electromagnets and levitates on the guide way, producing propulsion force electromechanically without any contact.

1.3 Objectives

The main objective of this study is to:

- Design a magnetic levitating system
- Build a maglev train model

1.4 Methodology

- To study the mechanism of the magnetic fields and the relationship between the levitation/movement and the magnets.
- Build a levitating moving ‘maglev’ train model
- Designing and modeling a levitation system

1.5 Project lay-out

The project consists of five chapters: Chapter One presents an introduction to the principles of the project, project motivation and objectives. Chapter Two consists of theoretical background of automatic control, magnetic levitation, magnetic levitation train, microcontroller system, PID controller, nonlinear systems, linearization of nonlinear systems, transistor and freewheeling diode. Chapter Three concerns with system description, system hardware and software and modeling. Chapter Four presents the simulation and result , the system fabrication , the system control circuit implementation, the prototype design and the testing. Finally, Chapter Five presents a conclusion and recommendations for future works.

CHAPTER TWO

THEORETICAL BACKGROUND and LITERATURE REVIEW

2.1 Control System

In our daily lives there are numerous “objectives” that need to be accomplished .For instance, in the domestic domain; we need to regulate the temperature and humidity of homes and buildings for comfortable living. For transportation, we need to control the automobile and airplane to go from one point to another accurately and safely. Industrially, manufacturing process contain numerous objectives for products that will satisfy the precision and cost effectiveness requirements. [1]

Automatic control has played a vital role in the advance of engineering and science. In addition to its extreme importance space-vehicle systems, missile-guidance systems, robotic systems, and the like, automatic control has become an important and integral part of modern manufacturing and industrial processes.

A control system consists of subsystems and processes (or plants) assembled for the purpose of obtaining a desired output with desired performance, given a specified input. It is used to manages, directs, or regulates the behavior of other devices or systems using control loops. It can range from a single home heating controller using a thermostat controlling a domestic boiler to large industrial control systems which are used for controlling processes or machines. [3]

Figure 2.1: Simplified description of a control system

There are two common classes of control systems, open loop control systems and closed loop control systems. In open loop control systems output is generated based on inputs .In closed loop control systems current output is taken into consideration and corrections are made based on feedback . A closed loop control systems is also called a feedback control system.

2.1.1Historical review

The first significant work in automatic control was James Watt's centrifugal governor for the speed control of a steam engine in the eighteenth century.

In 1922, Minorsky worked on automatic controllers for steering ships and showed how stability could be determined from the differential equations describing the system. In 1932, Nyquist developed a relatively simple procedure for determining the stability of closed-loop systems on the basis of open-loop response to steady-state sinusoidal inputs. In 1934, Hazen, who introduced the term servomechanisms for position control systems, discussed the design of relay servomechanisms capable of closely following a changing input.

During the decade of the 1940s, frequency-response methods (especially the Bode diagram methods due to Bode) made it possible for engineers to design linear closed loop control systems that satisfied performance requirements. From the end of the 1940s to the early 1950s, the root-locus method due to Evans was fully developed.

Since the late 1950s, the emphasis in control design problems has been shifted from the design of one of many systems that work to the design of one optimal system in some meaningful sense.

Since about 1960, because the availability of digital computers made possible time-domain analysis of complex systems, modern control theory, based on time-domain analysis and synthesis using state variables, has been developed to cope with the increased complexity of modern plants and the stringent requirements on accuracy, weight, and cost in military, space, and industrial applications. During the years from 1960 to 1980, optimal control of both deterministic and stochastic systems , as well as adaptive and learning control of complex systems, were fully investigated. From 1980 to the present, developments in modern control theory centered on robust control, H, control, and associated topics. [3]

Now that digital computers have become cheaper and more compact, they are used as integral parts of control systems. Recent applications of modern control theory include such no engineering systems as biological, biomedical, economic, and socioeconomic systems.

2.1.2 Open-loop control system

The open- loop control system refers to systems in which the output has no effect on the control action. In other words, in an open- loop control system the output is neither measured nor fed back for comparison with the input. One practical example is a washing machine. Soaking, washing, and rinsing in the washer operate on a time basis, the machine does not measure the output signal, that is, the cleanliness of the clothes.

In any open-loop control system the output is not compared with reference input .Thus, to each reference input there corresponds a fixed operating condition; as a result, the accuracy of the system depends on calibration. In the presence of disturbances, an open-loop control system will not perform the desired task. Open-loop control can be used, in practice, only if the relationship between the input and output is known if there are neither internal nor external disturbances. Clearly, such systems are not feedback control systems.

The figure 2.2 starts with a subsystem called an input transducer, which converts the form of the input to that used by the controller. The controller drives a process or a plant. Other signals, such as disturbances, are shown added to the controller and process outputs via summing junctions, which yield the algebraic sum of their input signals using associated signs .[2]

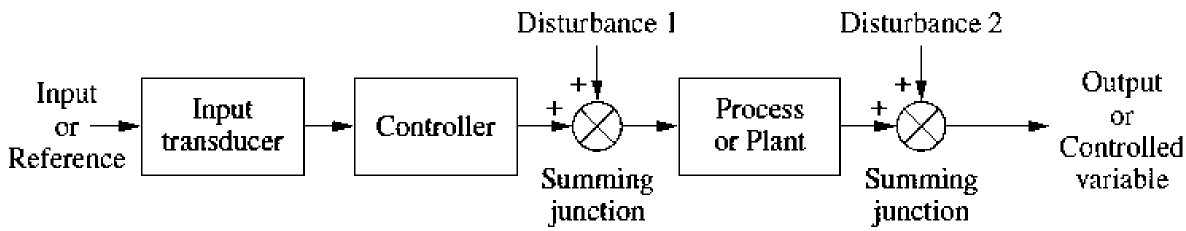

Figure 2.2: Block diagram of an open-loop control system

2.1.3 Closed – loop control systems

A system that maintains a prescribed relationship between the output and the reference input by comparing them and using the difference as a means of control is called a closed-loop control system .An example would be a room temperature control system. By measuring the actual room temperature and comparing it with the reference temperature, the thermostat turns the heating or cooling equipment on or off in such a way as the ensure that the room temperature remains at a comfortable level regardless of outside conditions.

In a closed-loop control system the actuating error signal, which is the difference between the input signal and the feedback signal (which may be the output signal itself or function of the output signal at its derivatives and/or integrals), is feedback to the controller so as to reduce the error and bring the output of the system to a desired value.

The term closed-loop control always implies the use of feedback control action in order to reduce system error.

In figure 2.3 the input transducer converts the form of the input to the form used by the controller. An output transducer, or sensor, measures the output response and converts it into the form used by the controller. The first summing junction algebraically adds the signal from the input to the signal from the output, which arrives via the feedback path, the return path from the output to the summing junction. The output signal is subtracted from the input signal. The result is generally called the actuating signal. The actuating signal's value is equal to the actual difference between the input and the output. Under this condition, the actuating signal is called the error.

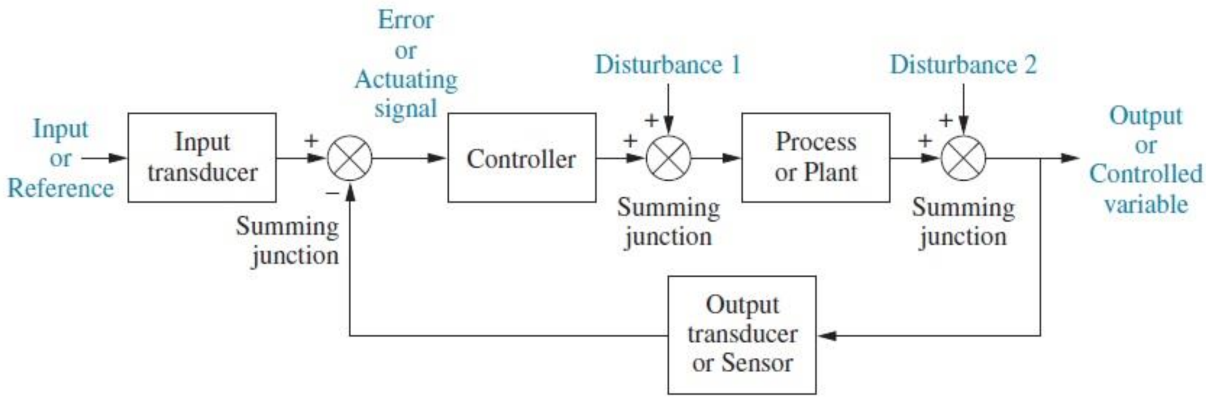

Figure 2.3: Block diagram of a close-loop control system

2.1.4 Advantages of Control System

With control systems we can move large equipment with precision that would otherwise be impossible. We can point huge antennas toward the farthest reaches of the universe to pick up faint radio signal controlling these antennas by hand would be impossible. Because of control systems, elevators carry us quickly to our destination, automatically stopping at the right floor. We alone could not provide the power required for the load and the speed; motors provide the power, and control systems regulate the position and speed. [2]

- **Magnets**

Magnet is a piece of iron or an ore ,alloy , or other material ,that has its component atoms so ordered that the martial exhibits properties of magnetism , such as attracting other iron –containing objects or aligning itself in an external magnetic flied .There are three main types of magnets .Temporary , Permanent , and electromagnets .

- **Temporary**

Iron can be easily magnetized by even a weak magnetic field .However, when the magnetic field removed, the object gradually loses its magnetism.

- **Permanent**

Examples are a linco (Aluminum Nickel Cobalt alloy) and ferrites .Once they are magnetized, these objects do not easily lose their magnetism.

- **Electromagnet**

They are model by placing a metal core inside a coil of wire that is caring an electrical current. The electricity going through the wire produces a magnetic field .while the electric current is flowing, the core acts as a strong magnet.

2.2 Magnetic Levitation

The term “levitation “refers to a class of technologies that uses magnetic levitation to propel vehicles with magnets rather than with wheels, axles and bearings.

Levitation provides contactless movement and removes friction problem, thus improves efficiency and removes noise.

Magnetic levitation (Maglev) is a technique to suspend an object without any mechanical support.

Magnetic levitation technology provides contactless movement and remove friction problem. It has been used in many industrial systems including in high- speed maglev trains, frictionless bearings, electromagnetic cranes, levitation of wind tunnel models, vibration isolation of sensitive machinery, levitation of molten metal in induction furnaces , rocket - guiding projects , levitation of metal slabs during manufacture and high- precision positioning of wafers in photolithography . This technology is able to serve reliable and high-speed operations with the use of feedback controllers [4,5]

2.3 Magnetic Levitation Train

Maglev train is a very fast type of High-speed rail, it does not have an engine; the train is powered by a magnetic field created by the electrified coils in the guide way walls and track.

2.3.1 History

In 1902 the first magnetic train was invented by “Alfred Zehden” of Germany.

In 1934 a series of German patents for magnetic levitation trains propelled by linear motors were awarded to “Hermann Kemper”.

The first use of “maglev” in a United States patent was in “Magnetic levitation guidance system” by Canadian patents and development limited.

“Trans rapid” was the first maglev train with long stator propulsion licensed for passengers transportation, it is a German developed high-speed monorail train using magnetic levitation, it ‘s operations were extended three months, having carried more than 50,000 passengers .

In 1959 the design for the first magnetic train was created.

In 1979 the first magnetic train was built in Hamburg, Germany but was closed month later.

In 1984 the first train that people could ride was built in Birmingham, England.

In 2004 the fastest maglev that people can ride on was created in Shanghai, China.

2.3.2 Advantages of maglev train

In order to appropriately serve the public, maglev train meets certain requirements such as: rapidity, reliability, safety.

In addition, maglev train achieves: convenient, environment-friendly, low maintenance, compact, light-weight and suited to mass-transportation.

While conventional train drives forward by using friction between wheels and rails , the maglev train replace wheels by electromagnets and levitates on the guide way , producing propulsion force electromechanically without any contact, so the advantages of the maglev train over the conventional wheel-on-rail system are :elimination of wheel and track wear providing consequence reduction in maintenance costs , distributed weight-load reduces the construction costs of the guide way, owing to its guide way maglev train will never be derailed, the absence of wheels removes much noise and vibration , noncontact system prevent it from slipping and sliding in operation , achieves higher grades and curves in smaller radius , accomplishes acceleration and deceleration quickly , makes it possible to eliminate gear, coupling , axels and bearings. And it’s less susceptible to weather conditions.

2.3.3 Types of maglev train

- EMS maglev train

  EMS refers to “Electromagnetic Suspension”, the levitation is accomplished based on the magnetic attraction force between a guide way and electro magnets.

The methodology is inherently unstable due to characteristic of the magnetic circuit. Therefore, precise air-gap control is indispensable in order to maintain the uniform air-gap.

Because EMS is usually used in small air gaps like ±10 mm, as speed becomes higher, maintaining control becomes difficult.

EMS is easier than EDS technically and it is able to levitation itself in zero or low speed (it is impossible with EDS type).

In EMS there are two types of levitation technologies:

-The levitation and guidance integrated type such as Korean UTM and Japanese HSST.

-The levitation and guidance separated type such as German Trans rapid.

The levitation and guidance separated type is favorable for high speed operation because; levitation and guidance do not interface with each other the number of controllers increases.

The levitation and guidance integrated type is favorable for: low-cost and low speed operation; because the number of electromagnets and controllers is reduced, and the guiding force is generated automatically by the difference of reluctance.

The rating of electric power supply of the integrated type is smaller than that of the separated type, but as speed increases, the interference between levitation and guidance increase and it is difficult to control levitation and guidance simultaneously in the integrated type.

In general, EMS technology employs the use of electromagnets but nowadays, there are several reports concerning EMS technology using superconductivity which is usually used for EDS technology.

Development of the high temperature superconductor creates an economical electromagnet even though it has some problems such as with the cooling system.

- EDS maglev train

  EDS refers to “Electrodynamics Suspension)”uses repulsive force for the levitation. When the magnets attached on board move forward in the inductance coils or conducting sheets located on the guide way, the induced currents flow through the coils or sheets and generate the magnetic fields.

  The repulsive force between this magnetic fields and the magnets, levitates the vehicle.

  EDS is so stable magnetically that it is unnecessary to control the air gap, which is around 100 mm, and so is very reliable for the variation of the load. The EDS is highly suitable for high speed operation and freight.

  This system needs sufficient speed to acquire enough induced currents for levitation.

  By the magnets, EDS may be divided into two types:

  _Permanent magnet type” PM”.

  _Superconducting magnet type “SCM”.

  For PM type the structure is very simple because there is no need for electric power supply, and the PM type is used for small systems only, because the absence of high powered.

- HEMS maglev train

  Refers to “Hybrid Electromagnets Suspension”, In order to reduce the electric power consumption in EMS, permanent magnets are partly used with electromagnets.

In certain steady-state air gab, the magnetic field from the PM is able to support the vehicle by itself and the electric power by the electromagnets that control the air-gab can be almost zero.

2.4 Motors

A motor is a machine , especially one powered by electricity or internal combustion, that supplies motive power for vehicle or for some other device with moving part .It is giving imparting or producing motion or action .It is estimated that nearly half of the word's energy consumption is consumed by motors, therefor increasing motor efficiency is expected to have a significant impact on the global energy crisis.

Types of motors can be classified into DC motors and AC motors .The DC motors include: Brush motors, Brushless motors and stepper motors. The AC motors include : Induction motors and Synchronous motors.

2.5 Sensors

A sensor is a device which provides a usable output in response to a specified measured. It acquires a physical quantity and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical).

Nowadays common sensors convert measurement of physical phenomena into an electrical signal. Active element of a sensor is called a transducer. [6]

2.6 Microcontroller

A microcontroller is a small computer on a single integrated circuit. In modern terminology, it is similar to, but less sophisticated than, a system on a chip or 'SoC'; an' SoC' may include a microcontroller as one of its components.

A microcontroller contains one or more CPUs (processor cores) along with memory and programmable input/output peripherals. Program memory in the form of ferroelectric” RAM, NOR flash or OTP ROM “is also often included on chip, as well as a small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips.

2.6.1 Microcontroller components

A microcontroller consists of many components such as:

- Central processing unit

Central Processing Unit is the brain of a microcontroller. CPU is responsible for fetching the instruction, decodes it, and then finally executed. CPU connects every part of a microcontroller into a single system. The primary function of CPU is fetching and decoding instructions. Instruction fetched from program memory must be decoded by the CPU.

- Memory

Memory in a microcontroller is same as microprocessor. It is used to store data and program. A microcontroller usually has a certain amount of RAM and ROM or flash memories for storing program source codes.

- Parallel input/output ports

Parallel input/output ports are mainly used to drive/interface various devices such as LCD’S, LED’S, printers, memories, etc. to a microcontroller.

- Serial interfacing ports

Serial ports provide various serial interfaces between microcontroller and other peripherals like parallel ports.

- Timers and counters

This is the one of the useful function of a microcontroller. A microcontroller may have more than one timer and counters. The timers and counters provide Program. The interrupt may be external (activated by using interrupt pin) or internal (by using interrupt instruction during programming).

- Special functioning block

Some microcontrollers used only for some special applications (e.g. space systems and robotics) these controllers containing additional ports to perform such special operations. This considered as special.

➢ Advantages

By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems.

➢ Applications

Microcontrollers are used in automatically controlled products and devices, such as:

- Automobile engine control systems.
- Implantable medical devices.
- Remote controls.
- Office machines.
- Power tools.
- Toys and other embedded systems.

2.7 Proportional Integral Derivative Controller

A Proportional Integral Derivative PID controller is a feedback control algorithm widely used in industrial control systems. A PID controller calculates the error value which is the difference between a measured process variable and a desired set point, the controller attempts to minimize the error by adjusting the process.

The PID controller algorithm involves three separate constant parameters as shown is Figure 2.7 and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. These values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element.

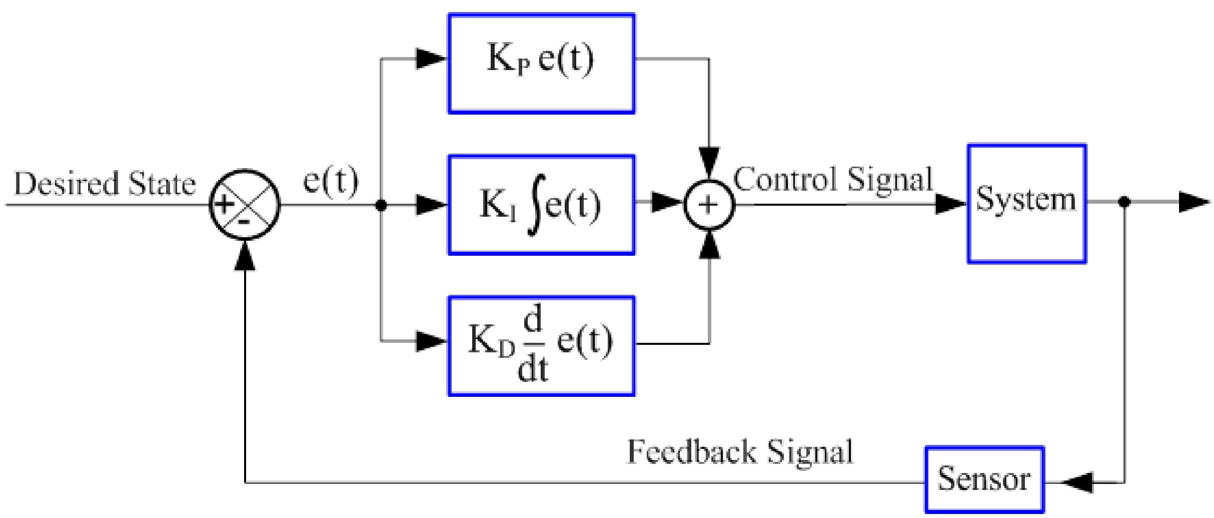

Figure 2.4: Proportional Integral Derivative Controller block diagram

2.8 Nonlinear Systems

A system is nonlinear if the principle of superposition does not apply. Thus, for a nonlinear system the response to two inputs cannot be calculated by treating one input at a time and adding the results. Although many physical relationships are often represented by linear equations, in most cases actual relationships are not quite linear. In fact, a careful study of physical systems reveals that even so-called “linear systems” are really linear only in limited operating ranges. In practice, many electromechanical systems, hydraulic systems, pneumatic systems, and so on, involve nonlinear relationships among the variables. For example, the output of a component may saturate for large input signals .There may be a dead space that affects small signals. (The dead space of a component is a small range of input variations to which the component is insensitive). Square-law nonlinearity may occur in some components. For instance, dampers used in physical systems may be linear for low-velocity operations but may become nonlinear at high velocities, and the damping force may become proportional to the square of the operating velocity.[3]

2.9 Linearization of Nonlinear Systems

In control engineering a normal operation of the system may be around an equilibrium point, and the signals may be considered small signals around the equilibrium. (It should be pointed out that there are many exceptions to such a case.) However, if the system operates around an equilibrium point and if the signals involved are small signals, then it is possible to approximate the nonlinear system by a linear system. Such a linear system is equivalent to the nonlinear system considered within a limited operating range. Such a linearized model (linear, time-invariant model) is very important in control engineering.

The linearization procedure to be presented in the following is based on the expansion of nonlinear function into a Taylor series about the operating point and the retention of only the linear term. Because we neglect higher-order terms of the Taylor series expansion, these neglected terms must be small enough; that is, the variables deviate only slightly from the operating condition. (Otherwise, the result will be inaccurate [3]

2.10 Transistor

The transistor is the fundamental building block of modern electronic devices. Made of semiconducting materials . Transistors are used as switches and amplifiers.

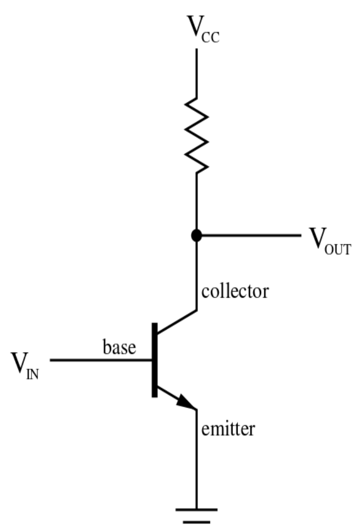

Figure 2.5: Transistor circuit diagram

2.11 Freewheeling diode:

Freewheeling diode is a diode connected across an inductor used to eliminate fly back, which is the sudden voltage spike seen across an inductive load when its supply current is suddenly reduced or interrupted. It is used in circuits in which inductive loads are controlled by switches, and in switching power supplies and inverters.

When an inductance connect to voltage source a current well flow throw the inductance, the increasing in current cases a back voltage across the inductor due to Faraday's law of induction which opposes the change in current. When the power cuts off the current drops rapidly. The inductor resists the drop in current by developing a very large induced voltage of polarity in the same direction of the source, positive at the lower end of the inductor and negative at the upper end. This large induced voltage could damage most of the electronics components, thus a use of freewheeling diode would be an excellence protection. As shown Figure (2.6) which represent circuit's diagram of a freewheeling diode connection . The diode doesn't conduct current while the switch is closed because it is reverse-biased by the battery voltage, so it doesn't interfere with normal operation of the circuit. However, when the switch is opened, the induced voltage across the inductor of opposite polarity forward biases the diode, and it conducts current, limiting the voltage across the inductor and thus preventing the arc from forming at the switch. The inductor and diode momentarily forms a loop or circuit powered by the stored energy in the inductor. This circuit supplies a current to the inductor to replace the current from the battery, so the inductor current does not drop abruptly, and it does not develop a high voltage. The voltage across the inductor is limited to the forward voltage of the diode, around 0.7 - 1.5V. This "freewheeling" or "flyback" current through the diode and inductor decreases slowly to zero as the magnetic energy in the inductor is dissipated as heat in the series resistance of the windings. This may take a few milliseconds in a small inductor.

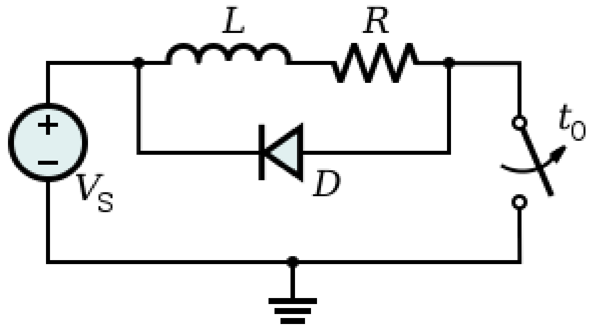

Figure 2.6: circuit diagram of freewheeling diode

CHAPTER THREE
MODELING AND DESIGNING

3.1 System Description

The proposed system consists of two separate prototypes. The main proto type consist of two units: The rail and the trailer. The second prototype describes the control system which controls the magnetic fields. The following block diagram describes the second system. The Hall Effect sensor measures the distance to the magnet using its magnetic field sensibility then it returns the values to the microcontroller (Arduino) which is in control of the power to the electromagnetic coil through the transistor using the power supply which supplies +12 v maximum.

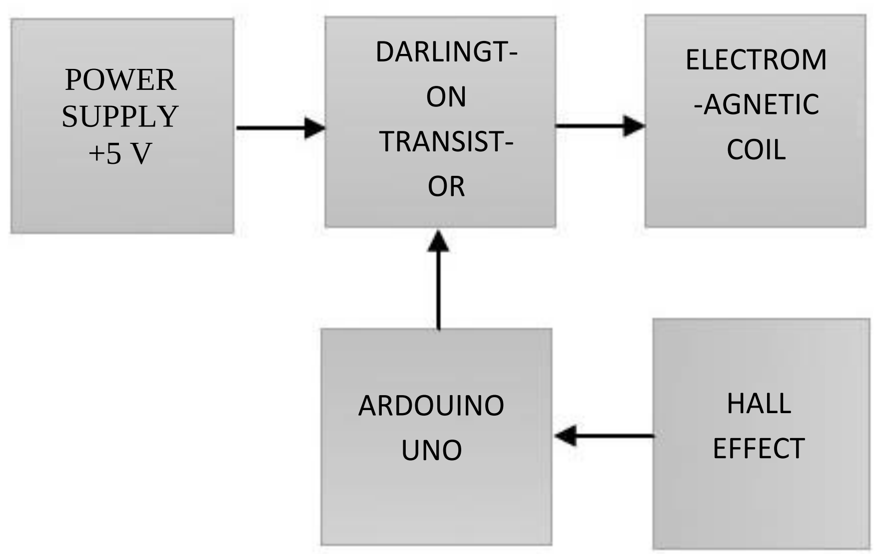

Figure 3.1: System block diagram

3.2 System Hardware

The control circuit of proposed system consists of Hall Effect sensor, Darlington transistor, +12v power supply, electromagnetic coil and Arduino uno.

3.2.1IRF540NS Mosfet

The IRF540NS mosfet achieves extremely low on-resistance per silicon area ,fast switching speed and an extremely efficient and reliable device for use in a wide variety of applications. Since the Arduino sold small current the IRF540NS mosfet transistor used to amplify the current.

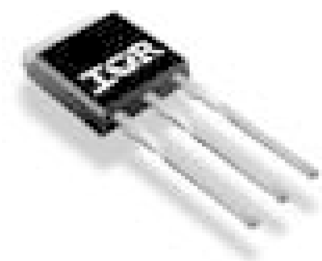

Figure 3.2: IRF540NS mosfet

3.2.2Hall Effect:

A Hall Effect sensor is a transducer that varies its output voltage in response to a magnetic field. And the Hall Effect sensors are very popular and have many contemporary applications. For example, they can be found in vehicles as wheel speed sensors as well as crankshaft or camshaft position sensors. Also they are often used as switches, MEMS compasses, and proximity sensors and so on.

Figure3.3: Hall effect sensor

The Hall Effect sensor used in this project is ss49e linear Hall Effect sensor its output set by the supply voltage and varies in proportion to the strength of the magnetic the output voltage and field intensity relationship is shown in figure 3.5. And it measures the length of the levitation air gap while the field intensity decrease and increase with the changes of the air gap between the electromagnet and the magnetic materials or the permanent magnets.

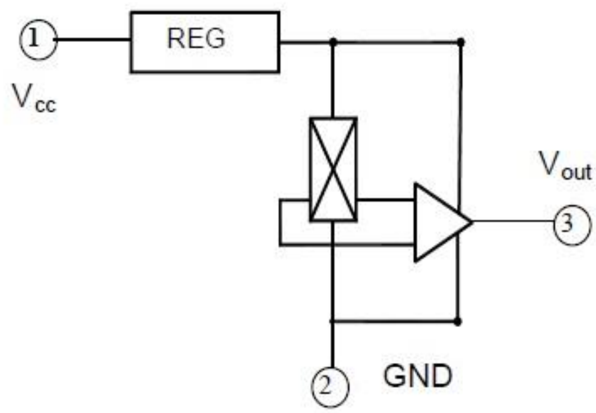

Figure3.4: Functional block diagram

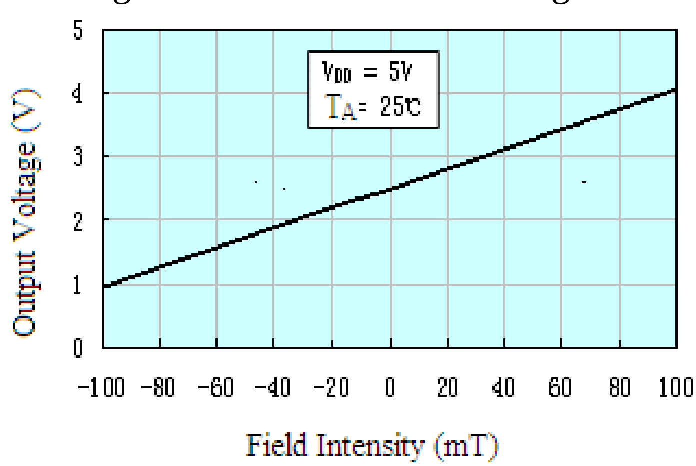

Figure 3.5: Relationship between output voltage and field intensity

3.2.3 Electromagnetic coil

An electromagnet is a type of magnet in which the magnetic field is produced by an electric current. The magnetic field disappears when the current is turned off.

In this project the electromagnetic coil used in the second prototype to attracts the magnet and maintains distance levitation.

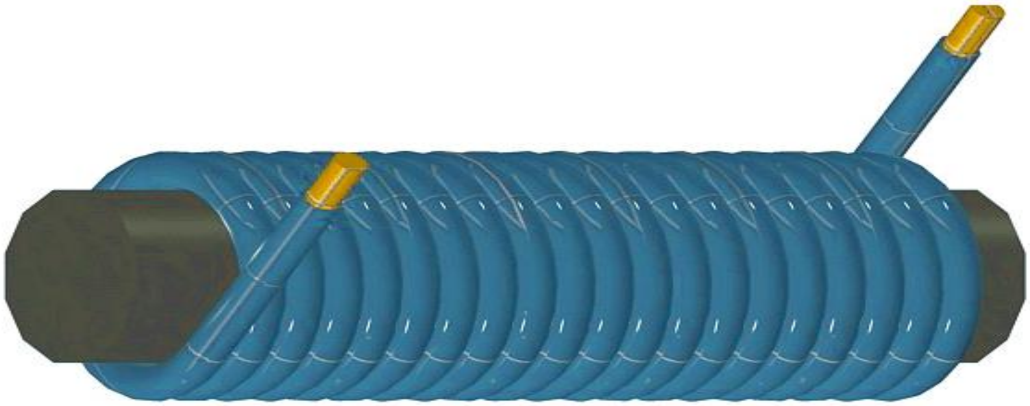

Figure3.6: Electromagnetic coil

3.2.4 Neodymium magnet

Neodymium magnet is considered one of the strongest permanent magnets, featuring: lightweight, strength and the consistency of their magnetization has made it a very popular choice in several industries. The Neodymium magnet used in this project in the two prototypes, in the first one: it uses the strength of the permanent magnetism to provide lift power, in the second prototype: it represents the levitation object to increase the air gap.

Figure3.7**:** Neodymium magnet

3.2.5 HC-05 Bluetooth Module

HC-05 Bluetooth Module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. Its communication is via serial communication which makes an easy way to interface with controller or PC. HC-05 Bluetooth module provides switching mode between master and slave mode which means it able to use neither receiving nor transmitting data. In this project the Bluetooth module is used to perform a remote control to the first prototype using a smart mobile phone.

Figure 3.8 : Hc-05 bluetooth module

3.2.6 L293D motor driver IC

L293D as shown in Figure 3.9 is a typical Motor driver or Motor Driver IC which allows DC motor to drive on either direction. L293D is a 16-pin IC which can control a set of two DC motors simultaneously in any direction. It means that you can control two DC motors with a single L293D IC.The l293D can drive small and quite big motors as well.

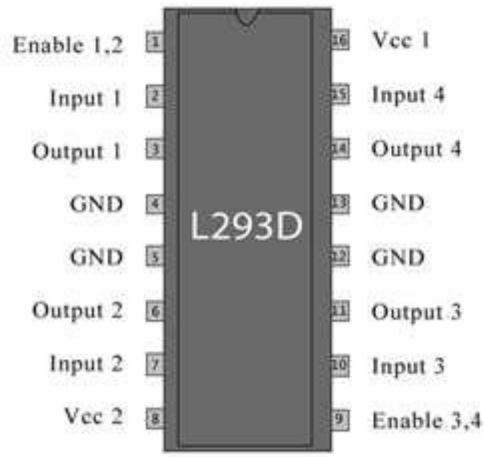

Figure 3.9: L293D motor driver IC

It works on the concept of H-bridge. In a single L293D chip there are two h-Bridge circuit inside the IC which can rotate two dc motor independently. Due its size it is very much used in robotic application for controlling DC motors and relay.in this study used to control of speed in DC motor and controlling in relay points.

3.2.7 1N4007 Diode

The 1N4007 is one of the 1N400X series which are general-purpose silicon rectifier diodes.These are fairly low-speed rectifier diodes, being inefficient for square waves of more than 15 kHz.

Figure 3.10: 1N4007 Diode

The 1N4007 is used in the project to protect as a freewheeling diode to protect the system components from the fly back voltage that occurs because of the electromagnet's inductance.

3.2.8 Power supply

A power supply is that device which control and supply load with specified amount of current, voltage and frequency. Since the power supply converts electrical energy so it referred to it as electrical power converters. Some power supplies are discrete, stand-alone devices, whereas others are built into larger devices along with their loads. All power supplies have a power input, which receives energy from the energy source, and a power output that delivers energy to the load.

Figure 3.11: Power supply

Figure 3.12: Wire diagram

3.2.9 Arduino uno

The Adriano UNO is an open-source microcontroller board developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 Digital pins, 6 Analog pins, and programmable with the Adriano IDE (Integrated Development Environment) via a type B USB cable. It can be powered by a USB cable or by an external 9 volt battery, though it accepts voltages between 7 and 20 volts. "Uno" means one in Italian and was chosen to mark the release of Adriano Software (IDE) . The Uno board is the first in a series of USB Adriano boards, and the reference model for the Adriano platform.

Adriano can be controlled from the computer or programmed by the computer and then disconnected and allowed to work independently.

Figure 3.13: Arduinouno

- **General Pin functions**

➢ **LED:** There is a built-in LED driven by digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

➢ **VIN**: The input voltage to the Arduino/Genuine board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.

➢ **5V**: This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 20V), the USB connector (5V), or the VIN pin of the board (7-20V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage the board.

➢ **3V3**: A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.

➢ **GND**: Ground pins.

➢ **IOREF**: This pin on the Arduino/Genuino board provides the voltage reference with which the microcontroller operates. A properly configured shield can read the IOREF pin voltage and select the appropriate power source or enable voltage translators on the outputs to work with the 5V or 3.3V.

➢ **Reset**: Typically used to add a reset button to shields which block the one on the board

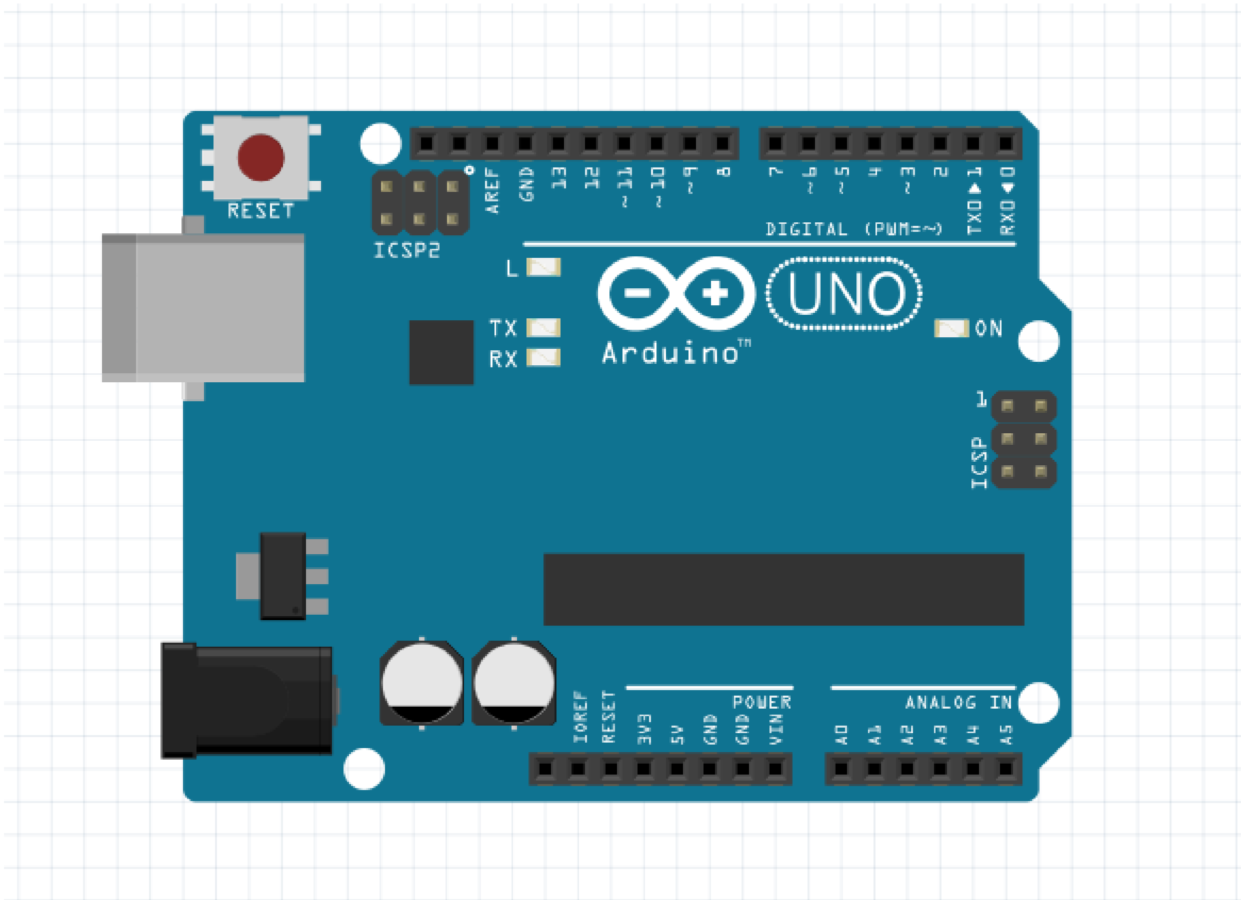

Figure 3.14: Arduino uno pins

3.3 System Software

The proposed system relies on two high level programming languages which are Matlab and Arduino C.

3.3.1 Arduino C

The Arduino C programming language has been used for programming the System.

The Arduino code was compiled with the Arduino to execute the sequence

Commands of the control operation. The code is shown in the append.

3.3.2 MATLAB

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. In this project Matlab used to simulate the second prototype.

SISO tool by MATLAB

It is Graphical User Interface which design single-input/single-output (SISO) compensators by graphically interacting with the root locus, Bode, and Nichols plots of the open-loop system. An automatic tuning was applied to the open loop transfer function of the second prototype to design an optimal PD controller.

3.4 Modeling

3.4.1 Mechanical part

As shown in figure (3.15) there are two forces acting on the ball, the gravitational force, mg, and the magnetic force, which is given by

$$f_m = k\frac{i^2}{x^2} \quad (3.1)$$

The magnetic force relation is a simplified approximation for the system; it ignores many non-ideal characteristics. Specifically, the equation does not account for effects including finite core reluctance, saturation of the core, magnetic hysteresis, and eddy currents in the core.

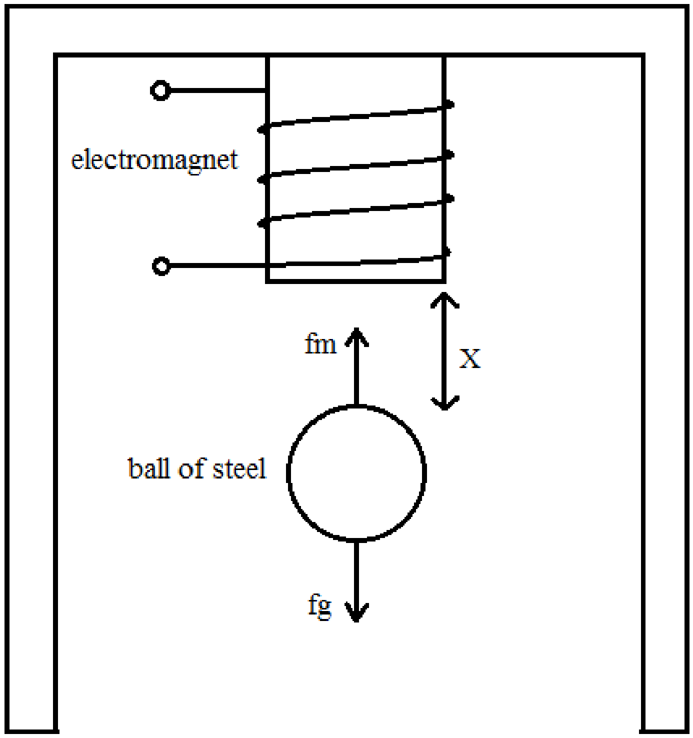

Figure 3.15: applied forces on the steel ball

Assuming the downward direction represents positive displacement, the dynamics of the system can be described by

$$m\frac{d^2x}{dt^2} = mg - k\frac{i^2}{x^2} \tag{3.2}$$

According to the discussion about linearization of nonlinear systems. To obtain a linear mathematical model for a nonlinear system, we assume that the variables deviate only slightly from some operating condition. Consider a system has input and output, the relationship between them is given by

$$y = f(x) \tag{3.3}$$

If the normal operating condition corresponds to $\bar{x}, \bar{y}$ then Equation (3.3) may be expanded into a Taylor series about this point as follows:

$$y = f(\bar{x}) - \frac{df}{dx}(x - \bar{x}) + \frac{1}{2!}\frac{d^2f}{dx^2}(x - \bar{x})^2 + \cdots \tag{3.4}$$

Next, consider a nonlinear system whose output y is a function of two inputs $x_1$and x_2, so that

$$y = f(x_1, x_2) \tag{3.5}$$

To obtain a linear approximation to this nonlinear system, we may expand Equation (3.5) into a Taylor series about the normal operating point Then Equation (3.5) becomes

$$y = f(\bar{x}_1, \bar{x}_2) + \left[\frac{\partial f}{\partial x_1}(x_1 - \bar{x}_1) + \frac{dy}{dx_2}(x_2 - \bar{x}_2)\right] + \cdots \tag{3.6}$$

Model Linearization

The suspension of a ball with an electromagnet is difficult because it is open-loop unstable and there is a nonlinear relationship between force, current, and gap between the pole of the electromagnet and ball. Equilibrium is reached when the magnetic force balances the gravitational force. Intuitively it makes sense that the system is unstable. Imagine the ball is sitting at the equilibrium point under a fixed magnetic field, a small deviation towards the magnet will increase the magnetic force perturbation or a small deviation away from the magnetic will decrease the magnetic force allowing the ball to fall, also growing the perturbation. One effective method to stabilize a nonlinear system around an operating point is to take the first order approximation of the system around that operating point, a linearization, and then proceed with standard control techniques for linear systems.[3,5]

By linearization the equation (3.1) about equilibrium point (x_0, i_0) :

$$\frac{d^2x}{dt^2} = \frac{2k{i_0}^2}{{x_0}^3 m}x - \frac{2ki_0}{{x_0}^2 m}i \tag{3.7}$$

3.4.2 Electrical part

From equivalent circuit of the electromagnet shown in figure (3.16) the description equation is:

$$\frac{di}{dt} = -\frac{R}{L}i + \frac{1}{L}v \tag{3.8}$$

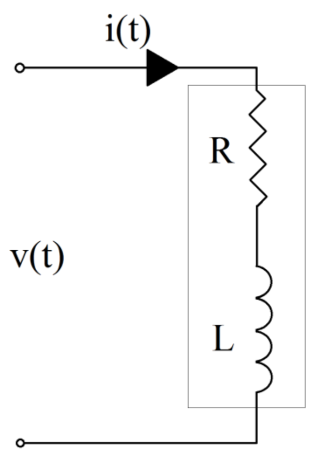

Figure 3.16: equivalent circuit of the electromagnet

Let

$$\dot{x}_1 = x_1 \tag{3.9}$$

From the equations (3.7) and (3.8),

The state space form becomes:

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ \frac{2ki_0{}^2}{x_0{}^3 m} & 0 & -\frac{2ki_0}{x_0{}^2 m} \\ 0 & 0 & -\frac{L}{R} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{L} \end{bmatrix} u(t) \tag{3.10}$$

CHAPTER FOUR

Simulation and Result

4.1 Simulation and result:

By using the second prototype variables shown in table(4.1) a state space model were defined as:

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 2805 & 0 & -52.4 \\ 0 & 0 & -8333.3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 631.31 \end{bmatrix} u(t) \tag{4.1}$$

$$y = x_1 = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

Variable	Value	Unit
R	13.2	Ω
L	1.584	mH
C	$3.92*10^{-5}$	Nm^2/A
x_0	8	mm
m	10	g
i_0	0.428	A

Table 4.1: Designed system parameter

Using MATLAB the open loop transfer is found as:

$$\frac{-33100}{s^3 + 8333s^2 + 2805s - 23380000}$$

the open loop transfer have three poles located at -8333, 53, -53 one of this poles at the right hand side of the s-plane so it's clear that the system is unstable. The step response plot of the close loop system drawn with MATLAB is shown in figure (4.1).

To stabilize this system a PD controller can be designed.

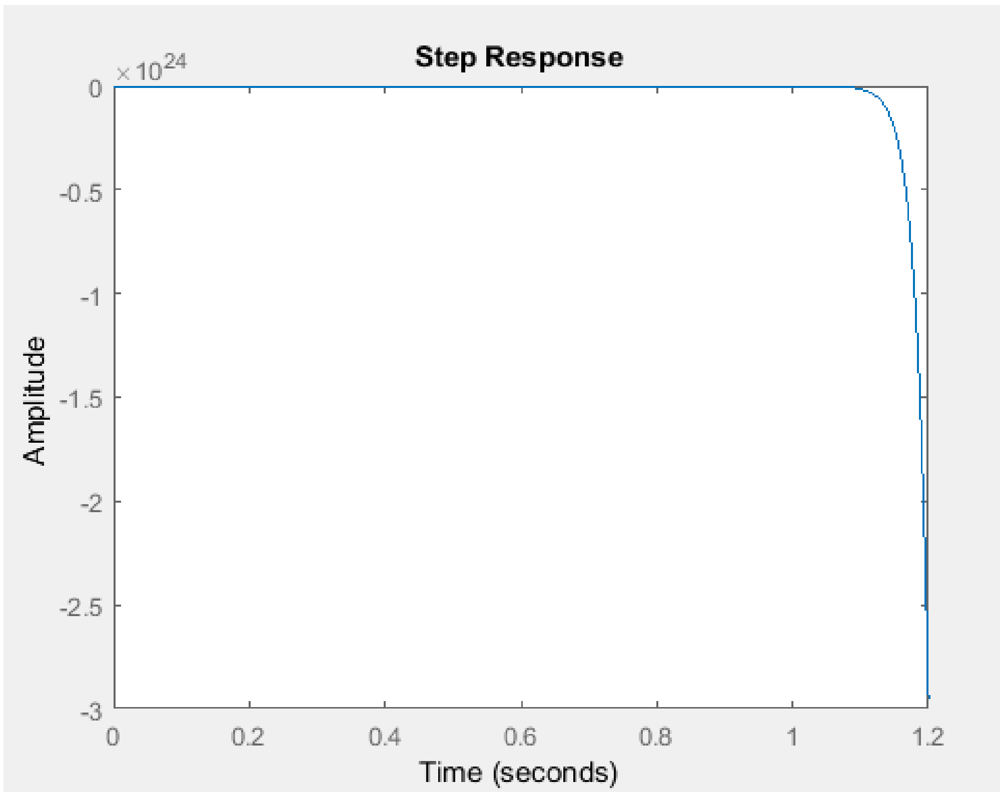

Figure 4.1: Step response of unstable system

4.2 Design of PD controller for the system:

with the help of **SISOtool** by MATLAB. While the objective is just to stabilize the model system automatic tuning were applied to the open loop transfer function and the designed PD controller is found as:

$$PD = -390110(1 + 0.007s) \tag{4.3}$$

Thus, the new open loop system is:

$$\frac{295000s + 1291 * 10^{10}}{s^3 + 8333s^2 - 2805s - 2338 * 10^7}$$

Also the overall transfer function of the unity feedback designed system obtained as flow:

$$\frac{2195000s + 1291 * 10^7}{s^3 + 8333s^2 + 21950000s + 1289 * 10^7}$$

It's clearly that the right hand pole of the s-plane had been canceled by the designed PD controller and the new system is stable. The root locus plot of the open loop system with PD controller drawn with MATLAB is shown in figure (4.2). The step response of the final system is shown in figure (4.3).

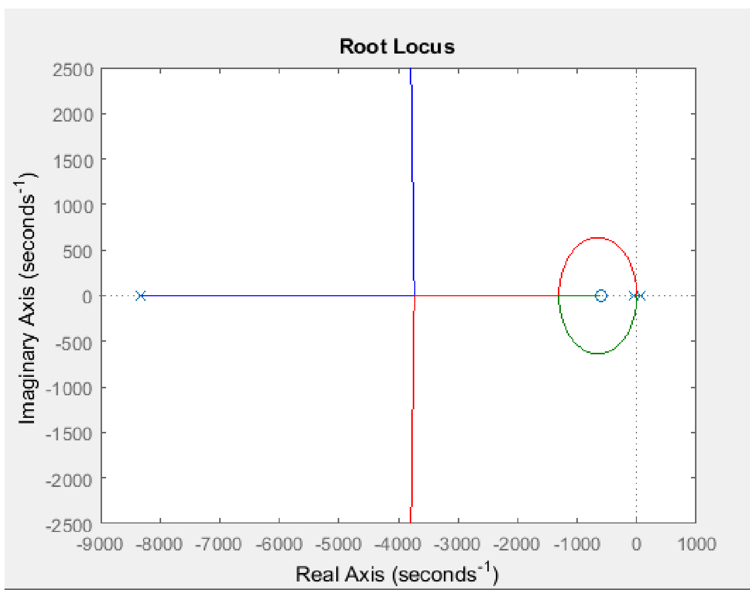

Figure 4.2: root locus of the new stable system

The new system has a specification of $0.4mSec$ Rise time, 17.5% over shoot and $4.15mSec$ settling time. By using this PD controller the new stability become very satisfying and need no any addition.

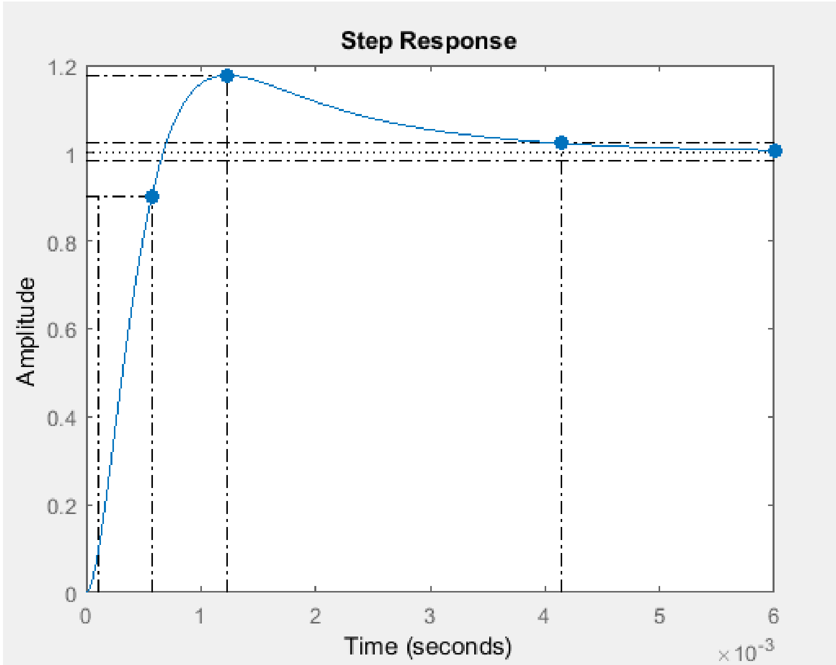

Figure 4.3: Step response of the new stable system

4.3 System fabrication:

The system was fabricated using two individual systems in order to explain it entirely. The two systems (rail and trailer) and (electromagnetic levitation) had been fabricated to accomplish best explanation of the maglev train.

4.4 Rail and trailer

4.4.1 The railway:

The railway was fabricated by using (12) cm widthand (80)cm length wooden piece as a platform and two pieces of cork (4) cm height and (80) cm length as sideways and other several pieces of cork as pillars. Forty pieces of neodymium magnets - (2.4) cm length and (0.8) cm width - used as railway's base for the trailer to levitate.

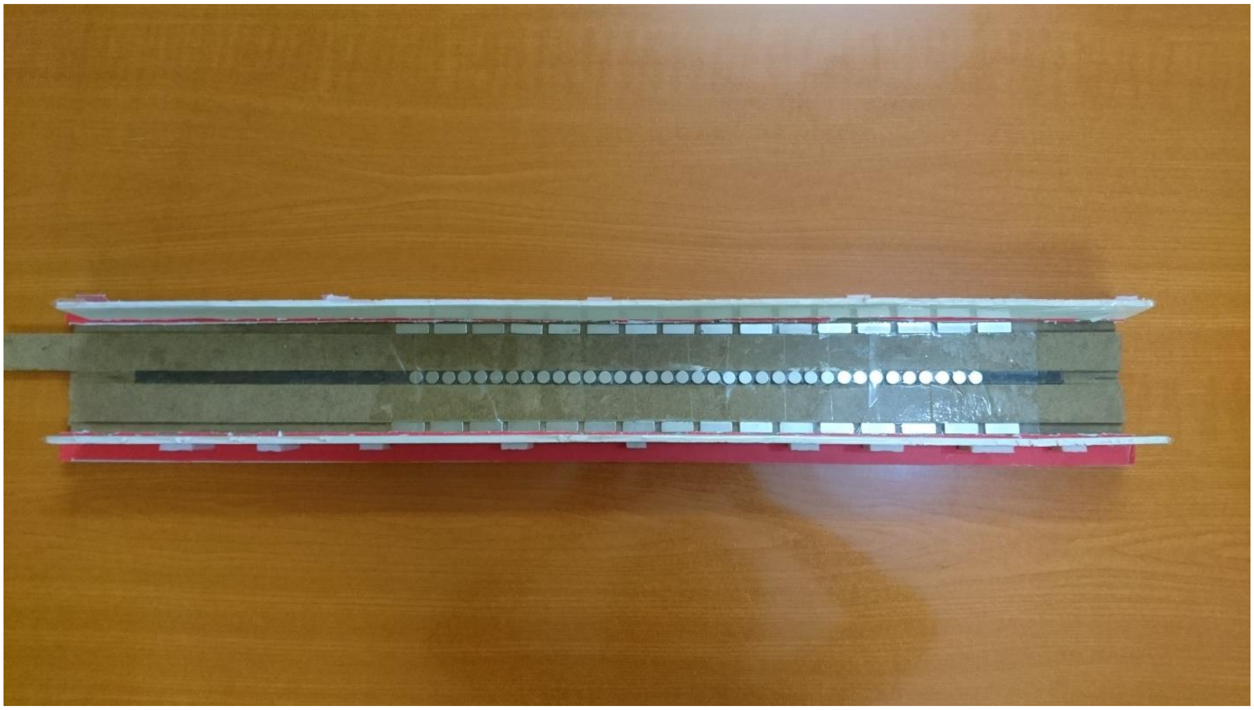

Figure 4.4: Rail

4.4.2 The trailer:

The trailer was fabricated using cork- (11.1) cm length and (8.5) cm width-. Eight pieces of neodymium magnets- (2.4) cm length and (0.8) cm width used to complete the levitation process between it and the railway’s magnets. The natural air-gap without any affecting force is (1.8) cm. A fan was attached to a DC motor to provide repulsion for the trailer.

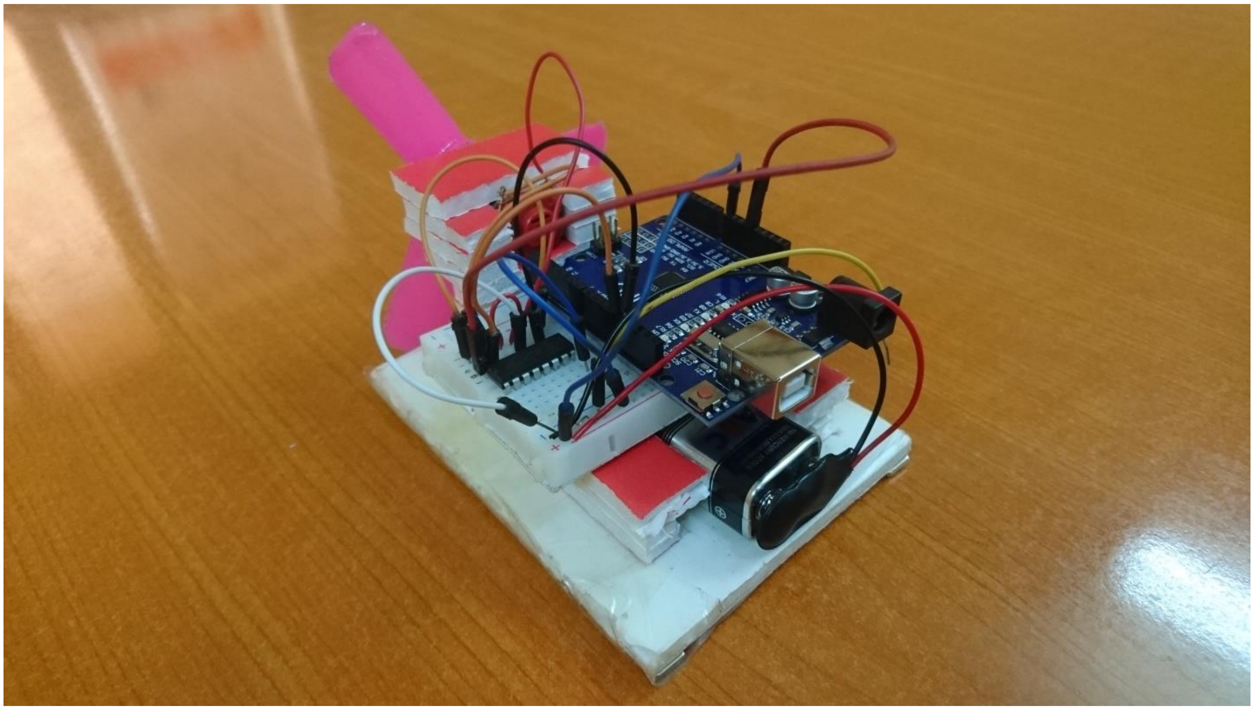

Figure 4.5: Trailer

4.5 Magnetic levitation

The second system is considered explanatory system to the previous system which had not been implemented in because of the weight of the coil according to our prototype and the mild effect of the coils.

The second system is fabricated by using a U shape piece of wood –two pieces are (30) cm height and (6) cm width and the remaining piece is (25) cm length and (6)cm width - , and cork (20.8) cm length and (3.2)cm width used as stand for the hall effect sensor(ss49e). The hall effect sensor (ss49e) was used to determine the distance to the magnet by calculating the magnetic flux. An electromagnetic coil (1520) turn and its core is bolt made of steel with (0.6) cm diameter- is used to provide the force necessary to counteract gravity and to stabilize the ball of steel (10) grams. The whole process is controlled by PID controller implemented in the Arduino code. An Arduino uno is used to control the system by receiving signals from the Hall Effect sensor (ss49e) and sending signal to activate the electromagnetic coil through a 1IRF540NS Mosfet transistor which is used as a current amplifier.

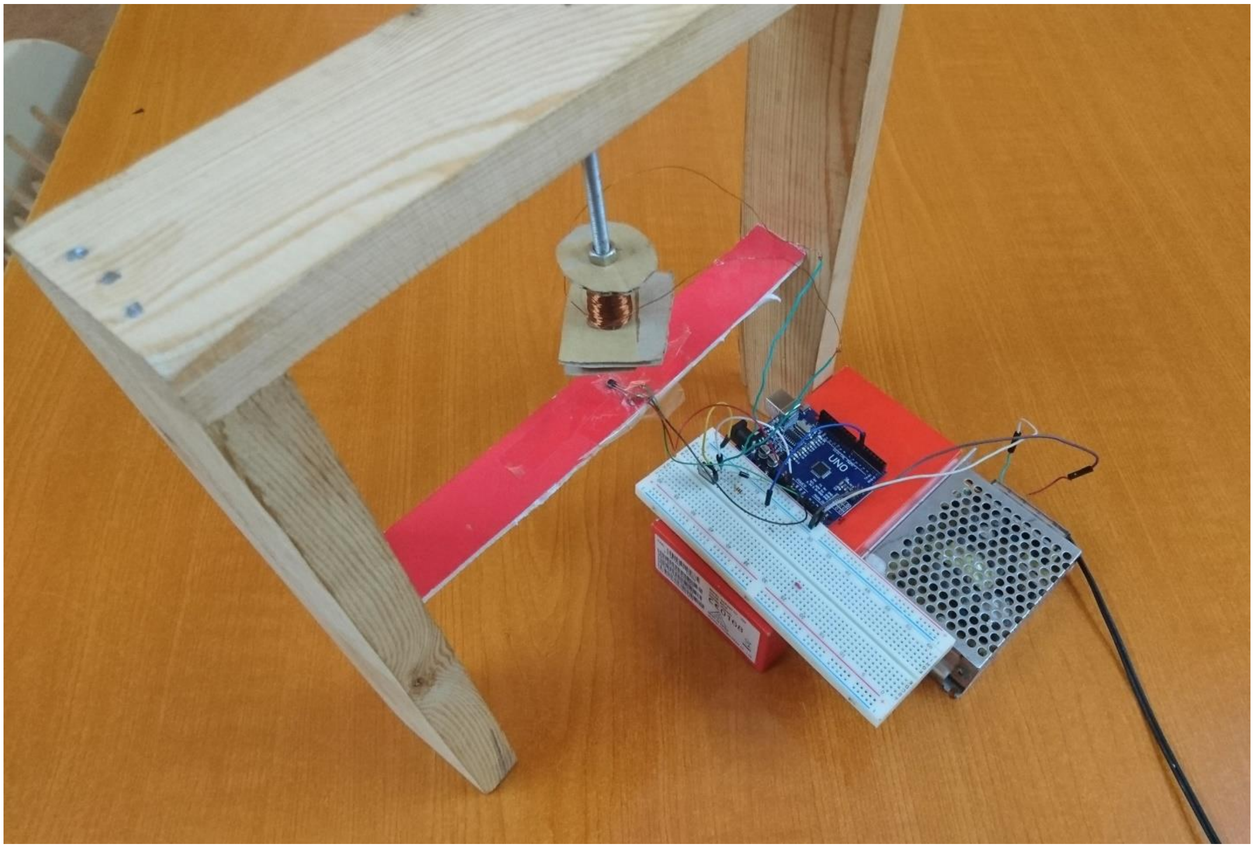

Figure 4.6: Magnetic levitation system

Second system modifications:

Since the original plant had not met the desired results, several tests had been done in order to accomplish the stabilization

Testing:

Using a simple circuit of IRF540NS Mosfet to control the electromagnet's current directly with the (ss49e) hall effect sensor, and using a small neodymium magnet as the levitating test subject instead of a ball of steel to increase levitation air-gap and to enhance hall effect sensor sensibility. The main purpose of this test is to study the plant's behavior which represent a single closed loop feedback system and no controller.

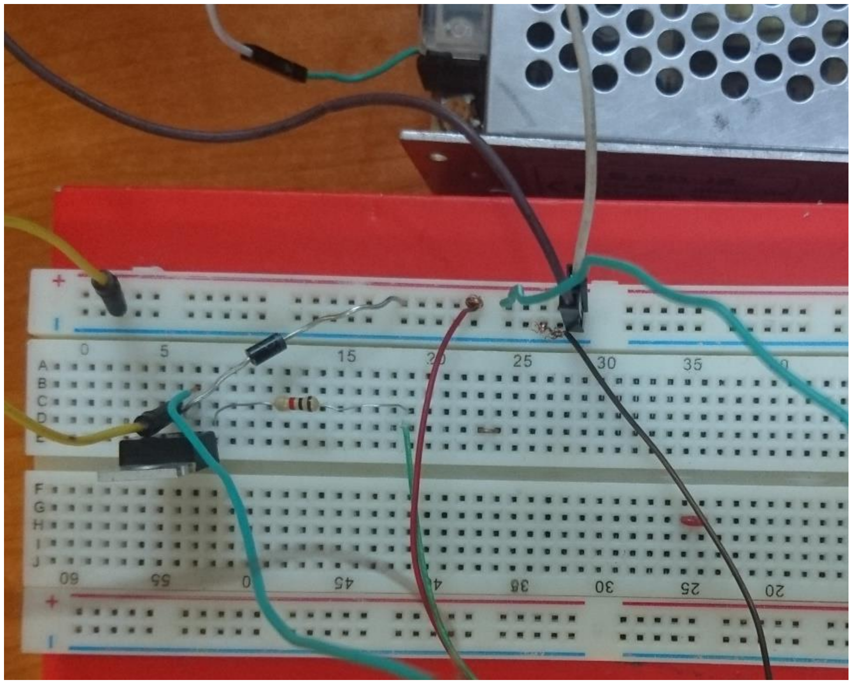

Figure 4.7: Magnetic levitation system plant wiring

The real time magnet’s position was plotted using the serial plotter by Arduino IDE where the Hall Effect signal was converted to a distance.

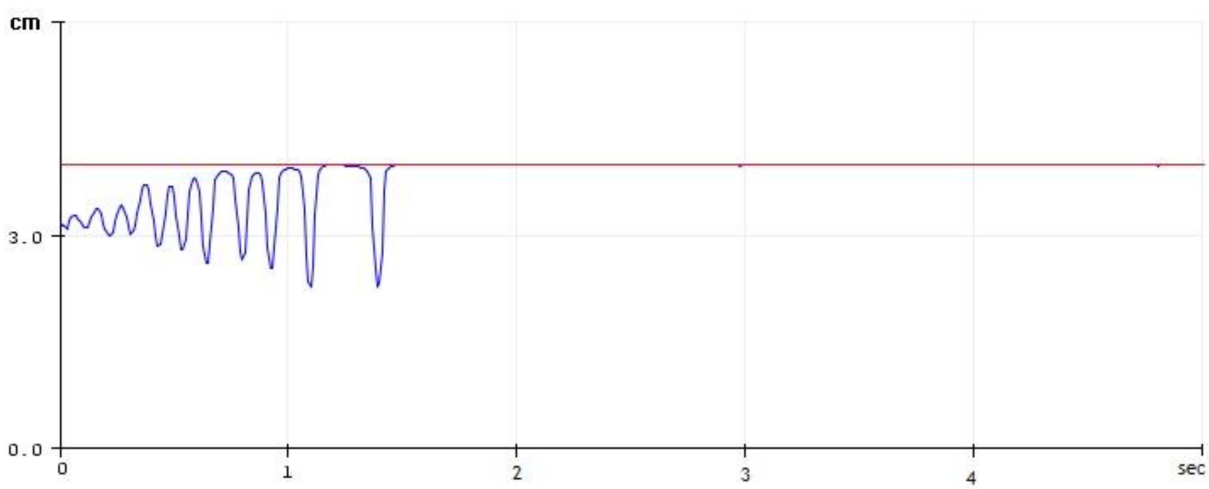

Figure 4.8: real time distance plot

As seen in the previous figure an increasing oscillation occurs till the magnet falls off, thus the system should implement a controlling method to accomplish stabilization.

By adding the PD controller to the plant using PID algorithm written in Arduino,the system's response still did not achieve the stabilization because of the lowPWM frequency of the Arduino according to the plant which causes to decrease the response, and considering the movement of the ball of steel is not affecting vertically only, acknowledging Eddy currents in the core and considering the hall effect sensor measure the distance linearly that is why a manual tuning should be applied to the system.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A magnetic levitation train model were designed and implemented. The model shows much less friction which indicates less use of power and much more efficiency thus the model indicates the ability to reach high speeds.

A mathematical model was concluded for the levitation system to develop a state space form with linearization for the mathematical model. Matlab was used to study system's stabilization and to design an automatic tuning PD controller. The latest simulation results were found to be very appealing. The system was tested using Arduino.

5.2 Recommendations

We recommend to:

- To use a suitable microprocessor with high PWM frequency to achieve a stable magnetic levitation system.
- To define a mathematical model for the magnetic levitation system with the suitable consideration.
- To combine the controlled magnetic levitation system with the rail and the trailer system.
- To design a linear motor system.

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APPENDIX A

MATLAB code for simulation and real time results

A.1 MATLAB code for pure system and PD design

```
f1=figure;
f2=figure;
a=[0,1,0;2805,0,-52.4;0,0,-8333.3];
b=[0;0;631.3131];
c=[1,0,0];
d=0;
[num,den]=ss2tf(a,b,c,d);
oplooptf=tf(num,den);
f1;
rlocus(oplooptf), hold on;
title('root locus of the open loop system');
cllooptf=feedback(oplooptf,1);
f2;
step(cllooptf), hold on;
title('step response of unstable system');
sisotool(oplooptf);
end
```

A.2 MATLAB code for of the new system with PD controller

```
f1=figure;
f2=figure;
s=tf('s');
pd=-390110*(1+.0017*s);
a=[0,1,0;2805,0,-52.4;0,0,-8333.3];
b=[0;0;631.3131];
c=[1,0,0];
d=0;
[num,den]=ss2tf(a,b,c,d);
oplooptf=tf(num,den);
pidsys=oplooptf*pid;
fbstablesys=feedback(pidsys,1);
f1;
rlocus(pidsys), hold on;
title('root locus of the new stable system');
f2;
step(fbstablesys), hold on;
title('step response of the new stable system');
end
```

APPENDIX B

Arduino microcontroller codes

B.1 Arduino microcontroller code of trailer

```
char data=0;
intbackword=13;
intforword=12;
void setup() {
Serial.begin(9600);
pinMode(backword,OUTPUT);
pinMode(forword,OUTPUT);
}
void loop() {
if(Serial.available()>0)
{
data=Serial.read();
if (data=='0')
  {
digitalWrite(forword,HIGH);
digitalWrite(backword,LOW);
  }
if (data=='1')
  {
```

```
digitalWrite(forword,LOW);

digitalWrite(backword,HIGH);

  }

delay(100);

  }

else

digitalWrite(forword,LOW);

digitalWrite(backword,LOW);

}
```

B.2 Arduino microcontroller code of testing and plotting for the pure levitation system response

```
double x;

floatsensorread;

doubledestance;

intsensorpin=A0;

void setup() {

Serial.begin(9600);

}

void loop() {

sensorread=analogRead(sensorpin);

if(sensorread<523)

 x=0;
```

```
else if(sensorread>881)
 x=4;
else x=0.0111732*sensorread-5.84;
destance=x;
Serial.println(destance);
Serial.print("   ");
}
```

B.3 PD controller

```
#include <PID_v1.h>
#define sensorPin A0
#define outputPin 6
#define outMIN 0
#define outMAX 255
#define kp 380
#define ki 0
#define kd 52
doubledestance, outVal,setPoint=160;
intsensorVal;
PID myPID(&destance, &outVal,&setPoint, kp, ki, kd, DIRECT);

void setup() {
pinMode(outputPin,OUTPUT);
myPID.SetOutputLimits(outMIN, outMAX);
```

```
myPID.SetMode(AUTOMATIC);
}
void loop() {
sensorVal=analogRead(sensorPin)
destance=0.6235*sensorVal-319.218;
myPID.Compute();
analogWrite(outputPin,outVal);
}
```