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Design and Fabrication of a Battery-Powered Standing Electric Scooter Using a 24 V, 350 W PMDC Motor with Chain-and-Sprocket Drive

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ABSTRACT

Short trips inside campuses, hospitals and industrial premises are poorly served by both walking and motorised transport. This paper reports the design, fabrication and theoretical performance analysis of a standing electric scooter built around a 24 V, 350 W permanent-magnet DC (PMDC) motor. Power reaches a 6-inch rear wheel through a chain-and-sprocket drive, steering is by a handlebar fixed to a vertical steel column, and the chassis is a welded steel frame with a riveted sheet-metal deck. Energy is stored in a rechargeable 24 V, 15 Ah (360 Wh) lithium-ion pack and the motor is regulated by a compatible 24 V PMDC controller. A longitudinal dynamics model covering rolling resistance, aerodynamic drag, gradient and inertia was used to estimate wheel torque, power, battery current, energy use and endurance for a 100 kg rider. Under the stated assumptions the model gives about 163 W at the wheel and 237 W from the battery at 20 km/h, which corresponds to an estimated endurance of about 1.2 h and a range of about 24 km on 80 % of the pack energy. All performance values are theoretical estimates; road tests to confirm them are planned.

Keywords: *electric scooter, PMDC motor, chain-and-sprocket drive, lithium-ion battery, vehicle dynamics, personal mobility*

1. INTRODUCTION

Short journeys within a university campus, a hospital complex or an industrial plant fall into an awkward range. They are too long to walk several times a day, yet too short to justify a car or a motorcycle. Light electric vehicles, and standing electric scooters in particular, suit this range well: they are quiet, burn no fuel, fold or park in a small space, and can be ridden with almost no training.

Most scooters on the market use sealed brushless hub motors with integrated electronics. Such units are efficient, but they are hard to repair in an ordinary institutional workshop and leave little room to change the gearing [1]. A permanent-magnet DC (PMDC) motor that drives the wheel through a chain and sprockets is a more accessible alternative. The motor is a simple two-terminal machine, its speed can be set by varying the armature voltage with a basic PWM controller, it develops high torque from standstill, and the overall ratio can be altered by changing a sprocket [2,3].

This paper documents a scooter built on that principle. The frame is welded from steel sections and carries a riveted sheet-metal deck, a vertical steel column with a handlebar provides steering, and a 24 V, 350 W PMDC motor drives a 6-inch rear wheel through a chain. A 24 V, 15 Ah lithium-ion pack supplies the energy through a compatible 24 V PMDC controller. The paper presents the mechanical and electrical design, the fabrication sequence and a theoretical performance analysis based on a longitudinal vehicle-dynamics model [4,5]. Every performance figure given is a model-based estimate; experimental validation is identified as future work.

2. LITERATURE REVIEW

2.1 Electric drives for light vehicles

Standard texts on electric and hybrid vehicles describe brushed DC machines as simple to control but limited by commutator and brush wear [3, 5]. In a PMDC machine the field is produced by permanent magnets, so the speed–torque characteristic is nearly linear and speed follows the terminal voltage [2]. A recent review of brushless machines credits them with higher efficiency and longer life, since there are no brushes, but notes that they depend on rotor-position sensing and electronic commutation [1]. The choice between the two types is thus a trade between simplicity and cost on one side and efficiency and maintenance on the other.

2.2 Standing personal vehicles

Work on an indoor standing vehicle showed that when the wheelbase itself carries the rider, no inverted-pendulum stabilisation is needed and speed and steering can be handled by simple control loops [6]. The design and control of a propulsion unit fitted to a kick-scooter frame has also been reported [7]. These studies support the use of a statically stable layout, which is the layout adopted here.

2.3 Tyres, energy models and service life

Dynamometer coast-down tests on e-scooter tyres give rolling-resistance coefficients well above those of bicycle tyres, and the difference appears directly in energy use [8]. A validated energy model for an electric scooter found that, at low urban speeds, rolling resistance and air drag account for most of the power demand [9]. Life-cycle studies add that the environmental performance of e-scooters depends strongly on how long a unit stays in service [10,11], which favours durable and repairable machines. Lithium-ion cells are the usual storage choice for such vehicles, and capacity, discharge rate and cut-off voltage must be matched to the load [12].

2.4 Research gaps

- To the authors' knowledge, few accessible reports describe a PMDC, chain-driven standing scooter in enough detail to be reproduced.
- Motor and battery sizing is rarely reconciled with a dynamics model of the intended rider and road.
- Rolling-resistance data for small pneumatic scooter tyres are scarce [8].
- Component-level construction details of workshop-built scooters are seldom published.

3. PROBLEM STATEMENT AND OBJECTIVES

Ready-made scooters are usually designed for general consumer use, so it is difficult to know how a given unit will behave under a particular rider mass and road. Their drives are sealed, their parts are proprietary, and repairs often mean replacing complete assemblies. An institution needs a simple scooter that can be built and mended in its own workshop, whose motor, battery and transmission have been sized on purpose, and whose design is documented well enough to be reproduced.

The objectives of this work are:

- To fabricate a statically stable standing scooter from welded steel sections and sheet metal;
- To drive the rear wheel with a 24 v, 350 w pmdc motor through a chain-and-sprocket transmission;
- To power the motor from a 24 v, 15 ah rechargeable battery through a compatible pmdc controller;
- To estimate wheel torque, power, battery current, energy use and endurance with a longitudinal dynamics model; and
- To separate clearly the theoretical estimates from measurements, and to define the tests needed to validate them.

4. EXISTING AND PROPOSED SYSTEMS

4.1 Existing systems

Two families of standing vehicle dominate. The first is the commercial kick-style scooter with a brushless hub motor built into one wheel and a sealed controller. The second is the self-balancing platform, which keeps itself upright through active control and therefore needs gyroscopic sensing, fast control electronics and a more expensive drive [6]. Both are capable machines, but neither is easy to repair, re-gear or reproduce in a college workshop. Table 1 compares typical features of the first family with the proposed scooter.

Table 1

TYPICAL HUB-MOTOR SCOOTER VERSUS THE PROPOSED SCOOTER

Feature	**Typical commercial hub-motor scooter**	**Proposed scooter**
Motor	Sealed brushless hub motor	Brushed PMDC motor, 24 V, 350 W
Transmission	Direct (motor inside the wheel)	Chain and sprockets
Controller	Integrated, matched to motor	Separate compatible 24 V PMDC controller
Frame	Proprietary tube or casting	Welded steel sections, riveted sheet deck
Gear ratio	Fixed	Changed by sprocket selection
Repair	Specialist service	Workshop-level repair
Balancing	Static (kick-scooter layout)	Static (kick-scooter layout)

4.2 Proposed system

The proposed scooter, shown in Fig. 1, keeps the statically stable kick-scooter layout and replaces the hub motor with a geared PMDC motor mounted on the frame. The motor's output sprocket drives a sprocket on the rear axle through a roller chain. The rider stands on the deck and steers with the handlebar; speed is commanded from the handlebar and regulated by the controller.



Fig. 1. Fabricated scooter (rear view) with numbered parts: 1 handlebar grip; 2 steering column; 3 column base plate; 4 riveted deck plate; 5 frame side rail; 6 rear tyre; 7 driven sprocket and chain; 8 brake-disc hub; 9 rear axle and nut; 10 kickstand; 11 handlebar cables.

5. METHODOLOGY

The work followed six stages: (i) definition of the requirements in Table 2; (ii) selection of the layout and the components; (iii) modelling of the vehicle's longitudinal dynamics; (iv) sizing checks on the motor, battery and transmission; (v) fabrication and assembly of the prototype; and (vi) definition of the validation tests. Items marked "assumed" in the tables are design assumptions and not measurements.

Table 2

SPECIFICATION OF THE FABRICATED SCOOTER

Item	Specification
Vehicle	Battery-powered standing electric scooter
Motor	PMDC (permanent-magnet DC), 24 V, 350 W
Battery	Rechargeable lithium-ion, 24 V, 15 Ah
Controller	Compatible 24 V PMDC motor controller
Wheel	6-inch pneumatic rear wheel
Drive	Chain and sprocket
Steering	Handlebar on vertical steel column
Frame	Fabricated steel frame with riveted sheet deck
Design rider mass	Up to 100 kg (design assumption)

6. SYSTEM ARCHITECTURE AND BLOCK DIAGRAM

Fig. 2 shows the architecture. Electrical energy flows from the battery to the controller, which converts the rider's speed command into a pulse-width-modulated armature voltage for the motor. The motor's shaft torque then travels mechanically through the chain-and-sprocket drive to the rear wheel. An external charger restores the pack when the scooter is parked. Because the controller is the only link between the energy store and the motor, its current rating must at least match the motor's requirement.

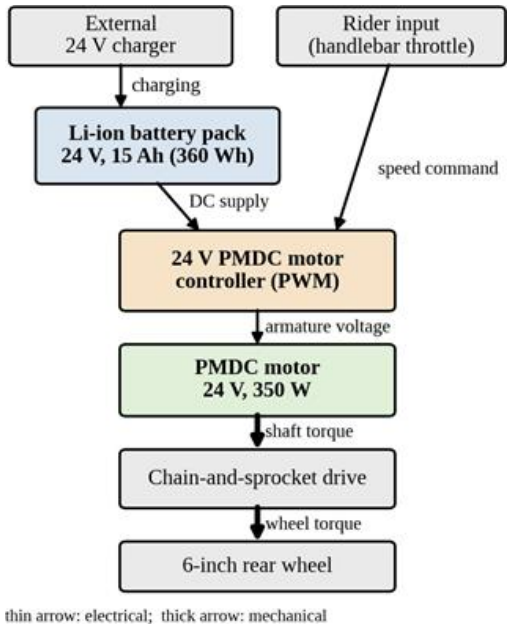


Fig. 2. Block diagram of the PMDC-driven scooter.

7. CIRCUIT DIAGRAM

Fig. 3 gives the power and signal connections. The battery positive and negative leads connect to the controller's supply terminals, and the motor's two armature leads connect to the controller's output terminals. The handlebar throttle sends a speed signal to the controller. A fuse or switch in the positive lead is drawn dashed because it is a recommended protective device and not a part identified on the prototype. Terminal names vary between controllers and should be taken from the controller's data sheet.

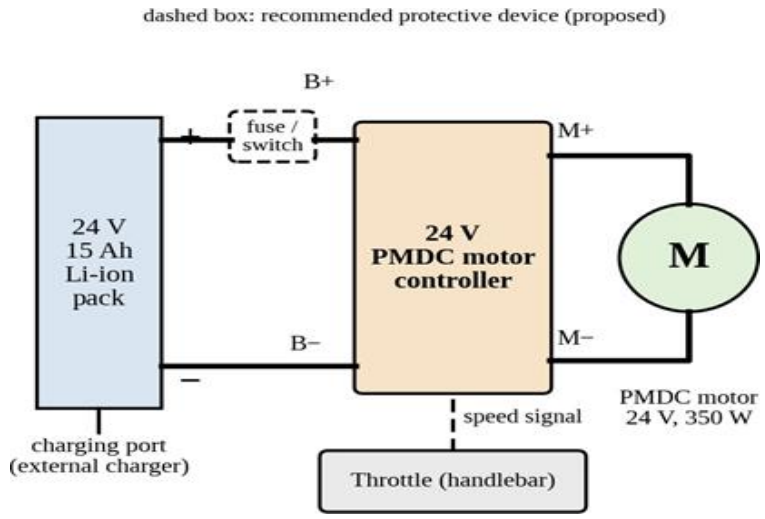


Fig. 3. Wiring (circuit) diagram of the power and signal paths. The dashed fuse/switch is a proposed addition.

7. HARDWARE COMPONENTS AND SPECIFICATIONS

Table 3 lists the main components. The battery pack and the motor appear in Fig. 4. The pack is a rectangular, shrink-wrapped nickel-manganese-cobalt (NMC) lithium-ion assembly with its own lead wires. The motor is a foot-mounted PMDC machine whose aluminium end housing carries the output shaft and a small sprocket.

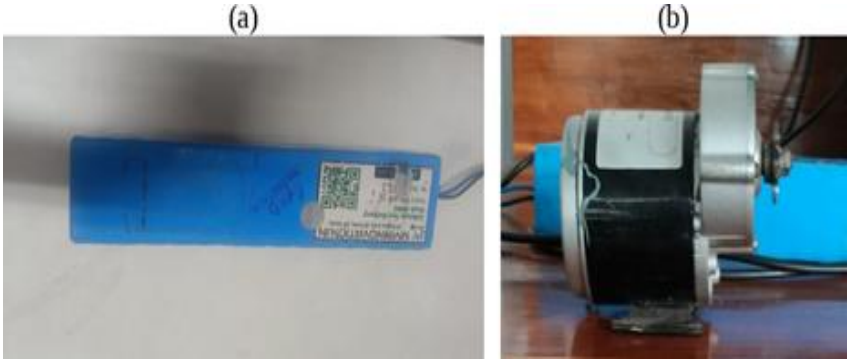


Fig. 4. Photographs of (a) the 24 V lithium-ion battery pack and (b) the PMDC motor with output sprocket.

Table 3

HARDWARE COMPONENTS

Component	Specification / description
PMDC motor	Permanent-magnet DC, 24 V, 350 W, foot-mounted, aluminium end housing, output sprocket. Rated speed and current to be taken from the nameplate.
Motor controller	Compatible 24 V PMDC controller; PWM control of armature voltage; current rating to exceed motor demand.
Battery	Lithium-ion (NMC) pack, 24 V nominal, 15 Ah, 360 Wh; pack-level protection.
Wheel and tyre	6-inch pneumatic tyre with block tread, on athrough-axle held between welded drop-out plates.
Transmission	Roller chain, small drive sprocket on the motor, larger driven sprocket on the rear axle.
Brake	Disc fitted on the rear axle; handlebar cables run down the steering column.
Steering	Handlebar with rubber grips; vertical square-section steel column fixed to the deck by a base plate.
Frame and deck	Welded steel sections; sheet-metal deck plate fastened with rivets.
Kickstand	Side stand on the left of the frame.

9. MECHANICAL DESIGN

9.1 Frame and deck

The frame is a closed, low rectangular structure of welded steel sections. A sheet-metal deck plate is riveted to it; the rider stands on this plate and it also covers the space below it. Vertical side members at the rear form the drop-outs for the wheel axle. Welding was chosen because it gives a stiff structure with ordinary workshop equipment, and the low deck keeps the rider's centre of gravity close to the ground.

9.2 Steering

A square-section steel column rises from a base plate bolted to the front of the deck. The handlebar is clamped at its top, and the control cables run down the column to the deck. Steering is conventional: the rider turns the handlebar, and the scooter leans and tracks as in a kick scooter.

9.3 Rear wheel, axle and transmission

The 6-inch wheel turns on a through-axle fixed between the two drop-out plates with nuts. The driven sprocket is on one side of the wheel and a brake disc on the other, as Fig. 1 shows. Fig. 5 gives a schematic top view of the arrangement and Fig. 6 the drive train. If the motor contains an internal reduction stage of own lead wires. The motor is a foot-mounted PMDC machine ratio i_g, and the chain sprockets have N_1 (motor) and N_2 (wheel) whose aluminium end housing carries the output shaft and a small teeth, the total reduction between motor and wheel and the resulting vehicle speed are

$$i_t = i_g (N_2 / N_1) \quad (1)$$

$$v = 2\pi r n_m / (60\, i_t) \quad (2)$$

$$T_w = T_m i_t \eta_t \quad (3)$$

where n_m is the motor speed in rpm, r the effective wheel radius, T_m the motor torque and η_t the transmission efficiency.

Roller-chain drives are well suited to this duty and are designed from the power, speed ratio and centre distance [13]. The tooth counts and chain size are fixed at assembly and are not varied in the analysis below, which works at the wheel; they will be reported with the test results. The chain and both sprockets are exposed, so a chain guard is recommended as a safety improvement.

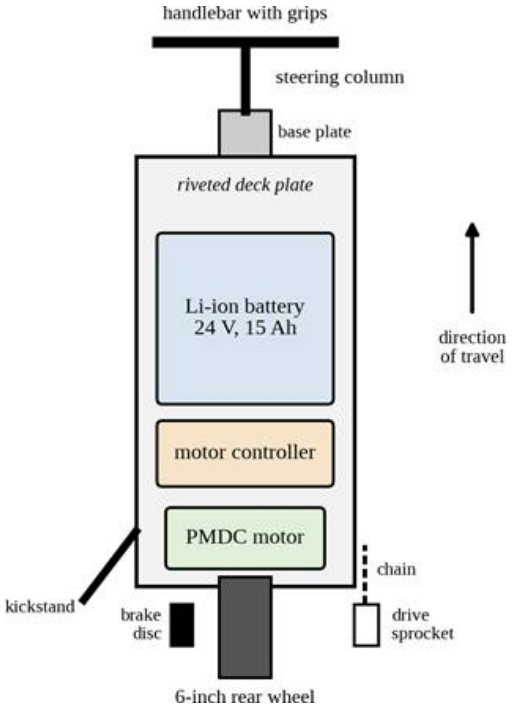


Fig. 5. Schematic top view of the component arrangement (not to scale; the front fork is not shown).

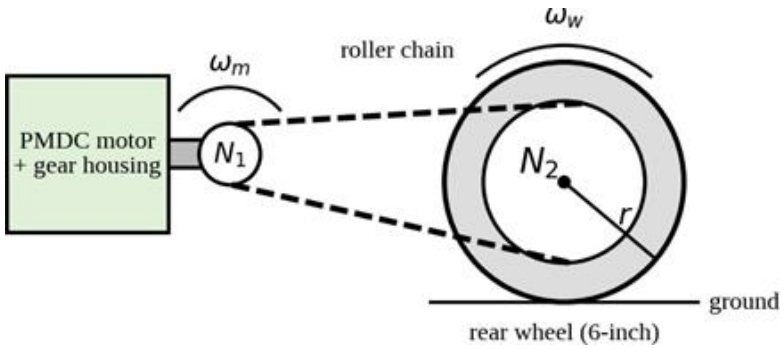


Fig. 6. Schematic of the drive train: motor with drive sprocket (N_2), roller chain, and driven sprocket (N) on the rear-wheel axle; r is the effective wheel radius.

10. ELECTRICAL DESIGN

The electrical system has three parts: the energy store, the controller and the motor. The pack operates at a nominal 24 V and stores 24 × 15 = 360 Wh. The controller chops the battery voltage at a fixed frequency and varies the duty ratio D, so the average armature voltage is

$$V_a = D\,V_b,\ 0 \le D \le 1 \qquad (6)$$

which is the usual way of controlling a DC motor from a fixed supply [14]. The throttle supplies the reference for D. The controller and the battery's protection circuit must each carry the motor's peak current; the current figures in Section 12 give the minimum rating to verify from their data sheets. A fuse or breaker in the positive lead and a main switch are recommended, together with a battery charger of the correct voltage and current for the pack.

11. WORKING PRINCIPLE

In a PMDC motor the permanent magnets set up a constant field. When armature current I_a flows in the rotor conductors, the field exerts a force on them, giving a torque $T_m = K_t I_a$. The brushes and commutator reverse the current in each coil as it passes between poles, so the torque keeps one direction. The rotating conductors also generate a back-EMF $E_b = K_e \omega_m$ which opposes the applied voltage [2]. The electrical equation of the armature, shown by the equivalent circuit in Fig. 7, is

$$V_a = E_b + I_a R_a + L_a \mathrm{d}I_a/\mathrm{d}t \qquad (4)$$

$$E_b = K_e \omega_m,\ T_m = K_t I_a \qquad (5)$$

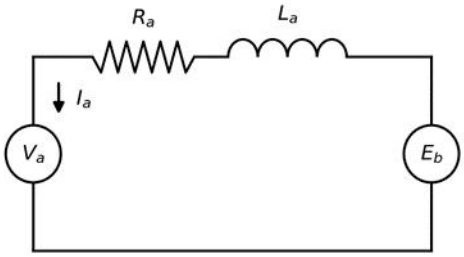


Fig. 7. Equivalent circuit of the PMDC armature.

At standstill the back-EMF is zero, so a modest voltage drives a large current and torque, which is why the scooter can start under load. As speed rises, E_b grows and the current falls until the motor torque balances the load torque. Raising the throttle raises V_a and so the equilibrium speed. The operating sequence is as follows: the rider turns on the supply and twists the throttle; the controller raises the armature voltage; the motor turns and the drive train multiplies its torque; the chain turns the rear axle; and the tyre pushes against the road to propel the scooter. The brake acts on the rear axle independently of the electrical system.

12. DESIGN CALCULATIONS

The calculations use the longitudinal model of vehicle dynamics [4,5]. The tractive force at the wheel is the sum of rolling resistance, aerodynamic drag, grade resistance and inertial force:

$$F_{rr} = C_{rr}\, m\, g \cos\theta \qquad (7)$$

$$F_{a} = \tfrac{1}{2}\rho\, C_{d} A\, v \qquad (8)$$

$$F_{g} = m\, g \sin\theta \qquad (9)$$

$$F_{t} = F_{rr} + F_{a} + F_{g} + m\, a \qquad (10)$$

$$T_{w} = F_{t}\, r \qquad (11)$$

$$P_{w} = F_{t}\, v \qquad (12)$$

Here C_{rr} is the rolling-resistance coefficient, m the total mass, θ the slope angle, ρ the air density, $C_d A$ the drag area, v the speed and a the acceleration. The battery power and current follow from the efficiency of each stage between battery and wheel:

$$P = P_w / (\eta_m \eta_t \eta_c \eta_b) \qquad (13)$$

$$I_b = P_b / V_b \qquad (14)$$

The parameters are in Table 4. The pack voltage, capacity and motor rating are the specified values; the remaining entries are assumptions, because no measured values are yet available. The overall efficiency from battery to wheel is $\eta = 0.80 \times 0.95 \times 0.95 \times 0.95 = 0.686$.

Table 4
PARAMETERS USED IN THE MODEL

Parameter	Symbol	Value	Basis
Total mass (rider + scooter)	m	135 kg (100 + 35)	Assumed; scooter mass to be measured
Rolling-resistance coeff.	C_{rr}	0.015	Assumed
Drag area	$C_d A$	0.5 m^2	Assumed
Air density	ρ	1.225 kg/m^3	Standard
Effective wheel radius	r	0.0762 m	From 6-inch nominal diameter
Motor rated power	P_r	350 W	Specified
Pack voltage, capacity	V_b, C_b	24 V, 15 Ah	Specified
Usable fraction of energy	—	80 %	Assumed
Efficiencies: motor, chain, controller, battery	η_m, η_t, η_c, η_b	0.80, 0.95, 0.95, 0.95	Assumed

The energy stored, the usable energy, the endurance at a steady power P_b and the range at speed v (km/h) are

$$E_u = 0.8\, V_b\, C_b = 0.8 \times 24 \times 15 = 288 \text{ Wh} \quad (15)$$

$$t = E_u / P_b \quad (16)$$

$$R = E_u\, v / P_b \quad (17)$$

For a worked check at 20 km/h (v = 5.56 m/s): $F_{rr} = 0.015 \times 135 \times 9.81 = 19.9$ N; $F_a = 0.5 \times 1.225 \times 0.5 \times 5.56^2 = 9.5$ N; so $F_t = 29.3$ N, $T_w = 29.3 \times 0.0762 = 2.23$ N·m and $P_w = 29.3 \times 5.56 = 162.9$ W. The battery then supplies 162.9 / 0.686 = 237.5 W, a current of 237.5 / 24 = 9.9 A, and the endurance is 288 / 237.5 = 1.21 h. The power available for climbing is limited by the motor rating, so the gradeability on a slope at speed v is

$$s = [P_r\, \eta_t / v - F_{rr} - F_a] / (mg) \quad (18)$$

13. BATTERY AND MOTOR PERFORMANCE

Table 5 summarises the electrical limits. The 350 W rating is treated as mechanical output at the motor shaft. At that load the battery must supply 350 / (0.80 × 0.95 × 0.95) = 485 W, or 20.2 A at 24 V, which is a 1.35 C discharge of a 15 Ah pack. If the 350 W were instead an electrical input rating, the current would be 350 / 24 = 14.6 A (0.97 C). The controller's current limit and the

pack's discharge rating should therefore be confirmed to be at least 20 A. Steady cruising draws much less than the rating, as the next section shows.

Table 5

BATTERY AND MOTOR ELECTRICAL FIGURES (THEORETICAL)

Quantity	Value
Nominal pack energy	360 Wh (24 V × 15 Ah)
Usable energy (80 %)	288 Wh
Battery power at rated shaft output	485 W
Battery current at rated shaft output	20.2 A (1.35 C)
Current if 350 W is electrical input	14.6 A (0.97 C)
Endurance at rated shaft output	36 min
Cruise current at 10 / 15 / 20 km/h	3.8 / 6.4 / 9.9 A

14. FABRICATION PROCESS

The scooter was fabricated in the following sequence:

- **Frame:** steel sections were cut to length and welded into the rectangular frame, with vertical members at the rear for the wheel drop-outs.
- **Rear wheel assembly:** the 6-inch wheel, driven sprocket and brake disc were mounted on the axle, and the axle was fixed between the drop-out plates with nuts.

- **Drive:** the PMDC motor was mounted on its foot bracket, and the chain was fitted and aligned between the motor sprocket and the wheel sprocket.
- **Steering:** the steel column was fixed to the front of the deck with a base plate, and the handlebar and cables were installed.
- **Electrical:** the battery pack and controller were placed in the frame and wired as in Fig. 3.
- **Finishing:** the kickstand was fitted and the assembly was inspected before testing.
- An itemised cost statement will be compiled from the purchase records of the components and reported in the final version; no cost figure is claimed here.

15. RESULTS AND DISCUSSION

Important: all values in this section come from the model of Section 12 and are theoretical. No measured test data are presented.

15.1 Resistive forces

Fig. 8 shows the resistance forces on level ground. Rolling resistance is constant at 19.9 N and is the main load over the whole range. Drag grows with the square of speed, from 2.4 N at 10 km/h to 5.3 N at 15 km/h (21 % of the total) and 9.5 N at 20 km/h (32 %). The total resistance is 22.2 N, 25.2 N and 29.3 N at 10, 15 and 20 km/h respectively.

- **Deck:** the sheet-metal deck plate was cut to size and fastened to the frame with rivets.

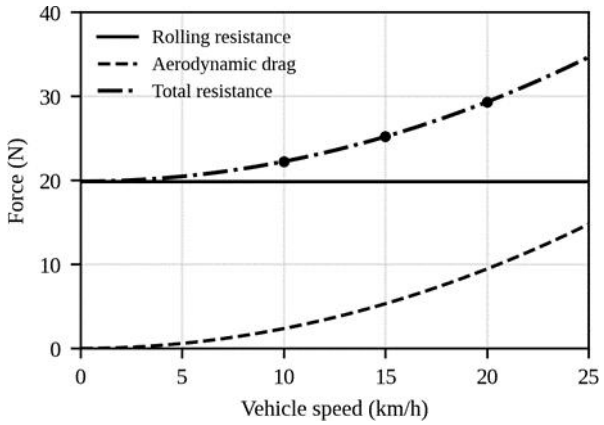


Fig. 8. Resistive forces against speed for a 135 kg rider-and-scooter mass on level ground (theoretical).

15.2 Operating points and energy use

Table 6 lists the operating points. At 20 km/h the wheel turns at 696 rpm and needs 2.23 N·m and 163 W; the battery supplies about 237 W (9.9 A), and the model gives 11.9 Wh/km. At 10 km/h the demand falls to 90 W (3.8 A) and 9.0 Wh/km. On 288 Wh of usable energy, the estimated range is therefore about 32 km at 10 km/h, 28 km at 15 km/h and 24 km at 20 km/h.

Table 6

EVEL-ROAD OPERATING POINTS (THEORETICAL)

Quantity	10 km/h	15 km/h	20 km/h
Tractive force (N)	22.2	25.2	29.3
Wheel speed (rpm)	348	522	696
Wheel torque (N·m)	1.69	1.92	2.23
Wheel power (W)	61.7	104.9	162.9
Battery power (W)	90.0	153.0	237.5
Battery current (A)	3.8	6.4	9.9
Energy use (Wh/km)	9.0	10.2	11.9
Endurance (min)	192	113	73
Range (km)	32.0	28.2	24.3

15.3 Power margin and gradeability

Fig. 9 compares the power needed with the motor rating. Taking the rating as 350 W at the shaft and a chain efficiency of 0.95, about 332 W is available at the wheel. The level-road demand reaches this value near 29.5 km/h, so a top speed of 15–20 km/h is a matter of gearing and controller setting, not of motor power. The reserve for climbing and acceleration is 271 W at 10 km/h, 228 W at 15 km/h and 170 W at 20 km/h (Table 7). From (18), the gradeability is 7.4 %, 4.1 % and 2.3 % at the same speeds, which is adequate for gentle ramps. Starting from rest at 0.5 m/sZ needs a wheel torque of about 6.7 N·m; this should be compared with the motor's torque limit once the total ratio i_t is recorded.

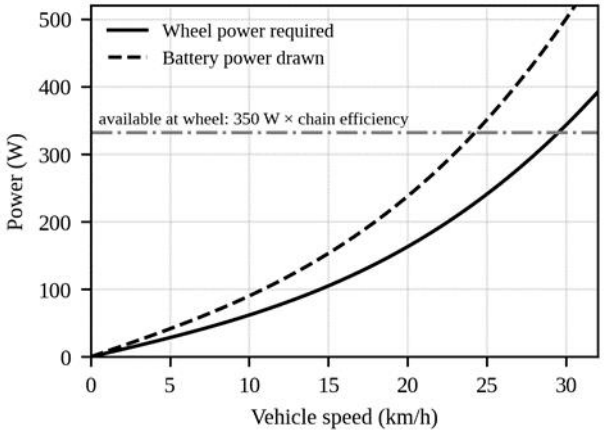


Fig. 9. Power required at the wheel and drawn from the battery against speed (theoretical).

Table 7

POWER RESERVE, GRADEABILITY AND ACCELERATION (THEORETICAL)

Quantity	**10 km/h**	**15 km/h**	**20 km/h**
Power available at wheel (W)	332	332	332
Reserve power (W)	271	228	170
Gradeability (%)	7.4	4.1	2.3
Acceleration capability (m/sZ)	0.72	0.40	0.23

15.4 Sensitivity to rolling resistance

The rolling-resistance coefficient is the least certain input, and small pneumatic scooter tyres are reported to have much higher values than bicycle tyres [8]. Table 8 shows its effect at 20 km/h.

A 30 % rise in C_{rr} raises energy use by 20 %, and at $C_{rr} = 0.03$ the range falls from about 24 km to about 14 km, although the wheel power of 273 W remains below the available 332 W. The coefficient of the actual tyre should therefore be measured before any range is quoted.

Table 8

EFFECT OF ROLLING RESISTANCE AT 20 KM/H (THEORETICAL)

C_{rr}	**Wheel power (W)**	**Battery power (W)**	**Energy (Wh/km)**	**Range (km)**
0.015	163	237	11.9	24.3
0.0195	196	286	14.3	20.2
0.03	273	398	19.9	14.5

15.1 Validation plan

The following tests are planned and their results will be compared with the estimates above: coast-down runs to obtain the actual C_{rr}

and $C_d A$; level-road runs at the target speeds while logging battery voltage and current; a controlled gradient test; a braking test; and a full-charge range test with a 100 kg rider.

16. ADVANTAGES, APPLICATIONS AND LIMITATIONS

16.1 Advantages

- Simple, low-cost drive: a brushed PMDC motor needs no rotor-position sensors and only a basic controller.
- High starting torque, which helps when pulling away with a rider on board.
- Transmission ratio can be changed by replacing a sprocket.
- Welded steel and riveted sheet construction can be made and repaired with ordinary workshop tools.
- Statically stable layout with no balancing electronics.

16.2 Applications

- Movement of staff and visitors within campuses, hospitals and industrial plants.
- Short last-mile trips on paved surfaces.
- Teaching and project work in electric-vehicle design and fabrication.

16.1 Limitations

- The brushes and commutator wear and need periodic inspection; a brushless drive would be more efficient and need less maintenance [1].
- The exposed chain needs lubrication, tensioning and a guard.
- Performance figures are theoretical and rest on assumed efficiencies and resistance coefficients.
- Rated speed, current and the sprocket ratio have yet to be reported, so the top speed is not stated.
- Intended for paved roads and gentle gradients only.

17. FUTURE SCOPE

- Complete the validation tests of Section 15.5 and publish the measured results.
- Add a fuse, a battery-state display, lights, fenders and a chain guard.
- Fit a folding steering column to ease storage and transport.
- Evaluate a brushless motor of similar rating against the present drive.
- Fit a speed sensor and a data logger to refine the energy model.
- Compile an itemised cost analysis and explore further weight reduction.

18. CONCLUSION

A battery-powered standing electric scooter was designed and fabricated around a 24 V, 350 W PMDC motor, a chain-and-sprocket drive, a 6-inch rear wheel and a 24 V, 15 Ah lithium-ion pack, on a welded steel frame with a riveted sheet-metal deck. A longitudinal dynamics model indicates that, for a 100 kg rider and the stated assumptions, steady cruising at 20 km/h needs about 163 W at the wheel and 237 W from the battery, which leaves more than half of the motor rating in reserve and gives an estimated range of about 24 km. The model also shows that the range depends strongly on tyre rolling resistance. These results are theoretical; the planned coast-down, current-logging, gradient and range tests will show how closely they agree with the real scooter.

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