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DESIGN AND DEVELOPMENT OF COMPACT FORKLIFT

Kushal Koli, Sibtain Malgundkar, Ziyad Mullaji, Mohit Gautam
Gajanan Thokal
Department of Mechanical Engineering, Pillai College of Engineering, New Panvel, Navi Mumbai - 410206.
Email: gthokal@mes.ac.in

Abstract

The compact battery-operated forklift has emerged as a transformative solution in material handling equipment. This abstract summarizes the essential aspects of this innovation. As industrial operations increasingly prioritize efficiency and environmental sustainability, the compact battery-operated forklift offers a promising alternative to traditional fuel-powered counterparts. This abstract provides an overview of the core features and advantages of the compact battery-operated forklift, including its unique combination of battery power and space-efficient design. It is characterized by its environmental friendliness and cost-effectiveness, making it particularly well-suited for navigating tight spaces and enhancing operational efficiency. Safety features and controls are addressed, as well as the potential applications across various industries. The report also highlights the latest market trends, advancements in compact battery-operated material handling equipment, and the integration potential with automation and the Internet of Things (IoT). In conclusion, this abstract underscore the economic and environmental benefits associated with adopting the compact battery-operated forklift within modern logistics and supply chain operations. It offers a comprehensive glimpse into a promising innovation that optimizes material handling practices for professionals in logistics, warehouse management, and manufacturing sectors.

1. INTRODUCTION

Forklifts, also known as lift trucks or forklift trucks, are essential pieces of material handling equipment used in a variety of industrial and commercial settings. These versatile machines are designed to efficiently lift, move, and transport heavy loads, making them indispensable for tasks involving the handling of goods, whether in a warehouse, manufacturing facility, construction site, or distribution centre. Forklifts are characterized by their distinctive features, including a pair of pronged forks attached to the front that can be raised and lowered, allowing them to engage with pallets, crates, and other materials [1]. These forks are used to lift and carry loads, and they are typically powered by either electric batteries or internal combustion engines, depending on the specific application and operational needs. The ability to lift and manoeuvre heavy objects with precision and ease is a hallmark of forklifts. They provide operators with a high level of control, allowing them to navigate through narrow aisles, congested workspaces, and elevated storage racks. Forklifts are known for their exceptional lifting capacities, with the capacity varying from smaller, compact forklifts suitable for light loads to larger, heavy-duty models capable of handling tons of materials [1].

Different types of forklifts are listed below:[1]

- 3 or 4-wheel Warehouse forklift
- Side Loader
- Counterbalance Forklift
- Telehandler
- Industrial Forklift
- Rough Terrain Forklift
- Pallet Jack or hydraulic forklift
- Walkie Stacker
- Order Picker
- Reach Fork Truck
- Turret Trucks forklift

The development of forklifts traces back to the early 20th century when companies began seeking more efficient ways to handle heavy loads in warehouses and factories [2]. The earliest forklifts, often called lift trucks, emerged in the 1910s and 1920s, utilizing basic designs and powered by gasoline or electric engines. However, it was during World War II that forklift technology saw significant advancements, as military logistics required efficient material handling equipment. After the war, the demand for forklifts grew rapidly in various industries, leading to further innovation. Hydraulic systems were introduced in the 1940s, greatly enhancing lifting capabilities. By the 1950s, forklift designs evolved to include features like enclosed cabs, better ergonomics, and improved safety features [3]. In the following decades, the development of forklift technology continued to progress, with the introduction of diesel-powered forklifts, rough terrain models, and specialized variations for specific industries. The 1980s and 1990s saw advancements in electric forklifts, driven by the growing emphasis on environmental sustainability and indoor air quality. Since the turn of the 21st century, forklifts have become increasingly sophisticated, incorporating features such as advanced sensors, telematics, and automation technologies. These advancements have not only improved efficiency and safety but also enabled the integration of forklifts into broader supply chain management systems [4] Today, forklifts are indispensable in warehouses, distribution centers, manufacturing facilities, and various other industries, playing a vital role in the movement and storage of goods worldwide. In recent times, there has been a major development of compact forklifts for material handling and used in tight and compact spaces [5].

2. MATERIAL AND METHODOLOGY

2.1 Problem identification: The existing compact forklifts face challenges in terms of load stability, vibrations, aesthetics, and counterbalance. There is a need to design and develop a new forklift that offers better stability, increased load-carrying capacity, optimized materials, and is cost-effective.

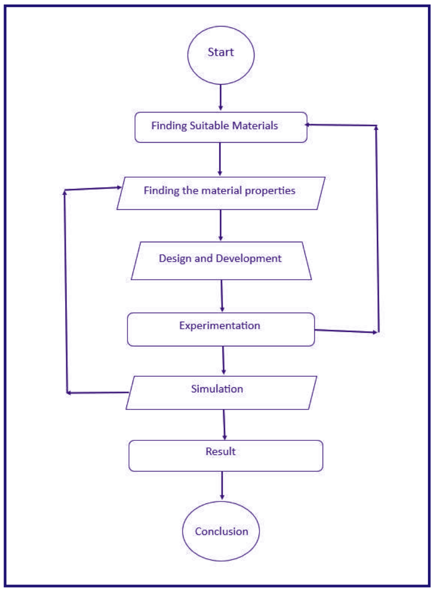
2.2 Aim: To Design and Develop a Compact Forklift for multipurpose.

2.3 Objectives of the Project:

1. To design and develop a compact forklift system with aesthetic and ergonomic conditions.
2. To find the different materials for the forklift and also find the load-carrying capacity.
3. To test the forklift load-bearing capacity and vibrational conditions of the component.
4. To perform a simulation of the component and analyse it with the help of software.
5. Optimization of forklift in all aspects.

2.4 Methodology: The flow chart given below is the complete process of development of the forklift. The given procedure is a step-by-step process for the completion of the project.

Figure 2.1: Flow Chart of Forklift



2.5 Components of forklift: The following is the list of various components used in our forklift:

1) Chassis/Frame: The core of our forklift's structural integrity rests upon a meticulously engineered Chassis, manufactured from MS square tubes. In tandem, the upper platform, fashioned from plywood, provides a space for operators and equipment. While plywood may not be the conventional choice for a forklift's framework, its cost-effectiveness makes it well-suited for smaller-scale or experimental projects, albeit with a slightly lower structural strength when compared to metal alternatives [6].

2) Motor: It is used to drive the gear and pinion. There are two motors used in the forklift one for driving the forklift and another for moving the forklift up and down. 24W DC motor used for moving the vehicle, it drives the secondary chain drive at 300rpm, the torque is about 20 N-m. 12W motor is used for lifting the fork with 5-amp power and 13 N-m torque [6].

3) Chain and sprocket: Chain drive helps to drive the system on both sides (one at a time) using an electric motor. Driving chain: Two Sprockets with Diameters 76mm and 39mm are used which have 30 and 19 teeth on them. A chain of length 185.78mm and 19 links is convenient. Lifting chain: Two Sprockets with Diameters 66mm and 26mm are used which have 32 and 13 teeth on it. A chain of length 156 mm and 56 links is convenient [6].

4) Bearings: 6 pedestal bearings are used in the forklift; 2 bearings are used for the winch mechanism and the remaining is attached to the chassis for smooth rotation of shaft connected to the tires. The bearing used is SKF 6202 [6].

5) Battery: At the heart of our forklift power source, we rely on a pair of 12-volt batteries, driving both wiper motors integral to the lifting mechanism. This strategic choice optimizes operational efficiency. Charging of the battery can be done separately [6].

6) Wheels: The selection and configuration of our forklift's wheels are critical to ensuring seamless mobility and unwavering stability. The wheels are 12 inches in diameter and 4 wheels are used [6].

7) Fork: Positioned at the forklift's forefront, our forks have been engineered to expertly slide beneath loads for lifting and transportation. Emphasizing safety and precision, our design ensures their secure handling of intended loads with unwavering alignment. The detailed design is explained in the coming chapter [6].

8) Switches: The control system consists of two switches used to move the vehicle front or back as well as to right and left and also to lift the fork up and down. This helps to navigate the vehicle in different directions.

9) Pulley: ensures a smooth interface for lifting. A pulley is a piece of equipment, consisting of a wheel and a rope that is used for lifting heavy things [6].

10) Wire rope: Our deliberate inclusion of a robust wire rope within our lifting mechanism underscores its strategic importance.

2.6 CAD Modelling

To carry out FEA of any component the first and the basic requirement is CAD model. There are various parts of a forklift like chassis, fork, handle, etc. So, for making CAD models we have to use modelling software like SolidWorks, AutoCAD Fusion, etc. Finite element analysis is carried out through software called Ansys 2021. The models are shown below next chapter.[7]

3. DESIGN OF FORKLIFT

3.1 Detail Design

CAD Modelling

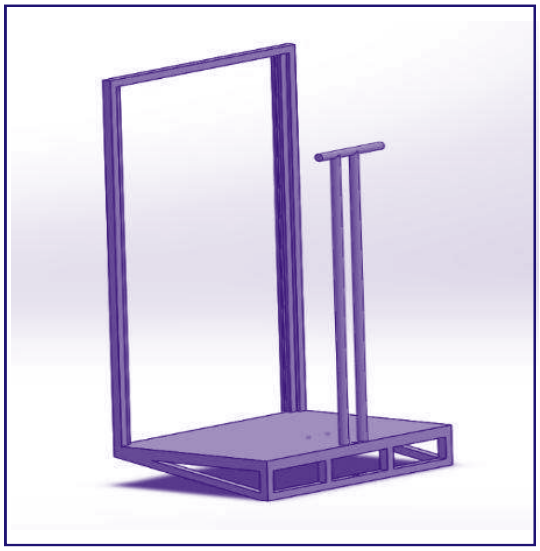
1) Front chassis

Dimension

- Length: 400mm
- Width: 400mm
- Height: 950mm
- Height of handle: 900mm
- Thickness of platform: 100mm

The material used for the fabrication of the front chassis is Mild steel. It is most commonly used, low cost, ease in fabrication with excellent weldability and ductility. The main purpose of this part of the forklift is that the winch mechanism and battery are placed on the front chassis. Used to rotate while taking turns. The mast is fixed on the front chassis for the moment of the fork

Figure 3.1: Front Chassis [7]



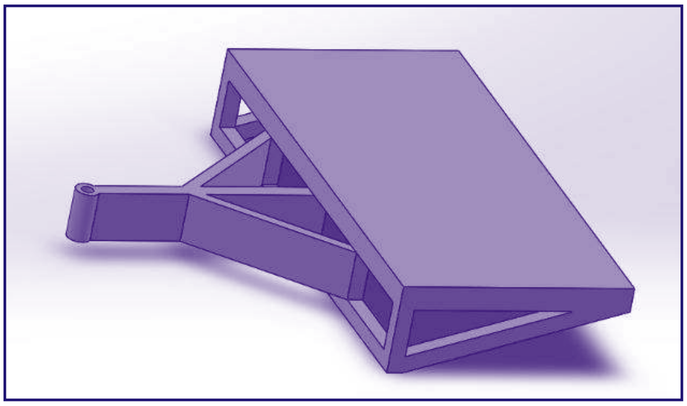
2) Rear chassis

Dimension

- Length: 600mm
- Width: 400mm
- Thickness of platform: 100mm

The material used for the rear chassis is also mild steel. The purpose of the rear chassis is such that the motor is attached to the rear chassis for forklift movement and it is the place for the driver to stand comfortably.

Figure 3.2: Rear Chassis [7]



3) Fork

Dimension

- Length: 400mm
- Width: 300mm
- Height: 500mm
- Thickness: 6mm

The material used for the fork is Carbon steel AISI 1060, which is widely used in wear rails and other applications with great hardness. The purpose of a fork is to lift the weight at a specific height. Bearing is used for smooth motion (up and down), Connected with a winch mechanism through a wire rope

Figure 3.3: Fork [7]

Assembly for CAD model of a forklift

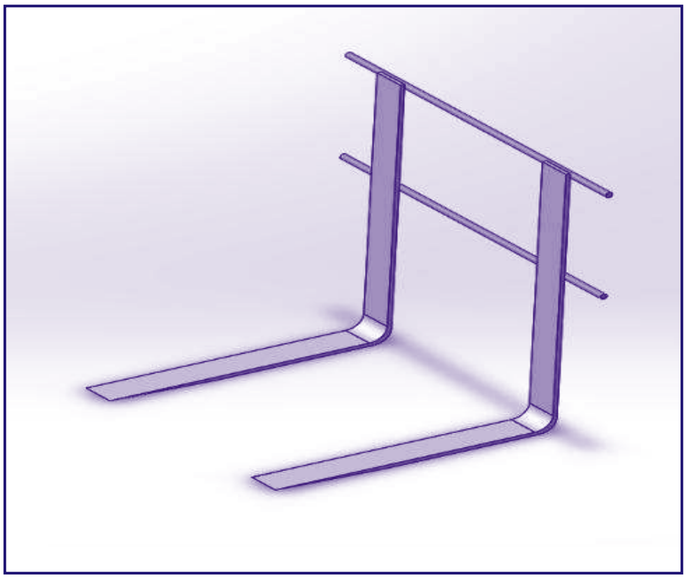
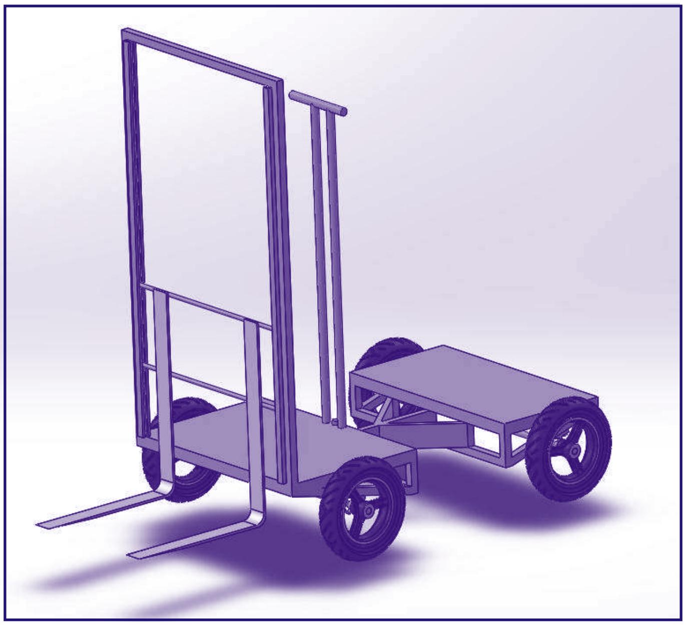


Figure 3.4: Assembly of CAD model [7]

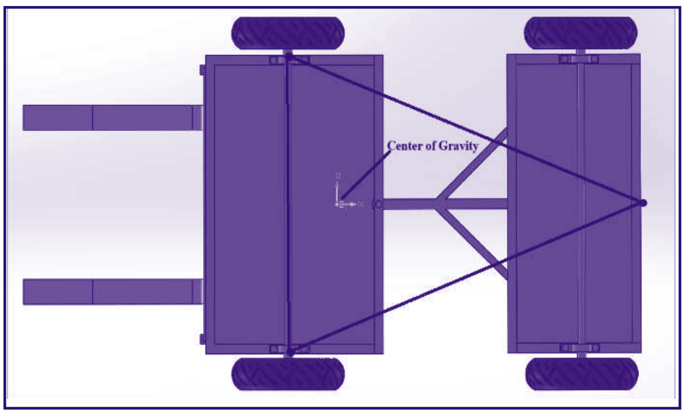


Working

The forklift described is electrically powered and features two motors: one for driving a vehicle and another for lifting the fork. The driving motor is connected to the wheel shaft via a chain drive, and its operation is controlled by a control unit with forward and reverse switches. The forklift is environmentally friendly as it produces no pollution.

Safety is a primary concern in its design, particularly during loading and movement. The stability system emphasizes maintaining three points of contact: the two front wheel drives and support from the rear wheel contact axle, forming a stability triangle. This triangle ensures stability and minimizes the risk of tip-overs, especially during sharp turns.

Figure 3.5: Stability Triangle and centre of gravity [7]



Weight calculation

Table 1 shows the weight of the specific part of the forklift as well as the total weight of the forklift: The weight distribution would be 30:70 in front and back. The driver's weight would be accounted in the rear chassis

Table 1: Weight Calculation

Components	Weight (Kg)
Front chassis and Mast	10
Rear Chassis	6
Fork	5
Shaft	3
Handle	4
Bearing, Motors, Chain sprocket	5
Total	33 kgs

3.2 Design of Fork

Mathematical calculations of the weight of the fork the forks on a forklift are used to contact a load for transport directly. They are attached to the forklift carriage and are designed to carry the load from the bottom. Forklift forks come in all shapes and sizes [8].

The size of our forklift is as follows:

1) Length of fork = 400mm = 0.4m

2) Weight of fork = 500mm =0.5m

3) Thickness of the fork = 6mm = 0.006

4) Width of single fork = 50mm=0.05m

5) Radius of fork = 25mm

The material used for the fork is AISI 4340 Carbon Steel

- Elastic modulus = 2*105 N/mm2
- Poisson's ratio = 0.285
- Mass density = 7200 Mpa
- Yield strength = 470 MP

Figure 3.6: Fork

Weight calculation
Section 1a ,
volume = length * breadth *height
 $= l*b*h = 0.394 * 0.05*0.006 = 1.182\ m^3$
Weight 1a = Volume * density
 $= 1.182*10^{-4}*7200 = 0.851$ kg
Section 1b,
volume = length * breadth * height
 $= l*b*h = 0.5* 0.05*0.006 = 1.5*10^{-4}\ m^3$
Weight 1b = Volume * density
 $= 1.5*10^{-4}*7200 = 1.08$ kg
Total weight is section 1 = 1.08+0.85 = 1.93 kg
Similarly, for section 2, the weight is 1.93 kg
Two MS rods are welded to the fork for support, the weight of one rod is around 0.34 kg, and the diameter of the rod is 15mm
Total weight of fork = 1.93+1.93+0.34+0.34

 = 4.54 kg

Mass properties of fork obtained from SolidWorks

Table 2: Mass Properties [7]

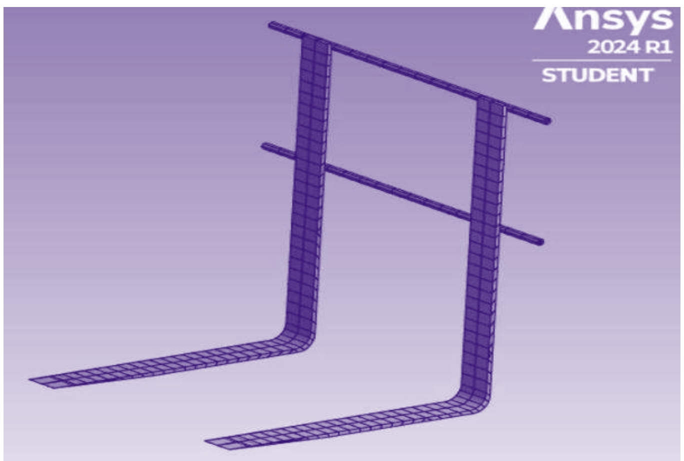
Mass of forklift	4578.07 grams
Volume of forklift	583193.80 mm^3
Surface area of forklift	234409.19 mm^2

Analysis of Fork in Ansys

I. Material selection: The material selected for a fork in Ansys is AISI 4340 annealed carbon steel.

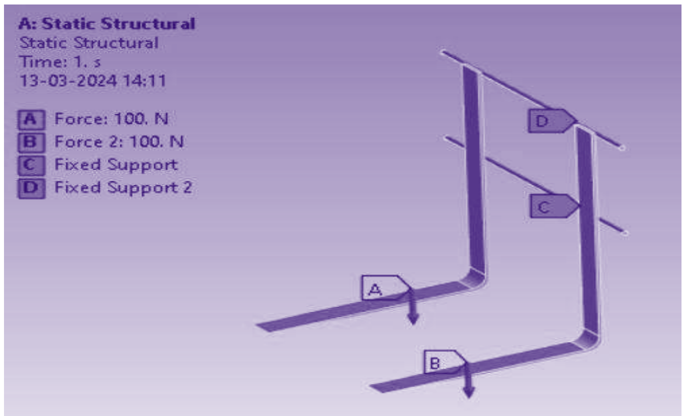
II. Meshing: ANSYS Meshing is an advanced tool for generating tailored meshes for precise multi-physics analyses. It's flexible, allowing expert users to fine-tune options, and utilizes parallel processing to minimize generation times. In this case, it produced 1589 nodes and 870 elements, providing sufficient discretization for the analysis.

Figure 3.7: Meshing of Fork [9]



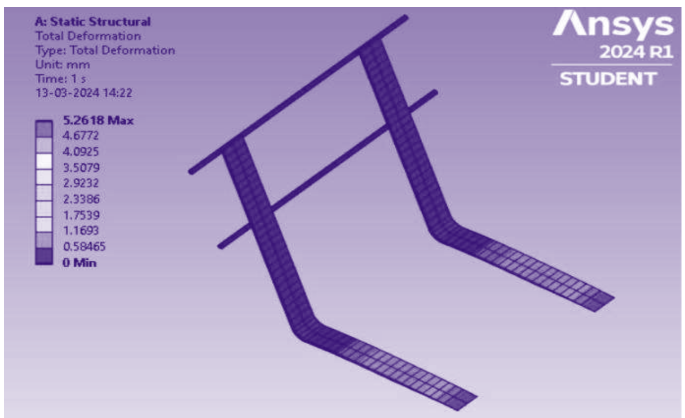
III. Boundary Conditions: In Finite Element Analysis (FEA), accurate simulation relies heavily on proper boundary conditions. These conditions involve assigning known values for displacements or loads like force, pressure, or temperature to components such as points, surfaces, or nodes. However, in a specific node, only one type of load or displacement can be assigned at a time. For instance, in the given scenario with two forks attached to a mast via sliding bearings, applying a pressure of 100 N to both forks while fixing the horizontal rod requires careful consideration to ensure accurate simulation results.

Figure 3.8: Boundary Condition [9]



IV. Total deformation: The figure shows the deformation for a load of 20kg on both forks. From this, it is observed that the deformation is maximum at the end of the fork. From this figure, it can be stated that the maximum deformation at the end of the forklift is 5.2 mm whereas the portion that is supporting the forklift has a maximum deformation of 0.5846 mm. From this analysis, it can be concluded that the forklift design is safe from the deformation point of view.

Figure 3.9: Total Deformation [9]



V. Stress and Strain: This section covers both the static and dynamic (fatigue) analysis of the forks. For the static analysis, it is already known that the maximum loading capacity of this forklift is 20 Kg. There are two forks and the structure is symmetrical, so each one of them carries half of the force, which is approximately 200 N. Figure 3.10 shows the equivalent strain of the fork. From this figure, it is observed that the maximum equivalent stress (Von-Mises) is 63.447 MPa. From this, it is observed that the yield strength of the material is 470 MPa, which is within the safety consideration. Figure 3.11 shows that the maximum principal strain is 0.00033197 MPa and the minimum is 3.688*10-5

Figure 3.10: Principle elastic strain [9]

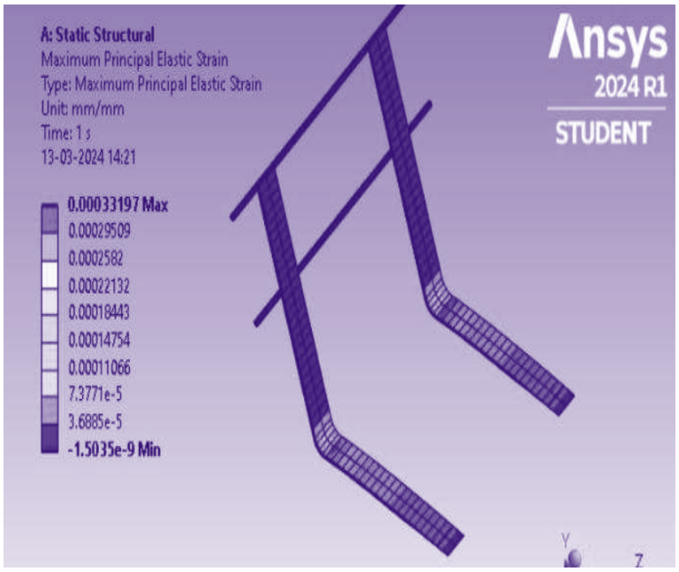
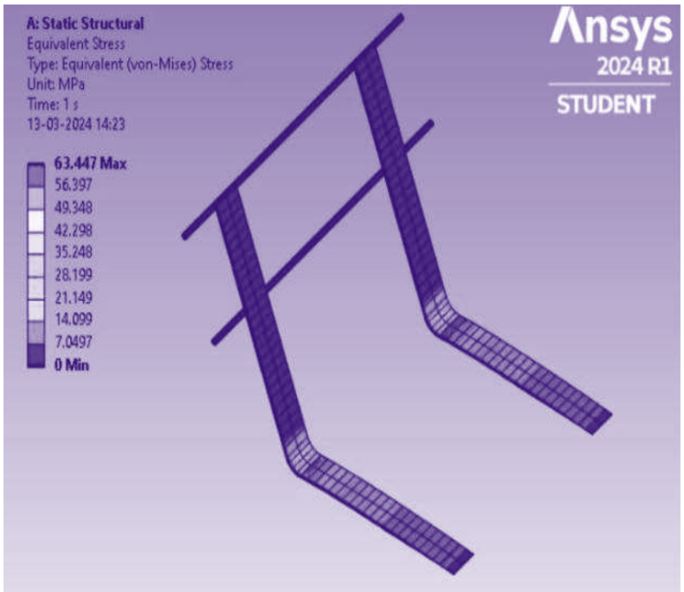
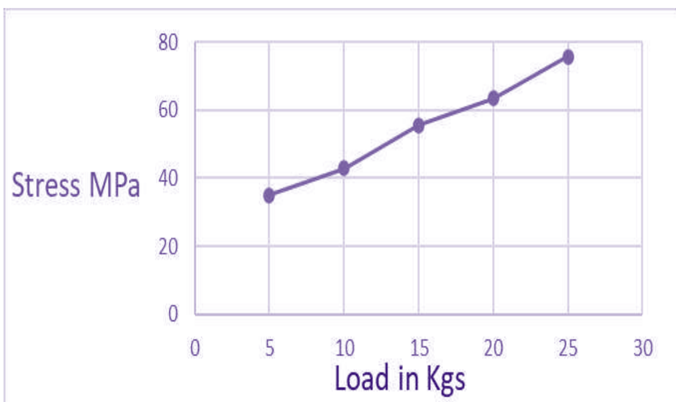


Figure 3.11: Equivalent Stress [9]



Load vs Stress Graph

Figure 3.12: Load Vs Stress



The load weight, load distribution size, and shape of the forklift play an important role in the movement of the vehicle while in operation. So, the load Vs stress graph has been plotted as shown in Figures. From Figure 3.12 it is observed that as the load on the fork gradually increases from 0 to 30 kg, as the load increases the stress also increases. This occurs due to insufficient torque exerted by the motor as the load increases above 30 Kg.

3.3 Design of Winch

1) Wire Rope

Load acting on wire rope Q=110 Kgf
No. of bends = 6
Effective bends & 6/2 =3
No of fall = 3+1=4
Selection wire rope (6x37) .... PSG 9.1[13]
D/d = 17
Dmin/d = 23 as no. of bends = 3
where, F=110/4=27.5
Breaking strength of wire rope
P = F*σu/{σu/n-d/Dmin*36000} = 345Kg
Selecting a standard rope diameter of 10mm for a breaking strength of 345kg
Stress, h = n* duty factor = 5*12 = 6
Checking the life of the rope
N = 0.4*Z /a*β*Z2
Where, a = 1000 for light duty
Z2=4
D/d=m*σ*C1*C2*C+8…………….PSG 9.7 [13]
Therefore, σ= 10F/πd^2 = 0.875
C1 = 0.89, C2=0.89, C=1.02
17= mx0.875x0.89×0.69×1.02 +8
∴ m= 12.7
Z30 ∴N =12.1 months

2) Bearing

Axial load on the bearing, Fa = 0N
Radial load on the bearing, Fr = 1000N
P= (X Fr +Y Fa) = 1000N
Let the speed of bearing operated, N = 50 rpm
Assuming the life of the bearing is 6000 hrs.
And chances of survival are 95%
Then, Bearing Life L10h = (L10 h * 60 * N) /106
= (60*50*6000) / 106
= 18 Life in Million revolutions
Dynamic load carrying capacity,
$C = P \times (L10\ mr)^{1/k}$
Where, k = 3 for ball bearing

$C = 1000 \times (18)^{1/3} = 2620.74$ N
∴ The selected bearing is DGBB SKF 6202
Where, Inner diameter = d = 15mm;
Outer diameter = D = 35 mm; Width = B = 11mm

3) Chain and Sprocket

For the given chain and sprocket,
The diameter of the bigger sprocket = D = 66mm, and smaller sprocket = 26mm
No. of teeth on bigger sprocket = N = 32 and smaller sprocket

= N1 = 13

1. Determine Chain Pitch

$P = \frac{\pi \times D}{N} \qquad P = \frac{\pi \times 66}{32}$

$P \approx 6$ mm

2. Calculate Chain Length

$L = \frac{P}{\pi} \times \left(N + N_1 + \frac{(2C)}{P}\right)$

Assuming $C = 100$ mm

$L = \frac{6}{\pi} \times \left(32 + 13 + \frac{(2 \times 100)}{6}\right)$

$L \approx 150$ mm

3. Determine of Speed of the driven sprocket

Given the motor speed is 250rpm, calculate the speed of the driven sprocket:

Speed of Driven Sproet $= \frac{\text{Motor Speed}}{i} = \frac{250}{32/13}$

The speed of the Driven Sprocket ≈ 100pm

4. Determine Torque

$T = \frac{T_{\text{motor}} \times N_1}{N} = \frac{0.8 \times 32}{13}$

$T \approx 1.96$Nm

5. Determine Center Distance

$C = \frac{P}{2} \times (N + N_1) \qquad C = \frac{6}{2} \times (13 + 32)$

$C \approx 135$ mm

6. Calculate Angular Velocity

$\omega = \frac{2\pi \times \text{ Speed of Driven Sprocket}}{60} \qquad \omega = \frac{2 \times \pi \times 100}{60}$

$\omega \approx 10.47$rad/s

7. Determine Linear Velocity

$R_p = \frac{D}{2} = \frac{26}{2} = 13$ mm

$V = R_p \times \omega = 13 \times 10.47$

$V \approx 136.1$ mm/s

8. Determine Tension in the Chain

$T_c = \frac{2 \times P_t}{V} \qquad T_c = \frac{2 \times 0.0166}{0.01361}$

$T_c \approx 0.243$kN

9. Determine No. of Links

$Ln = \frac{2C}{P} \times \left(\frac{(Z1+Z2)}{2} + \frac{(Z1-Z2)}{2} \quad + \frac{P}{C}\right) = 56$ links

Given that the number of links is 56 and the standard weight is 0a .02 kg/ link for a roller chain commonly used in automotive applications:

Chain Mass = 56 × 0.02

Chain Mass = 1.12 kg

10. Calculate Chain Sag

With the vehicle speed, the chain sag is still calculated as before:

Chain Sag = $0.02 \times C$

Chain Sag = 0.02 × 170.50

Chain Sag ≈ 3.41 mm

4) Motor

The selection of the motor is made based on how much weight the forklift is made to carry.

Let us assume that the motor will be used to carry 20kgs of weight.

Required torque of motor (Mt) = 1969.23 N-mm

Required speed of motor (N) = 100 rpm

Type of supply to motor = 12 Volt D.C.

The torque required to raise the maximum load in N-mm

= (Mt)/ (9.81 ×10)

= 1969.42*9.81 ×20)

= 386317.8 N-mm

= 38.63 N-m

Required speed of motor shaft in rpm = 50 rpm

We had to search the market carefully then we found no motor available with this specification so we chose a motor with 100 rpm 100 Kg-cm torque motor.

Table 3: Selection of battery

Parameter	Motor specification
Type of motor	DC Wiper Motor
Speed of Motor	100 RPM
The output torque of the motor	130 N-m
Input Voltage and current	12V 5A at maximum load

5) Battery Calculations

Battery Size in AH = $W \times H / V$

W = Total load = 300 watts (assuming the maximum of 50 kg load can be lifted and drive the motor for the wheel as well)

H = Backup time in hours = 6 hours (assumption … for 4 hrs testing and 2 hrs for presentation)

V = battery voltage = 12 volt

Load Assumption = 300 watt

$= \frac{\text{total load} \times \text{backuptime in hours}}{\text{batter voltage}}$

= 300 × 6/12

= 150 AH (standard size available)

Since the motor is of 24 V, hence 2 batteries of 12 V each would be connected in series**.**

From the battery available range in the market, we assume the battery capacity is 12V, 7.2 Ah

Required battery capacity = V × I = 12 × 7.2

= 84.4 Watt

But consider the deep cycle of the battery is 80% of the total capacity of the battery

Running capacity of battery = 0.80 × required battery capacity

= 70 Watt

We consider the following working times –

Load raise time = 5 min

Load lower time = 5 min

Travel time = 15 min

Total time of one operation cycle = 25 min
So, a total time of 25 min battery requires 10 min and in 1 hour we use 1 times battery when fully charged.
From above calculation we can say that a fully charged battery of 12V can be used approximate 3 hour.
Battery usage can decrease with increase in load.

3.4 Design of Driving chain and sprocket and motor selection

For the given chain and sprocket,
The diameter of the bigger sprocket = D = 76mm, and smaller sprocket = 38mm
No. of teeth on bigger sprocket = N = 30 and smaller sprocket = N1 = 19
1. Driving chain and sprocket
1. Determine Chain Pitch

$$P = \frac{\pi \times D}{N}$$

$$P = \frac{\pi \times 38}{19}$$

$$P \approx 6.2 \text{ mm}$$

Calculate Chain Length $L = \frac{P}{\pi} \times \left(N + N_1 + \frac{(2C)}{P}\right)$

Assuming $C = 100$ mm :

$$L = \frac{6}{\pi} \times \left(19 + 30 + \frac{(2 \times 100)}{6}\right)$$

$$L \approx 157.24 \text{ mm}$$

2. Determine Motor Speed
Given the motor speed is 50rpm, calculate the speed of the driven sprocket:

Speed of Driven Sprocket $= \frac{\text{Motor Speed}}{i} = \frac{50}{\frac{19}{30}}$

The speed of Driven Sprocket $\approx$ 78.95rpm
Determine Torque

$$T = \frac{T_{\text{motore}} \times N_1}{N} = \frac{0.8 \times 30}{19}$$

$$T \approx 1.26\text{Nm}$$

Determine Center Distance

$$C = \frac{P}{2} \times (N + N_1)$$

$$C = \frac{6}{2} \times (19 + 30)$$

$$C \approx 147 \text{ mm}$$

3. Calculate Angular Velocity

$$\omega = \frac{2\pi \times \text{ Speed of Driven Sprocket}}{60}$$

$$\omega = \frac{2 \times \pi \times 78.95}{60}$$

$$\omega \approx 8.26\text{rad/s}$$

4. Determine Linear Velocity

$$R_p = \frac{D}{2} = \frac{38}{2} = 19 \text{ mm}$$

$$V = R_p \times \omega$$

$$V = 19 \times 8.26$$

$$V \approx 156094 \text{ mm/s}$$

5. Determine Tension in the Chain

$$T_c = \frac{2 \times P_t}{V}$$

$$T_c = \frac{2 \times 0.0166}{0.156}$$

$$T_c \approx 0.212 \text{ kN}$$

6. Calculate Chain Speed
Given the motor speed is 50rpm, calculate the chain speed:

Chain Speed $= \frac{\pi \times D}{60} \times$ Motor Speed

Chain Speed $= \frac{\pi \times 20}{60} \times 50$

Chain Speed ≈ 5.24 m/s
7. Determine Chain Mass
Given that the number of links is 19 and the standard weight is 0.15 kg/ link for a roller chain commonly used in automotive applications:
Chain Mass $= 19 \times 0.15$
Chain Mass $= 2.85$ kg
8. Calculate Centrifugal Force
Calculate the centrifugal force acting on the chain:

$$F_c = m \times \left(\frac{V}{g}\right)^2$$

Given that $m = 2.85$ kg/m, $V \approx 5.24$ m/s, and $g = 9.81$ m/s^2 :

$$F_c = 2.85 \times \left(\frac{5.24}{9.81}\right)^2$$

$$F_c \approx 3.02 \text{ N}$$

9. Calculate Chain Sag
With the vehicle speed, the chain sag is still calculated as before:
Chain Sag $= 0.02 \times C$
Chain Sag $= 0.02 \times 170.50$
Chain Sag ≈ 3.41 mm

2. Selection of Motor

The motor selected for this chain and sprocket is a DC wiper motor of 24V which is double the power of the previous motor the torque of the motor is 0.8 N-m and the speed is 250 RPM.

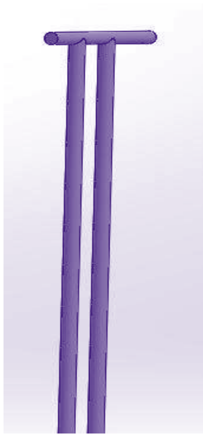
3.5 Design for Ergonomics

A. Design Optimization: In design optimization for ergonomics, the goal is to fine-tune various elements to ensure maximum comfort, safety, and efficiency for users. It is optimized in all the aspects such as functionality, performance, cost-effectiveness, sustainability, reliability and safety, manufacturability, and scalability the most important are physical aspects such as size, shape, etc. Physical aspects are discussed below in detail.

B. Environment Optimization: Environmental optimization in design for ergonomics involves considering the impact of design decisions on the surrounding environment and incorporating strategies to minimize negative environmental effects such as proper material selection, energy efficiency, waste reduction, and regulatory standards. Our forklift design uses less material due to its compact size and shape; it is electrically operated hence it is green.

C. Physical Ergonomics: Handle, The design of the handle is one of the most important aspects of ergonomics in forklifts. Handel is meant for comfort and smooth driving of the vehicle. The handle is arranged in such a way that two rods are attached vertically to the front chassis and a small rod is attached to those two vertical rods shown in the figure. The material used for the handle is aluminum circular rod. The height of the efficient handle is determined:The height of the forklift from the ground is approximately 1.2 meters. the height of the mast is 950mm.

Figure 3.13: Handle [7]



1. Determine the Height of the Handle from the Base –

Taking an average of male & female height

= 1000 mm

As we know in workplaces workers always wear shoes or any kind of footwear so the thickness of footwear is also to be taken into account. So, considering a normal shoe sole is approximately 25.4mm.

Adding this extra height in average1000.2 + 25.4 = 1025.4mm

So, let's take the height of the handle from the base as 900 mm.

Seat

Seat is not installed in the prototype model of the forklift. The seat can be adjusted on the rear chassis at a height of an average human height as shown in the figure.

Fig 3.14: Seating arrangement on the forklift [7]

3.6 Steering System

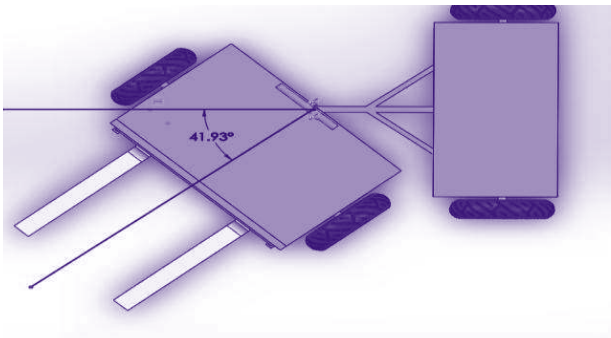
Turning Mechanism: In this forklift design, a nut and bolt steering arrangement is utilized, a simple and mechanical mechanism commonly found in older or simpler vehicles.

Figure 3.15: Turning Mechanism

The key components include a threaded rod (bolt), a steering wheel, and a nut. The threaded rod connects to the steering wheel and passes through the nut, which is affixed to the rear chassis via a tube. As the steering wheel is turned, the threaded rod rotates, causing the nut to move along its length due to the threaded connection. This movement is transmitted to the chassis, steering linkage, and ultimately to the wheels, resulting in the desired direction of motion. This mechanism translates steering wheel movements into lateral movement of the chassis, facilitating steering control of the vehicle.

Turning Angle: The turning angle, also known as the steering angle, is a crucial parameter in vehicle dynamics, indicating the degree to which the wheels are turned from their straight-ahead position. It determines the sharpness of a vehicle's turns and is controlled by the steering mechanism. In the case of the forklift discussed, the turning angle is depicted in Figure 5.14, showing that the front chassis of the forklift can be turned at an angle of 42 degrees. This measurement provides valuable insight into the manoeuvrability and turning capabilities of the forklift during operation.

Figure 3.16: Turning Angle [7]



4. TESTING

4.1 Load Test on Fork: For Lifting we are using a motor with a pulley and motor having a power rating of 12V, which gives approximately 20 Nm torque and can lift easily up to 30 kg. Hence, we are going with this reversible motor having this much torque and an output speed of 30 rpm. The material of the fork is carbon steel which can carry loads up to 20 - 25 kg without deformation.

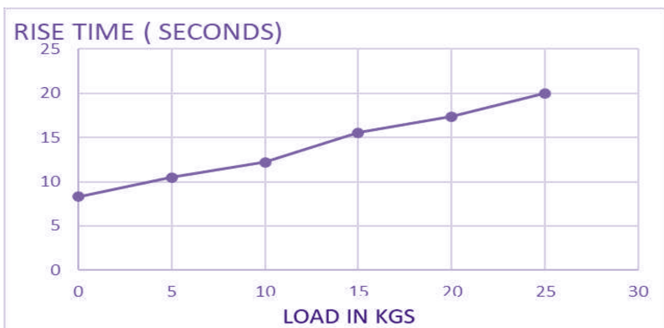
Load calculations:
Total load that has to be lifted by the motor [10]
= weight to be lifted + fork weight + some extra
= 25 + 5 + 1 = 31 kg ≤ loading capacity
Our motor can easily take load therefore safe for capacity,
Velocity of lifting = π × Pulley dia. × output speed
= π × 0.07 × 30 = 6.59 m/min

Since the recommended maximum velocity of lifting is 8 to 10 m/min such that no accident takes place because of inertia,

Velocity = 6.59 m/min ≤ 8 m/min, hence safe

The graph shown below is of the Total load on the fork and the rise time of the fork at 1-meter height. In the initial condition, the fork was lifted without any load the only weight acting on the motor was of the fork i.e. 5kg. Let us consider this as zero weight according to the graph which has a rise time of 6 seconds. The weight of the fork is gradually increased by 5kg up to 25 kg. The result is shown in the given graph. This graph states that the time increased by the increase in load.

Figure 4.1: Load Vs Rise Time



4.2 Speed Test on Vehicle: A vehicle speed test involves measuring the vehicle's speed under controlled conditions. Key factors to consider include selecting a suitable testing area, preparing equipment accurately, marking the course, and following a standardized testing procedure. This typically involves accelerating smoothly along a designated course while recording time and distance. Average speed is then calculated using the formula Speed = Distance/Time. To enhance accuracy, multiple runs may be conducted, accounting for external factors like wind resistance or road conditions. Results should be documented for analysis and verification.

Load Vs Speed

Load vs. speed describes the relationship between the load (or weight) applied to a system and its resulting speed. Generally, as the load increases, the speed at which the system operates decreases. This is often observed in various mechanical systems such as motors, batteries, or even human movement. The load can create resistance, which requires more energy to overcome, thus reducing the speed of the system. Conversely, reducing the load can lead to an increase in speed, assuming other factors remain constant.

For driving we are using 1 motor on the rear wheels separately of PMDC type because the manufacturer is using the same motor that can easily take 90 kg load. It has to carry lifting mechanism weight in addition to that body, motor, and battery weights.

Load calculations: let us consider a driver weight of approximately 60kgs [10]

Total load = total load lifted +driver weight + battery + body weight

= 30 + 60 + 10 =100kg ≤ loading capacity

Our motor can easily take load therefore safe capacity

Velocity of vehicle = π × tire dia. × output speed

=π × 0.27 × 200× 3.6 /60

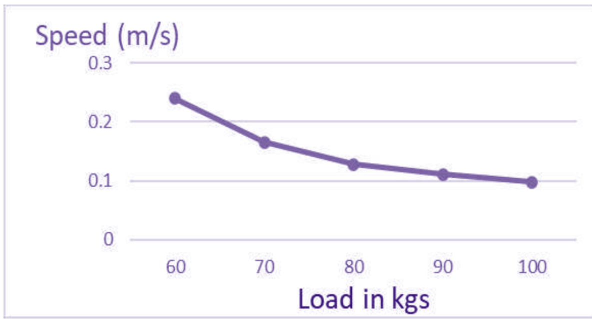
=10 kmph = 3.02 m/s

Which is within the range recommended hence safe. The above value of speed is numeric calculation of vehicles speed without any load on the fork as well as on the vehicle. Let us consider the overall dead weight on the forklift to be a minimum of 60 kg and increase up to 100 kg. The test course is taken for 10 meters same for all loads on plane surface road.

Table 4: Speed Calculation

Load (kg)	Time (sec)	Speed (m/s)
60	49	0.24
70	60	0.166
80	78	0.128
90	90	0.111
100	102	0.098

Figure 4.2: Speed VS Load



Speed test at various conditions

A forklift speed test at various road conditions typically involves measuring the forklift's speed on different surfaces like concrete, asphalt, gravel, and uneven terrain. The purpose is to evaluate how the forklift performs in terms of stability, traction, and overall efficiency across these conditions.

Concrete: Forklifts usually perform well on concrete surfaces due to their smooth and even texture, allowing for higher speeds with good stability. It took 45 seconds to reach a distance of 10 meters.

Asphalt: Similar to concrete, asphalt provides a relatively smooth surface, enabling forklifts to maintain decent speeds with stability. It took 43 seconds to reach the same distance.

Gravel: Forklifts may experience reduced speed and stability on gravel due to the uneven surface and reduced traction. Careful driving is required to prevent slippage and maintain control. The forklift required approximately 1 minute to reach 10 meters.

Uneven terrain: Forklifts may encounter challenges such as bumps, potholes, or inclines on uneven terrain. Speeds may need to be reduced significantly to ensure safety and stability while navigating these conditions. It took a much longer time to reach 10 meters compared to the other three conditions.

4.3 Cost Estimation: Cost estimating is a way of finding the cost that is likely to be incurred in manufacturing a forklift before it is manufactured. This calculates material cost, labor cost, and various miscellaneous costs. Based on these estimated cost data, the cost of production, selling price, and profit estimates.

Components Cost

Table 5: component Cost

Components	Quantity	Cost in Rs/-
Battery 24W	1	2000
Tires (30 cm)	4	1200
Pulley and wire	1	350
Motor (12 and 24V)	2	1000
Pedestal Bearing	4	20
Switches and wires	2	400
Chain and sprocket	2	800
Wooden block	1 mtr	100
MS hollow square pipe	8 mtr	800
Metal Rod	4 mtr	400
Steel Plate	6 mtr	580
Nut and bolt	20	350
Fasteners	15	50
Welding Rod	1 box	320
Grinding Wheel	1	105
Labour		2000

Total Cost of Project

Total Cost = Cost of various components + Metals + Labour Cost + Miscellaneous Cost

= Rs. 10,650/-

5. RESULT AND DISCUSSION

5.1 Result: In the context of evaluating forklift performance, load tests assess the system's capability to handle varying levels of simulated user activity by gradually increasing loads. This evaluation helps determine capacity, response time, and overall effectiveness, crucial for optimizing scalability and ensuring user demand can be met without compromising performance. From the above load test, it can be stated that fork can take maximum of 25kg of load without deformation. Conversely, speed tests focus on assessing responsiveness and latency under load conditions, providing insights into system efficiency and user experience. Together, these tests offer a comprehensive evaluation of forklift performance. Speed test gives results such that maximum effective load carrying capacity of forklift is 80kgs including all kind of loads. Additionally, cost estimation involves projecting expenses associated with the project, aiding in budget allocation and resource management. In the case of the forklift, the minimum estimated cost for fabrication is approximately Rs.11,000, considering various expenses like labor, materials, and equipment.

5.2 Discussion: Our forklift is environment-friendly because we use stored energy i.e. battery and not any fossil fuel. From the design calculation of battery usage, a fully charged battery can be used for 3 hours continuously, where we required more amount of fossil fuel which increase the cost. The forklift is optimized in by size, shape, orientation, cost, mode of work compared to traditional forklift. It is optimized by 80% by traditional forklift in all aspects. Our compact forklift is used in small industries, workshops, supermarkets, departmental stores, etc. where traditional bulky and costly forklifts are not needed. Hence our main priority is to make it cost effective which was made possible so that small workshops can purchase it easily. The cost of our forklift increases when high quality materials are used and to increase load carrying capacity.

6. CONCLUSION AND FUTURE SCOPE

6.1 Conclusion: The research work focuses on the design and fabrication of a forklift, leading to several key conclusions. Firstly, the forklift can effectively carry a maximum load of 25kg and operate on a rechargeable battery, providing continuous functionality for 3 to 4 hours per charge. Secondly, analysis confirms the forklift's ability to withstand loads while remaining economical, reliable, and environmentally friendly. Thirdly, motor specifications are calculated based on desired load and acceleration parameters, contributing to the forklift's efficiency. Fourthly, the successful design and fabrication of a prototype model are achieved. Future research avenues include investigating weight changes and stability during turning and speeding processes. Overall, the developed mechanical forklift enhances ergonomics, reduces manual labor, and improves safety, benefiting production industries and individuals alike. Its compact design, electric power source, and eco-friendly operation further underscore its utility and appeal. Thorough testing validates the design's effectiveness and comprehensive consideration of all aspects.

6.2 Future Scope: The future outlook for compact forklifts is promising, driven by several key trends and technological advancements. Firstly, there's a growing demand for efficiency and space optimization in warehouses and industrial settings, fueling the need for compact equipment that can navigate tight spaces and handle smaller loads with precision. Compact forklifts offer flexibility and agility, enabling businesses to maximize storage capacity and streamline operations. Moreover, advancements in electric and autonomous vehicle technology are shaping the development of compact forklifts by use of IOT. Electric models offer cost savings, reduced emissions, and quieter operation, while autonomous features such as obstacle detection and remote monitoring enhance safety and productivity. In summary, the future of compact forklifts lies in their ability to provide enhanced maneuverability, efficiency, and sustainability, meeting the evolving demands of warehouse and industrial operations.

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