COOLING TECHNOLOGY INSTITUTE

75th Anniversary

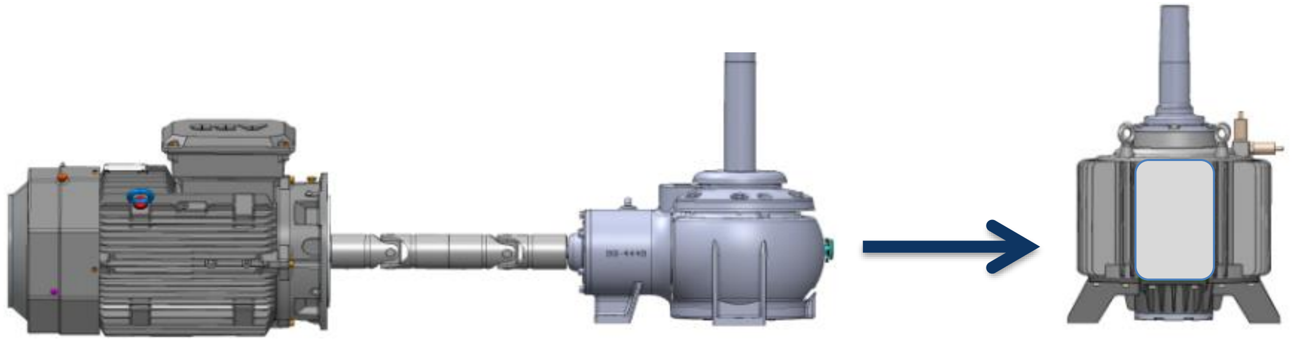
Annual Conference 2025
Memphis, Tennessee

Direct Drive Cooling Tower Fans

Practical Solutions that Leverage Emerging Motor Technology

Scott Reynolds, Electric Torque Machines

February 3, 2025



Abstract
The promise of direct drive cooling tower fans with Permanent Magnet (PM) motors is not new, but so far, this approach has not seen significant adoption. Why is this? The requirements for successful direct drive implementation are reviewed, including performance and economic gaps that have impeded adoption.

The ability to create efficient torque at the low speeds required for direct drive has been a critical constraint. Crossing this gap requires increasing motor pole count without increasing coil resistance. This combination has not been practical with PM Radial Flux (RF) or Axial Flux (AF) machines, given their fundamental design and construction.

A third, emerging motor topology known as Transverse Flux (TF) offers promise to both increase pole count and simultaneously reduce coil resistance, a combination which is unique to this motor type. TF motors, originally invented in the 1980's, have now been successfully commercialized in several markets including direct drive pumps and fan applications.

Outline

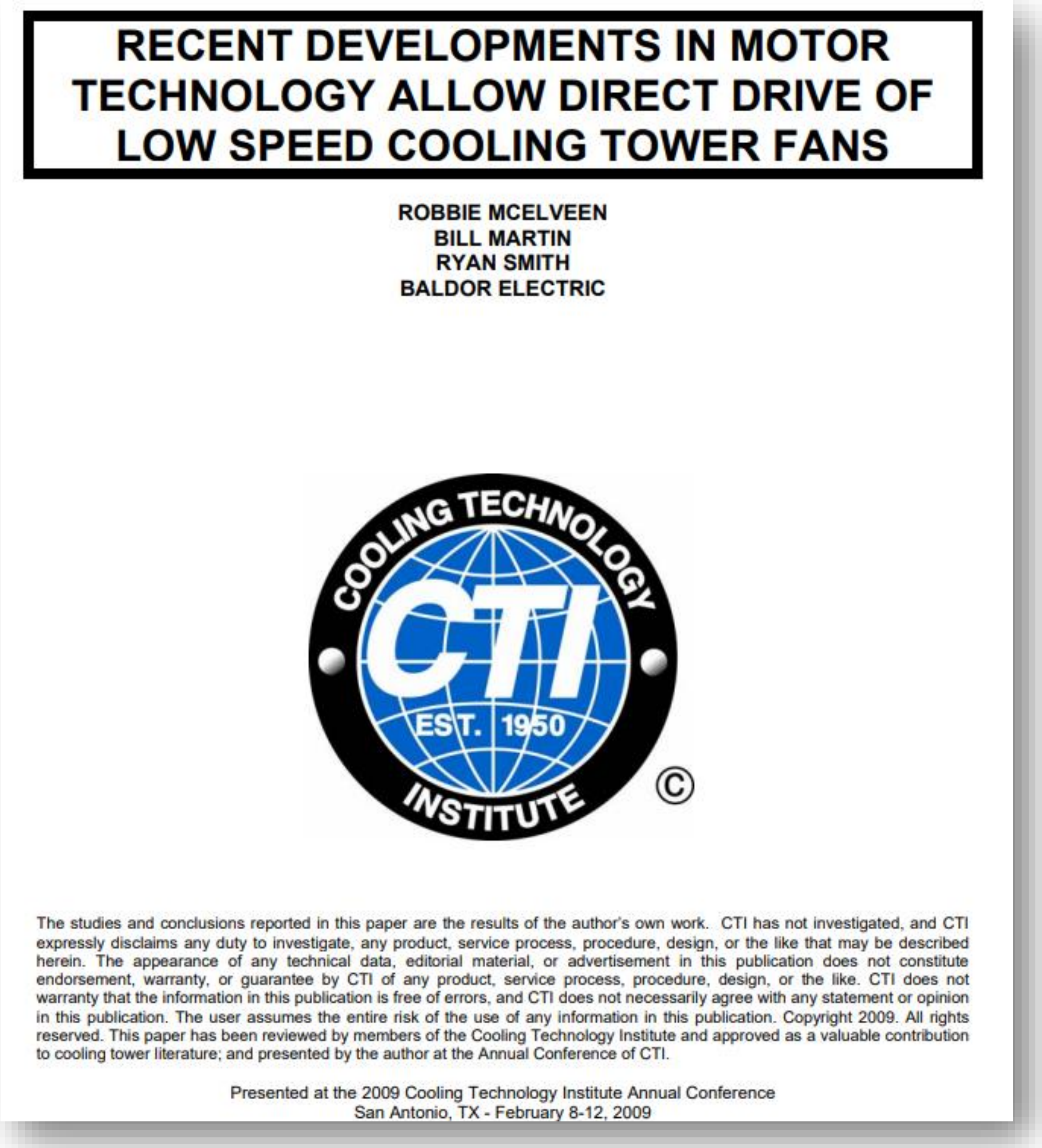
- Direct Drive History
- Motor Challenges
- Helpful Physics
- Direct Drive is All About Torque
- Radial Flux and Transverse Flux
- Recent Commercialization of TFM
- Application Specific Requirements

Why still this?
Is there hope of moving forward?

Direct Drive History
2009 Introduction

Direct Drive Advantages

- Energy savings 13%
- Quieter
- Simplified installation
- Reduced current draw
  - Starting
  - Running
- Improved reliability
- Reduced maintenance
- Reduced vibration
- VFD can trickle current to minimize moisture


RECENT DEVELOPMENTS IN MOTOR TECHNOLOGY ALLOW DIRECT DRIVE OF LOW SPEED COOLING TOWER FANS

ROBBIE MCELVEEN
BILL MARTIN
RYAN SMITH
BALDOR ELECTRIC

Presented at the 2009 Cooling Technology Institute Annual Conference
San Antonio, TX - February 8-12, 2009

Direct Drive History

2019 Update

Fast-forward 10 years…

Pros and Cons of Cooling Tower Power Transmission Technologies

By Jerome Jennings, SPX Cooling Technologies, Inc.

04/29/2019

CHILLER & COOLING BEST PRACTICES

Table 1 – Comparison of Cooling Tower Power Transmission Technologies

	Belt Drive	Gear Drive	Direct Drive	
			EC	PM
Applicable Power	<100 HP	No Limit	<10 HP	<250 HP
Applicable Fan Diameter	<14 feet	No Limit	<4 feet	<30 feet
First Cost	$	$$	$$$	$$$$
Operating Cost	$$$	$$	$	$
Energy Efficiency	+	++	++++	+++
Weight	+	++	+	+++
Sound				
VFD Required?	No	No	Yes, Integral	Yes, External

<u>**Affirms Advantages**</u>

- Energy savings, reduced maintenance, quieter
- EC motors effective <u>up to 10HP</u>

However…

1) "Initial costs can be two to three times more than a gearbox. Due to the high first cost, payback can extend to 10 or more years"

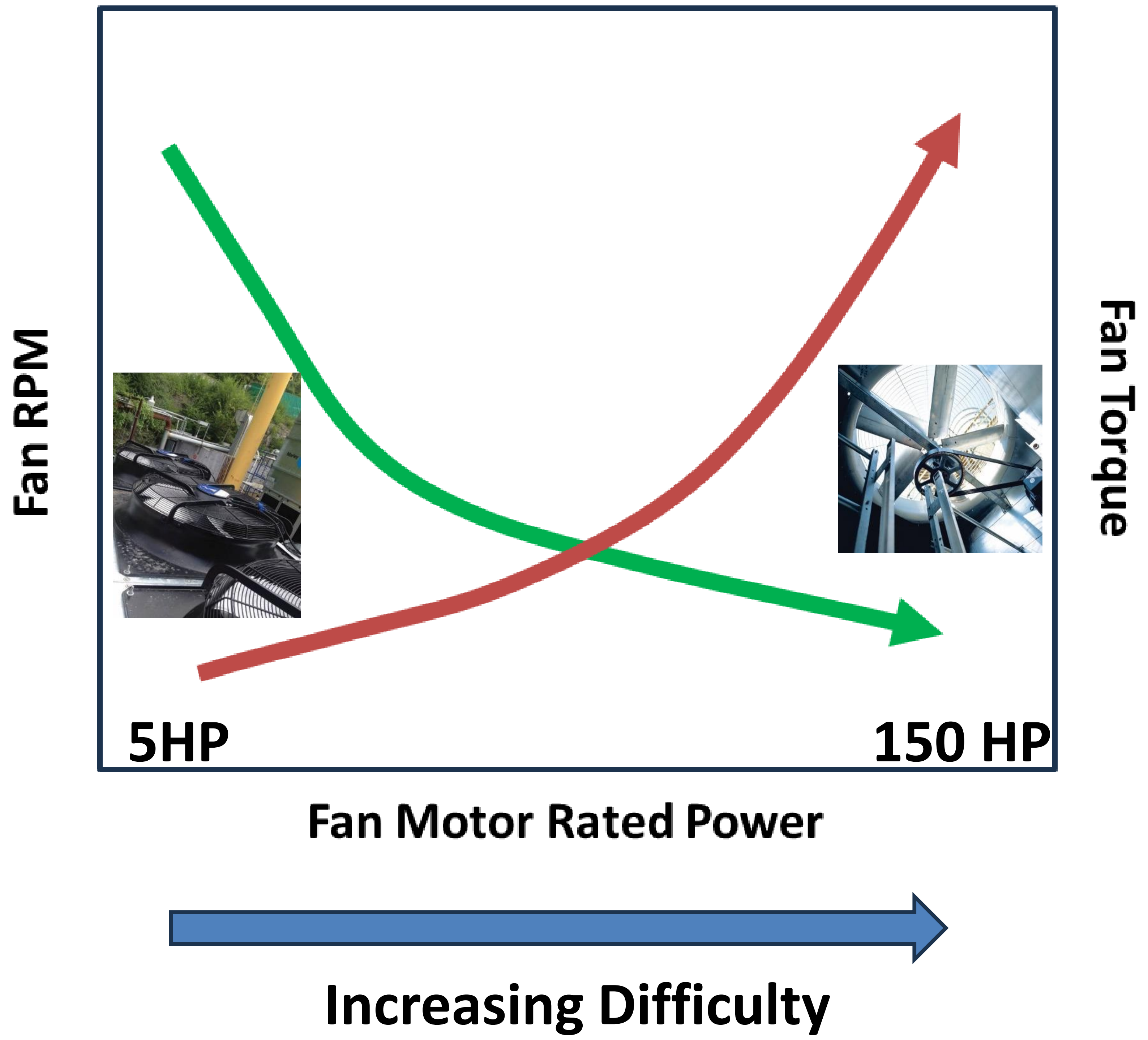
2) "PM Direct Drive motors are bigger and heavier"

<u>Motor cost and weight are directly related</u>

"motors are sold by the pound"

Direct Drive Challenges

Torque Increase with RPM Decrease



Variables:

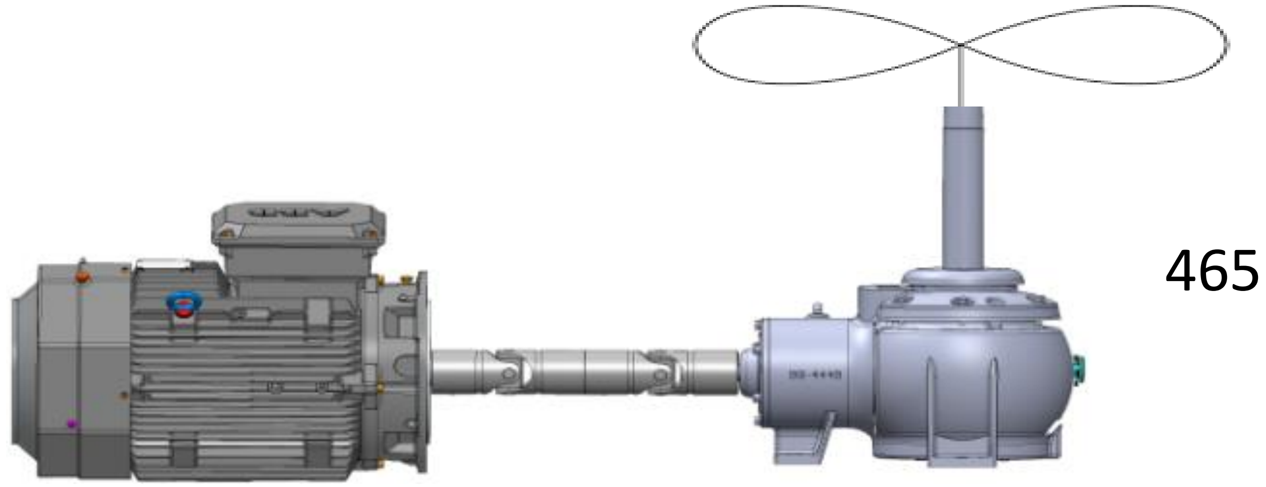
- Propeller size
- Cooling system type
- Max allowable propeller tip speed
- Fan pressure

As DD fan motor size increases, RPM decreases and torque increases.
These are non-linear relationships

Direct Drive Challenges

40HP Example

Legacy Design



<u>Output</u>
450 RPM
465 Ft-lb (630 N-m)

<u>AC Induction Motor</u>
4 Poles
1800 RPM
60 Hz
116 Ft-lb (158 Nm)
500-600 Lbs

<u>4:1 Gearbox</u>
800 lbs

Direct Drive PM Radial Flux

<u>RFM DD Motor</u>
4 Poles
450 RPM
15 Hz
465 Ft-lb (630 Nm)
800 Lb

Magnets
Lamination Steel
Copper Windings

$$$$

Helpful Motor Physics

It's All About Efficient Low Speed Torque

Faraday's Law of Induction

Electromotive Force

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

Change in Magnetic Flux

Change in Time

Divide by Rotational Speed

K_e "Voltage Constant" (Volts/RPM)

$$k_e = \frac{\varepsilon N}{\omega}$$

N is Number of Coil Turns
ω is Rotational Speed

Electrical Frequency

$$\left(\frac{1}{dt}\right) = 2\pi p\omega$$

p is Number of Poles

$$k_e = 2\pi N\Phi_B p$$

"Torque = Flux * Poles"

Pro Tip: K_m "Motor Constant"
The best way to compare DD motors

$$K_m = \frac{K_T}{\sqrt{R}}$$

$$k_m = \frac{k_e}{\sqrt{RN^2}}$$

Motor's ability to create Torque divided by Coil Loss

$$k_m = \frac{2\pi\Phi_B p}{\sqrt{R}}$$

R is Coil Resistance

Two Options for Increasing Torque:

1. Increase Magnetic Flux Φ_B
2. Increase Pole Count p

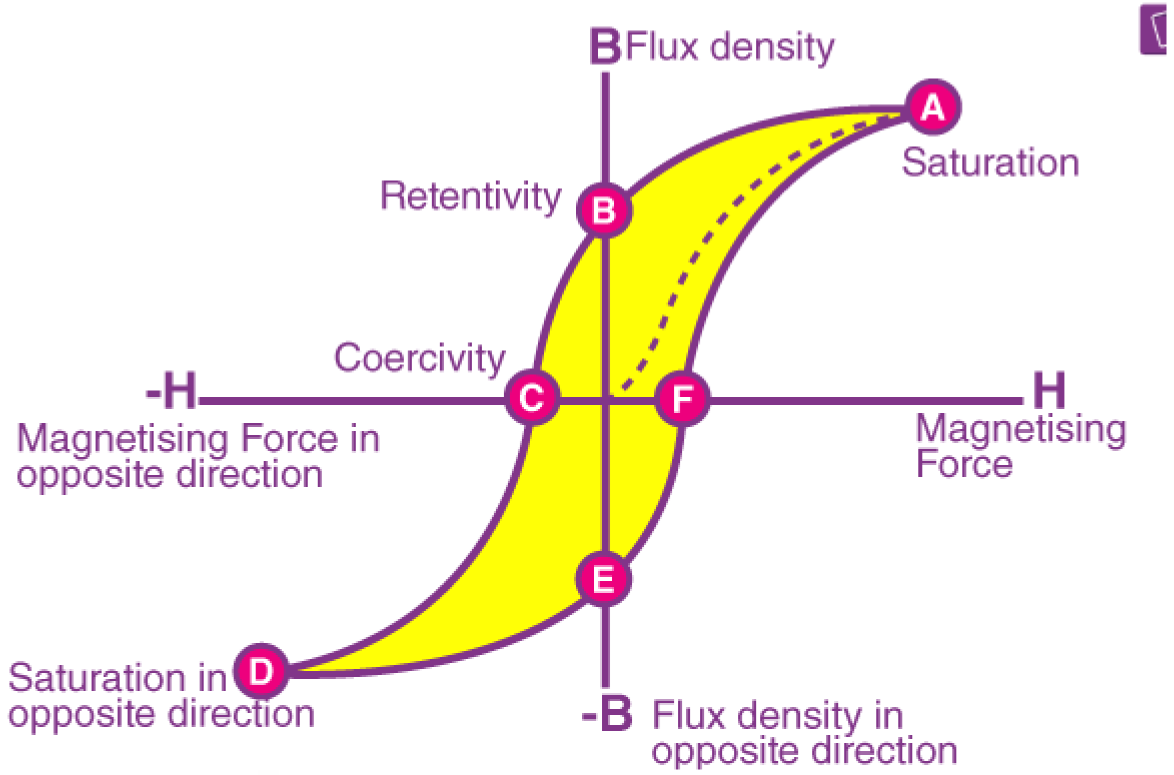
And…

Coil Resistance, *R is the enemy.*

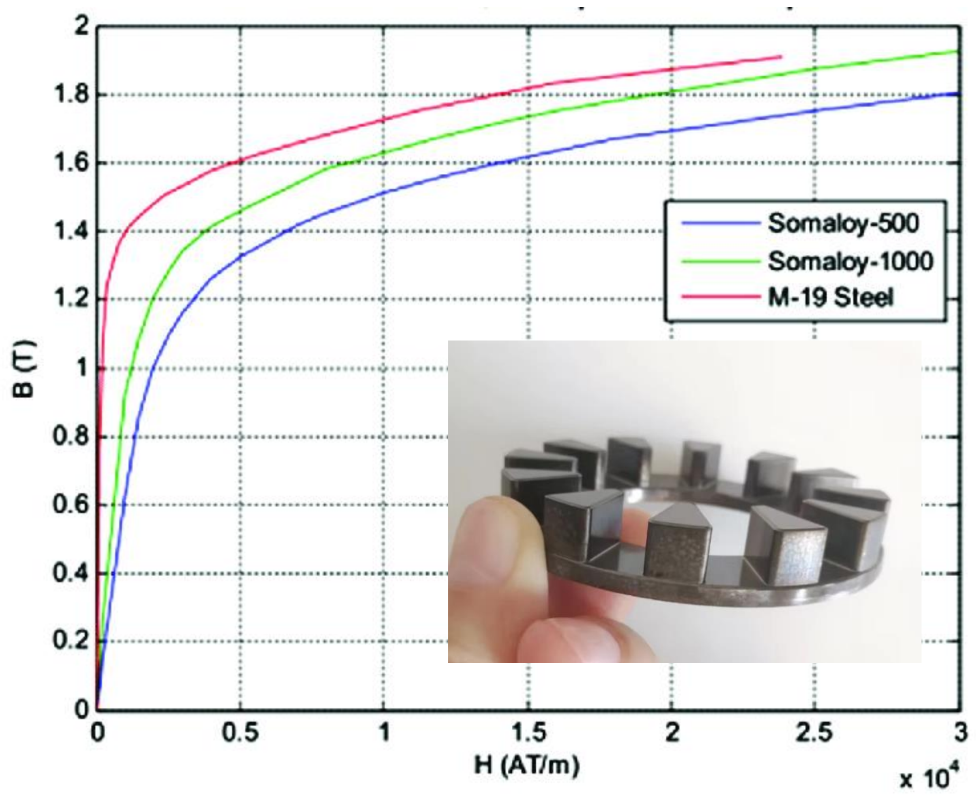
How to Increase Motor Torque

Option 1 – Increase Flux

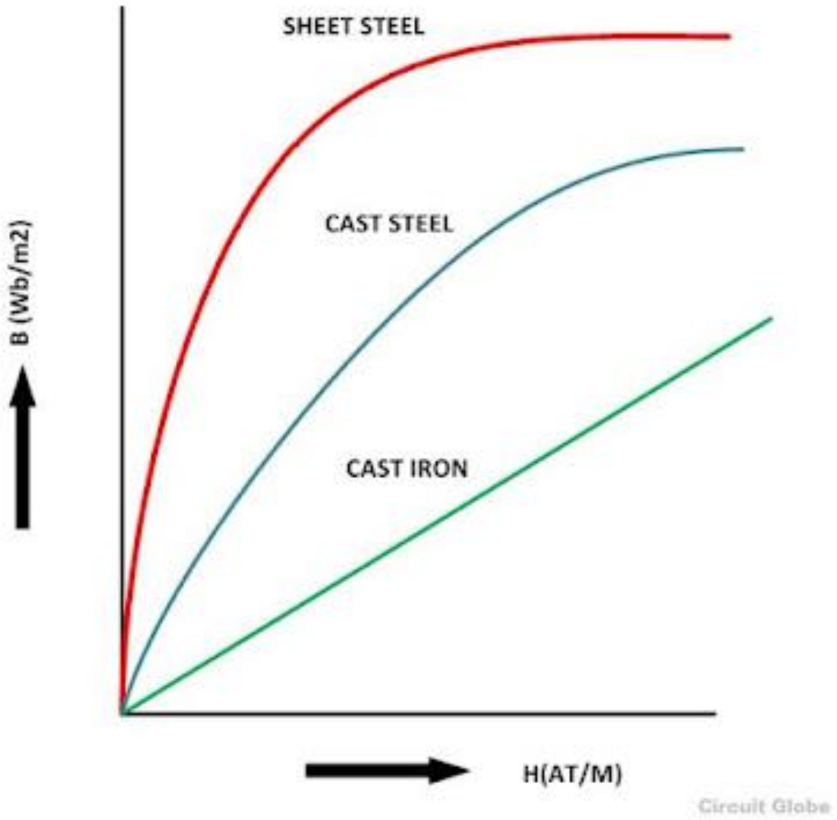
$$\varepsilon = -\frac{d\Phi_B}{dt}$$

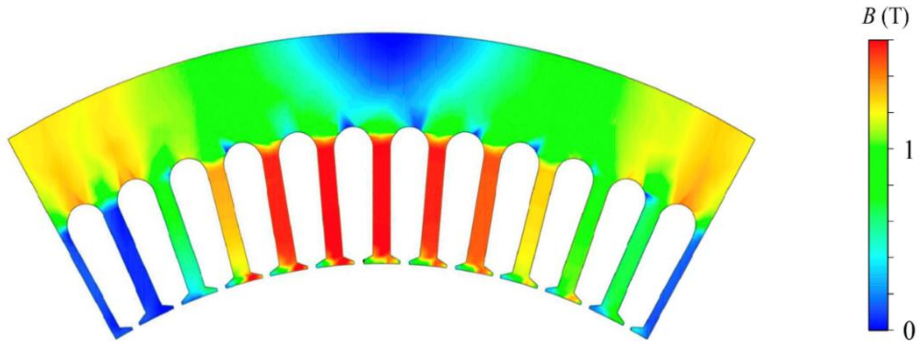


Stator Lamination Stack



B-H curves of M19 steel, SMC 500 and SMC 1000





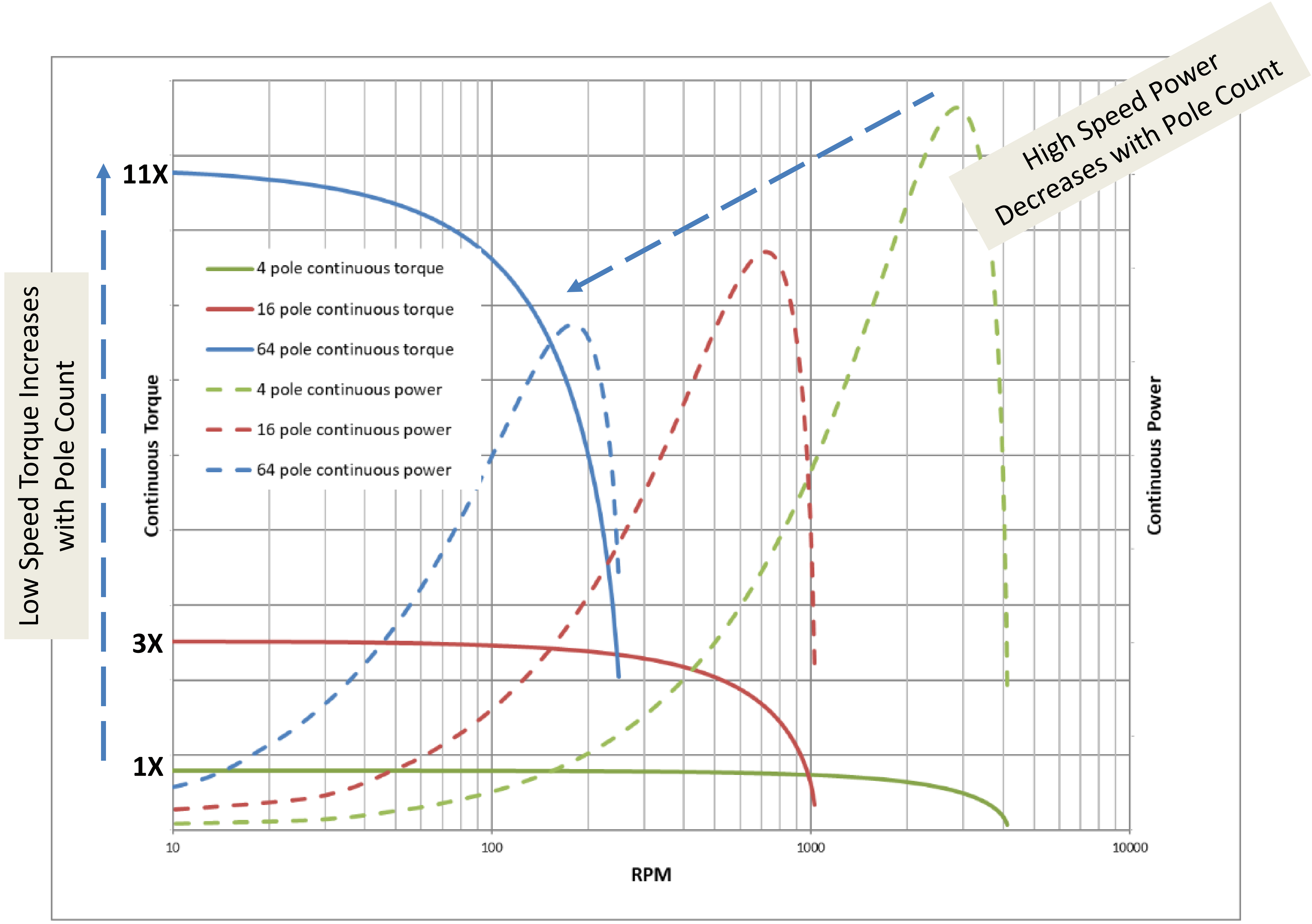
Magnetic saturation of Stator Teeth

Flux density is limited by steel saturation and magnet strength. Thus, the only way to significantly increase flux is to increase motor size.

How to Increase Motor Torque

Option 2– Increase Pole Count

$$\varepsilon = -\frac{d\Phi_B}{dt}$$



* Transverse Flux Simulations provided by ETM

Aren't all motors using similar pole count??

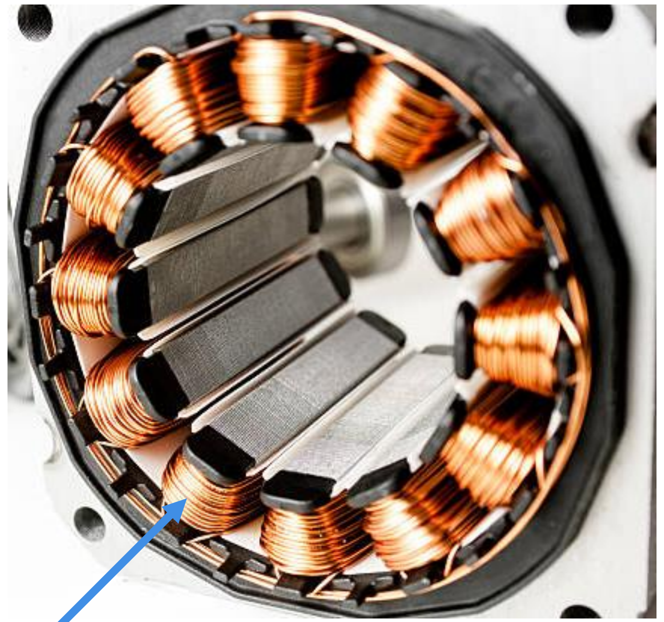
	Radial Flux	Transverse Flux
40 HP	4-8 Poles	48 Poles
75 HP	4-8 Poles	108 Poles

Although Radial Flux motors use similar pole counts, Transverse Flux motors have 10-20X more poles.

Increasing pole count increases torque.

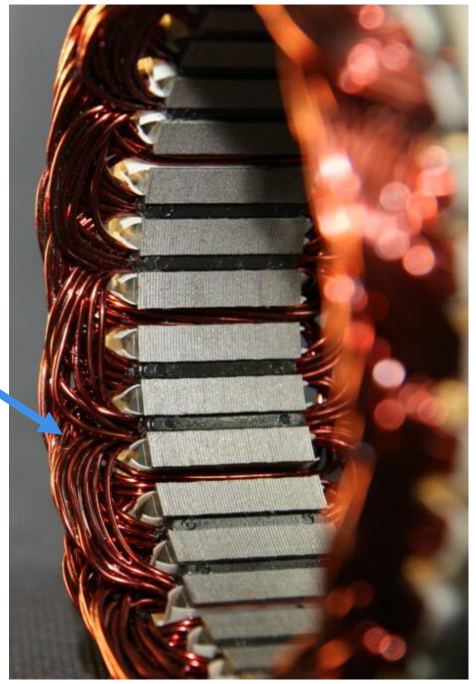
Why can't we just increase the pole count for Radial Flux motors?

PM Motor Types
Radial Flux

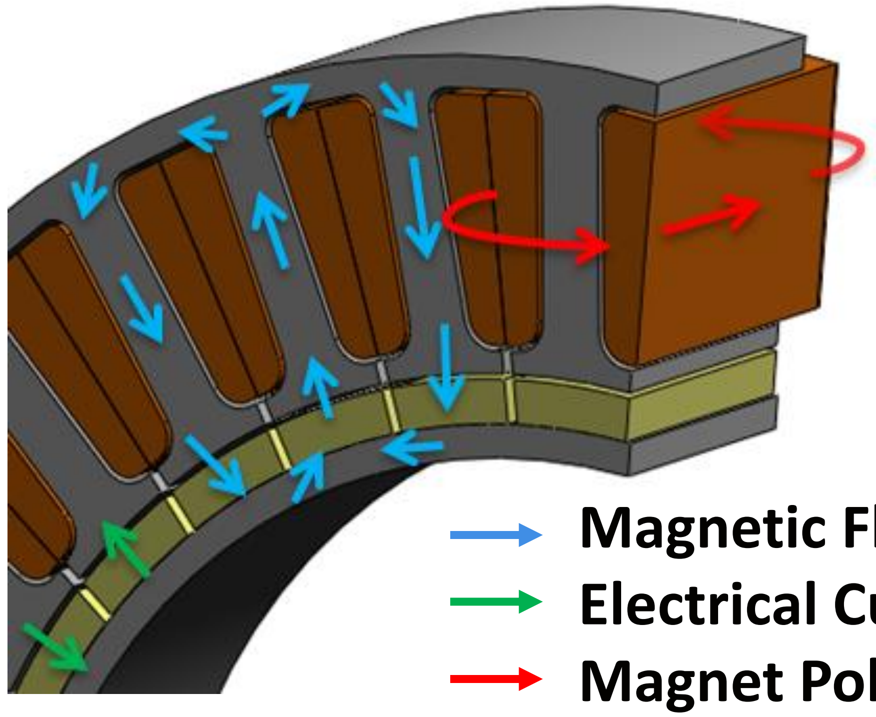


Concentrated Winding

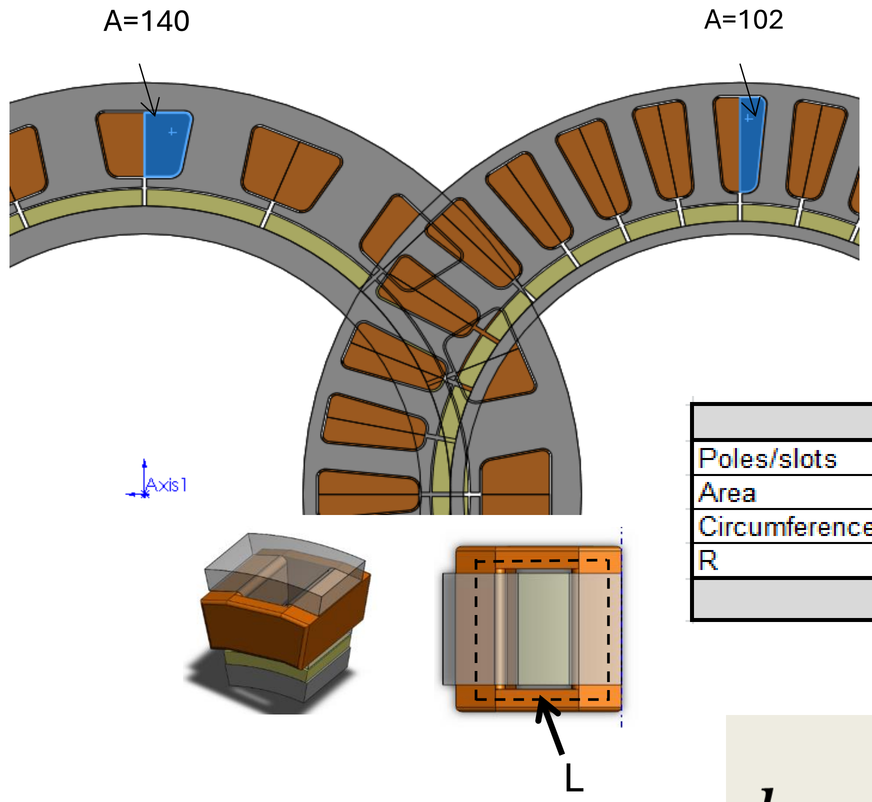
End Turns ☹



Distributed Winding



Magnetic Flux
Electrical Current
Magnet Polarity



	Reference	2X pole count
Poles/slots	16	32
Area	140	102
Circumference	116	88
R	13.26	27.61
	Ratio:	2.08

$$k_m = \frac{2\pi \Phi_B p}{\sqrt{R}}$$

$$R = \rho \frac{L}{A}$$

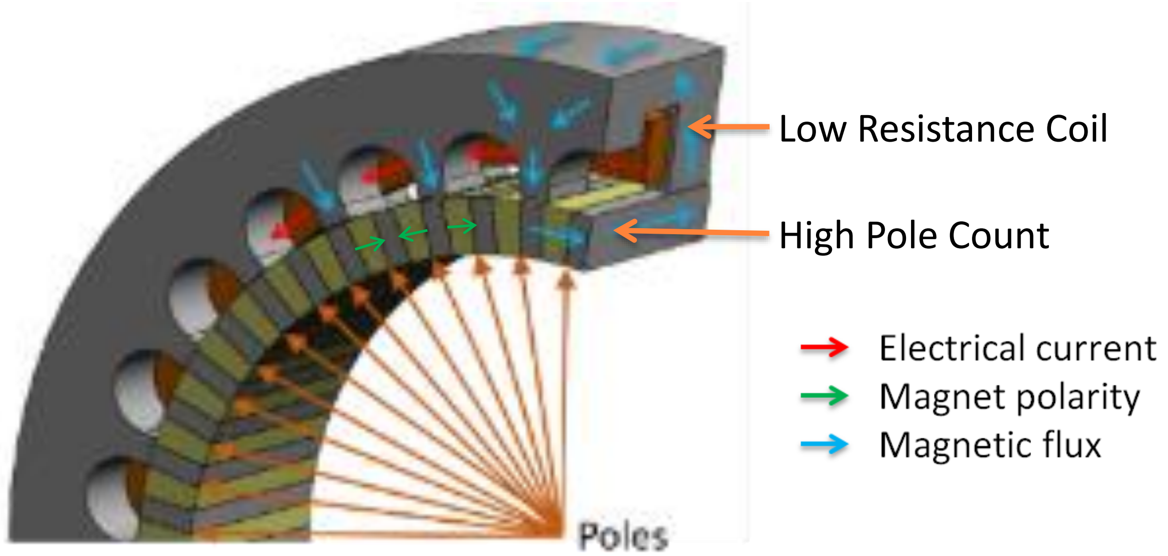
Where
R is Coil Resistance
ρ is the Wire Resistivity per Length
L is the Coil Wire Length for 1 Slot Pair
A is the Cross-sectional Area of the Slot

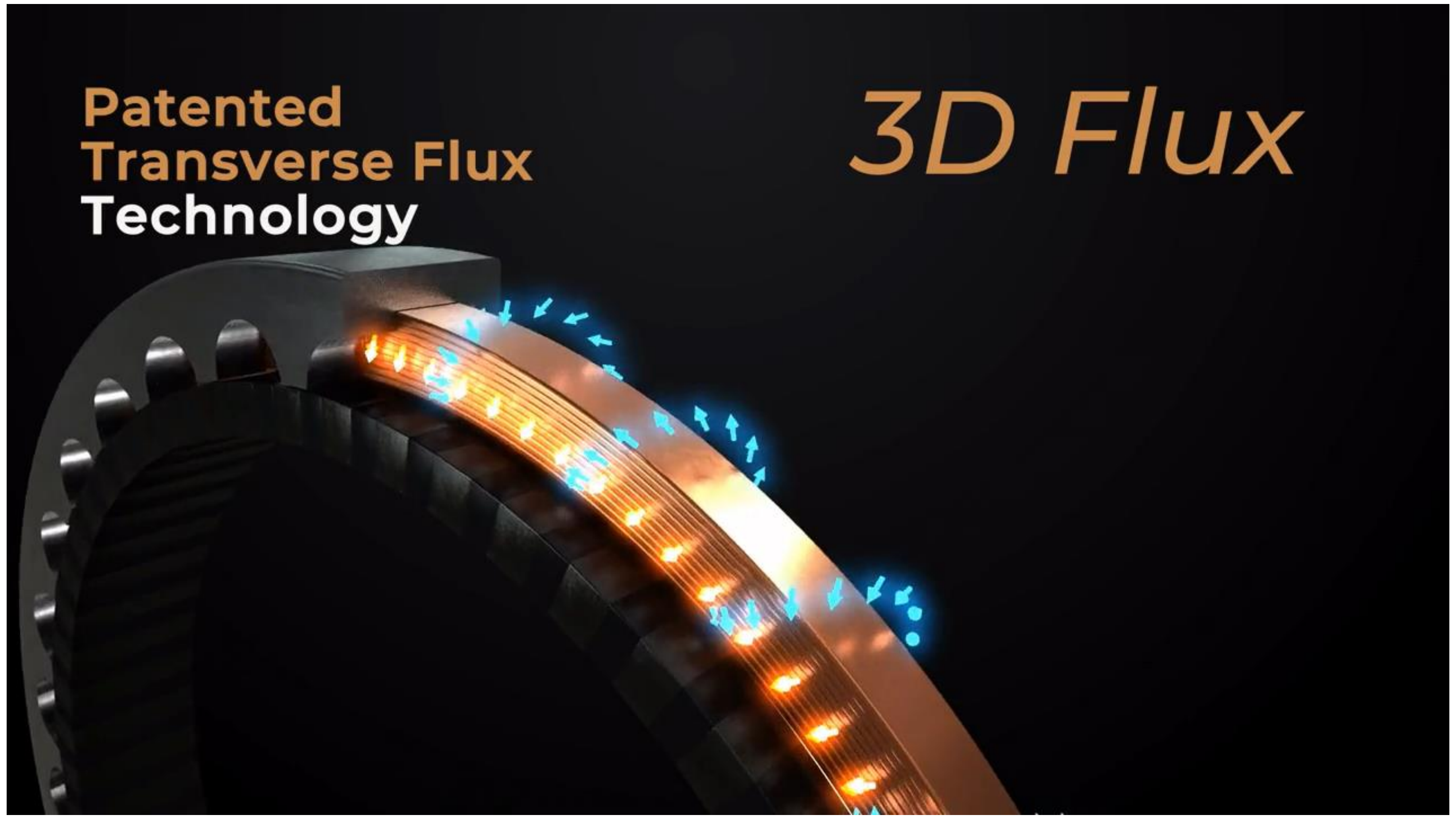
Increasing pole count in Radial Flux motors also increases resistance.

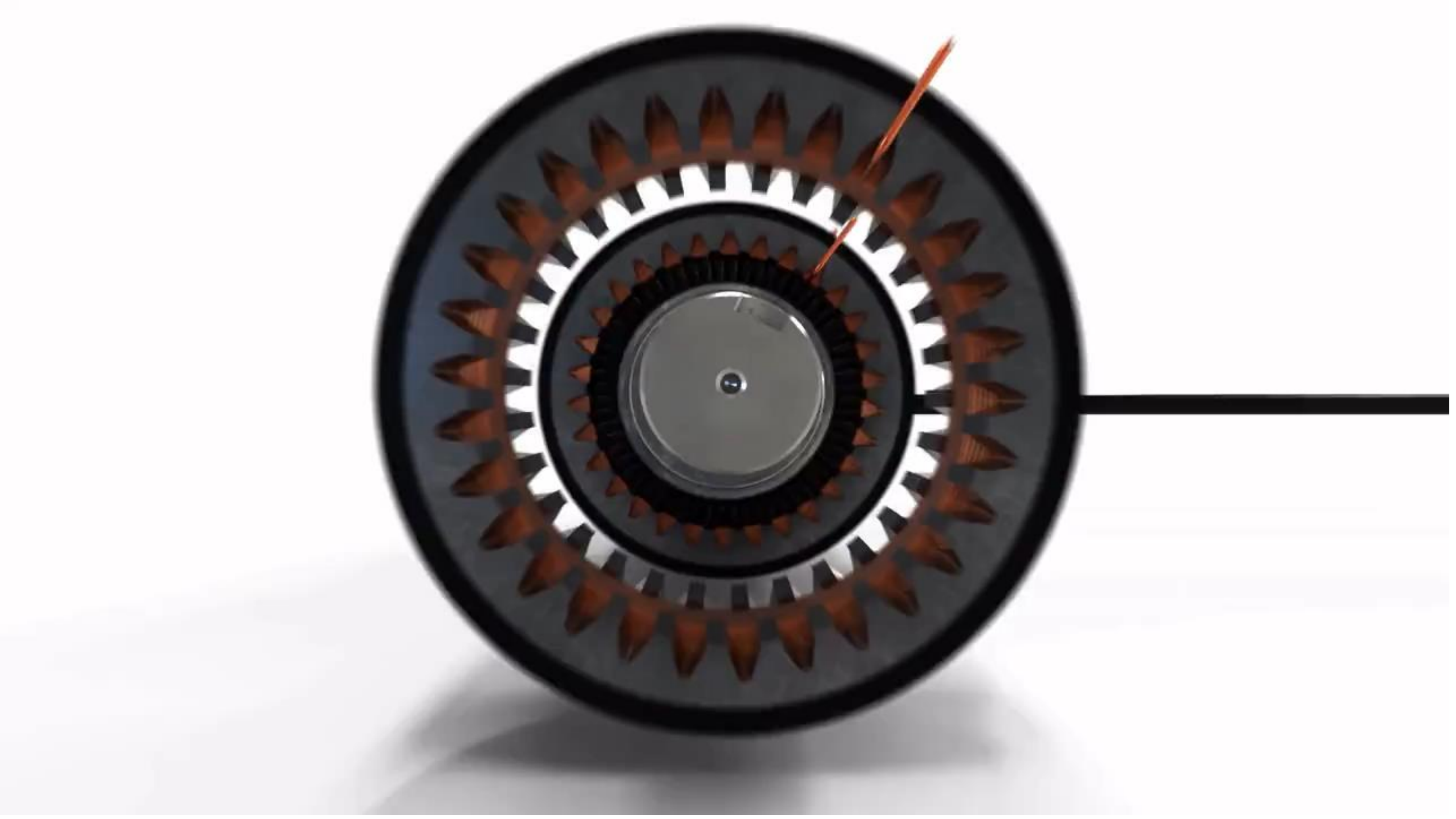
PM Motor Types

Transverse Flux

Same Materials, Rearranged

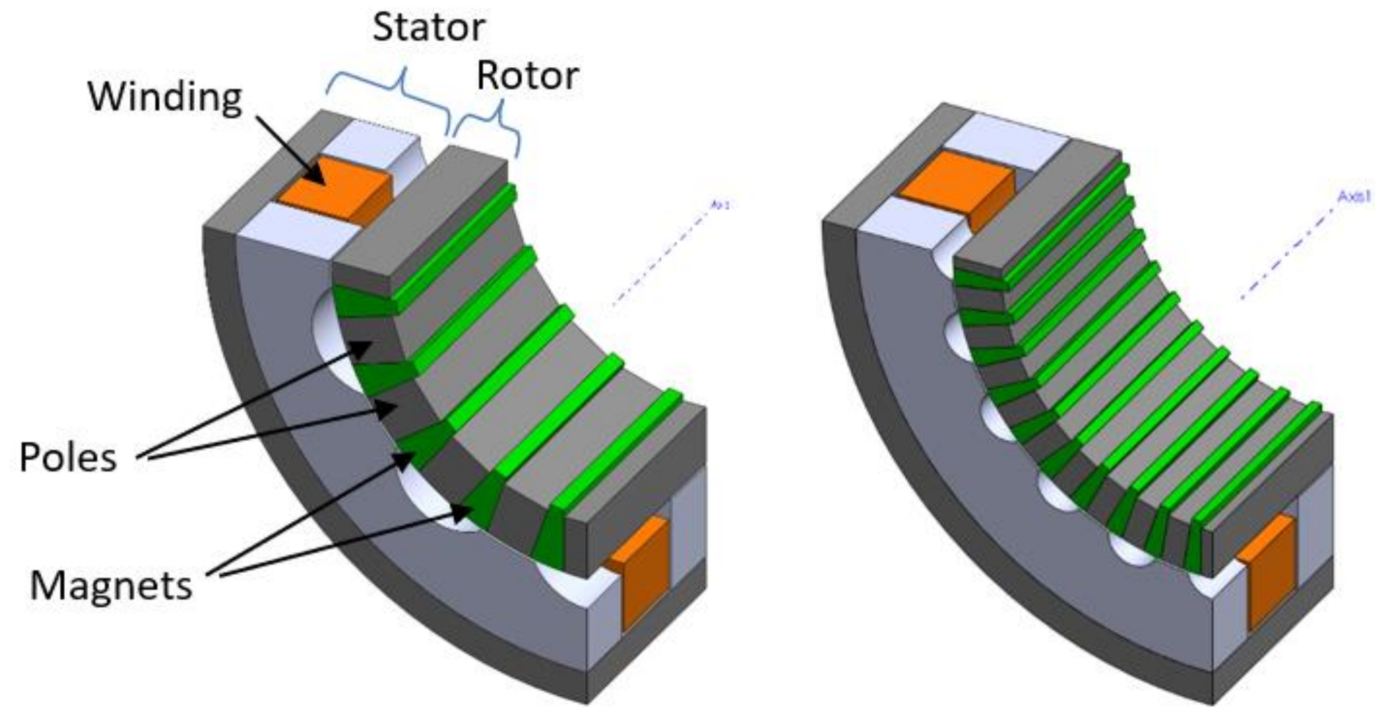






PM Motor Types

Transverse Flux



20 Poles

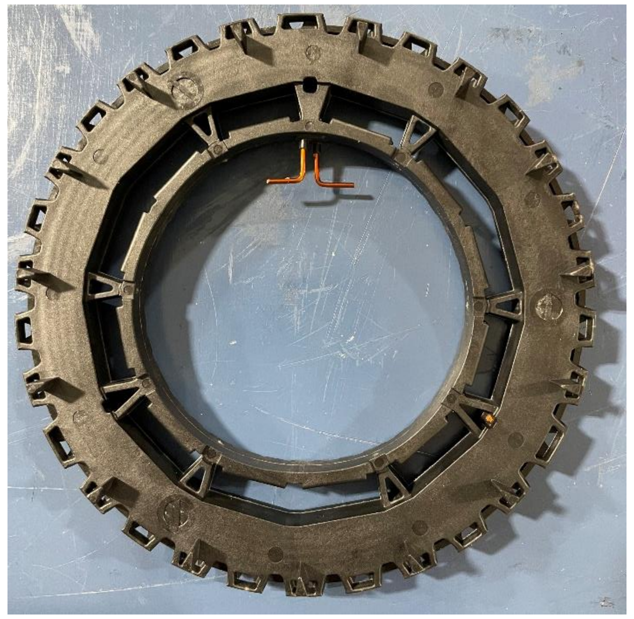
40 Poles

$$k_m = \frac{2\pi\Phi_B p}{\sqrt{R}}$$

Transverse Flux motors do not trade off Pole Count and Resistance.

TFM Coil (single phase)

Overmolded Coil



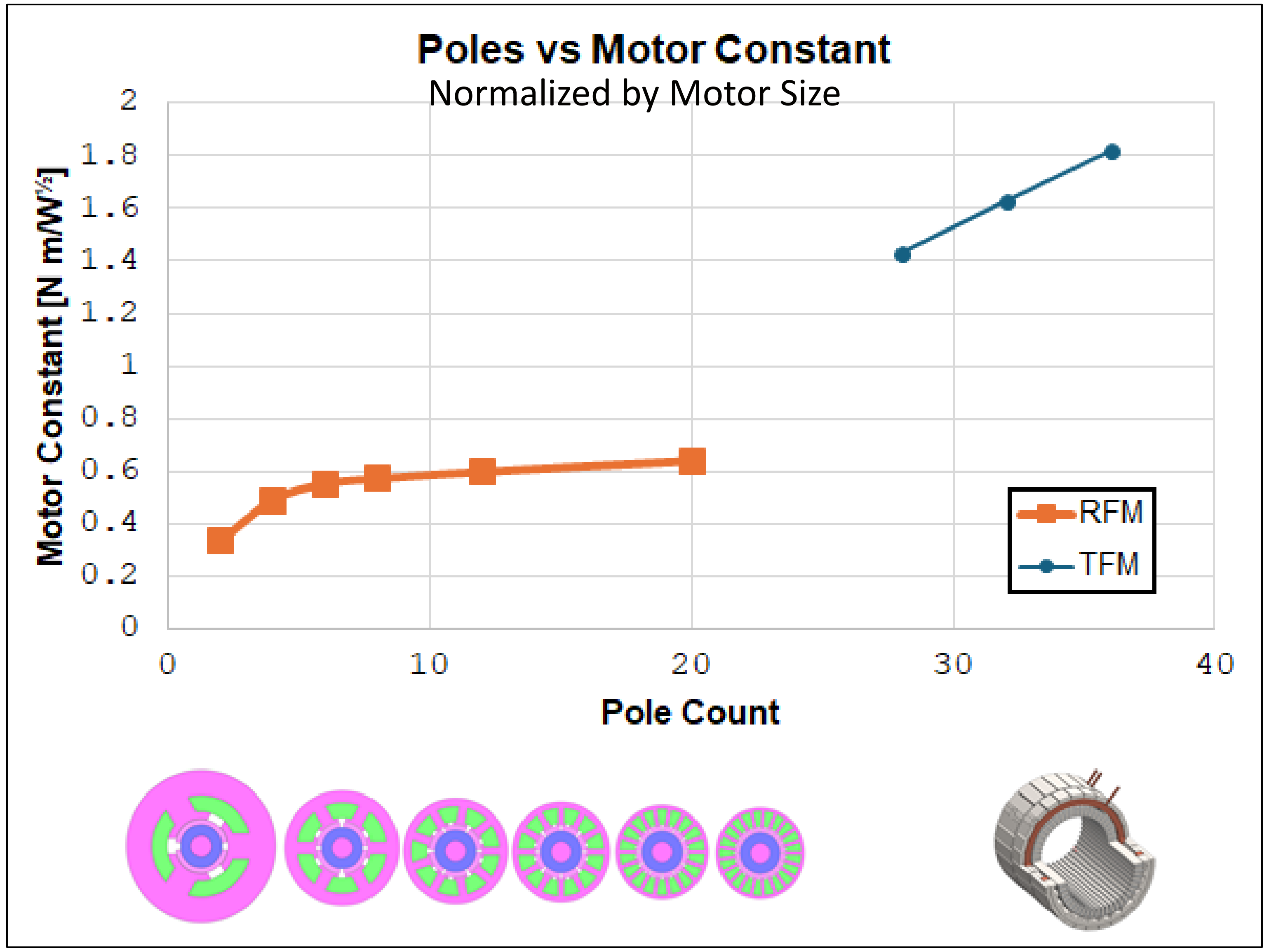
Cross Section

3 Phase Motor

Motor Constant Comparison

An Unfair Fight

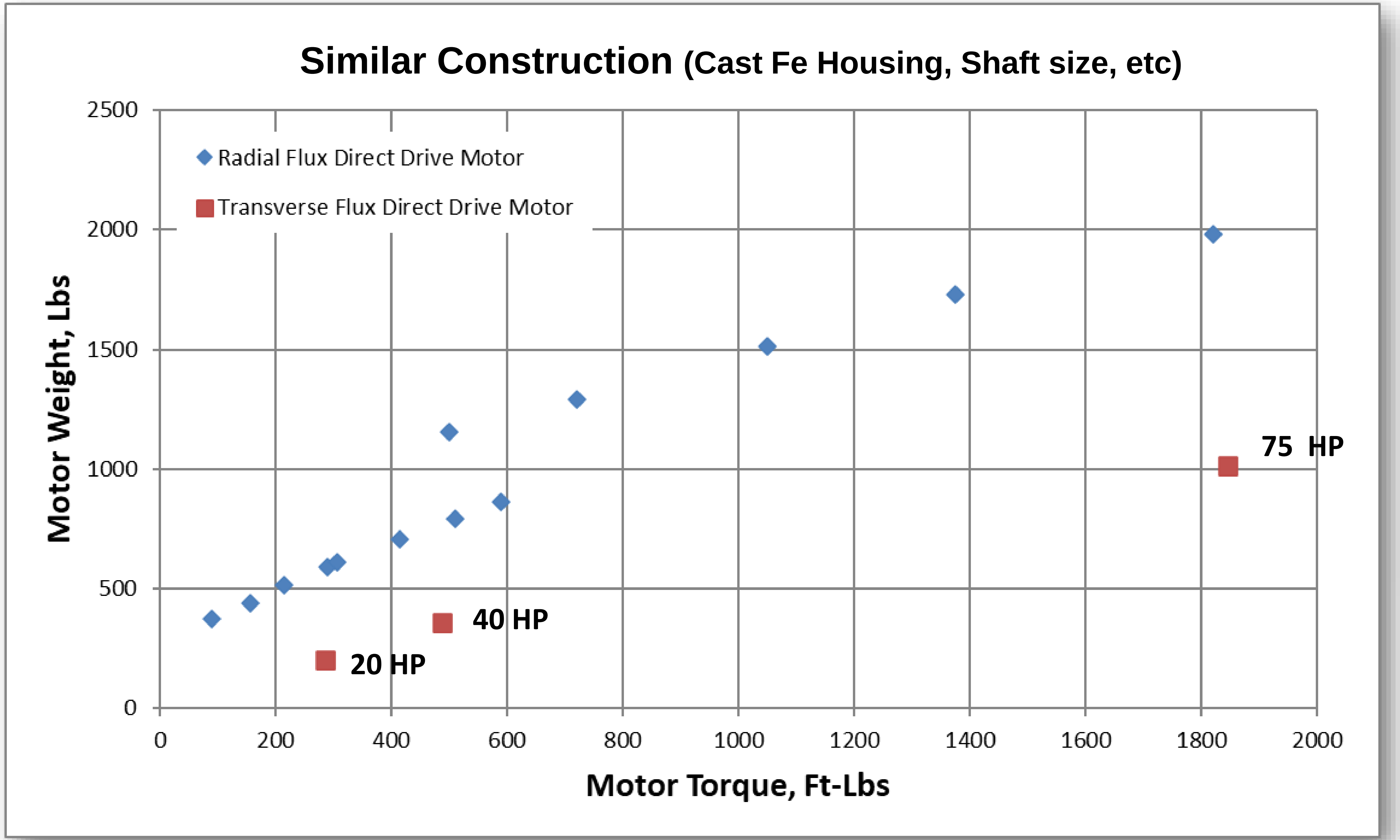
$$k_m = \frac{2\pi \Phi_B p}{\sqrt{R}}$$

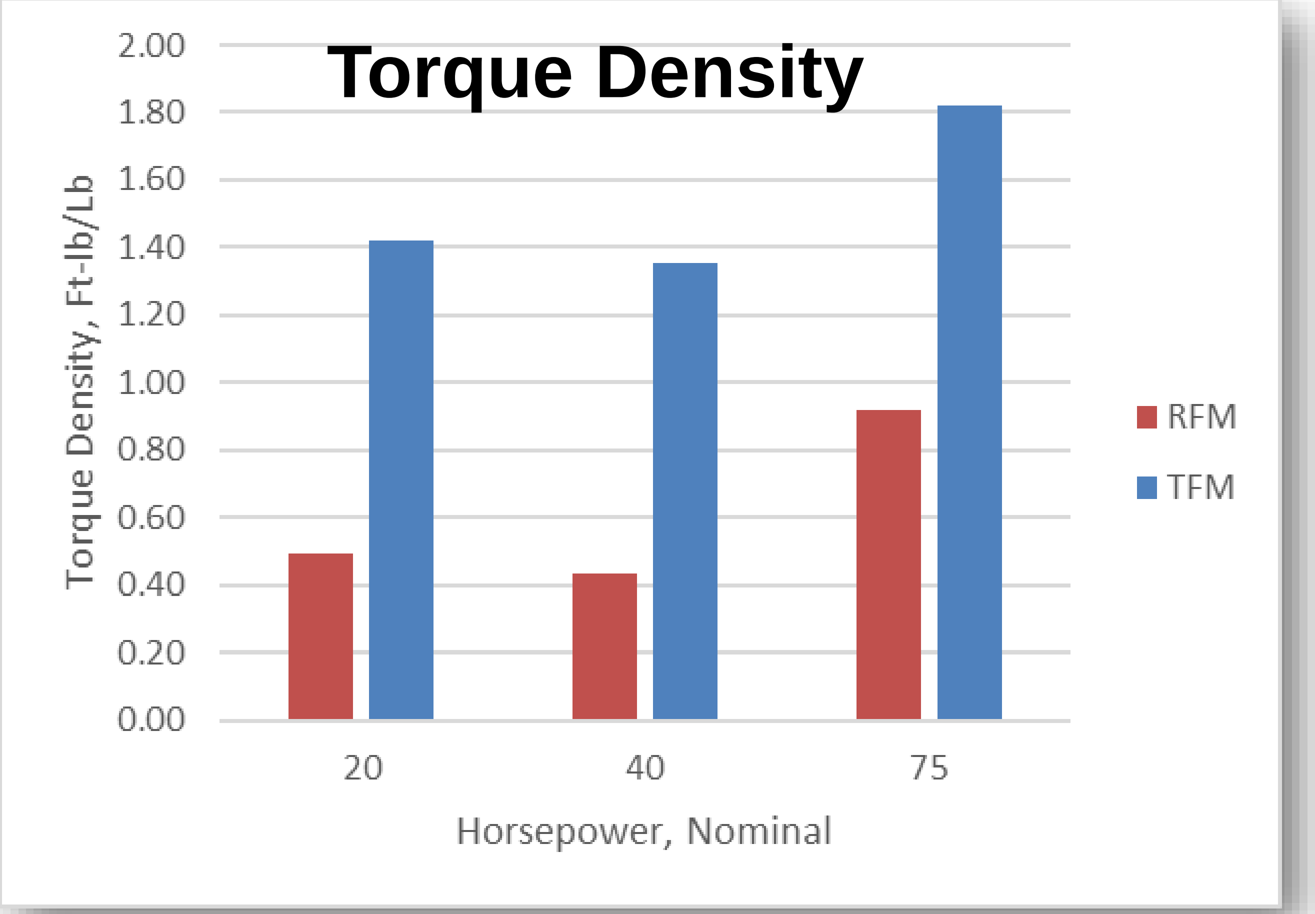


Simulations provided by ETM

Weight Comparison

TFM vs RFM



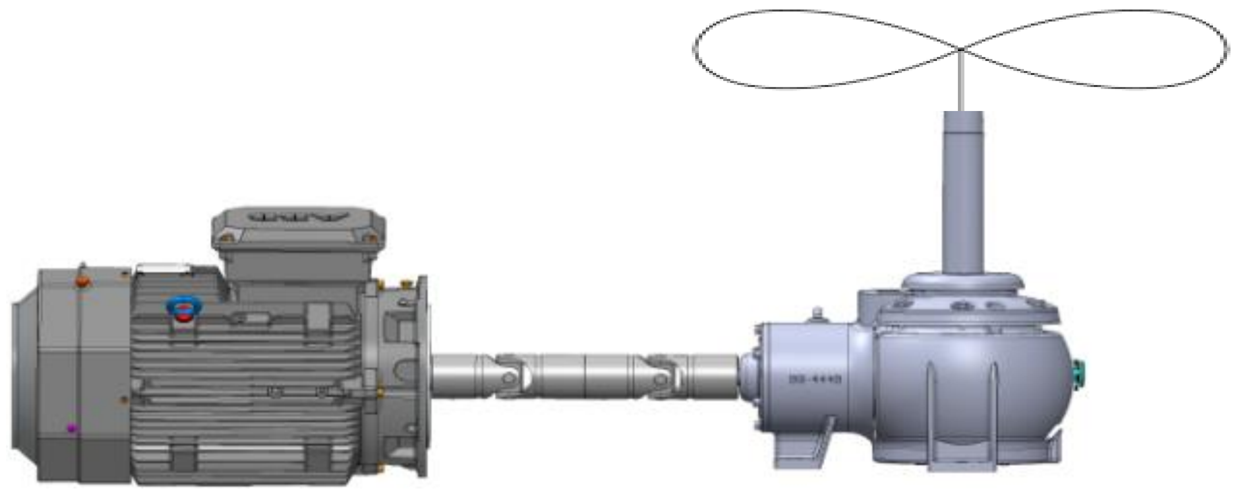


TFM torque density 2-3X higher than RFM

Torque Density

40 HP Example

Legacy Design

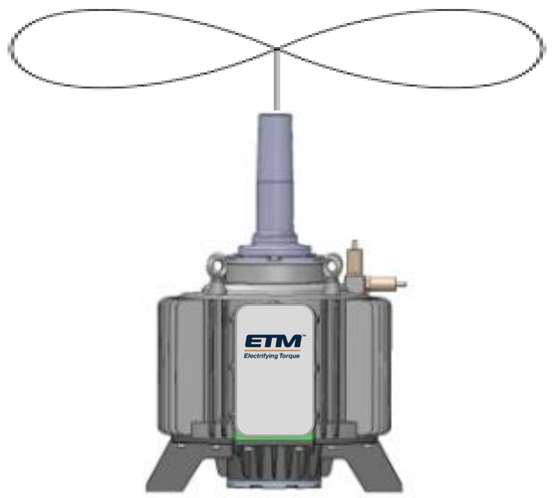


<u>AC Induction Motor</u>
4 Poles
1800 RPM
60 Hz
116 Ft-lb (158 Nm)
500-600 Lbs

<u>4:1 Gearbox</u>
800 lbs

Direct Drive

PM Transverse Flux



<u>TFM DD Motor</u>
48 Poles
450 RPM
180 Hz
465 Ft-lbs (630 Nm)
360 Lb

PM Radial Flux

<u>RFM DD Motor</u>
4 Poles
450 RPM
15 Hz
465 Ft-lbs (630 Nm)
800 Lb

Transverse Flux Motors for Direct Drive Fans

40HP TF Motor

520 Ft-lb (700 Nm)

360 Lbs

UL1004, C1D2 Certified

75HP TF Motor

1,840 Ft-lb (2,500 Nm)

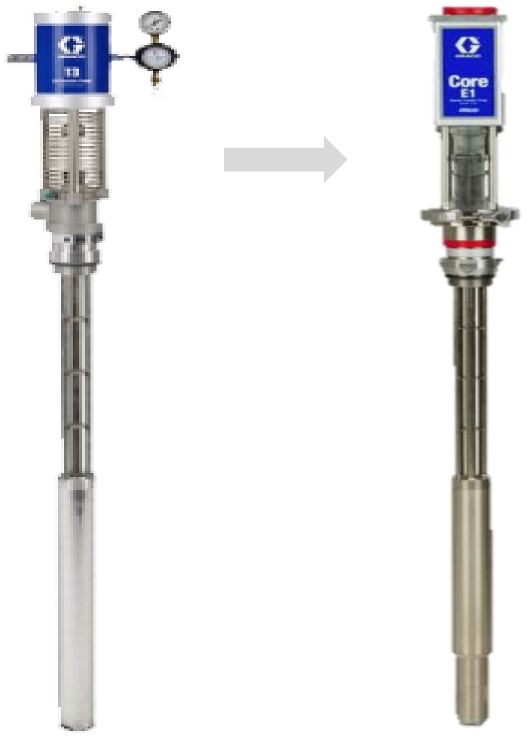
1,000 Lbs

What About Cost?

TFM in High-volume High-reliability Industrial Applications

Graco Pumps and Sprayers

Core™ E1 Pumps
Electrification of air power



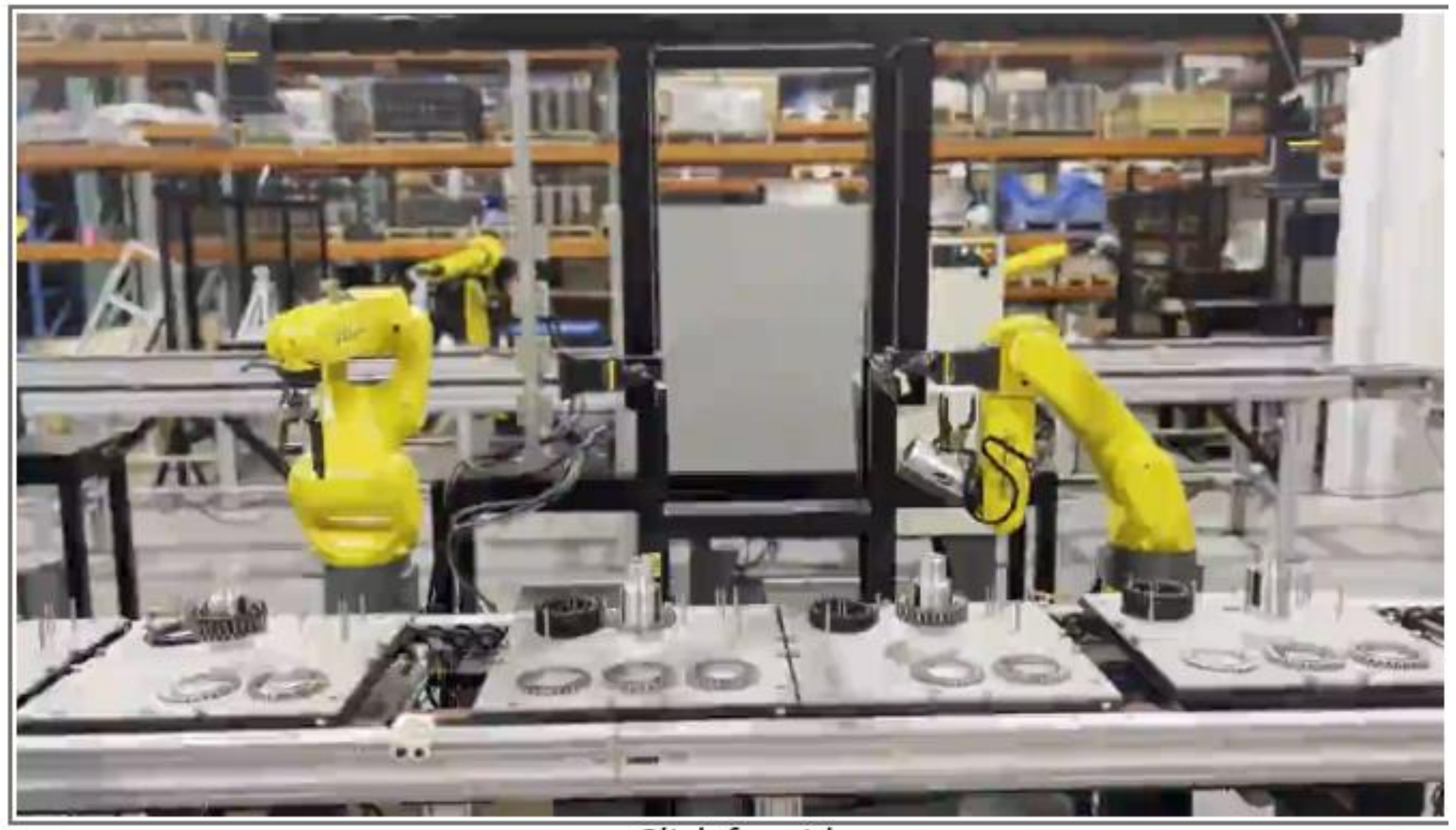
E-Flo® Dci™
Next generation E-Flo

Quantm™ Pumps
Next generation EODD

Ultra® XT Sprayers
Next generation sprayers

HVLS Fans

High Volume TFM Factory



Stator Assembly

Laser Coil Termination

Further Direct Drive Considerations

Environmental

- Direct Drive motors see: Temperature extremes, high humidity, condensing moisture, vibration, corrosive alkalinity.

- Features: Cast iron housings, durable paint systems, shaft seals, fully encapsulated electromagnetics, integrated space heaters, drain ports.

- Petro-chemical installations may require hazardous location certification such as Class 1, Division 2.

Further Direct Drive Considerations
Efficiency and Motor Cooling

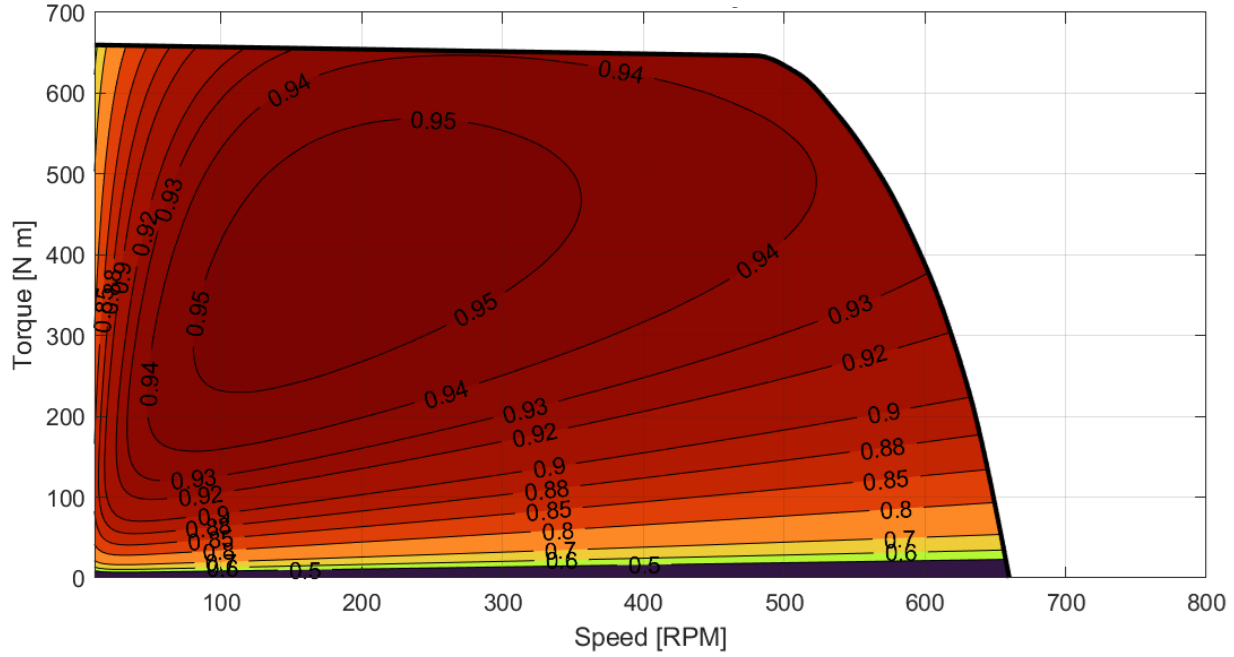
Efficiency

DD fan system efficiency gains come from 3 changes:

1. Moving from fixed to variable speed.
2. Elimination of gearbox and belt/sheave losses.
3. Efficiency gains within the motor itself.

- Important to reduce internal motor temperature rise, especially with higher ambient temperatures and variable cooling airflow. The low resistance coils used in TF motors are helpful, <u>especially with high turn-down ratios</u>.

40HP TFM Motor Efficiency



Motor Cooling

TEFC (Totally Enclosed Fan Cooled) motors have on-board fans attached to the motor shaft. Cooling airflow is controlled by the motor design.

TEAO (Totally Enclosed Air Over), typical for Direct Drive, rely on cooling air from the load fan and <u>must be tested in the system to verify temp rise.</u>

TEFC

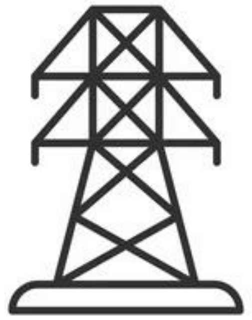
TEAO

Further Direct Drive Considerations

Power Factor

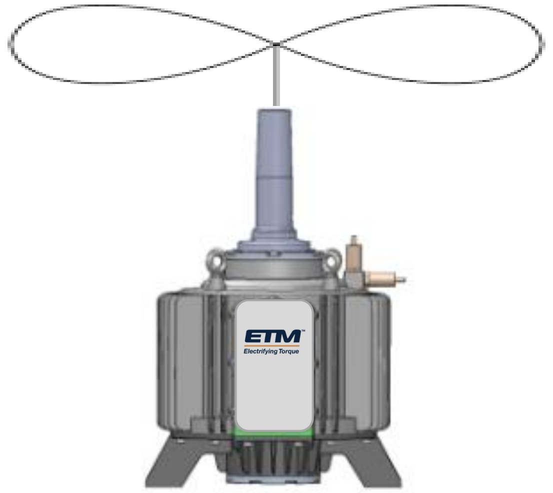
- Ratio between real and apparent power between the motor and VFD.
- Low motor PF can lead to VFD upsizing which increases system cost.
- Rule-of-thumb for PM DD motor selection is an upsized VFD is needed to achieve rated motor performance *“Can I run your 50HP motor with a 50HP VFD?”*

Don’t confuse Motor PF with VFD PF, which concerns the electrical load presented by the VFD to the utility grid. This type of Power Factor may be regulated by the local power utility.



Utility Regulations

Low PF = Upsized VFD



Further Direct Drive Considerations

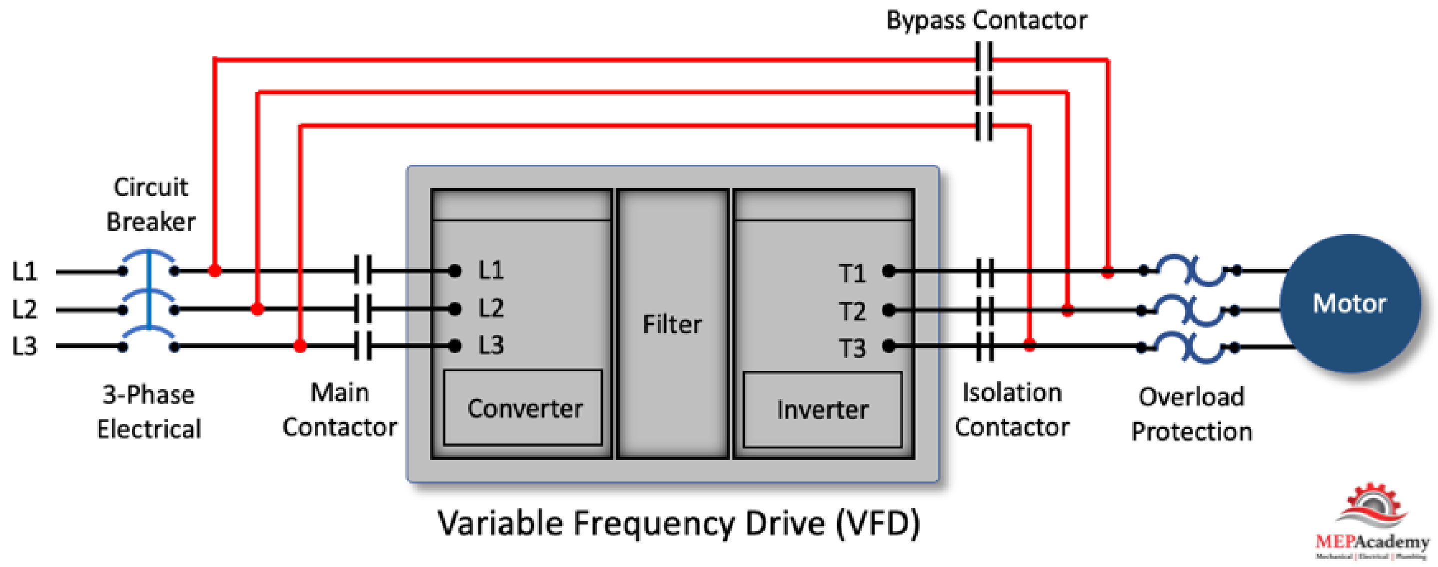
VFD Bypass

- Can I run my PM motor on grid bypass?
  Unfortunately, no. Includes all PM motor types (TFM, RFM, AFM)

- Slip in AC induction motors acts like a clutch enabling the motor to accelerate the propeller while fed a fixed (grid) frequency.

- Synchronous motors have no slip and are not able to start without a VFD to ramp frequency.

- For critical applications, cooling system OEMs may consider a parallel backup VFD, ready to engage when needed.



Further Direct Drive Considerations
Acoustic Signature

<u>Acoustic Signature</u>

- Heat rejection equipment is often installed in locations where acoustic noise is a concern.

- Direct drive motors need to be tested acoustically by the equipment manufacturer <u>in a representative system</u>. Acoustics are specific to the equipment.

- Direct drive systems are often quieter given the elimination of high-speed rotating components such as driveshafts, belts and sheaves.

Further Direct Drive Considerations

<u>Industry Standards</u>

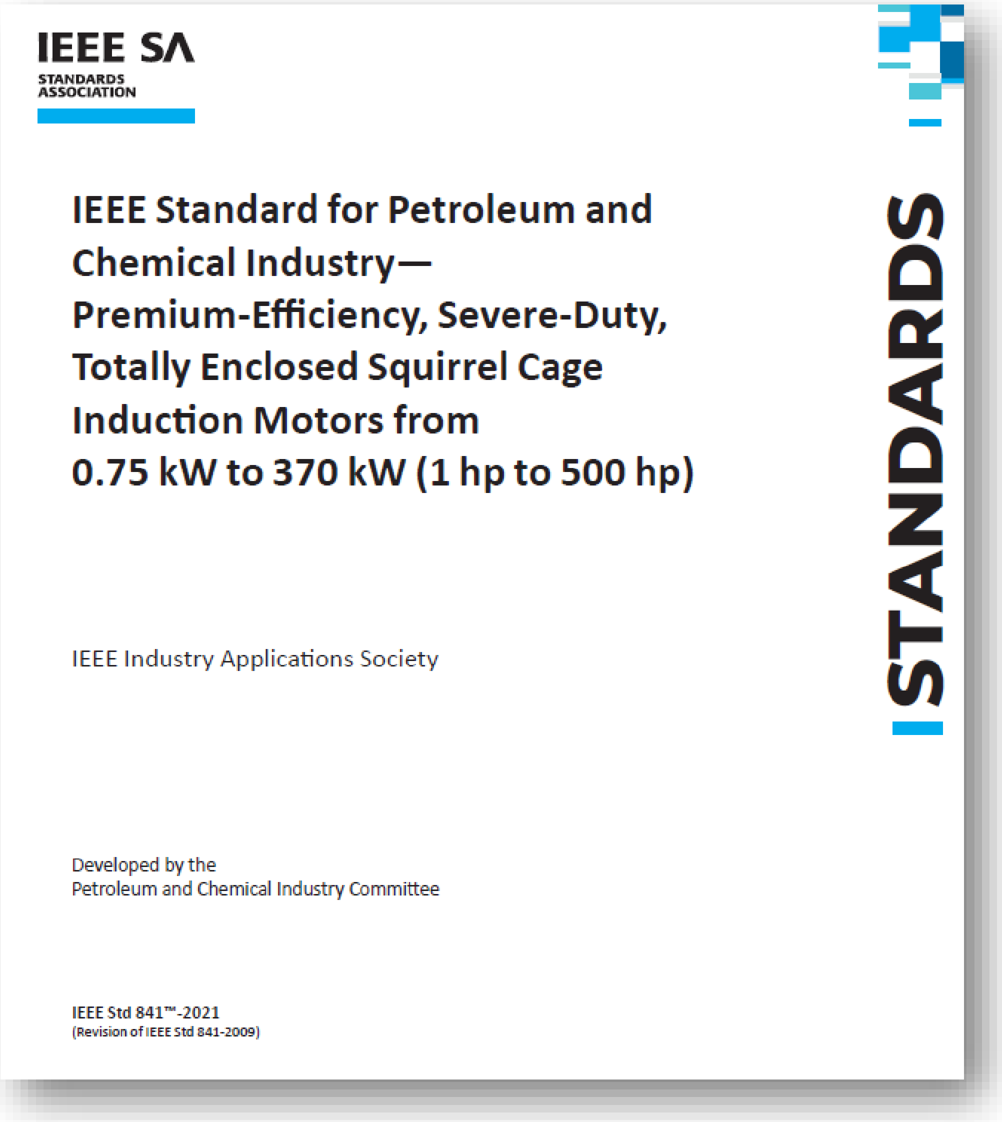
Industry standards for motors used in heat rejection systems have not yet been widely adapted to the PM motor market.

IEEE 841 2021 revision <u>excludes PM motor types</u>:

"14.5 Options that do not allow a motor to reference IEEE 841 in any way:

Alternate motor technology (e.g., <u>permanent magnet</u>, synchronous, synch. reluctance, etc.)"

Further specification development is needed to include new direct drive motor technologies and enable cooling system OEMs to procure and supply motors that meet standards specific to the cooling system industry.



IEEE SA
STANDARDS ASSOCIATION

IEEE Standard for Petroleum and Chemical Industry—Premium-Efficiency, Severe-Duty, Totally Enclosed Squirrel Cage Induction Motors from 0.75 kW to 370 kW (1 hp to 500 hp)

IEEE Industry Applications Society

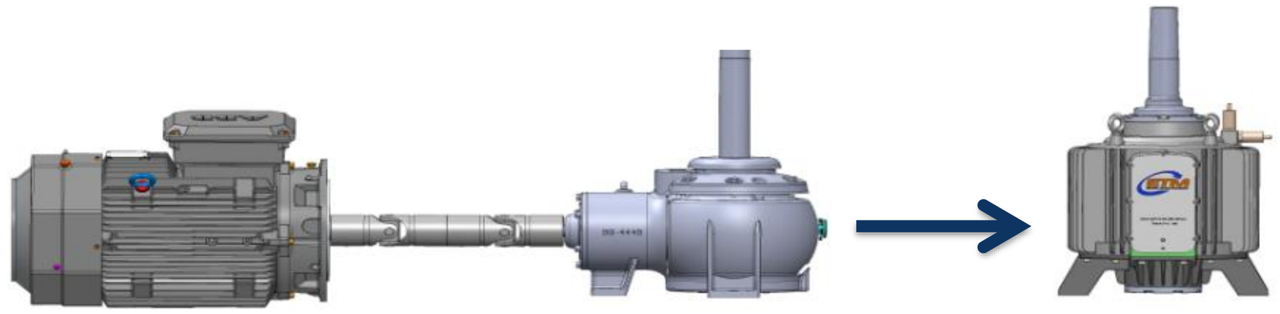
Developed by the
Petroleum and Chemical Industry Committee

IEEE Std 841™-2021
(Revision of IEEE Std 841-2009)

STANDARDS

Conclusions

- The advantages of direct drive PM fan motors in cooling systems are well established.
- Direct drive systems over 10 HP not yet been widely adopted due to motor weight and initial cost.
- Conventional (Radial Flux) PM motors have struggled with the high torque and low speed needed for direct drive.
- Transverse Flux Motors close this practicality gap with smaller, lighter motors that take advantage of higher pole counts and lower coil resistance.
- Recent TFM commercial success in markets shows commercial viability of this motor technology.
- Now scaled to direct drive fans in heat rejection systems.



Thank You

Scott Reynolds
sreynolds@etmpower.com
+1.928.699.4108 cell

ETM™
Electrifying Torque

75 YEARS