

Improving Induction Motor Efficiency with Die-cast Copper Rotor Cages

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Acknowledgement:

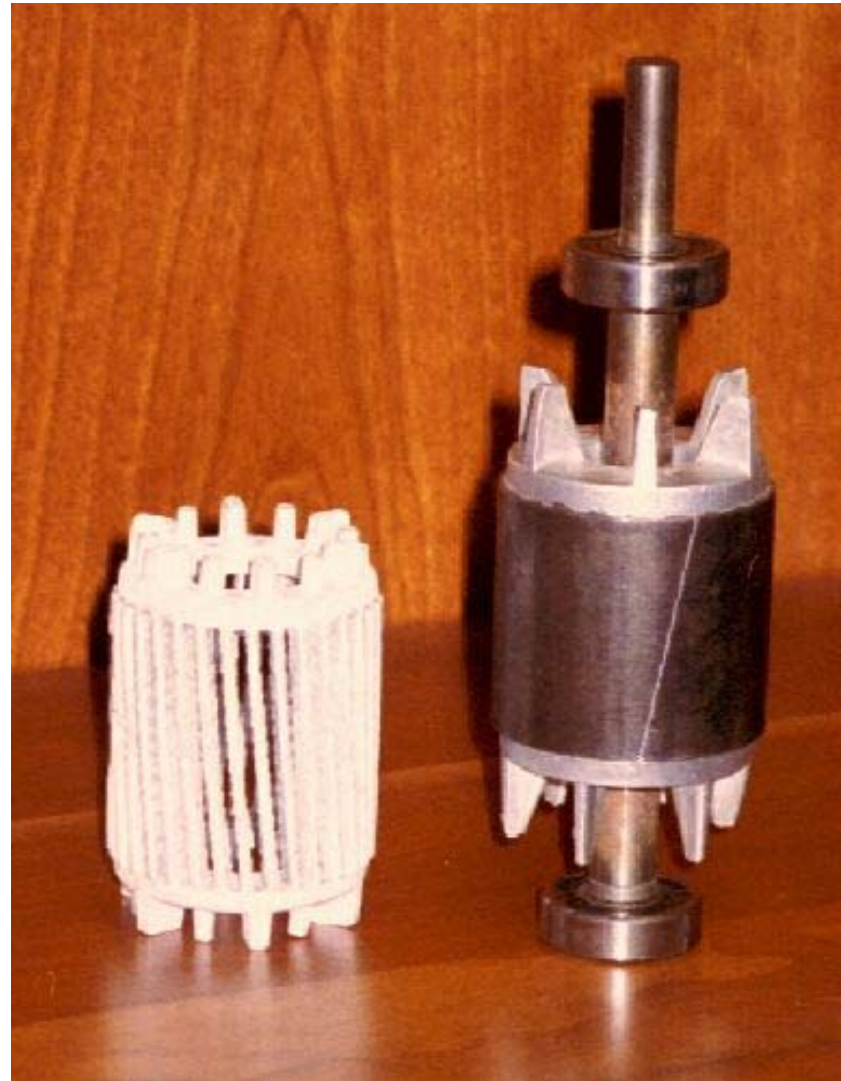
**John G. Cowie, Dale T. Peters,
Copper Development Association
Edwin F. Brush, Jr BBF Associates
Ranier Kimmich SEW Eurodrive**

Here is a cast aluminum rotor.

Works well: aluminum is easy to cast.

The electrical conductivity of aluminum is good, but not as good as copper.

Can we improve motors by replacing the aluminum with copper?



QuickTime™ and a decompressor are needed to see this picture.

Here is the target:

High Efficiency Motor

10 HP

Aluminum Rotor

This is the 'Loss Budget' for that motor:

Core Loss	99 W
Stator Winding Loss	313 W
Rotor Cage Loss	110 W
Stray Loss	12 W
Friction and Windage	43 W
Motor Efficiency	92.8 %

Simple substitution of copper would

Make Cage Loss equal to 60 watts

Improve efficiency to 93.5%

Increase locked rotor current to > 85 A

(NEMA B standard is < 81 A)

So there is opportunity for some design improvements

Must consider:

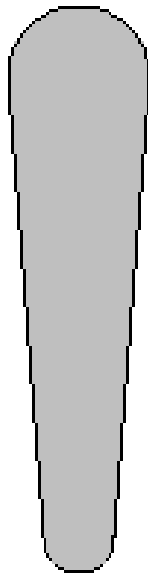
Locked Rotor Torque and Current

Pullup and pullout Torque

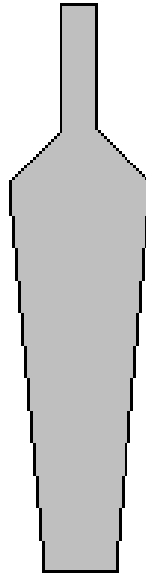
Efficiency and Power Factor

Size (shaft height) and materials

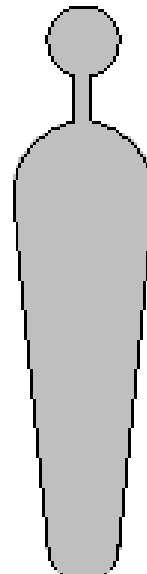
Examples of Possible Squirrel Cage Bar Shapes



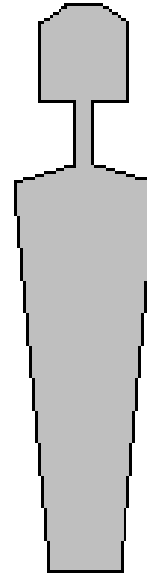
Conventional Bar



**Narrow Top to
Reduce Locked
Rotor Current**



Starting Bar and



Leakage Slot

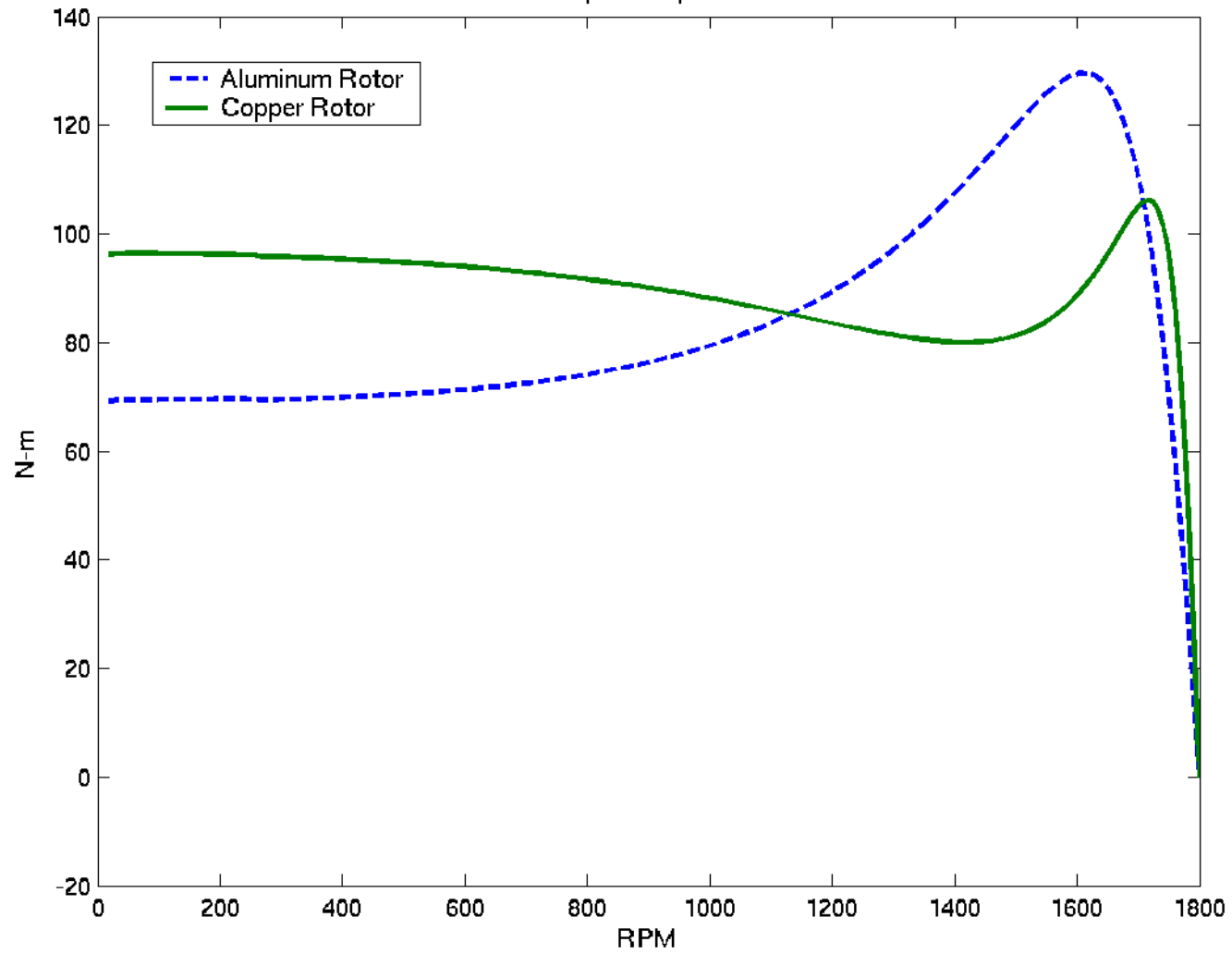
Results of a modified design using copper

Cage and stray loss are directly reduced

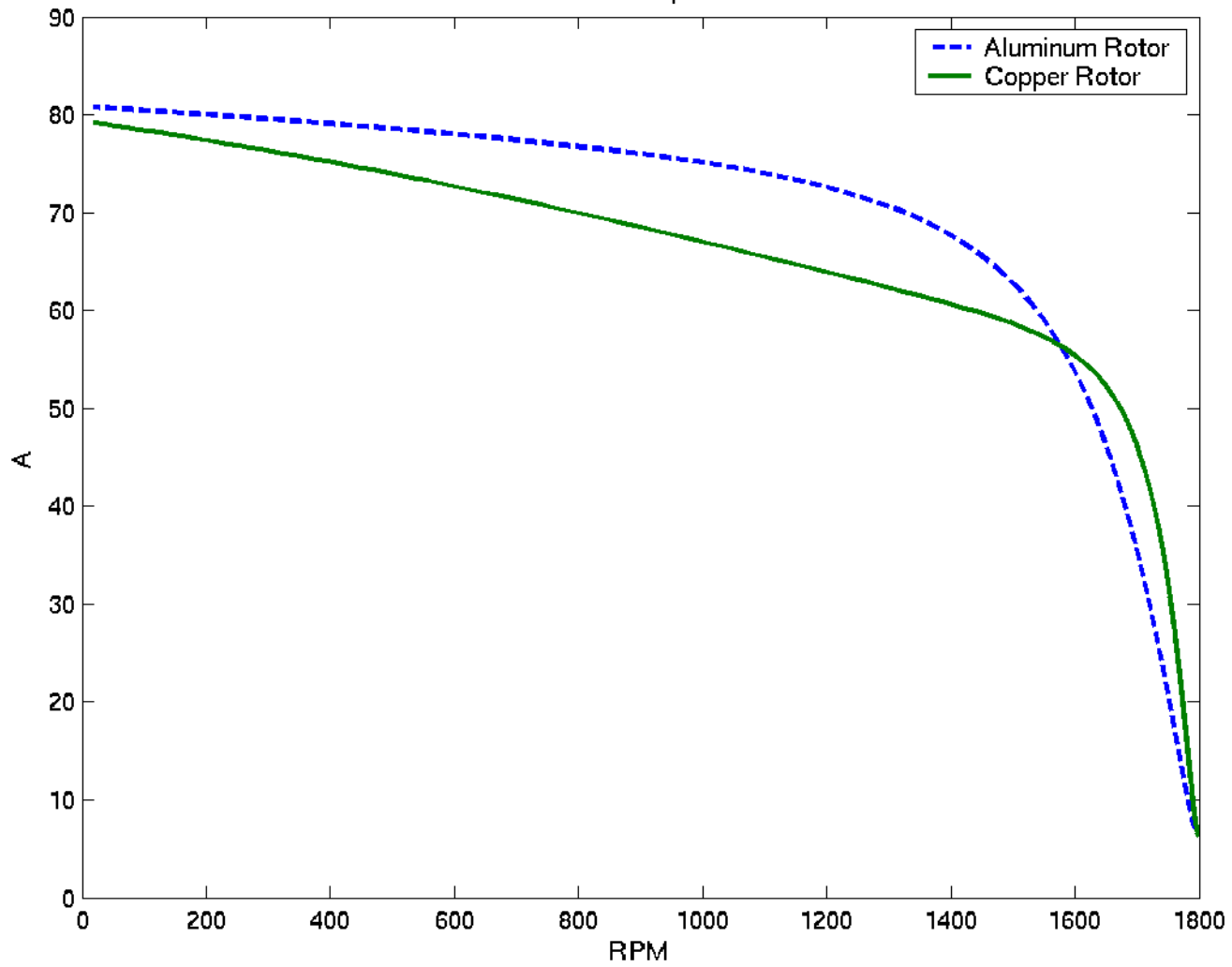
Fan can be a bit smaller too

	Aluminum	Copper
Core Loss	99 W	99 W
Stator Winding Loss	313 W	314 W
Rotor Cage Loss	110 W	60W
Stray Loss	12 W	8 W
Friction and Windage	43 W	40 W
Motor Efficiency	92.8 %	93.5%

Torque Comparison

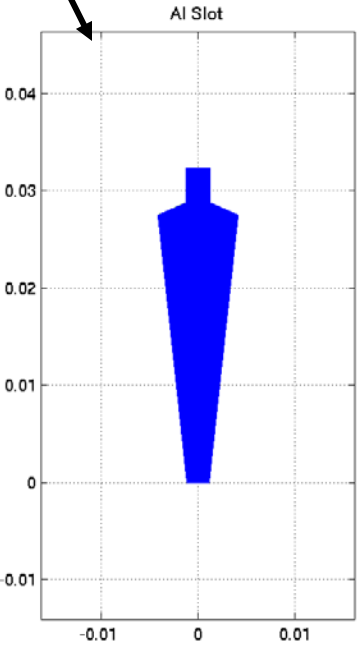
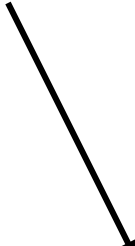


Current Comparison

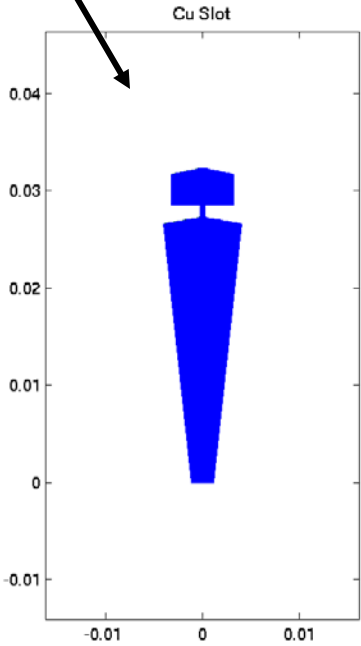
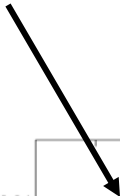


Here are the bar shapes used in these motors

Aluminum



Copper



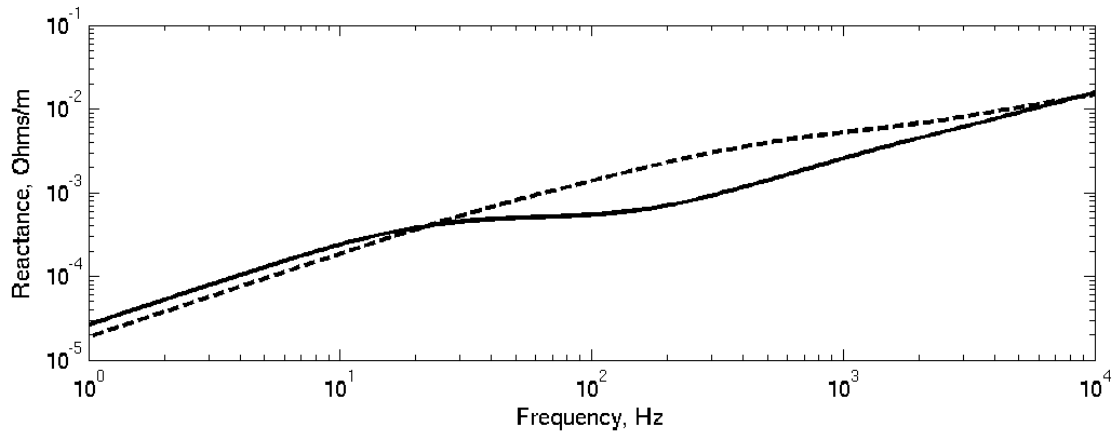
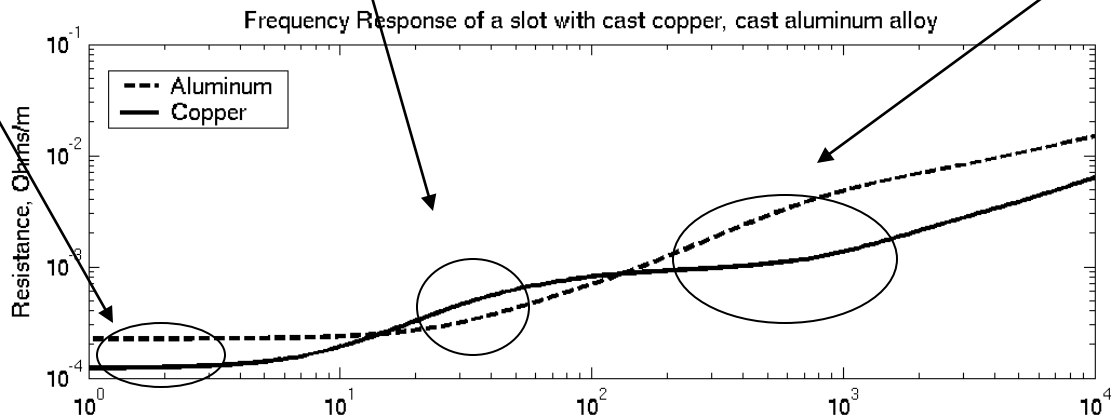
QuickTime™ and a decompressor are needed to see this picture.



Running (low is good)

Starting (High is good)

Harmonics (low is good)



Bar Impedance comparison

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Another country heard from: SEW Eurodrive Development

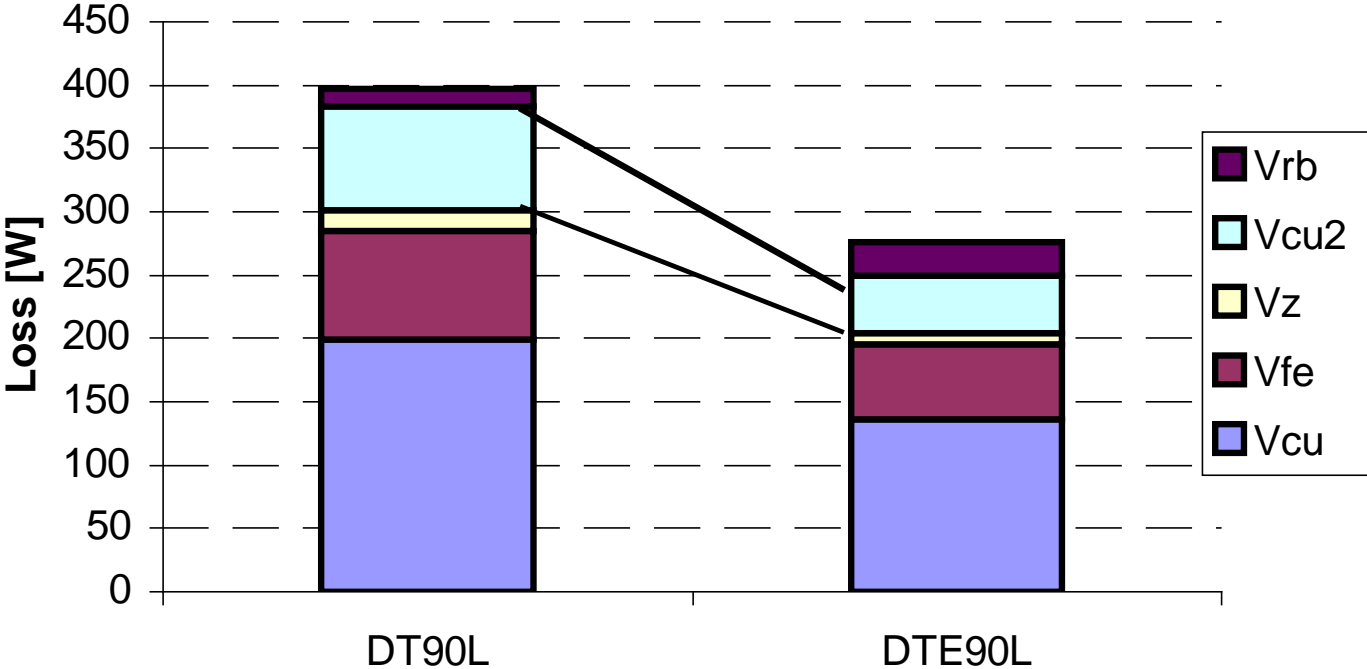
	DT90L4 Al Rotor	DTE90L4 Cu Rotor
Rated Power (kW)	1.5	1.5
Rotor Bar Material	Al	Cu
Grade of Electrical Steel (W/ kg, typical @ 1.5 T, 50 Hz)	8	6.6
Stack Length (mm)	75	95
Rotor Diameter (mm)	89.45	89.45
Stator Diameter (mm)	150	150
Active Volume (dm ³)	1.33	1.68
Air Gap (mm)	0.275	0.275
Efficiency (IEEE112B, 50Hz)	78.8 %	84.1 %
Current (A)	3.5	3.2
Slip (%)	5.3	2.9
Temperature Rise (K)	55	30
Power Factor	0.78	0.80

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decompressor
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Loss Distribution Comparison

1.5 kW motors



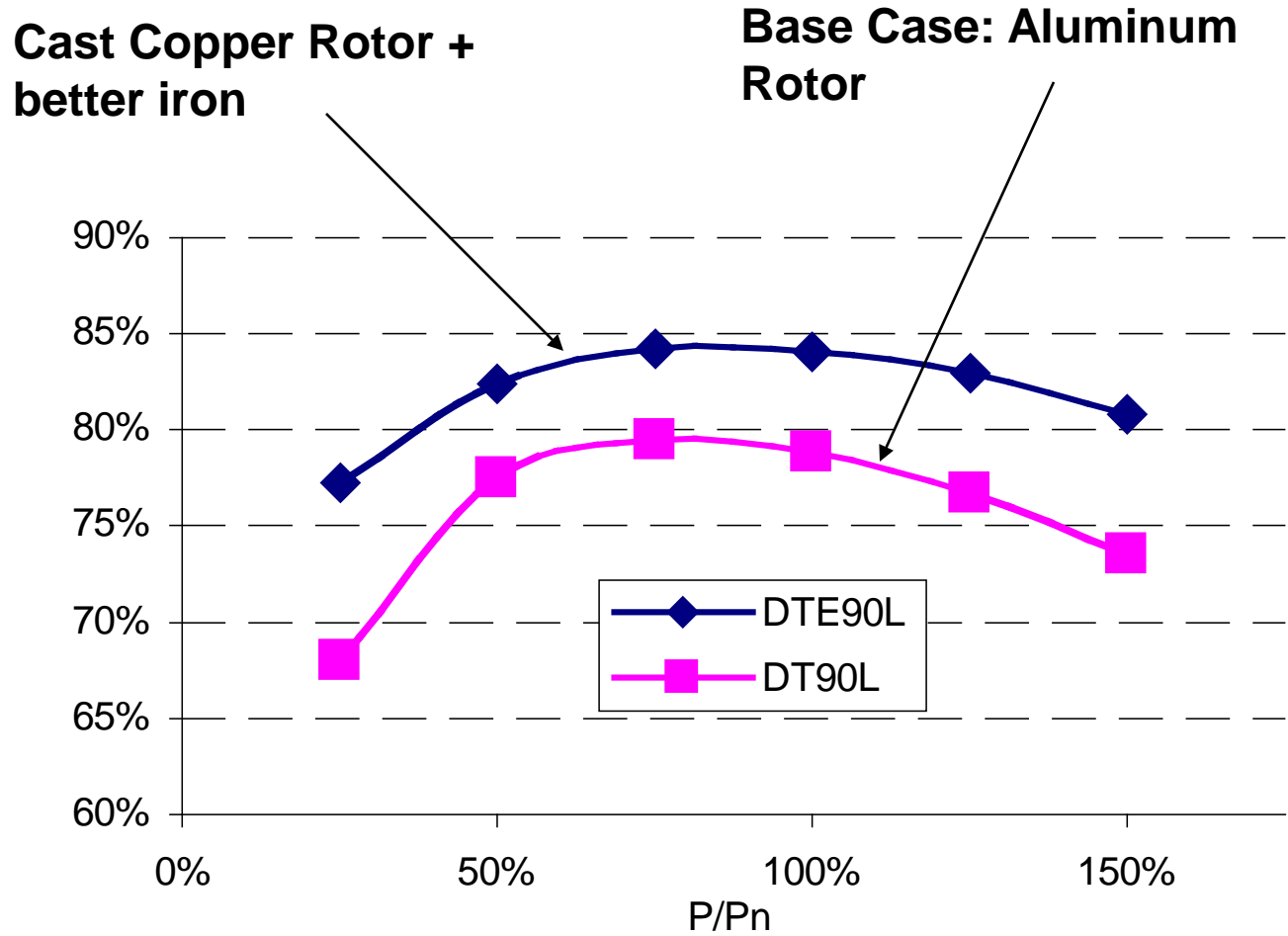
Aluminum Rotor

Cast Copper Rotor

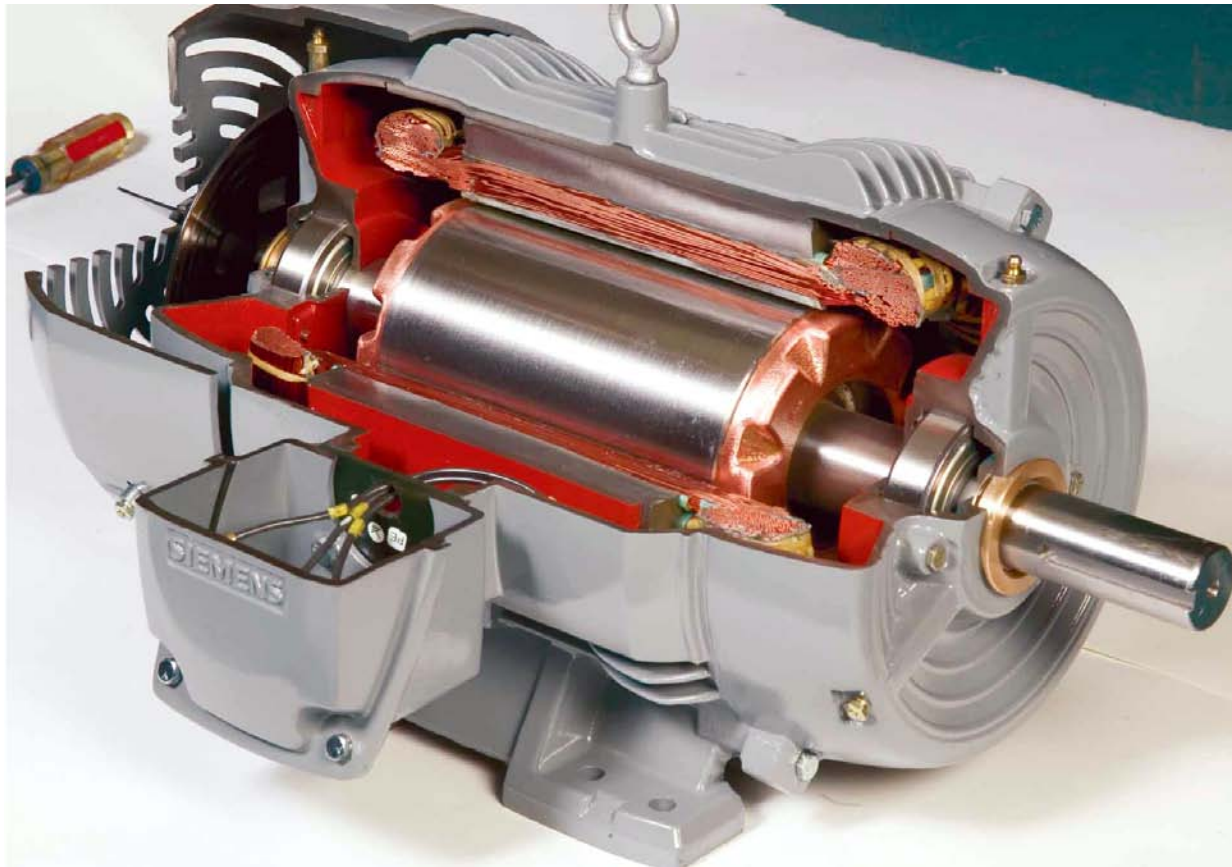
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Efficiency Comparison Vs. Load



Cut Away Section of Siemens Motor



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Nominal Full Load Losses of Siemens 10-Hp GP100A Copper Rotor Motor (kW)

Rotor Loss	0.12
Core Loss	0.122
Stator Loss	0.26
Windage & Friction	0.045
Stray Load Loss	0.05
Total Losses	0.597
Efficiency, %	92.7

Design Task: Motor for a hybrid automobile

- Comparison with Prius drive motor
- Peak power 50 kW
- Speed range: 1,200 to 1,540 RPM
- Peak speed: 6,000 RPM

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PM Motor:

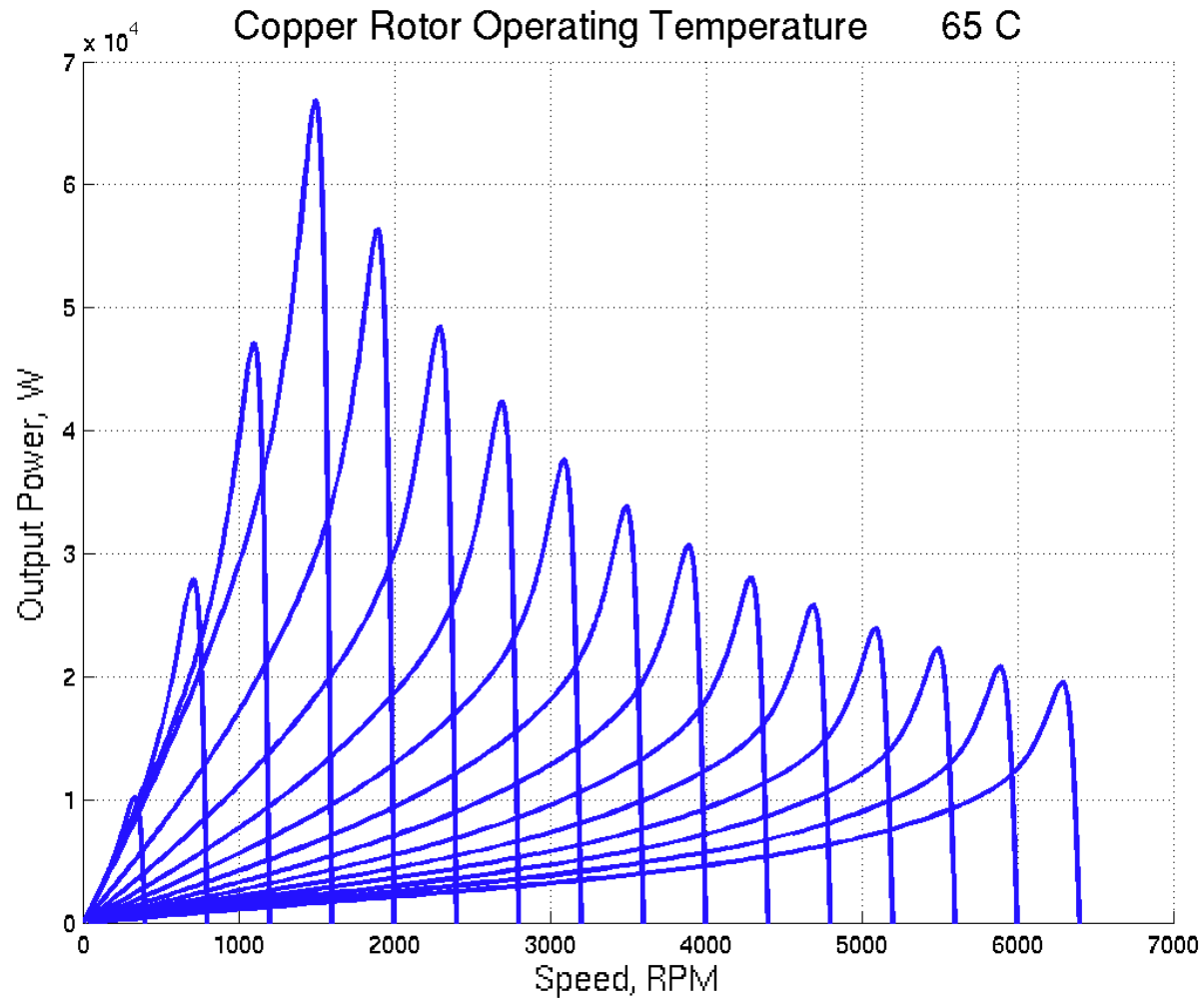
- Highly salient
- Design compromises
- Limited Data
- From ORNL
- Thermally limit
 - 12 to 22 kW

	Copper Motor Rotor	Aluminum Motor Rotor	PM Rotor
Rotor Radius	78.3 mm	78.3 mm	
Active Length	88.9 mm	107.9 mm	
Stator Slot Height	22.8 mm	22.8 mm	
Rotor Slot Height	31.7 mm	37.7 mm	
Stator Back Iron	19.0 mm	19.0 mm	
Pole Count	6	6	
Number of Stator Slots	54	54	
Number of Rotor Slots	39	39	
Number of Stator Turns	108	108	
Coil Pitch	8/9	8/9	
Overall Diameter	245.9 mm	245.9 mm	260 mm
Overall Length	172.0 mm	191.1 mm	173 mm
Weight Active Material	40.7 kg	40.6 kg	
Efficiency	91 %	91%	87%
Power Factor	73%	68%	

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Power Capability of Induction Motor

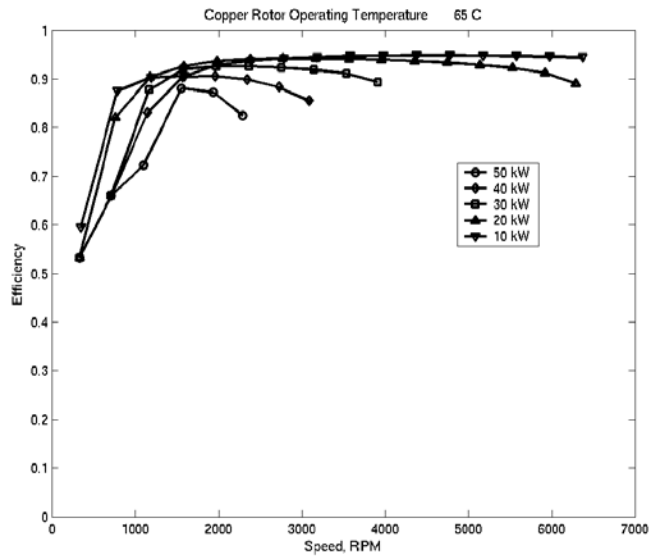


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decompress
are needed to see it.

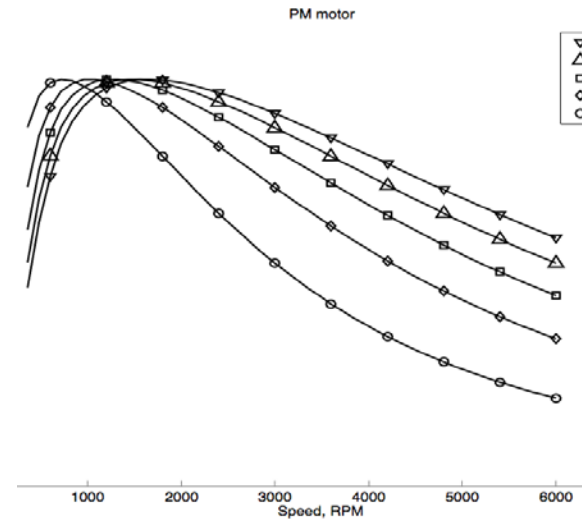


Estimated Operating Efficiencies

Induction Motor



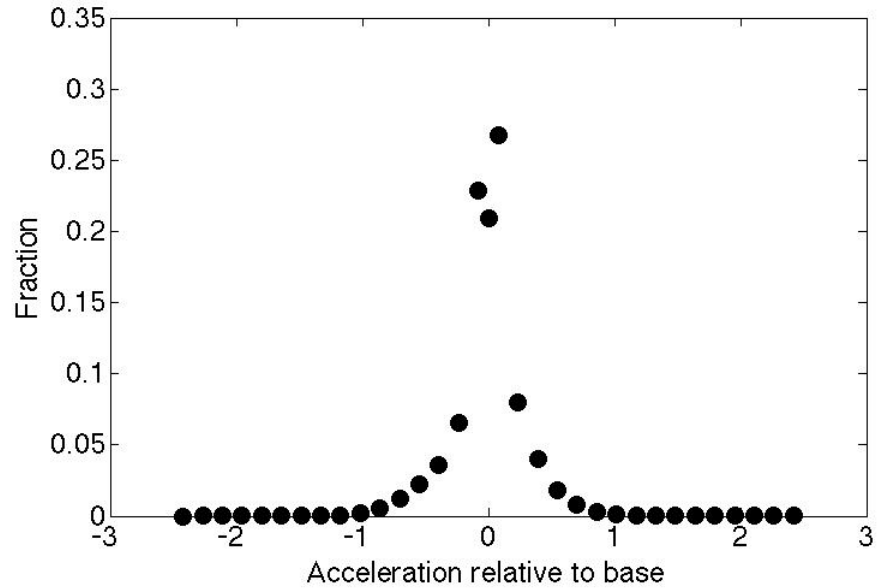
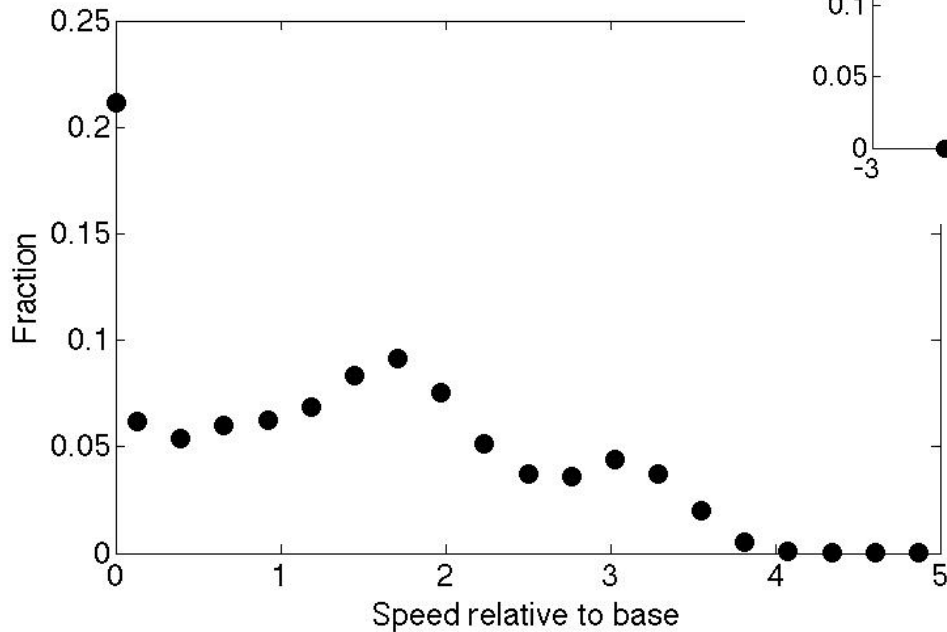
Permanent Magnet Motor



Drive Cycle Data from EPA

Speed and Torque

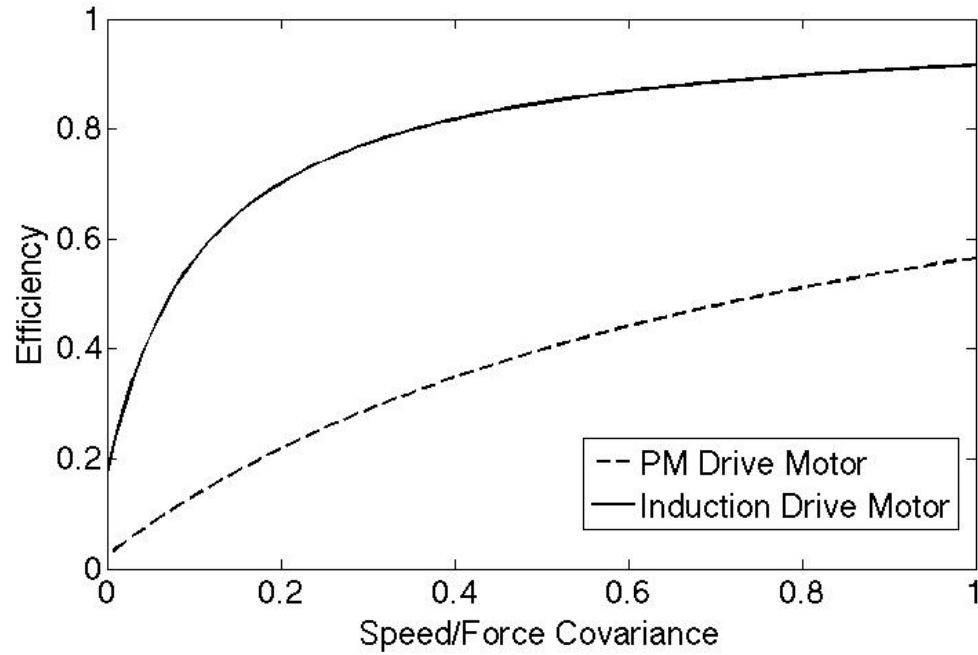
Not Power



QuickTime™ and a decompressor are needed to see this picture.



Net overall drive efficiency



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Conclusions:

Copper is a good material for induction motor rotors

- **Reduced size and weight**
- **Higher conductivity -- Higher efficiency**
- **Now that rotor manufacturing issues have been solved**

Induction motors are a good solution for traction applications

- **High Effective Efficiency**
- **No serious issues with faults**