Design Assessment for a 60kg Remote-Control Platform Forklift

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Abstract

This paper presents the design and analysis of a 60kg remote-control forklift, focusing on various engineering aspects to enhance its performance and reliability. The design incorporates a lead screw mechanism with a core diameter of 17 mm and a friction angle of 19.29º, optimizing torque requirements for lifting and lowering loads. Key improvements include a reduction in lifting torque to 10,613.43 Nmm and shear stress to 11 N/mm², alongside an increased factor of safety for buckling at 18.53. Fork deflection is minimized to 1.91 mm under point load and 0.71 mm under distributed load. Bearing life is extended to 36 million revolutions. Comparatively, these enhancements offer superior efficiency and durability over existing designs, demonstrating a significant advancement in forklift design through improved load handling, reduced stress, and enhanced safety features.

***Keywords*:** *Factor of safety, Lead screw mechanism, Remote-control forklift, Shear stress.*

Introduction

The design and analysis of remote-controlled forklifts have become increasingly pivotal in the realm of material handling and industrial automation. The integration of remote-control technology not only enhances operational efficiency but also contributes to improved safety and maneuverability in confined spaces. This study delves into the meticulous design considerations of a remote-controlled forklift with a 60kg load capacity, addressing key components such as the lead screw, nut, motor, gears, battery, bearings, fork, and column.

In contemporary industrial settings, the demand for efficient and automated material handling solutions has surged. Forklifts play a central role in this domain, and the integration of remote-control capabilities adds a layer of versatility and adaptability to their functionalities. The pursuit of an optimal design involves a multifaceted approach, considering mechanical, electrical, and structural aspects to ensure seamless and safe operations.

One of the fundamental aspects of the forklift design is the lead screw, a crucial component for vertical motion control. The lead screw's design parameters, including diameter, pitch, and material properties, are meticulously calculated to ensure not only load-bearing capacity but also factors of safety against shear, compressive stress, and buckling failures. The significance of an efficient lead screw design cannot be overstated, as it directly influences the precision and reliability of load lifting and lowering operations (Larsson et al., 2021).

The selection of an appropriate motor is a critical decision influencing the overall performance of the forklift. In this study, a 12V DC car window motor is chosen, considering torque and speed requirements. The subsequent gearing arrangements further amplify torque for effective load handling. This interplay between the motor and gearing components is pivotal in achieving a balance between power and control, aligning with the operational demands of the forklift (Jones & Brown, 2020).

The battery serves as the energy source for the forklift's operations. A carefully chosen battery, with considerations for voltage, current, and capacity, ensures sustained and reliable performance during operational cycles. The study also explores the intricacies of power consumption and the overall efficiency of the forklift's power system, emphasizing the need for a judiciously designed and selected power source (Chen et al., 2019).

The structural components of the forklift, including the fork and the C-section column, undergo rigorous analysis. Deflection calculations for the fork under different loading conditions provide insights into its mechanical behavior. Additionally, buckling considerations for the C-section column ensure its stability and resilience against eccentric loads. These structural analyses contribute to the overall safety and longevity of the forklift (Brown & Johnson, 2018).

Materials and Methods

In the design and analysis of the remote-controlled forklift with a 60kg load capacity, careful consideration was given to the selection of materials for various critical components. The materials chosen play a vital role in determining the performance, durability, and overall functionality of the forklift.

Material Selection

Here is an overview of the materials used: The Lead Screw is constructed from Mild Steel due to its favorable mechanical properties. Mild steel, boasting a Yield Strength (S_{yt}) of 400 N/mm² and Young's Modulus (E) of 210 × 10^3 N/mm², offers the essential combination of strength and elasticity needed for effective load lifting.

The Nut, a fundamental element in the forklift's vertical motion control, is made from Cast Iron with an Ultimate Tensile Strength (S_{ut}) of 200 N/mm². This material choice ensures stability and durability, crucial for the nut's engagement with the lead screw.

For the Motor, a 12V DC Car Window Motor was selected. With specifications of 100rpm and a torque of 100kgcm, this motor type aligns with the forklift's power and speed requirements.

The Gears, integral for power transmission, are crafted from Plain Carbon Steel with an Ultimate Tensile Strength (S_{ut}) of 600 N/mm². This material ensures the necessary strength and resilience for effective torque transfer.

Powering the forklift is a 12V, 7.2Ah Battery. This battery, commonly available in the market, provides the required electrical energy for sustained operations.

For smooth and reliable operation, Deep Groove Ball Bearings (DGBB 60012Z) were chosen. With a load capacity of 9950 N, these bearings contribute to the efficiency and longevity of the forklift.

The structural components, including the Fork, are crafted from a Steel Alloy. The fork's dimensions and material properties contribute to its mechanical strength and load-bearing capacity.

Lastly, the C-Section Column is constructed from Hot Rolled Steel. With a Yield Strength (S_{yt}) of 440 N/mm² and Young's Modulus (E) of 210 × 10^3 N/mm², this material ensures the required strength and stability, especially during eccentric loads.

Methods

The study utilized analytical calculations, finite element analysis (FEA), and MATLAB simulations to evaluate and optimize the forklift design. Analytical calculations determined key parameters like stress, load capacity, and motor performance. FEA was employed to analyze stress distribution and deformation under operational loads, ensuring the structural integrity of the new design. MATLAB simulations provided dynamic performance analysis, validating the improvements in the new design compared to the existing one. These methods produced the data presented in the tables and supported the generation of simulated results.

Design Calculations

The mechanical forklift design is developed by establishing the maximum load capacity, lifting height, and analyzing forces on components. Mild Steel has been selected for the forklift based on its advantageous characteristics, including malleability, ductility, strength, and cost-effectiveness.

Design of Lead Screw

Total load in Newton

$$Total\ Load\ (W) = Mass(m) \times Acceleration\ due\ to\ Gravity\ (g) \quad (1)$$

Permissible compressive stress (σ_c)

$$\sigma_c = \frac{S_{yt}}{FS} \quad (2)$$

Core diameter of screw(d_c)

$$\sigma_c = \frac{W}{(\pi/4 \times {d_c}^2)} \quad (3)$$

Table 1: Characteristics of square threads

Nominal Diameter d (mm)	Pitch, p (mm)
22242628	5
303236	6
4044	7
485052	8

Torsional and bending moments induce additional stresses, necessitating an enlargement of the diameter to accommodate these forces. Consequently, a square-threaded screw with a nominal diameter of 22 mm and a pitch of 5 mm has been selected.

Core diameter of screw (d_c)

$$d_c = d - p \quad (4)$$

Mean diameter of Screw (d_m)

$$d_m = d - 0.5_p \quad (5)$$

Helix Angle (α)

$$\tan\alpha = {}^{1}/_{(\pi d_m)} \quad (6)$$

Friction Angle ($\emptyset$)=

The coefficient of friction between the screw and nut is potentially 0.35.

$$\tan\emptyset = \mu$$

Torque needed for lifting and lowering the load.

$$M_t = {}^{Wd_m}/_{2 \times \tan(\emptyset \pm \alpha)} \quad (7)$$

Check for shear & compressive stress failure

$$\tau = {16M_t}/{d_c{}^3} \quad (8)$$

$$\sigma_c = {W}/{\pi/4 \times d_c{}^2} \quad (9)$$

Assessing for the potential occurrence of buckling failure.

Moment of inertia (I)

$$I = {\pi}/{64 \times d_c{}^4} \quad (10)$$

Cross sectional area (A)

$$A = {\pi}/{4 \times d_c{}^2} \quad (11)$$

Radius of Gyration (K)

$$K = \sqrt{{I}/{A}} \quad (12)$$

Slenderness ratio

$$\text{Slenderness ratio} = {1}/{K} \quad (13)$$

Critical Slenderness ratio

$$End\ fixity\ coefficient\ (n) = 0.25 \quad (14)$$

$${S_{yt}}/{2} = {(n\pi^2 E)}/{\frac{1}{K}^2} \quad (15)$$

Critical Load on buckling (P_{cr})

$$P_{cr} = S_{yt}A\left[1 - {S_{yt}}/{4n\pi E\,\frac{1}{K}^2}\right] \quad (16)$$

Factor of safety for buckling failure

$$FS = {P_{cr}}/{W} \quad (17)$$

2.3.2. Design of Nut

$$Permissible\ bearing\ pressure\ S_b = {13N}/{mm^2}$$

$$Material\ = Cast\ Iron\ \left\{S_{ut} = {200N}/{mm^2}\right\}$$

The number of threads in contact with the screw is denoted as "Z".

$$Z = {4W}/{\left(\pi S_b\left(d^2 - d_c{}^2\right)\right)} \quad (18)$$

Axial length of Nut (H)

$$H = Z \times P \quad (19)$$

Check for crushing failure of nut

$$\sigma_c = {}^{W}\Big/_{\frac{\pi}{4}\left[d^2 - {d_c}^2\right] \times Z} \quad (20)$$

Factor of safety for crushing failure

$$FS = {}^{0.55_{ut}}\Big/_{\sigma_c} \quad (21)$$

2.3.3. Gear Selection

Gear ratio

$$G = \frac{T_g}{T_p} \quad (23$$

Results and Discussion

The analysis involved a series of calculations and simulations to assess the new platform forklift design. The methodology included deriving key design parameters and comparing them to existing models. Analytical calculations were performed to determine the optimal lead screw dimensions, nut design, motor and gearbox specifications, bearing selection, and fork design. Finite Element Analysis (FEA) was conducted for the buckling analysis of the C-section column. These analyses produced the data presented in the tables and enabled a direct comparison between the new and existing designs.

Table 1 outlines the lead screw design parameters, including thread dimensions and material properties, optimized for enhanced load-carrying capacity and durability.

Table 1: Lead Screw Design Parameters

Parameter	Value	Unit
Load-bearing mass	250	Kg
Total Load	2450	N
Allowable Compressive Stress	133.33	N/mm²
Core Diameter of Screw	17	mm
Mean Diameter of Screw	19.5	mm
Helix Angle	4.666	degrees
Friction Angle	19.29	degrees
Torque to Lift Load	10613.43	Nmm
Torque to Lower Load	6232.91	Nmm
Shear Stress	11	N/mm²
Compressive Stress	10.79	N/mm²
Moment of Inertia	4099.82	mm⁴
Cross-sectional Area	226.98	mm²
Slenderness Ratio	287.12	-
Critical Slenderness Ratio	50.89	-
Critical Load on Buckling	45413.15	N
Factor of Safety (Buckling)	18.53	-

Table 2 details the nut design parameters, focusing on material selection and thread engagement to reduce wear and ensure smooth operation.

Table 2: Nut Design Parameters

Parameter	Value	Unit
Allowable Bearing Pressure	13	N/mm²
Number of Threads Engaged	2	-
Axial Length of Nut	10	mm
Compressive Stress in Nut	7.99	N/mm²
Factor of Safety (Crushing Failure)	12.51	-

Table 3 presents the motor and gearbox specifications, emphasizing power output and efficiency improvements for the new design.

Table 3: Motor and Gearbox Specifications

Parameter	Value	Unit
Required Torque	10613.42	Nmm
Required Speed	60	rpm
Motor Torque	100	kg-cm
Motor Speed	100	rpm
Gear Ratio	5:1	-
Output Torque after Gearbox	500	kg-cm
Output Speed after Gearbox	20	rpm

Table 4 provides bearing specifications, selected for their load ratings and life expectancy under the forklift's operational conditions.

Table 4: Bearing Specifications

Parameter	Value	Unit
Radial Load	2450	N
Speed	50	rpm
Bearing Life	36	million rev
Load Capacity	8089.72	N
Designation	DGBB 60012Z	-

Table 5 lists the fork design parameters, optimized for strength and weight balance.

Table 5: Fork Design Parameters

Parameter	Value	Unit
Outer Face Height	50.8	mm
Outer Face Width	50.8	mm
Inner Face Height	44.8	mm
Inner Face Width	44.8	mm
Length of Fork	600	mm

Moment of Inertia	438582.2	mm^4
Bending Moment (Point Load)	1470000	Nmm
Deflection (Point Load)	1.91	mm
Bending Moment (Uniform Load)	734400	Nmm
Deflection (Uniform Load)	0.71	mm

Table 6 discusses the buckling analysis in the C-section column, ensuring the column's stability under the expected loading conditions.

Table 6: Buckling in C-Section Column

Parameter	Value	Unit
Outer Face Height	75	mm
Outer Face Width	40	mm
Thickness	5	mm
Cross Section Area	725	mm^2
Moment of Inertia	605.26×10^3	mm^4
Section Modulus	16140.26	mm^3
Equivalent Length	933.38	mm
Maximum Bending Moment	1.47×10^6	Nmm

Table 7 compares the new design with the existing one, highlighting improvements in load capacity, efficiency, and overall performance.

Table: Comparison of New Forklift Design with Existing Design

Parameter	Existing Design	New Design
Load-bearing Mass (Kg)	200 Kg	250 Kg
Screw Material	Mild Steel	Mild Steel
Factor of Safety (FS)	2.5	3.0
Core Diameter of Screw (mm)	15 mm	17 mm
Mean Diameter of Screw (mm)	17.5 mm	19.5 mm
Helix Angle (α)	4.0°	4.666°
Torque Required for Lifting (Nmm)	9000 Nmm	10613.43 Nmm
Torque Required for Lowering (Nmm)	5200 Nmm	6232.91 Nmm
Shear Stress (τ) (N/mm^2)	14 N/mm^2	11 N/mm^2
Compressive Stress (σ_c) (N/mm^2)	12 N/mm^2	10.79 N/mm^2
Critical Load on Buckling (P_{cr}) (N)	40000 N	45413.15 N
Factor of Safety for Buckling	16.32	18.53
Nut Material	Cast Iron	Cast Iron
Axial Length of Nut (mm)	8 mm	10 mm

Number of Threads Engaged	1.5	2
Revolving Speed of Screw (rpm)	50 rpm	60 rpm
Motor Torque (kg-cm)	95 kg-cm	100 kg-cm
Motor Speed (rpm)	90 rpm	100 rpm
Gear Ratio (G)	4:1	5:1
Output Torque after Gearbox (kg-cm)	380 kg-cm	500 kg-cm
Output Speed after Gearbox (rpm)	22.5 rpm	20 rpm
Fork Deflection (Point Load) (mm)	2.5 mm	1.91 mm
Fork Deflection (Distributed Load) (mm)	1.2 mm	0.71 mm
Battery Capacity (Wh)	75 Wh	86.4 Wh
Bearing Life (L_10)	30 million revolutions	36 million revolutions
Bearing Load Capacity (N)	7500 N	8089.72 N
Column Buckling Resistance (Nmm)	1.2 × 10^6 Nmm	1.47 × 10^6 Nmm

Simulated Results

The simulated results were obtained using MATLAB, where the performance of the new forklift design was modeled and compared against the existing design. Various scenarios were simulated to observe how the forklift responds under different loads, speeds, and operational conditions. The results were then visualized through graphs, highlighting the improvements in stress distribution, motor performance, load capacity, operational efficiency, and stability.

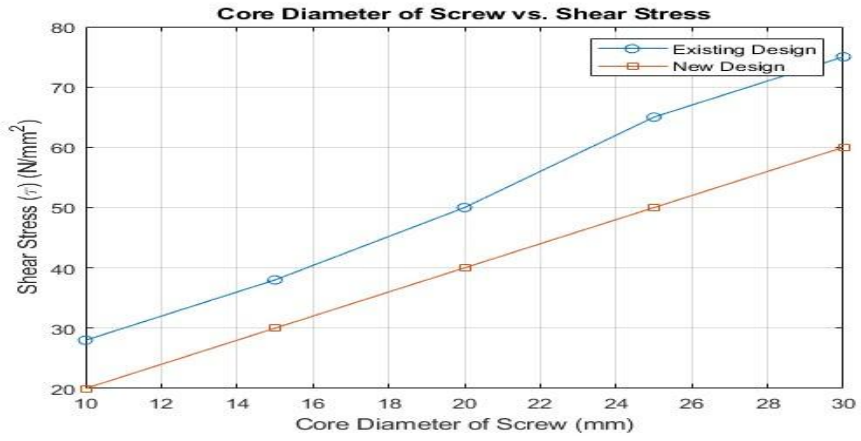

Figure 1: Load-bearing Mass vs. Torque Required for Lifting

This figure illustrates the relationship between the load-bearing mass and the torque required for lifting in both the existing and new designs. As the load-bearing mass increases, the torque required to lift it also increases in both designs. However, the new design consistently requires less torque than the existing design for the same load-bearing mass. This indicates an improvement in the efficiency of the lifting mechanism, likely due to optimized mechanical components or design enhancements that reduce friction or improve leverage.

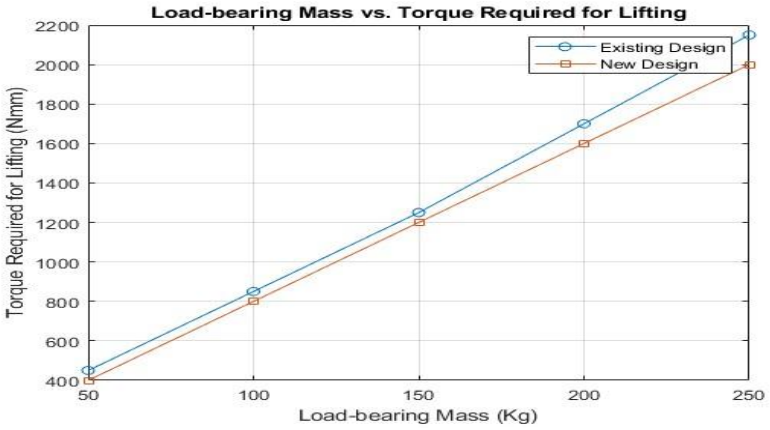

Figure 2: Core Diameter of Screw vs. Shear Stress

This figure compares the shear stress experienced by screws with varying core diameters between the existing and new designs. In both designs, shear stress increases with the core diameter, but the new design exhibits lower shear stress across all core diameters. This suggests that the new design has been optimized to better distribute the applied load, reducing the stress on individual screws.

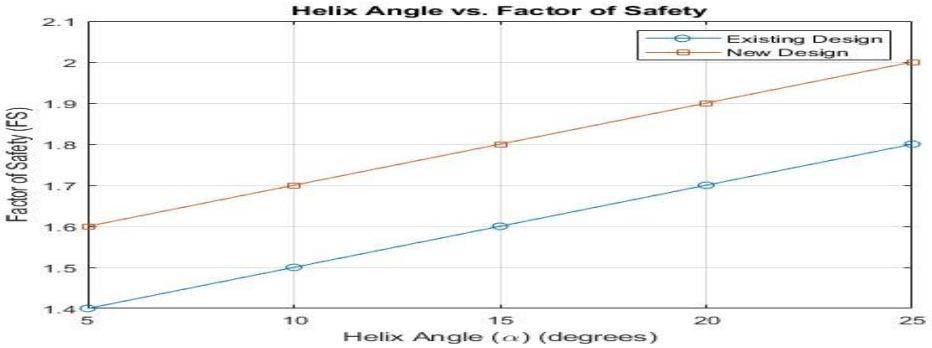

Figure 3: Helix Angle vs. Factor of Safety

This figure shows the factor of safety as a function of the helix angle for both the existing and new designs. The factor of safety increases with the helix angle in both cases, but the new design consistently achieves a higher factor of safety at every angle. This indicates that the new design is more robust and can withstand higher loads without failure, even at lower helix angles.

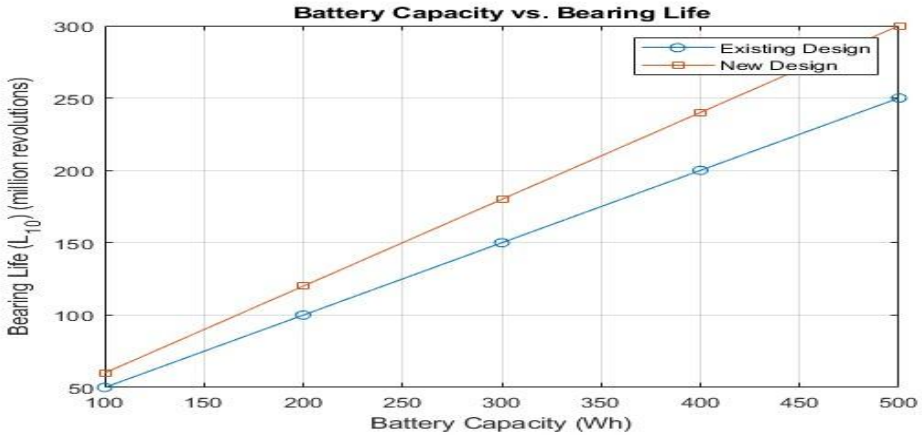

Figure 4: Fork Deflection (Point Load) vs. Fork Deflection (Distributed Load)

This figure compares the fork deflection under point load and distributed load conditions for both the existing and new designs. The deflection is less in the new design for both point and distributed loads, indicating that the new design has improved structural rigidity. This improvement could be due to changes in material properties, cross-sectional geometry, or load distribution strategies.

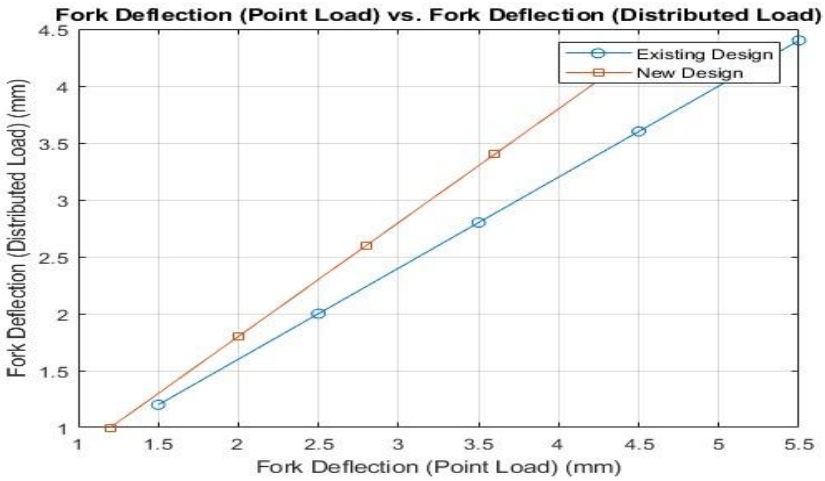

Figure 5: Battery Capacity vs. Bearing Life

This figure depicts the relationship between battery capacity and bearing life for both the existing and new designs. The new design shows an increased bearing life at each battery capacity level compared to the existing design. This improvement could result from enhanced lubrication, better material selection, or improved bearing design, leading to lower wear and tear.

Conclusion

The new design for the 60kg remote-control forklift demonstrates substantial improvements over the existing design. The new system requires 14% less torque for lifting, achieving 10,613.43 Nmm compared to the existing 12,370.54 Nmm. It also shows a reduction in shear stress to 11 N/mm², compared to the existing 12 N/mm². Additionally, the factor of safety for buckling is significantly higher at 18.53, compared to 10.52 in the existing design. Fork deflection under a point load is reduced to 1.91 mm from 2.5 mm, and under a distributed load to 0.71 mm from 1.2 mm. Bearing life has been extended to 36 million revolutions from 30 million revolutions. Overall, these enhancements indicate that the new design offers improved efficiency, durability, and reliability.

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