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DEPARTMENT OF MECHANICAL ENGINEERING

FINAL YEAR PROJECT REPORT

DESIGN AND FABRICATION OF A COIN-BASED COLA AND SODA VENDING MACHINE

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A PROJECT REPORT SUBMITTED AS A PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE BACHELOR'S DEGREE OF SCIENCE IN MECHANICAL ENGINEERING

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DECLARATION

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I would like to share our sincere gratitude to all those who helped me in the completion of this project.

During the work, I faced many challenges due to the lack of some knowledge and experience, but my supervisors helped me to get over all the difficulties and the completion of my idea into a useful design.

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ABSTRACT

A Vending machine is an automated machine that dispenses products such as snacks, beverages, etc. to consumers based on a cash or cashless transactions. Different products can be stacked in each tray of the vending machine. In modern vending machines, heavy items cannot be stacked as the item falls from a higher level into a lower compartment, so the main objective of the product is to take the item from the level at which it is placed and dispenses it into the delivery compartment which makes it easier to hold heavier items as well. There are two problems in the current market, one is the Single axis movement which makes it difficult to hold delicately packed food items and the other one is the Collection Bin which at the bottom of the machine makes it difficult for elderly people to bend down and pick the product. The product vending machine which is now been developed eliminates the problem of the product falling from a higher level as this machine has both X and Y axis movements. The delivery bin moves near the item which is selected by the user and delivers it safely. This ensures that the delicately packed items are dispensed with no real damage. The main advantage of the other machine is that the collection bin is kept at a certain height from the bottom and that makes the machine user-friendly. Soon cashless transaction methods can include Paytm, Debit card/Credit card transactions, etc. The display used here is an LCD and there can be improvements in the future by replacing the LCD with a touchscreen display. Android apps can also be used for transactions. Voice recognition technology can also prove to be a big breakthrough in the field of vending machines.

Portable vending machines are very useful devices for dispensing small, easily available, and necessary pieces of equipment for the use of the common man. The aim is to construct an automatic vending machine prototype model, which can be installed in schools, colleges, hospitals, and other public places to dispense pens, pencils, and sanitary napkins during needs with appropriate mechanical designs for item collection. Also, microcontroller circuitry for coin checking, validation, and dispensing for items is to be proposed and implemented in real-time.

Because it is very convenient and not only can save the time of customers but also the vendors, thus it brings great convenience to the masses.

CHAPTER 1: INTRODUCTION

1.1 Background;

A vending machine is defined as one that provides products after the payment is made using itsmode of payment and the products are available 24/7.

The first vending machine was introduced at a temple in Alexandria in 215 BC to dispense holywater in return for a small coin. The oldest extant machines are cigarette-vending devices installed in English pubs and hostels as early as 1615.

English inventors subsequently devised additional designs to sell books, postage stamps, and many other products as well, but the devices were not commercially practical.

The first commercially viable vending machines were gum dispensers introduced in the United States. In Japan, the first viable machines were juice vending machines that appeared during thehigh-growth period following World War II.

While vending machines appear to work without human intervention, an entire support network is active behind the scenes.

Machine makers, product manufacturers, operators, service personnel, and location owners are just some of the individuals involved in marketing and management efforts. Other individuals are responsible for route systems that carry out collection,replenishment, and service.

In the case of beverage machines, the crucial requirements are to maintain merchandise in optimal drinking conditions and to ensure safety.

Beverage machines fall into two major categories: the original type that pours the beverage into a cup, and the more recently developedtype that delivers prepackaged drinks.

Cash collection equipment for vending machines has been widely standardized, which in turn contributes to effective maintenance. Coin mechanisms have advanced from mechanical to electronic. Jamming in the coin channel, which was the biggest problem, was greatly reducedand the number of supported coins increased.

Four categories of vending machines account for around 97% of all vending machines in operation namely beverage vending machines (48%), tobacco vending machines (10%), other vending machines (16%), and automatic service machines (23%).

Similarly, three categories of vending machines account for over 92% of all vending machine sales figures, namely beverage vending machines (40%), tobacco vending machines (28%), andticket vending machines (25%) [1].

1.2 Examples of vending machines include;

Ice-cream vending machines, chocolate vending machines, water or tea or coffee vending machines, and ATM (Automatic Teller Machine), e.t.c. All these and other similar machines areoperated using Finite State Machine principles whereby the machine will be at one state in time.

There are over 15 million vending machines worldwide and many of the operators are now considering adding connectivity. Analysts forecast that the number of connected vending machines worldwide will grow at a CAGR of 16.3% from 4.2 million units in 2019 to reach 8.9 million units by 2024. The penetration rate will then reach 52% at the end of the forecast period.Over 28% of the 15-million vending machines are connected online. USA Technologies is the largest provider in terms of the installed base, having more than 1 million connected vending machines.

The market developed via automatic vending machines has grown quickly since it is convenient, faster, and cheaper.

The global vending machine market size was evalued at 18.28 billion dollars in 2019 and anticipated to reach 25.25 billion dollars by 2027 at a CAGR of 6.7 from 2021 to 2027. The market is expected to exhibit an incremental revenue opportunity of about 6.97-billion dollarsfrom 2019 to 2027 [3].

According to the vending machine market analysis, the market is segmented into type, application, technology, sales channel, and region. Based on type, the market is segregated intofood vending machine, beverages vending machine, tobacco-vending machine, and e.t.c. The beverages vending machine segment held the largest market share in 2019 and is expected to lead the vending machine market in the near future [4].

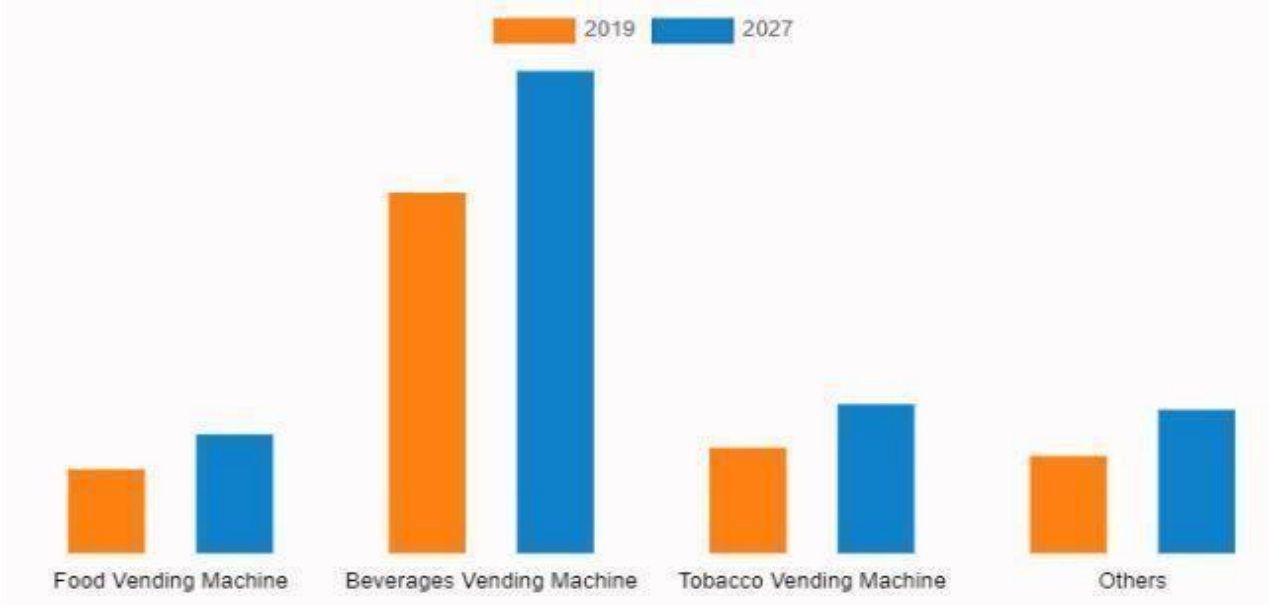


Figure 1: Vending machine market by type

Nowadays these machines are found in various places across the world like in schools, offices, restaurants for selling snacks and drinks, even found at railway stations for selling tickets in some countries and are accessible 24/7 thus saving time. Also, automated vending machines are most in use as they make various activities not only easierbut also more efficient.

The machine has numerous inputs and outputs to provide service to the customer. This machine accepts a payment such as cash as input and delivers a product. This machine has a huge market with high annual revenues for both developed and developing countries.

Gradually, vending machines have become a wide channel with an increase in sales and even competition between the manufacturers.

Vending machines have some advantages which include the following;

- They are easy to use.
- They operate automatically.
- They keep employees happy and alert.
- They save time and labor costs since they do not need a full-time operator.
- They are easy to set up because they occupy less space.
- Some vending machines such as ATMS, reduce the time and human efforts required to search, recognize and stand in a queue to make cash payments and even for cash withdrawals.

At the core of the beverage industry, is the carbonated soft drink category. The dominant players

are Coca-cola and Pepsi cola who own virtually the market's most widely distributed and best-known brands.

Uganda has over twenty soft drink and water companies, which include Century bottling Company Ltd (Coca-Cola), Crown Beverages Ltd (Pepsi-Cola), Highland natural mineral water,Victoria Beverages Ltd, Blue Wave Beverages Ltd, House of Eden (U)

Limited and many others including Hema Beverages Ltd, Delight (U) Ltd, Saturn Limited, and other new entrants will soon launch their services in the country [**5].**

Cola and Soda are carbonated soft drinks and have become one of the most known soft drinks of the century. The rapidly rising population and changing lifestyles have increased the need for Cola and Soda. Despite accounting for 16% of the global population, rising to 25% by 2050, Africa accounts for just 3% of the total value of soft drinks consumed across the world. By 2023,this will rise to 3.9% [**6**].

Japan has the largest number of vending machines in the whole world per capita.

Generally, people are a challenging consumer audience to provide convenient and cost-effective service to. To address this, particularly in the major cities, companies on-the-gofridges to shops to extend the services to the customers. However, these establishments sufferfrom some issues.

Approximately 4.27 million vending machines were operating in Japan at the end of 2006, with annual sales of over 7 trillion yen. We have focused our research on beverage vending machines because these account for over half of all the installed machines (at 2.60 million) [1].

The price of vending machines stated by manufacturing companies ranges from $1,200-3,000 for used and refurbished ones and $ 3,000-10,000 for new ones. These varying prices depend on the size and the different features of various types of vending machines. However, many vending machine operators recommend buying used and refurbished vending machines [8].

In Uganda, the drinks market was 116 million USD in 2015. Until 2025, the market was forecasted to reach 470.45 million USD at retail prices, increasing at a CAGR of 11.75% per annum for the period 2020-2025. It is a decrease compared to the growth of about 19.56% peryear, registered in 2015-2019. The average consumption per capita value terms reached 2.99 USD per capita at retail prices in 2015. It grew at a CAGR of 15.66% per annum in the next fiveyears. In the medium term (by 2025), the indicator is forecast to slow down its growth and increase at a CAGR of 8.31% per annum [9].

Selling and buying soft drinks is common in shops, bars, supermarkets, hotels, schools, hospitals, stadiums, airport stations, and on the road sideways.

In some countries, this is done with the helpof vending machines These machines are mostly used in areas like commercial areas, industrial areas, shops, organizations, etc.
However, in Uganda, vending machines are rare so customers mostly access drinks mostly from shops, bars, restaurants, and supermarkets, which are sometimes distant and do not operate 24/7.

1.3 Problem statement

In some areas, customers travel long distances to access the drinks in shops, which is tiresomeand time-wasting.
Another issue is that these establishments are not available 24/7. The shops' services may close at certain hours or not be open on weekends.
To solve these problems, I propose the design and fabrication of a coin-based cola and soda vending machine to deliver Cola and Soda to the public 24/7 by using sensors and microcontrollers based on Mechatronics principles.
It will be cheaper and more economical forbulk production.

1.4 Objectives of the project;

1.4.1 Main objective;

To design and fabricate a coin-based vending machine providing one drink at a time.

1.4.2 Specific objectives;

- To determine the design requirements and specifications.
- To develop a preliminary design.
- To develop a detailed design.
- To construct and test the fabricated prototype.

1.5 Justification;

This project focuses on the design and fabrication of a coin-based cola and soda vending machine dispensing one drink at a time.
Through this, soft drinks will be closer to customers hence improving the accessibility of the drinks. This implies that customers will access the drinks at any time they want thus thirst emergencies will be sorted with immediate access.
The machine will have low maintenance with very low overhead costs; the drinks will be available

24/7, this machine eliminates contact between the seller and buyer, therefore, reducing the spread of infections and thus will increase customer satisfaction.

This project will also boost the manufacturing sector here in Uganda, especially the soft drinks sector, which in turn increases the country's GDP.

However, the most common method of payment in Uganda generally is cash either coins or notes.

1.6 Project scope;

This project will focus on designing and fabricating a coin-based cola and soda vending machine capable of storage.

The machine will aim at dispensing one drink at a time when the customer inserts a coin into the machine to easily access drinks at any time with convenience.

Due to a variety of soft drinks as well as different preferences, the project will aim at providing at least one of the low-cost soft drinks such as sodas that are consumed here in Uganda.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction;

Although some machines may have advanced technology that allows them to determine the chemical composition of coins, most vending machines simply compare the physical characteristics of coins, such as their diameter, thickness, and the number of ridges on the edge. The most important component of a vending machine is the detection of the coin that accepts and determines the value of the inserted coin.

This is a microcontroller-based vending machine. It mainlyconsists of 3 parts, the coin insertion part, coin detection, and validation, and giving out the product according to the amount inserted. The principle is simple: the customers insert a coininto the machine and it returns the drink.

As we now live in a digitalized environment, vending machines are continuously getting smarter and smarter.

With the improvement in technology, many vending machines were invented, one of them being a coin-operated telephone. With the same technology, we will design a coin-basedcola and soda vending machine as the name indicates is based on coin operation.

Companies across the world have successfully implemented the following payment methods in vending machines;

The modes of payment are categorized under cash and cashless mode.

- Cash can be in form of coins or notes.
- Cashless mode examples are credit cards, debit cards, closed systems, contactless payment and M-payment, e.t.c.

In Uganda, the most widely used mode of payment is cash, which is in form of either coins or notes.

Vending machines validate money in the following ways;

- Some vending machines use ultraviolet scanners to measure the glow from a bill to verify it is real. Genuine notes contain fluorescent ink, they will glow when ultraviolet light shines on them.
- Real currency bills are also printed using magnetic ink; so many vending machines also use a magnetic reader to detect the magnetic signature of a bill to ensure it is real and determine its denomination.

2.2 Existing vending machines;

Several types of vending machines have been introduced into the industry some of which are discussed below.

2.2.1 Automatic Vending Machine Prototype Model

The user can drop a coin through the slot provided and press the button of the required item. After the insertion and sense of the coin, the execution of the process starts. A sensed coin waits for the entire process to be completed before it is deposited into the collection box. An un-sensedcondition ensures that the coin is given back. The process ends with one item being dispensed to the collection area, the rotation mechanism of the stepper motor and the associated load ensure that proper operation takes place and the item is vended properly. The item as it gets dispensed ismade to pass through the infrared sensor. As the object cuts the infrared rays, we can say that the process is complete. If the item doesn't come out and if there is no obstruction sensed by the sensor, then it is assumed that there is some problem in the system. In that case, the control goes to the coin stepper motor and sends the coin to the rejection area. [13]

2.2.2 Coin-Operated Portable Water Vending Machine

This machine pours purified water into a cup orbottle when you insert a coin into the machine.



Figure 2: Coin-Operated Portable Water Vending Machine

2.2.3 Soda Vending Machine



Soda vending machine Product Description: Soda vending Machine with high efficiency. Under the stern supervision of nimble professionals, the offered machine is developed using quality checked components and innovative technology. This machine provides different types of beverages and colddrinks in bars, restaurants, clubs and many other places. Moreover, the offered soda machine is obtainable for our patrons at pocket friendly rates.

Figure 4: Soda Vending Machine

2.2.4 Fresh juice vending machine



Figure 3: Fresh juice vending machine

After making the payment through Paytm, a signal is generated from the raspberry to the relay module through a transistor to amplify the current; the relay output then actuates the actuator. Through the motor of required torque, the crushing load applies to the fruits, the timing sequenceprogram runs the motor for a particular time, and water is added to reduce the concentration of the juice.

After the dilution process, the motor runs for a particular time and then stops. Juice pours into a cup,the wastes from the squeezer are collected when the process ends, and after finishing the juice, the machine is cleaned.

Usually, the required quantity of cola and soda depends on the respective amount of money affordable for the common people.

Newer advanced vending machines can determine the chemical composition of coins and use optical scanning to identify notes. Some vending machines have miniature digital cameras whichscan images of the notes and verify whether the real currency was inserted, by looking for specific patterns.

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter details the methods and steps taken to realize the specific objectives statedearlier in this project.

3.2. Design flow chart

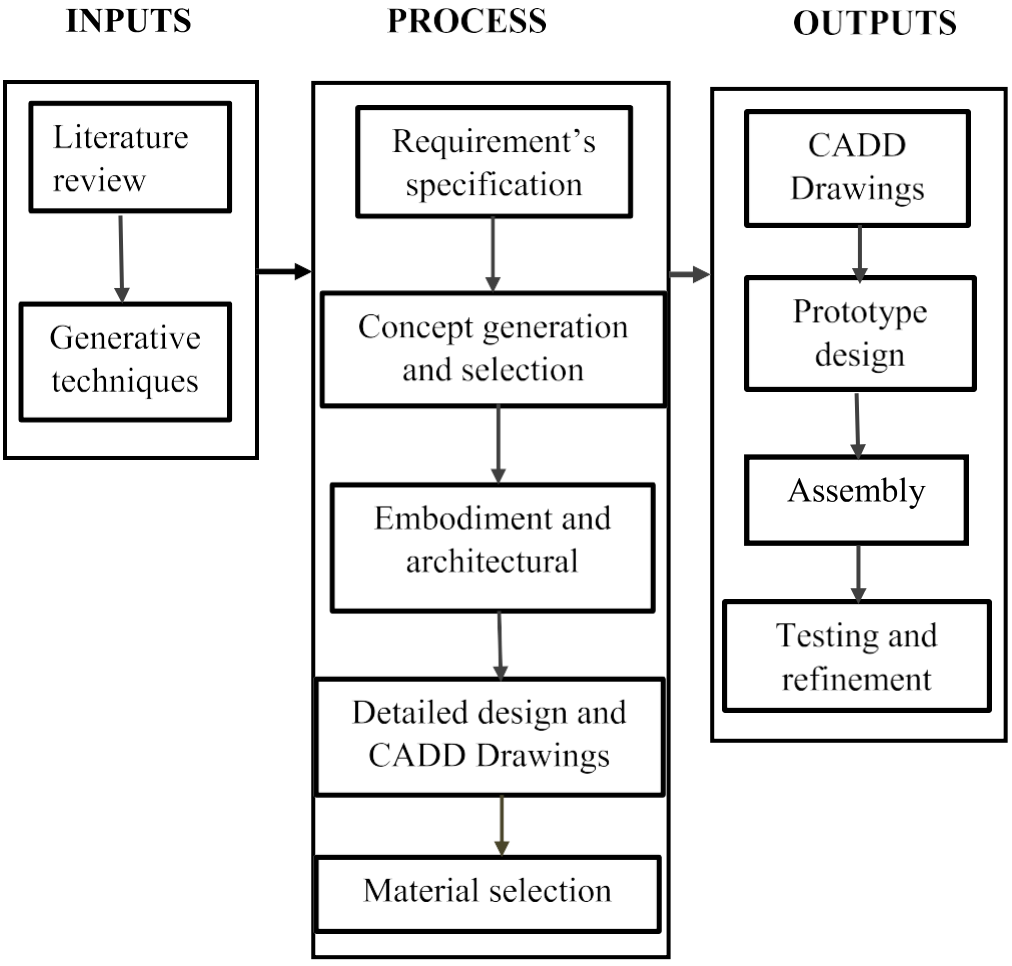


Figure 5: Design process flow chart

3.3. Determination of design requirements and specifications;

To achieve the above specific objective, the following methods were employed;

- Observing products in use.
- Reviewing existing documents on dispensing i.e., journals, reports, articles

3.3.1 Observing products in use;

This involves physical observation without direct interaction with customers to view and understand the different mechanisms employed in existing vending machines. Critical attention will be paid to the dispensing mechanisms used for example use of a coil spring mechanism rotatedby a high-torque motor. This was used to understand the number of drinks to be dispensed in what time.

3.3.2 Reviewing existing documents;

Through reviewing different research journals, reports, and articles on vending machines necessary information will be obtained for example design analysis, and certain customer requirements for the machines. The majority of the published information was accurate and accepted internationallyhence will be analyzed and incorporated into my design.

3.4. Developing a preliminary design;

The following methods were employed to be able to develop a preliminary design;

- Concept generation and selection
- Architectural design

3.4.1 Concept generation and selection;

Through concept generation, several concepts are developed about different design features of the machine. Concept generation involves clarifying the problem, carrying out internal and external searches to obtain solutions, and developing a concept combination table.
The system concept generated is summarized in the following diagram.

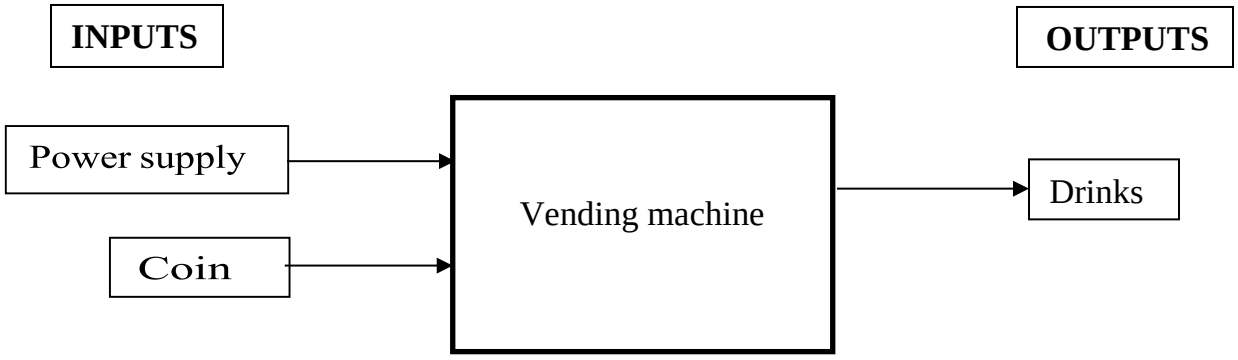


Figure 6**:** Summary of the system

3.4.1.1 Concept combination table.

Energy source	Energy conversion	Sensing	Apply energy to dispense
Rechargeable battery	Rotary motor	Infrared sensors	Springs
Power adapter	Pedals	Starter motor	Conveyor belts
Human-powered	Belt drives	Buttons	Hydraulics
Solar power	Chain drives		
Hydraulic power	Linear motor		

Table 1**:** Concept combination table

3.4.1.2 Concept selection

A structured approach is used in the selection of the best possible concepts generated. This approach uses a relative score of **+, 0, and -** to rate the generated concepts. In this criterion, concepts that perform better are rated with **[+]**, concepts that perform similarly compared to the reference are rated with [**0]** and concepts that perform worse than the reference are rated with **[-].**

After rating, the sums will be obtained for the different concepts and thereafter ranked.

Several selection criteria used in this screening process include;

- Cost of the solution.
- Applicability in rural areas.
- The energy efficiency of the concept solution.
- Ease of use.
- Affordability of end solution.
- Maintainability.
- The efficiency of the concept solution.
- Flexibility.
- Safety.

3.4.1.3 Ranking the concepts:

The concepts are rated against the reference concept using a simple code i.e + for "better than," 0for "same as," - for "worse than" to identify some concepts for further consideration.

The ranking of the concepts is shown in the table and the recommendation about each concept.

3.4.1.4 Energy source sub-problem

SelectionCriteria	Concepts					
	Reference	**Human Powered**	**Solar Energy**	**Rechargeable Battery**	**Power Adapter**	**Hydraulic Power**
Cost of solution	0	+	-	+	+	-
Applicability in rural areas	0	+	+	+	0	-
Energy efficiency	0	-	-	-	+	-
Flexibility	0	-	-	0	+	-
Safety	0	+	+	+	0	-
Ease of use	0	+	-	-	+	-
Affordability	0	+	-	0	0	-
Maintainability	0	-	-	-	+	-
Efficiency in output	0	-	-	0	+	+
Sums +'s	0	5	2	3	6	1
Sums 0's	9	0	0	3	3	0
Sums – 's	0	4	6	3	0	8
Net score	0	1	-4	0	6	-7
Rank	3	2	4	3	1	5
Continue?	**No**	**Revise**	**No**	**No**	**Yes**	**No**

Table 2**:** Ranking the energy source sub-problem concepts

Thus, the power adapter is chosen to act as the energy source concept.

3.4.1.5 Energy conversion sub-problem

Selection Criteria	**Concepts**					
	Reference	**Rotary motor**	**Pedals**	**Linear Motor**	**Belt drives**	**Chain drives**
Cost of solution	0	+	-	-	-	-
Applicable to rural regions	0	-	-	-	+	+
Energy efficiency	0	+	+	+	+	+
Flexibility	0	+	+	+	-	-
Safety	0	+	-	+	+	+
Ease of use	0	+	+	+	-	-
Affordability	0	+	-	-	+	+
Maintainability	0	+	-	-	+	+
Efficiency in output	0	+	+	+	+	+
Sums +'s	0	8	4	5	6	6
Sums 0's	9	0	0	0	0	0
Sums – 's	0	1	5	4	3	3
Net score	0	7	-1	1	3	3
Rank	0	1	4	3	2	2
Continue?	**No**	**Yes**	**No**	**No**	**Combine**	**Combine**

Table 3**:** Ranking the energy conversion sub-problem concepts

Thus, the rotary motor is chosen to act as the energy conversion concept.

3.4.1.6 Application of energy to dispense sub-problem

Selection Criteria	**Concepts**			
	Reference	**Spring mechanism**	**Conveyor belts**	**Hydraulic mechanism**
Cost of solution	0	+	-	-
Applicable to rural regions	0	-	-	-
Energy efficiency	0	-	+	+
Flexibility	0	+	+	+
Safety	0	+	-	+
Ease of use	0	+	+	+
Affordability	0	+	-	-
Maintainability	0	+	-	-
Efficiency inoutput	0	+	+	+
Sums +'s	0	7	4	5
Sums 0's	9	0	0	0
Sums – 's	0	2	5	4
Net score	0	5	-1	1
Rank	0	1	3	2
Continue?	**No**	**Yes**	**No**	**No**

Table 4**:** Ranking the application of energy concepts

Thus, the spring mechanism is chosen to act as the application of the energy concept.

3.4.1.7 Sensing sub-problem

Selection Criteria	**Concepts**			
	Reference	**Starter motor**	**Infrared sensors**	**Buttons**
Cost of solution	0	-	+	-
Applicable to rural regions	0	-	-	-
Energy efficiency	0	+	+	+
Flexibility	0	+	+	+
Safety	0	+	-	+
Ease of use	0	+	+	+
Affordability	0	-	+	-
Maintainability	0	-	+	+
Efficiency in output	0	+	+	+
Sums +'s	0	5	7	6
Sums 0's	9	0	0	0
Sums – 's	0	4	2	3
Net score	0	1	5	3
Rank	0	3	1	2
Continue?	**No**	**No**	**Yes**	**No**

Table 5**:** Ranking the triggering concepts

Thus, an infrared sensor is chosen to act as the sensing concept.

3.4.1.8 Microcontroller board sub-problem;

Selection Criteria	**Concepts**			
	Reference	**ArduinoUno**	**STM32 Nucleo-144**	**ATSAMD11-XPRO**
Cost of solution	0	0	-	-
Applicable to rural regions	0	0	0	0
Energy efficiency	0	+	+	+
Flexibility	0	+	+	+
Safety	0	+	+	+
Ease of use	0	+	+	+
Affordability	0	0	-	-
Maintainability	0	+	+	+
Efficiency in output	0	+	+	+
Sums +'s	0	6	6	6
Sums 0's	9	3	1	1
Sums – 's	0	0	2	2
Net score	0	6	4	4
Rank	0	1	2	2
Continue?	**No**	**Yes**	**Revise**	**Revise**

Table 6: Ranking the microcontroller board sub-problem

[18]

3.4.1.9 Final concepts chosen

Problem	**Concept**
Energy source	Power adapter
Energy conversion	Rotary motor
Application of energy	Spring mechanism
Trigger/ sensing	Infrared sensors
Microcontroller board	ArduinoUno

Table 7: Final concepts that are chosen.

3.5 Developing a detailed design;

After concept generation and selection, the following methods will be used to obtain a detaileddesign of the selected concepts.

- Design analysis of the machine components.
- Electronics design.
- Development of the governing code.
- Designing a CAD model.

3.5.1 Design analysis of the machine components

3.5.1.1 Design for coil spring

Standard numerical formulae will be used to calculate the different parameters of the machinecomponents.



Figure 7**:** Coil spring

The coil spring design procedure is as follows; [16]

I. Choose the spring wire material.
II. Choose a wire diameter, d.
III. Assume a suitable spring index, C.

IV. Calculate the mean diameter, D=Cd.

V. Obtain the outer and inner diameter;

VI. Outer diameter, D_O =D+d

VII. Inner diameter, D_i =D-d

VIII. Determine the number of turns.

IX. Determine coil-free length and solid length.

X. Calculate the spring rate $K = \frac{d^4 G}{8D^3 N_a}$

XI. Determine minimum tensile strength, $S_{ut} = \frac{A}{d^m}$ where A and m are standard values.

XII. Determine the maximum allowable shear stress, $\tau = 0.45 S_{ut}$

XIII. Design for safety, $\tau = \frac{8FD}{\pi d^3} \times K_S$, where $K_S = \frac{4C-1}{4C-4} + \frac{0.615}{C}$ and F is the load.

3.5.2 Electronics design

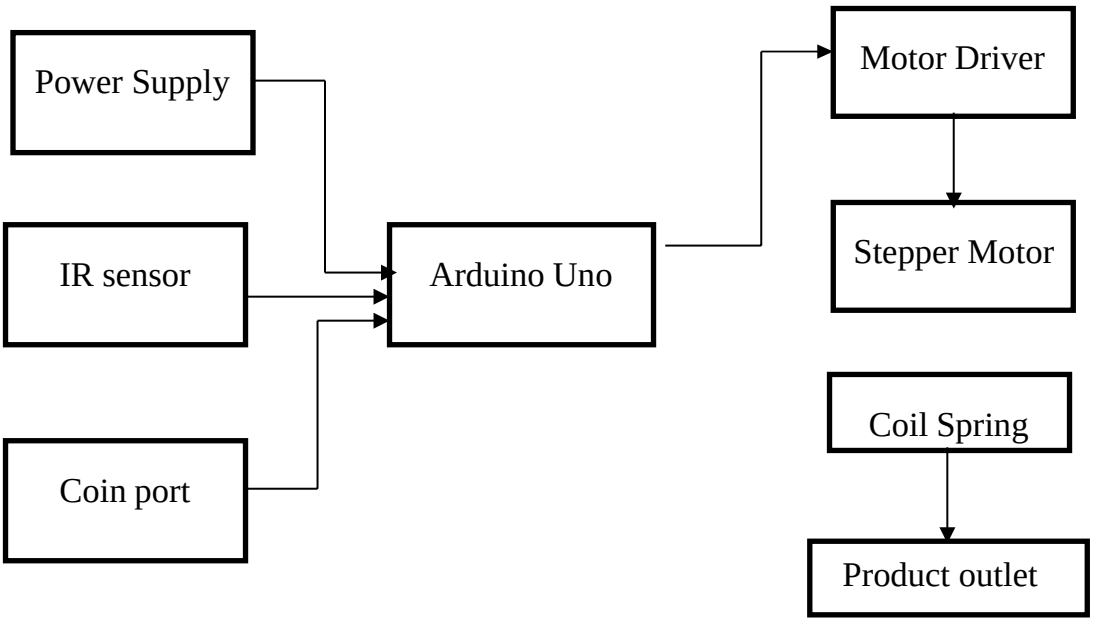


Figure 8**:** Block diagram of the dispensing system

3.5.3 Development of the code

Since the microcontroller board chosen is Arduino Uno, the code to control the components will developed in the Arduino environment IDE software and loaded onto the Arduino board via a USBcable.

This code will control the entire dispensing system from the IR sensors to the rotation of the

motor.The code instructs the IR sensor to send a signal to the Arduino board once motion is detected, then the Arduino instructs the motor driver to control the speed of the motor as well as the rotation.

3.5.4 CAD model

After the design analysis of the machine components, the obtained dimensions and other component specifications will be used to generate a 3D model using modeling software.
The CAD model will be developed using Solid Works 2019 software by modeling the parts as wellas assembling them.

3.5.5 Materials Selection

Materials selection will be done by rating and ranking different possible materials based on several material properties.
The material properties to consider include;

- Weldability.
- Cost.
- Availability.
- Strength.
- Stiffness.
- Stability.
- Corrosion resistance.

The material ranked highest will be chosen as the best material for the specific machinecomponent considered.

3.5.5.1 Material for the outside casing;

Selection Criteria	Concepts			
	Reference	**Stainless steel**	**Aluminum**	**Cast iron**
Cost of solution	0	-	+	0
Weldability.	0	+	-	0
Availability	0	+	+	+
Strength	0	+	-	0
Stiffness	0	+	-	0
Stability	0	+	-	0
Corrosion resistance		+	-	0
Sums +'s	0	6	2	1
Sums 0's	9	0	0	6
Sums – 's	0	1	5	0
Net score	0	5	-3	-5
Rank	0	1	2	3
Continue?	**No**	**Yes**	**Revise**	**No**

Table 8: Ranking the material for the outside casing.

Thus, the material for the outside casing chosen is Stainless steel.

3.6. Construction and testing of the prototype

Some machine components will be acquired through purchase for example Arduino boards, infrared sensors, DC motor, and power adapter. These machine components will be purchased specifically fitting the design variables i.e., dimensions, tolerances, material, etc.

After the acquisition of the components, a suitable workshop and labor will be identified as well as a determination of the fabrication processes required. Other machine parts will be welded onto the machine for example the spring holder compartment as well as the fabrication of the machineframe.

Testing of the prototype is done to check for the presence of vibrations and noise from the machineand to determine the performance of the machine to check if it can fulfill its purpose.

The presence of vibrations and noise will be noticed after powering on the machine while determining the performance of the machine will be done by inserting a coin and then waiting forthe drink to pop out through the outlet.

CHAPTER FOUR: DETAILED DESIGN

4.1 Determine requirements and specifications

4.1.1 Needs requirements

The data collected through various methods suggested the following requirements;

- Affordability.
- Durability.
- Quick access.
- Ease of use.
- Ample holding capacity.
- Lightweight.
- Little Power consumption.
- Easy installation.
- Allows viewing of products.

4.1.2 Specifications

The following are the specifications to be considered during the design process.

Target Specification	Metric	Target Value	Unit
1.	Holding capacity	1 product	-
2.	Total Mass	< 0.2	Kg
3.	Dispensing time	< 5	s
4.	Products dispensed at a time	1	-
5.	Power rating	< 24	W
6.	Unit Manufacturing cost	< 300,000	UGX
7.	Operating voltage	< 12	V

Figure 9: specifications to be considered during the design process

4.1.3 Parametric Design

4.1.3.1 Spring design

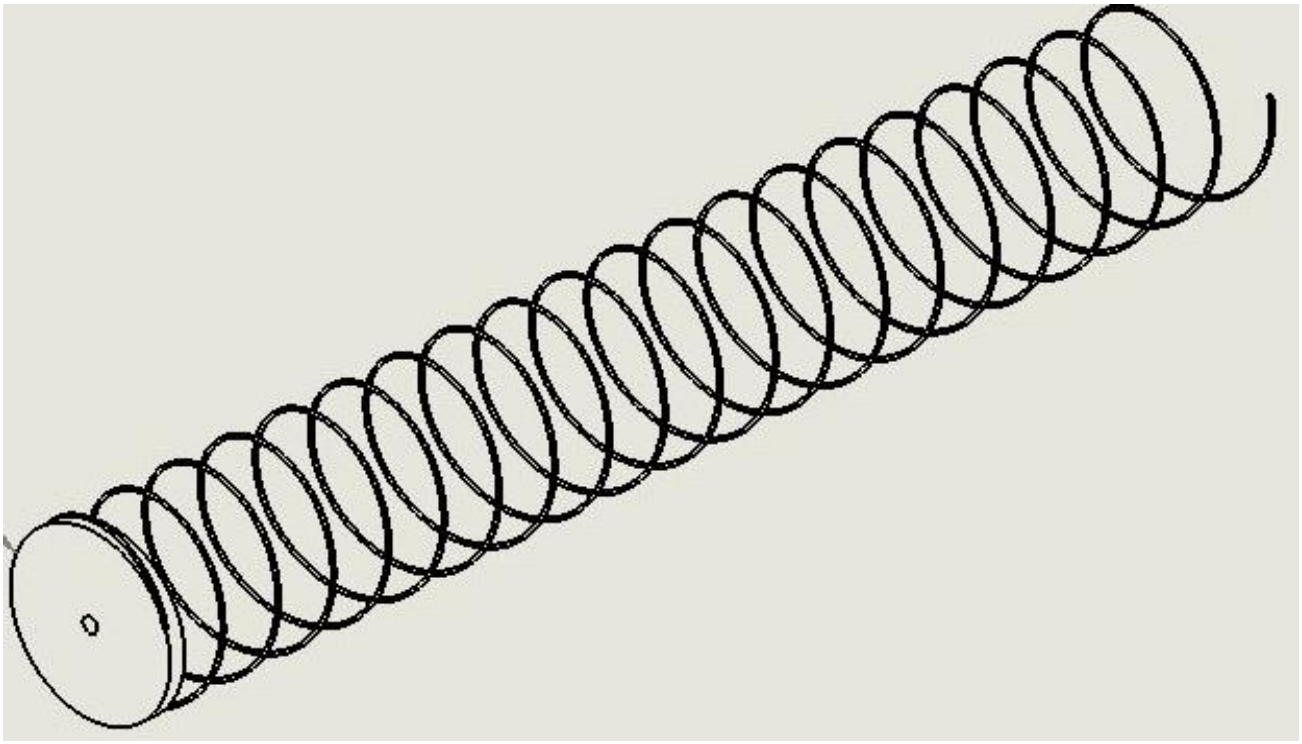


Figure 10: CAD model of the Coil spring

Assume a spring of hard-drawn wire with a wire diameter, of $d = 2.2mm$

Assume a spring index, $c = 12$

Mean diameter of the spring, $D = Cd = 12.5 \times 2.4 = 30mm$

The outer diameter of the spring, $D_O = D + d = 30 + 2.4 = 32.4mm$

The inner diameter of the spring, $D_i = D - d = 30 - 2.4 = 27.6mm$

Number of turns, N_a

Allowed free length = 100mm

Pitch of spring = 20mm

Consider a spring with plain ends.

From table 10-1;

Free length, $L_O = pN_a + d$

$$100 = 20 \times N_a + 2.4$$

$$N_a = 5 \text{ turns}$$

Spring rate, $K = \frac{d^4 G}{8D^3 N_a} = \frac{2.4^4 \times 79.3 \times 10^3}{8 \times 30^3 \times 5} = 2.44 N/mm$

Minimum Tensile strength of the spring, $S_{ut} = \frac{A}{d^m}$

From table 10-4;

Hard-drawn wire A227 has the following specifications;

$m = 0.190$ and $A = 1783 \text{MPa}.\text{mm}^m$

$$S_{ut} = \frac{1783}{5^{0.190}} = 1313.25 \text{MPa}$$

Maximum allowable stress, $\tau = 0.45\, S_{ut} = 0.45 \times 1313.25$

$$\tau = 591 \text{ MPa}$$

Design for safety, Shear stress $\tau = \frac{8FD}{\pi d^3} \times K_S$

Assume a maximum weight of 0.2kg on the coil spring

F = 2N

$$K_S = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4 \times 12.5 - 1}{4 \times 12.5 - 4} + \frac{0.615}{12.5} = 1.11$$

$$\tau = \frac{8 \times 2 \times 30}{\pi \times 2.4^3} \times 1.11$$

$$\tau = 11.05 \text{MPa}$$

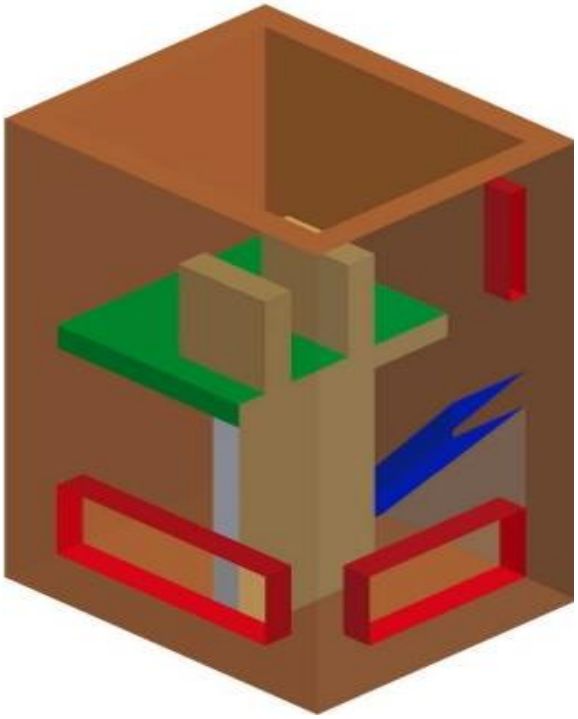
Since 11.05MPa <591 MPa, the design is safe.

Coil spring specifications

Parameter	**Specification**
Wire diameter	2.4mm
Mean diameter	30mm
Outer diameter	32.4mm
Inner diameter	27.6mm
Free length	100mm
Pitch	20mm
Minimum tensile strength	1313.25MPa
Maximum allowable stress	591Mpa
Shear stress	11.05MPa

Table 9: Coil spring specifications

4.1.3.2. Design of the frame



The frame houses the components of the system and also contains the viewing window, coin port as well as a product outlet.

Initial designed spring free length, L_O = 60mm

Motor width = 30mm

Motor disc diameter = 40mm

Allowance = 60mm

Length of the frame = 60+30+60 = 150mm

Width of the spring compartment = 30mm

Allowance 10mm

Width of the frame = 30+10+60 = 100mm

Height of the frame = 90+110 = 200mm

Figure 11: CAD model of the machine frame

4.1.3.2.1 Frame specifications

Parameter	Specification
Length	150mm
Width	100mm
Height	200mm

Table 10: Machine frame specifications

4.5. Electronic system design

4.5.1. Motor selection

A motor with moderate speed and high torque was required given the load it had to push. Therefore, a DC motor with gears to reduce the speed and increase the torque was used i.e., geared motor.

Force, F = 0.2Kg and Radius, r = 3cm

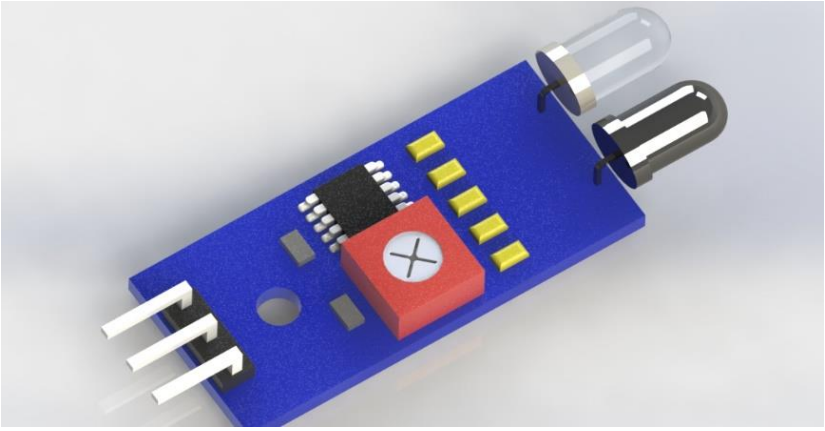
Torque required, T = 0.2 x 3 = 0.6Kgcm

4.5.1.1 Motor Specifications

Parameter	Specifications
Operating voltage	12V
Rotational speed	200rpm
Rated torque	181.3Nmm
Outer diameter	49mm
Step angle	7.5^0
Rated current	0.431A

Table 11: The motor specifications

4.5.2. Sensors



Infrared sensors were needed to detect coins to actuate the dispensing system by starting the motor.
They detect any motion within its nearby radius hence were used as the actuating mechanism.

Figure 12: CAD model of Infrared sensor

4.5.3. Arduino microcontroller board

The Arduino board controls all the components within the electronic system by use of a given program. They receive signals from the infrared after coin detection and send signals to the motor driver to turn on the motor which turns the spring.
The Arduino board is also the source of the voltage used by the system components.

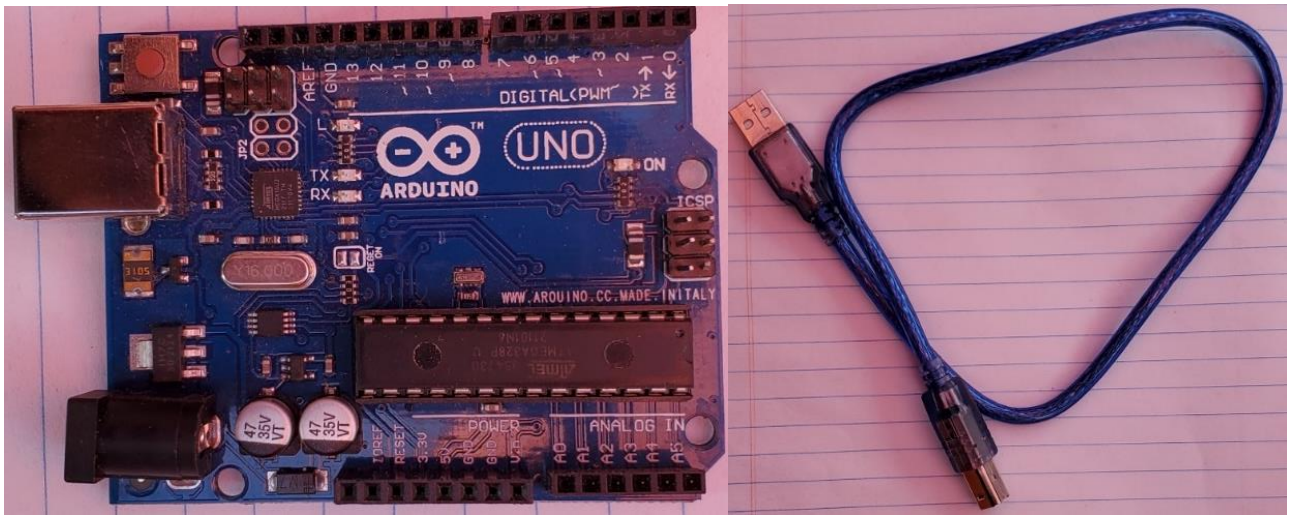
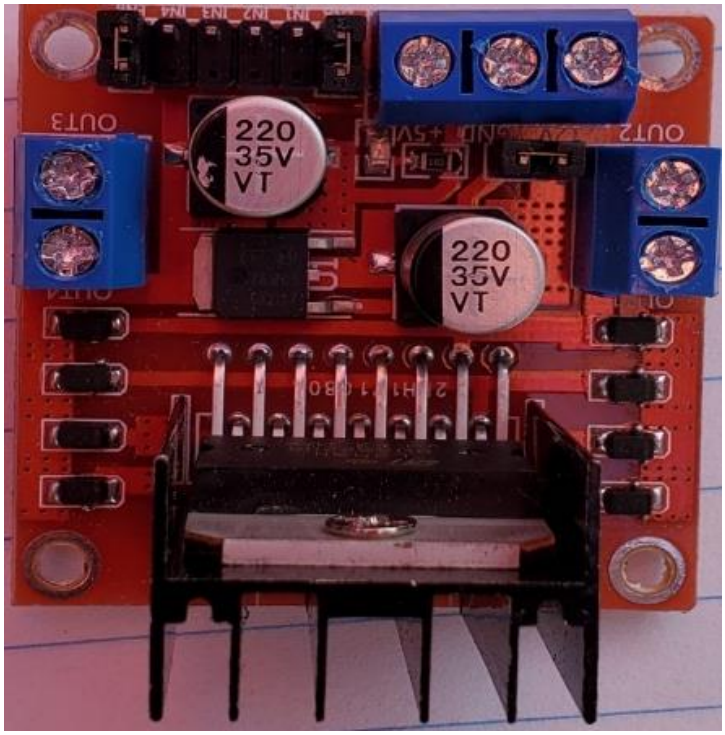


Figure 13: Arduino Uno board with its USB

4.5.4. Motor driver



Motor driver simply turns on the motor as per given program. Motors require high current while the Arduino board uses low current, so the motor driver takes that low-current signal and turns it into a high current signal that can driver the motor.

An L298N type of motor driver was used since it was readily available and cheap as compared to other motor drivers.

Figure 14: Motor driver L298N

4.5.5. Power Rating analysis of the design

The design was powered by a power adapter of 12V, 2A specifications. The power adapter converts AC from the single-phase socket to DC which is then supplied to the Arduino Uno board.

The motor used required an operating voltage of 12V, therefore a power source of higher voltage was needed to meet the requirements.

Power required, $P = V \times I = 12 \text{ X } 2 = 24W$

Energy rating, $E = V \times I \times t = 24 \times (5/3600) = 0.0333KWh$

4.5.6. Developing the code.

The governing program of the electronic system was created in the Arduino environment IDE software. The code controls the IR sensor, and the motor driver through the Arduino UNO board intending to turn on the motor.

Throughout the project, various iterations of the code were formulated. Starting from the most basic and building on it to test its functionality and track overall progress and further developed to derive the final code.

4.5.6.1 Code Organisation

The code was organized by;

- Declaring the component connections into the Arduino.
- Declaring the inputs and the outputs.
- Setting up the IR sensor with the Arduino.
- Setting up the stepper motor and adjusting the rotations into the Arduino.
- Setting up the buttons in the Arduino.

Starting by declaring all of the components connected to the Arduino Void Setup and Void loop.

These were the brief steps that we used to organize out code that would work best for the machine. It also gave a clear layout of what code results in what outcome. Having the code organized in such a way was very helpful when we were troubleshooting problems with the code as we knew which area to target when the motor was not working. It eliminated any confusion that could have been caused.

This organization of the code is the standard way for it to be done. So, after defining the declaration, stating where every component was connected, we stated the void setup as it's been read by the Arduino before and then went to define the void loop. This then caused the motor rotations to take place which made it rotate.

The code is as follows;

```
#include <Stepper.h>
#define IR_SENS_TWO 2 // sensor at coin slot
int IRSensor = 2; // connect ir sensor to arduino pin 2
int stepsPerRevolution = 1024;
int motSpeed = 3;
int dt = 1000;
Stepper myStepper(stepsPerRevolution, 8, 9, 10, 11);

void setup()
{
  // put your setup code here, to run once:
  pinMode (IRSensor, INPUT); // senzor pin INPUT
  pinMode (8, OUTPUT);
  pinMode (9, OUTPUT);
  pinMode (10, OUTPUT);
  pinMode (11, OUTPUT);

  Serial.begin(9600); // troubleshooting and printing some stuff out
  myStepper.setSpeed(motSpeed); // motor speed
}

void loop()
{
  // put your main code here, to run repeatedly:
  int statusSensor = analogRead (2);

  if (statusSensor > 1)
  {
    digitalWrite(8, LOW);
    digitalWrite(9, LOW);
    digitalWrite(10, LOW);
    digitalWrite(11, LOW);
    analogWrite(5, 100);
    delay(dt);
  }
  else
  {
    digitalWrite(8, HIGH);
    digitalWrite(9, HIGH);
    digitalWrite(10, HIGH);
    digitalWrite(11, HIGH);
    analogWrite(5, 0);
    delay(dt);

  }
}
```

Figure 15: The Code

4.5.6.2 Explanation of the code

The developed code is explained as follows;

- #include <stepper.h>; specifies the type of motor i.e., stepper motor.
- #define IR_SENS_TWO 2; means the infrared sensor is at the coin slot.
- int IRSensor = 2; means the infrared sensor inputs a signal to the Arduino UNO board through pin 2.

- int stepsPerRevolution = 1024; there are 1024 steps per revolution.
- int motSpeed = 3; the motor speed is 3 rpm (revolutions per minute).
- int dt = 1000; delay the time by 1 second.
- Stepper myStepper(stepsPerRevolution, 8, 9, 10, 11); pins 8,9,10, and 11 are connected to the motor.
- The void setup: the code is put here to run once. The code specifies that pin 2 is the input while pins 8,9,10, and 11 are the output to the motor set at a speed of 3rpm.
- void loop(): the code is put here to run repeatedly. The code specifies that if the sensor detects the coin, the motor rotates for 5 seconds and stops for 1 second then repeats continuously.

4.5.7. The system flowchart

The system flow chart below shows the steps undergone starting from the coin input to the dispensing of the product for the user to pick.

When a coin is inserted through the coin slot, the sensor detects the coin and signals the Arduino board which then commands the stepper motor to rotate clockwise together with the spring that in turn dispenses the product within 5s for the customer to pick.

This process is repeated for every coin input.

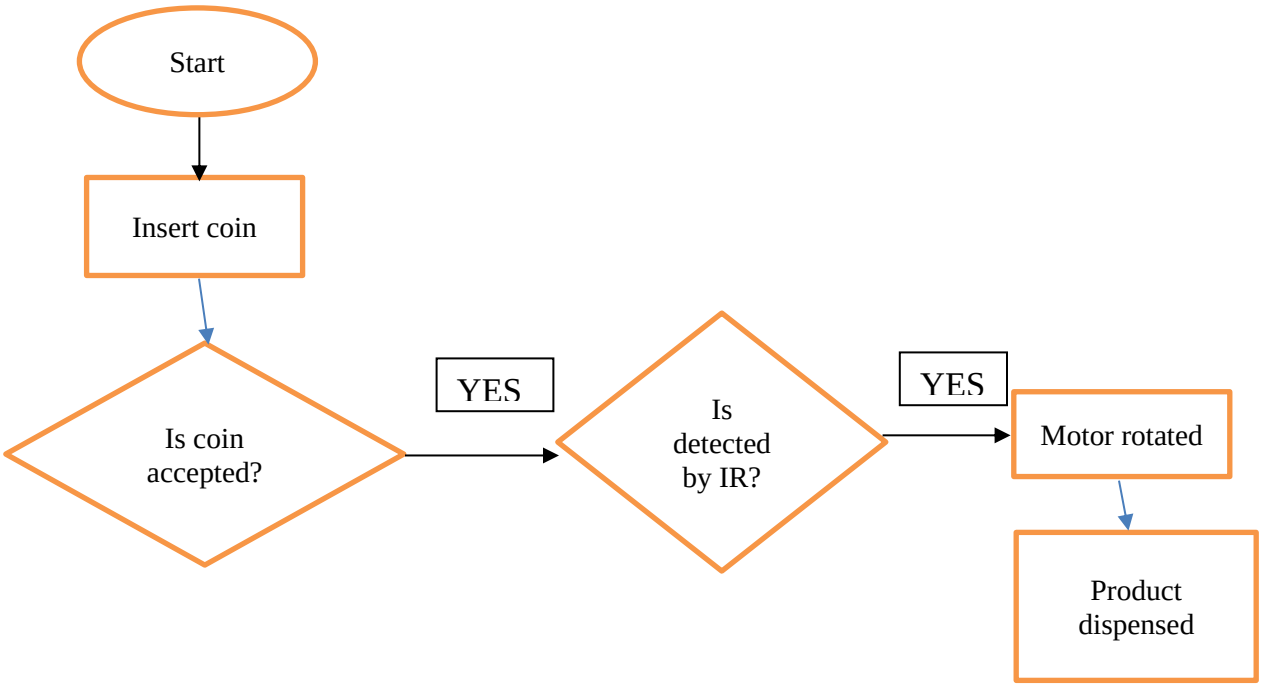


Figure 16: The system flow chart

4.5.8 Materials Selection

Material properties considered for selection;

- Weldability
- Strength
- Corrosion resistance
- Stiffness
- Cost
- Stability
- Availability

Range rates for the materials to be screened;

Range	**Rate**
Poor	1
Fair	2
Good	4
Excellent	5

Table 12: Range rates for the materials to be screened;

4.5.8.1 Weighting factors

Factors	**Weights**	**Material properties**
Least important	1	Stiffness
Important	3	Stability, corrosion resistant
Very important	4	Cost, availability
Most important	5	Weldability, strength

Table 13: Weighting factors

Properties	**Mild steel**		**HC steel**		**Wood**		**Aluminum**	
	Rate	**WF**	**Rate**	**WF**	**Rate**	**WF**	**Rate**	**WF**
Weldability	5	5(25)	3	5(15)	1	5(5)	1	5(5)
Strength	4	5(20)	5	5(25)	3	5(15)	2	5(10)
Corrosion resistance	2	3(6)	3	3(9)	1	3(3)	2	3(6)
Stiffness	3	1(3)	4	1(4)	4	1(4)	2	1(2)
Cost	4	4(16)	2	4(8)	4	4(16)	4	4(16)
Stability	3	3(9)	3	3(9)	2	3(6)	2	3(6)
Availability	4	4(16)	2	4(8)	5	4(20)	3	4(12)
Weighted score	95		78		69		57	
Rank	1		2		3		4	

Table 14:Different materials ranking

Mild steel which ranks highest above the other materials was chosen as the material choice for the machine frame.

However, it was expensive to purchase so I used wood as a replacement to make the simple prototype.

The following materials were selected for the different components of the machine.

Component	**Material**
Machine Frame	Wood
Coil spring	Aluminum wire
Spring compartment	Wood

Table 15: Materials were selected for the different components of the machine.

4.5. Fabrication and Assembly

4.5.1. Frame Construction

The housing and enclosure of the entire machine where the coil spring and electronics are contained. Wood, nails, screws, and wood glue were purchased as the materials for the frame casing.

After obtaining the materials to be used, they were joined together to obtain the desired machine frame.

4.5.2. Coil spring



Due to the failure to obtain a standard coil spring from the local market, a coil spring had to be engineered. A long Aluminum wire was obtained and wound over a hollow rod of diameter 30 mm to obtain the coil spring of the desirable turns.

Figure 17: Coil spring

4.5.3. Electronics setup

The electronics included an Arduino board, motor driver, stepper motor, and infrared sensor all connected with the help of jumper wires. The Arduino board and motor driver were screwed on a wooden board, the infrared sensor attached to the coin port on the machine frame, and the stepper motor onto the coil spring.

4.5.4 The Coin

A 500-shilling coin was chosen as the amount required to make the payment. It has a diameter of 23.5 mm and a thickness of 3 mm.



Figure 18: 500-shilling coin

4.5.5 Jumper wires

4.5.5.1 Male-to-male and Male to female jumper wires

Male-to-male and male-to-female jumper wires were used as the connection wires through which the signals are sent from the IR sensor to the Arduino UNO board to the L298N motor driver and then finally to the motor.

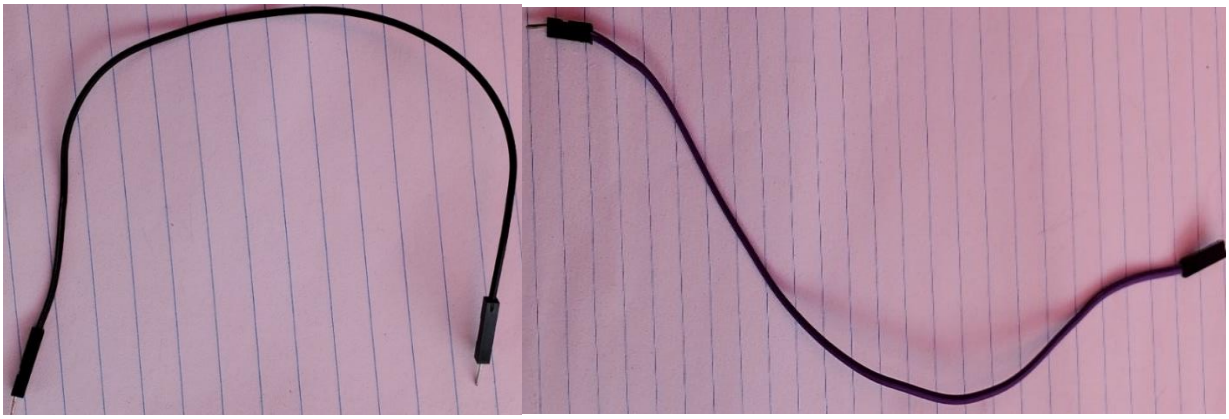


Figure 19: Male-to-male and Male to female jumper wires respectively

4.5.6 The 12V power adapter

A 12V power adapter was used to regulate the voltage required by the L298N motor driver to avoid

short circuits.



Figure 20: A 12V power adapter

4.5.7. Final fabricated prototype

Having sorted out the code and knowing the mechanism works, I put it all together within the outer body to see how it all works as a unit.

To make the outer body, I used wood because I couldn't afford the cost of using steel. To glue it all together I used wood glue, nails, and screws as they hold the wood together very well.

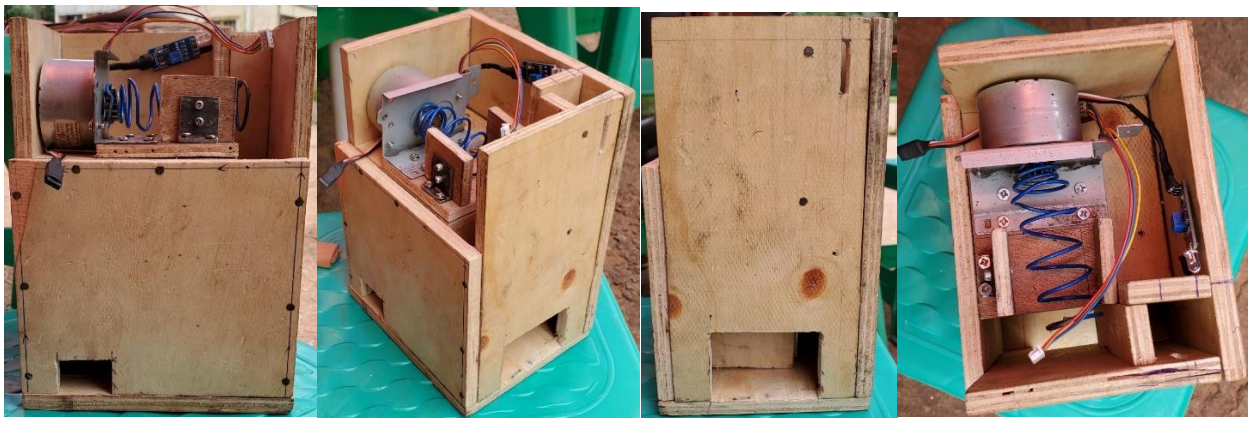


Figure 21: Final fabricated prototype

CHAPTER FIVE: RESULTS AND DISCUSSIONS

After fabrication was completed, the system was tested to check for performance as regards how efficient it is in dispensing the bottles, capacity as well as the dispensing time taken from when the user inputs the coin to pick the bottle.

The prototype has the following advantages;

- The overall cost of the prototype is very low in comparison with other machines in the market.
- The product occupies very less space i.e., 150 x 100 mm on the floor.
- The prototype is portable as it is small in size and can work on either direct power or battery power in case of blackouts.
- Availability of the products increases when installed around the place.
- The design and development of the prototype were tough though the maintenance is highly reduced.
- The machine consumes less power.

5.1. Dispensing

The coin is detected within a 24mm radius of the infrared sensor. Once detected the machine dispensed a product per coin input.

Since the coil spring was simply made from locally available materials its rotation is not free and therefore the product rub against the walls of the spring compartment sometimes causing a jamming of the products during dispensation.

The spring coil during rotation rattles on the walls of the spring compartment producing considerable noise.

The spring rotates for 5s then stops, this happens continuously even after dispensing the product.

So if the spring could hold more products say four, all four products would be dispensed at a single coin input. This could've been due to inaccuracies in the development of the code otherwise it's supposed to run for 5s and then stop the wait for the next coin input.

This, in turn, provides faster delivery of the products to the customers during peak time, and the unnecessary crowd near its location for example shops near the educational institutions, during examination season would be avoided with reduced human effort.

5.2. Capacity

The machine can hold one product due to the small holding torque provided by the motor since it's a small prototype and I was minimizing costs incurred in the fabrication of the machine. Therefore, this prototype can dispense a product at coin input.

5.3. Dispensing time

The dispensing system was programmed to dispense a product within 5 seconds. When tested from the time of inputting the coin, the machine was able to dispense a product within the programmed 5 seconds.

Therefore the machine provides easy and quick access to the products hence no delays are incurred.

5.4 Economic calculations

5.4.1 Assumptions made;

- The owner gets the product at shs 400 per bottle at wholesale price.
- The product being vended and sold to customers costs shs 500.
- The average number of products sold per day is 50.

The owner makes returns of shs 100 per bottle i.e., 25% per bottle.

5.4.2 Cost Estimation

The costs incurred in acquiring the components, fabrication, and miscellaneous expenses throughout the whole project to develop the prototype are summarized in the table below.

Number	Components	Cost (shs)
1.	Arduino UNO board	70,000
2.	L298N stepper motor driver	21,000
3.	M49SP-1 stepper motor (hired)	30,000
4.	Infrared sensor	10,000
5.	Spring	2,000
6.	Jumper wires	5,000
7.	Labor + material	70,000
8.	12V power adapter	30,000
9.	LED	2,000
10.	Coin	500
11.	Miscellaneous	100,000
12.	**Total**	**340,500**

Table 16: The cost estimation

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

To conclude, since I set this project, the idea of creating my very own vending machine fascinated me and I was excited to learn new skills that I would now be applying to something that works. It made me put all the Arduino coding into practice and see a result that I had never done before. The coding aspect of the project amused me and I am glad I challenged myself to learn how to code in my own time and do some hands-on research. This led me to explore all the different variations of a simple command and how it can be executed.

Implementation of this machine is a step towards future technology and it is a step to enter an eco-friendly world.

The Prototype function after extensive testing and modifications to original designs and components was not reasonably reliable per the design specification. Throughout testing, material choices became apparent problems regarding moving components. The shelving that movement components are attached to being made from wood led to some slight warping that caused binding and movement issues.

This machine is cheap and easy to use simply requiring input through the coin port. It is also immediate and fast in dispensing the products. The machine gives out one product at a time.

Most target specifications were achieved i.e., holding capacity of at least one product, dispensation within 5 seconds, and manufacturing cost as well as the operating voltage being below 12V.

The machine was constructed using locally available materials and therefore certain machine components differed from those within the designed mechanism.

The Vending Machine can be used for other fluids i.e., drinking water and juice. Can be used in small shops as an additional income for the shopkeeper.

As per the public requirement, a Coin operated vending machine is designed and fabricated, and should be tested in real-time conditions.

6.2. Challenges and Limitations

Since locally available materials were used in the construction, there was a challenge regarding the coil spring differing from the designed coil spring. This caused some delays in dispensing.

Due to the inability to purchase a coin acceptor since it was expensive, there was a challenge of the actual coin sensing given that now any coin could be sensed and hence a product dispensed.

The motor used didn't have a large torque enough to handle a certain quantity of products and hence causing disruptions within the dispensation.

The insertion of fake currency coins inside the currency collector could not be prevented, so the user can still get the product on insertion of any coin that fits in the coin slot.

In regards to the code, due to time constraints to meet deadlines for prototype delivery, and lack of experience dealing with Arduino programming and advanced functions, the choice to exclude the coin verification makes it easier for users to access the drinks with fake coins.

Some of the other challenges experienced throughout the project include;

- Difficulty in buying some components i.e., some electrical components such as the Mitsumi M49SP-1 stepper motor, L298N stepper motor driver, and Arduino UNO board components were ordered one month in advance and imported which was cheaper since they were rare and expensive to purchase in the shops that had them.
- During the testing of some electrical components such as the L298N stepper motor driver to check if it could drive the motor, this component short-circuited due to excess power before acquiring the 12V power adapter, which was replaced and still stopped working due to overheating that resulted from over staying on power. So, I purchased this component thrice
- During the development of the code, the computer crashed leading to the loss of my project work which included the project report, the code, and other important documents. The computer laboratories at the College of Engineering were closed thus making it difficult to get another computer to use since all my classmates had returned gone for holidays.
- Lastly, I was short of money since most of it had been used to pay for my tuition to be eligible to sit for my final examinations.

6.3. Recommendations

Multiple coin detection can be enabled and utilized. Since the coin acceptor (DG600F) is a 6-type coin detection system, multiple coin modes can be easily achieved. This would make detection and verification of the coins to avoid false coins.

RFID tag identification and reading can be developed to accept Money cards.

Arduino Mega 2560 is recommended rather than Arduino UNO for scaling up to bigger machines. It has 54 digital input/output pins, a 16 MHz crystal oscillator, and an ICSP header. It contains everything needed to support the microcontroller. The Mega 2560 board is compatible with most shields designed for the Uno.

A better design of the coil spring could be developed dependent on the locally available materials.

Stepper motors such as Mitsumi m49sp-3ka with much higher holding torque could be used to avoid the issue of failure to handle certain quantities of products loaded as well as the weight of the coil spring.

The machine can be redesigned for it to be aesthetically pleasing and for its better usability. This would provide a larger holding capacity that could be developed as well as give the possibility of holding different varieties of products given that users have preferences.

I did well however, the mechanics aspect of the vending machine did not operate as well as I could have made it work. It all came down to time management and if I had more time, I would improve a lot such as;

- Improve the outer body and make it more aesthetically pleasing.
- Improve the inner mechanism which is connected to the stepper motor so that the products come out with better flow.
- I would have improved the cable management and made it more effective.

All in all, I have learned a lot from this project and was happy with my skills improvement. It was a challenging and stimulating project but it was worth the stress.

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APPENDIX

Table 10–4

Constants A and m of $S_{ut} = A/d^m$ for Estimating Minimum Tensile Strength of Common Spring Wires

Source: From *Design Handbook*, 1987, p. 19. Courtesy of Associated Spring.

Material	ASTM No.	Exponent m	Diameter, in	A, kpsi · in^m	Diameter, mm	A, MPa · mm^m	Relative Cost of Wire
Music wire*	A228	0.145	0.004–0.256	201	0.10–6.5	2211	2.6
OQ&T wire†	A229	0.187	0.020–0.500	147	0.5–12.7	1855	1.3
Hard-drawn wire‡	A227	0.190	0.028–0.500	140	0.7–12.7	1783	1.0
Chrome-vanadium wire§	A232	0.168	0.032–0.437	169	0.8–11.1	2005	3.1
Chrome-silicon wire‖	A401	0.108	0.063–0.375	202	1.6–9.5	1974	4.0
302 Stainless wire#	A313	0.146	0.013–0.10	169	0.3–2.5	1867	7.6–11
		0.263	0.10–0.20	128	2.5–5	2065	
		0.478	0.20–0.40	90	5–10	2911	
Phosphor-bronze wire**	B159	0	0.004–0.022	145	0.1–0.6	1000	8.0
		0.028	0.022–0.075	121	0.6–2	913	
		0.064	0.075–0.30	110	2–7.5	932	

Table 10–1

Formulas for the Dimensional Characteristics of Compression Springs. (N_a = Number of Active Coils)

Source: From *Design Handbook*, 1987, p. 32. Courtesy of Associated Spring.

	Type of Spring Ends			
Term	Plain	Plain and Ground	Squared or Closed	Squared and Ground
End coils, N_e	0	1	2	2
Total coils, N_t	N_a	$N_a + 1$	$N_a + 2$	$N_a + 2$
Free length, L_0	$pN_a + d$	$p(N_a + 1)$	$pN_a + 3d$	$pN_a + 2d$
Solid length, L_s	$d(N_t + 1)$	dN_t	$d(N_t + 1)$	dN_t
Pitch, p	$(L_0 - d)/N_a$	$L_0/(N_a + 1)$	$(L_0 - 3d)/N_a$	$(L_0 - 2d)/N_a$

Decimal Equivalents of Wire and Sheet-Metal Gauges* (All Sizes Are Given in Inches) *(Continued)*

Name of Gauge:	American or Brown & Sharpe	Birmingham or Stubs Iron Wire	United States Standard†	Manufacturers Standard	Steel Wire or Washburn & Moen	Music Wire	Stubs Steel Wire	Twist Drill
Principal Use:	Nonferrous Sheet, Wire, and Rod	Tubing, Ferrous Strip, Flat Wire, and Spring Steel	Ferrous Sheet and Plate, 480 lbf/ft³	Ferrous Sheet	Ferrous Wire Except Music Wire	Music Wire	Steel Drill Rod	Twist Drills and Drill Steel
18	0.040 30	0.049	0.05	0.047 8	0.047 5	0.041	0.168	0.169 5
19	0.035 89	0.042	0.043 75	0.041 8	0.041 0	0.043	0.164	0.166 0
20	0.031 96	0.035	0.037 5	0.035 9	0.034 8	0.045	0.161	0.161 0
21	0.028 46	0.032	0.034 375	0.032 9	0.031 7	0.047	0.157	0.159 0
22	0.025 35	0.028	0.031 25	0.029 9	0.028 6	0.049	0.155	0.157 0
23	0.022 57	0.025	0.028 125	0.026 9	0.025 8	0.051	0.153	0.154 0
24	0.020 10	0.022	0.025	0.023 9	0.023 0	0.055	0.151	0.152 0
25	0.017 90	0.020	0.021 875	0.020 9	0.020 4	0.059	0.148	0.149 5
26	0.015 94	0.018	0.018 75	0.017 9	0.018 1	0.063	0.146	0.147 0
27	0.014 20	0.016	0.017 187 5	0.016 4	0.017 3	0.067	0.143	0.144 0
28	0.012 64	0.014	0.015 625	0.014 9	0.016 2	0.071	0.139	0.140 5
29	0.011 26	0.013	0.014 062 5	0.013 5	0.015 0	0.075	0.134	0.136 0
30	0.010 03	0.012	0.012 5	0.012 0	0.014 0	0.080	0.127	0.128 5
31	0.008 928	0.010	0.010 937 5	0.010 5	0.013 2	0.085	0.120	0.120 0
32	0.007 950	0.009	0.010 156 25	0.009 7	0.012 8	0.090	0.115	0.116 0
33	0.007 080	0.008	0.009 375	0.009 0	0.011 8	0.095	0.112	0.113 0
34	0.006 305	0.007	0.008 593 75	0.008 2	0.010 4		0.110	0.111 0
35	0.005 615	0.005	0.007 812 5	0.007 5	0.009 5		0.108	0.110 0
36	0.005 000	0.004	0.007 031 25	0.006 7	0.009 0		0.106	0.106 5
37	0.004 453		0.006 640 625	0.006 4	0.008 5		0.103	0.104 0
38	0.003 965		0.006 25	0.006 0	0.008 0		0.101	0.101 5
39	0.003 531				0.007 5		0.099	0.099 5
40	0.003 145				0.007 0		0.097	0.098 0

*Specify sheet, wire, and plate by stating the gauge number, the gauge name, and the decimal equivalent in parentheses.

Mechanical Properties of Some Spring Wires

Material	Elastic Limit, Percent of S_{ut} Tension	Torsion	Diameter d, in	E Mpsi	E GPa	G Mpsi	G GPa
Music wire A228	65–75	45–60	<0.032	29.5	203.4	12.0	82.7
			0.033–0.063	29.0	200	11.85	81.7
			0.064–0.125	28.5	196.5	11.75	81.0
			>0.125	28.0	193	11.6	80.0
HD spring A227	60–70	45–55	<0.032	28.8	198.6	11.7	80.7
			0.033–0.063	28.7	197.9	11.6	80.0
			0.064–0.125	28.6	197.2	11.5	79.3
			>0.125	28.5	196.5	11.4	78.6
Oil tempered A239	85–90	45–50		28.5	196.5	11.2	77.2
Valve spring A230	85–90	50–60		29.5	203.4	11.2	77.2
Chrome-vanadium A231	88–93	65–75		29.5	203.4	11.2	77.2
A232	88–93			29.5	203.4	11.2	77.2
Chrome-silicon A401	85–93	65–75		29.5	203.4	11.2	77.2
Stainless steel							
A313*	65–75	45–55		28	193	10	69.0
17-7PH	75–80	55–60		29.5	208.4	11	75.8
414	65–70	42–55		29	200	11.2	77.2
420	65–75	45–55		29	200	11.2	77.2
431	72–76	50–55		30	206	11.5	79.3
Phosphor-bronze B159	75–80	45–50		15	103.4	6	41.4
Beryllium-copper B197	70	50		17	117.2	6.5	44.8
	75	50–55		19	131	7.3	50.3

Table 17: mechanical properties of some spring wires