UNITECH

AlFe Motor Cost **Reduction Strategy**

Reducing electric motor cost is possible by adopting lower cost materials in a way that does not compromise power density or efficiency.

AlFe DRIVE

AlFe-Drive Motors

Aluminium carries current at 12% the cost of copper. Ferrite delivers magnetic energy at around 40% the cost of that energy delivered using rare earth. Combining the two and designing traction motors with cost in mind, typically results in products that deliver the same performance at half the cost.

It is well understood that although aluminium is a weaker conductor than copper that for some applications it is more economical than copper to carry current. This is why aluminium is used almost universally for transporting electrical energy over long distances above or below ground.

The important metric is not the relative ability of the two materials to carry electrical current but the relative cost of carrying the same current for the two materials

In a similar manner it is not the relative strength of rare earth and ferrite magnets but the relative costs of the magnetic energy delivered by the two materials.

THE ALUMINIUM/COPPER COMPARISON

The chart below tables the important metrics for the two materials **$5.96×10^7 3.5×10^7$**

PROPERTY	UNIT	VALUE FOR COPPER	VALUE FOR ALUMINIUM
Material grade		>99% pure	>99% pure
Conductivity	σ (S/m)	5.86×10^7	3.5×10^7
Density	Kg/m^3	8,960	2,700
Cost	$/kg	11.24*	2.77*

* Price for bulk material at 29th 11 2025

This means that in order to achieve the same current carrying capacity of one cubic meter of copper from aluminium you need $1.674m^3$ of aluminium.

Converted to weight this is 8,960kg of copper and 4,519.8kg of aluminium.

The copper will cost $100,710.40 and the aluminium will cost $12,519.84

Copper is <u>more expensive</u> than aluminium by a factor of **8.04**	**Copper <u>is heavier</u>** by a factor of **1.98**	**Aluminium is <u>volumetrically larger</u>** by a factor **1.67**

THE FERRITE AND RARE EARTH COMPARISON

The chart below tables the metrics important to this comparison. This assumes that the grade of rare earth does not contain any heavy rare earths and the grade of ferrite does not contain any lanthanum or cobalt.

PROPERTY	UNIT	VALUE FOR RARE EARTH	VALUE FOR FERRITE
Material grade		N35	Y40
Magnetic energy	kJ/m^3	270	40
Density	Kg/m^3	7,500	4,900
Cost	$/kg	42.10*	3.8*

* Price for bulk material at 29th 11 2025

This means that the magnetic energy in one cubic meter of rare earths is 270kJ.

In order to achieve this quantity of energy using ferrite you need 6.75 cubic meters

The weight of one cubic meter rare earth is 7,500kg while 6.75 cubic meters of ferrite weighs 33,075kg

The cost of the rare earth is $315,750 while the cost of the ferrite is $125,685

Rare earth is more expensive than ferrite
by a factor of
2.51

Ferrite is heavier
by a factor of
4.41

Ferrite is volumetrically larger by a factor
6.75

The relative magnetic properties of these two grades of magnets are below. Although the magnetic energy is being used as the most important cost comparison factor other properties must be considered in a real design.

Properties	B_r		H_{cB}		H_{cJ}		$(BH)_{max}$		Temp. Coef.		T_w
Grade**	Typical mT	Typical gauss	min kA/m	min oersteds	min kA/m	min oersteds	Typical kJ/m^3	Typical MGOe	$\alpha(B_r)$ %/°C	$\alpha(H_{cJ})$ %/°C	max °C
N30	1105	11050	796	100000	955	12000	235	30	-0.12	-0.750	80
N33	1150	11500	836	10500	955	12000	259	33	-0.12	-0.750	80
N35	1210	12100	860	10800	955	12000	265	35	-0.12	-0.618	80
Y35	440	4400	230	2900	230	2900	36	4.6	-0.14	+0.3	200
Y36	440	4400	260	3300	260	3300	37	4.7	-0.14	+0.3	200
Y38	450	4500	300	3700	300	3700	38	4.8	-0.14	+0.3	200
Y40	450	4500	350	4300	350	4400	39	5.0	-0.14	+0.3	200

There is a general misconception that ferrite is only 10% as powerful as rare earths and that is almost correct if comparing a lower grade ferrite with a high grade rare earth. However it is also related to volume not weight and the density difference means that when comparing like for like the ferrite carries around 25% of the energy carried by a similar weight of rare earth. This means that for applications like a hub motor you need 4 times the weight of ferrite as is needed for rare earth provided the lower surface Gauss can be multiplied by around three times into the airgap. These concentrations are possible using uniquely innovative Halbach arrays. This multiplication is achieved by the innovative arrangement of magnetic material in the rotor and stator associated with the AlFe invention.

When it is possible to combine the use of ferrite with aluminium the increased weight of the ferrite can be offset by the light weight aluminium. If workable designs are possible they are typically around 15% larger volumetrically but the same weight. Generally the efficiency of a ferrite based motor will never match that of a rare earth motor although the difference will be only a fraction of a percent. Often the ferrite design can deliver higher speeds because phase weakening currents needed at high speed are reduced.

In many ways it can be seen that in order to extract the full benefit of using rare earth magnets the conductor must be copper while the weaker performance of ferrite matches the weaker performance of the aluminium. Provided the volumetric downside is acceptable the economics of ferrite and aluminium will often make sense.

Applications of this cost advantage can range from small air-cooled hub and mid mount motors to motors competing with mainstream passenger vehicle motors to direct drive wind turbines.

The Bill of materials shown below compares the material costs of a 4.5kW (peak) 120Nm wheel hub motor manufactured using a conventional rare earth design and using ferrite and aluminium. The material saving after a reasonable license fee is 28% and the manufacturing processes are almost identical. The motor in this case is 16mm wider but no heavier.

This cost comparison is made using Indian Rupee currency and can be converted to $US using a current factor of ₹86.00 = $1.00

The Indian motor used as the bench mark is the one used by BGauss in their C12i bike.

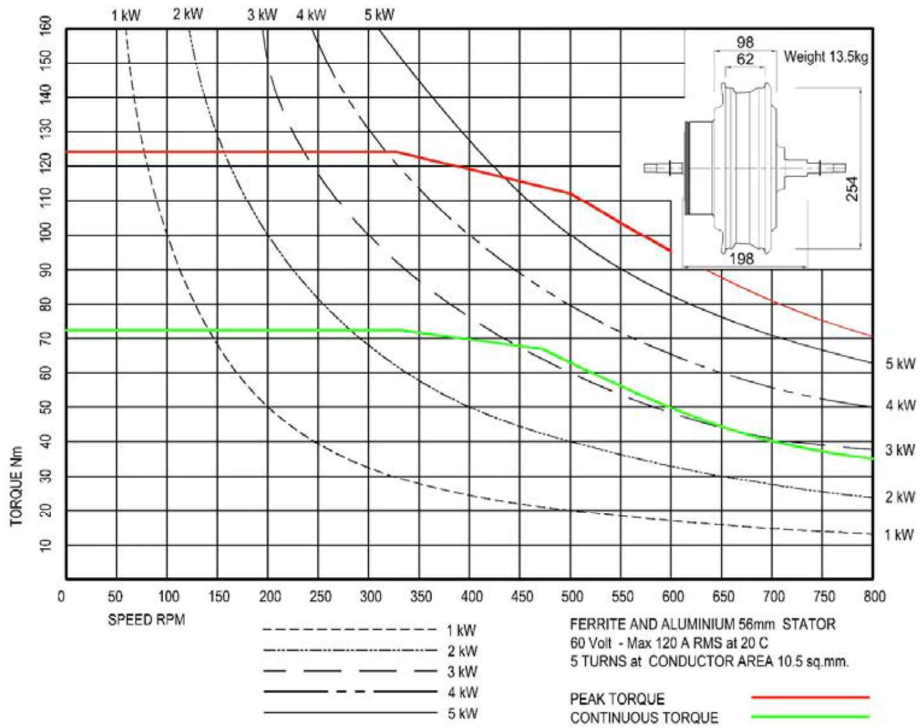
It can readily be seen that in this example the cost of the ferrite magnets are ₹630.00 while the rare earth magnets are ₹1,800.00. The cost of copper windings ₹1,442.00 while aluminium windings are ₹324.00.

Offsetting these savings is an increase in cost of steel while most of the other costs remain the same. Both motors weigh 13.5kg. Their performance including thermal performance and efficiency are almost identical.

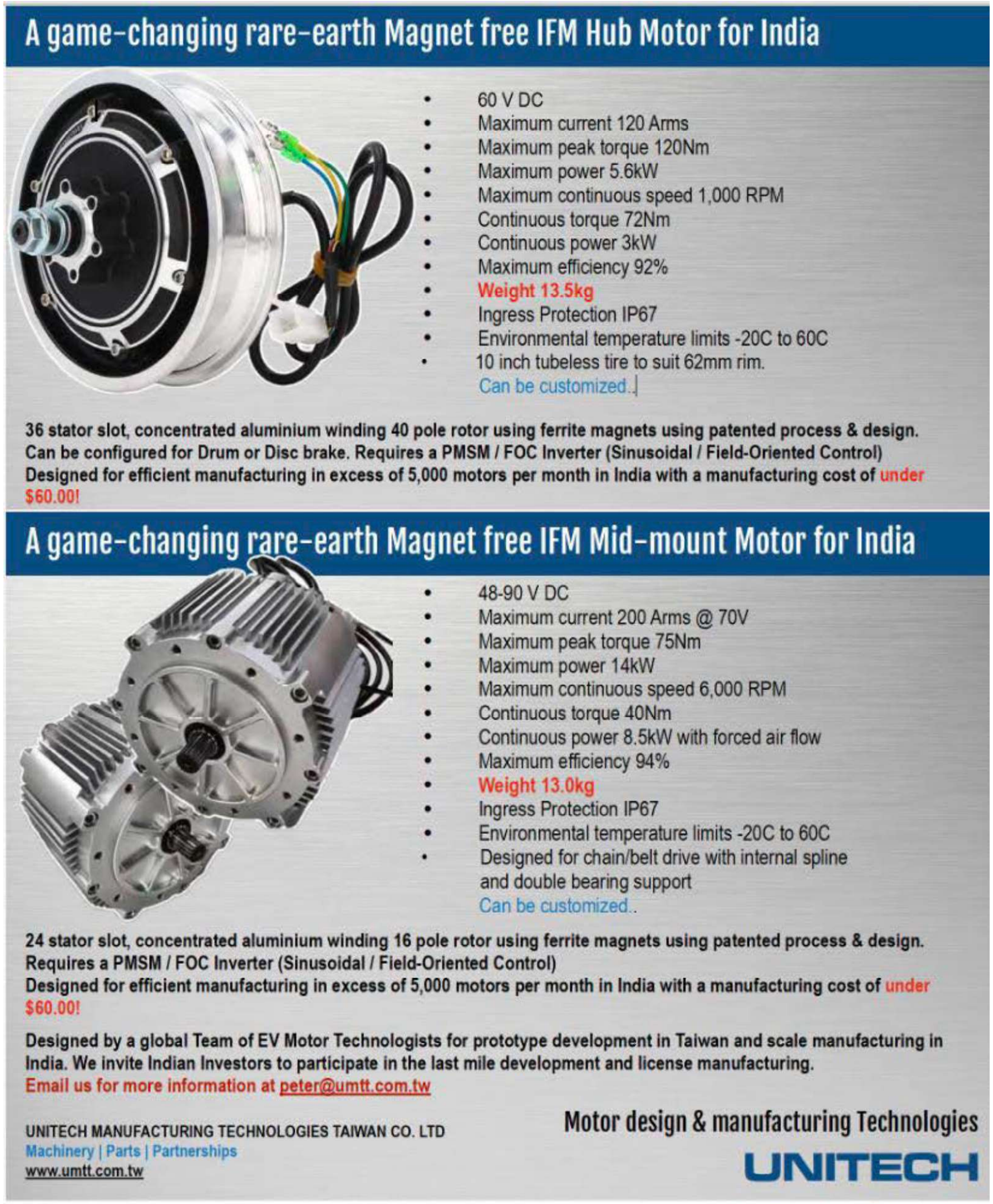
COMPARISON OF RARE EARTH AND COPPER WITH FERRITE AND ALUMINIUM

					RARE EARTH	IFHM
SR. No.	**DESCRIPTION**	**PER MOTOR CONSUMPTION**	**UNIT**	**RATE INR**	**CURRENT MOTOR COST**	**ESTIMATED COST INR**
1	Stator Shaft	1	nos	400	400.00	400.00
2	Slinky Stator Stamping	2.894	kg	137	396.48	
2a	Slinky Stator Stamping	3.42		137		468.54
2b	H Pieces	0.85	kg	137		116.45
3	Stator Assembly Hub Sheet Metal	2	nos	44	88.00	
3a	Hub Aluminium	0.185	kg	420		77.70
4	Winding Slot Wedge	0.018	kg	370	6.66	6.66
5	Winding Copper Wire	1.4	kg	1030	1442.00	
5a	Aluminium Winding Wire	0.72	kg	450		324.00
6	Insulation Paper	0.036	kg	570	20.52	20.52
7	Insulation Safety Sheet	2	nos	6	12.00	12.00
8	Insulation Ring	1	nos	6	6.00	6.00
9	Wire Harness Copper	1	mtr	519	519.00	
9a	Wire Harness Aluminium	1	mtr	435		435.00
10	Wheel Rim	1	nos	520	520.00	
10a	Die Cast Rim Incl Brake	2.6	kg	425		1105.00
11	Rotor Magnet - N35sh	30	nos	60	1800.00	
11a	Ferrite Rotor Magnets	40	nos	15.75		630.00
12	Rhs Plain Cover – Aluminium	0.78	kg	420	327.60	327.60
13	Lhs Drum Break Cover – Aluminium	1.4	nos	420	588.00	
14	Rhs Radial Shaft Seal	1	nos	34	34.00	34.00
15	Lhs Radial Shaft Seal	1	nos	34	34.00	34.00
16	Rhs Plain Cover Ball Bearing	1	nos	72	72.00	72.00
17	Lhs Drum Break Cover Ball Bearing	1	nos	78	78.00	78.00
18	Fiber Glass Sleeves 4mm	0.69	mtr	10	6.90	6.90
19	Fiber Glass Sleeves 8mm	0.19	mtr	20	3.80	3.80
20	Fiber Glass Sleeves 12mm	0.8	mtr	35	28.00	28.00
21	Circlip	1	nos	3.89	3.89	
22	Axle Bush	1	nos	56	56.00	
23	Pcb Assembly	1	nos	130	130.00	130.00
24	Heat Shrink Sleeve	0.31	mtr	7.55	2.34	2.34
25	Butt Connector	3	nos	5.99	17.97	17.97
26	Hall Sensor Adhesive Locktite Si 5699	1.5	300ml	17	25.50	25.50
27	Stator Shaft Potting Adhesive Teroson Ms-930	12	310ml	4	48.00	
28	Hc12 Pcb Tray	1	nos	5.45	5.45	5.45
29	Hc12 Soldering Wire	0.015	KGS	1800	27.00	
30	Rotor Magnet Sticking Glue Locktite Aa-324	2.5	250ml	21	52.50	
31	Rotor Magnet Sticking Glue Activator-7075	2.5	100ml	12	30.00	
31a	Encapsulation Epoxy	0.05	litre	450		22.50
32	Thread Locking Fluid Loctite 243	1.8	50ml	15	27.00	27.00
33	Side Covers Sealant Loctite Si 596	4	85gm	4.5	18.00	18.00
34	Cable Tie	3	nos	0.68	2.04	2.04
35	Allen Bolt (5*14)	16	nos	2.34		37.44
35.5	Allen Bolt (5*14)	8	nos	2.34		18.72
36	O Ring	3	nos	5.5	16.50	11.00
37	Serated Hex Nut	2	nos	8.28	16.56	16.56
38	Spring Lock Washer	2	nos	4.48	8.96	8.96
39	Anti Rotation Bracket	2	nos	10	20.00	20.00
40	Rotation Lock Washer	2	nos	4.26	8.52	8.52
41	High Voltage Sticker	1	nos	2	2.00	2.00
42	I/P	0.02	LTR	160	3.20	3.20
43	Flux	0.03		210	6.30	6.30
44	Varnish	0.1	LTR	205	20.50	20.50
45	Insulation Tape	0.4		5	2.00	2.00
46	Gloves	35		0.3	10.50	10.50
47	Gress	0.02		160	3.20	3.20
48	Pp Thread Yellow	5		1	5.00	5.00
49	Feviquick	0.1		5	0.50	0.50
50	Soldering Bar	0.035	kg	1200	42.00	0.00
					₹ 7,031.83	₹ 4,573.93
					GROSS SAVINGS	₹ 2,457.90
					Production based royalty based on 20% of the gross savings	₹ 491.58
					NET SAVING	₹ 1,966.32
					NET SAVING	27.96%

The performance packaging and weight of this specific ten inch motor, equipped with a drum brake is shown below.



In the 2 Wheeler space The same design philosophy can be applied to hub motors and mid mount motors delivering high performance low cost light weight motors that may be slighter larger volumetrically than their rare earth copper equivalents.



<u>The AlFe design applied to traction motors</u>

When it is possible to combine the use of ferrite with aluminium the increased weight of the ferrite can be somewhat offset by the light weight aluminium. When workable designs are possible they are typically around 15% larger volumetrically but the same weight. Generally, the efficiency of a ferrite based motor will never match that of a rare earth motor although the difference will be only a fraction of a percent. Often the ferrite design for traction motors can deliver higher speeds because phase weakening currents needed at high speed are reduced.

In many ways it can be seen that in order to extract the full benefit of using rare earth magnets the conductor must be copper while the weaker performance of ferrite matches the weaker performance of the aluminium. Provided the volumetric downside is acceptable the economics of ferrite and aluminium will often make sense for traction motors. **Typically the BOM costs of the active materials of steel, magnets and windings are halved.**

Applications of this cost advantage can range from small air-cooled hub and mid mount motors to motors competing with mainstream passenger vehicle motors to direct drive wind turbines.

Application of AlFe design to large air handling motors

Air handling motors are never required to produce high torque at low speed so must be designed quite differently to traction motors. They are typically speed controlled as distinct to torque control applied to traction motors. However the same cost benefits can be delivered **typically reducing BOM costs of active materials by 50%.**

Most air handling motors are based on Induction motors designed to accept mains supply at 50Hz or 60 Hz . AlFe technology cannot be applied to these motors and is only applicable to brushless commutation, synchronous motors. Most of these synchronous motors used for air handling are based on permanent magnet designs driven by an inverter or MCU. Most of them use rare earth magnets and copper windings although ferrite magnets are sometimes seen in very low power motors. Typically, they are air cooled. Radial flux designs dominate both axial flow fans and centrifugal blowers although axial flux is being seen more often with brands such as DEC Star centrifugal blowers. We assume that DEC Star uses rare earth magnets and copper windings.

It is expected that any radial flux motor using rare earth magnets and copper windings could be redesigned using ferrite and aluminium in a way that maintains its weight but needs around 15% increase in overall motor length. It is also expected that an axial flux motor could be replaced with a out-runner radial flux design maintaining the hollow shaft characteristics.

If the comparison motor is already using ferrite magnets then it would be expected that a redesign would replace copper with aluminium and reduce both weight and overall size saving considerable cost.

Application of AlFe design to HVAC compressors

Compressor motors behave somewhat similar performance to traction motors. It is expected that any of these motors can take advantage of the AlFe design and reduce cost with small increase in motor volume, same weight and almost identical efficiency.

Application of Alfe design to ceiling fans

Some studies have been carried out on typical BLDC 1.2 meter Indian ceiling fans that prove significant savings when compared to motors using rare earth and motors using ferrite.

Application of AlFe design to pump motors

Centrifugal pump motors are very similar to fan and blower motors with torque requirement increasing with speed. Positive displacement pumps require motors similar to HVAC compressor motors. It is highly likely that the same cost advantages will exist along with the volumetric compromises. For submersible centrifugal motors the volumetric compromise will only be an increase in length.

Application of AlFe design to direct drive wind turbines

Some simulations have been carried out to assess the cost savings possible with direct drive wind turbines around one Megawatt that use rare earth and copper. As expected the BOM of the active materials reduces by almost 50%.

Application of AlFe design to Stepper motors and Servo motors

It is anticipated that the same savings along with similar compromises will exist but no direct studies of this have been carried out.

Application of AlFe design to Drone motors.

There may be drone applications where cost savings outweigh possible weight penalties. No study of this has been carried out. The highly similar efficiencies will mean that the most signific weight component of the drone, the battery, is unaffected.