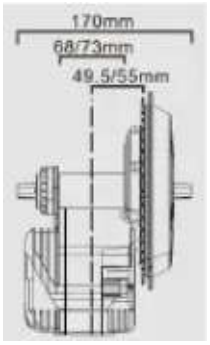
Informal Anlysis

Build around: Tongsheng TSDZ8 750W



Rated power is around 750 watt, max power is 1150W

Power Requirements

$c_{rolling} := 0.015$ $m := 200\ lb$ $g := 9.81\ \frac{m}{s^2}$

velocity, x as input

$v(x) := x\ mph$

$c_{drag} := 1.1$ $A := 5.5\ ft^2$ $\rho := 1.222\ \frac{kg}{m^3} = 0.0763\ \frac{lb}{ft^3}$

Cruising power

$P_{total}(x) := P_{rolling}(x) + P_{drag}(x)$

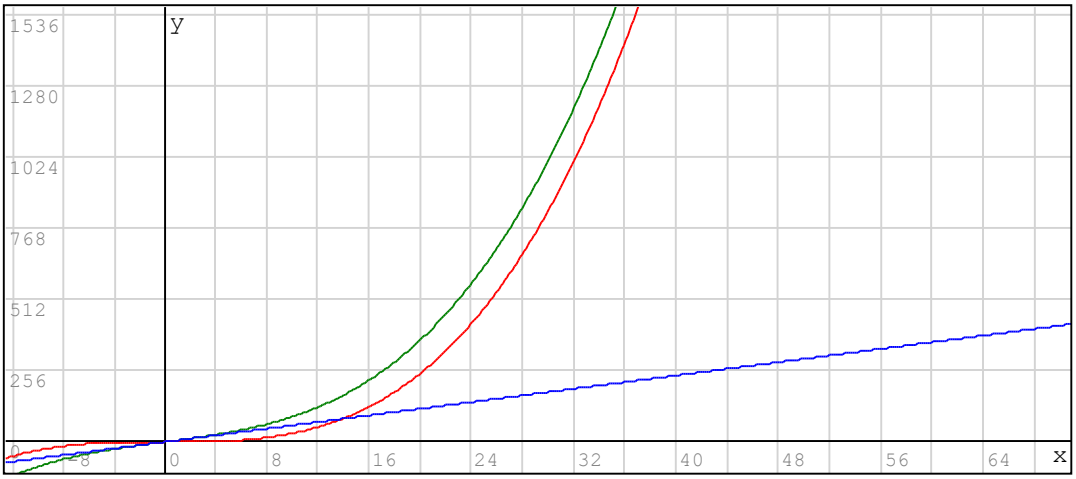
Power required for rolling resistance

$W := m \cdot g = 889.9482\ N$

$F_{rolling} := c_{rolling} \cdot W = 13.3492\ N$

$P_{rolling}(x) := F_{rolling} \cdot v(x)$

$P_{drag}(x) := c_{drag} \cdot \frac{\rho}{2} \cdot A \cdot v(x)^3$



$P_{rolling}(x)$
$P_{drag}(x)$
$P_{total}(x)$

red is drag, blue is rolling and green is the total power. y axis is power(W)

and x axis is velocity(mph)

At 28 mph - class 3 ebike and power for each is: $speed1 := 28$

$P_{rolling}(speed1) = 167.0938\ W$ $P_{drag}(speed1) = 673.5033\ W$

$p_{total}(speed1) = 840.5972\ W$

Maximum Required Power

Hill climbing is a situation where the bike is going to output the greatest amount of its power; on a day-to-day commute, a 10% gradient is going to be extreme

note for future: apparently gradient is not directly translate to angle,10% gradient is moderate steep hill, which has an angle of 5.71. Also, convert the number to actual DEGREE and not radian.

$\theta := 5.71\ °$

$F_{gx} := W \cdot \sin(\theta) = 88.544\ N$

$P_{gx}(x) := F_{gx} \cdot v(x)$

$P_{uphill} := P_{drag}(speed1) + P_{rolling}(speed1) \cdot \sin(\theta) + P_{gx}(speed1) = 1798.4438\ W$

R:
https://www.researchgate.net/figure/ROLLING-RESISTANCE-COEFFICIENTS-four-types-of-cycles-cyclists-masses-wheel-diameters_fig2_279323381

https://www.princeton.edu/~maelabs/hpt/mechanics/mecha_55.htm

https://ebikestuff.eu/en/content/16-tsdz8-review-and-tsdz2-osf-comparison-tsdz8-vs-tsdz2-osf

Range - Energy

$Range_{target} := 15\ mile$ no pedaling, just thorttle. With human assist, the value probably double?

$t := \frac{Range_{target}}{speed1\ mph}$ $t = 32.1429\ min$ $P := p_{total}(speed1)$

$E := P \cdot t = 450.3199\ watt\ hr$

Average 21700 capacity is around 45000mah, 13s or 14s is a good starting point as most ebike electronics work with it, 48v or 52v nominal respectively

$capacity := 4500\ mA\ hr$ $v_{.nominal} := 3.6\ V$

13s battery configurations

$battery_{13s1p} := v_{.nominal} \cdot capacity \cdot 13 \cdot 1 = 210.6\ watt\ hr$

$battery_{13s2p} := v_{.nominal} \cdot capacity \cdot 13 \cdot 2 = 421.2\ watt\ hr$

14s battery configurations

$battery_{14s1p} := v_{.nominal} \cdot capacity \cdot 14 \cdot 1 = 226.8\ watt\ hr$

$battery_{14s2p} := v_{.nominal} \cdot capacity \cdot 14 \cdot 2 = 453.6\ watt\ hr$

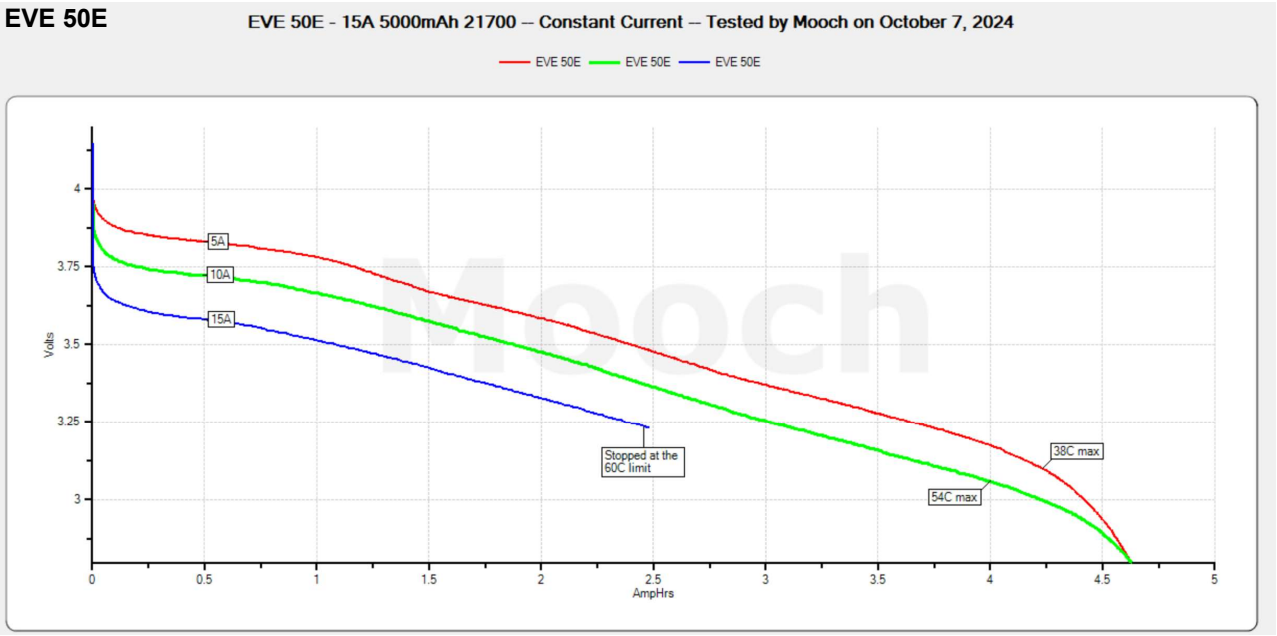
Probably going to go with the 14s2p config, better top speed compare to 13s2p. Not too big and also doesn't stand out too much

Battery Selection

EVE 50E 21700 5000mAh 15A Battery
Molicel 21700 P42A 4200mAh 45A Battery

Reputable comapny, good review and 2 of the cheapest batteries on www.18650batterystore.com. A
The trade off going to be the current output and capacity. Not sure if the EVE50E able to sustain the power output

EVE 50E



https://www.e-cigarette-forum.com/threads/bench-test-results-eve-50e-15a-5000mah-21700.987296/

Actual test value

$capacity_{eve10A} := 4625\ mA\ hr$ $Cost_{eve} := 2.85$

$battery_{14s2p} := v_{.nominal} \cdot capacity_{eve10A} \cdot 14 \cdot 2 = 466.2\ watt\ hr$

$Power_{sustain} := p_{total}(speed1) = 840.5972\ W$

$current_{10A} := 10$ $MaxCurrent_{eve} := 15 \cdot A$

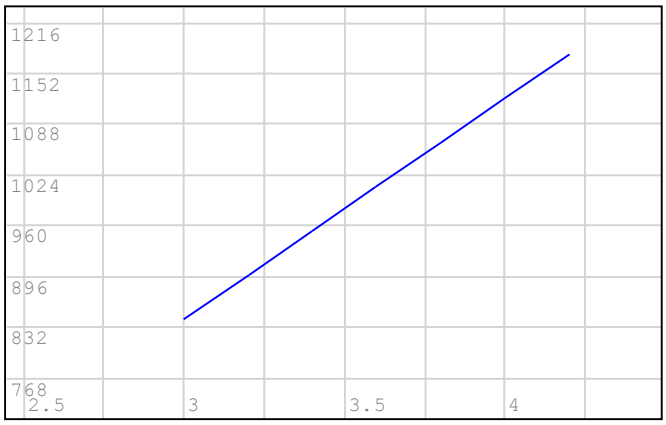
can this battery sustain power needed through out its voltage range between 3v - 4.2v?, going to use 10A as reference

$Power_{sustain} := 14 \cdot 2 \cdot 4.2 \cdot current_{10A} = 1176$ at peak voltage of 4.2v

$voltage := [3, 3.2 .. 4.2]$

$$Power_{sustain}(x) := 14 \cdot 2 \cdot voltage \cdot current_{10A} = \begin{bmatrix} 840 \\ 896 \\ 952 \\ 1008 \\ 1064 \\ 1120 \\ 1176 \end{bmatrix} \quad Power_{max}(x) := 14 \cdot 2 \cdot voltage \cdot 15 = \begin{bmatrix} 1260 \\ 1344 \\ 1428 \\ 1512 \\ 1596 \\ 1680 \\ 1764 \end{bmatrix}$$

$$plot := \text{augment}\left(voltage, Power_{sustain}(voltage)\right)$$

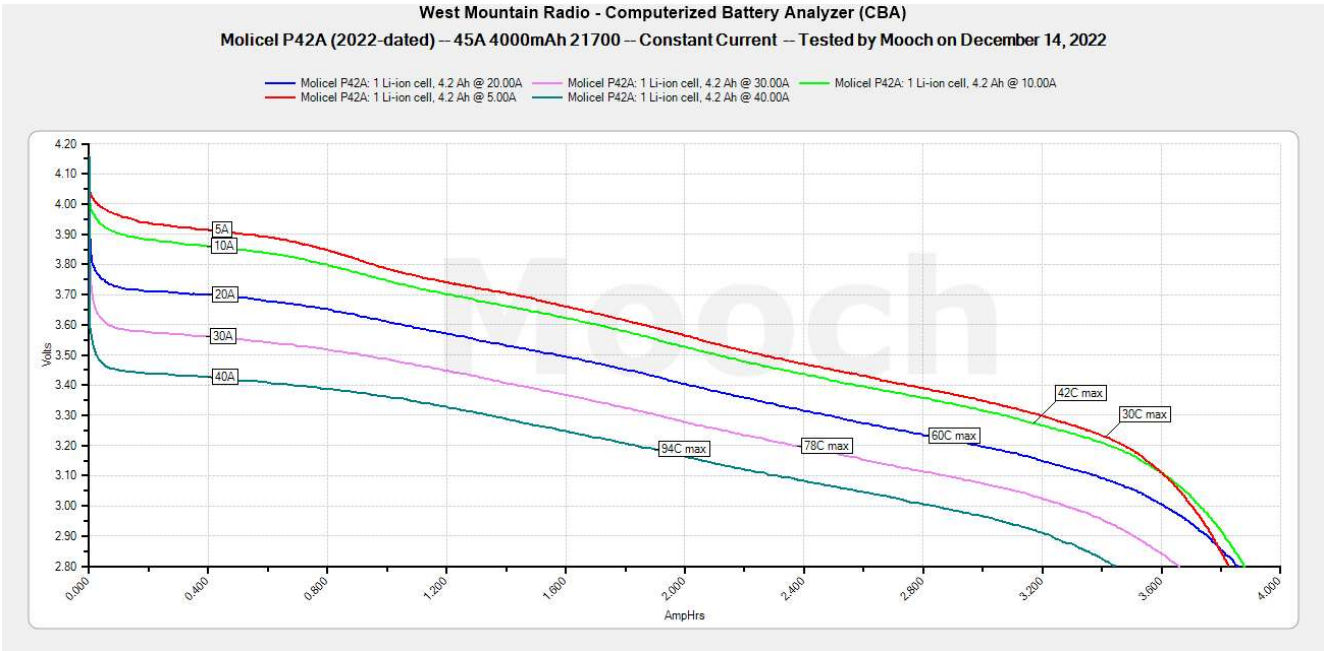


$plot$

THOUGHT: At 10A discharge and the botom end of the battery, it is able to sustain 840W, on normal cruising, likely not going to use the full potential, as well just only going to use pedal assistant only.

At the moment of instant torque, the cell still able to provide 15A Max cont discharge for a good of amount of time, it is likely able to provide a burst of $16 - 20\ A$. On the safe side, probably go to just limit it to 14-15A in the BMS

Molicel 21700 P42A 4200mAh 45A Battery



https://www.e-cigarette-forum.com/threads/bench-test-results-molicel-p42a-2022-dated-45a-4000mah-21700.979123/

Actual test value

$$capacity_{Moli10A} := 3850\ mA\ hr \qquad Cost_{Moli} := 3.40$$

$battery_{14s2p} := v_{.nominal} \cdot capacity_{Moli10A} \cdot 14 \cdot 2 = 388.08\ watt\ hr$

$Power_{sustain} := p_{total}(speed1) = 840.5972\ W$ Power needed to sustain 28mph

estimated max discharge current

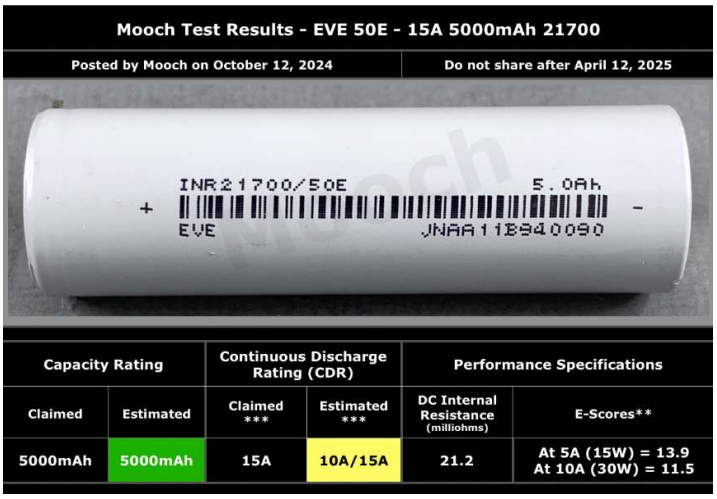
$current_{10A} := 10$ $MaxCurrent_{40} := 40$

$$Power_{max}(x) := 14 \cdot 2 \cdot voltage \cdot MaxCurrent_{40} = \begin{bmatrix} 3360 \\ 3584 \\ 3808 \\ 4032 \\ 4256 \\ 4480 \\ 4704 \end{bmatrix}$$

THOUGHT: good battery for high performance ebike, there no point using this battery for just a pedal assisted ebike

Thermal Requirements

R:
https://sengpielaudio.com/FormulaWheel-ElectricalEngineering.htm



Capacity Rating		Continuous Discharge Rating (CDR)		Performance Specifications	
Claimed	Estimated	Claimed ***	Estimated ***	DC Internal Resistance (milliohms)	E-Scores**
5000mAh	5000mAh	15A	10A/15A	21.2	At 5A (15W) = 13.9 At 10A (30W) = 11.5

50 Eve Battery $maxTemp := 60\ °C$

$R_{cell} := \frac{21.2\ ohm}{1000}$

$R_{14s} := R_{cell} \cdot 14 = 0.2968\ \Omega$

$$\frac{1}{R_{14s2p}} = \frac{1}{R_{14s}} + \frac{1}{R_{14s}}$$

$$\text{solve}\left(\frac{1}{R_{14s2p}} = \frac{1}{R_{14s}} + \frac{1}{R_{14s}}, R_{14s2p}\right) = \blacksquare$$ hmmm doesn't work, **Reminder:**

$R_{142p} := \frac{1}{\frac{1}{R_{14s}} + \frac{1}{R_{14s}}} = 0.1484\ \Omega$ solve it the normal instead...

$R := R_{142p}$ $P := Power_{sustain} = 840.5972\ W$

Sustain current

$I_{10} := 10\ A$

$P_{genCruise} := R \cdot I_{10}^{2} = 14.84\ W$ dissipated power

Peak current

$I := 15\ A$

$P_{genPeak} := R \cdot I^{2} = 33.39\ W$ dissipated power for 15A

$P_{cell} := R_{cell} \cdot I_{10}^{2} = 2.12\ W$

Thermal generation process of the battery $E_{gen} := P_{genPeak}$

Heat Transfer

need cooling in the design or not?

Basic thermal example

Assumptions:
1. Steady-state conditions.
2. One-dimensional heat transfer in the radial (cylindrical) direction.
3. Constant properties for insulation.
4. Negligible radiation exchange

emissivity of abs plastic $\varepsilon := 0.92$

$stefan - boltzmann$ $\sigma := 5.67 \cdot 10^{-8}\ \frac{watt}{m^{2}\ K^{4}}$

$k_{air} := 0.026\ \frac{W}{m\ K}$ $k_{abs} := 0.18\ \frac{W}{m\ K}$

$r_{bat} := \frac{21\ mm}{2}$ $h_{bat} := 70\ mm$ $m_{bat} := 70\ g$ $t_{airgap} := 0.4\ mm$ $t_{wall} := 1.5\ mm$

$r_{wall} := r_{bat} + t_{airgap} + t_{wall} = 12.4\ mm$ $r_{innerWall} := r_{wall} - t_{wall} = 10.9\ mm$

$h_{covAir} := 8.5\ \frac{W}{m^{2}\ K}$ $h_{wall} := 75\ mm$ $pi := 3.14$ $q := P_{cell} = 2.12\ W$

$T_{amb} := 25\ °C$

$A_{ExtWall} := 2 \cdot pi \cdot r_{wall}^{2} + 2 \cdot pi \cdot r_{wall} \cdot h_{wall} = 0.0068\ m^{2}$ the total area of a cylinder enclosure

$A_{ExtSideWall} := 2 \cdot pi \cdot r_{wall} \cdot h_{wall} = 0.0058\ m^{2}$ only the side-area of the cylinder

What if it is just the battery with no enclosure

simple lumped model, it assumes internal temp is uniform, and its internal temp gradient is negligible

$$T_s := \frac{q}{h_{covAir} \cdot A_{ExtWall}} + T_{amb} = 61.6458\ ^\circ C$$

look pretty comparable to what people got online, when the battery is discharge at 10A ~54 max celcius

$$T_s := \frac{q}{h_{covAir} \cdot A_{ExtSideWall}} + T_{amb} = 67.7046\ ^\circ C$$

just to side area, (no top or bottom)

Enclosure
Battery --> Air gap --> Enclosure wall --> outside: Convection

$$q = \frac{T_{surface} - T_{amb}}{R_{condInnerAir} + R_{condWall} + R_{convAmb}}$$

the whole system

$$R_{condInnerAir} := \frac{\ln\left(\frac{r_{innerWall}}{r_{bat}}\right)}{2 \cdot pi \cdot h_{bat} \cdot k_{air}} = 3.2711\ \frac{K\ S}{A^2}$$

$$R_{condWall} := \frac{r_{wall} - r_{innerWall}}{4 \cdot pi \cdot r_{wall} \cdot r_{innerWall} \cdot k_{abs}} = 4.9089\ \frac{K\ S}{A^2}$$

$$R_{convAmb} := \frac{1}{h_{covAir} \cdot A_{ExtWall}} = 17.2858\ \frac{K\ S}{A^2}$$

What is the battery surface temp?

$$q = \frac{T_{batSurface} - T_{amb}}{R_{condAir} + R_{condWall} + R_{convAmb}}$$

$$T_{batSurface} := q \cdot \left(R_{condInnerAir} + R_{condWall} + R_{convAmb}\right) + T_{amb} = 78.9874\ ^\circ C$$

What is the enclosure temp - external

$$q\left(T_{extWallSurface}\right) := \frac{T_{extWallSurface} - T_{amb}}{R_{convAmb}}$$

testing out SMath roots function, this is celcius

$T_{extWallSurface} := \text{roots}\left(q\left(T_{extWallSurface}\ °C\right) = q,\ T_{extWallSurface}\right) = 61.6458$

Thought: The model here is just a simplified model, and it only models a single battery, which I think is good enough for this case. To be clear, the model is super simple; it is just a 1D model and only accounts for radial heat transfer and only account for just cond and conv.

Anyway, it looks good. No need for major design considerations for cooling. This is based on a 10A output in still air, which is quite silly, unless doing a burnout or something. If talking about the heat transfer coefficient during a ride, the outer surface of the battery would be much cooler(with h.covAir = 38 the battery temp went down to 47).

SCRATCH NOTES:

External enclosure wall: Rad and Cov

emissivity of abs plastic

$\varepsilon := 0.92$

$stefan - boltzmann$

$\sigma := 5.67 \cdot 10^{-8}\ \frac{watt}{m^2\ K^4}$

$T_{inf} := 25\ °C$

$Q := 2\ W$

$r := \frac{21\ mm}{2}$

$h := 70\ mm$

$mass := 70\ g$

$A_E := 2 \cdot pi \cdot r \cdot h + 2 \cdot pi \cdot r^2 = 0.0053082\ m^2$

$h_{ERad}\left(T_3\right) := \varepsilon \cdot \sigma \cdot \left(T_3 + T_{inf}\right) \cdot \left(T_3^2 + T_{inf}^2\right)$

$\left(R_E \cdot Q - \left(T_3 - T_{inf}\right)\right) = 0$

$T_3 := R_E \cdot Q + T_{inf}$

$R_{EConv} := \frac{T_3 - T_{inf}}{Q}$

$R_{ERad} := \frac{1}{A_E \cdot \varepsilon \cdot \sigma \cdot \left(T_3 + T_{inf}\right) \cdot \left(T_3^2 + T_{inf}^2\right)}$

$R_{.total}\left(T_3\right) := \frac{1}{\frac{1}{R_{ECov}} + \frac{1}{R_{ERad}}}$

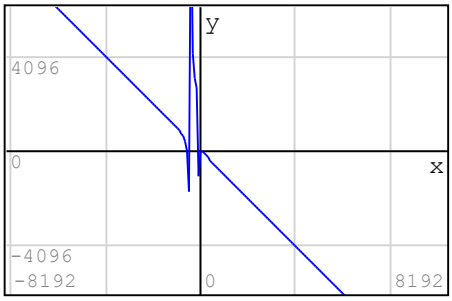
$Q \cdot R_{total} = T_3 - T_{inf}$

$$Q \cdot R_{total} - \left(T_3 - T_{inf}\right) = 0$$

$$f\left(T_3\right) := Q \cdot R_{total} - \left(T_3 - T_{inf}\right)$$

$$f\left(T_3\right) := Q \cdot \frac{1}{\frac{1}{\frac{T_3 - T_{inf}}{Q}} + A_E \cdot \varepsilon \cdot \sigma \cdot \left(T_3 + T_{inf}\right) \cdot \left(T_3^{\,2} + T_{inf}^{\,2}\right)} - \left(T_3 - T_{inf}\right)$$

$\text{roots}\left(f\left(x\ °C\right), x\right) = 25$ hmmm value doesn't make sense, can't be the same as ambient temp



$f\left(x\ °C\right)$

NOTE: REMINDER: Solve() can't handles unit, and don't forget unit for plot, if it is needed...