International Journal on Mechanical Engineering and Robotics

ISSN: 2321-5747

Volume 11 Issue 1 (2022) | Pages: 1-5

Design and Manufacturing of an Attachable Power-Assist Electric Wheelchair for Mobility Enhancement of Physically Challenged Persons

Ravindra Awale[1], Akash Kumbhare[2], Krushanu Meshram[3], Pranay Kamble[4], Ashwini Admane[5*]

[1,2,3,4,5]Department of Mechanical Engineering, Shree Chanakya Education Society's Indira College of Engineering and Management, Parandwadi, Savitribai Phule Pune University, Pune, Maharashtra, India

Corresponding Author: ashwiniphalke65@gmail.com

Peer Review Information

Type: *Article*
Received: *16 April 2022*
Revised: *12 May 2022*
Accepted: *15 June 2022*
Published: *05 July 2022*

Abstract

Manual wheelchair propulsion causes severe physical fatigue and limits long-distance autonomy for lower-limb impaired individuals. This research presents the end-to-end design, kinematic modeling, FEA verification, and fabrication of a quick-attach front-drive electric assist kit that converts standard manual wheelchairs into powered tricycles. Driven by a 24 V, 350 W BLDC hub motor powered by dual 12 V, 7.2 Ah lead-acid batteries, the system generates 206.35 W required drive power to achieve 16 km/h under 100 kg total payload on an 2 ℃ incline. Structural stress and FEA evaluations yield a minimum Factor of Safety (FOS) of 1.528. Total prototype fabrication cost was ₹23,190.

Keywords: Electric Wheelchair; Power-Assist Mechanism; BLDC Hub Motor; Structural Analysis; Kinematic Modeling.

How to Cite This Article

Awale, R., Kumbhare, A., Meshram, K., Kamble, P., & Admane, A. (2022). Design and manufacturing of an attachable power-assist electric wheelchair for mobility enhancement of physically challenged persons. *International Journal on Mechanical Engineering and Robotics,* 11(1), 1–5.

2321-5747/ © 2022 The Authors. This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0).

Introduction

Worldwide, an estimated 10% of individuals with disabilities require a wheelchair for daily locomotion. Standard manual wheelchairs impose high metabolic strain, leading to upper-limb joint degradation and caregiver fatigue. Commercial electric wheelchairs solve these physical limitations but remain financially inaccessible in developing regions. This work introduces a low-cost, quick-attach front-drive power-assist unit that clamps directly onto standard manual wheelchairs without structural alterations.

Literature Review

Prior studies highlight the efficacy of modular electric attachments in lowering financial barriers and improving autonomy:

Vigneshwar et al. & Shaikh et al, demonstrated that attachable direct-drive hub motors minimize mechanical vibration, reduce transmission loss, and improve outdoor transit.

Jayaprabakar & Sidik et al, Emphasized low center-of-gravity design, ground clearance, and the psychological benefits of independent personal mobility.

Kumbar et al. & Khatib, confirmed that modular front-wheel propulsion offers superior indoor maneuverability combined with stable outdoor transit.

Binismail, Identified critical stress concentrations across wheelchair seating frames and front casters during obstacle negotiation.

Research Gap & Novelty

Existing solutions are either cost-prohibitive, excessively heavy (30–50 kg), or require permanent chassis modification. The key novelties of this design are:

1. Dual-Mode Attachment: Quick-detach clamp mounting in under two minutes without modifying the base wheelchair frame.
2. Integrated Drive-Steer Hub: Direct integration of a 24 V, 350 W BLDC hub motor into a single front assembly.
3. Rigorous Design Validation: Analytical dynamic force calculations paired with finite element displacement verification.

Objectives

- Design and prototype an attachable electric drive unit that connects to standard manual wheelchairs.
- Derive analytical force equations for total vehicle motion resistance (rolling, gradient, and aerodynamic drag) to size the electric motor and battery bank accurately.
- Perform Finite Element Analysis (FEA) on the primary steering handle structure to determine factor of safety and deformation patterns.
- Complete prototype assembly and cost estimation to confirm financial viability.

System Specifications

Table 1. *Overall Wheelchair Specification Parameters*

Parameter	**Value / Specification**
Overall Dimensions (L*W * H)	1150 (mm* 660(mm) *910(mm)
Rear Wheel / Castor Wheel Diameter	24 inch / 12 inch
Seat-to-Ground Height / Backrest Height	480(mm)* 460(mm)
Push Rim Diameter	18 inch

Mathematical Modeling & Governing Equations

The total resistive force F(Total) acting on a 100 kg system (m = 100kg) moving at v = 16km/h 4.44m/s is:

F{Total} = F{Rolling} + F{Gradient} + F{Aerodynamic Drag}

1. Rolling Resistance Force (Cr = 0.004):

F{Rolling} = Cr *m*g = 0.004 *100 *9.81 = 3.924 N ………………………………(1)

2. Gradient Resistance Force (θ= 2 ℃ incline):

F{Gradient} = m*g *sin(θ) = 100 * 9.81*sin(2 ℃) = 34.236 N…………….(2)

3. Aerodynamic Drag Force (ρ= 1.23 $\frac{kg}{m^3}$ Ca = 0.88, At = 0.7917m^2

F{Aerodynamic Drag} = 0.5 ρ V^2 *Ca * At = 0.5 * 1.23 (4.4^2 0.88 0.7917 = 8.27N

4. Total Force & Power Requirement:

F{Total} = 3.924 + 34.236 + 8.27 = 46.43 N

P{req} = F{Total} * V = 46.43 N *4.44 m/s = 206.35 W

The calculated power demand 206.36 W is well within the 350 W rating of the chosen motor.

Motor Kinematics & Current Draw

- Nominal Current Draw I: At 24 V rating, I = 350W/24 V= 14.58 A.
- Wheel Angular Speed (N): For wheel radius r = 0.155m (circumference Cw = 0.9734m), top speed 333 m/min requires:
  N = 333 m/min /0.9734 m/rev = 342 RPM…………………………….(1)
- **Shaft Torque Output (T):**
  T = 60 P/ 2*π *N} = 60 *350 / 2 * π * 342 = 14.73 N m

Battery Storage & Charging Kinetics

- Capacity Requirement: Operating a 350 W motor for 1 hour requires 350 Wh}, translating to AH = 350Wh / 24 V = 14.58 Ah.
- Charging Kinetics: Setting safe charging current at 30% capacity (Ic = 0.3 * 14.58 = 4 A), estimated charge time is Tc = 14.58/4 = approx 3.65 hours (operational benchmark accounting for efficiency losses is ~4.98 hours).

Steering Kinematics & Turning Radius

For wheelbase Wb = 0.94 m and maximum steering angle α = 70 ℃:

R(front) = Wb/sin(α) = 0.94 / sin(70 ℃) = 1.003 m…………………..(1)

r{rear} = Wb/ tan(α) = 0.94 \tan(70 ℃) = 0.3421 m ………………….(2)

Page 4: Mechanical Structural Analysis

Structural Stress Calculations

Table 2. Mechanical Properties of Shaft Steel (C45 Grade)

Property	**Value**
Tensile Strength / Yield Strength	655 MPa / 415 MPa
Elastic Modulus / Poisson's Ratio	190–210 GPa / 0.27–0.30

Hollow Motor Shaft (Do = 15mm di = 6 mm L = 20 mm

Z_shaft =π(15^4 - 6^4) /(32 .15) = 102.77 m^3 ………………………………..(1)

W_allow = (σ b *Z_shaft)/L = 655 . 102.77/20 = 3365.71 N (342.9kg) ………(1)

The allowable shaft load (3365.71) far exceeds the applied static load (981 N).

Steering Handle Hollow Tube (Do = 20 mm, di = 17\text{ mm, L = 250 mm)

Z_pipe =π *(20^4- 17^4)/32.20 = 375.41 m^3

For C45 steel (σ allow = 270 MPa), allowable handle bar force is W = 270. 375.41/250 = 405.44 N (41.3 kg).

Steering Handle Solid Shaft (d = 20mm , L = 215 mm)

Z_solid = π *20^3 / 32= 785 m^3 W solid = 270 . 785/ 215 = 985.81 N (100.4 kg)....(1)

Fastener Bolt Tension (M10, Root dc = 8 mm)

Sigma-bolt = 981 N/ (π/4 8^2) = 19.51 N/mm^2 (<<420 N/mm^2 yield point) …….(1)

*Chassis Tube Section (25 mm *25 mm *3 mm)*

Z_square = (25^3 - 19^3)/ 6 = 1461 mm^3 W_chassis = 270.146/ 250 = 1577.88 N (160.7 kg)

Page 5: Structural Schematics & CAD / FEA Verification

System Component Layout

- Structural Layout: Padded seat frame, push handles, 24-inch rear wheels with 18-inch push rims, and dual front caster wheels.
- Drive Assembly: Detachable T-bar handle housing twist-throttle, controller, dual 12 V SLA batteries, and 6-inch BLDC front hub motor.
- Bearing Support: P204 pedestal bearing unit (20mm bore) securing the solid steering column.

Finite Element Analysis (FEA) Results

Static stress and displacement simulations were conducted on the T-bar handle structure under maximum load vectors in SolidWorks Simulation:

- Elastic Displacement (U_RES): Zero displacement at fixed constraint nodes; maximum deflection of 0.8144 mm at the outer handle tips.
- Factor of Safety (FOS): Minimum localized FOS recorded at 1.528 (critical node 11072), proving high structural stability under maximum operating conditions.

Page 6: Fabrication Cost Analysis & Performance Evaluation

Component & Fabrication Cost Estimation

Table 3. *Complete Prototype Cost Breakdown*

Item Description	**Specification / Material**	**Qty**	**Cost (INR ₹)**
Standard Wheelchair Base	Steel Tubular Chassis	1 Unit	5,000
Electric Hub Motor	24 V, 350 W BLDC	1 Unit	9,000
Lead-Acid Batteries	12 V, 7.2 Ah SLA	2 Units	2,200
Motor Controller	24 V PWM Unit	1 Unit	1,800
Mild Steel Profiles & Shafts	C45 Mild Steel Square/Round Tubes	8 kg	1,080
Steering Bearings (P204)	Pedestal Ball Bearings	2 Units	800
Fasteners, Charger & Wiring	M10 Bolts, AC Charger, Copper Cables	Various	1,290
Throttle, Paint & Fabrication	Twist Throttle, Coating, Shop Labor	Various	1,720
Total Fabrication Cost			**₹23,190**

Experimental Validation

- Speed & Range: Reached a top speed of 16 km/h with a 16 km single-charge operating range under 100 kg load.
- Attachment Capability: Quick-clamping interface enables attachment/detachment in under 2 minutes.

Page 7: Future Scope, Conclusion & References

Future Improvements

- Intelligent Assist Integration: Incorporating voice-command or BCI sensor modules for quadriplegic users.
- LiFePO4 Battery Upgrade: Switching to Lithium Iron Phosphate batteries to reduce pack weight by >50%.
- Active Safety: Integrating ultrasonic range sensors and automated collision avoidance.

Conclusion

This project successfully demonstrates a low-cost, quick-attach electric power-assist module for manual wheelchairs. Mathematical dynamic modeling verifies that a 350 W BLDC hub motor fulfills all power requirements (206.36 W required) up to 16 km/h on 2° slopes. Bending stress calculations and FEA simulation establish structural safety with a minimum Factor of Safety of 1.528. At a fabrication cost of ₹23,190, this system offers an effective and accessible mobility solution for developing regions.

Nomenclature

- At: Frontal Area (0.7917m^2)
- Ca / Cr: Drag Coeff. (0.88) / Rolling Coeff. (0.004)
- F_Total: Total Resistive Force (N)
- P_req: Required Power Output (W)
- Z: Elastic Section Modulus (m^3)
- sigma_allow: Allowable Design Stress (N/ mm^2)

Abbreviations

- BLDC: Brushless Direct Current
- FEA: Finite Element Analysis
- FOS: Factor of Safety
- PWM: Pulse Width Modulation
- SLA: Sealed Lead-Acid

References

1. M. Reddi Sankar et al., "Design and Development of Solar Assisted Bicycle," *IJSRP*, vol. 3, no. 3, 2013.
2. R. C. Simpson, "Smart wheelchairs: A literature review," *JRRD*, vol. 42, no. 4, pp. 423–438, 2005.
3. S. Yadav and P. Sheoran, *IJIERT*, vol. 3, no. 2, pp. 12–18, 2016.
4. Varun N., "Power Assist Wheelchair for Physically Challenged Person," *JETIR*, vol. 8, no. 8, 2021.
5. A. Shaikh, "Handcycle Attachment for Wheelchair," *IRJMETS*, vol. 3, no. 2, 2021.
6. Rollick, "Products - Firefly Electric Attachable Bike," 2016.
7. N. Agarwal et al., "Combination hand and electric tricycle," *NSF Grantee Conf.*, 2007.