Design of a Electric Tiller

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Contents

1 Introduction

Electric Tillers are used to cultivate land, to prepare it for planting. The majority however are powered by internal combustion engines which are costly exhausts pollutants.
This has motivated the design of efficient Electric tiller.

2 Agricultural Cultivation Principles

2.1 Soil

The physics of soil is a complex phenomenon that allows particles to behave like a fluid in terms of movement and solid when enough particles gather in one place. Unlike fluids, which can be mathematically represented using the Navier-Stokes equations, the behavior of soil is a complex topic that is still under research. Characteristics of soil, such as particle size, shape, and texture, influence its hardness and its capacity for transportation (G. Ranjan, 2001).
There are many different kinds of soil, with the most common types being:

Clay Soil : Clay Soil: It is typically brown in appearance and is a fine-textured, grainy soil. It has the smallest particle size of 0.002mm or less in diameter. Clay soil is smooth and lumpy, and it dries slowly, becoming very firm. While it can store a large amount of water and is rich in minerals, it allows water to travel very slowly, reducing the rate of water drainage. For this reason, it is not suitable for farming.

Figure 1: Image of clay soil

Silt Soil: Silt soil is light, granular, and feels powdery when dry and slippery when wet. It often consists of a mixture of sand and clay. It is composed of small to medium-sized particles ranging from 0.002mm to 0.06mm in diameter. Silt soil has a moderate water-holding capacity and maintains a good balance between water drainage and retention. It is also rich in minerals. However, its biggest drawback is that it can easily wash away in the rain. Additionally, it becomes very compact when wet, reducing its aeration.

Sand Soil: This type of soil is light, granular, and feels gritty. It easily flows like a fluid due to its particle size and texture, which range from 0.05mm to 2mm in diameter. Sand soil is well-aerated

Figure 2: Image of silt soil

and has good water drainage, allowing for the exchange of gases and atmosphere. However, it has low water-holding capacity due to its particle size, causing water to dry quickly. It is also more susceptible to soil erosion, making it unsuitable for farming.

Figure 3: Image of sand soil

Loam Soil: Loam soil is crumbly and granular, offering a good balance between grittiness and stickiness. It is composed of a mixture of sand, silt, and clay, benefiting from the advantages of each soil type. Loam soil is fertile, workable, contains a good amount of nutrients, and allows for optimal root penetration. For these reasons, it is the preferred soil for farming.
Soil preparation is one of the initial steps that a farmer must undertake before engaging in farming. This crucial process involves several steps, including:

- **Testing Soil**: Before planting any crops, it's essential to test the soil to determine its nutrient content, pH levels, and other relevant characteristics. Soil testing helps farmers understand the specific needs of their soil and what amendments may be required.

Figure 4: Image of loam soil

- **Soil Amending**: Based on the results of soil testing, farmers may need to amend the soil to optimize its conditions for plant growth. This can involve adding organic matter (such as compost or manure), adjusting pH levels, and supplementing with necessary nutrients through fertilizers.
- **Watering**: Adequate water management is essential for successful crop growth. Farmers need to ensure that the soil has the right moisture content for the specific crops they intend to cultivate. Proper irrigation methods are crucial for maintaining consistent soil moisture.
- **Tillage**: Depending on the farming method and crop type, tillage may be necessary. Tillage involves preparing the soil by plowing, cultivating, or otherwise breaking up the ground to create a suitable seedbed. However, conservation tillage practices are increasingly used to minimize soil disruption.

3 Existing Cultivating Mechanisms

Tilling is the process of breaking up and loosening soil to prepare it for planting. Various types of machinery can be used. To decide on the appropriate machinery, one needs to consider the following factors:

Capacity: This refers to the amount of work a machine can accomplish per hour on a particular area. It can be calculated using the equation:

$$C_a = \frac{v \cdot w \cdot n_f}{100}$$

Where v = travel speed $\frac{km}{h}$, w = machine working width (m), n_f = field efficiency(int) C_a = Capacity field Efficiency.

Field Efficiency: This represents the theoretical amount of time required to execute field operations and can be calculated using the formula:

$$T_t = \frac{A}{C_a}$$

Where T_t is the time required. A is the area to be processed. C_a is the field capacity. Below are some modern cultivating tools and machinery.

Hoe: A hoe is a simple and effective tool that is used in domestic and medium-sized environments. The head, which also acts as the pivot, is the working principle of the hoe. It is bladed to increase the amount of pressure so that it can cut through soil effectively. It is connected to the shaft at a 90-degree angle, from which the load is applied.

Figure 5: Hoe

Sub-soiler: Also known as a flat-lifter or chisel plow, it is a deep soil cultivation tool used for breaking soil at depths of approximately 15 to 7 inches.
Its main components include a shank that penetrates the soil, a blade at the lower end for fracturing and compacting soil layers. Typically, it is mounted onto a tractor, and a control mechanism is adjusted to set the desired depth. Finally, the tractor travels at a steady speed over the working area.

Figure 6: Subsoiler

3.1 Non-Electric Tillers

Moldboard Plow: This equipment dates back to ancient times when it was used to turn sod and prepare fields for crops. It can cut at depths between 15 to 30 inches and is used to cut, lift, and partly turn the soil at an angle during the initial cultivation preparation stage.

It consists of the moldboard, a curved metal plate that turns and lifts the soil, and a Coulter, which can be a blade or a sharp disk.

Similar to a Subsoiler, it is mounted on a tractor, and the plow's depth is adjusted and positioned at an angle to slice through the soil.

Figure 7: Moldboard Plow

Disc Harrow: Unlike the tillers mentioned above, the disc harrow is primarily used for secondary tilling to cut out weeds and crop residues. It is also employed for leveling and preparing seedbeds. The depth and operations depend on the specific use; however, it typically cuts within the range of 7.5 cm to 15 cm.

It is composed of circular and concave disc blades mounted on a horizontal shaft. The disc blades are arranged in gangs that are coupled together to till the soil.

The working principle is similar to other machinery; the disc harrow is mounted to a tractor and positioned at an angle along the edge of the field to drive the harrow in vertical overlapping intervals.

Figure 8: Disc Harrow

Roller-Packer: Also known as a land presser, cultipacker, or land roller, it is used as a secondary tillage implement, typically in dry seasons, to compact and compress soil after plowing. It seals the top millimeters of worked soil and breaks down clods, thereby leveling the land.

Its main component is the heavy roller, which is cylindrical in shape and is often made of steel or cast iron. Attached to the roller are evenly spaced wheels that create pressure points for soil compaction.

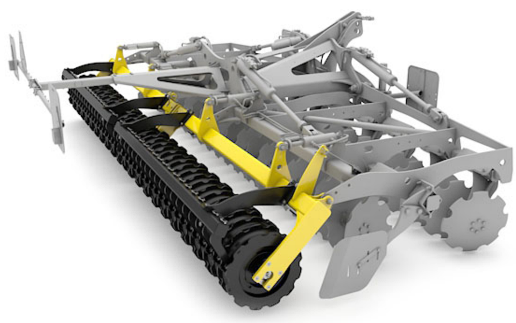


Figure 9: Roller Packer

Tractor-Mounted Tiller: As the name suggests, this implement comprises a frame and rotating blades mounted to a tractor for primary cultivation. The depth of cutting can vary according to its design. Common uses include seed preparation, leveling, weed control, and soil aeration.

The rotating blades are attached to a horizontal shaft, which is supported by the frame.
Although this type of tiller is versatile and highly efficient, its biggest drawback is the need for fuel consumption and surface disturbance.

Figure 10: Tractor Mounted Tiller

3.2 Commercial Electric Tillers

LawnMaster TE138W1 : measures 56cm in length, 45.7cm in width, and 32cm in height. It is powered by a 13.5A motor and features a safety lock that can be engaged by pulling the trigger upwards to start it.

The rotor is equipped with 6 steel blades and 6 durable blades capable of effectively cutting a width of 40cm and a depth of 22cm at a rotational speed of 390 RPM.

The total weight of LawnMaster is approximately 11kg.

Figure 11: LawnMaster

Bilt Hard: measuring 72cm in length, 44cm in width, and 45cm in height, this machine differs from the LawnMaster in that it is powered by gas. It features a 22fl.oz fuel tank capable of producing 1.36hp.

The rotor is equipped with 4 sturdy tiller steel blades, and each blade possesses 12 tines, allowing it to cut through a width and depth of 22cm while rotating at a maximum speed of 222 rpm.

The total weight of this machine is approximately 13kg and it requires coding into an electric plug.

Figure 12: Bilt Hard Gas Tiller

Earthwise TC70125: measures 135cm in length, 31cm in width, and 45cm in height. It is equipped with a 12.5Amp electric motor designed for cultivating small to medium-sized gardens.

Featuring 6 tines, it can effectively cultivate a working width of 40cm and a depth of 20cm. It requires connection to an electrical plug for power.

This garden tool weighs approximately 9kg and is priced at $170.

Figure 13: Earthwise TC70125

4 Battery Technology

4.1 Theory

A battery is a device that converts chemical energy into electrical energy through an electrochemical electrolysis process.

Electricity is nothing more than the flow of electrons in a wire. In direct current (DC), electrons flow in one direction, while in alternating current (AC), electrons alternate back and forth, creating a charge.

The negative electrode is called the anode. This is where oxidation occurs during the discharge phase of the battery. A material such as lithium-carbon releases lithium ions and carbon.

As shown in the equation above, lithium ions are extracted from the anode, which is normally made out of graphite, and move through the solvent to the cathode.

The cathode is the positive electrode where reduction takes place. It is typically made of a metal oxide. For instance, lithium cobalt oxide discharges lithium ions and copper oxide.

4.2 Primary Batteries

Primary batteries are non-rechargeable cells whose electro-chemical reactions cannot be reversed. For instance, in alkaline batteries, zinc from the negative electrode discharges hydrogen ions, resulting in the formation of zinc oxide, water, and electrons.

Meanwhile, manganese dioxide from the positively charged cathode reacts with water to produce negative electrons, ultimately depleting the charge. This process cannot be easily reversed.

Zinc Carbon Battery: These are dry galvanic cells, the oldest type, and were the first to be created in 1866 by George Leclanché. The anode is made from zinc metal, where electrons become positively charged during the oxidation phase. The cathode is made of manganese dioxide (MnO_2) with a small amount of ammonium chloride (NH_4Cl) electrolyte paste.
The manganese dioxide accepts electrons that are released at the anode.

The equations are as follows:

$$\begin{aligned}
\text{Anode:}\quad & Zn \rightarrow Zn^{2+} + 2e^- \\
\text{Cathode:}\quad & MnO_2 + H^+ + e^- \rightarrow MnO(OH) \\
\text{Overall:}\quad & Zn + MnO_2 + NH_4Cl \rightarrow ZnCl_2 + MnO(OH) + H_2O
\end{aligned}$$

Zinc reacts with manganese dioxide and ammonium chloride to produce zinc chloride, manganese hydroxide, and water. It's worth noting that the water is given out in the form of vapor. Additionally, the battery has a sealed design, preventing external reactions, and materials can be reabsorbed by the material.

Mercury Cell: Mercury batteries, also known as Ruben Mallory, mercuric oxide batteries, or mercuric-oxygen batteries, offer the advantage of a long shelf life and a steady voltage output. They use mercury compounds (Hg) as the cathode and zinc (Zn) at the anode, with potassium hydroxide (KOH) serving as the electrolyte.
They were widely employed in various small and large appliances, including watches, cameras, and calculators.

The chemical equations for the cell reactions are as follows:

Anode Reaction:

$$Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$$

Cathode Reaction:

$$HgO + H_2O + 2e^- \rightarrow Hg + 2OH^-$$

The overall reaction can be summarized as:

$$Zn + HgO \rightarrow ZnO + Hg$$

However, it's important to note that mercury cells have been discontinued and are no longer used due to the toxic nature of mercury, which poses environmental and health risks.

Alkaline Cell: As the name implies, it has a pH above 7. Manganese dioxide makes up the cathode, the positive electrode, while the anode, which is negatively charged, is made of zinc metal. There is a separator between the anode and cathode to prevent direct contact while allowing the movement of ions between them. Additionally, the electrolyte is comprised of a potassium hydroxide solution, which serves as a solvent that allows the flow of ions.

The discharge reactions are as follows:

Anode Reaction (Oxidation):

$$Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$$

Cathode Reaction (Reduction):

$$MnO_2 + H_2O + 2e^- \rightarrow Mn_2O_3 + OH^-$$

The overall equation for the cell reaction is:

$$Zn + MnO_2 \rightarrow ZnO + Mn_2O_3$$

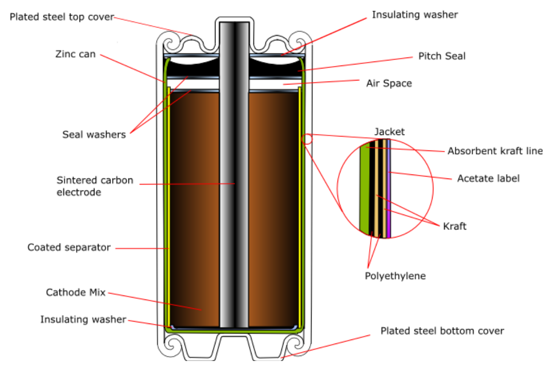


Figure 14: Diagram of a Zinc carbon diagram

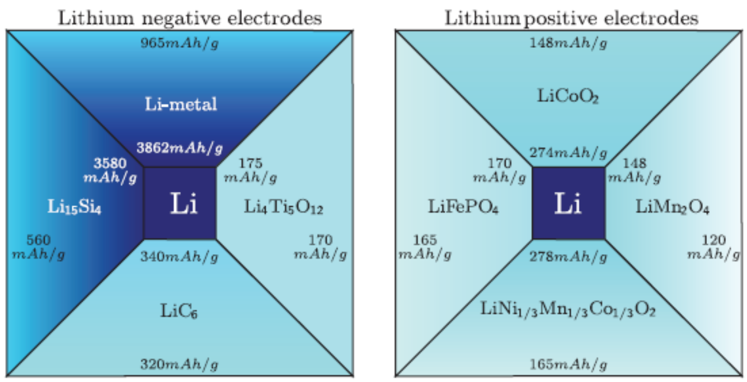
4.3 Secondary Batteries

Rechargeable batteries are those that can be discharged and recharged multiple times without significant degradation, offering a long-term and sustainable energy storage solution.

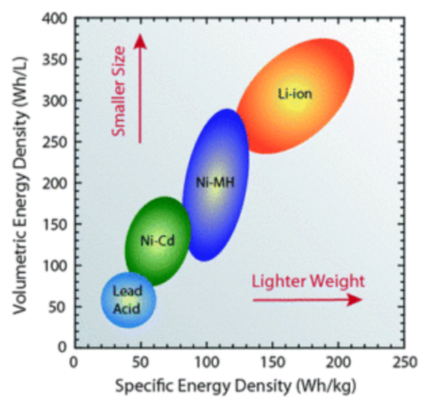
Batteries can be connected either in series or parallel. In a series connection, the total voltage output is equal to the sum of the individual cell voltages. In contrast, a parallel connection provides the greatest capacity, thereby increasing the current.

Batteries can be classified as either wet or dry. If the electrolyte is in the form of a paste, the cell is considered dry. Conversely, if the electrolyte is a liquid solution, then it is a wet cell.

Different chemical elements and compounds give different characteristics of battery performance.



(a)



(b)

Figure 15: Image of showing energy densities chemical elements

As shown from above, lithium has has the highest energy density to weight ratio.

Voltage : Voltage is the energy required per unit charge. It represents the energy needed to move a unit of positive charge from one point to another and signifies the potential energy difference between these two points, thereby quantifying the force that drives an electric charge. Voltage is also related to the electric field strength within a circuit.

Current : Current is the flow of charged particles, representing the quantity of charge passing through a point in a unit of time. It is also described as the rate of electron movement through a conductor, similar to flow rate in a fluid system. Current is responsible for the transfer of electric energy within a circuit.

Internal Resistance: This property refers to the electrode's inherent material resistance that opposes the flow of current within the battery, leading to inefficiencies in energy transfer.

Shelf Life: This is the duration for which a battery can retain its charge before it becomes disposable or no longer functional. Longer shelf life is desirable for batteries used in applications where infrequent use is common.

State of Charge (SOC): SOC is a measure of the percentage of a battery's capacity that has been discharged, expressed as a percentage of its maximum capacity. It provides insight into how much charge remains in the battery at any given time.

Cut-off Voltage: This refers to the minimum allowed voltage at which a battery is considered fully discharged. It's a critical parameter to prevent over-discharging, which can damage batteries and reduce their lifespan.

Energy (Ah) / Nominal Capacity (C-rate): This parameter represents the battery's energy capacity, typically measured in ampere-hours (Ah). The C-rate indicates the rate at which the battery is charged or discharged relative to its nominal capacity. Higher C-rates allow for faster charging and discharging but may affect the battery's overall performance and lifespan.

Nickel-Cadmium Cell: **Nickel-Cadmium**: Nickel-Cadmium (NiCd) cells are high-power, high-density rechargeable batteries. They can be manufactured in various sizes and capacities, offering a good cycle life and providing a consistent voltage output. NiCd batteries are capable of withstanding high discharge rates and efficient charging, making them suitable for various types of appliances, including emergency lighting and portable electronics.

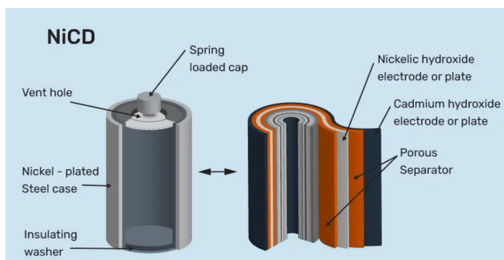


Figure 16: Cut-out diagram of a Nickel-Cadmium Battery

The cathode is composed of nickel oxide (NiOOH), while the anode consists of metallic cadmium (Cd). The commonly used electrolyte is potassium hydroxide (KOH), which facilitates the movement of ions.
The discharge reactions are as follows:

At the Anode (Oxidation):

$$Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$$

At the Cathode (Reduction):

$$NiOOH + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$$

The overall combination of these reactions is:

$$Cd + NiOOH \rightarrow Cd(OH)_2 + Ni(OH)_2$$

Due to the toxicity of cadmium, which poses health and environmental risks, NiCd batteries have been largely replaced by more environmentally-friendly options such as Lithium-ion (Li-ion) and Nickel-Metal Hydride (NiMH) batteries.

(a) (b)

Figure 17: Image of rechargeable NiCD batteries

Nickel Metal Hydride: Nickel Metal Hydride (NiMH) batteries represent an improvement over Nickel-Cadmium (NiCd) batteries, offering a good balance between energy density, environmental friendliness, and cost-effectiveness. The cathode is composed of nickel oxyhydroxide (NiOOH), while the anode is made of a metal that's a hydrogen-absorbing alloy, serving as the source of electrons. The electrolyte used is potassium hydroxide (KOH).

The discharge reactions occur as follows:

Anode Reaction (Oxidation):

$$MH + OH^- \rightarrow M + H_2O + e^-$$

Cathode Reaction (Reduction):

$$NiOOH + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$$

The overall discharge equation is:

$$MH + NiOOH \rightarrow M + Ni(OH)_2$$

The charging reactions are as follows:

Anode Reaction (Oxidation):

$$M + H_2O + e^- \rightarrow MH + OH^-$$

Cathode Reaction (Reduction):

$$Ni(OH)_2 + OH^- \rightarrow NiOOH + H_2O + e^-$$

These reactions allow for the charging of NiMH batteries.

Lithium Ion (Li-ion): are modern rechargeable batteries that offer the same energy production as lithium-metal (NiMH) batteries but are approximately 20% to 35% lighter in weight. They possess the highest energy density and capacity, making them the most practical choice for various applications.

The electrolyte used in Li-ion batteries is typically lithium salt, the anode is typically composed of graphite, and the cathode consists of lithium metal oxide or phosphate compounds.

The discharge reactions occur as follows:

Anode Reaction

$$LiC_6 \rightarrow C_6 + Li^+ + e^-$$

Cathode Reaction

$$LiCoO_2 + Li^+ + e^- \rightarrow Li_2CoO_2$$

Figure 18: Image of lithium battery in a phone

(a) Lithium Laptop Battery (b) Inside of Lithuim battery with cells

Figure 19: Image of rechargeable NiCD batteries

These reactions facilitate the discharge of Li-ion batteries, providing power for various applications.

Lithium Iron Phosphate (LiFePO4): also known as LFP batteries, offer distinct advantages over traditional lithium-ion batteries. They are renowned for their high energy density, extended cycle life, and remarkable safety features, primarily due to their stable chemical reactions that prevent overheating or fire hazards.

LiFePO4 batteries find valuable applications in various fields, including:
Electric Vehicles (EVs): LiFePO4 batteries power electric vehicles, providing reliable energy storage and a longer cycle life compared to conventional lithium-ion batteries.

Renewable Energy : They are employed in renewable energy systems, such as solar setups and wind energy storage, as an efficient and durable energy storage solution.
Portable Electronics: LiFePO4 batteries are used in portable electronic devices, ensuring a safe and long-lasting power source for everyday use.

The chemical reactions within LiFePO4 batteries contribute to their performance and safety:

Discharge Reaction (Power Generation):
At the anode (discharge), lithium ions (Li+) are released from the anode material (usually graphite) and migrate to the cathode. Simultaneously, electrons are generated at the anode:

$$C + LiFePO_4 \rightarrow Li_xC_6 + LiFePO_4$$

Charge Reaction (Recharging): At the cathode (charge), lithium ions (Li+) are received from the anode and stored in the cathode material (LiFePO4). During this process, electrons are consumed at the cathode:

$$Li_xC_6 + LiFePO_4 \rightarrow C + LiFePO_4$$

These reactions involve the movement of lithium ions (Li+) between the anode and cathode, facilitating the release and storage of electrical energy.

The anode is typically made of carbon, such as graphite, which produces lithium ions during discharge.

The cathode consists of lithium iron phosphate (LiFePO4), and a separator and electrolyte made of salt are integral components of LiFePO4 batteries, ensuring their safe and efficient operation.

LiFePO4 batteries have become a preferred choice for applications that demand a high level of safety, reliability, and performance while also prioritizing environmental sustainability.

(a) 12 Volts 200Ah LiFePO4

(b) LiFePO4 cells stacked to make battery pack for an EV

Figure 20: Image of rechargeable Lithium Iron Phosphate

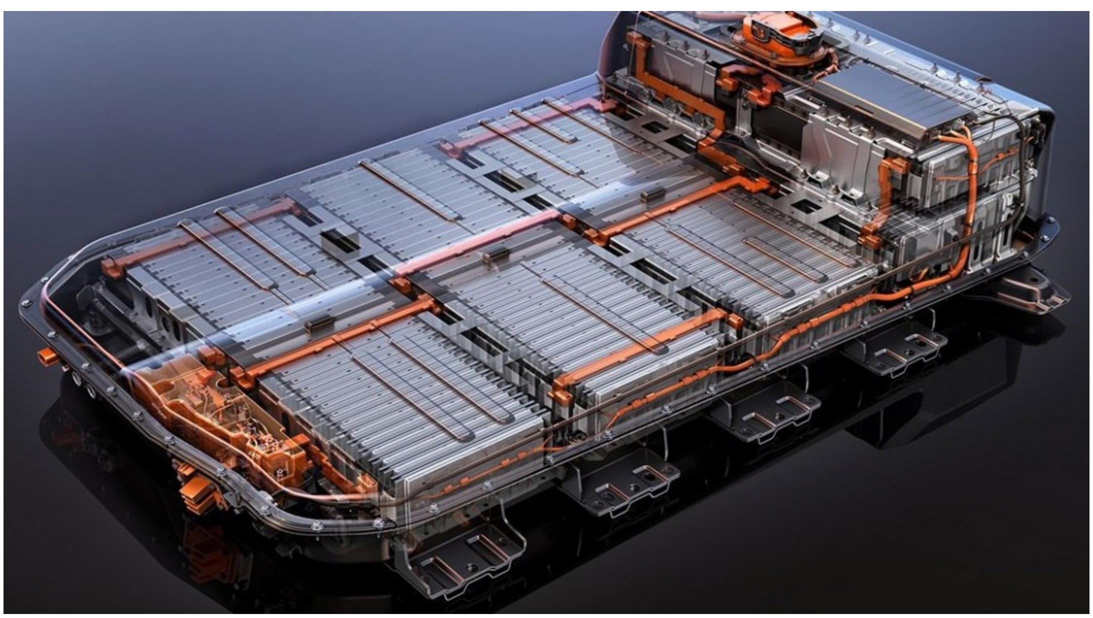


Figure 21: Diagram of a Zinc carbon diagram

5 Battery Design

According to Kirchhoff's current law, the sum of all currents entering a node is equal to current of all nodes, exiting the node.
According to Kirchhoff's voltage law, the algebraic sum around a loop must be equal to zero.

$$\sum V = V_1 + V_2 + V_3 + \ldots = 0$$

Total resistance , would be

$$R_{eq} = R_1 + R_2 + \cdots + R_n$$

According to ohms law, the current is directly proportional to the voltage. By combining the above two equations;

$$I = \frac{V_{total}}{R_{eq}}$$

This conclusion shows that in **series current** remains constant but **voltage** increases.
whilst in textbfparallel, **voltage** remains the same, whilst **current** increases.
Therefore, batteries can cleverly configured in parallel and series to make for the right total **voltage** and total **current**.

For a configuration with a voltage rating of 72V and a current rating of 39A, one possible arrangement is to divide these values into three packs, resulting in 24V and 13A for each pack. Considering a standard 18650 battery with a voltage of 3.7V and a capacity of 9900mA, the configuration would require arranging 72/3.7V batteries in series and stacking them in rows of 39A/10A. This leads to an approximate configuration of 20S/4P, yielding a total power output of 80kW.

5.1 Battery Management System

The Battery Management System (BMS) stands as the most critical and essential component within a battery system, diligently monitoring and managing the performance, state, and health of individual cells.
Its responsibilities include:

- **Voltage Monitoring:** Ensures that each cell's voltage lies within the threshold; no cell should be undercharged or overcharged.
- **Cell Balancing:** Maintains constant or close-to-constant voltage variations within batteries by redistributing energy, hence preventing overcharge.
- **Overcharge/Discharge Protection:** Performs operations such as cutting off charging if the limit is set, thereby preventing overcharging or overdischarging.
- **State of Charge and State of Health Monitoring:** Measures the amount of remaining battery capacity as well as health by assessing capacity fade, internal resistance, and other mechanisms.
- **Temperature Monitoring and Control:** Monitors and controls the temperature of each cell to ensure its temperature is consistent within safe limits.

(a) 11$ B0CGVM87VD BMS for 13S Battery for 48V/54.6V from Amazon

(b) 77$ BMS with Bluetooth

Figure 22: Images of battery management systems boards

5.1.1 Battery Management System Circuit Configuration

The overall functionality of the circuit board of the Battery Management System (BMS) is to ensure safety and reliability. The inputs encompass cell voltage, overall pack voltage, temperature, and current. Utilizing an algorithm, the BMS calculates and outputs the State of Charge (SOC). More advanced systems may also provide outputs for State of Health (SOH) and Safety Operating Envelope (SOE). Additionally, through the use of LEDs or other mechanisms, the BMS can indicate and output faults.

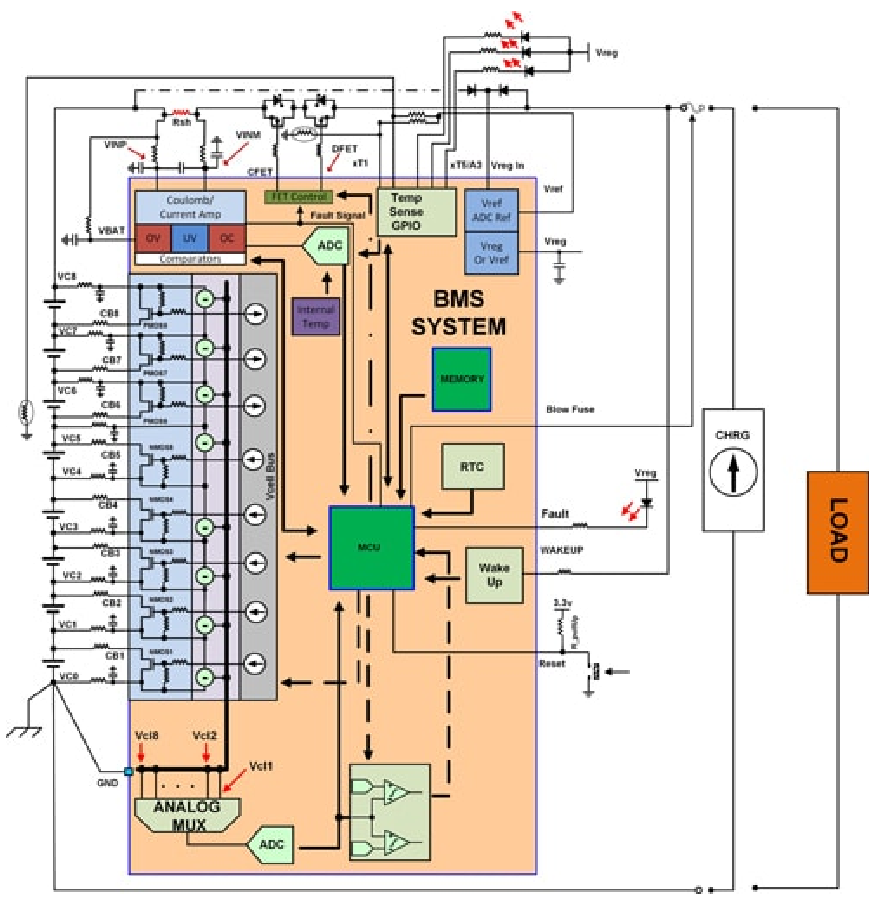
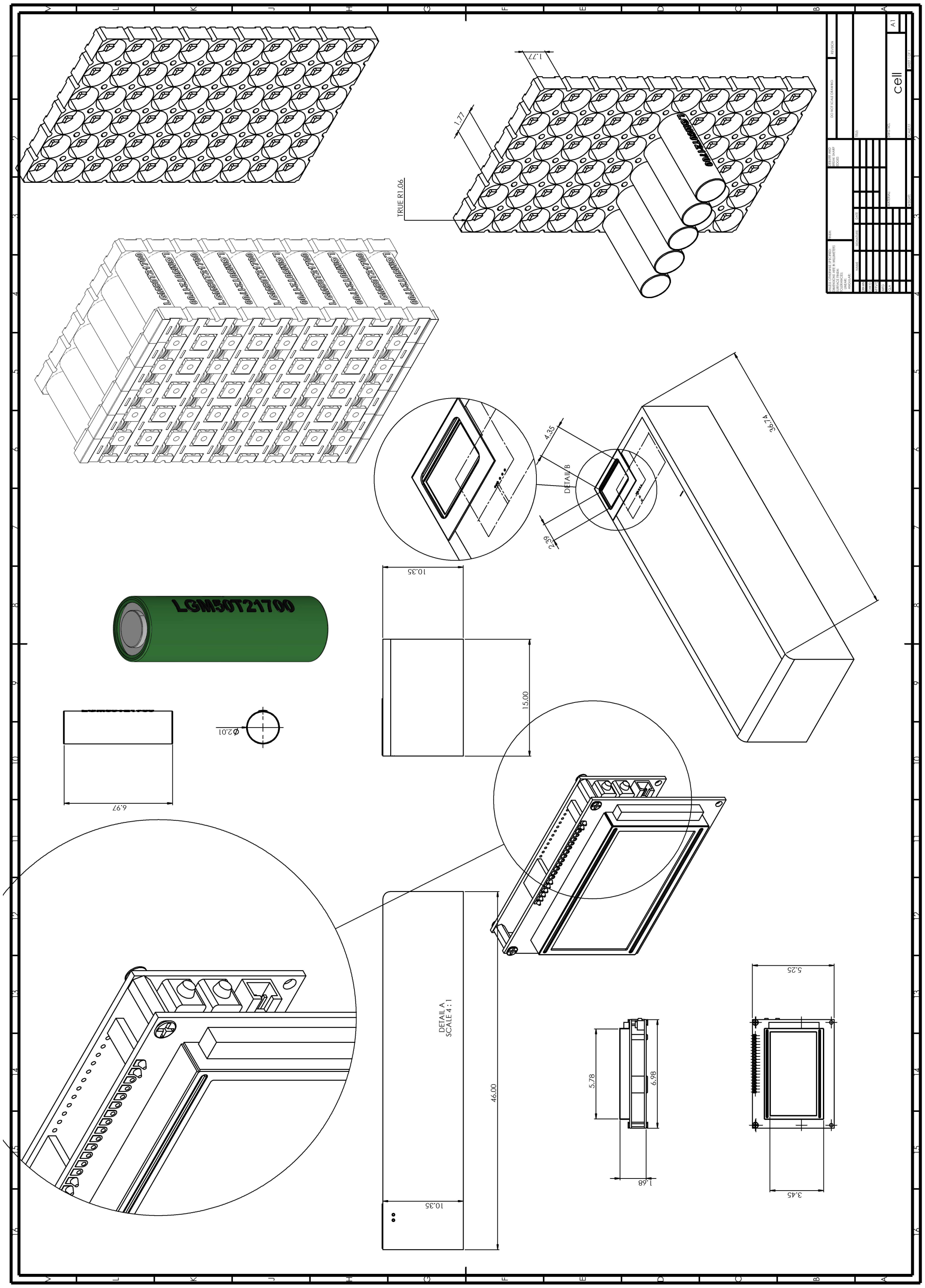


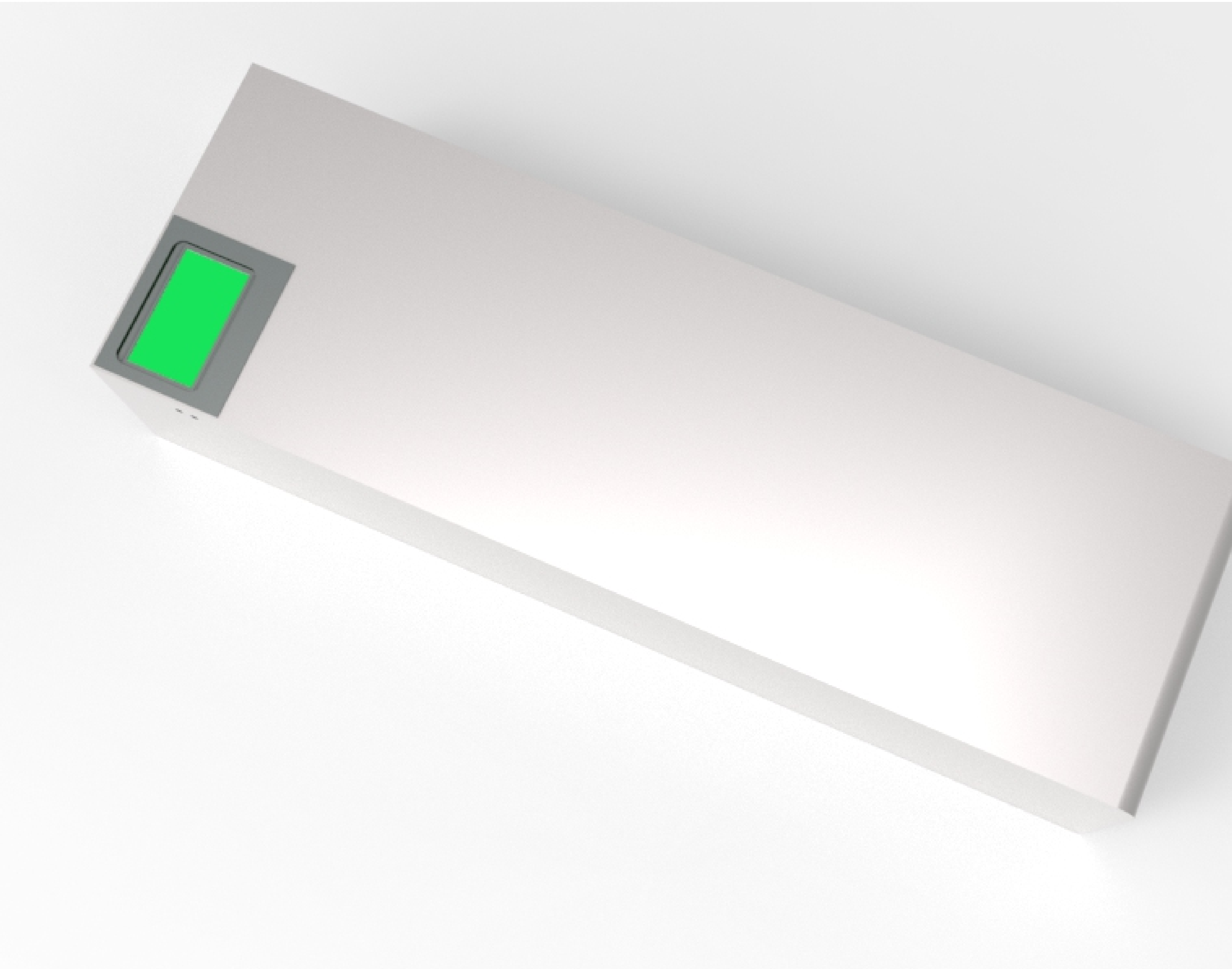
Figure 23: Battery Circuit Configuration

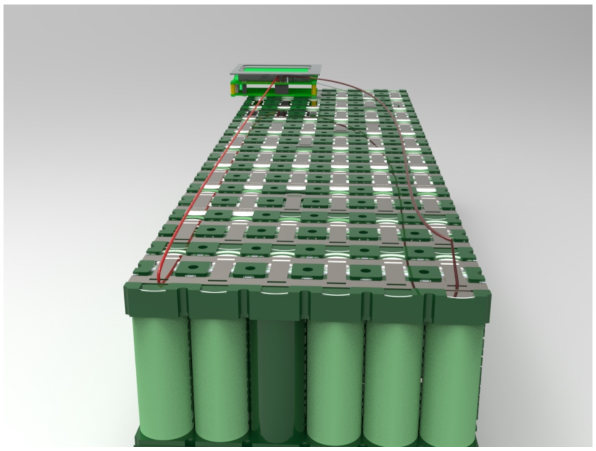
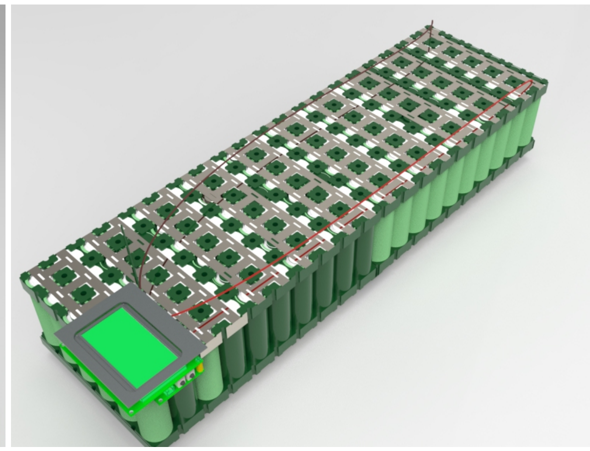
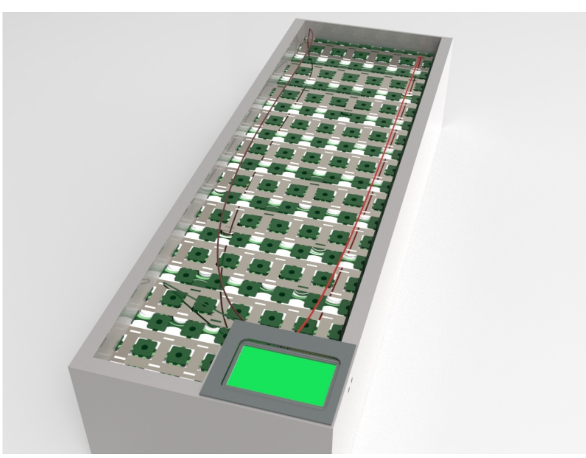
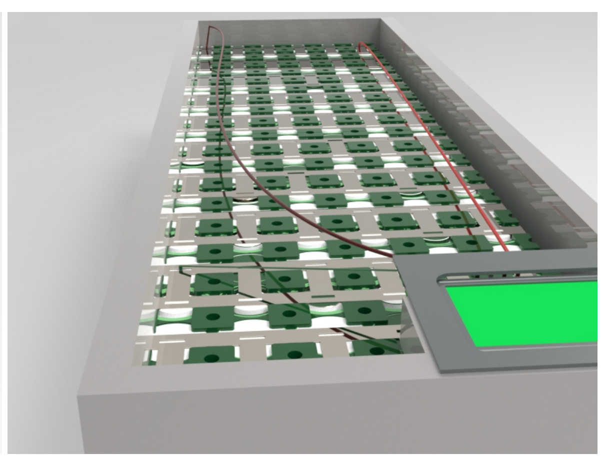
The FET driver functional block can connect or isolate the battery pack between the load and charger, it allows the battery pack to operate while charging.

5.2 Technical Drawings



5.3 CAD Renders



6 Motors

6.1 Theory

As industries increasingly prioritize sustainability, electric motors have gained favor over traditional engines due to their efficiency and ease of maintenance.
The discovery of electric motors can be attributed to pioneers such as Zenobe Gramme, who stumbled upon the concept accidentally. Gramme's inadvertent connection of an AC generator to a battery resulted in a fascinating phenomenon—rotation. This serendipitous event sparked curiosity and further exploration.

Another significant contributor to the understanding and development of electric motors was Michael Faraday. Through extensive experimentation and research, Faraday provided valuable insights that contributed to both the theoretical foundations and practical designs of electric motors.

Electric motors serve as remarkable devices that transform electrical energy into mechanical energy. They can be categorized into two primary types: DC Motors and AC Motors.

DC Motors, or Direct Current Motors, operate on a continuous flow of electric current, resulting in consistent rotational motion. AC Motors, or Alternating Current Motors, derive their power from periodically changing electric currents, leading to versatile applications and capabilities.

The physics behind electric motors involves the interaction between magnetic fields and electric currents. This interplay generates the mechanical force needed for motion. Understanding this fundamental principle is essential to comprehend the inner workings of these indispensable machines.

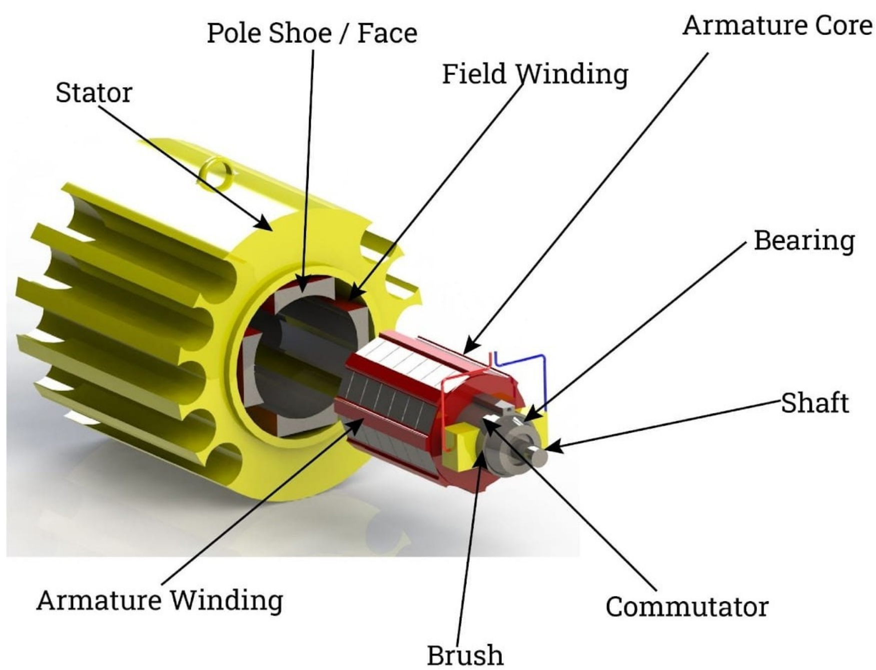
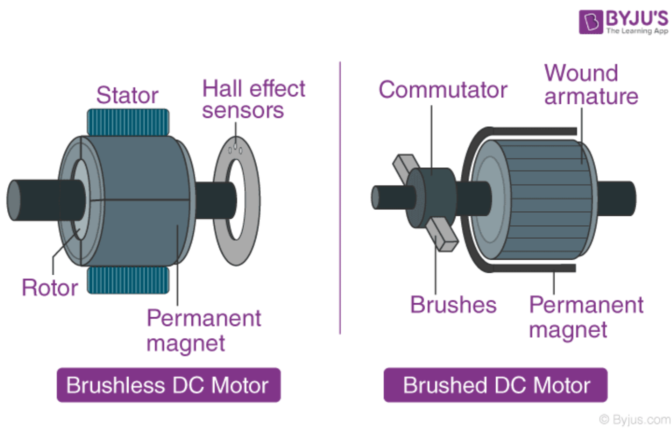


Figure 24: Image diagram of DC motor

Permanent Magnet Motors

Sometimes called Brushed DC motors, they provide the most simplified DC motor design where magnetic fields are solely provided by permanent magnets. The rotor is wound and connected to a circuit to create an opposing magnetic field to the stationary permanent magnets.



The speed can be increased by increasing armature voltage, which boosts the back electromotive force. However, this would result in a reduction of torque, as the two are inversely proportional to the applied voltage.

Reverse motion can be triggered by changing the polarity of the armature voltage, resulting in a change in current flow, or by using external switching devices.

The permanent magnets are normally made from neodymium-iron-boron (NdFeB) or samarium-cobalt (SmCo), eliminating the need for external field windings.

The brushed design of the motors allows the reversal of current flow, enabling bidirectional motion of the motor. Additionally, the absence of field windings allows for high efficiency.

Furthermore, the simplicity of the design results in a low weight. These advantages make them suitable for use in hybrid electric vehicles, robotics and automation, fans and blowers, and small household appliances.

Shunt Motor: A Shunt Motor is a type of self-excited motor in which the configuration of the rotor and stator are connected in parallel. It can be wound using an armature with a wave winding, where the armature coils are interconnected with each other. This winding is typically used in settings where the machine has high voltage capacity and low current capacity.

Alternatively, it can be configured using lap winding, where the number of parallel paths is equivalent to the number of poles. This winding is typically used in settings where the current capacity of the machine is high, and the voltage capacity is low.

The armature current equation is given by:

$$V = I_a \cdot R_a + E_b$$
$$E_b = k \cdot \phi \cdot \omega$$

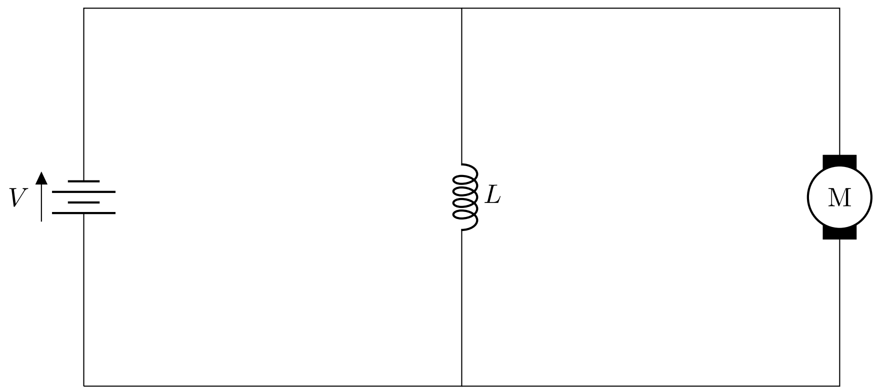


Figure 25: Circuit Diagram of a DC Shunt Motor

The shunt motor can also be configured using field winding.

Due to the armature's resistance voltage drop, torque has an inverse relationship with speed; it reduces over time as speed increases.

Shunt motors are normally classified as constant-speed motors. They are used in industries where precise control of speed and torque is required. For instance, they are employed in lifts, centrifugal pumps, lathe machines, and fans.

Figure 26: Image of shut diagram

Separately Excited DC Motors: As the name implies, these are a type of DC motor where, instead of permanent magnets, a separate voltage source is used to provide magnetic fields through a field winding. The motor is also connected to a separate voltage source to complete the circuit.

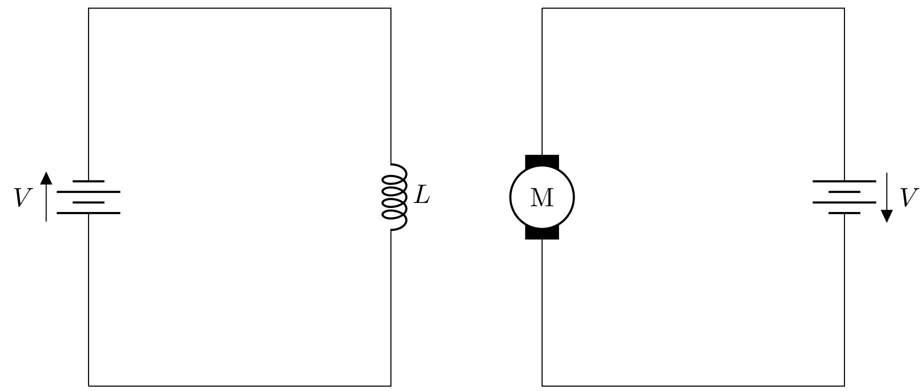


Figure 27: Circuit Diagram of a DC Seperately exicited motor

The key equations for this motor include:

$$V = I_a \cdot R_a + E_b$$
$$E_b = K \cdot \phi \cdot \omega$$

Where: V = Applied voltage, I_a = Armature current, R_a = Armature resistance, E_b = Back electromotive force , K = Motor constant, ϕ = Flux, ω = Angular speed, L_a = Armature inductance

The back electromotive force (E_b) is generated due to the motor's angular speed. The torque (T) is a constant depending on the motor's geometry, flux, and current, given by $T = K \cdot \phi \cdot I_a$.
By applying Faraday's law and Kirchhoff's voltage law, we can see that torque can be controlled by altering the armature voltage, as it is directly proportional to the motor's torque. This allows for precise control of torque. Similarly, current, used to provide the magnetic field, can also be adjusted to increase speed and torque.

Field flux is inversely proportional to the back electromotive force (E_b) from the armature windings, which is directly proportional to the armature speed and flux product. Therefore, an increase in speed results in a reduction of armature voltage, armature speed, and torque. Voltage, current, and flux can be altered to increase or reduce speed and torque.

Separately excited DC motors offer several advantages, including stable operation with any excited field, allowing for a wide range of output voltages. However, a disadvantage is that providing an external power supply can be challenging, and the ability to alter flux is complex.

Series DC Motors: As the name implies, this is a type of DC motor with a configuration where a single voltage supply is connected in series to both the armature winding (R_a) and the field winding to provide magnetic fields. Commutators and brushes are used to maintain electrical contact with the rotor.

This motor exhibits the capability to generate high torque at low speeds and low torque at high speeds, making it suitable for diverse applications, including vehicles. The field flux is directly proportional to the armature current, easily controllable using a diverter for torque regulation. Additionally, resistors can be connected to the field windings to diversify high current.
The series connection of the armature and field windings grants the motor the ability to start with high torque, making it particularly well-suited for applications such as trains, trams, cranes, hoists, and forklifts where critical starting torque is essential.

Since the armature current of the motor is load-dependent, it is recommended to start the motor without a load to prevent potential damage. While this may initially appear as a limitation, the motor's unique ability to vary its speed and torque based on the load finds extensive applications.

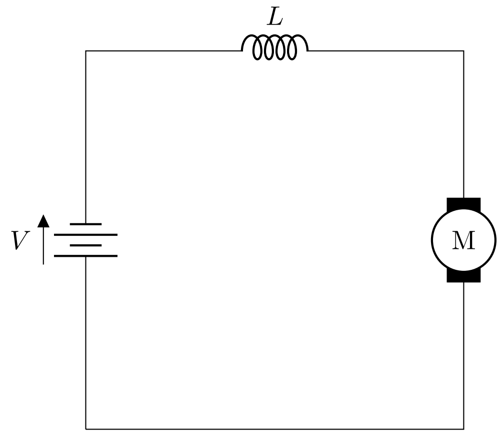


Figure 28: Circuit of a series motor

Notably, they are employed in creating exciting dynamics for amusement park riders in roller coasters and ferris wheels. In drill presses, where force on the load increases, the speed and torque can be adjusted according to the material and load being processed. DC motors are also utilized in irrigation pumps and conveyor belts. Additional advantages include their ease of maintenance, assembly, and design, as well as their cost-effectiveness.

Unfortunately, in the case of excessive load, an increase in armature current leads to a decrease in speed. Additionally, their inherent design and the relationship with field flux, speed, and back electromotive force (EMF) make them unsuitable for high-speed applications. Moreover, the interaction of back EMF and armature current restricts the motor to unidirectional applications unless additional electrical control is implemented. Finally, cooling mechanisms such as fans become necessary to prevent overheating at low loads, primarily due to the high field windings.

Compound DC Motor: This motor, classified as a compound motor, inherits its configuration from both the shunt motor and the series motor, thereby gaining superior advantages. In this design, the armature windings are connected in series, while the field winding is in shunt or parallel connections.

Compound DC motors combine the superior advantages of both shunt motors and series motors. They can be tailored to specific applications, adopting characteristics from both shunt and series motors. However, building them can be challenging, as winding makes for a complex design. Additionally, controlling speed and torque can be more challenging.

Overall, compound DC motors can be used in settings where both shunt and series motors find application, such as elevators, lifts, electric trains and trams, conveyors, and more.

Figure 29: Image of compound motor

Brushless DC Motors/Electronically Commutated Motor: These are brushless motors that use an electronic controller to excite the windings in the rotor. This excitation causes the magnetic fields to infinitely attempt to align with the polarity of the windings, thus producing motion. Through an electronic controller, the windings are turned on and off, resulting in the attraction that drives the motor.

The absence of brushes in brushless motors eliminates friction, contributing to greater efficiency. Additionally, these motors require minimal to no maintenance. Certain brushless motors can also be designed for regenerative braking, enabling the conversion of kinetic energy back into electric energy during deceleration.

A significant characteristic of these motors is their high power-to-weight ratio. This feature renders them essential in various industries, such as aerospace for drone lift generation, marine applications for underwater drones and boats, the medical industry for quiet operation, and the manufacturing sector where they can be employed in flammable environments.

AC asynchronous Induction Motors: Also known as asynchronous motors, these operate through electromagnetic induction. The stator's winding generates a magnetic field, inducing eddy currents in the rotor, featuring a short-circuited winding. The alternating current creates a revolving flux that opposes the rotor's flux, compelling the rotor to synchronize with the stator's rotating magnetic field.

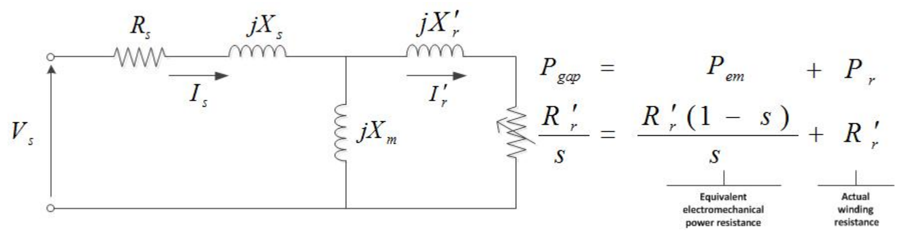


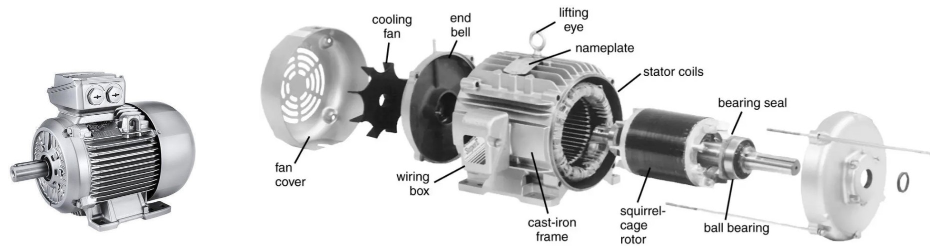
Figure 30: Steinmetz equivalent circuit

This can be single-phase, two-phase, or three-phase alternating current. The slip, defined as the difference between the stator's synchronous speed and the actual rotor speed, is given by the formula:

$$\text{Slip} = \frac{N_s - N_r}{N_s}$$

where N_s is the synchronous speed and N_r is the rotor's speed.

The rotor of the motor can be designed with either a squirrel cage or a wound rotor, also known as a slip ring. In the squirrel cage design, a cylindrical core with slots is twisted at an angle to prevent magnetic locking and maximize slip. On the other hand, the wound rotor design incorporates a laminated cylindrical core with slots on the outer periphery and insulated windings arranged uniformly or in star connections.



(a) Perspective image of induction motor

(b) Exploded view of induction motor

Induction motors feature a simple and rugged design, proving to be cost-effective and requiring minimal maintenance. Notably, they eliminate the need for additional starting motors. As only the stator is connected to the circuit, the electromagnetic flux can be adjusted by varying the voltage, leading to a linear variation in torque. Additionally, speed control is achieved by altering the frequency of the AC power. This adjustment can be efficiently accomplished using variable frequency drives, frequency converters, frequency generators, or motor-generator sets.

Due to their high torque, induction motors find extensive use in diverse industrial applications, driving pumps, compressors, and conveyors. They are also prevalent in HVAC systems for ventilation and air conditioning. Additionally, they serve as traction motors in electric traction for both trains and electric vehicles. In fact, they are used in Tesla and Lucid Motors

AC synchronous Induction motors : Synchronous motors operate based on the principle of synchronism, wherein their rotation is synchronized with the frequency of the current.

$$N_s = \frac{120 \cdot f}{P}$$

Where: N_s = Synchronous speed (RPM) f = Frequency of the AC power supply (Hz) P = Number of poles in the motor

The stator is equipped with coils that receive a three-phase current, inducing magnetic fields. Conversely, the rotor is excited with direct current, generating magnetic fields with alternating polarity. The addition of coils in both the rotor and stator allows the motor to operate at lower speeds while delivering higher torque.

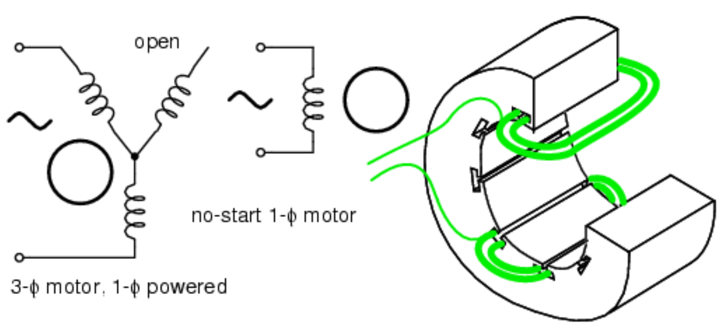


Figure 31: Diagram of an a single phase induction motor

$$T = k \cdot \phi \cdot I_a \cdot \sin(\delta)$$

Where: T = Developed torque k = Constant ϕ = Rotor flux produced by the excitation current I_a = Armature current δ = Power factor angle

These motors find applications in scenarios demanding precise speed control, such as clocks and timing devices, radars and are also utilized in electric vehicles, such as those manufactured by Lucid Motors.

Figure 32: Synchronous motor for the Koenigsegg electric sports car

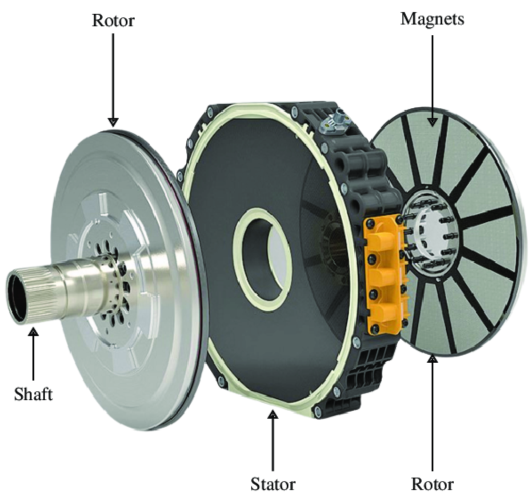


Figure 33: Exploded view of an synchronous axial motor

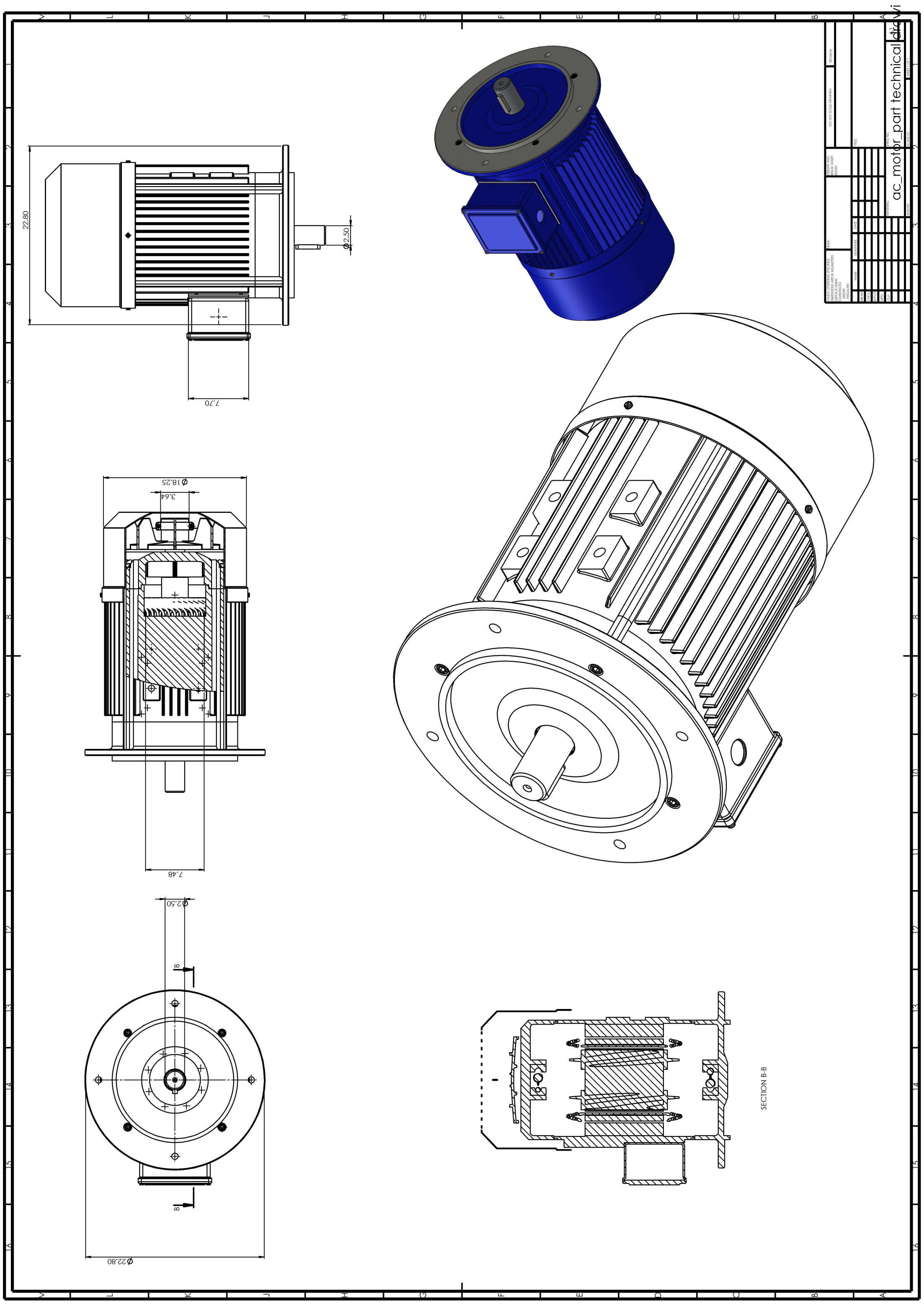
Synchronous motors possess a notable characteristic of maintaining a constant speed even under fluctuating loads. However, when subjected to loads surpassing their capacity or external forces, the magnetic fields may lose synchronization, resulting in the rotor coming to a halt.

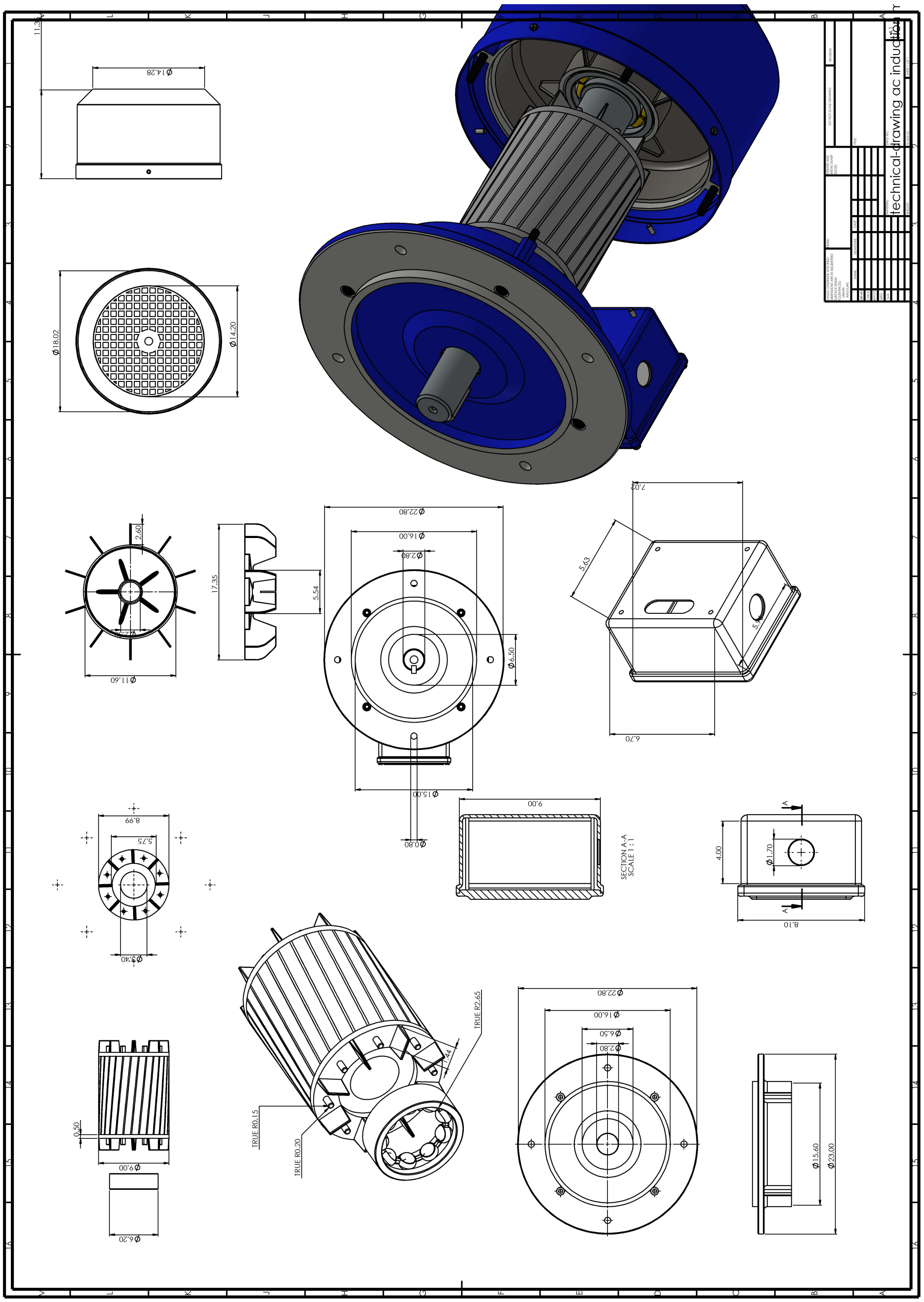
Various strategies, such as squirrel cage rotors and high speed sensors, have been devised to mitigate this issue.

7 Motor Design

The below designs showcase an induction motor.

7.1 Technical Drawings

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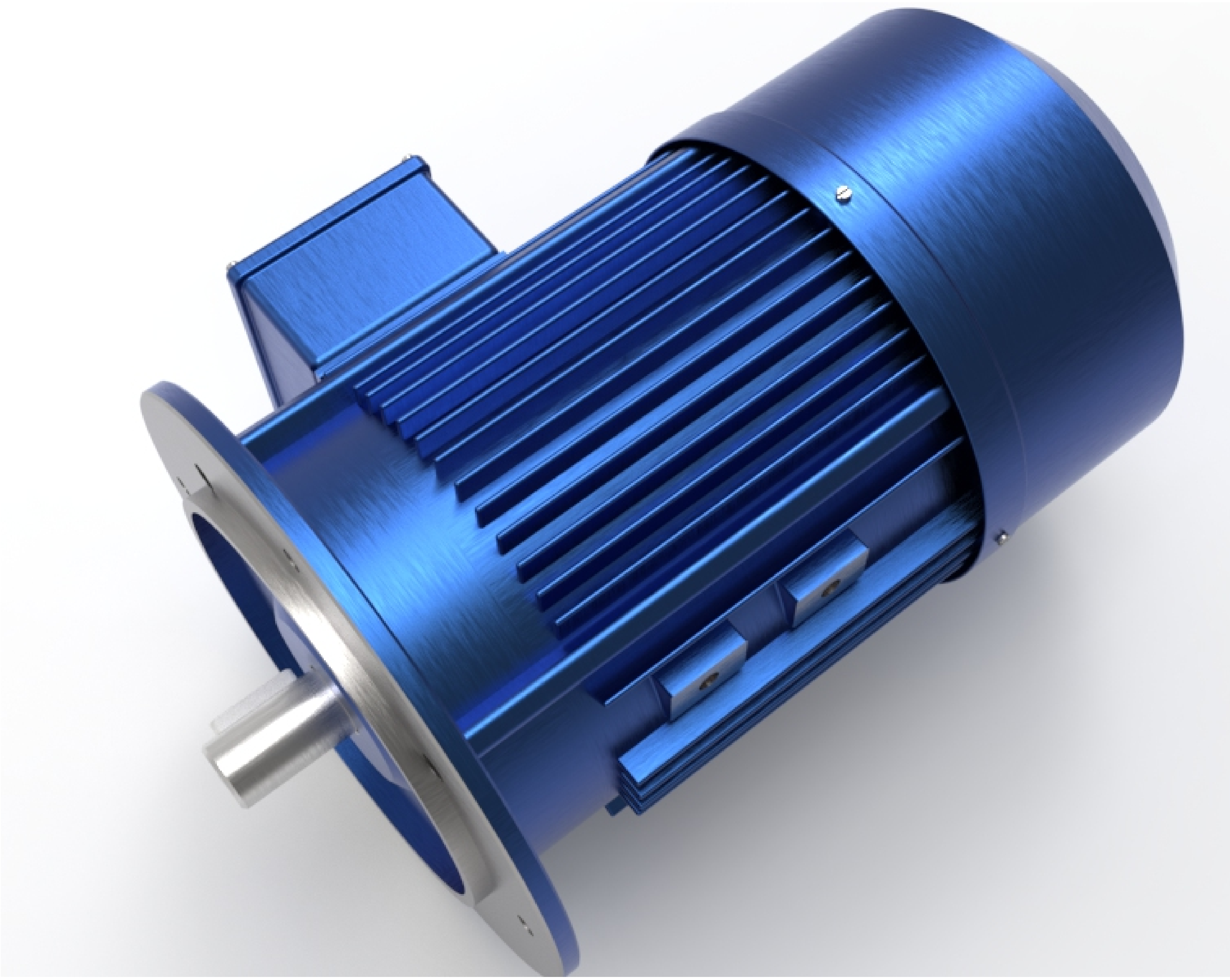
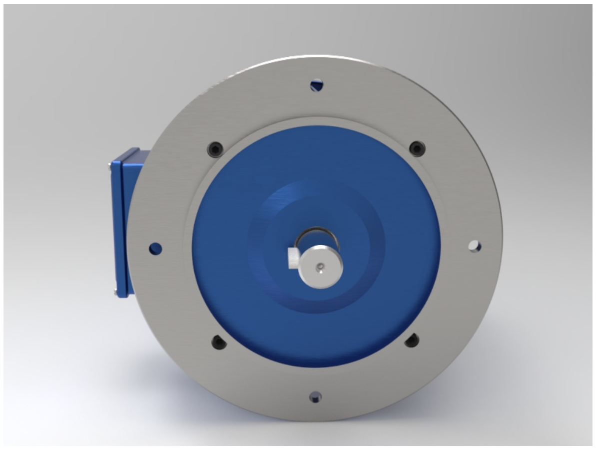
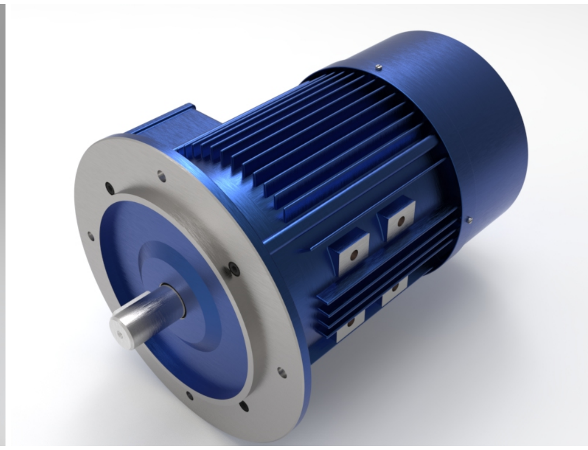
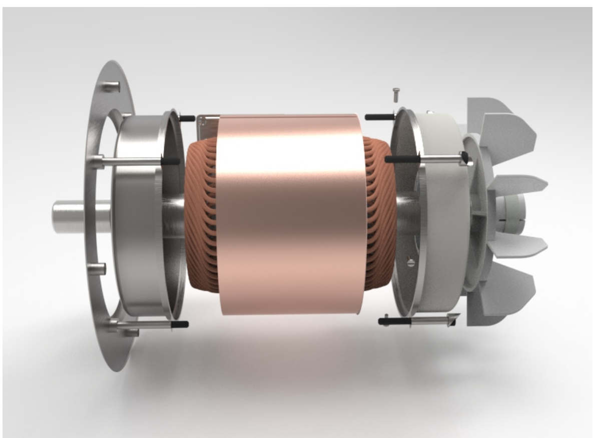
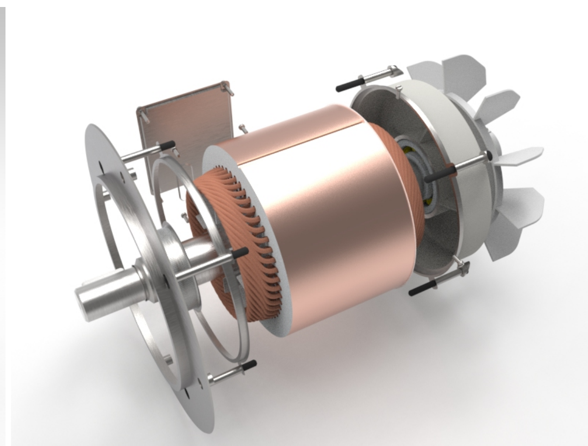
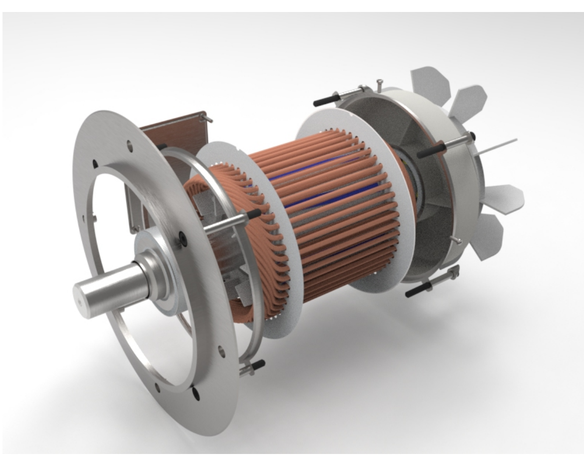
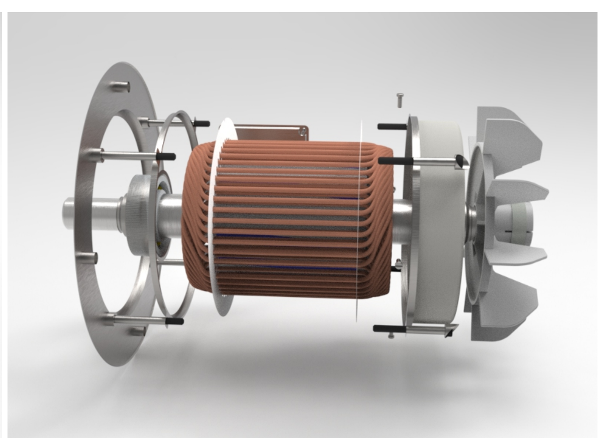
TRUE R0.20
TRUE R2.65

7.2 CAD Renders

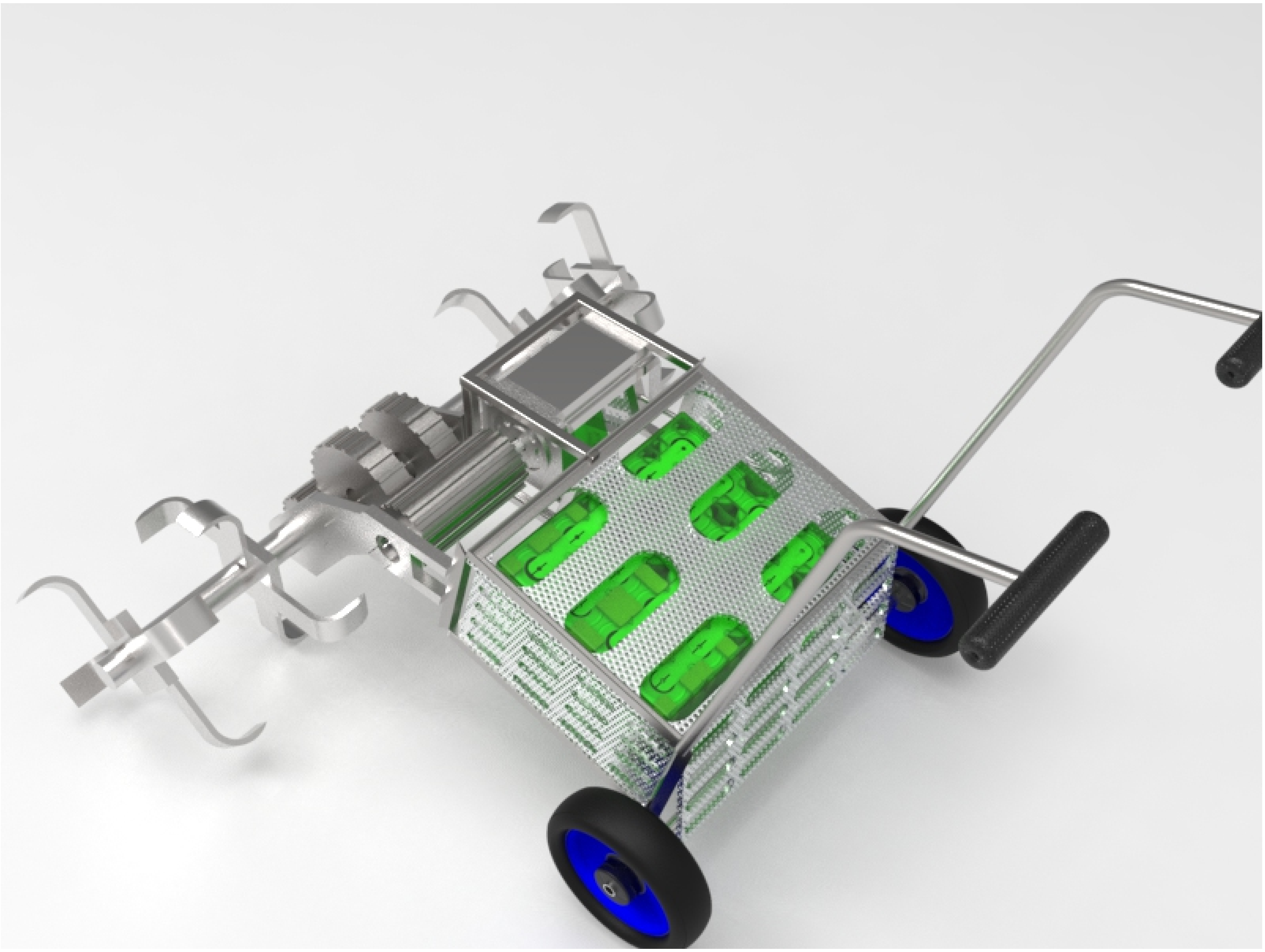


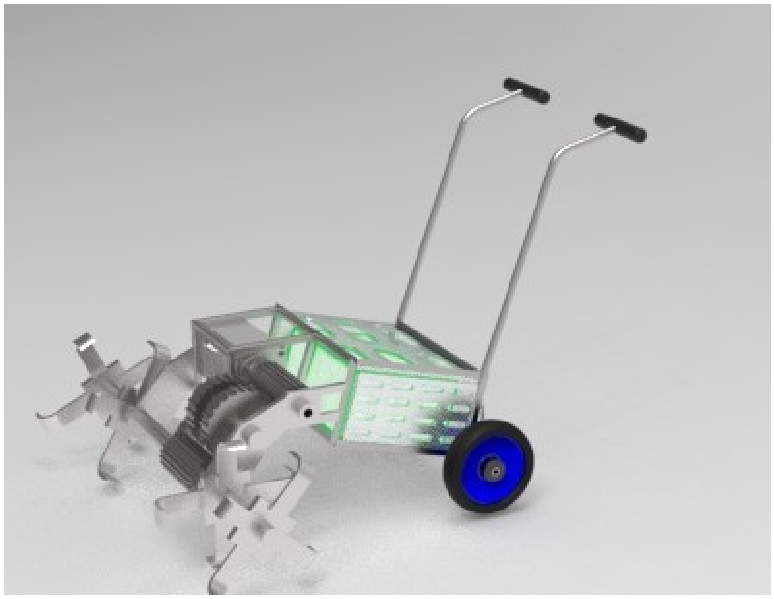







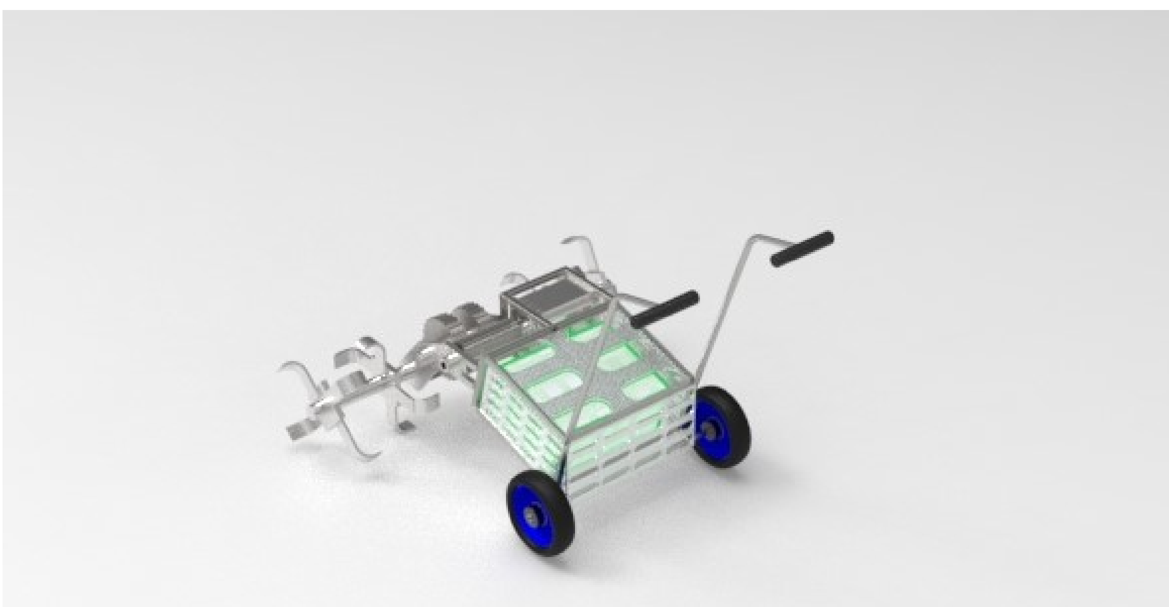
8 Rotary Tiller Design Concepts

8.1 Concept A

The initial design concept entails a shallow configuration, wherein the primary structure encompasses a battery pack. The motor is vertically mounted and aligned in parallel with the shaft, facilitating the transfer of torque via spur gears.

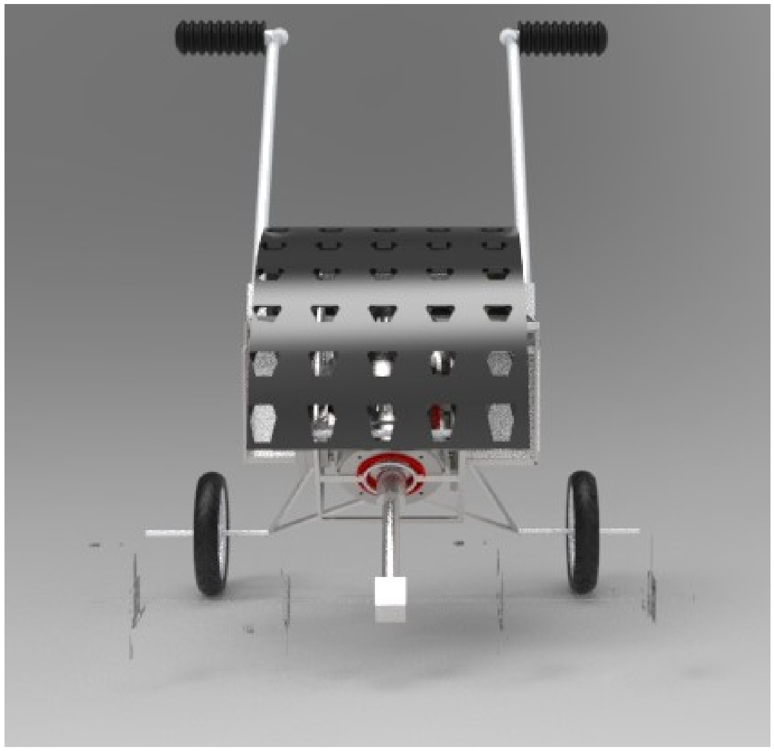






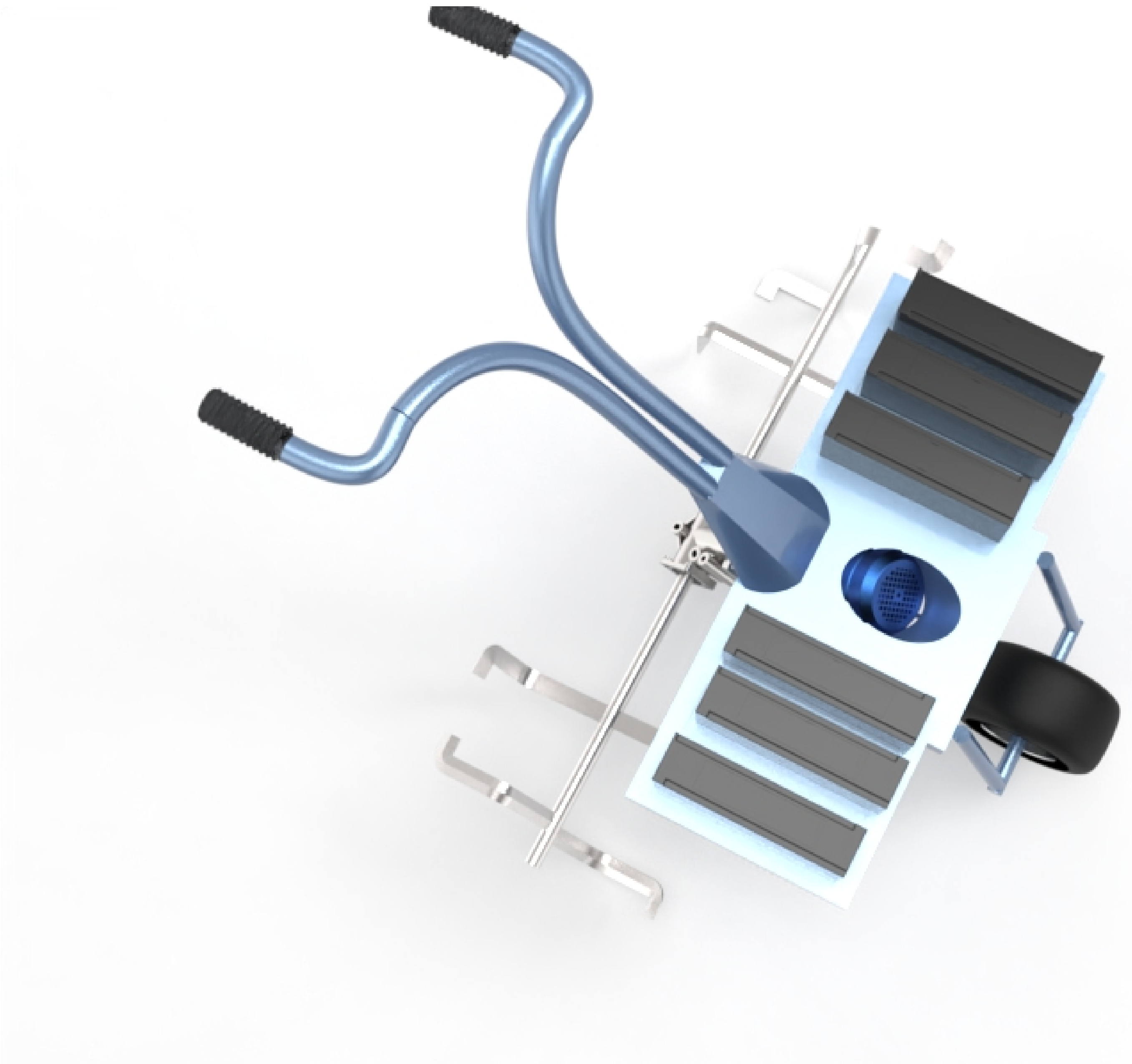
8.2 Concept B

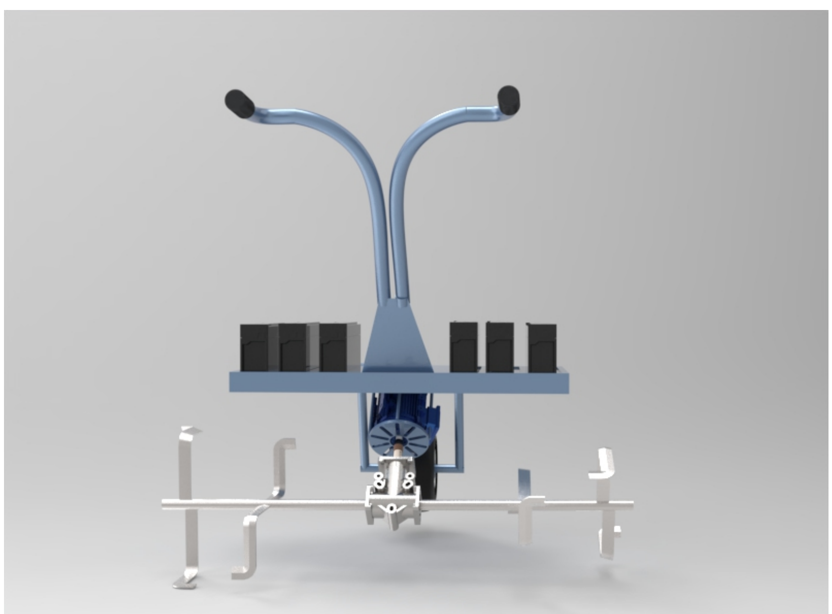
In this electric rotary tiller design, the structure incorporates batteries mounted on the sides. A motor is positioned horizontally, parallel to the ground, and is connected to a right-angled gearbox. This configuration facilitates the efficient transfer of torque throughout the tiller's shaft



8.3 Concept C

In this design concept, the electric rotary tiller features a structural platform designed to securely house the batteries. The electric motor is strategically oriented at a 190-degree diagonal angle, intricately linked to a right-angled gearbox. This gearbox plays a pivotal role in efficiently transmitting torque to the shaft, which accommodates the tillers, ensuring precision and optimal functionality.





9 Detailed Design

Requirements for the detailed rotary tiller include

9.1 Power Requirements For Loam Soil Tillage

As stated earlier, the Force, Torque, Power required to penetrate through loam soil, parameters are essential in establishing a detailed design of the tiller.

Draft force is the force required for tine to penetrate, that is to push or and pull through the soil medium. calculation of the draft force depends on soil type, moisture content, compaction, depth of operation, speed of operation, bulk density, surface roughness, depth of operation, equipment size, etc.

By comparison to similar equipment's, empirical estimates show a depth of 10cm, according to (Mohammad et al, 2020) requires draft force of 20Nm, whilst (Iman et al, 2020) a torque required is from 11.8Nm to 13Nm. Given a draft torque of 12Nm the graph below shows the plausible motors.

Therefore ;

Hp(Nm)	**Watts(Kw)**	**Current(Amps)**	**Torque(Nm)**	**Depth(cm)**	**Width(cm)**	**Speed(rpm)**
1.2	0.88	4	12	14	2	1500
2	1.5	6.8	20	16	10	1800
2.5	1.8	8	30	18	60	3000
0.6	0.45	18	30	18	60	220

Table 1: Design Failure Mode and Effects Analysis (DFMEA) for Electric Rotary Tiller

ID	Potential Failure Mode	Potential Effect of Failure	Severity (S)	Occurrence (O)	Detection (D)	RPN	Recommended Actions
1	Motor Burnout	Inoperable tiller	8	5	6	240	Regular motor maintenance
2	Blade Wear	Reduced tilling efficiency	6	7	4	168	Periodic blade inspection and replacement
3	Frame Deformation	Structural failure	9	3	5	135	Use of high-strength materials, structural analysis
4	Handlebar Malfunction	Loss of control	9	4	7	252	Reinforcement of handlebar assembly
5	Electrical Short Circuit	Fire hazard	10	3	8	240	Insulation checks, electrical system maintenance
6	Depth Control Failure	Inconsistent tilling depth	7	6	5	210	Regular maintenance, calibration checks
7	Blade Misalignment	Uneven tilling	6	5	6	180	Regular inspection and adjustment
8	Gearbox Failure	Loss of power transmission	8	4	7	224	Lubrication maintenance, gearbox inspection
9	Overheating	Motor damage	9	4	6	216	Cooling system improvement, thermal monitoring
10	Control Panel Malfunction	Inability to adjust settings	7	5	8	280	Redundant control system, regular checks
11	Belt Slippage	Reduced power transmission	6	6	5	180	Tension adjustment, belt replacement
12	Wheel Damage	Impaired maneuverability	5	7	5	175	Durable wheel material, regular inspection
13	Noise/Vibration Increase	User discomfort	4	8	6	192	Vibration dampening, noise insulation
14	Corrosion	Structural degradation	7	5	7	245	Corrosion-resistant materials, protective coatings
15	Safety Guard Failure	Operator injury risk	10	3	9	270	Robust safety guard design, regular inspection
16	Battery Failure	Loss of power	8	4	6	192	Battery monitoring, replacement schedule
17	Wiring Damage	Electrical malfunction	7	5	7	245	Protective shielding, regular inspection
18	Sensor Malfunction	Inaccurate data	6	6	6	216	Redundant sensors, calibration checks
1	Brake Failure	Uncontrolled movement	9	2	7	126	Brake system redundancy, regular maintenance

9.2 Motor Selection

In order to consider a motor, we resolt to the key parameters, namely,torque and desired horsepower. Given a minimum required torque of 13, we consider a safety factor of 2 based on overheating,[more reasons] 2 = **26 Nm**. Horspower can range between 1.2Hp to 3Nm, the higher horpower is more favourable due to higher capacity. Therefore the desired motor should have at least **26Nm** least 2Hp, 1.5KW.

Below are some of competitive options

- Ampflow : It has a maximum torque of 48Nm, 380Watts an rpm of 340V at 12V has option comes with gear,
- FlipSky BLDC x 3,costs $86,it has maximum power of 2450 watts equivalent to 3 horsepower, weighs only about 0.56kg it has a maximum torque of 7Nm,, therefore two would e needed.
- Wewin motor comes withe protection casing, it has only 2 poles, it takes in 12V and 150 watts, it has a diameter of about 7mm, and output shaft of 12mm-14mm, its maximum torque is about 30Nm and low speed of 50rpm
- the Nema 42 is high stepper motor which has a torque of 30nm, it has a rated current of 8A, Resistance of 0.71 ohms an, it is 200mm long and weights 11.7Kg it costs roughy $ 105

Selection should consider the highest **torque**, lowest weight, dimension, lowest current and voltage for the lowest price.
Based on the above details, Ampflow seems to be a suitable and reliable option.

9.3 Battery Selection

Selection of the suitable battery depends on the motors power consumption, that is current

9.4 brakes

There are various types of fields to consider in regards to choosing the appropriate brake, hydraulic brakes :

Electromagnetic Brake

- **Overview:** Utilizes electromagnetic force to create friction and halt shaft rotation.
- **Advantages:** Quick response time, precise control, high reliability.
- **Disadvantages:** Requires continuous power supply, potential overheating during prolonged use.

Hydraulic Brake

- **Overview:** Applies hydraulic pressure to clamp brake pads onto a rotor, stopping shaft rotation.
- **Advantages:** High braking force, minimal maintenance, suitable for heavy-duty applications.
- **Disadvantages:** Requires hydraulic fluid, potential for fluid leakage.

Mechanical Brake

- **Overview:** Physically presses brake pads or shoes against a rotor, typically actuated by a lever or pedal mechanism.
- **Advantages:** Simple design, reliable operation, wide availability.
- **Disadvantages:** Limited precision, may require periodic adjustment and maintenance.

Regenerative Brake

- **Overview:** Operates motor in reverse to generate electrical energy, resisting shaft rotation.

- **Advantages:** Energy-efficient, can recover kinetic energy, reduces wear on traditional brakes.
- **Disadvantages:** Requires sophisticated control system, less effective at low speeds.

Motor Disconnection Safety Brake

- **Overview:** This safety brake mechanism involves disconnecting the motor from the shaft to prevent unintended movement or rotation during maintenance or emergency situations.
- **Advantages:** Provides a fail-safe mechanism to ensure the safety of personnel and equipment, prevents accidental operation of the machinery.
- **Disadvantages:** May require additional components for motor disconnection, can result in downtime during activation, needs manual or automated reset after activation.

Power Disconnection Safety Brake

- **Overview:** This safety brake operates by automatically disconnecting the power supply to the motor when activated, halting shaft rotation.
- **Advantages:** Instantaneous motor shutdown, no mechanical engagement required, reduces risk of injury or damage during emergencies.
- **Disadvantages:** Requires an additional control system for activation, potential for unintended activation causing downtime.

9.5 Bearings Consideration

plain bearings	thrust bearings	cylindrical bearings
		

Table 2: Image Examples of Bearings

9.6 Gearbox Consideration

Helical Gear	46cm helical_gear_image.jpg
Properties	Smooth and quiet operation High efficiency Handles moderate to high loads
Use Cases	Industrial machinery Conveyor systems Marine applications
Advantages	Smooth and quiet operation High efficiency Handles moderate to high loads
Disadvantages	More complex design Higher manufacturing cost

Table 3: Helical Gear Properties, Use Cases, Advantages, and Disadvantages

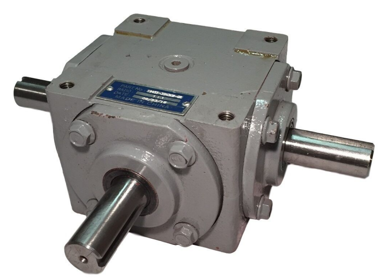
helical gearbox	worm gearbox	bevel gearbox
		

Table 4: Image Examples of Bearings

9.7 References

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