Axial flux motor Calculations

The following readings are the basic calculations required to model a axial flux motor. the values were changed to get the best fit in the motor calculator.

	Description	Symbol	Value 1	Units
1	*Rated power*	P	25132.74	Watts
2	*Nominal Motor Speed*	N	3000	RPM
3	*Nominal Torque*	t	80	Nm
4	*Number of Phases*	m1	3	
5	*Coil Pitch*	Wc	1	
6	*Outer Diameter of Magnets*	Dmagout	0.28	m
7	*Inner Diameter of Magnets*	Dmagin	0.2	m
8	*Outer Diameter of Stator Windings*	Dsout	0.324	m
9	*Inner Diameter of Stator Windings*	Dsin	0.164	m
10	*Thickness of Magnet*	hm	20	mm
11	*Single Sided Mechanical Clearance*	g	1	mm
12	*Number of Stator Slots*	s1	12	
13	*Armature turns of Single Stator per phase*	N1	100	
14	*Diameter of Copper Wire*	dw	0.2	mm
15	*Thickness of Copper wire with Insulation*		0.24	mm
16	*Class of Insulation Of copper Wire*		F	
17	*No of Wires IN parallel*	aw	100	
18	*Air Gap magnetic Flux Density due to magnet*	Bmg	0.4	T
19	*Supplied Voltage*	V	200	V
20	*Number of poles (ie no of magnets*	2p	8	
21	*Rectangular Semi closed Slot Dimensions*	h11	40	mm
22		h12	2	mm
23		h13	0	mm
24		h14	0	mm
25		b12	17	mm
26		b14	17	mm
27	*Copper Conductivity (Mega Siemens / meter)*	Sigma	*47*	*M S/m*
28	*Length of stator Coil side*	Li	*30*	*mm*

	Description	Symbol	Value 1	Units
29	*Length of inner end connection*	Lin	*44*	*mm*
30	*Length of outer End connection*	Lout	*62*	*mm*
31	*Average length of stator turn*	Lavg	*166*	*mm*
32	*Average Length of stator end connection*	Lstaavg	75	*mm*
33	*Average Diameter of Coils*	Dsavg	0.244	*m*
34	*Average Diameter of magnets*	Dmag	0.24	m
	General			
	Phase Voltage	V1	115.470 1	V
	Rotations per second	n	50	rps
	Pole pairs	p	4	
	Magnetic Constant	mu0	12.5663 7	*10^-7H/M
	Minimum Slot pitch	t1min	43	mm
	Narrowest tooth Width	c1min	26	mm
	Magnetic Flux density in the narrowest tooth	B1tmax	0.66	T
	Carters Coefficient			
	b14/2g ratio	Const1	8.5	
	gamma value	gamma	12.9990 2	
	Average Slot pitch t1	t1	63.8790 5	mm
	kc value	kc	1.25548 4	
	Factious Air gap	g'	1.25548 4	
	Windings Calculations			
	Number of slots per pole	Q1	1.5	
	Number of slots per pole per phase	q1	0.5	
	Number of Conductors per coil	Nc	2500	
	Average Coil pitch in terms of coils	tau -c	1.5	
	Coil Pitch to pole ratio beta	beta	0.66666 7	
	Distribution Factor	kd1	1.15470 1	
	Pitch Factor	Kp1	0.86602 5	

	Description	Symbol	Value 1	Units
	Winding Factor	kw1	1	
	Electrical angle Gamma2	gamma2	120	degrees
	Torque production			
	Average Pole pitch	tau	96	mm
	Pole width	bp	50	mm
		alpha-i	0.520833	
	Average Magnetic Flux	Bavg	0.208333	T
	Torque Constant	kt	0.813333	Nm/A
	Required current for rated torque	Ia	98.36066	A
	Stator Line Current Density			
	EMF constant	Ke	5.110324	V/rps
	Voltage	V	255.5162	
	Power Confirmation	P	25132.74	
	Magnetic Flux			
	Inner to outer coil diameter ratio	kd	0.506173	
	Magnetic flux	phi-f	0.001597	Wb
	Cross Section of Stator Conductor	Sa	0.031416	mm^2
	Stator Winding Losses			
	Stator Winding Resistance per phase for DC	R1dc	0.112424	ohm
	Frequency	f	200	hz
	Skin effect Coefficient	k1r	7.818678	
		Const2(Epsilon)	1.010793	
		Const3(Epsilon)	0.040463	
		epsilon / ep	0.590989	

	Description	Symbol	Value 1	Units
		k1r-adj	3.464582	
		R1dc-real	0.389503	ohm
	Width of all Conductors in Slot	b1con	1.6	mm
	Height of Conductors in slot	hc	10	mm
	conductors per slot arranged above each other	Msl	34	
	Stator winding resistance in AC	R1ac	0.068163	ohm
	Power Loss Due to stator	delp1w	1978.397	
	Current Density and fill factor			
	Stator line current density	Am	108880	Amp
	Cross Section of stator Conductor	Sa	0.031416	mm^2
	Current Density	ja	3.913646	Amp
	Fill factor	ff	0.461999	
	Inductance			
	Armature Reaction Inductance	lapp	1.17E-05	H
	Armature Reactance	Xl	0.014653	Ohm
	Power loss due to reactance	Parm	53.16355	W
	Stator Core Losses			
	Electrical conductivity of Iron	sigmafe	10000000	S/m
	thickness of laminations	Dfe	0.0003	m
	Specific Density of iron/laminations	rofe	7860	kg/m^3
	Mass of laminations	mFe	11.678	kg
	Coefficient of distortion of magnetic flux density	eta D	1	
	Harmonic Component of magnetic flux density in x direction	Bmx1	0.3	T

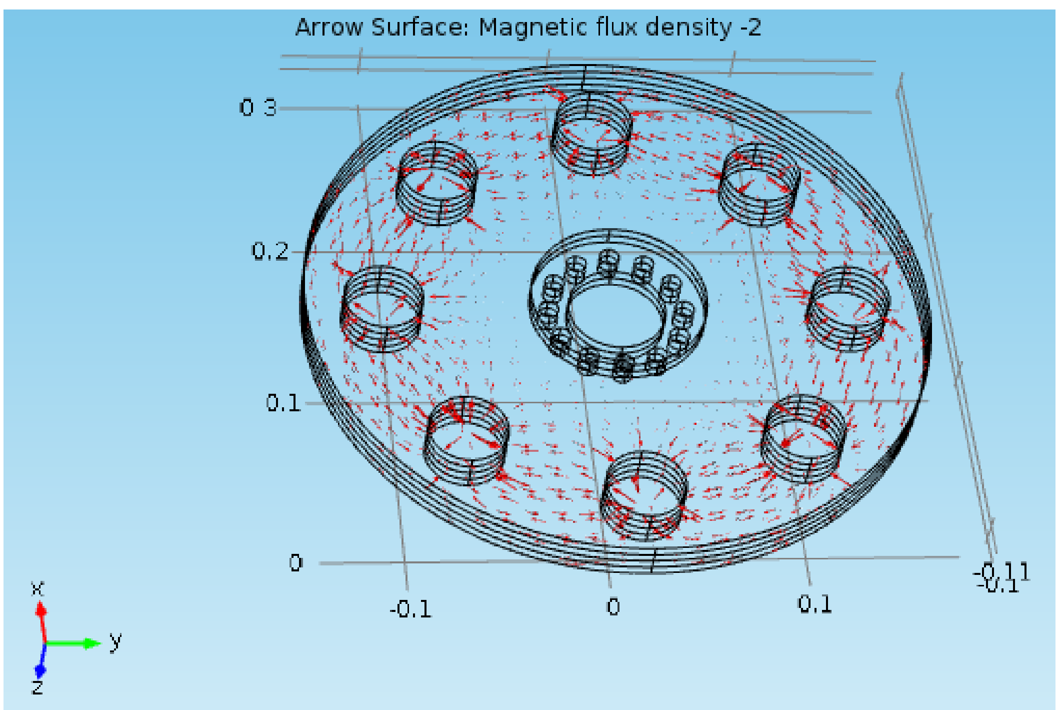
	Description	Symbol	Value 1	Units
	Harmonic Component of magnetic flux density in z direction	Bmz1	0.3	T
	Stator Core power Loss	Del-Psfe	15.8368 7	w
	Hysteresis Core loss			
	Richter formulas Constant epsilon			
	for electrical steel with 2 percent silicon	eps	3.8	m^4/H.kg
	Hysteresis Core Power loss	Del-Phfe	15.9755	W
	Total Core Loss			
	Coefficient of additional core losses	kad	2.4	
	Total Core Power Loss	Del-P1fe	76.3497	
	Permanent Magnet Losses			
	Fundamental Frequency of magnetic flux component	fsl	2400	Hz
	Magnetic Flux density Component due to Slot opening	Bsl	2.31E-0 5	T
	Alpha sl	alphasl	0.75684 7	
		Betasl	0.11664	
		Const4	0.26612 8	
		ko	0.83731	
	Stator slot opening equivalent air gap	g"	20.3031	mm
	Circumferential component Coefficient for PMs	kz	1.79848 8	
	Active Surface Area of permanent magnets	Spm	0.25132 7	m^2
	First harmonic angular frequency	Wv	1256.63 7	
		kv	197.396	
		alpharv	1.00689 4	
		betav	32.7249 2	m^-1
		alphav	786.885 6	
	Power Loss in Magnet	DelPpm	5.53785 1	w

	Description	Symbol	Value 1	Units
	Rotor Core losses			
	Neyman constant	alphar	1.5	
	Neyman constant	alphax	0.8	
	Variable magnetic field coeff	alpharfe	1.475194	
	Hysteresis loss coeff	alphaxfe	0.733972	
	Surface area of disc	sFe	0.061324	
	Power loss due to variable magnetic field	Delp2fe1	11.87812	w
	Power loss due to Hysteresis	Delp2fe2	5.909868	w
	Eddy current loss in Stator conductors			
	Volume of all conductors effected	Vcon	0.000226	m^3
	Density of copper	rocu	8960	kg/m^3
	Mass of all conductors effected	mcon	2.026704	kg
	Power loss in stator conductor due to eddy	Delpe	7.554617	W
	Rotational Losses			
	Frictional losses	Delpfr	66	W
	Constant for frictional loss	kfb	2	m^2/s^2
	mass of shaft	msh	5	kg
	Mass of rotor	mr	6	kg
	Winding losses with drag			
	Radius of shaft	Rsh	0.03	m
	Reynolds number	Re	536165.1	
	Dynamic viscosity of air	mu	0.000018	Pa.s
	Outer radius of rotor	Rout	0.16	m
	Density of air	ro air	1.2	kg/m^3
	Coefficient of drag	cf	0.005285	
	Winding losses with drag	DelPwind	10.3077	W

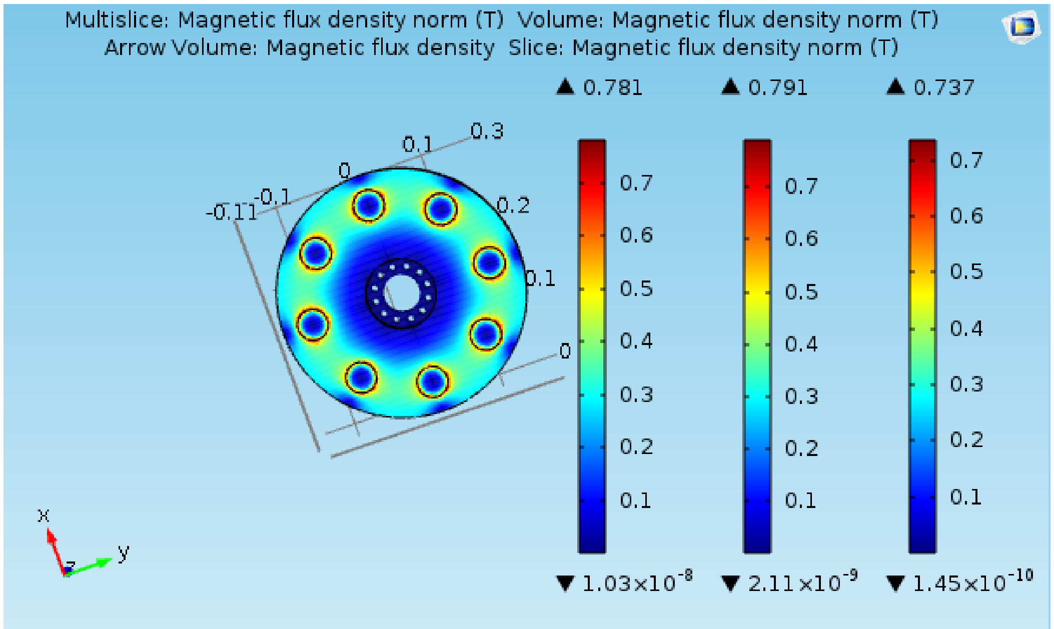
	Description	Symbol	Value 1	Units
	Efficiency			
	total input power	Pintot	27281.84	w
	total output power	pouttot	25132.74	w
	efficiency	eta-total	0.921226	w

The above motor configuration is designed for a peak efficiency of 92% with a peak power output of 25kw.

The Basic simulations in COMSOL were done to ascertain values

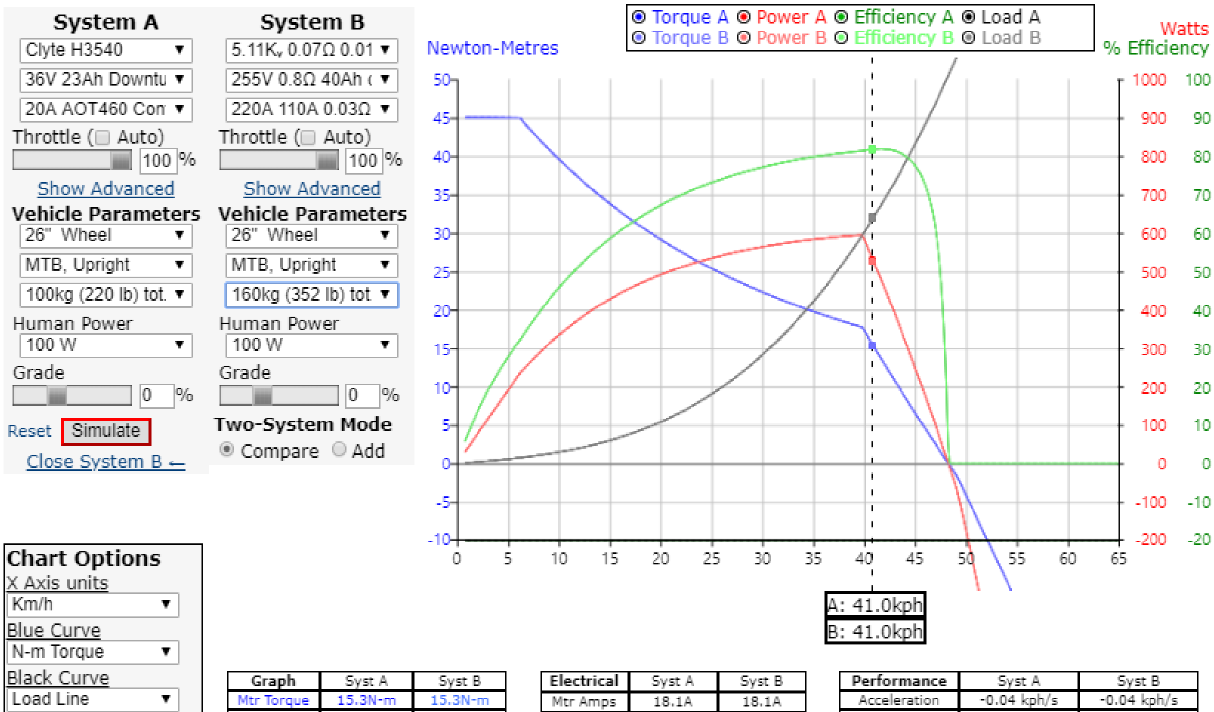


Arrow surface plot of the magnetic flux density in the layered rotor made with epoxy and silicon steel laminations.



Magnetic flux density showing an average of 0.4 Tesla at the critical sections even after having epoxy layers

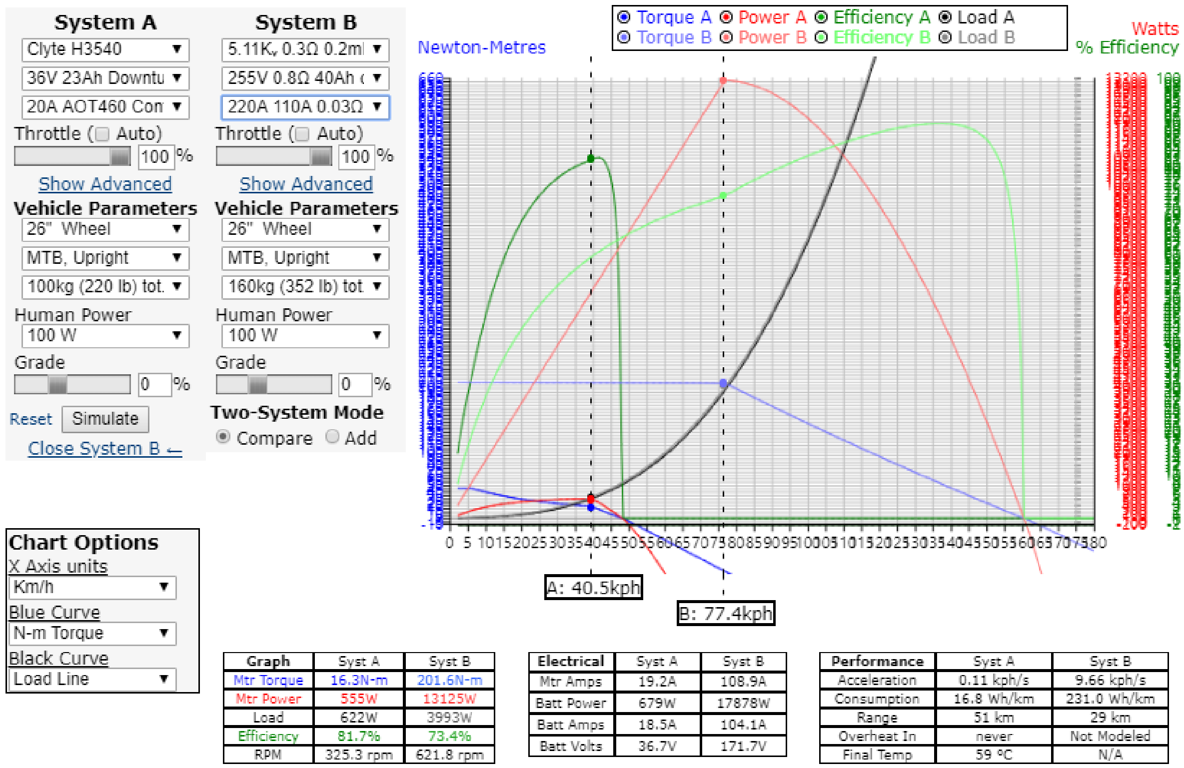
Electric Bike parameter Simulations



Graph	Syst A	Syst B
Mtr Torque	15.3N-m	15.3N-m
Mtr Power	527W	527W
Load	641W	641W
Efficiency	81.8%	81.8%
RPM	329.0 rpm	329.0 rpm

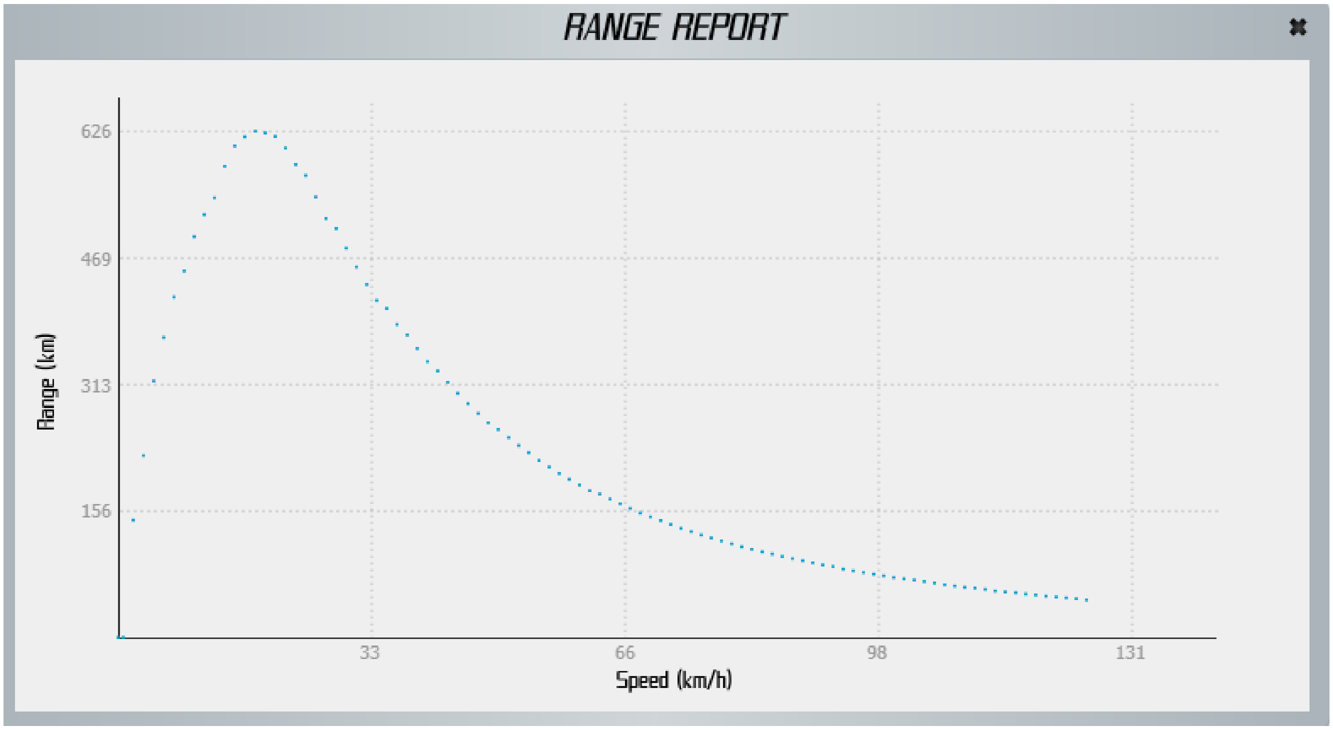
Electrical	Syst A	Syst B
Mtr Amps	18.1A	18.1A
Batt Power	644W	644W
Batt Amps	17.5A	17.5A
Batt Volts	36.8V	36.8V

Performance	Syst A	Syst B
Acceleration	-0.04 kph/s	-0.04 kph/s
Consumption	15.7 Wh/km	15.7 Wh/km
Range	54 km	54 km
Overheat In	never	never
Final Temp	57 °C	57 °C

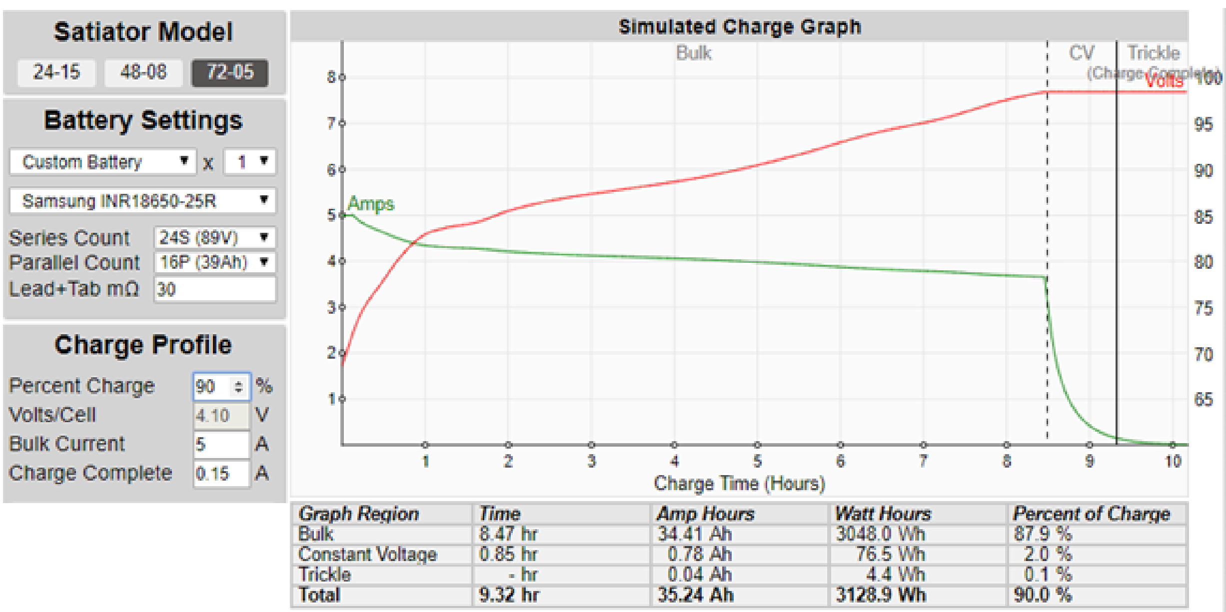


The above are basic parameter simulations for a competed bike with the specified motor.

The values could vary over 20 to 30 percent from the final

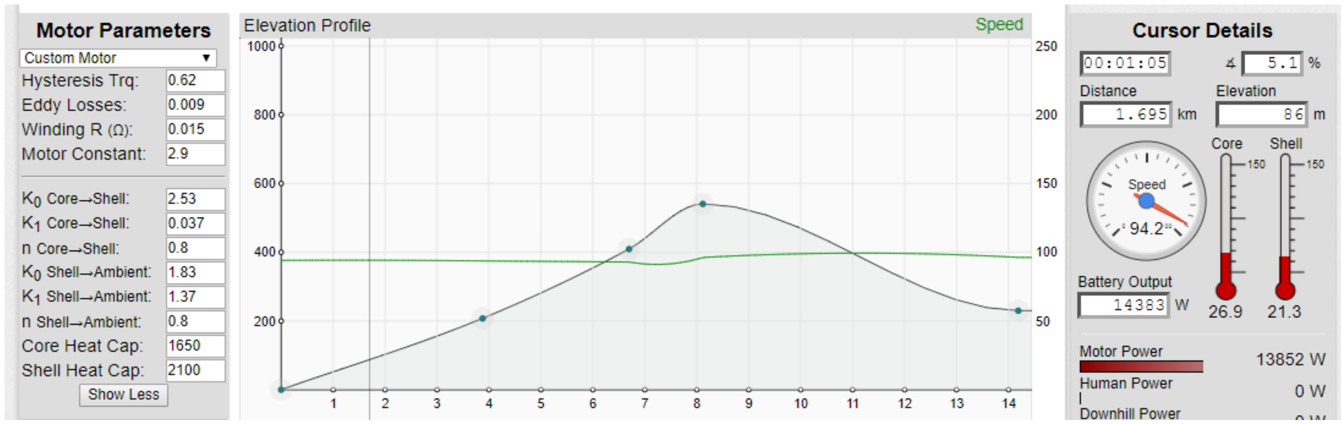


Basic range report giving us an average range of over 156 km at 65 kmph

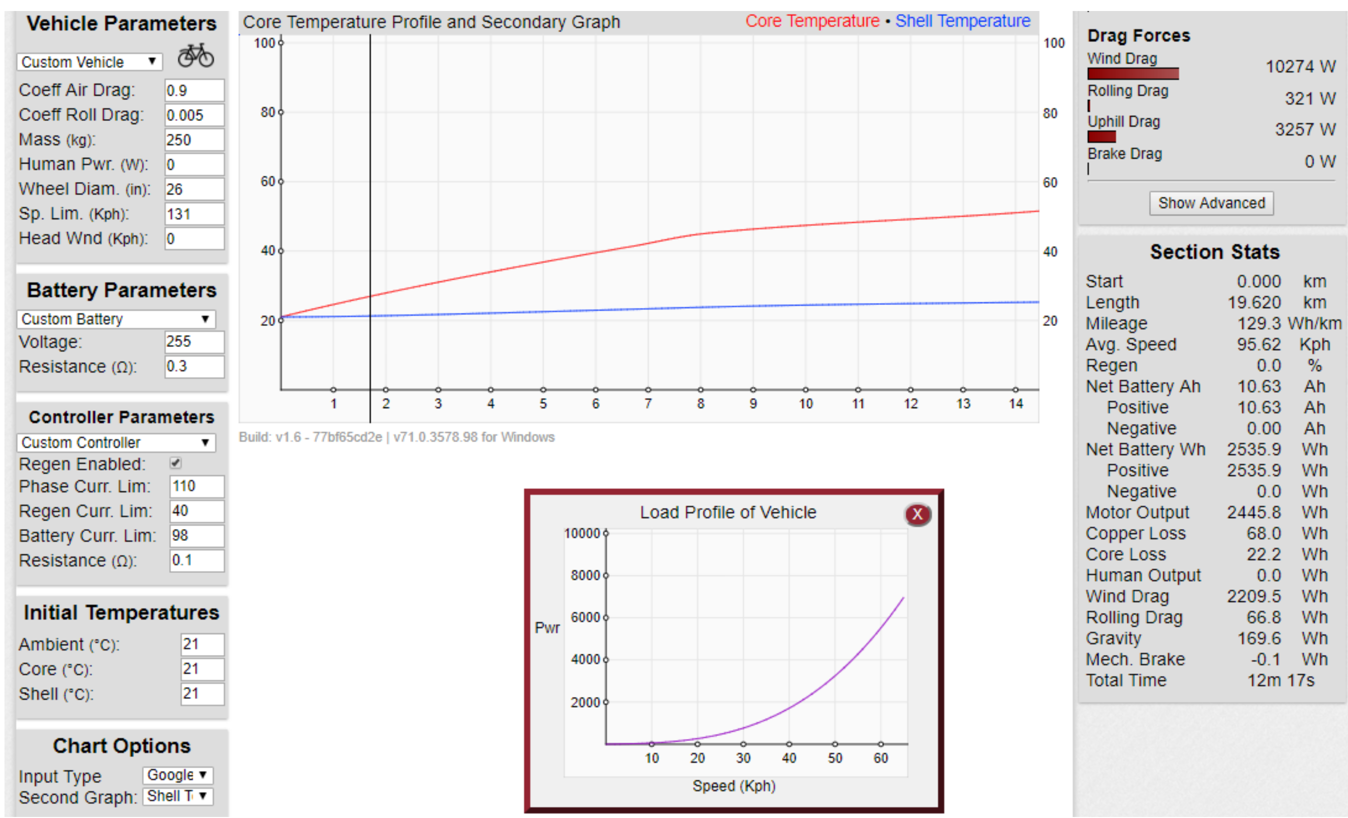


Graph Region	Time	Amp Hours	Watt Hours	Percent of Charge
Bulk	8.47 hr	34.41 Ah	3048.0 Wh	87.9 %
Constant Voltage	0.85 hr	0.78 Ah	76.5 Wh	2.0 %
Trickle	- hr	0.04 Ah	4.4 Wh	0.1 %
Total	**9.32 hr**	**35.24 Ah**	**3128.9 Wh**	**90.0 %**

A simple battery charge profile for 1/3rd our rated battery pack at 90V giving an estimated charge time of over 9.32 hours

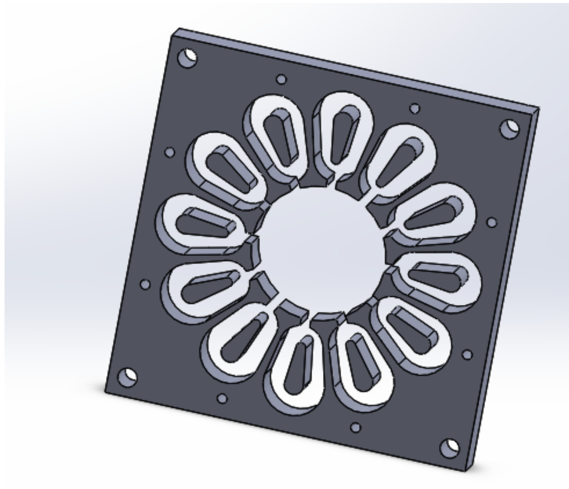
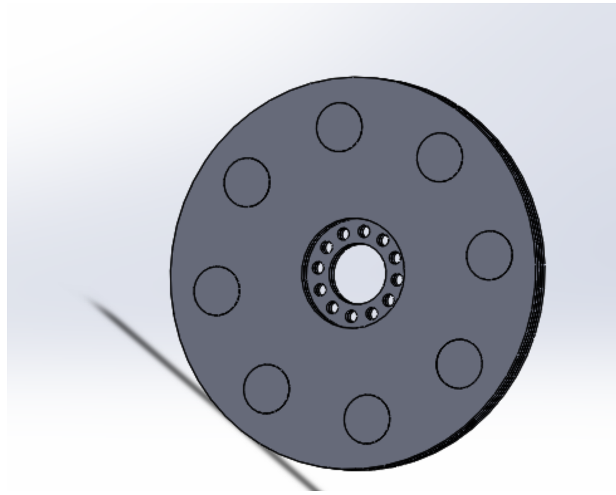
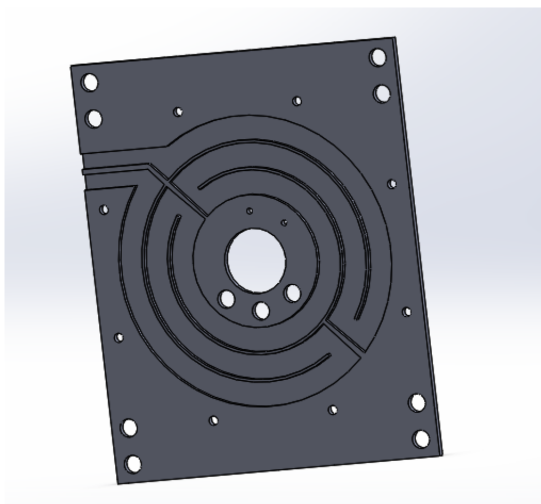
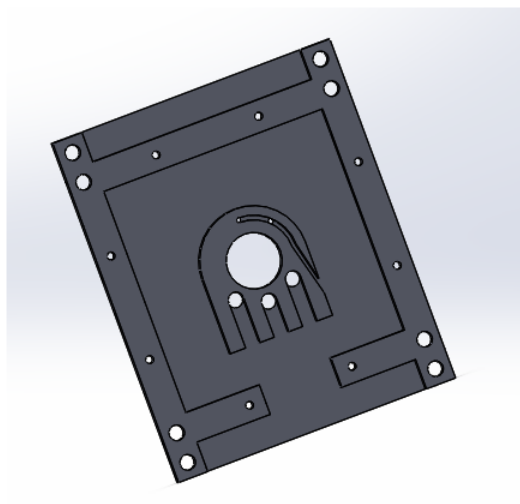


Simple profile simulation of electric bike



Basic performance and heating of motor under the given profile and elevation of road.

The solid works motors parts

1.Stator with soft iron silicon steel cores

2.Rotor model with layers

3..Cooling Layer

4.Bearing hold and wiring layer

3. Brief description of the idea highlighting innovative element.
   (Please use a separate sheet)

   Around an year ago, when we were retrofitting a Maruti Omni 96 and building an electric vehicle platform, we faced lots of problems in procuring a reliable traction motor. Most motors that we found in India were rated at a maximum power output of under 5Kw. Most motors were not designed for traction vehicle applications. We then found out that there are multiple motor manufacturers in China, Germany etc. who supply electric vehicle traction motors at exorbitant costs with long lead times.
   There is a massive shift towards electric vehicles and we foresee a major demand in the coming years as multiple manufacturers shift their product line from internal combustion engine vehicles to purely electric ones. This presents a huge opportunity as well as shows a large gap in the existing Indian market for traction motors. Hence to fill this large void, I would like to start manufacturing traction electric motors indigenously.

   On an average, a 20Kw radial flux brushless DC motor with a motor controller imported to India costs over Rs 96,000. I plan to manufacture equivalent 20Kw motors for under Rs 45,000 in India.

   Most traction motors are of radial flux configuration. After doing rigorous literature survey, I came to know about the distinct advantages that axial flux motors have over radial flux specifically for traction application, namely, they can produce higher torque at lower RPMs with higher efficiency and have an optimal form factor for fitting them inside rims of wheels.

   I started to do analytical calculations and designed an equivalent 25Kw motor using the Excel based axial flux motor calculator developed by me. A simple analysis on COMSOL and FEMM was done to validate the results obtained by the calculator.

   Currently, I'm developing and building a miniature version of the motor and will be experimenting with larger prototypes in the coming months.

The Axial flux motor is a new type of motor configuration where the magnets and coils are mounted in axial direction. It is a brushless DC motor and works on the principle of electromagnetism.
Motor has a compact Form factor such that it can be fit in the wheel hub of a vehicle. There is a higher amount of flux linkage when compared to an equivalent radial flux motor, which is widely prevalent in the market today .Due to its axial flat coil pattern it experiences higher efficiencies.
We chose to build an axial flux motor due to higher power density and higher torque constant to enable its use in Traction applications like that of electric vehicles.

(c) Final outcome/deliverable of the project

The final outcome would be in terms of a working 10Kw motor with a testing rig and a custom electric vehicle platform to test future versions of the motor.

(d) Who would be the beneficiary of this innovation and why?

(Please use a separate sheet)

Currently, Indian electric vehicle manufacturers mostly depend on foreign vendors for supplying their motors at a premium.

If electric vehicle manufacturers were to buy indigenous motors built in India for, either retrofitting IC engine vehicles with electric motors or for building independent electric vehicle platforms, it would reduce their product development time by reducing the supply chain delays.

Thus, we would like to manufacture and sell cost effective, reliable electric motors to these manufacturers. An added advantage of axial flux motors is that they are inherently more efficient than their radial flux counterparts due to their form factor.

4. Proposed costs and time frame

Sr.No	Items	Project Cost Own Share	PRAYAS support sought
1.	Outsourcing Charges for R&D/Design Engg/Consultancy/Testing/Expert cost	NA	2,00,000
2.	Raw material/ Consumables/Spares	NA	4,40,000
3.	Fabrication /Synthesis charges of working model or process	NA	60,000
4.	Business Travel and Event participation Fees (Ceiling 10% of approved project cost)	NA	10,000
5.	Patent filing Cost – (PCT- Ceiling 10% of approved project cost)	NA	60,000
6.	Contingency - (Ceiling 10% of approved project cost)	NA	67,000

Project period in months: ___________1 year 2 months (14 months)_____________

(Not more than 18 months)

5. Activity details/work plan

Sr.No	Activities	Monitorable Milestones	Duration (months)
1	Validation of mini prototypes of axial flux motor configurations	A mini model of DSSR (Double stator single rotor) and DRSS (Double rotor single stator) configurations of AFPM (axial flux permanent magnet) BLDC motors will be built, tested and validated	3
2	Design and development of large 10Kw AFPM BLDC for traction application	Material procurement and Construction of large 10Kw motor	3
3	Testing and validation of back-emf waveform as well as other motor parameters in a custom constructed motor rig	Construction of motor testing rig as well as tabulated result for 10Kw motor	4
4	Practical testing under variable load and real conditions (Testing using a custom manned EV platform)	Construction of the EV platform with motor mounting to validate its functioning	4

6. Have you received financial support / award for your present work from any other sources? (if so, please furnish details)

Mini Demo Axial flux motor development

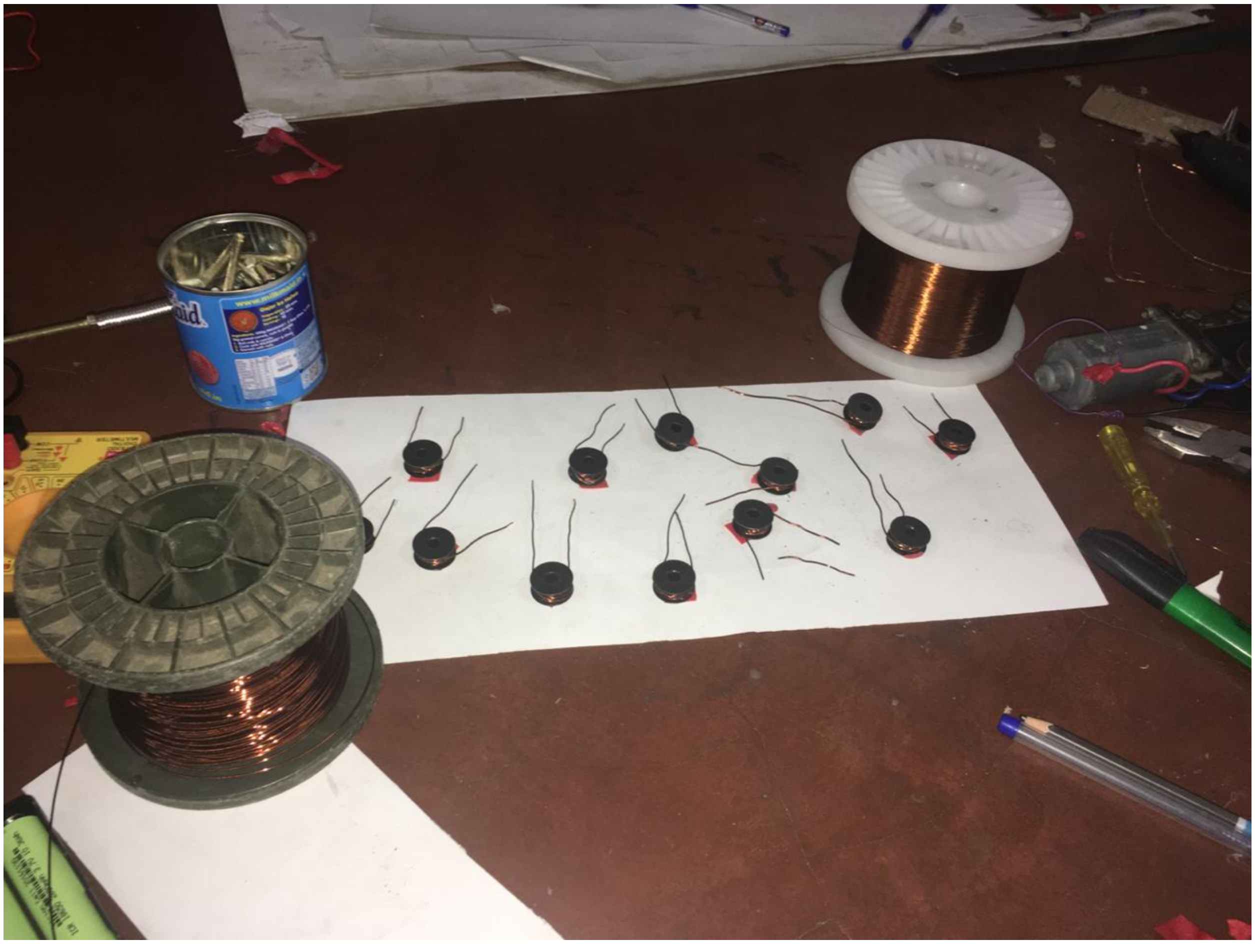


Fig 1 - 0.8 mm dia Copper magnet wire 50 turn winding over iron core

Fig 2 - Scraping of wire ends / removal of enamel

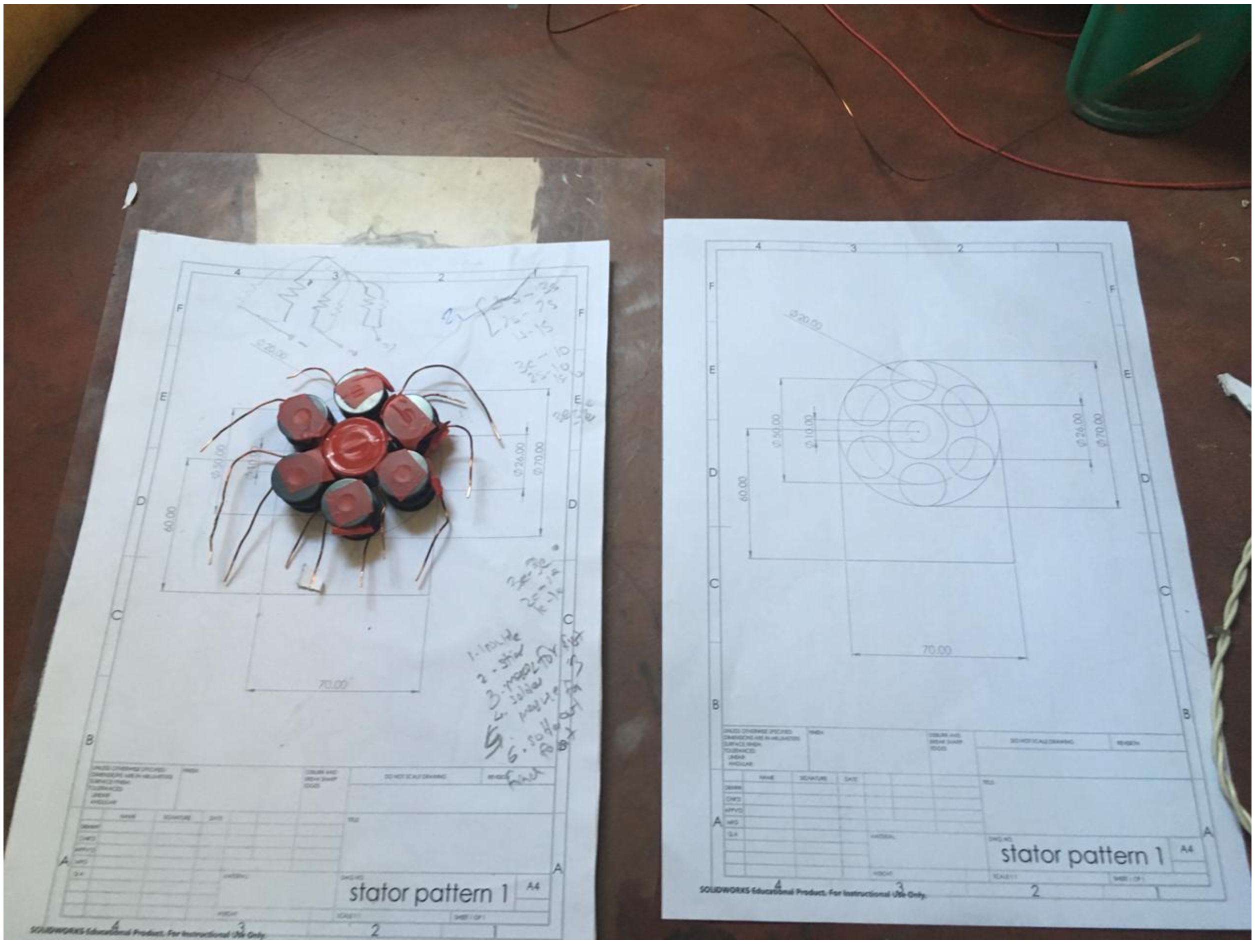


Fig 3- Stator plan and arrangement

Fig 4,5 - Preparation of mould for casting, taping to reduce epoxy leakage

Fig 6,7 - Measurement and mixing of resin and hardener

Fig 8 - Final cast with epoxy