# Design and Development of Automated Pneumatic Braking Control System for Sinotruck

**By**

**Yared Admassu**

A Thesis Submitted to

**Mechanical Systems and Vehicle Engineering Department**

**School of Mechanical, Chemical and Materials Engineering**

Presented in partial fulfillment of the requirements the award of the degree of Master of Science in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

**September, 2019**

**Adama, Ethiopia**

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# APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by **Yared Admassu Taffere** have read and evaluated his thesis entitled "**Design and Development of Automated Pneumatic Braking Control System for Sinotruck**" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Automotive Engineering.

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|---|---|---|
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| Chairman, department graduate committee | Signature | Date |
| 3. ______________________ | ______________ | ____________ |
| Internal Examiner | Signature | Date |
| 4. ______________________ | ______________ | ____________ |
| External Examiner | Signature | Date |

# CANDIDATE DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: Yared Admassu Taffere

Signature: ____________________

Date: ____________________

This MSc Thesis has been submitted for examination with my approval as a thesis advisor.

Name: Mekonnen Liben (Asst.Prof.)

Signature: ______________________

Date of submission: ________________

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# ACRONYMS

| | |
|---|---|
| IR | Infrared sensor |
| AEB | Automatic emergency braking |
| CWAB-PD | Collision Warning with Full Auto Brake and Pedestrian Detection |
| ADAS | Advanced Driver Assistance Systems |
| AABS | Anti-lock and Automatic Braking system |
| IBS | Intelligent braking system |
| ABS | Automatic braking system |
| $D_B$ | Braking Distance |
| $D_r$ | Reaction Distance |
| $s_d$ | Stopping Distance |

# NOMENCLATURE

| | |
|---|---|
| $A_w$ | Cross-sectional area of coil ($m^2$) |
| B | Flux density (wb/$m^2$), (Tesla), (N/Am) |
| $d_2$ | Inner diameter (mm) |
| $d_1$ | Outer diameter (mm) |
| $d_w$ | Coil wire diameter (mm) |
| F | Force (N) |
| g | Clearance between plunger and bobbin |
| H | Magnetic field intensity (A/m) |
| i | Current (amp) |
| $l_c$ ,$l_z$ | Length of the Coil (m) |
| $l_w$ | Length of wire in the Coil (m) |
| L | The coil's Inductance (H) |
| N | Number of turns |
| R | Coils Resistance (Ω) |
| S, v | Area of cross-section of plunger ($m^2$) |
| V | Voltage (v) |
| X | Stroke length (mm) |
| $\rho_w$ | Resistivity of wire |
| Φ | Magnetic flux (Weber) |
| $\mu_o$ | Permeability |
| $\mu_r$ | Relative permeability |
| θ | Angle of plunger |

# ABSTRACT

*It has been observed that Sinotrucks are causing collision frequently in Ethiopia. Even though there are many different reasons, foot valve reaction time delay may be one of the problem reason behind such collision. The purpose of this thesis is to improve the brake system of Sinotruck by altering the design and development of automated pneumatic braking control system. The methods employed for this work are modeling component parts using Catia software, programmed using Arduino programming software and preparing a prototype. The model was developed with ultrasonic sensors and controllers such as Arduino Uno microcontroller, solenoid plunger, relay, etc. to apply the brakes before a collision can occur. Furthermore, the prototype of the automated braking system was constructed for demonstration and checked its functionality. The overall design was based on the Arduino Uno microcontroller. Also Ultrasonic sensor which is used for detecting object, and a solenoid for actuating the brake were included in the design. The microcontroller acts as the bridge between the sensor and solenoid by receiving an electrical signal from the ultrasonic sensors and sending the signal to the relay to activated a solenoid. It observed that the new automated braking system reduced 27.6m at maximum speed (75km/h) compared to existing one (42.2m). As a result this thesis contribute to efforts of increasing road safety and minimizing collision by reducing stopping distance of Sinotruck.*



***Keywords**: Arduino Uno microcontroller, solenoid plunger, ultrasonic sensors, foot valve, relay.*

# CHAPTER ONE

# 1. INTRODUCTION

## 1.1. Background

The construction in Ethiopia is a sector that opens the door for growth of many additional industries such as cement and cement product industries, clay work, metal product industries, plastic pipe industries etc.

As such growth of this industry will surely follow the growth of the construction industry. Similarly, when construction and renovation of housing are increasing, the demand for transportation of construction materials increased; thereby, directly, opening the door of the growth of the transport industry. All in all, Sino truck has a greater role in this industry. Road traffic accidents are becoming a major public safety and development obstacle; various studies have indicated that Ethiopia has one of the highest fatality rates per vehicle in the world, it is an excess of 100 fatalities per 10000 vehicles. This should be compared with Kenya and the United Kingdom, where the number is about 19 and 2 per 10000 vehicles, respectively thus Ethiopia loss about $65 million annually due to traffic accidents. In addition, the victims are mainly public transport travelers in the working-age group (18-30 years).

Brakes are required to stop the vehicle with the smallest possible distance and this is done by converting kinetic energy of the vehicle in to heat energy which is dissipated into the atmosphere.

Air brake system is used in heavy commercial vehicles like buses, straight truck and combination vehicles such as tractor-trailer. Proper functioning of the brake system of commercial vehicle is critical not only from the safety viewpoint of the vehicle itself, but also for the vehicles and passengers in traffic. Any accident involving in commercial vehicle result not only in economic loss of the goods transported bust also loss of life. As air brake systems are highly sensitive to maintenance, periodic maintenance and inspection procedures have to be strictly followed (WHO, 2017).

Vehicle accidents might be a consequence of rash driving, driving under influence, fatigue etc. Most of these can be mapped down to a single cause, driver’s inability to hit the brakes at right time. Some drivers are careless thus, drive a vehicle out of their profession like driving a vehicle after taking an alcohol or chat and also communicate with each other using mobile or within a cabin as well as out of the cabin through the window. Some traffic accidents also occurred when the obstacle is out of sight especially around densely traffic area, at parking stations and during reversing. The numbers of peoples who are dead during vehicle accidents were also large as compared to the other causes of death. The traffic accident is increasing as vehicle production is increasing. All these problems combine together resulted in traffic accidents that everyone has seen today like property damage, personal injury, or even death (Girma et al., 2018).

Figure 1.1. Accident caused by Sinotruck.

## 1.2. Statement of the problem

Accident involving in commercial vehicles occurs due to brake failures such as foot valve reaction time delay, carried more than load limit and drive more than the speed limit. But occurs frequently due to brake defects. Typical brake-related defects include oversize drums, worn-out brake linings, out of adjustment push rod strokes and oil leakage in the system.

The statistics from “Addis Ababa zuria Oromia liyu zone police report of 2007 E.C” indicated that heavy commercial vehicles accounted for 23.33% of fatal crashes, 14.16% injures and 62.51% property damage. From the above data, Sino truck accounted for 79% of fatal crashes, 29% of injuries and 39% of property damage (Girma et al., 2018). And from July 1, 2009 E.C up to June 30, 2010 E.C number of traffic accidents and victims of motor vehicle traffic accidents occurred in Ethiopia. The victims of motor vehicle traffic accidents both male and female in Addis Ababa was 3621, Oromia 5178 & Amhara 4257 and the maximum property damage occurred in Addis Ababa is 24,928,Oromia 1806 & Amhara 1098 and total property damage estimate in birr 109,882,371; 236,362,117 & 326,101,815.1 respectively. Totally in Ethiopia in one-year property damage lost 920,771,314.78 birr (Federal Police Commission Central Information &Crime intelligence Directorate, 2010). According to the latest WHO data published in 2017 road traffic accidents deaths in Ethiopia reached 27,140 or 4.27% of total deaths. The age-adjusted Death Rate is 36.36 per 100,000 of the population putting Ethiopia at the rank of 22 in the world (WHO, 2017).

Therefore, a great deal of consideration should be given to improve the braking system of Sinotruck in Ethiopia since its contribution to fatal crashes is high. This thesis proposes a new automatic braking control system to work jointly with the original. This option allows increased safety because the braking system is duplicated. The advantage of this concept is that decreasing stopping distance to reduce the collision.

## 1.3. Objectives

### 1.3.1. General Objective

The general objective of this thesis work is to design and development of automated pneumatic braking control system of Sinotruck.

### 1.3.2. Specific Objectives

The specific objectives are:

- To design a solenoid plunger for automated brake control system.
- To prepare the part and assembly drawing of the system using Catia software.
- To develop a system of programming code of automated pneumatic braking controls system for Sino Truck.
- To prepare the prototype.
- Test the programming code on the prototype.

## 1.4. Significance of the thesis

The traffic accidents which are caused by Sinotruck are increasing from day to day in Ethiopia thus; the study will help to minimize the accident caused by the brake stopping distance. So that it will reduce road traffic accident in property and humans lives in Ethiopia.

Also reduce the accident means reduce maintenance work and since the Sinotruck in Ethiopia is expensive to import it will save more foreign currency.

## 1.5. Beneficiaries

Automotive industries, contractors, vehicle owners, researchers, society and the country as a whole get benefitted with this work.

## 1.6. Scope of the study

The scope of this thesis work is limited to designing, programming with Arduino program and prototyping of automated pneumatic braking control system for Sinotruk Howo 336.

## 1.7. Limitation of the study

The limitation of the study is that there is no enough reference books in automated brake system and finding the exact data of existing stopping distance of Sinotruck. This thesis has done by browsing different literatures from internet. The sensor work only in the front direction rather than side and back.

## 1.8. Organization of the thesis

The thesis organized into five chapters. Chapter one is the introduction part which presents background of the problem, objective the study, scope and limitation of the thesis, chapter two deals on literature review part which is focused on brief overview of automatic braking system and a typical air brake system found in commercial vehicles, chapter three deals on material and methods that which focused on the basic geometric modeling of the existing and the new brake system was done using CATIA software and mathematical modeling was described for both system, chapter four deals on the result and discussion that which the result obtained were discussed and comparison between the existing braking system and the new brake system circuit diagram of the electrical part drawn within Proteus software, chapter five deals on conclusion and recommendation that was the basis of the results achieved conclusion were drawn in recommendation were also presented.

# CHAPTER TWO

## 2. LITERATURE REVIEW

### 2.1. Intelligent electronically braking control system

Kushal et al., (2017) designed and developed a control system based intelligent electronically controlled automotive bumper activation and automatic braking system is called automatic bumper system. Infrared sensor provided on the front end of the vehicle detects the presence of the obstacle. The use of a pneumatic system can prove to be useful in automation due to its simplicity and ease of operation. So, the aim is to design and develop a system based on automatic control of a vehicle. The System has few limitations in densely traffic road.

Shinde et al., (2016) developed in the Automatic pneumatic-bumper braking system it is used in four-wheeler vehicles & heavy vehicles. This system consists of two mechanisms i.e. automatic braking system and pneumatic bumper system. The automatic braking system uses the infrared sensor (IR), which is used to sense the vehicle coming from the front of our vehicle and which is responsible for an accident. Then the sensor sends a feedback signal to the engine through the relay control to stop the working of the engine. Their main goal of designing this system is to improve the prevention technique of accidents and also reducing the hazard from accidents like damage to the vehicle, injury of human, etc. The limitation of the system is additional cost is required to use the system, vehicle speed above 40-50 km/hr, the system has few limitations in densely traffic road, the system has no provision to prevent accidents from a rear side of the vehicle.

Kuchimanchi et al., (2015) dealt with a model of cost-effective collision warning system for low budget cars. Rear-end collisions are common accident scenarios and a common cause of these accidents is driver distraction and thus not reacting in time. This aims at reducing impact speeds and thus the risk of consequences. Finally, it has been discussed how the benefit of such systems can be judged from a real-life safety perspective using traffic accident statistics. This system is very economical when compared to the technologies being used in luxury cars.so there can be a tremendous decrease in the death rate due to accidents.

Erik et al., (2010) focused on describing and comparing the theoretical and practical performance of the automatic emergency braking provided by CWAB-PD in commonly used test scenarios. This paper describes one of the latest AEB systems called Collision

Warning with Full Auto Brake and Pedestrian Detection (CWAB-PD). It helps the driver with avoiding both rear-end and pedestrian accidents by providing a warning and, if necessary, automatic braking using full braking power. A limited set of accident scenarios is selected to illustrate the theoretical and practical performance of this system. It is shown that the CWAB-PD system can avoid accidents up to 35 km/h and can mitigate accidents achieving an impact speed reduction of 35 km/h. To the best of the author's knowledge, CWAB-PD is the only system on the market that automatically can avoid accidents with pedestrians.

Jordan et al., (2016) focused on designing a device that can successfully scan the surroundings during driving and apply a brake to avoid front end collision of the vehicle, along with the extension of the bumper. The ultrasonic sensor provided on the front end of the vehicle detects the presence of the obstacle. The Pneumatic braking circuit applies a brake and brings the vehicle to stop, and the latter provides the safety of the vehicle during impact. Driver alert mechanism is included to alert the driver at a safe braking distance from a collision. It can easily brake to complete still up to a speed of 10km/hr. The model can sense an obstacle up to 200cm and display “Normal” on the LCD screen provided at safe distance. Response time was very low, thus it provides better braking when compared to that of IR sensors.

Sus et al., (2018) dealt with designing and implementing automatic emergency braking using the concepts of mechanical and electronics engineering or ‘Mechatronics’. It also explains the benefits of various parts and why they are used specifically. The advantages of AEBS over conventional braking system are explained along with the future developments which may be possible in this field. The futures AEB are just the beginning of the revolution in crash avoidance. Advanced Driver Assistance Systems (ADAS), such as AEB, designed to prevent or mitigate different crash types, and are entering the market every year. The future will bring autonomous steering to prevent head-on collisions and run-off-road crashes which are often very serious, or even fatal.

Venkatesh et al., (2017) designed and developed a control system based on an intelligent electronically controlled automotive braking system is called “Automatic Reverse Braking System”. This Braking system is consists of an IR transmitter and Receiver circuit, Control Unit, Pneumatic breaking system. The IR sensor is used to detect the obstacle. There is an obstacle in the path, the IR sensor senses the obstacle and giving the control signal to the braking system. The pneumatic braking system is used to break the system. The “Pneumatic Braking Circuit” can stop the vehicle within 2 to 3 seconds running at a speed of 50 KM. The Reverse braking system is a fully automation project.

Hameed et al., (2017) developed a control system along with an effective electronic controlled automotive braking and clutch method is called “Automatic pneumatic clutch and braking system”. Pneumatic Brake and clutches operated through sensors with IR transmitter and Receiver unit, Control Unit, and Pneumatic breaking system. Pneumatic operation technology is very essential and important for any technicians or engineers to get a better knowledge of the pneumatic system, air-operated valves, and others. In this project, eddy current is used to make effective action of break-in rotating wheel and the braking arrangement is in a wheel as a model.

Hemalatha et al., (2016) designed and developed a control system based on an automatic, intelligent and electronically controlled automotive braking system for automobiles is called “Intelligent Braking System”. This Braking system consists of an IR transmitter and receiver circuit used to detect the obstacle and the vehicle. This project facilitates an electromagnetic braking system using solenoid. Here in the fabrication module include a circular disc associated with a dc motor and a solenoid. Embedded system module includes a microcontroller with a solenoid and sensor. The intelligent braking system provides total safety in the negligence of the driver in the emergency situation thus saving reduction in loss of precious human lives and properties.

Rupesh et al., (2017) ensured that safe the vehicles by using Anti-lock and Automatic Braking system (AABS) Technology. It basically controls the speed of the vehicle by continuously monitoring the distance of the obstacle or any other vehicle ahead using ultrasonic sensors and checking the speed of the vehicle in concern using wheel speed sensors. The components used are an Arduino board, ultrasonic sensors, Hall Effect sensors, and motors. The sensors measure the speed of the vehicle and detect the obstacle ahead, thereby, initiating automatic braking. If the speed of the vehicle is above a set velocity for a predefined safety distance, then the microcontroller system performs the actuating mechanism to bring back the vehicle to a safe speed thereby minimizing the chances of accidents.

Sourabh et al., (2017) designed and developed a control system based on an intelligent electronically controlled automotive braking system is called “Automatic Brake For Hills

Station”. This Braking system is consists of an IR transmitter and Receiver circuit, Control Unit, Pneumatic braking system. The IR sensor is used to detect the hill’s obstacle. There is an obstacle in the path, the IR sensor senses the hills obstacle and giving the control signal to the braking system. The mechanism has been developed to stop the vehicle from rolling backward when the vehicle is moving in the hill roads. This construction made of two phases in the first design of ratchet and pawl mechanism, frame, shaft, etc. is done and in second sensor selection and interference is done. Ratchet and pawl mechanism has been fabricated and assembly with sensor interface is tested.

Milind et al., (2016) focused on a system known as 'Intelligent braking system' (IBS) which employ several sensors to respond when emergency conditions occur. The system includes an infrared wave emitter provided on the front portion of the car. An infrared receiver is also fitted to receive the signal. The reflected wave gives the distance between the obstacle and the vehicle. Then a microcontroller is used to detect the pulses and apply brakes to the vehicle. IBS car provides an indication of the future of automotive safety. By IBS system we can prevent more accidents and save more lives.

Shubham et al., (2017) studied an intelligent electronic control with automatic bumper activation system is known as “Automatic braking with the pneumatic bumper system”. This system is assembled on a four-wheeler vehicle. Generally, this system consists of two mechanisms and these are automatic braking systems and pneumatic bumper system. The automatic braking system uses the infrared sensor (IR) which senses the vehicles which come in front of our system and which may be cause for an accident. Then the sensor gives feedback to the engine through the relay to stop the working of the engine. This provides pre-crash safety for the vehicle. As well as this system improves the response time of vehicle braking to keep a safe distance between two vehicles. By using this system we control the speed of the vehicle in a small distance. Limitations of the System have few limitations in densely traffic road, System has no provision to prevent and cure the accidents of the rear side of the vehicle, IR sensor range is small, Proximity sensors may sense obstacle due to the presence of dirt and Sensors may stop working due to random reasons.

Tushar et al., (2017) described that the vehicles are often equipped with active safety systems to reduce the risk of accidents. The project was using Ultrasonic sensors and Microcontroller with which the speed of the vehicle is automatically reduced and voice alarms are given to the user when it approaches an object by automatically sensing the position of the object/vehicle. They presented somewhat preliminary and needed for further significant investigations. While the car is taking a turning sensor can give a false indication of an obstacle. To avoid this they will make an arrangement such that this system goes off while turn. This can be achieved by mounting sensors on car wheels that are capable of measuring wheel turning. At present, this system is readily suitable for an automatic transmission. While making some changes we can use this on any available vehicle. Also improved and precise programming is necessary for real-time operation. So the application of the intelligent braking system for critical dynamic condition needs to be analyzed.

Li et al., (2011) studied air brake system has been widely used in heavy trucks and intercity buses for its great superiority over another brake system. The components of the air brake system are decomposed to several basic standard pneumatic components, and then build the system based on these basic standard pneumatic components. An air brake system which contains a brake valve, relay valve, brake chamber, and pipelines is made based on the standard pneumatic components. The dynamic ma-thematic model of the air brake system is very complicatedly, which makes the model hard to be solved. Then some standard pneumatic components are introduced and built-in software- M works. The integrate air brake system is also built using the key components, and the simulation results show dynamic characteristics of air brake system such as delay time brake system can be obtained.

Shinde et al., (2016) developed an automatic braking system based on an intelligent electronic control system. The system consists of two mechanisms, the first one was an automatic braking system the second one was a pneumatic bumper system. Automatic braking system uses the infrared sensor to sense the vehicle coming from the front and sends a signal to the engine through relay control to stop working of the engine. The limit switch activates the pneumatic bumper system and brake to reduce the damage or pre-crash safety to the vehicle. The system used for a four-wheeler vehicle and heavy vehicles. The limitation was the system has no provision to prevent an accident from the rear side of a vehicle and system has few limitations in densely traffic roads.

Li and Yang (2017) proposed the concept of intelligent braking, pneumatic automatic braking, and then a kind of pneumatic automatic braking circuit is designed. The pressure change rate is used as a new index to evaluate automatic braking and control. This study provides a new theoretical basis for the design and application of the pneumatic braking system. They proposed to identify the basic characteristics of pneumatic components, to design an automatic pressure regulator for pressure control, to adjust the supply pressure independently with a pneumatic booster valve, and use the braking pressure change rate as a control target and other concepts, all of them prove a reference for improving the brake system of autonomous vehicles.

Sandeep et al., (2016) focused on systems currently in production like traction control (TC), electronic brake-force distribution (EBD), brake assist (BA) and electronic stability control (ESC) functions and future systems that are currently in development. A system which can operate automatically with the help of high profile sensors based relay circuit and some modification in the traditional braking system that can alert the driver in a front collision and apply the brake automatically in emergency or critical situation.

Praveen et al., (2015) designed a magnetic actuator to deal with the modeling and optimization of Solenoid actuator. The study’s proportional solenoid valve design is very important and designed to find out the magnetic force (N), magnetic field intensity (A/m), magnetic flux density (Tesla or wb/$m^2$). To enhance the magnetic force and reduction of size by the magnetic field in the air gap of a solenoid valve. Permanent magnetic bias magnetic actuator study for the bidirectional application using different permanent magnet material and optimization of the size of armature.

**Summary of literature**

Most of the above researchers are studied improving braking efficiency by using a control system of automatic braking system works using the automatic bumper system and braking system to prevent technique of accident and also reducing the hazard from the accident. And the other researcher is tried to increase braking efficiency by solenoid valve system to disc brake with a cylinder. But still now the braking distance of heavy vehicles, especially Sinotruck is not decreasing. Hence braking system needs to enhance for efficient braking. Braking with an additional electromagnetic brake of a solenoid plunger is found that improve the brake efficiency by inducing magnetic on the solenoid plunger and push the foot valve using an electric coil. Therefore it design an automated pneumatic braking control system using solenoid plunger controls and an ultrasonic sensor to prevent the collision.

## 2.2. Electromagnetic actuator technology

A various electromechanical linear actuators, electromagnetic actuators have drawn special attention. Electromagnetics actuator actuation uses magnetic fields to generate forces that lead to motion. In an electromagnetic actuation system, the input electrical energy in the form of a voltage and a current is converted magnetic energy. The magnetic energy creates a magnetic force which produces mechanical motion over a limited range. Typically, the magnetic force is generated due to the magnetic field interaction built by the current-carrying coil or the permanent magnet. Thus, the magnetic actuator converts input electrical energy into output mechanical energy.

In order to analyze the electromagnetic actuators is important to understand the governing principle for these actuators. The electromechanical conversion mechanisms in electromagnetic actuators are governed by the Lorentz force law and Reluctance force law (Vahid, 2013).

**Lorentz force law** states that if a current-carrying conductor is placed in a magnetic field, a force will act upon it. The magnitude of this force is determined by the magnetic flux density, the current, and the length of the conductor placed in the magnetic field. The Lorenz force is proportional to the product of the magnetic field and the current, in a direction perpendicular to both of them by reversing the polarity of the voltage in the conductor, the direction of the force will change (Steven, 2016).

**Reluctance force law** states that for a current-carrying conductor in a stationary coil, the electromagnetic system always tries to move toward the status of minimum reluctance in its magnetic circuits. Therefore, if any part of the magnetic circuit is free to move like a plunger in a solenoid, a force is generated which causes the plunger to move in order to minimize the magnetic reluctance of the magnetic circuits. The generated pulling force is proportional to the square of the current in the winding and inversely proportional to the square of the length of the air gap (Steven, 2016).

## 2.3. Basic design concepts of electromagnetic brake system

### 2.3.1. Electromagnetism

When current passes through a conductor, a magnetic field will be generated around the conductor and the conductor becomes a magnet. This phenomenon is called electromagnetism (Jack, 2009).

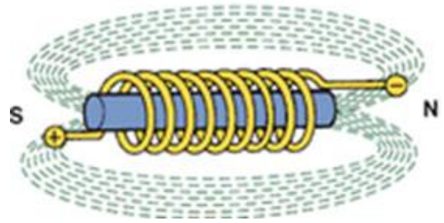


Figure 2.1. Electromagnetism (Jack, 2009).

Whenever a current-carrying conductor is placed in a magnetic field, it experiences a force that acts in a direction perpendicular to the current and the field. The force on the current-carrying conductor in a magnetic field depends on:

i. The flux density of the field (B).
ii. The strength of current (I).
iii. The length of the conductor perpendicular to the magnetic field (L).
iv. The direction of the field and current.

When the magnetic field, the current and the conductor are mutually perpendicular to each other than the force exerted is given as (Theraja, 2005).

$$F = I \times B \times L \qquad (2.1)$$

Where: F = force (N)

B = flux density (wb/$m^2$)

L = length of coil (m)

I = current (A)

### 2.3.2. Electromagnetic

An electric current can be used for making temporary magnets known as electromagnets. An electromagnet works on the magnet effect of current. It has been found that if a soft iron rod called core is placed inside a solenoid, then the strength of the magnetic field becomes very large because the iron ore is magnetized by induction (Kattimani et al., 2018).

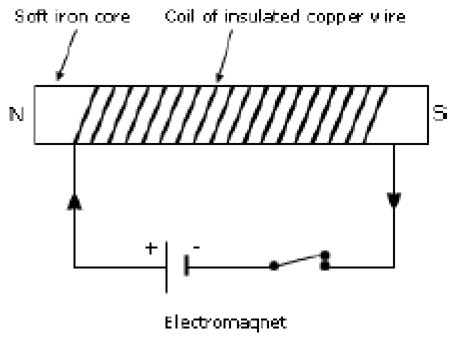


Figure 2.2. Magnetic field lines (Kattimani et al., 2018).

## 2.4. Air brake system

To move a vehicle, an internal combustion engine must convert its heat energy to mechanical energy. This mechanical energy goes from the engine to the driving wheel tires by means of a system of connecting rods, shafts and gears. The final factor that moves a vehicle is the amount of traction its tires have on the road surface.

Traction is the ability of a tire to grip the road surface on which it rolls. The vehicle's acceleration rate depends on the power the engine develops and the amount of traction the tires have on the road surface.

Friction is the force which resists movement between two surfaces in contact with each other. To stop a vehicle, brake shoe linings are forced against the machined surfaces of the brake drums, creating friction. This friction produces heat.

The engine converts the energy of heat into the energy of motion, the brakes must convert this energy of motion back into the energy of heat. Friction between brake drums and linings generates heat while reducing the mechanical energy of the revolving brake drums and wheels. The heat produced is absorbed by the metal brake drums, which dissipate heat by passing it off into the atmosphere.

The amount of heat the brake drums can absorb depends on the metal thickness of which they are made. When enough friction is created between brake linings and drums, the wheels stop turning. The final factor that stops a vehicle is not the brakes, but the traction between tires and road surface.

If a 200 horsepower engine accelerates a vehicle to 100 km/h in one minute, imagine the power needed to stop this same vehicle. Not only that, the vehicle might have to be stopped in an emergency, in as little as six seconds (just 1/10 of the time it took to reach 100 km/h).

To stop a vehicle in 1/10 the time it takes to accelerate requires stopping power of 10 times the acceleration power equivalent to 2,000 horsepower.

If the vehicle had six wheels, each wheel would have to provide 1/6 of the braking power. If one or two wheels had brakes that were not properly adjusted, the other wheels would have to do more than their share of the braking, and that might be more than their brakes were constructed to stand. Excessive use of the brakes would then result in a build-up of heat greater than the brake drums could absorb and dissipate. Too much heat would result in brake damage and possible failure (Saskatchewan driver's licensing and vehicle registration, 2019).

## 2.5. Stopping distance

The distance required to stop a vehicle depends on its speed and weight in addition to the factors of energy, heat, and friction. The brake power required to stop a vehicle varies directly with its weight and the "square" of its speed. For example, if weight is doubled, stopping power must be doubled to stop in the same distance. If speed is doubled, stopping power must be increased four times to stop in the same distance. When weight and speed are both doubled, stopping power must be increased eight times to stop in the same distance.

Stopping distance ($\boldsymbol{s_d}$) consists of two factors:

Driver's reaction distance + Braking distance.

The total stopping distance of the vehicle can be calculated. (https://en.wikipedia.org/wiki/stopping distance).

$$\boldsymbol{s_d} = \text{Reaction Distance + Braking Distance} \quad \text{.......... (2.2)}$$

**Reaction Distance**

Reaction distance is the distance in which the vehicle travels before the driver senses the hazard and starts applying brakes. It can be calculated as follows.

(https://en.wikipedia.org/wiki/)

$$\boldsymbol{d_r} = \frac{(v \times t_r)}{3.6} \quad \text{.......... (2.3)}$$

Where: $d_r$= reaction distance (m)

$V$ = speed (km/h)

$t_r$ = reaction time (sec)

The Standard reaction time of a driver is in between 0.5-3 seconds (M.I. Gonzalez, Experiments with eddy currents: the eddy current brake, European Journal of Physics, 25(2004) pp 463-468). It takes 0.7 seconds for perfect reaction time from the standard driving regulation act.

**Braking distance**

The actual distance a vehicle travels after the brake is applied until the vehicle stops. This distance depends on the ability of the lining to produce friction, the brake drums to dissipate heat and the tires to grip the road (Kushal, 2017).

$$D_B = \frac{V^2}{(2\times\mu\times g)} \quad \text{.............................................................} \quad (2.4)$$

Where: $D_B$ = brake distance (m)

$V$ = velocity before applying brake (m/s)

$\mu$ = coefficient of friction asphalt road 0.8

g = acceleration due to gravity (m/$s^2$)

Stopping distance is also affected by your reaction time and braking distance is shown below Figure 2.3.

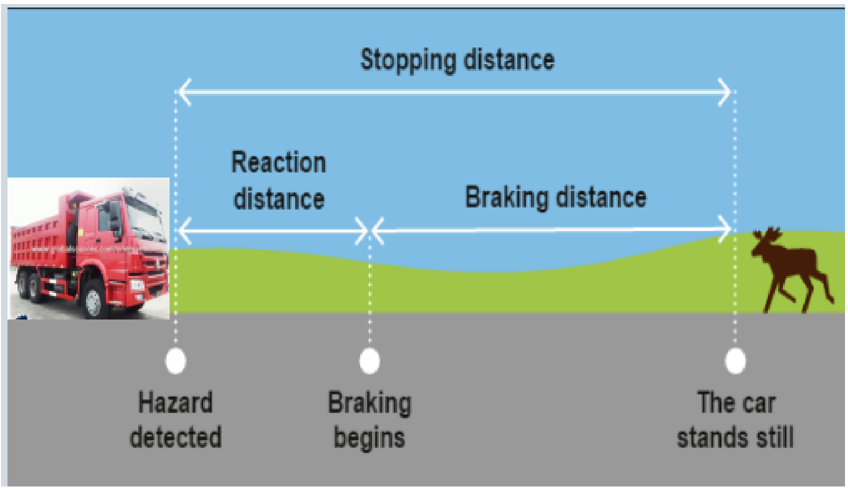


Figure 2.3. Normal braking distance of the vehicle.
(https://korkortonline.se/en/theory/reaction-braking-stopping/)

## 2.6. System components and conceptual design

An automatic pneumatic brake system consists of two main components. These are:

1. The conventional air brake components and
2. The electronic components.

### 2.6.1. Conventional air brake components

The conventional air brake components are those from the air compressor to foundation brake which is used to make the simplest possible air brake system as shown in Figure 2.4 and Figure 2.5 below.

These are:

- ✓ Air compressor
- ✓ Governor
- ✓ Air reservoir
- ✓ Air tubes
- ✓ Foot valve
- ✓ Quick-release valve and

Foundation brakes (brake chambers, slack adjusters, S-cams, brake linings and drums or rotors).

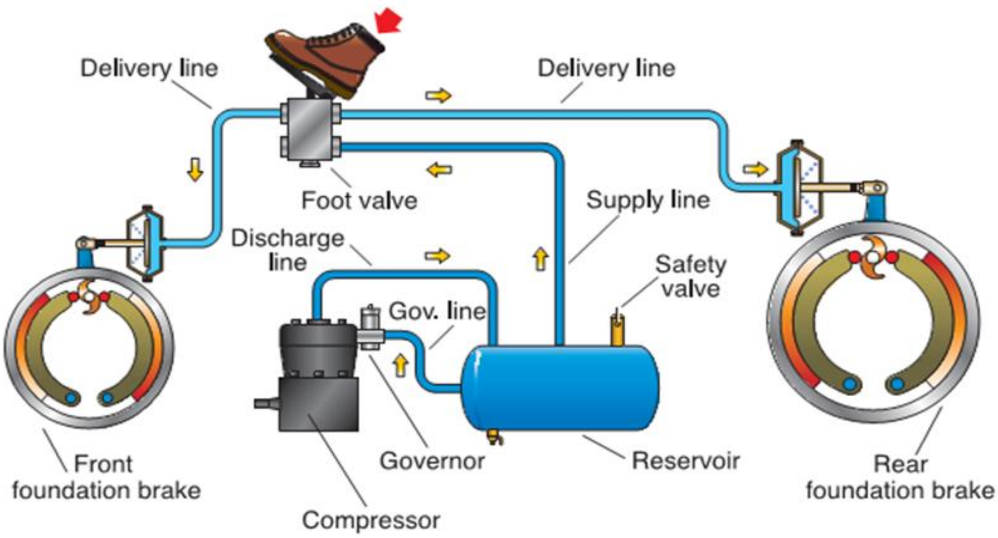


Figure 2.4. Simple air brake components. (Saskatchewan driver's licensing and vehicle registration, 2019).

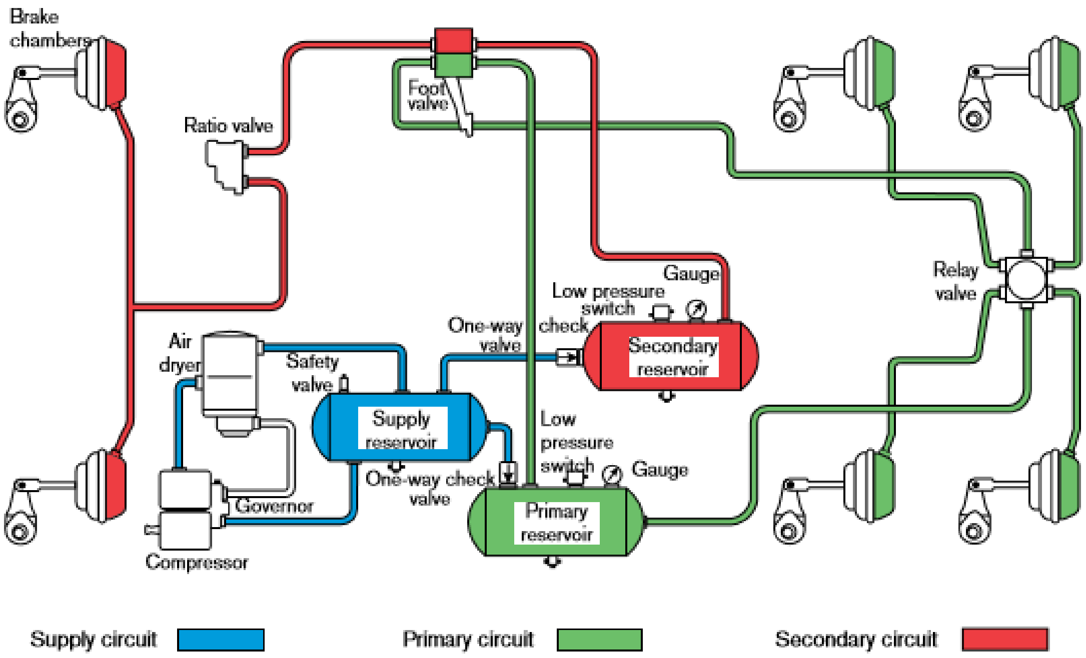


Figure 2.5. Simple dual circuit with brakes components. (Saskatchewan driver's licensing and vehicle registration, 2019).

In Figure 2.4 and Figure 2.5 above, air at full system pressure is indicated by the dark shading in the line connecting the supply reservoir to the foot valve. The driver is making a brake application. This can be seen by the light shading in the airlines connecting the foot valve to the air chambers. Arrows show the direction of airflow. The air chambers are pressurized and the brake linings have contacted the brake drums, slowing the vehicle.

When the driver’s foot offs the brake pedal, it allows the brakes to release. This action has caused an exhaust port (quick release valve) in the bottom of the foot valve to open, allowing the air that was applied to the brake chambers to escape. The return springs in the air chambers have returned the pushrod assembly to the released position, and the slack adjusters and S-cams have rotated to their released position. Brake shoe return springs (not shown) have retracted the brake linings away from the brake drums.

#### 2.6.1.1. Compressor

The first requirement of an air brake system is a means of compressing air and storing it in reservoirs (tanks) so that it is available for instant use. The source of the compressed air is the compressor, which takes in air from the atmosphere and compresses (pressurizes) it. The compressed air is then pumped through an airline to a supply reservoir. The compressor is mounted on the engine of the bus or truck. On most new engines, the compressor is mounted on the side of the engine and driven by gears. A belt, like a fan belt, drives some compressors. As long as the engine is running, the compressor will be running. In a SINOTRUK HOWO 336, air compressor operates at a pressure of 120 psi. (827kPa).This compressor for conventional brake system is used directly in the automatic pneumatic brake system (Government of Yukon, 2014).

#### 2.6.1.2. Governor

The compressor is capable of compressing air to over 500p.s.i. (3,448kPa).This is far higher than is needed to operate an air brake system. Most current air brake systems operate with a maximum pressure of 125p.s.i. (862kPa). There needs to be a way to stop compressing air once a certain air pressure has been reached. And, if the air pressure in the tank drops below a certain level (such as after a series of brake applications), it needs to be a way to start compressing the air again. This is the job of the governor. When sufficient pressure has been built up, the governor causes the compressor to go into an “unloading” stage (Government of Yukon, 2014).

Governors are usually set to unload the compressor (stop the compressor from pumping air) when the air pressure reaches about 125p.s.i. Although the maximum pressure on different vehicles may vary between 105 and 135p.s.i. (724 and 931kPa), the range between minimum and maximum pressure should be approximately 20p.s.i. (138kPa). For example, if the maximum air pressure was 125p.s.i. the governor would restart the compressor if the air pressure in the reservoirs dropped to 105p.s.i. (applying the brakes several times would likely cause the air pressure to drop to this level). At any rate, the governor must restart the compressor if the air pressure drops below 80-85p.s.i. (552-586kPa).

This governor for conventional brake system is used directly in the automatic pneumatic brake system.

#### 2.6.1.3. Reservoir

Steel tanks (known as reservoirs) are used to store the compressed air from the compressor. Air reservoir, showing safety valve on top and drain cock on the bottom. The minimum pressure is used for the design of a single-acting cylinder which is 689kPa.

A safety valve will be installed on the first reservoir to protect the reservoirs from being over-pressurized and bursting if the governor was to fail to unload the compressor. The safety valve consists of a spring-loaded ball to allow reservoir air to exhaust into the atmosphere. The valve's pressure setting is determined by the force of the spring. Safety valves are normally set to vent the excess pressure at approximately 150p.s.i. (1,034kPa). If the safety valve has to relieve the pressure, this means that the governor or compressor needs service or repair. Only a qualified mechanic should do this.

The air that is delivered from the compressor usually contains some water vapor that condenses into liquid water. This is why the supply reservoir is often called the wet tank. Most compressors also pass a small amount of oil and carbon particles. The oil and any other contaminants mix with the water, making a grey sludge.

If allowed to accumulate, this sludge would enter other components of the braking system. An excess of water in the system causes trouble with valves and other parts. In winter, water in the system may freeze, causing malfunction of valves or brake chambers.

To prevent this sludge from contaminating the air valves in the system, drain valves (also known as drain cocks) are installed in all reservoirs. Draining the reservoirs can prevent this sludge build-up. Most manufacturers recommend that reservoirs be drained daily. This reservoir for conventional brake system is used directly in the automatic pneumatic brake system (Government of Yukon, 2014).

#### 2.6.1.4. Airlines

Airlines allow the pressurized air to flow between the air brake systems components. The 1/4" outside diameter tubes are the only 3A or N tubes that comparison for air brake circuits.

#### 2.6.1.5. Foot valve

Pressing on the brake pedal (called the foot valve treadle) applies the air brakes, just like stepping on the brake pedal applies the brakes in a car. A brake pedal which is shown in Figure 2-6 is used to apply the brakes by directing compressed air from the reservoir to the brakes. The maximum brake application will not exceed the pressure in the reservoirs 0.85mpa.

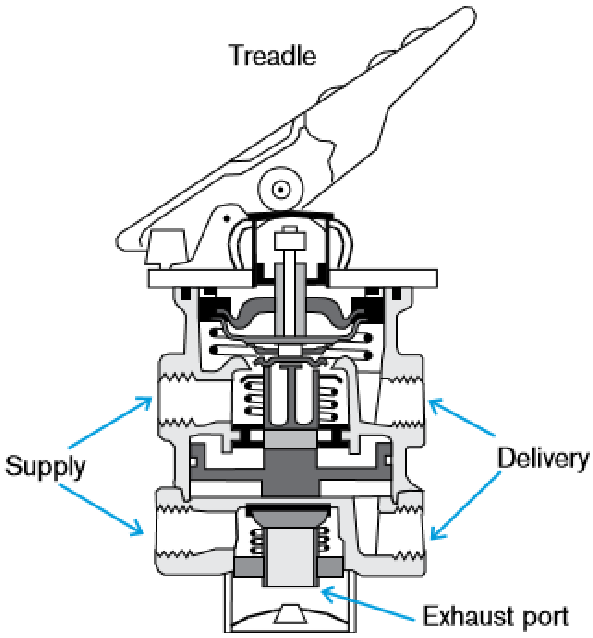


Figure 2.6. Dual-circuit foot valve (Government of Yukon, 2014).

In the automatic pneumatic brake system, the foot valve is used with the same function as it uses in the conventional brake system and a solenoid plunger is added for the automatic base.

#### 2.6.1.6. Quick-release valve

The quick-release valve exhausts brake chamber air pressure and speeds up brake release by reducing the distance the air would have to travel back to the brake valve exhaust port. When the brakes are engaged, air from the brake valve enters into the quick-release valve, forcing the diaphragm down and closing off the exhaust port. This action allows air pressure to rush through the quick-release valve outlet ports to the wheel brake chambers. When the brakes are released, the air pressure above the quick-release diaphragm is exhausted at the brake valve. As air pressure above the diaphragm is released, the air pressure below the diaphragm raises off the exhaust port. This action allows the air in the brake chambers to exhaust at the quick-release valve.

Quick-release valves were developed to speed up the release of air from the brake chambers to let the brakes release quicker. There is typically a single supply port and two delivery ports. As the brake pedal is depressed and air flows toward the brake chamber, it passes through the quick-release valve which is mounted nearby the chamber. The air pressure is held until the pedal is released. When the supply pressure at the quick-release valve drops, the air in the brake chamber is released out the bottom of the quick-release valve rather than having to travel Comparison back to the relay valve's exhaust port (Government of Yukon, 2014).

#### 2.6.1.7. Foundation brakes

The foundation brake consists of air brake chamber, slack adjuster, S-cam and brake drums. Air brake chamber: It converts the force of compressed air into a strong mechanical force through the pushrod and slack adjuster. The air brake chamber consists of a flexible diaphragm clamped between two steel housings. The diaphragm construction is similar to a tire sidewall, consisting of a reinforced fabric core with a rubber coating. Other main parts are the pushrod and plate assembly, and a return spring.

### 2.6.2. Electronic Components

These are components that are integrated to the conventional brake system components to make an automatic brake system. These are:

- ✓ Arduino UNO
- ✓ Ultrasonic sensor
- ✓ Relay module
- ✓ Solenoid plunger
- ✓ Buzzer
- ✓ LED lights
- ✓ Breadboard

#### 2.6.2.1. Arduino UNO Microcontroller

Arduino UNO is a widely used open-source microcontroller board based on the ATmega328P microcontroller and developed by Arduino.cc (What is Arduino?".Learn.sparkfun.com, 2018). The board is equipped with sets of digital and analog input/output pins that may be interfaced to various expansion boards (shields) and other circuits (Arduino UNO for beginner’s makerspaces.com, 2018). The board features 14 Digital pins and 6 Analog pins. It is programmable with the Arduino Integrated Development Environment via a type B USB cable (Introduction to Arduino priceton.edu, 2018). It can be powered by a USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts.

Every Arduino board needs a way to be connected to a power source. The Arduino UNO can be powered from a USB cable coming from your computer or a wall power supplies. It’s not allowed to use a power supply greater than 20 Volts as you will overpower and thereby destroy the Arduino. The recommended voltage for most Arduino models is between 6 and 12 Volts. The pins on the Arduino are the places where it will connect wires to construct a circuit probably in conjunction with a breadboard and some wire. They usually have black plastic ‘headers’ that allow you to just plug a wire right into the board.

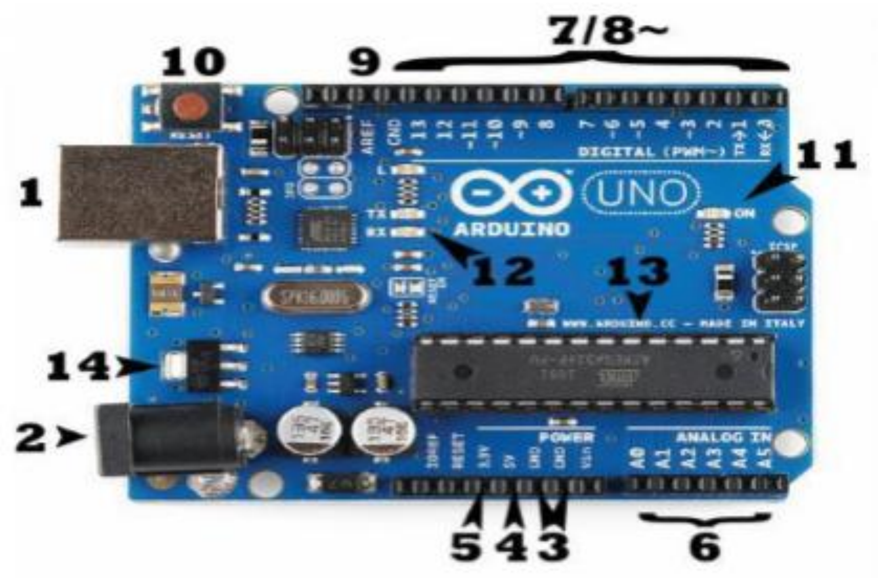


Figure 2.7. Arduino Uno Microcontroller (https://en.wikipedia.org/wiki/Arduino_Uno).

The Arduino Uno which is shown in Figure 2.7 above has several different kinds of pins, each of which is labeled on the board and used for different functions.

**Board Breakdown**

Here are the components that make up an Arduino board and what each of their functions are.

1. **USB Connection** – Used for powering up your Arduino and uploading sketches.
2. **DC Power Barrel Jack** – This is used for powering your Arduino with a power supply.
3. **Ground Pin** – There are a few ground pins on the Arduino and they all work the same.
4. **5V Pin** – This pin supplies 5 volts of power to your projects.
5. **3.3V Pin** – This pin supplies 3.3 volts of power to your projects

6. **Analog Pins** – These pins can read the signal from an analog sensor and convert it to digital.
7. **Digital Input/Output** – Pins 0-13 can be used for digital input or output.
8. **PWM** – The pins marked with the (~) symbol can simulate analog output.
9. **AREF** – Stands for "Analog Reference" and is used to set an external reference voltage.
10. **Reset Button** – This will restart any code that is loaded to the Arduino board.
11. **Power LED Indicator** – This LED lights up anytime the board is plugged in a power source
12. **TX/RX** – Transmit and receive data indication LEDs.
13. **ATmega Microcontroller** – This is the brains and is where the programs are stored.
14. **Voltage Regulator** – This controls the amount of voltage going into the Arduino board.

#### 2.6.2.2. Ultrasonic sensor

Ultrasonic sensor (sometimes called ultrasonic transducers), is non-contact distance measurement module. It is perfect for measuring distance between two moving or non-moving bodies. Ultrasonic sensors measure the distance to or the presence of a target object by sending a sound pulse, above the range of human hearing (ultrasonic), toward the target and then measuring the time it takes the sound echo to return. Knowing the speed of sound, the sensor determines the distance of the target and sets its outputs accordingly.

The Ultrasonic transmitter transmits an ultrasonic wave, this wave travels in air and when it gets objected by any material it gets reflected back toward the sensor this reflected wave is observed by the Ultrasonic receiver module as shown in Figure 2.8.


Figure 2.8. Ultrasonic sensor (Imran, 2016).

Sensor outputs are set based on the measured distance, or under override conditions, a lack of target detection or user-selected response algorithms. Outputs can be:

• An analog voltage or current signal proportional to the measured distance.
• Switches or relay contact closures that open or close at specific distances.
• Distance data transmitted digitally as serial data communications.

The maximum range of these products is presently 30 meters and varies by model. The distance at which an object is detected depends on its size, shape, and orientation. In general, the target must be larger to be detected at longer distances – the object must reflect a sufficiently strong ultrasonic echo back to the sensor to be detected. Curved objects or sound-absorbing materials such as fabrics or non-wovens reflect less energy directly back to the sensor. Granular materials may absorb sound or deflect sound energy away from the sensor due to surface variation and/or angle of repose. Sensor maximum range should be de-rated for these targets.

Ultrasonic sensor has four pins. These are: Vcc, Trigger, Echo and Ground

- ✓ **Vcc:** The Vcc pin powers the sensor, typically with +5V
- ✓ **Trigger:** Trigger pin is an input pin. This pin has to be kept high for 10us to initialize measurement by sending US wave.
- ✓ **Echo:** Echo pin is an output pin. This pin goes high for a period of time which will be equal to the time taken for the US wave to return back to the sensor.
- ✓ **Ground:** This pin is connected to the Ground of the system.

#### 2.6.2.3. Relay module

A relay is an electrically operated switch of mains voltage. It means that it can be turned on or off, letting the current go through or not. Controlling a relay with the Arduino is as simple as controlling an output such as an LED. The relay module shown in Figure 2-9.


Figure 2.9. Relay (www.teachmemicro.com).

In relation to mains voltage, relays have 3 possible connections:

- ✓ **COM:** common pin.
- ✓ **NO (Normally open):** there is no contact between the common pin and the normally open pin. So, when you trigger the relay, it connects to the COM pin and supply is provided to a load.
- ✓ **NC (Normally closed):** there is contact between the common pin and the normally closed pin. There is always a connection between the COM and NC pins, even when the relay is turned off. When you trigger the relay, the circuit is opened and there is no supply provided to a load. The operating principle of relay connected to Arduino is shown in the figure.

#### 2.6.2.4. Solenoid plunger

A solenoid plunger is an electromechanically operated plunger. The plunger is controlled by an electric current through a solenoid. Solenoid plunger is the most frequently used control air in the foot valve. Their tasks are to shut off, release, push, and pull the object. They are found in many application areas.

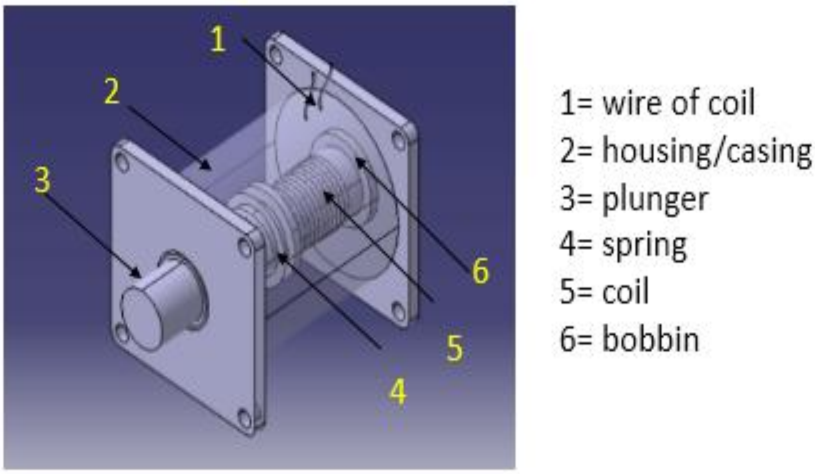


Figure 2.10. solenoid plunger

In the automatic braking system, solenoid plunger in Figure 2.10 above is used. The plunger will push the foot valve rod and allow the passage of compressed air if there is an obstacle in the path of the vehicle which is actuated by the relay module. When an obstacle is detected by the sensor, the relay module gets power and it becomes closed which allows the transmission of electric power from the battery to the solenoid plunger. After the solenoid plunger gets power, the magnetic fields push the plunger and the foot valve delivery port opens.

### 2.6.2.5. Buzzer Module (5v rated)

A buzzer or beeper is a signaling device, usually electronic, typically used in automobiles, household appliances such as a microwave oven, or game shows. It most commonly consists of a number of switches or sensors connected to a control unit that determines if and which button was pushed or a preset time has elapsed, and usually illuminates a light on the appropriate button or control panel, and sounds a warning in the form of a continuous or intermittent buzzing or beeping sound. Initially, this device in Figure 2.11 was based on an electromechanical system which was identical to an electric bell without the metal gong (which makes the ringing noise). Usually these were hooked up to "driver" circuits which varied the pitch of the sound or pulse the sound on and off.

Figure 2.11. Buzzer (Imran, 2016).

Active buzzer 5V Rated power can be directly connected to a continuous sound, this section dedicated sensor expansion module and the board in combination, can complete a simple circuit design.

The buzzer is used to alarm the driver to take a further safety action like depressing the clutch pedal in order to prevent the load on the engine during automatic braking.

### 2.6.2.6 Light Emitting Diodes (LEDs)

An LED is a small light (it stands for "light-emitting diode") that works with relatively little power. LEDs have polarity, which means they will only light up if you orient the legs properly. The long leg is typically positive, and should connect to a digital pin on the

Arduino board. The short leg goes to GND; the bulb of the LED will also typically have a flat edge on this side as shown in Figure 2.12. To blink the LED takes only a few lines of code. The first thing we do is define a variable that will hold the number of the pin that the LED is connected to. We don't have to do this (we could just use the pin number throughout the code) but it makes it easier to change to a different pin. We use an integer variable (called an int).

Current flows from the anode to the cathode and never the opposite direction. We have used two LEDs. The red-colored LED indicates that the vehicle is braking due to the presence of an obstacle in the path and the green LED indicates that there is no obstacle in the path of the vehicle and the brake is not held.

Two LEDs (green and red) are used which are installed in the dashboard in front of the driver. The green LED indicates that the vehicle is in safe condition and also there is no obstacle in the path of the vehicle.

The red LED indicates that the vehicle is braking automatically.

Figure 2.12. LED (Imran, 2016).

#### 2.6.2.7 Breadboard

Breadboard is a device to make prototype circuits. It has several sockets in which electronic components get inserted. It has power line sockets that provide power to the circuit. The arrow line shows the breadboard internal connectivity. Image of a plus one size breadboard in Figure 2.13 seen below.

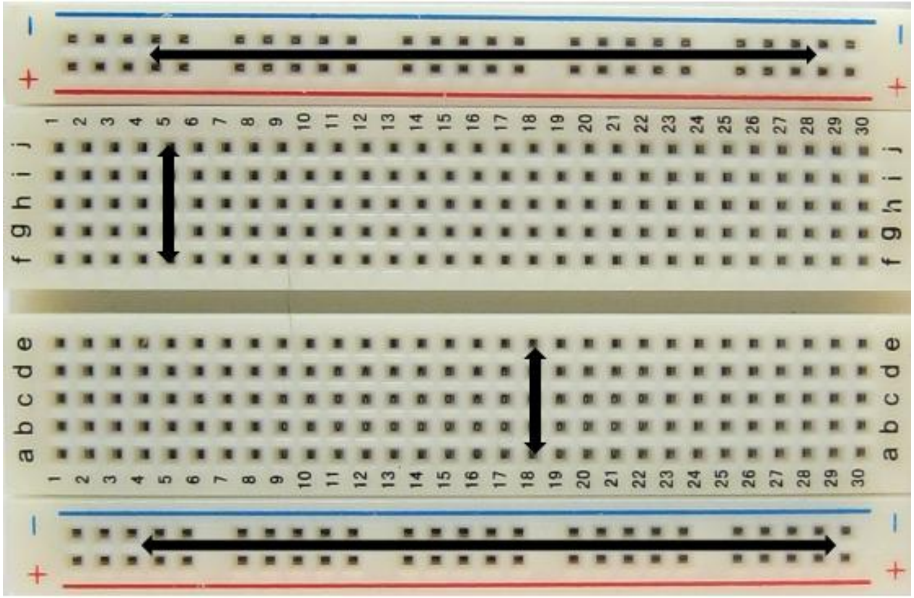


Figure 2.13. Breadboard (Imran, 2016).

The plus one size breadboard has two power lines which are internally connected. If power is given to one power line, it can be taken out from all other socket of the power line. If a circuit uses two types of power, for example, 5V and 3.3V, in this condition one power line can be used for 5V and the other power line can be used for 3.3V. Socket of main sections are internally connected in a set of 5 sockets from A to E and from F to J. A plus one breadboard has such 30sets.

### 2.6.3. Working Principle

The whole system operates only when the car is moving. In the sensor unit, the ultrasonic sensor transmitter will transmit the wave. If there is any obstacle in the vehicle path, the sound waves will reflect. This reflected waves are received by the receiver circuit is called ultrasonic receiver.

If there is no obstacle in a path, the receiver circuit will not receive any signal and the solenoid valve remains closed. But, if there is an obstacle the microcontroller will receive an input signal and sends an output signal to the relay module to actuate the solenoid plunger. When the solenoid plunger is electrically energized a magnetic field is created which pushes the plunger to outwards the center of the coil, this action pushes the foot valve rod so the compressed air can flow through. If the solenoid plunger is activated, the compressed air passes through a foot valve.

The compressed air activates the braking circuit moves the push rod of the brake chamber. If the piston moves forward, then the breaking arrangement activated. During this situation a brake will be held. After the obstacle is removed from the vehicle path, the solenoid plunger will not be energized and it will back to the former position. Finally, the spring inside the foot valve pushes the compressed air in the cylinder backward through the quick-release valve to the environment. Then, the brake will be released shown in Figure 2.14.

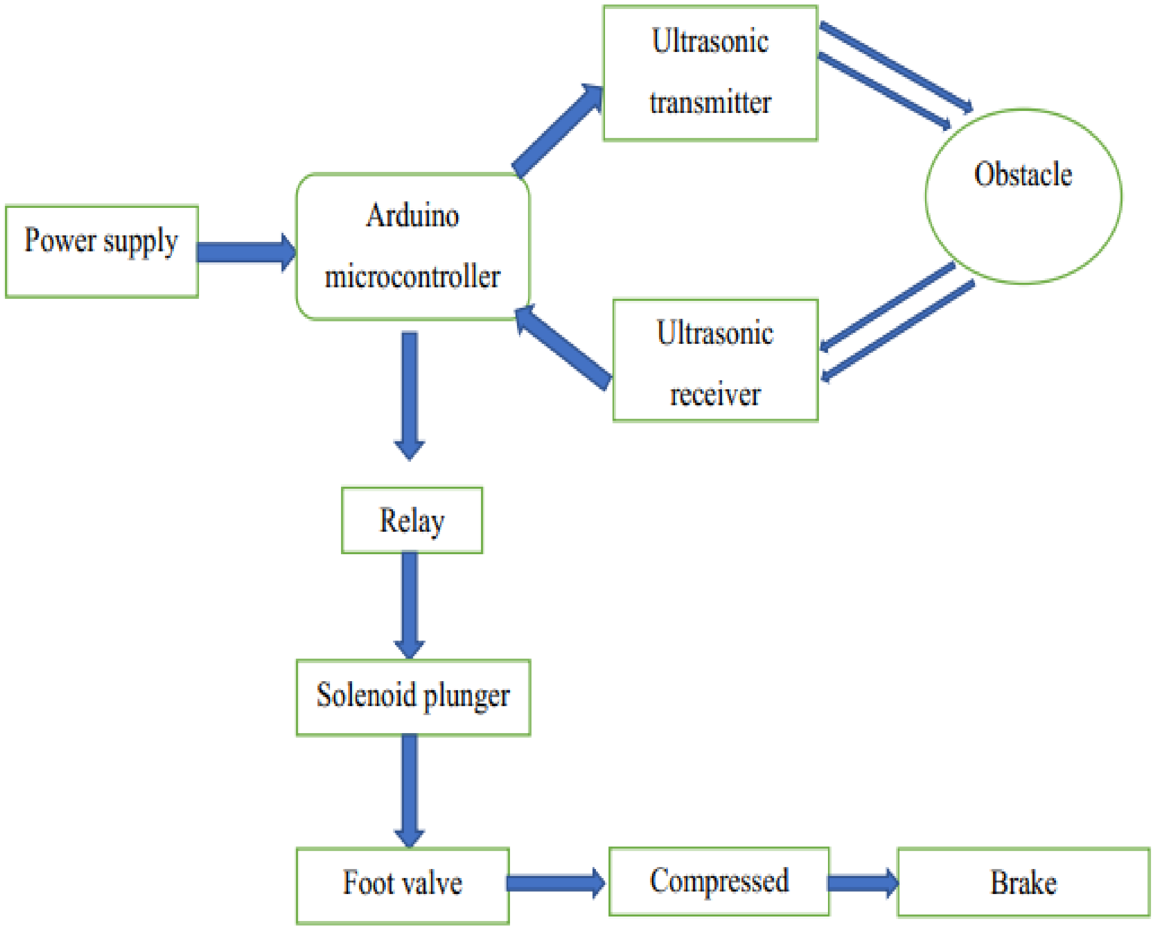


Figure 2.14. The working principle of automatic pneumatic braking control system.

# CHAPTER THREE

## 3. MATERIALS AND METHODS

### 3.1. Materials

The materials required for this thesis work are listed in Table 3.1 given below.

Table 3.1. The materials required

| No. | Components | Model number | Qty |
|---|---|---|---|
| 1. | Arduino Uno Compatible Board | Robo India C-UNO-01 | 1 |
| 2. | Breadboard 400 point plus | BB-400 | 1 |
| 3. | Arduino Breadboard Base-plate | MB-102 | 1 |
| 4. | Jumper Wire Male to Female | 40-pin M/F jumper wires | 3 |
| 5. | Jumper Wire Male to Male | 40-pin M/M jumper wire | 2 |
| 6. | Jumper Wire Female to Female | 40-pin F/F jumper wires | 4 |
| 7. | Resistors | 220ohm | 2 |
| 8. | Buzzer | PEIZO 5v | 1 |
| 9. | LED Green | B00C7432889 | 1 |
| 10. | LED Red | B00C7432889 | 1 |
| 11. | Arduino Motor Shield | Roinco ZX-L293D-SH | 1 |
| 12. | Ultrasonic Sensor HCSR-04 | Robo India SR-04 | 1 |
| 13. | HC-SR04 base Module | Roinco XB-AD-KT-02 | 1 |
| 14. | BO Motor L-Type | roinco ZX-LTSS1TO48 | 2 |
| 15. | BO Rubber Wheel | roboCraze RC-A-573 | 2 |
| 16. | Metal Caster Wheel | Generic B01AQQK34U | 1 |
| 17. | Relay 5v, PCB Mountable | SRD-O5VDC-SL-C | 1 |
| 18. | Battery Holder with DC Jack | 6AA | 1 |
| 19. | 1.5v Battery | AA Alkaline Batteries | 06 |
| 20. | USB Cable A to B | Robo India USB-A-B | 1 |
| 21. | Robotic chassis set | RK2WD-DL | 1 |
| 22. | Arduino Base Plate Screw set | M3x8 | 10 |
| 23. | Motor screw set | M2.5x12 | 4 |
| 24. | Battery holder screw set | M3x8 | 6 |
| 25. | Caster wheel screw set | M3x8 | 6 |

## 3.2. Material Selection

To design the proper components, the following properties of materials are considered.

- ✓ Strength
- ✓ Durability
- ✓ Machinability and
- ✓ Weldability

The best material is one which serves the desired objective. The following factors are considered while selecting the material. These factors are:-

- ✓ Availability of the material
- ✓ Suitability of the materials for the working conditions and
- ✓ The cost of the material.

### 3.2.1. Material Selection for solenoid plunger components

Coming to material properties plunger and cover, is made up of Stainless Steel 410 (SS410) because it is having retentively property and residual magnetism. SS410 also provides good corrosion resistance to air, water, and some mild chemicals and has reasonably good cold working properties. It has selected Stainless Steel 304(SS304) material for bobbin based on the following properties. In the case of corrosion resistance, it has excellent in a wide range of atmospheric environments and many corrosive media and subject to pitting and crevice corrosion in warm chloride environments, and to stress corrosion cracking above about 60°C. SS304 has also a good heat resistance or good oxidation resistance, has higher strength at elevated temperatures and excellent weldability by all standard fusion methods, both with and without filler metals.

## 3.3. Methods

This thesis work is concerned with the implementation of automatic pneumatic brake control system vehicles especially, SINO TRUCK HOWO 336 model by following the following procedures.

- ✓ Data collection and organization.
- ✓ Material selection.
- ✓ Solenoid component system design.
- ✓ Programming the system using Arduino software.
- ✓ CATIA modeling
- ✓ Draw circuit diagram using Proteus software.

✓ Implement prototype

The overall method is in Figure 3.1 shows the basic flow of methods and approaches for this thesis. The thesis began with research and planning. This is done in order to identify the suitable component needed for hardware implementation and circuits.

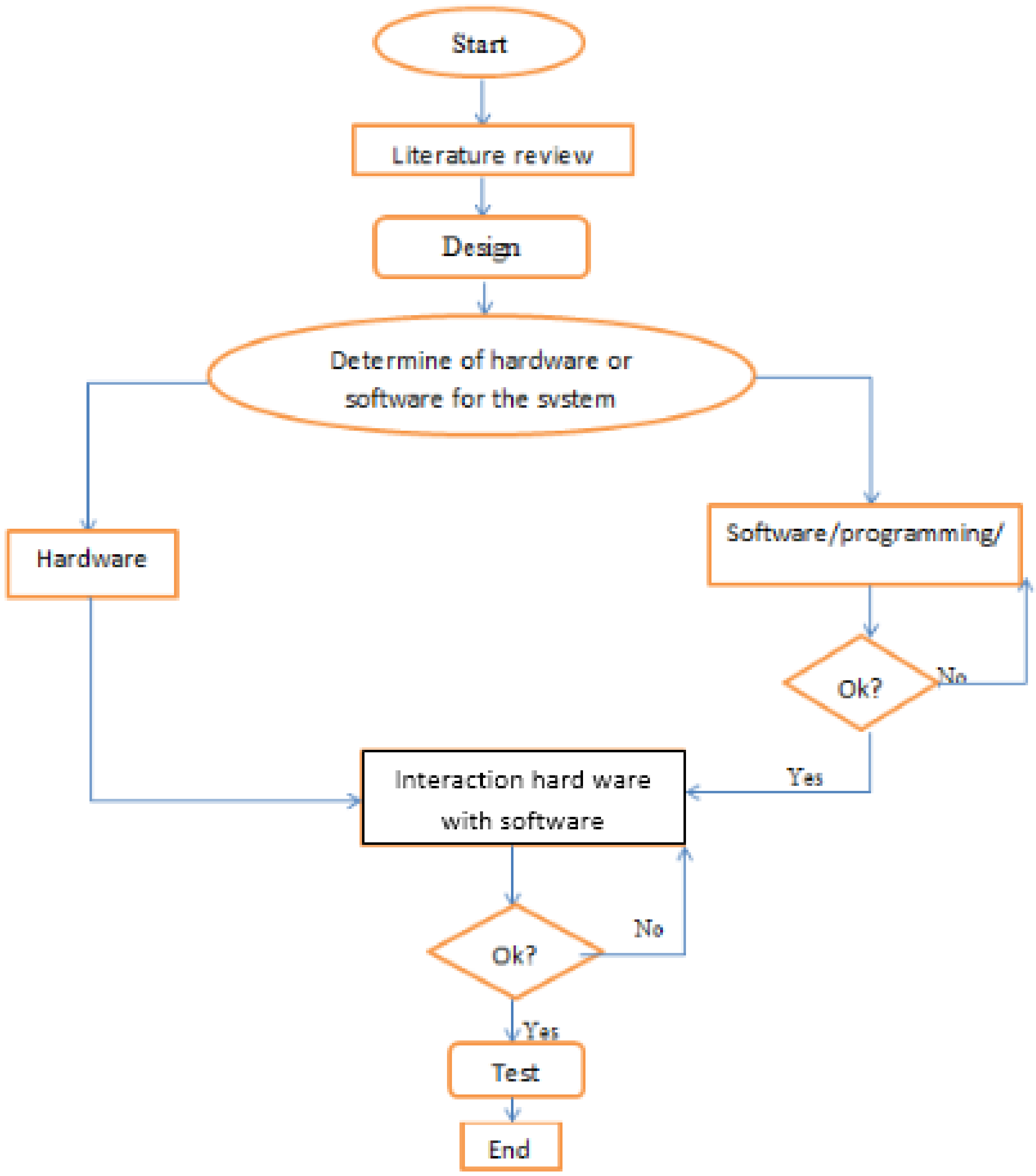


Figure 3.1. Flow Chart Methodology of the Thesis.

### 3.3.1. Data Collection and Organization Methods of data collection:

The method of data collection used for this thesis work is only primary and secondary method of data collection. The primary data collection method was interview. The secondary data collection method, were the internet, books, articles, seminar etc. Generally, data and specifications of SINO TRUCK HOWO 336 that are used for this thesis are presented in Table 3.2 (Oriemac, 2019).

Table 3.2. Specifications of SINO TRUCK HOWO 336

| Parameters | Details | Values |
|---|---|---|
| Weight Parameter | Complete Vehicle Kerb Mass(kg) | 12,380 |
| | Maximum authorized total mass (kg) | 25000 |
| External Dimensions(mm) | Length (mm) | 7835 |
| | Width(mm) | 2,496 |
| | Height(mm) | 3386 |
| Performance Parameter | Maximum Speed(km/h) | 75 |
| Rolling Resistance Coefficient | Truck tire on asphalt | 0.8 |
| Slack adjuster dimension(in) | Pin to pin center | 5.5 |
| Compressed air pressure(kpa) | Maximum | 827 |
| | Minimum | 689 |
| Gradability (%) | For loaded Sino-truck | 20 |

An engine of SINO TRUCK HOWO 336 has 2200rpm at the maximum engine speed and gearbox of SINOTRUK HOWO 336 has 10-speed manual type transmission (Oriemac, 2019).

The main dimension of the foot valve of Sino-truck is measured by using Vernier caliper and the values are given from Figure 3.2.

- ✓ Outer diameter of foot valve = 60 mm
- ✓ Inner diameter of foot valve = 45 mm

- ✓ Diameter of plunger on foot valve = 20 mm
- ✓ Depth of plunger on foot valve = 23 mm

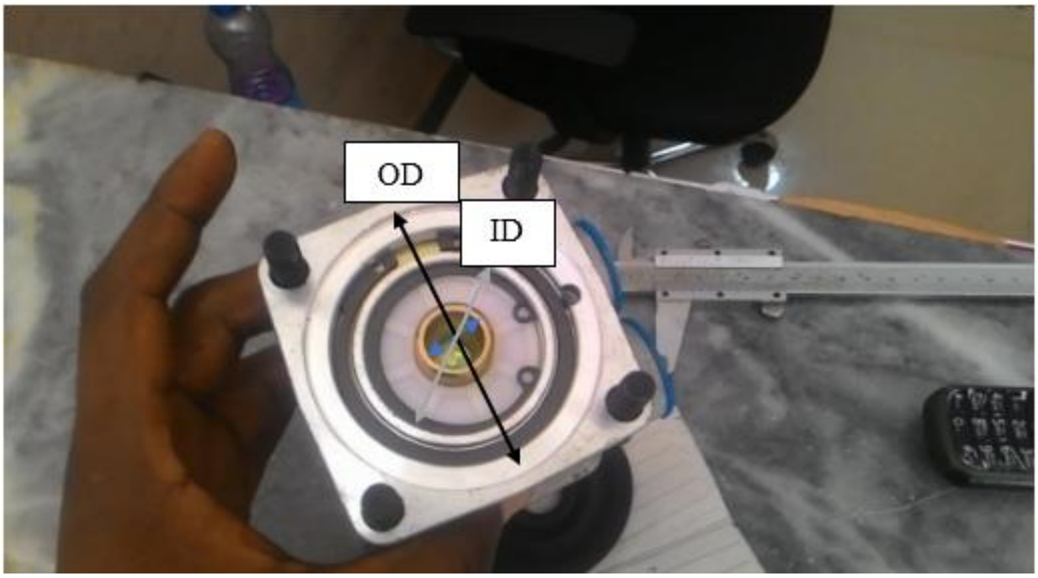


Figure 3.2. Foot valve dimension

Table 3.3. Considerations of solenoid plunger dimensions

| Parameter | Dimension(mm) |
|---|---|
| $l_z = l_c$ | 40 |
| $l_{eq}$ | 100 |
| $X$ | 40 |
| $L$ | 4 |
| $d_1$ | 30 |
| $d_2$ | 22 |
| $T$ | 3 |
| $l_b$ | 60 |
| $d_w$ | 1 |

Table 3.4. Properties of selected materials

| Component | Material | Relative Permeability (μr) |
|---|---|---|
| Plunger and housing | Stainless steel 410 | 1000 |
| Bobbin | Stainless steel 304 | 1.05 |

Table 3.5. Mild steel properties

| Material | Allowable Tensile Stress | Allowable Shear Stress | Yield Strength | Allowable Bending Stress | Young's Modulus | Density | Ultimate Tensile Stress |
|---|---|---|---|---|---|---|---|
| Mild Steel | 150Mpa | 75Mpa | 250Mpa | 165Mpa | 200Gpa | 7.8g/cm$^3$ | 410Mpa |

## 3.4. System Component Design and Analysis

The usual air brake system has only pneumatic mechanical components, but in my design, the brake system has two main parts. These are:

1. Pneumatic mechanical parts-which exists in the usual air brake system and
2. Electronic parts.

From the maintenance operation manual of Howo truck the force applied on the brake pedal is 190N with assistance, pedal travel maximum stroke 200mm, push 40mm. So the design solenoid force must not less than the brake pedal force.

### 3.4.1. Design of Solenoid plunger

A conventional linear actuator is used which consists of a plunger, magnetic-circuit housing, a return spring, and a coil. An electric power is positioned around the plunger. As soon as the coil is electrically energized a magnetic field is created which pushes the plunger to outwards the center of the coil, this action pushes the foot valve and opens the orifice so the air can flow through. The resistivity of copper wire is $1.68*10^{-8}$ohmmeters (http://hyperphysics.phy-astr.gsu.edu/).

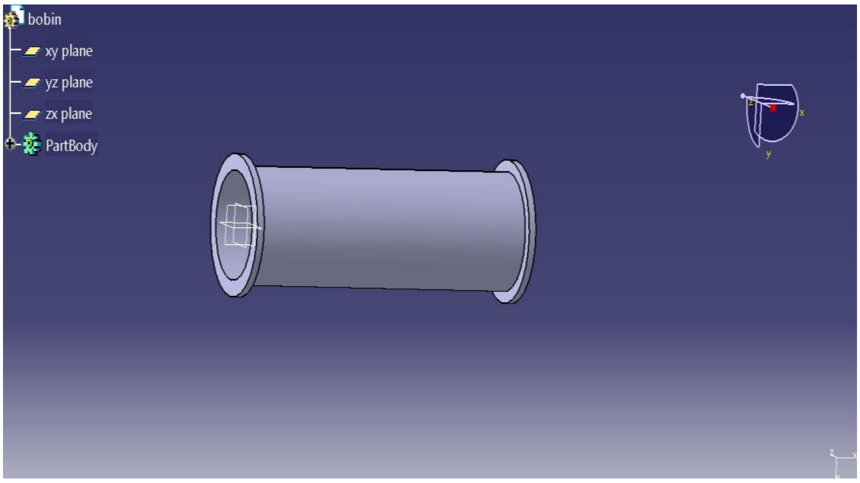


Figure 3.3. CATIA model of bobbin.

Then, magnetic flux flowing inside the magnetic actuator (solenoid) can be explained from the following (reluctance) expression.

$$\emptyset = \frac{N\mu_r\mu_o s}{l_z + l_{eq} + x(\mu_r - 1)} \quad \ldots\ldots (3.1)$$

Where: $\emptyset$ = magnetic flux (Weber)

N = number of turn

$\mu_r$ = Relative permeability

$\mu_o$ = Permeability

S = cross-sectional area plunger$(mm^2)$

$l_z$ = length of the coil (m)

$l_{eq}$ = plunger length (mm)

X = stroke length (mm)

✓ Find the number of turns in the bobbin.

$$N = \frac{l_c}{d_w}\left(\frac{d_1 - d_2}{2d_w}\right) \quad \ldots\ldots (3.2)$$

Where: $l_c$ = length of coil (m)

$d_w$ = coil wire diameter (mm)

$d_1$ = outer diameter (mm)

$d_2$ = inner diameter (mm)

$$N = \frac{40}{1}\left(\frac{30-22}{2\times 1}\right) = 160\text{turns}$$

- ✓ Find the resistance of wire in the coil given by equation 3.3.

$$\mathrm{r} = \frac{\rho_w l_w}{a_w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Where: r = coil resistance (Ω)

$\rho_w$ = resistivity wire

$a_w$ = cross-sectional area of the coil ($m^2$)

$l_w$ = length of wire in the coil (m)

- ✓ Find the length of the wire in the coil i.e. wounded to bobbin in equation 3.4.

$$l_w = \pi\left(\frac{d_1+d_2}{2}\right)\mathrm{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

$$l_w = \pi\left(\frac{30+22}{2}\right)160 = \ 13062.4mm = 13m$$

$$a_w = \frac{\pi {d_w}^2}{4}$$

$$a_w = \pi \ \times \ \frac{1^2}{4} = 0.7854\mathrm{mm}^2 = 7.854 \times 10^{-7}m^2$$

$$\text{Then,} \ \mathrm{r} = \frac{\rho_w l_w}{a_w} = \ \frac{1.68\times 10^{-8}\times 13}{7.854\times 10^{-7}} = 0.2782\text{ohm}$$

$$s = \left(\frac{d_1+d_2}{2}\right) l \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

$$\mathrm{s} = (\frac{22+20}{2}) \times 4 = 84\mathrm{mm}^2$$

Using equation 3.1 magnetic flux (∅)is found to be and $\mu_r$ found in Table 3-4, permeability of free space is 4π x $10^{-7}$ Wb/A-t-m (Masters, G. M., 2004), $l_z$, $l_{eq}$and x found in Table 3.3.

$$\emptyset \ = \frac{160 \ \times \ 1000 \ \times \ 4\pi \times \ 10^{-7} \times \ 84}{40 \ + \ 100 \ + \ 40(1000 \ - \ 1)}$$

$$\emptyset \ = \ 0.000134wb$$

Flux density (B) given by equation 3.6.

$$B = \frac{\emptyset}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.6)}$$

Where: B = Flux density (wb/$m^2$) (Tesla) (N/Am)

A = cross-sectional area of bobbin ($m^2$)

$$A = \frac{\pi({d_1}^2 - {d_2}^2)}{4}, let\ d_1 = 30mm \text{ , And } d_2 = 20mm$$

$$A = \frac{\pi \times (30^2 - 20^2)}{4} = 392.5\text{mm}^2 = 0.0003925m^2$$

$$B = \frac{\emptyset}{A} = \frac{0.000134}{0.0003925} = 0.3414wb/m^2\text{(Tesla)}$$

Since we have a 12v battery current will be given by equation 3.7 below.

$$\text{I} = \frac{\text{V}}{\text{r}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.7)}$$

Where: I = current (A)

V = volt (v)

r = resistance (Ω)

$$\text{I} = \frac{12}{0.2782} = 43\text{A}$$

Forces on current-carrying wire in magnetic fields. When a current-carrying coiled wire is placed at right angle in a magnetic field, the force experienced on a plunger will be:

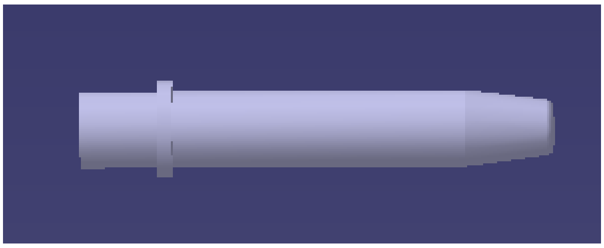

Figure 3.4. CATIA model of plunger.

From equation 2.1, the force on the plunger is:

$$\text{F} = \text{B} \times \text{I} \times \text{l}_\text{w}$$

$$F = 0.3414\ {}^{N}/_{Am} \times 43A \times 13m$$

$$F = 190.84N$$

Finally, select the spring for the plunger.

The restoring force on a spring with extension x is given by equation on 3.8 below.

$$F = k\,x \quad \text{……………………………………………………………………..} \quad (3.8)$$

$$K = \frac{F}{x}$$

Where: k = restoring force of spring (N/mm)

X = extension (mm)

F = force on the plunger (N)

$$K = \frac{190.84}{40mm}$$

$$K = 4.771N/mm$$

Therefore, a spring with a spring constant less than $4.771N/mm$ is appropriate for plunger play and selected from the catalog seen in Figure 3.5.

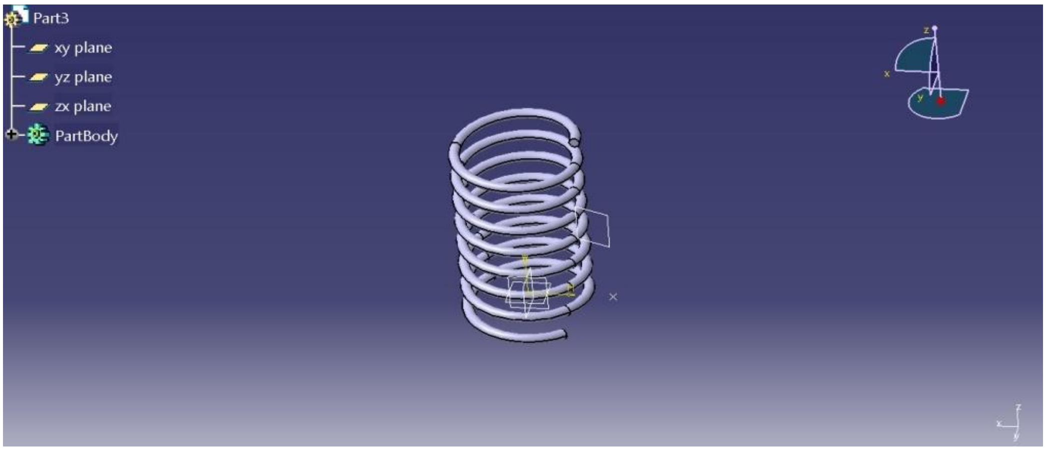


Figure 3.5. CATIA model of solenoid spring

## 3.5. System Programming

The code developed using Arduino Software and which relates the braking time, stopping distance and vehicle speed.

**Braking time:** is the time taken from the point at which fully developed braking is reached to the time at which the vehicle stops; braking time is gotten by inter-relating the following equations:

$$a = \frac{dv}{dt} \text{ ……………………………………………..……………… (3.9)}$$

Integrating velocity of vehicle per acceleration vehicle is used to calculate the braking time of the vehicle. The code should have written for the maximum braking time, and maximum braking time is happened when the loaded vehicle is driven at a maximum speed.

$$\int d_t = \int \frac{d_v}{a} \text{ ………………………………………………………………. (3.10)}$$

$$a = \frac{F_b}{m_v}$$

$$t_b = \frac{V_v}{a}$$

Braking time is equal to the mass of vehicle multiplying by initial velocity of vehicle per some of all forces that contribute to the overall braking effort as shown in equation 3.11.

i.e. $$t_b = \frac{m_v v}{F} \text{ ………………………….……………………………. (3.11)}$$

Where: $t_b$ = brake time (s)

$m_v$ = mass of vehicle (kg)

$v$ = vehicle speed (m/s)

F = brake force (N)

Then, the stopping distance that the vehicle will travel at this time is given in equation 3.12

$$s = ut - {}^1\!/_2\, at^2 \text{ ………………………………………………….. (3.12)}$$

Where: $s$ = stopping distance of the vehicle (m)

$u$ = speed of vehicle (m/s)

t = time (s)

a = acceleration (m/$s^2$)

Notice that, t = $t_b$ and$-a = -\frac{F}{m_v}$

So, $s = ut - 1/_2 \frac{F}{m_v} t^2$…………………………………..………….. (3.13)

The speed sensor is considered to be mounted in the propeller shaft and it counts the rpm of the shaft as the vehicle moves. So, the maximum rpm in which the sensor measurement is determined from the maximum rpm of the engine using gear ratio of the transmission.

$$\text{Gear ratio} = \frac{\text{rpm of driving gear}}{\text{rpm of driven gear}}$$

Using the specifications (gear ratio and engine maximum rpm) of Sino-truck Howo 336; given above in the data collection part.

The maximum rpm of the propeller shaft is achieved at the minimum gear ratio (i.e. Gear ratio =1).

Therefore, the maximum rpm of the propeller shaft $= \frac{\text{maximum engine rpm}}{\text{minimum gear ratio}}$ …………. (3.14)

The maximum rpm of propeller shaft $= \frac{2200}{1}$ = 2200rpm

And then, since the linear speed of the vehicle and the rpm of the shaft are directly proportional, the vehicle will have 2200rpm at a liner speed of 20.8m/s. So, as the linear speed approaches zero, the rpm of the shaft will also approach zero linearly.

Finally, it is possible to determine the rpm of the shaft at different car speeds as shown below.

It has divided the braking distances into four cases according to the vehicle speed, which are:

- ✓ From 15 m/s to 20.8 m/s - (1586rpm to 2200rpm)
- ✓ From 10 m/s to 15 m/s - (1073rpm to 1586rpm)
- ✓ From 5 m/s to10 m/s - (528rpm to 1073rpm)

- ✓ Below 5 $\mathrm{m/s}$ (528rpm)

To find the braking force required for my model truck the kinetic energy must find first in equation 3.15.

The kinetic energy of a body in motion is defined as:

$$\text{KE} = \frac{1}{2} m_v {v_v}^2 \quad \text{………………………………………………………….. (3.15)}$$

Where: KE = kinetic energy (kJ)

$m_v$ = mass vehicle (kg)

$v_v$ = vehicle speed (m/s)

The gross weight of the model vehicle is 25000kg and has a maximum speed of 75$km/hr$(20.8m/s)

$$KE = \frac{1}{2} \times 25{,}000kg \times (20.8\, m/s)^2 = 5{,}425KJ$$

This is equal to work done (W); $i.e.\ W = KE = 5{,}425KJ$

### 3.6 Stopping Distance of the Vehicle

Since one of the aims of this thesis is that reducing the stopping distance of Sino Truck by increasing the performance of its brake using automatic brake control system, so that the stopping distance of this Sino truck model is reduced by eliminating the reaction time to apply brake. For the sake of design it will consider different speed ranges like:

Speed range at **75km/h, 70km/h, 60km/h, 50km/h, 40km/h, 30km/h, 20km/h, and 10km/h**

**Braking Distance ( $\boldsymbol{D_B}$)**

When the vehicle is equipped with an automated braking system and travel at a maximum speed of 75 km/ hr. Calculated the braking distance from equation 2.4 as shown below.

$$D_B = \frac{(\frac{75km/h}{3.6})2}{(2 \times 0.8 \times 9.81\mathrm{m}/s^2)} = 27.6\text{m}$$

**Reaction Distance ( $\boldsymbol{d_r}$)**

Reaction distance is the distance in which the vehicle travels before the driver senses the hazard and starts applying brakes.

Therefore, the reaction distance can be as equation 2.3 it can be calculated as follows.

$$\boldsymbol{d_r} = \frac{(75km/h \times 0.7)}{3.6} = 14.6\text{m}$$

But using Automatic braking system reaction distance resulting from driver reaction time delay is eliminated because the system will automatically start applying brakes immediately as it senses an obstacle.

**Stopping Distance ($\boldsymbol{s_d}$)**

If a driver puts on the brakes of a car, the car will not come to a stop immediately. The stopping distance is the distance the car travels before it comes to a rest. It depends on the speed of the car and the coefficient of friction (μ) between the wheels and the road. The total stopping distance of the vehicle can be calculated as equation 2.2.

$$\boldsymbol{s_d} = 14.6\text{m} + 27.6\text{m} = 42.2\text{m}$$

When the vehicle is equipped with an automatic braking system the normal stopping distance is reduced from 42.2m to 27.6m.

Table 3.6. Stopping distance of the vehicle.

| | Vehicle speed (km/h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Distance(m) | 75 | 70 | 60 | 50 | 40 | 30 | 20 | 10 |
| $D_B$ | 27.6 | 24 | 17.7 | 12.9 | 7.86 | 4.4 | 1.96 | 0.49 |
| $d_r$ | 14.6 | 13.6 | 11.67 | 9.72 | 7.78 | 5.8 | 3.89 | 1.49 |
| $s_d$ | 42.2 | 37.6 | 29.37 | 22 | 15.64 | 10.2 | 5.85 | 2.43 |

As it has seen the above calculation data the speed of the vehicle is directly proportional to the stopping distance of the vehicle.

The vehicle is designed to stop at a distance of 27.6m after brake force is applied when moving at a maximum speed. So the stopping distance ($S_d$) of the vehicle is 27.6m.

From the general formula of work done equation 3.16 would get brake force.

$$W = F \times S_d \text{ ......................................................................... } (3.16)$$

Where: $W$ = work done (kJ)

$S_d$ = stopping distance (m)

F = brake force (N)

From equation 3.15 work done is 5,425KJ.

$$\therefore F \times S_d = 5{,}425KJ$$

$$F \times 27.6m = 5{,}425KJ$$

$$F = \frac{5{,}425KJ}{27.6m}$$

$$F = 196.5KN$$

## 3.6. Vehicle speed at different condition

The vehicle starts its movement at 5m/s (528rpm) minimum speed and varying up to 20.8m/s (2200rpm) maximum speed; application of brake at every 5m/s (528rpm) result in speed change that makes the vehicle decelerate within an interval of time.

If the vehicle speed increases both deceleration time and stopping distance is rapidly increases but the vehicle speed decreases both deceleration time and stopping distance also decreases compared to the new braking system as shown in Table 4.4. Vehicle speed has directly proportional to both deceleration time and stopping distance.

**Case -1:** Find braking time and stopping distance at $20.8\text{m/s}$ (2200rpm).

From equation 3.11, the braking time can be calculated as:

$$t_b = \frac{25{,}000kg \times 20.8\text{m/s}}{196.5kN}$$

$$t_b = 2.64\text{sec}$$

From equation 3.13, the stopping distance can be calculated as:

$$s_d = \frac{20.8\text{m}}{\text{s}} \times 2.64sec - {}^{1}\!/_{2} \times \frac{196.5\text{kN}}{25000\text{kg}} \times (2.64sec)^2$$

$$s_d = 27.6m$$

Table 3.7. Braking time and stopping distance at different speed.

| | Case-1 | Case-2 | Case-3 | Case-4 |
|---|---|---|---|---|
| v(m/s) | 20.8 | 15 | 10 | 5 |
| $t_b$(s) | 2.64 | 1.9 | 1.27 | 0.63 |
| $s_d$(m) | 27.6 | 14.3 | 6.36 | 1.59 |

When the vehicle moves at a speed of less than $5\text{m/s}$ (528rpm) obstacles are not sensed.

If the obstacle is present at a distance less than the safe distance, then the vehicle automatically applies brake. The system has a defined safe distance if the obstacle is present at a safe distance zone.

The braking time and stopping distance calculated from case 1 up case 4 as shown in the flow chart in Figure 3.6 below, by adding the allowance stopping distance of 30cm.

The code on Arduino software is written using the following block diagram.

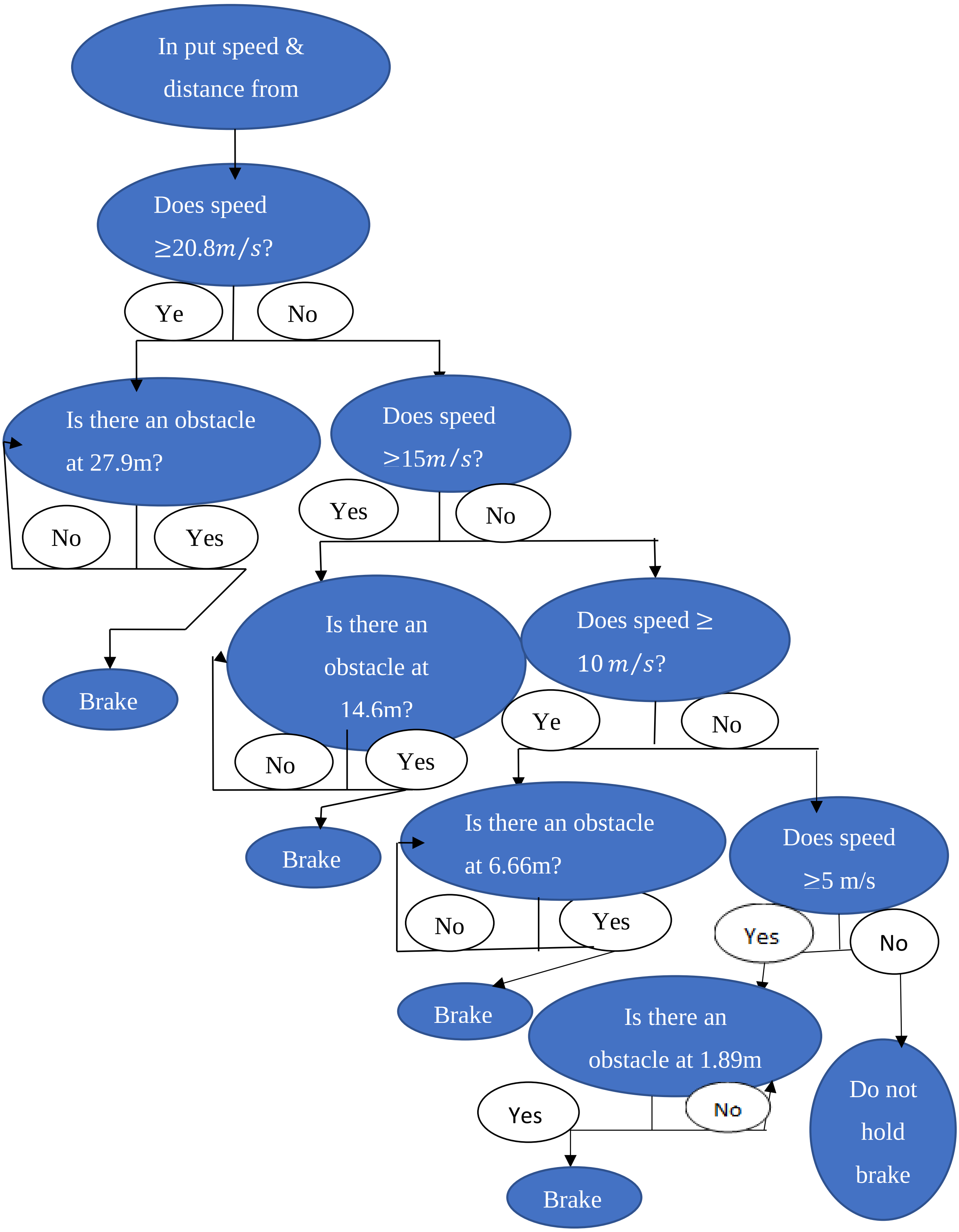


Figure 3.6. System code using flow chart

# CHAPTER FOUR

## 4. RESULTS AND DISCUSSION

### 4.1. The result of automatic braking control system data

The automatic braking control system code as shown in the flow chart in Figure 3.6 can work in any traffic condition and at any moving speed of the vehicle. The geometric dimension design that took place was to fit the solenoid plunger system in Figure 4.1 and assembly into a fixed dimension of the foot valve in Figure 3.2. The following analyzed quantities are obtained from the study of the motion of the vehicle and the parts used to build the system are shown in Table 4.1 below.

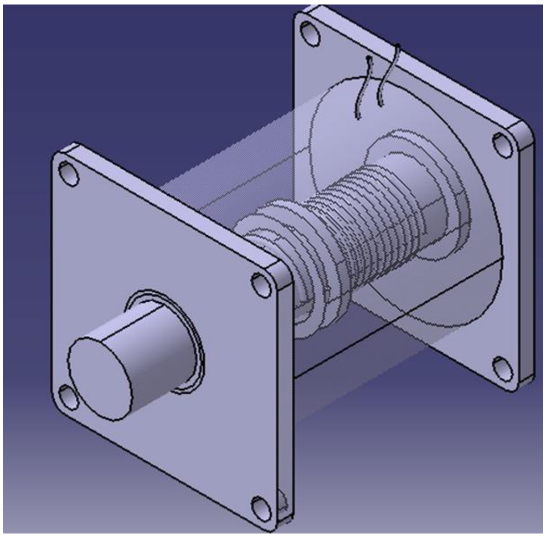

Figure 4.1. CATIA model solenoid plunger

The proposed solenoid plunger in Figure 4.1 has been design for the Automatic braking control system of Sinotruck starts with analytical calculation results from equation 2.1. The result showed that the magnitude of the electromagnetic force required to press the foot valve system is 190.84N. Then a theory and sizing equation that can express components of the required electromagnetic force is applied to the equivalent electromagnetic circuit model of Automatic braking control system shown in Figure 4.7. Equation 3.1 showed that the required electromagnetic force is a factor of the magnitude of electromagnetic flux density induced an effective cross-sectional area of electromagnetic system. Another component of electromagnetic force that should be determined is number of turns of the coil required to induce the flux density of 0.3414T. Analytical calculation results from equation 3.2 showed that 160 number of turns of coil are required.

Finally, the analytical calculation result has shown that the proposed Automatic braking control system provides a reduction of stopping distance at maximum speed the vehicle to 27.6m as shown in Table 4.1.

Table 4.1. Designed quantities for SINO-TRUCK HOWO 336.

| **Determined Quantities** | **Obtained Outcomes** |
|---|---|
| kinetic energy | $5{,}425KJ$ |
| Stopping distance at maximum speed | 27.6m |
| Length of coil wire | $13m$ |
| Number of turns of solenoid valve | 160turns |
| Plunger diameter | 20mm |
| Forces of magnetic field | 190.8N |

The sensor mounted in the front of the vehicle can sense an obstacle up to 30m. The braking distance is determined from the speed of the vehicle which is sensed by the speed sensor and let the obstacle sensed with the allowance of 30cm as shown in Table 4.2 below.

Table 4.2. Speed and braking distance relation.

| Speed of Vehicle | Braking (Sensing) distance(m) | Stopping distance(m) |
|---|---|---|
| 20.8 m/s | 27.9 | 27.6 |
| 15 m/s | 14.6 | 14.3 |
| 10 m/s | 6.66 | 6.36 |
| 5 m/s | 1.89 | 1.59 |
| Below 5 m/s | No detecting | ----- |

## 4.2. Comparison with stopping distance

If the vehicle speed increases the existing brake system stopping distance is rapidly increase compared to the new one but the new brake system stopping distance is slowly increases compared to the existing ones. And the vehicle speed is decreased the existing brake system stopping distance is slowly decreases compared to the existing one but the new brake system stopping distance is rapidly decreases compared to the existing one as shown in Table 4.3 and Figure 4.2.

A new brake system applied at a vehicle speed of 10km/h reduces the distance covered to stop the vehicle from 2.43m to 0.49m.

At 40km/h vehicle speed the braking effect of the new braking system reduces distance covered from 15.64m to 7.86m.

At 75km/h vehicle speed the braking effect of the new braking system reduces distance covered from 42.2m to 27.6m.

Table 4.3. Performance comparison of a new braking system with the existing brake system.

| No. | Vehicle speed | Stopping distance (m) | |
|---|---|---|---|
| | Km/h | Existing braking system | New braking system |
| 1 | 10 | 2.43 | 0.49 |
| 2 | 20 | 5.85 | 1.96 |
| 3 | 30 | 10.2 | 4.4 |
| 4 | 40 | 15.64 | 7.86 |
| 5 | 50 | 22 | 12.29 |
| 6 | 60 | 29.37 | 17.7 |
| 7 | 70 | 37.6 | 24 |
| 8 | 75 | 42.2 | 27.6 |

The speed of the vehicle is directly proportional to the stopping distance of the vehicle as shown in Figure 4.2 below.

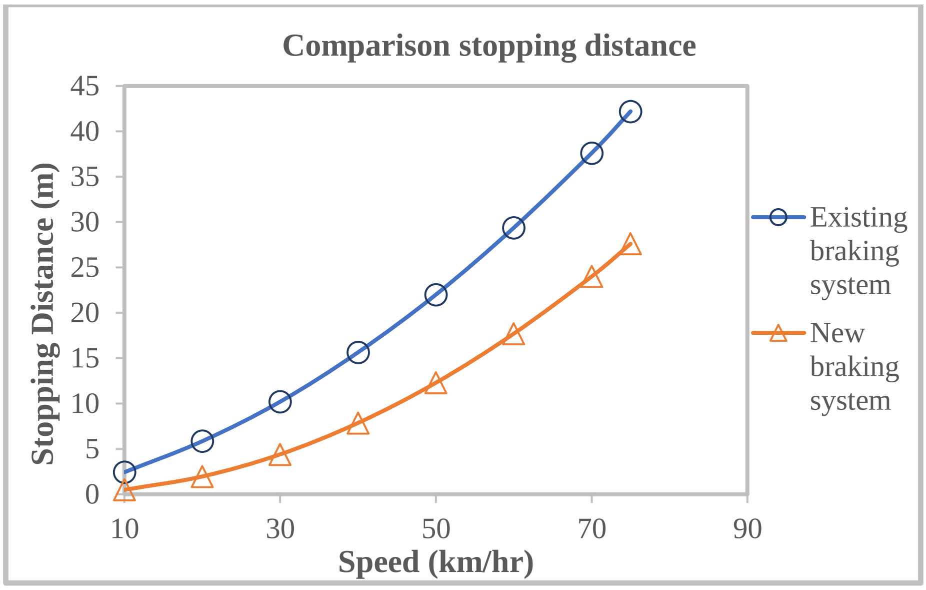


Figure 4.2. Comparison of stopping distance between an existing and new brake system.

## 4.3. Braking time and stopping distance of new brake system

At different speed condition of vehicle braking system starts its movement at 5m/s (528rpm) minimum speed and varying up to 20.8m/s (2200rpm) maximum speed; application of brake at every 5m/s (528rpm) result in speed change that makes the vehicle decelerate within an interval of time as shown in Table 4.4.

If the vehicle speed increases the new brake system, braking time and stopping distance increase slowly but the vehicle speed decreases both braking time and stopping distance also rapidly decrease as shown in Figure 4.3. Vehicle speed is directly proportional to both braking time and stopping distance.

Table 4.4. Braking time and stopping distance of optimized valve of vehicle.

| No | Vehicle speed | | Braking time (s) | Stopping distance (m) |
|---|---|---|---|---|
| | m/s | Rpm | | |
| 1 | 5 | 528 | 0.67 | 1.59 |
| 2 | 10 | 1073 | 1.27 | 6.36 |
| 3 | 15 | 1586 | 1.9 | 14.3 |
| 4 | 20.8 | 2200 | 2.64 | 27.5 |

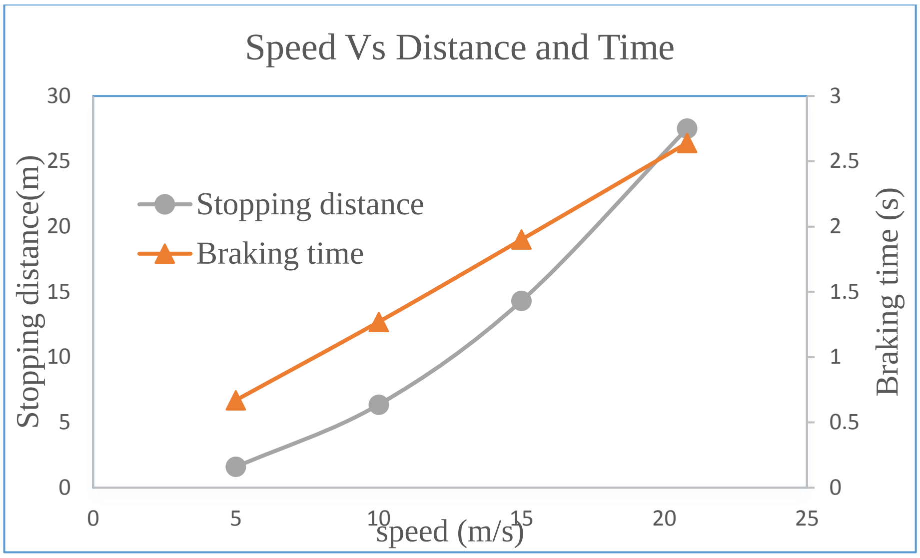


Figure 4.3.Braking time and stopping distance of optimized valve of vehicle.

The parts of the system are having two different operating conditions; which are normal operating conditions and braking conditions. The characteristics of the parts are described in Table 4.5.

Table 4.5. Component operating conditions.

| **System Components** | **Normal operating condition** | **Braking condition** |
|---|---|---|
| Relay | Opened | Closed |
| Buzzer | Silent | Ring |
| Red LED | Off | Glow |
| Green LED | Glow | Off |
| Solenoid plunger | Pulled | Pushed |

## 4.4. **Prototype of the Electronic System**

In normal operating conditions and braking conditions, all the components are operated as is described in the above Table 4.5.

1. At normal operating condition.

   At this condition, the green LED light will glow which is mounted in the dashboard informs the driver the vehicle is in normal operating condition.
2. At braking condition.

   At this condition, the red LED glows which will mount in the dashboard of the vehicle. Then after its indicator light glows it will turn off the motor.

**Overall set up of the experiment on AMK- 01 robot**.

1. Fix Arduino and breadboard with breadboard holder plate with screw set using screw driver.

2. Take robot main chassis and fix L-type motor on it using motor screw set.

3. Fix caster wheel on chassis using caster screw set.

4. Fix Arduino and breadboard holding plate with chassis using screw set.

5. Fix 6AA battery holder to chassis using screw and nut.

6. Fix rubber wheel to the motor.

7. Attach motor shield to the Arduino.

8. Connect the motor to the motor shield.

9. Connect the sensor to the motor shield and the Arduino using jumper wires.

Ultrasonic to motor shield

Vcc--------------5v

Trig--------------D8

Echo-------------D7

GND-------------GND

Arduino to breadboard

13---------------B26 +led + resistor

D10-------------E10+buzzer

D9---------------E2+led +resistor

GND-------------GND

10. Upload the code using USB cable A to B.

11. Connect the power supply to Arduino.

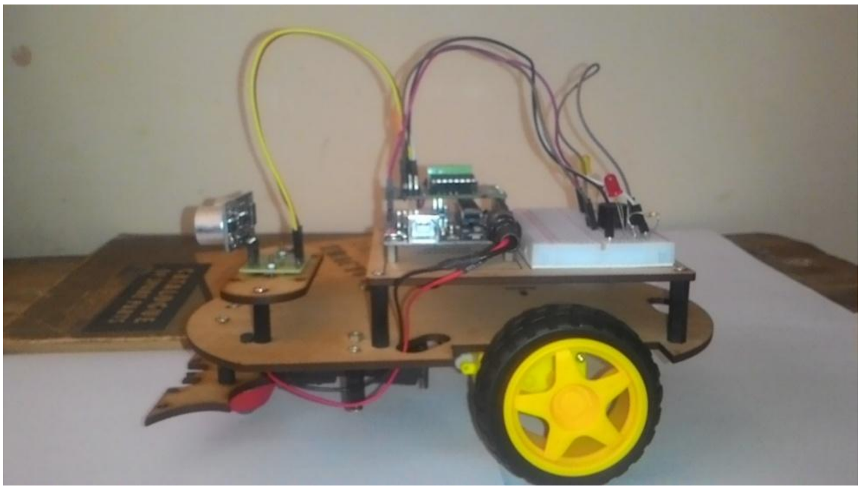

Figure 4.4.System prototype at side view direction.

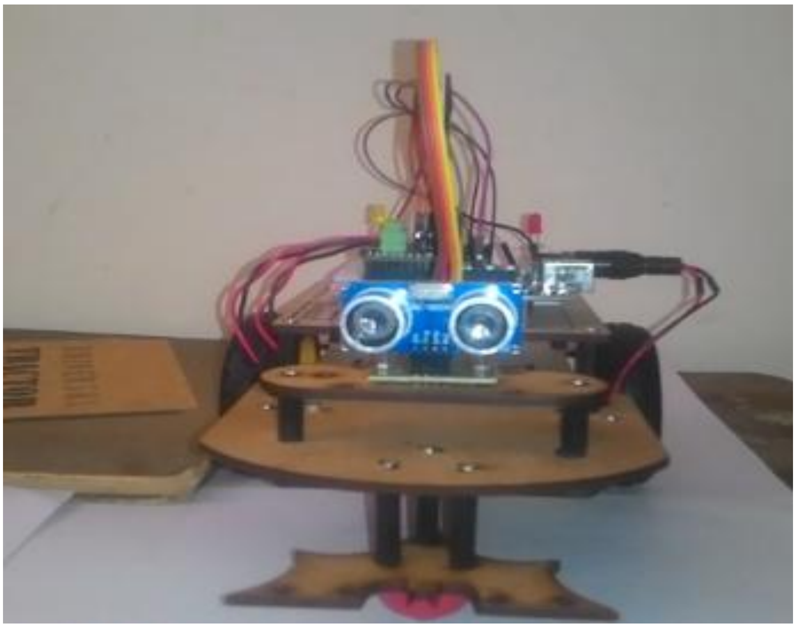

Figure 4.5. System prototype in front view direction.

## 4.5. Schematic Circuit Diagram of the Electronic System

The electronic components of the schematic circuit diagram are drawn in Proteus software. This result shows the operations of the ultrasonic sensor, Arduino Uno microcontroller, battery, resistor, buzzer, LEDs, relay and solenoid plunger.

In normal operating conditions and braking conditions, all the components are operated as is described in the above Table 4.5.

1. Prototype of the automatic braking control system circuit diagram shown in Figure 4.6 works as the code written in Appendix A.1. And the result of stopping distance is safe as tested on the prototype.

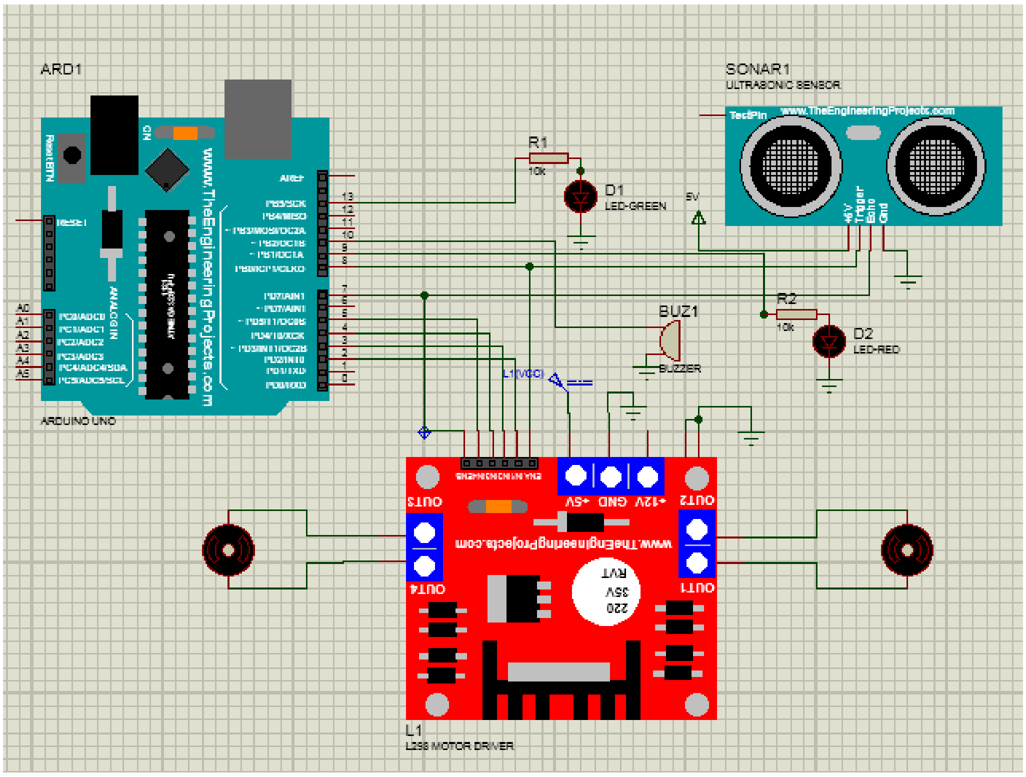


Figure 4.6. Schematic circuit diagram of a prototype automatic braking control system.

2. The automatic braking control system for the Sinotruck circuit diagram shown in Figure 4.7 works the code written in Appendix A.2.

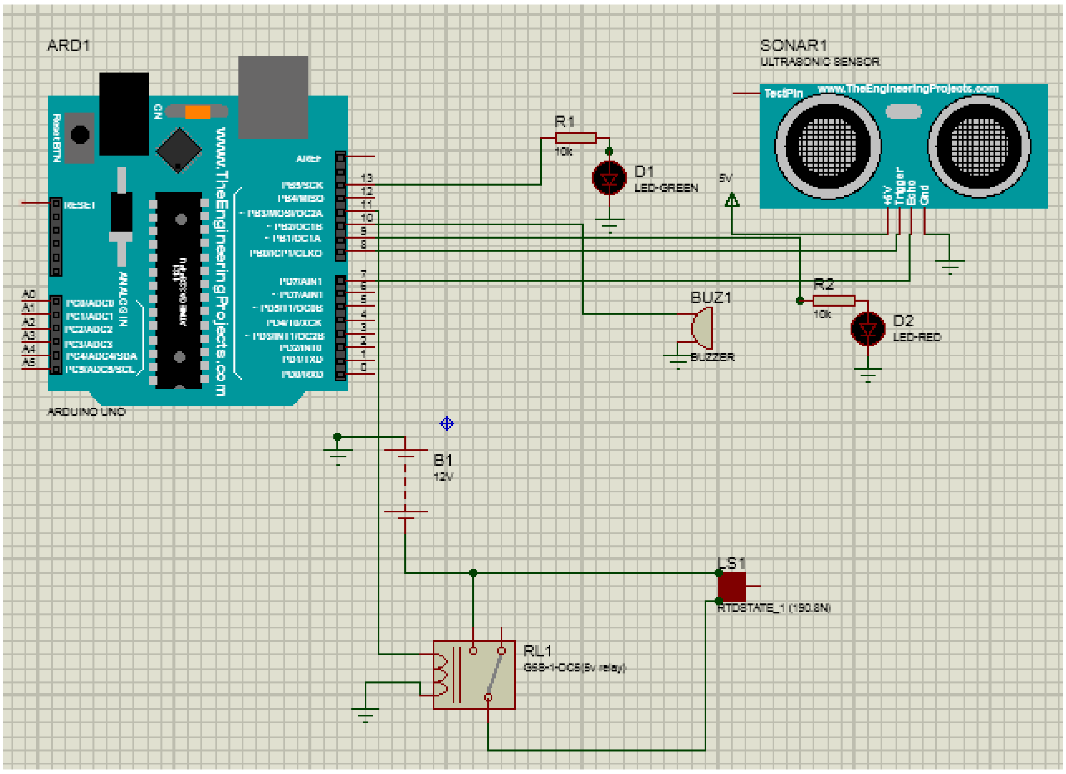


Figure 4.7. Schematic circuit diagram of automatic braking control system.

# CHAPTER FIVE

## 5. CONCLUSION AND RECOMMENDATION

### 5.1. Summary

To accomplish the system all data are collected from a reliable source. The collected data are organized and detailed analysis and CATIA modeling are made for the system components. The system is programmed using Arduino software and schematic circuit diagram is made with Proteus software.

The automatic braking control system of Sinotruck work using different sensor and electrical component. Ultrasonic sensors work on the principle of reflected sound waves and are used to measure distance. One sensor can detect others operating nearby. Sound waves are emitted by the ultrasonic sensor and they are reflected back if there is an object in front of it. The sensor detects these waves and measures the time it takes between transmitting and receiving those sound waves. Distance is then estimated by the time interval between sensor and object. Then the programmed data in Arduino Uno microcontroller transfer data to green Led will on to show the warning distance then the buzzer will make sound to the driver and on red led then relay will on to actuate the solenoid plunger. When the plunger actuates the foot valve will be pressed and the braking system will work.

### 5.2. Conclusion

Based on the design analysis the result of the following conclusion is drawn.

- ✓ The design analysis has shown the proposed solenoid plunger system can fit the foot valve and have the required force to actuate.
- ✓ The new brake system is better than that of the existing brake system; the stopping distance at maximum speed and at maximum load is 27.6m which is reduced 14.6m from the existing brake system.
- ✓ It observed that the automatic braking control system is better than the manual braking system by reducing collision, so that it conclude to use automatic braking control system.
- ✓ The components of the automatic braking control system such as; Arduino Uno, ultrasonic sensor, led, buzzer, relay and solenoid plunger can be easily replaced.

- ✓ The system is a feasible and less expensive system and it can be implemented in a simple way by modifying foot valve components of the conventional air brake and also the driver does not required to have an additional skill of driving.

## 5.3. Recommendation

- ✓ It is recommended that it is better if the system is implemented for other vehicle types like automobiles, buses, heavy vehicles, etc other than Sino-truck models.
- ✓ The system is programmed by relating the obstacle sensing distance with a range of vehicle moving speed, but it is recommended that the speed of the vehicle and obstacle sensing distance can be related linearly.
- ✓ Connecting the system with a brake light to warn other drivers as that of manual brake systems operation is recommended while braking automatically.
- ✓ Deactivating the whole system while unnecessary by implementing a power switch button of the dashboard is recommended.
- ✓ A model is a good demonstration tool for anyone who wants to do research on automatic braking control system.
- ✓ Interested research can manufacture and assemble the designer of solenoid plunger and interface the system to the Sinotruck vehicle.

## 5.4. Future work

In this study it is recommended to further study when a solenoid is energized an outside voltage supply, some heat is generated which increases the temperature of the coil. This temperature rise has some undesired effects, since resistance of the coil winding varies with temperature: i.e. increasing temperature rises, which in turn, reduces the electrical current. This will result in a reduction in the front output. Therefore extra studies should be carried on solenoid by considering those effects.

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**APPENDIX: A Code for prototype and actual Sino truck**

1. Code prototype collision avoidance automatic braking system.

```
////yared admassu////
const int trigPin=8;
const int echoPin=7;
const int Motor_L_F = 2;
const int Motor_L_B = 3;
const int Motor_R_F = 4;
const int Motor_R_B = 5;
int buzz=10;
long duration;
int distance;
//the setup function runs once when you press reset or power the board.
void setup() {
  // initialize digital pin 13 as output:
  pinMode(trigPin,OUTPUT);
  pinMode(echoPin,INPUT);
  pinMode(13,OUTPUT);
  pinMode(9,OUTPUT);
  pinMode(Motor_L_F,OUTPUT);
  pinMode(Motor_L_B,OUTPUT);
  pinMode(Motor_R_F,OUTPUT);
  pinMode(Motor_R_B,OUTPUT);
  Serial.begin(9600);
}
//the loop fuction runs over and over again forever:
void loop() {
  // run the motor
//digitalWrite (Motor_L_F,HIGH);
//digitalWrite (Motor_L_B,LOW);
//digitalWrite (Motor_R_F,HIGH);
//digitalWrite (Motor_R_B,LOW);
  // clears the trigPin:
digitalWrite (trigPin,LOW);
delayMicroseconds(2);
```

```
//sets the trigPin on high state for 10 micro seconds:
digitalWrite(trigPin,HIGH);
delayMicroseconds(10);
digitalWrite(trigPin,LOW);
//Reads the echoPin,returns the sound wave travel time in microseconds:
duration=pulseIn(echoPin,HIGH);
//calculating the distance:
distance=duration*0.034/2;
//prints the distance on the serial mointor:
if(distance <= 30)
 {
  // stop the motor
  digitalWrite (Motor_L_F,LOW);
  digitalWrite (Motor_L_B,LOW);
  digitalWrite (Motor_R_F,LOW);
  digitalWrite (Motor_R_B,LOW);
  }
  else
  {
  digitalWrite (Motor_L_F,HIGH);
  digitalWrite (Motor_L_B,LOW);
  digitalWrite (Motor_R_F,HIGH);
  digitalWrite (Motor_R_B,LOW);
  }
if(distance <= 100 && distance > 80)
{
  digitalWrite(13,HIGH);
  //digitalwriter(13,LOW);
  //turn the LED on(HIGH is the voltage level)
}
else
{
  digitalWrite(13,LOW);//turn the LED off by making the voltage LOW
  //wait for a second:
}
```

```
if(distance <= 80 && distance >=31)
{
  digitalWrite(9,HIGH);
  tone(buzz,2000);
  delay(100);
  noTone(buzz);
  delay(100);
  tone(buzz,2000);
  delay(100);
  noTone(buzz);
  delay(100);
  tone(buzz,2000);
  delay(100);
  noTone(buzz);
  delay(100);
  tone(buzz,2000);
  delay(100);
  noTone(buzz);
  delay(100);
}
else
{
  digitalWrite(9,LOW);// turn the LED off by making the volatge low
  //wait for a second:
}
}
```

**2. Code collision avoidance automatic braking system of Sinotruck.**

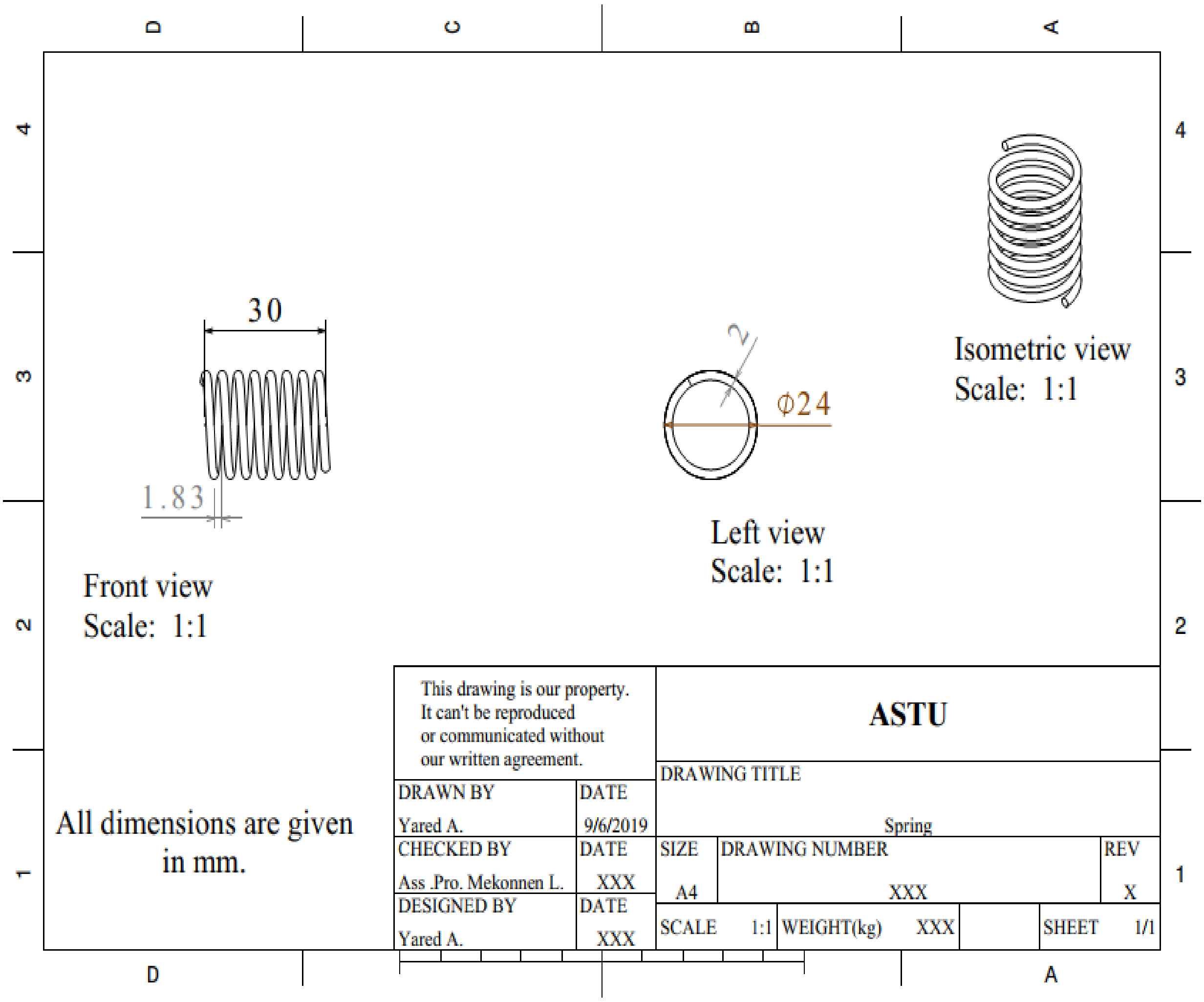
```
////Yared Admassu////
///code of solonied actutor///
const int trigPin = 9;
const int ecoPin = 10;
const int relay = 11;
const int buzzer = 13;
const int green = 6;
const int redlight = 7;
```

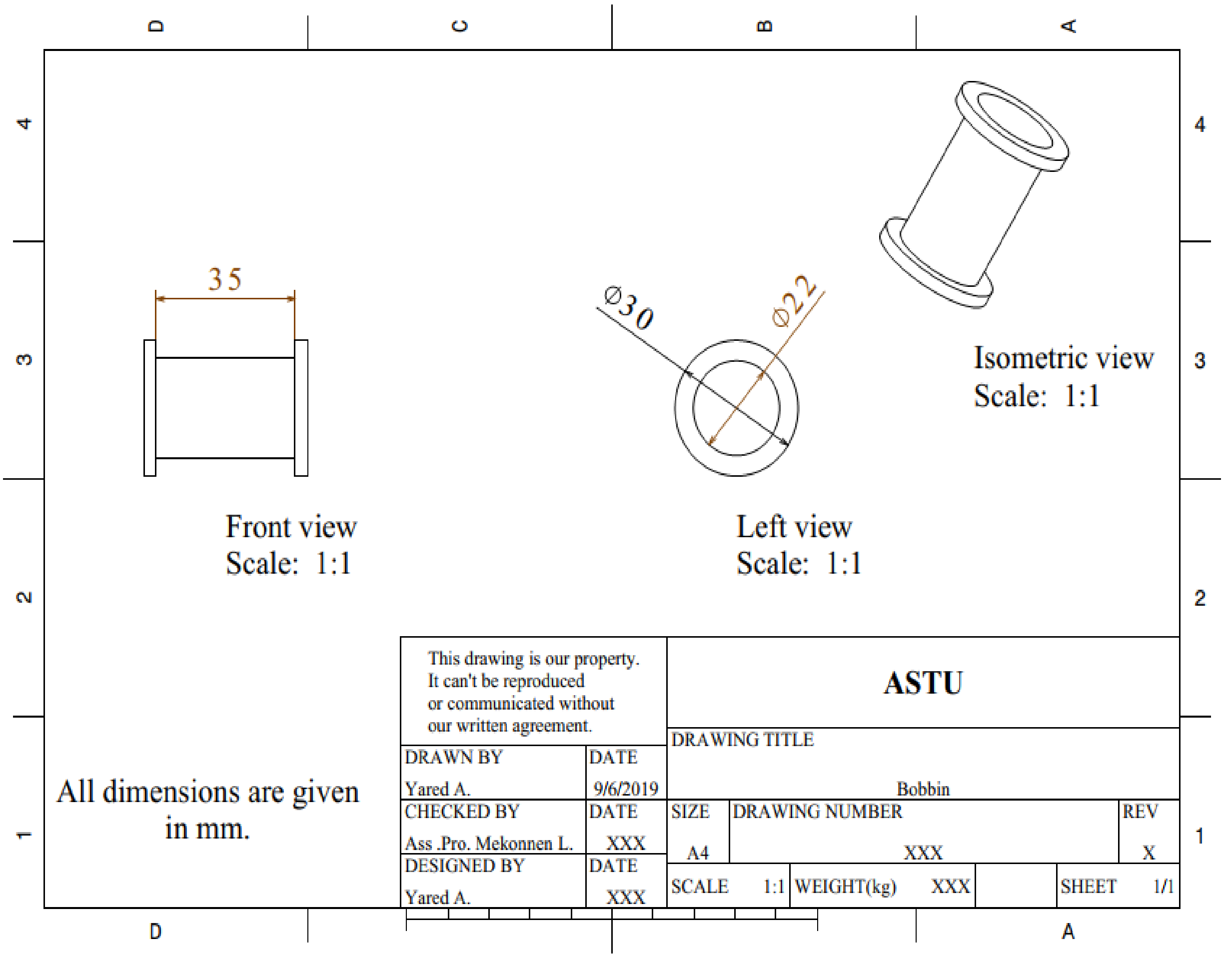
```
long duration;
int distance;
int safetyDistance;
int speeds;
void setup() {
Serial.begin(9600); // put your setup code here, to run once:
pinMode(ecoPin, INPUT); //used as an input to the arduino:
pinMode(trigPin, OUTPUT);
pinMode(relay, OUTPUT);
pinMode(buzzer, OUTPUT);
pinMode(redlight, OUTPUT);
pinMode(green, OUTPUT);
}
void loop() {
// put your main code here, to run repeatedly:
digitalWrite(trigPin, LOW);
delayMicroseconds(5);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
/*calculate the time taken or duration of
the signal to reflect back to the receiver of the sensor as follows
*/
duration=pulseIn(ecoPin, HIGH);
distance=duration*0.034/2; //to change distance in to centimeter
safetyDistance=distance;
Serial.print("distance=");
Serial.println(distance);
Serial.println("cm");
Serial.print("speed=");
Serial.println(speeds);
Serial.println("rpm");
if(speeds = 2200)
{ if(safetyDistance<= 2790)
{ digitalWrite(relay, HIGH);
```

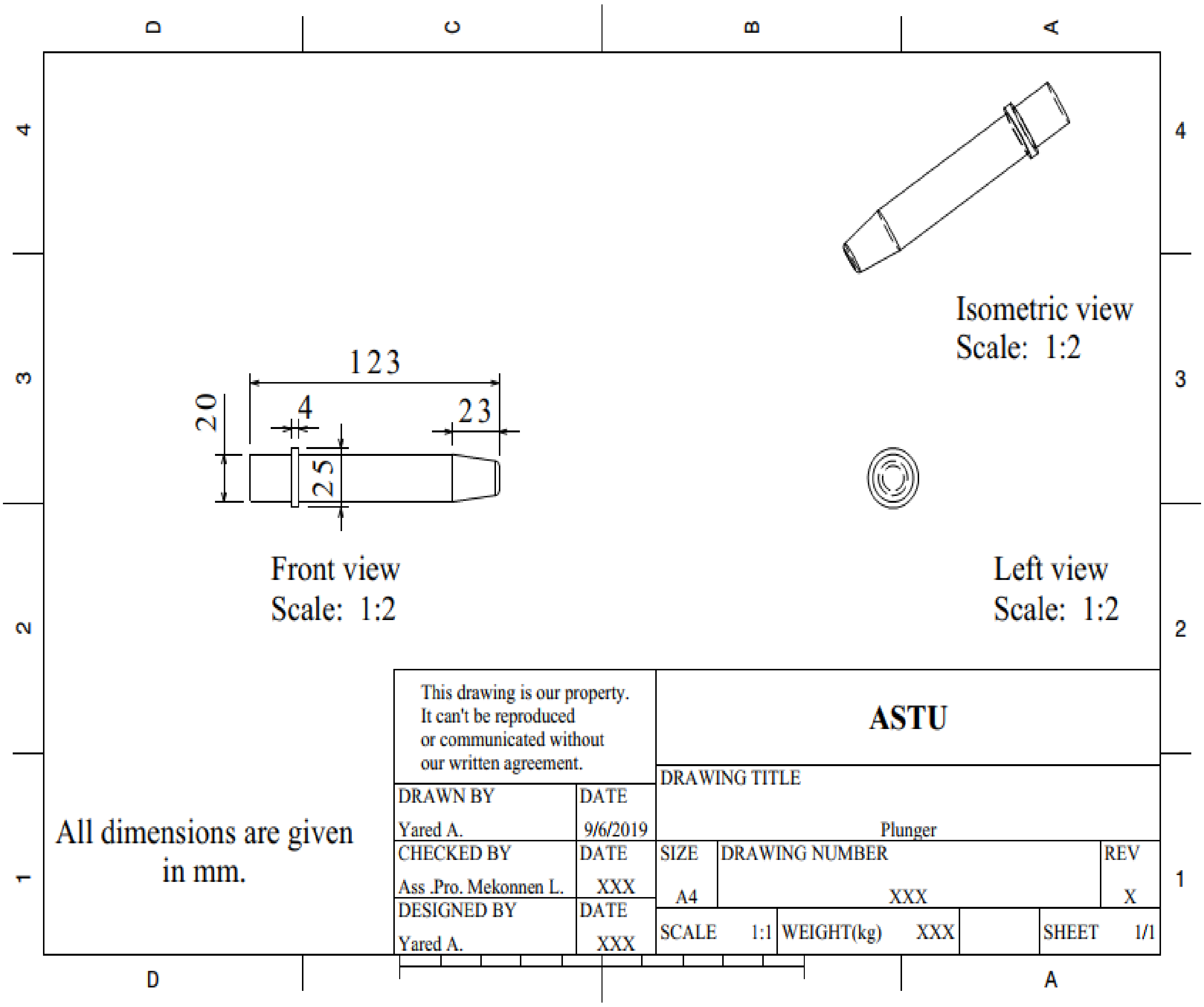
```
digitalWrite(buzzer, HIGH);
digitalWrite(redlight, HIGH);
digitalWrite(green, LOW);
delay(100);
}
else{
digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(redlight, LOW);
digitalWrite(green, HIGH);
delay(100);
}
}
if(speeds >= 1586)
{ if(safetyDistance<= 1460)
{ digitalWrite(relay, HIGH);
digitalWrite(buzzer, HIGH);
digitalWrite(redlight, HIGH);
digitalWrite(green, LOW);
delay(100);
}
else{
digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(redlight, LOW);
digitalWrite(green, HIGH);
delay(100);
}
}
else if (speeds>=1073)
{if(safetyDistance<= 666)
{digitalWrite(relay, HIGH);
digitalWrite(buzzer, HIGH);
digitalWrite(redlight, HIGH);
digitalWrite(green, LOW);
```

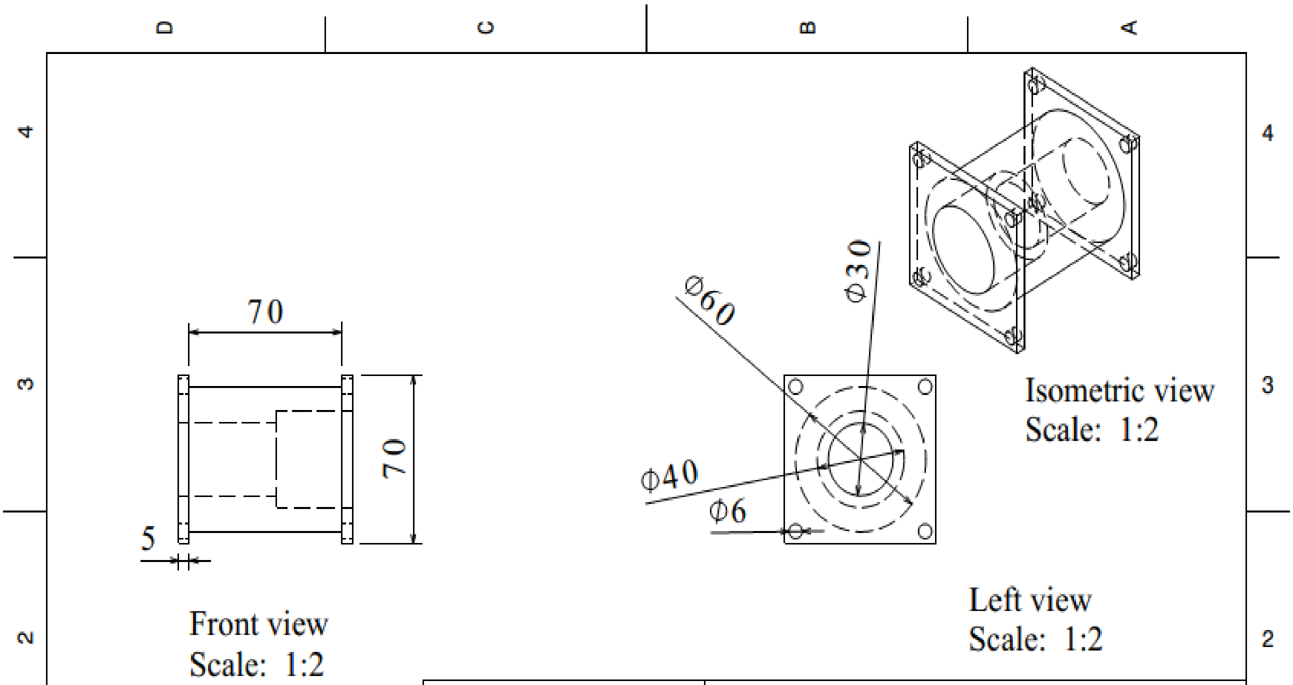
```
delay(100);
}
else{digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(redlight, LOW);
digitalWrite(green, HIGH);
}
}
else if(speeds>=528)
{if(safetyDistance<= 189)
{digitalWrite(relay, HIGH);
digitalWrite(buzzer, HIGH);
digitalWrite(redlight, HIGH);
digitalWrite(green, LOW);
delay(100);
}
else{
digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(redlight, LOW);
digitalWrite(green, HIGH);
}
}
else{digitalWrite(relay, LOW);
digitalWrite(buzzer, LOW);
digitalWrite(redlight, LOW);
digitalWrite(green, HIGH);
delay(20);
 }
Serial.println(distance);
}
```

# APPENDIX: B Part Drawing




35
Front view
Scale: 1:1
Ø30
Ø22
Left view
Scale: 1:1
Isometric view
Scale: 1:1
All dimensions are given in mm.
This drawing is our property. It can't be reproduced or communicated without our written agreement.
ASTU
DRAWN BY
Yared A.
DATE
9/6/2019
DRAWING TITLE
Bobbin
CHECKED BY
Ass .Pro. Mekonnen L.
DATE
XXX
SIZE
A4
DRAWING NUMBER
XXX
REV
X
DESIGNED BY
Yared A.
DATE
XXX
SCALE 1:1
WEIGHT(kg) XXX
SHEET 1/1


123
4
23
20
25
Isometric view
Scale: 1:2
Front view
Scale: 1:2
Left view
Scale: 1:2
All dimensions are given in mm.
This drawing is our property. It can't be reproduced or communicated without our written agreement.
ASTU
DRAWING TITLE
Plunger
DRAWN BY
Yared A.
DATE
9/6/2019
CHECKED BY
Ass .Pro. Mekonnen L.
DATE
XXX
DESIGNED BY
Yared A.
DATE
XXX
SIZE
A4
DRAWING NUMBER
XXX
REV
X
SCALE
1:1
WEIGHT(kg)
XXX
SHEET
1/1

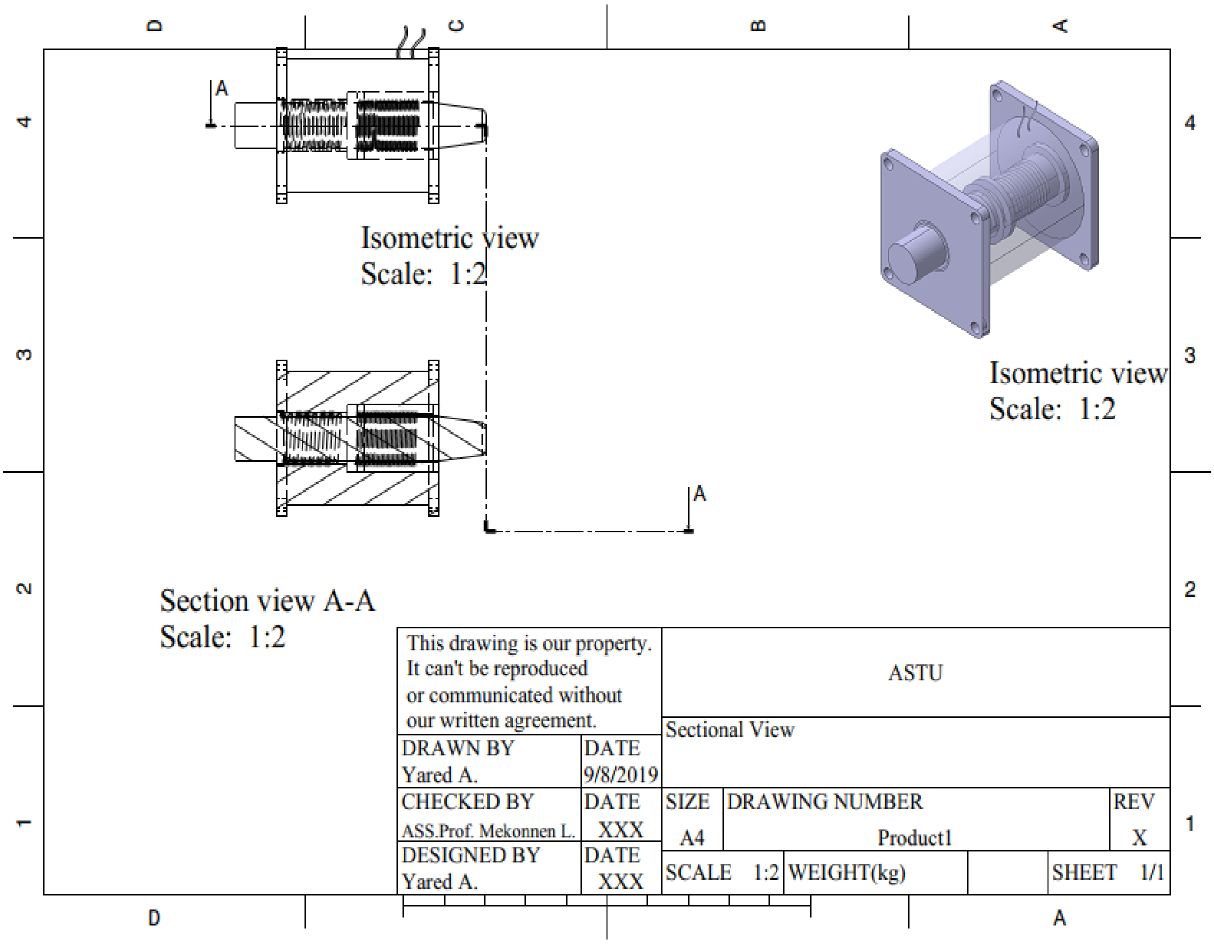


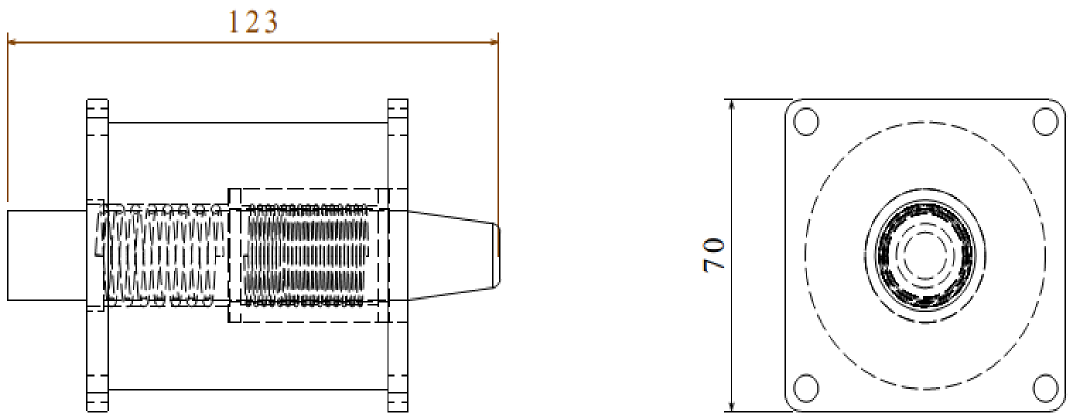

All dimensions are given in mm.



**ASTU**

| | | | | | | |
|---|---|---|---|---|---|---|
| DRAWN BY: Yared A. | DATE: 9/6/2019 | DRAWING TITLE: Housing | | | | |
| CHECKED BY: Ass .Pro. Mekonnen L. | DATE: XXX | SIZE: A4 | DRAWING NUMBER: XXX | | | REV: X |
| DESIGNED BY: Yared A. | DATE: XXX | SCALE: 1:2 | WEIGHT(kg): XXX | | SHEET: 1/1 | |


A
Isometric view
Scale: 1:2
Isometric view
Scale: 1:2
A
Section view A-A
Scale: 1:2
This drawing is our property. It can't be reproduced or communicated without our written agreement.
ASTU
Sectional View
DRAWN BY
Yared A.
DATE
9/8/2019
CHECKED BY
ASS.Prof. Mekonnen L.
DATE
XXX
DESIGNED BY
Yared A.
DATE
XXX
SIZE
A4
DRAWING NUMBER
Product1
REV
X
SCALE 1:2
WEIGHT(kg)
SHEET 1/1



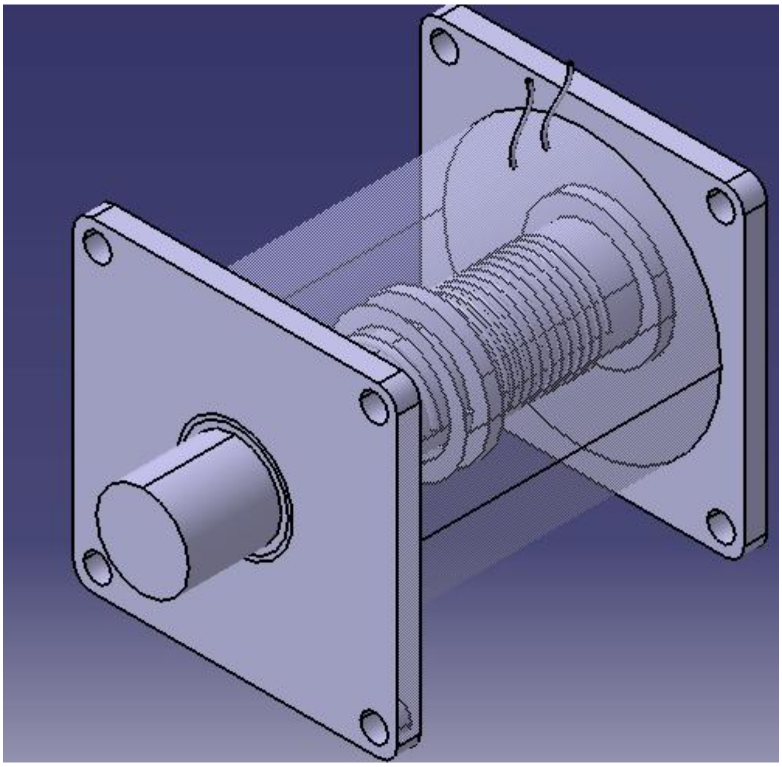

Front view
Scale: 1:1

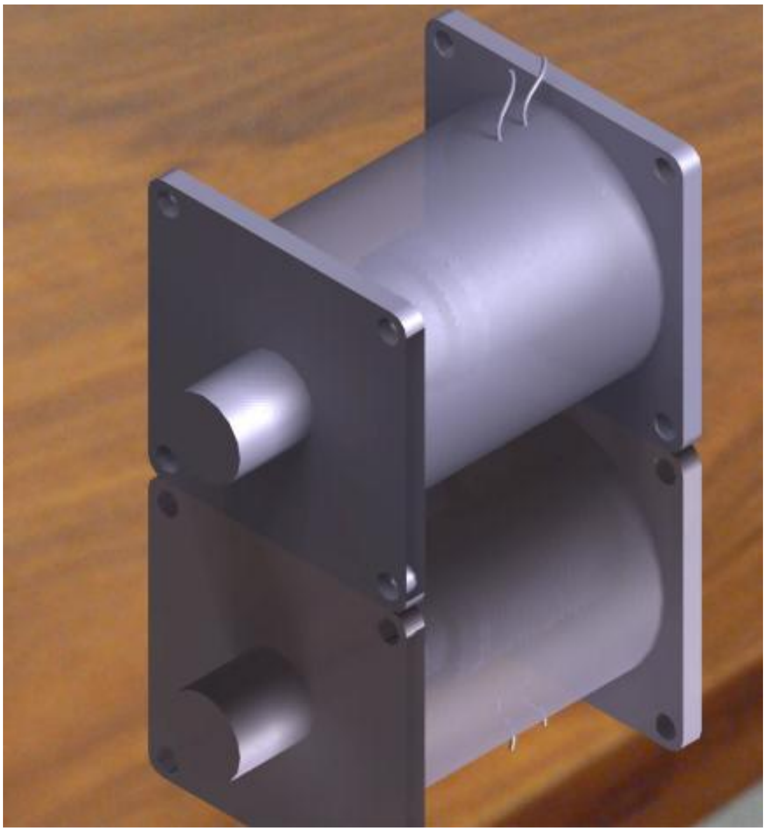
Left view
Scale: 1:1

All dimensions are given in mm.

| | | | | | |
|---|---|---|---|---|---|
| This drawing is our property. It can't be reproduced or communicated without our written agreement. | | ASTU | | | |
| DRAWN BY: Yared A. | DATE: 9/6/2019 | DRAWING TITLE: Solenoid Plunger | | | |
| CHECKED BY: Ass .Pro. Mekonnen L. | DATE: XXX | SIZE: A4 | DRAWING NUMBER: XXX | | REV: X |
| DESIGNED BY: Yared A. | DATE: XXX | SCALE: 1:1 | WEIGHT(kg): XXX | | SHEET: 1/1 |

## APPENDIX: C Assemble drawing of solenoid plunger



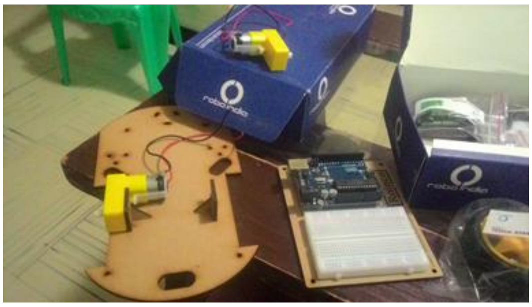


# APPENDIX: D Assemble picture of Prototype

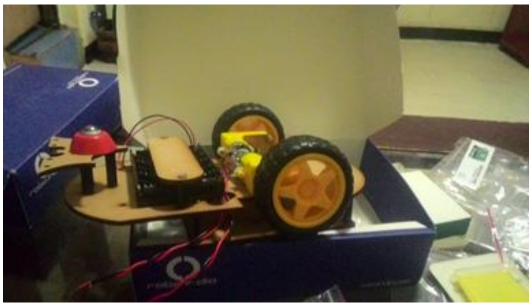
,

A / Arduino kit box

B/ Gather the components



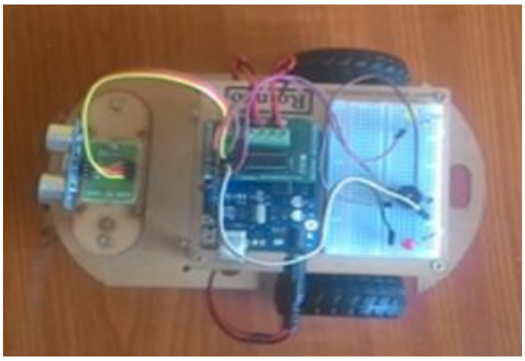
,



C/ Assembling BO motor L- type

D/Assembling wheels

,

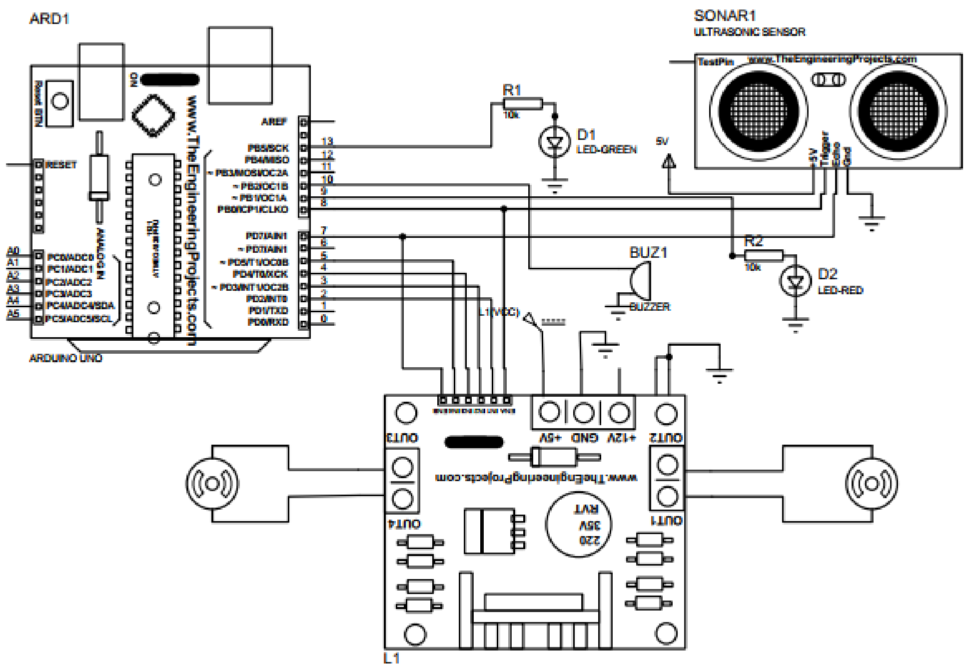


E/Assembling breadboard & Arduino

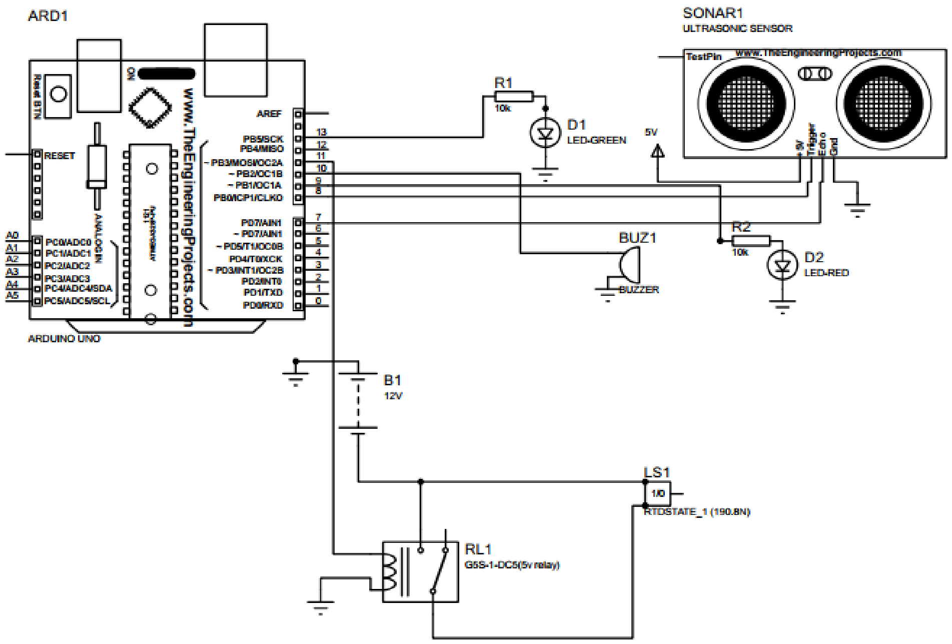
F/ Assembling the whole prototype car

# APPENDIX: E Circuit diagram

## 1. Prototype automatic braking control system.




## 2. Automatic braking control system of Sinotruck.

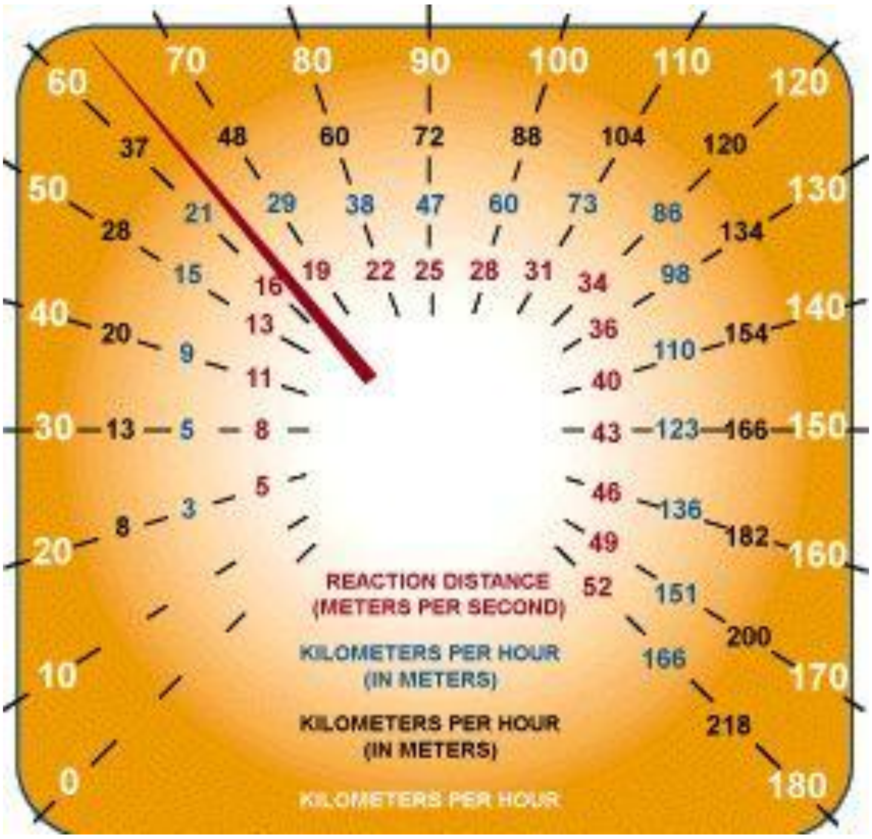


## APPENDIX: F Braking & Stopping Distance Chart

**(Government data)**

(http://www.sdt.com.au/safedrive-directory-STOPPINGDISTANCE.htm)

This is a chart issued by the transport department. It shows reaction distance, braking distance and total stopping distance in a convenient diagram.




This diagram suggests 60 meters of braking distance will be required by a car at 100 km/h. resulting in a total stopping distance of 88 meters. There are many of these diagrams issued around the world and most tend to have a total stopping distance at 100 km/h within the range of 80 meters to 94 meters.

## APPENDIX: G 25-ton SINOTRUK HOWO 6x4 Dump Truck, 336HP


Product Details

Year of made 2015

Model Number: ZZ3257N3447

Brand Name: ORIEMAC

Origin: China (mainland)

25-ton SINOTRUK HOWO 6x4 dump truck, 336HP 371HP See table below:

| | | |
|---|---|---|
| Truck Model | | ZZ3257N3447A1 |
| Dimension(Lx W xH)(unloaded) | | 7835×2496×3386 |
| Cargo body size (LxWxH)(mm) | | 5200x2300x1400, T middle lift, bottom 8mm, side 6mm |
| Approaching angle/Departure angle(°) | | 19/27 |
| Overhang(front/rear) (mm) | | 1500/1560 |
| Wheel base (mm) | | 3425+1350 |
| Max speed(km/h) | | 75 |
| Curb weight(kg) | | 12380 |
| Loading Weight(kg) | | 12490 |
| Engine (Steyr technology, made in China) | Model | WD615.69,water-cooled,four strokes,6 cylinders in line with water cooling, turbocharged and intercooling, directly injection |
| | Fuel type | Diesel |
| | Horse Power, max(kw/rpm) | 336HP,247/2200 |
| | Emission | EURO2 |
| Fuel tanker capacity | | 300 |
| Transmission | Model | HW15710 |

| | | |
|---|---|---|
| Brake system | Service brake | Dual circuit compressed air brake |
| | Parking brake | spring energy, compressed air operating on rear wheels |
| Steering system | Model | ZF8098 |
| Front axle | HF9 Drum, Steering with double T-cross section beam | |
| Rear axle | HC16, Pressed axle housing, central double reduction with differential locks between axles and wheels | |
| Tyre | 12.00R20, radial tire | |
| Electrical system | Battery | 2X12V/165Ah |
| | Alternator | 28V-1500kw |
| | Starter | 7.5Kw/24V |
| Cab | HOWO76 cab, single-sleeper, all-steel forward control,55ºhydraulically tilt able to the front,2- arm windscreen wiper system with three speeds, laminated windscreen with casted-in radio aerial, hydraulically damped adjustable driver's seat and rigid adjustable co-driver's seat, with heating and ventilating system, outer sun visor, adjustable roof flap, with stereo radio/cassette recorder, safety belts and adjustable steering wheel, air horn, with 4-point support fully floating suspension and shock absorbers | |

## APPENDIX: H Traffic Accidents in Ethiopia

**2010 ANNUAL**

**ከሐምሌ 1 ቀን 2009 እስከ ሰኔ 30 ቀን 2010 ዓ/ም ድረስ ባለው**
**አንድ ዓመት ውስጥ በአገር አቀፍ ደረጃ የደረሰ የትራፊክ አደጋና**
**በትራፊክ አደጋ ተጎጅ የሆኑ ሰዎች ብዛት በጉዳት ዓይነትና በጾታ**

| ክልል መስተዳድር | የደረሰው የትራፊክ አደጋ ብዛት | | | | | በትራፊክ አደጋ ተጎጂ የሆኑ ግለሰቦች ብዛት | | | | | | | | | በትራፊክ አደጋ በንብረት ላይ የደረሰ ጉዳት በገንዘብ ሲተመን | REGION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ሞት | | ከባድ የአካል ጉዳት | | ቀላል የአካል ጉዳት | | ድምር | | ጠቅላላ ድምር | | |
| | ሞት | ከባድ የአካል ጉዳት | ቀላል የአካል ጉዳት | የንብረት ጉዳት | ድምር | ወንድ | ሴት | ወንድ | ሴት | ወንድ | ሴት | ወንድ | ሴት | | | |
| ትግራይ | 301 | 459 | 97 | 550 | 1,407 | 268 | 106 | 632 | 226 | 447 | 137 | 1,347 | 469 | 1,816 | 47,397,561.18 | Tigray |
| አፋር | 53 | 24 | 6 | 71 | 154 | 66 | 6 | 40 | 9 | 26 | 5 | 132 | 20 | 152 | 89,781,800.00 | Afar |
| አማራ | 857 | 502 | 575 | 1098 | 3,032 | 882 | 270 | 848 | 333 | 1349 | 575 | 3,079 | 1,178 | 4,257 | 326,101,815.1 | Amhara |
| ኦሮሚያ | 1319 | 729 | 532 | 1806 | 4,386 | 1475 | 407 | 1286 | 424 | 1072 | 514 | 3,833 | 1,345 | 5,178 | 236,362,117. | Oromia |
| ሶማሌ | 142 | 219 | 33 | 16 | 410 | 164 | 40 | 391 | 142 | 369 | 78 | 924 | 260 | 1,184 | 35,850,000.00 | Somalia |
| ቤን/ገሙዝ | 24 | 78 | 122 | 42 | 266 | 32 | 4 | 97 | 29 | 157 | 58 | 286 | 91 | 377 | 4,970,550.00 | Ben.Gumuz |
| ደቡብ | 582 | 608 | 199 | 154 | 1,543 | 557 | 163 | 829 | 292 | 648 | 274 | 2,034 | 729 | 2,763 | 29,557,590.00 | S N N P |
| ጋምቤላ | 15 | 15 | 21 | 38 | 89 | 13 | 5 | 13 | 7 | 30 | 18 | 56 | 30 | 86 | 3,894,677.50 | Gambella |
| ሐረሪ | 31 | 102 | 286 | 346 | 765 | 25 | 9 | 146 | 78 | 277 | 230 | 448 | 317 | 765 | 22,972,900.00 | Harari |
| አ/አበባ | 456 | 1903 | 1074 | 24928 | 28,361 | 392 | 193 | 1481 | 323 | 819 | 413 | 2,692 | 929 | 3,621 | 109,882,371 | A/ Ababa |
| ድሬዳዋ | 40 | 101 | 128 | 316 | 585 | 31 | 10 | 97 | 31 | 169 | 110 | 297 | 151 | 448 | 13,999,933.00 | Dire Dawa |
| ድምር | 3,820 | 4,740 | 3,073 | 29,365 | 40,998 | 3,905 | 1,213 | 5,860 | 1,894 | 5,363 | 2,412 | 15,128 | 5,519 | 20,647 | 920,771,314.78 | Total |
| | | | | | | 5,118 | | 7,754 | | 7,775 | | 20,647 | | | | |
| | Death | Serious Injury | Slight Injury | roperty Damage | General Total | Male | Female | Male | Female | Male | Female | Total Male | Total Female | General Total | Total Property Damage Estimate In Birr | |
| | | | | | | Death | | Serious Injury | | Slight Injury | | | | | | |
| | NUMBER OF TRAFFIC ACCIDENTS | | | | | VICTMS OF MOTOR VEHICLE TRAFFIC ACCIDENTS | | | | | | ALL CASES | | | | |