# ADAMBOTS Team 245

# Review of Motors used for FIRST FRC Robots





# Common Motors Used for FIRST FRC Robots

## Common motors used for FRC Robot applications:


BAG Motor


775 Motor

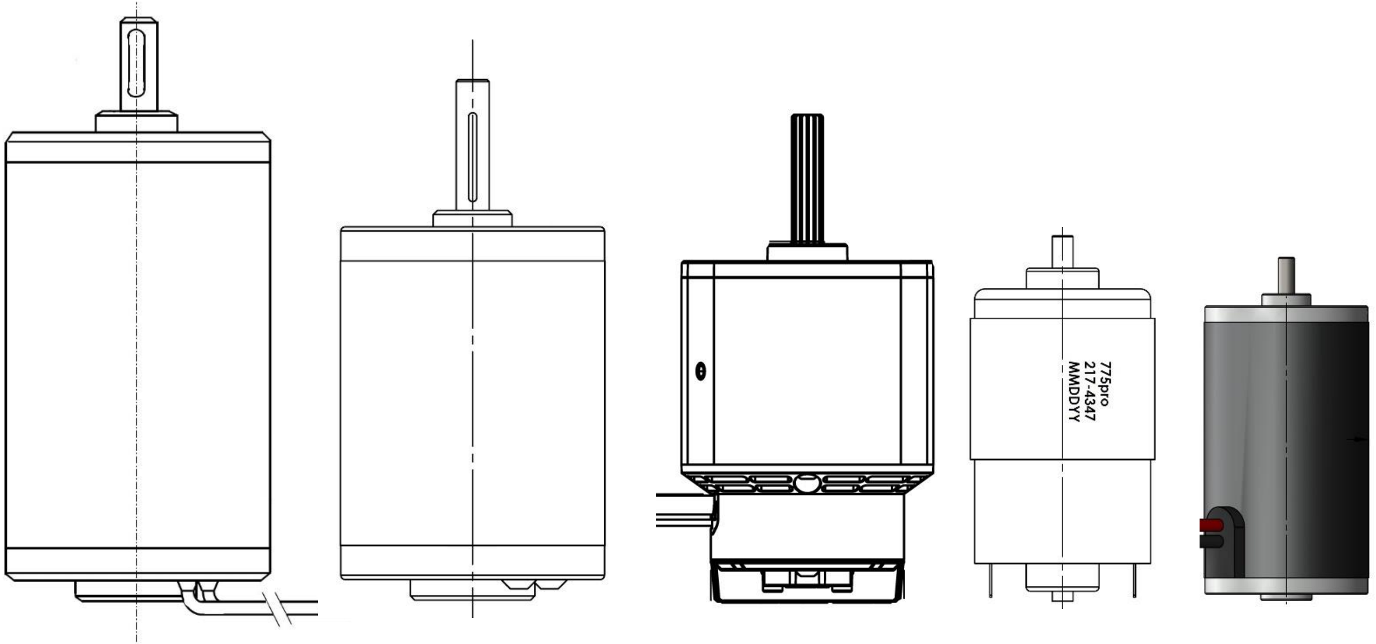

Mini CIM


Full Size CIM


Falcon Brushless

Neo Brushless and other motors are not included in this review

# Scale Comparison of Motors




Full Size CIM:
5.50“ Long
2.52” Dia
2.8 Lbm

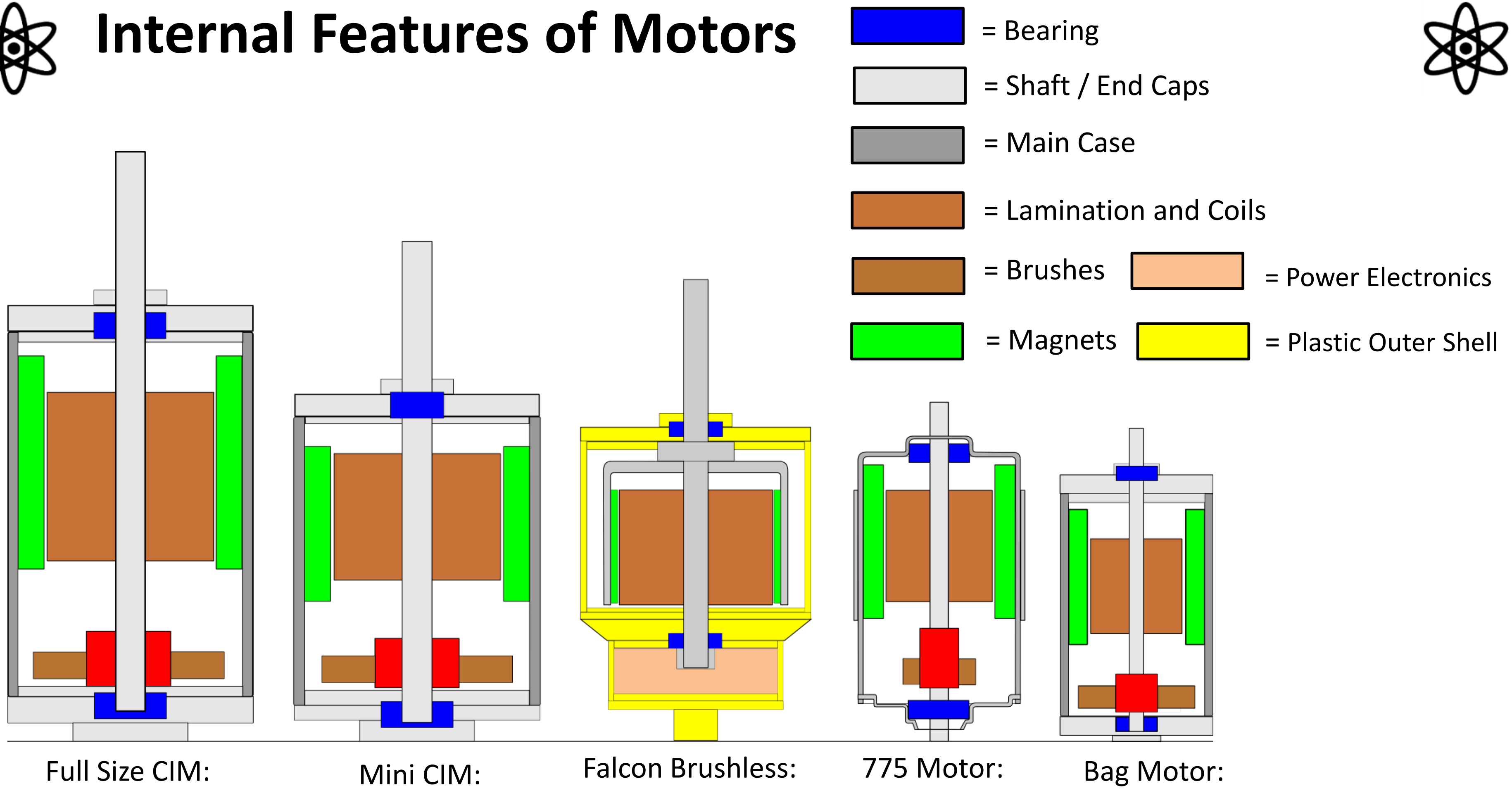
Mini CIM:
4.95“ Long
2.52” Dia
2.16 Lbm

Falcon Brushless:
4.57“ Long
2.36” Dia
1.10 Lbm

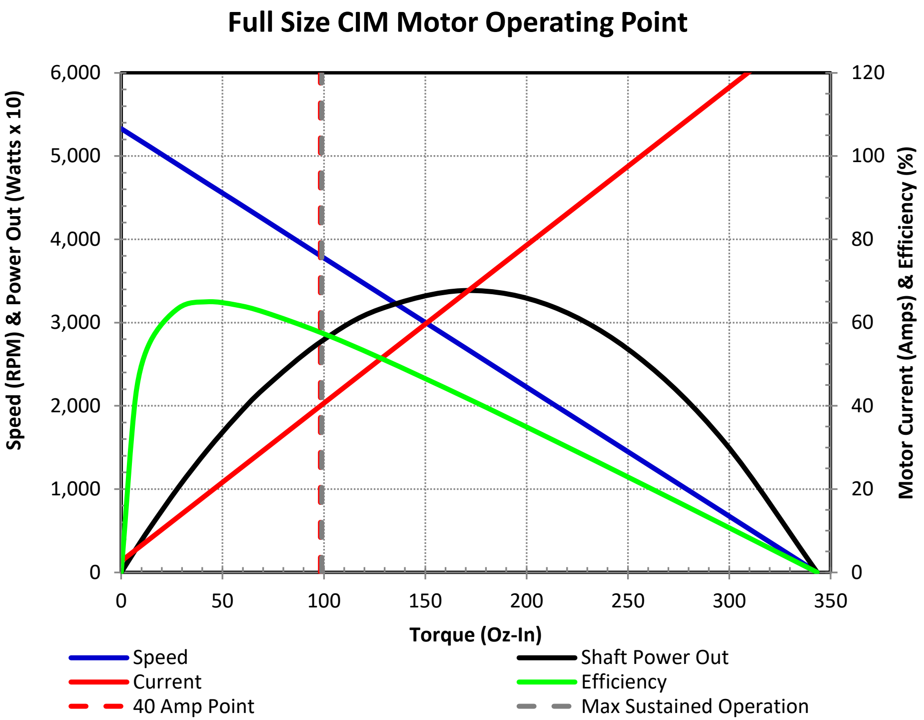
775 Motor:
3.47“ Long
1.74” Dia
0.81 Lbm

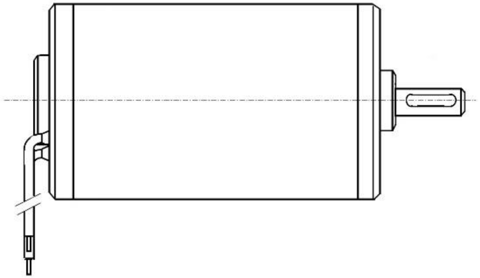
Bag Motor:
3.27“ Long
1.59” Dia
0.71 Lbm

# Internal Features of Motors



# Performance Summary: Full Size CIM

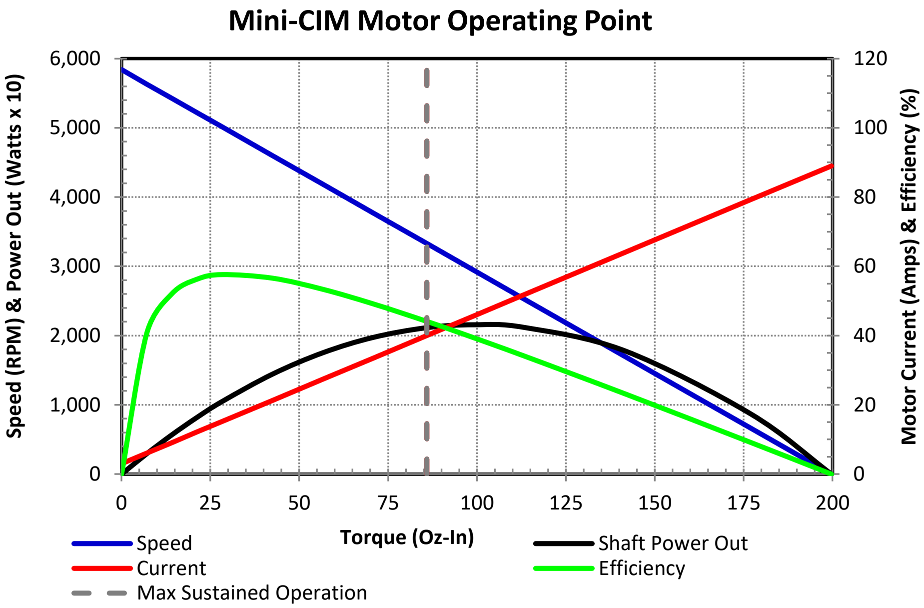


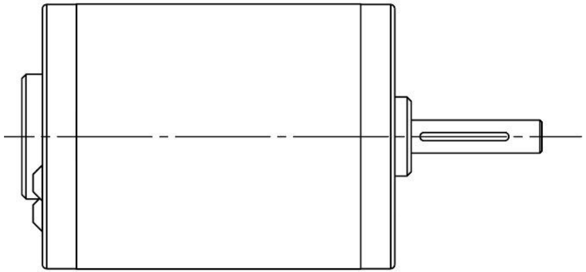



Full Size CIM:
5.50“ Long
2.52” Dia
2.8 Lbm

| Full Size CIM | | | | | |
|---|---|---|---|---|---|
| 12.0 Volt Performance | Free Speed (RPM) | 5330 | Performance at Max Power Output | Torque (Oz-In) | 170 |
| | Idle Current (Amp) | 2.7 | | Speed (RPM) | 2692 |
| | Stall Torque (Oz-In) | 343.4 | | Current (Amps) | 67.2 |
| | Stall Current (Amps) | 133 | | Power Out (Watts) | 338 |
| | | | | Efficiency (%) | 42.0 |
| Performance at Peak Efficiency | Torque (Oz-In) | 42.5 | Performance at Max Power Continuous Operation | Torque (Oz-In) | 98.3 |
| | Speed (RPM) | 4671 | | Speed (RPM) | 3804 |
| | Current Amps) | 18.82 | | Current (Amps) | 40 |
| | Power Out (Watts) | 146.8 | | Power Out (Watts) | 276.7 |
| | Efficiency (%) | 65.0 | | Efficiency (%) | 57.6 |

# Performance Summary: Mini CIM

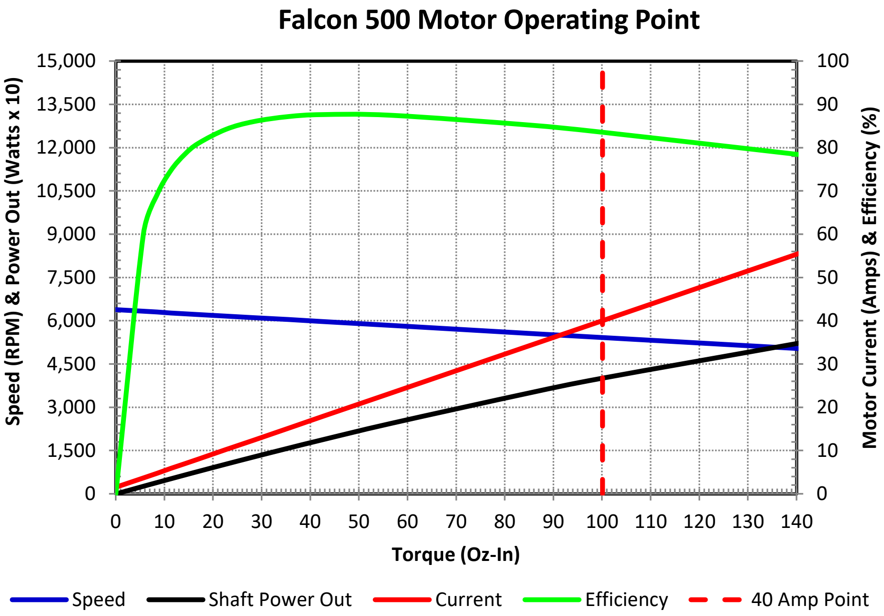


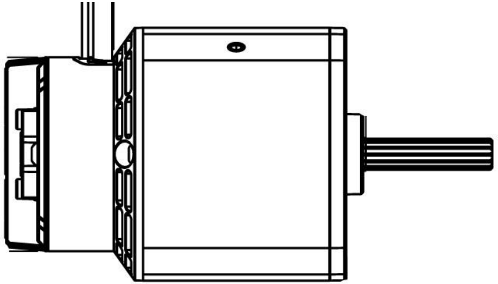



Mini CIM:
4.95“ Long
2.52” Dia
2.16 Lbm

| Mini CIM | | | | | |
|---|---|---|---|---|---|
| 12.0 Volt Performance | Free Speed (RPM) | 5840 | Performance at Max Power Output | Torque (Oz-In) | 100.6 |
| | Idle Current (Amp) | 3.0 | | Speed (RPM) | 2899 |
| | Stall Torque (Oz-In) | 199.7 | | Current (Amps) | 46.3 |
| | Stall Current (Amps) | 89 | | Power Out (Watts) | 215.7 |
| | | | | Efficiency (%) | 38.8 |
| Performance at Peak Efficiency | Torque (Oz-In) | 31.2 | Performance at Max Power Continuous Operation | Torque (Oz-In) | 85.9 |
| | Speed (RPM) | 4929 | | Speed (RPM) | 3328 |
| | Current Amps) | 16.42 | | Current (Amps) | 40 |
| | Power Out (Watts) | 113.6 | | Power Out (Watts) | 211.5 |
| | Efficiency (%) | 57.7 | | Efficiency (%) | 44.1 |

# Performance Summary: Falcon 500

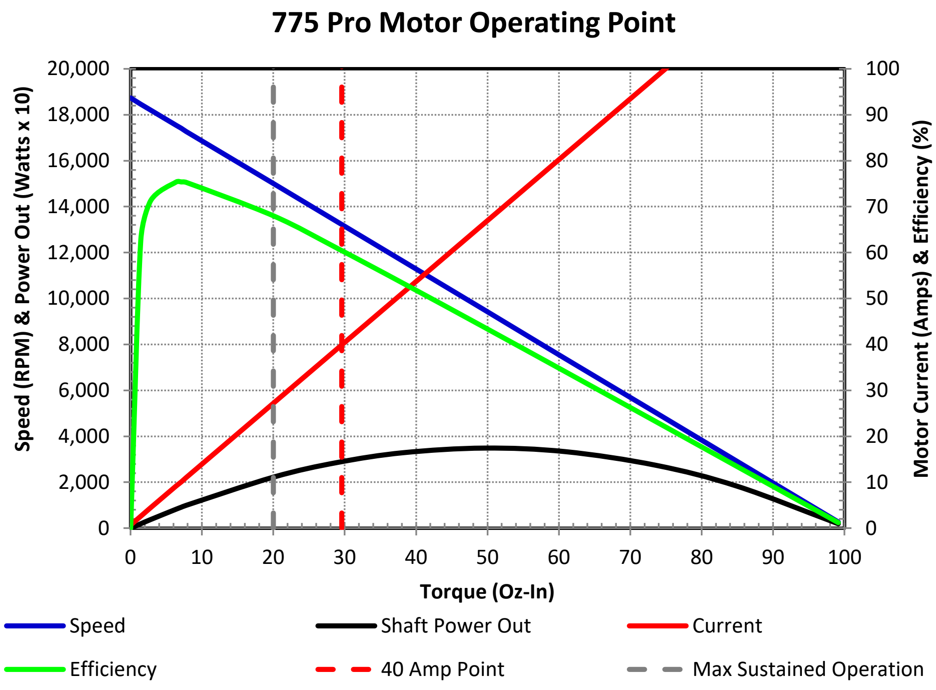


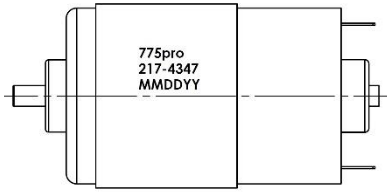



Falcon Brushless:
4.57" Long
2.36" Dia
1.10 Lbm

| Bag Motor | | | | | |
|---|---|---|---|---|---|
| 12.0 Volt Performance | Free Speed (RPM) | 6380 | Performance at Max Power Output | Torque (Oz-In) | N/A |
| | Idle Current (Amp) | 1.5 | | Speed (RPM) | N/A |
| | Stall Torque (Oz-In) | 664 | | Current (Amps) | N/A |
| | Stall Current (Amps) | 257 | | Power Out (Watts) | N/A |
| | | | | Efficiency (%) | N/A |
| Performance at Peak Efficiency | Torque (Oz-In) | 46.7 | Performance at Max Power Continuous Operation | Torque (Oz-In) | 100.1 |
| | Speed (RPM) | 5931 | | Speed (RPM) | 5419 |
| | Current Amps) | 19.48 | | Current (Amps) | 40 |
| | Power Out (Watts) | 205.1 | | Power Out (Watts) | 401.1 |
| | Efficiency (%) | 87.71 | | Efficiency (%) | 83.6 |

# Performance Summary: 775 Motor

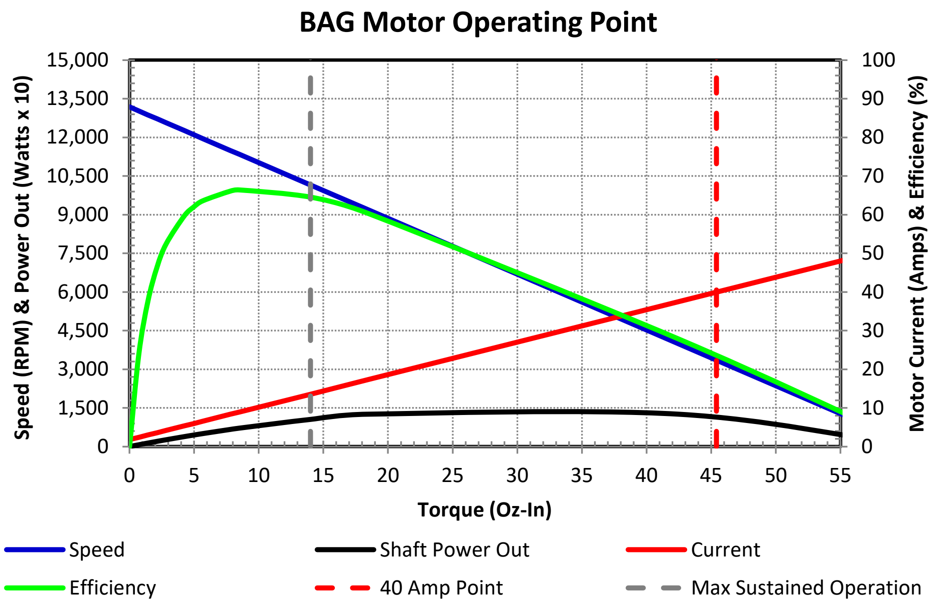


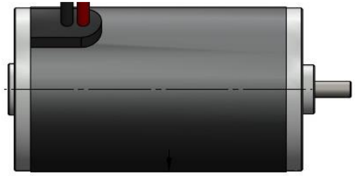




775 Motor:
3.47“ Long
1.74” Dia
0.81 Lbm

| 775 Motor | | | | | |
|---|---|---|---|---|---|
| 12.0 Volt Performance | Free Speed (RPM) | 18730 | Performance at Max Power Output | Torque (Oz-In) | 49.6 |
| | Idle Current (Amp) | 0.7 | | Speed (RPM) | 9497 |
| | Stall Torque (Oz-In) | 100.6 | | Current (Amps) | 66.41 |
| | Stall Current (Amps) | 134 | | Power Out (Watts) | 348.3 |
| | | | | Efficiency (%) | 43.7 |
| Performance at Peak Efficiency | Torque (Oz-In) | 7.1 | Performance at Max Power Continuous Operation | Torque (Oz-In) | 20 |
| | Speed (RPM) | 17411 | | Speed (RPM) | 14997 |
| | Current Amps) | 10.09 | | Current (Amps) | 27.27 |
| | Power Out (Watts) | 91.2 | | Power Out (Watts) | 222.3 |
| | Efficiency (%) | 75.35 | | Efficiency (%) | 68 |

# Performance Summary: Bag Motor

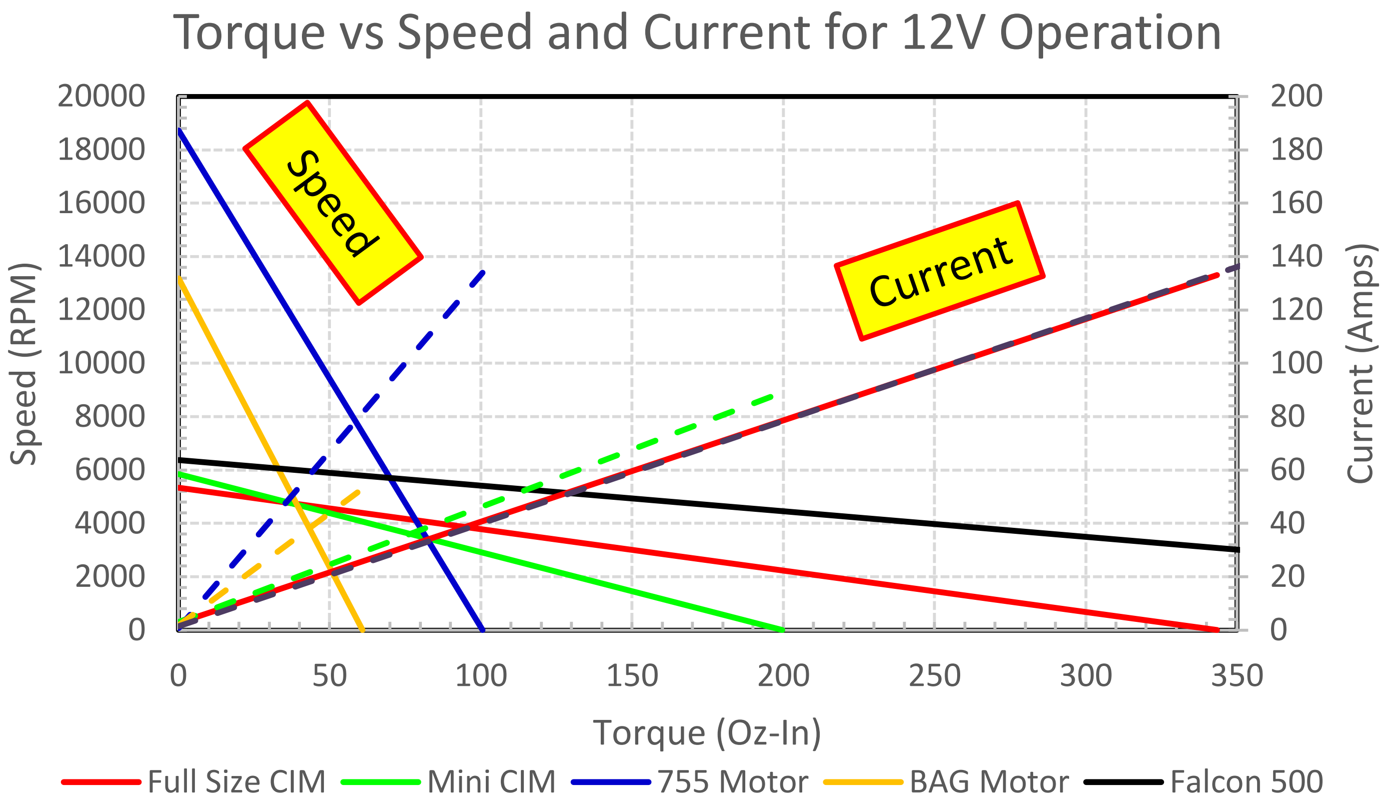


Bag Motor:
3.27" Long
1.59" Dia
0.71 Lbm

| Bag Motor | | | | | |
|---|---|---|---|---|---|
| 12.0 Volt Performance | Free Speed (RPM) | 13180 | Performance at Max Power Output | Torque (Oz-In) | 29.7 |
| | Idle Current (Amp) | 1.8 | | Speed (RPM) | 6743 |
| | Stall Torque (Oz-In) | 60.9 | | Current (Amps) | 26.8 |
| | Stall Current (Amps) | 53 | | Power Out (Watts) | 148.4 |
| | | | | Efficiency (%) | 46.1 |
| Performance at Peak Efficiency | Torque (Oz-In) | 9.3 | Performance at Max Power Continuous Operation | Torque (Oz-In) | 14 |
| | Speed (RPM) | 11157 | | Speed (RPM) | 10150 |
| | Current Amps) | 9.66 | | Current (Amps) | 13.57 |
| | Power Out (Watts) | 77.2 | | Power Out (Watts) | 105.1 |
| | Efficiency (%) | 66.6 | | Efficiency (%) | 64.6 |

# Motor Performance Comparison



# Proper Applications for Different Motor Types

- Falcon 500 and Full Size CIM motors are best for high torque load, high duty cycle applications
  - Falcon 500 Brushless motor was designed to be a high efficiency, smaller package size, weight saving drop in replacement for the Full size CIM motor
  - Good applications for these motors are:
    - Chassis drive wheels
    - Wheels for shooters
    - Large arm manipulation
- Mini CIM's can also be used for less demanding similar applications

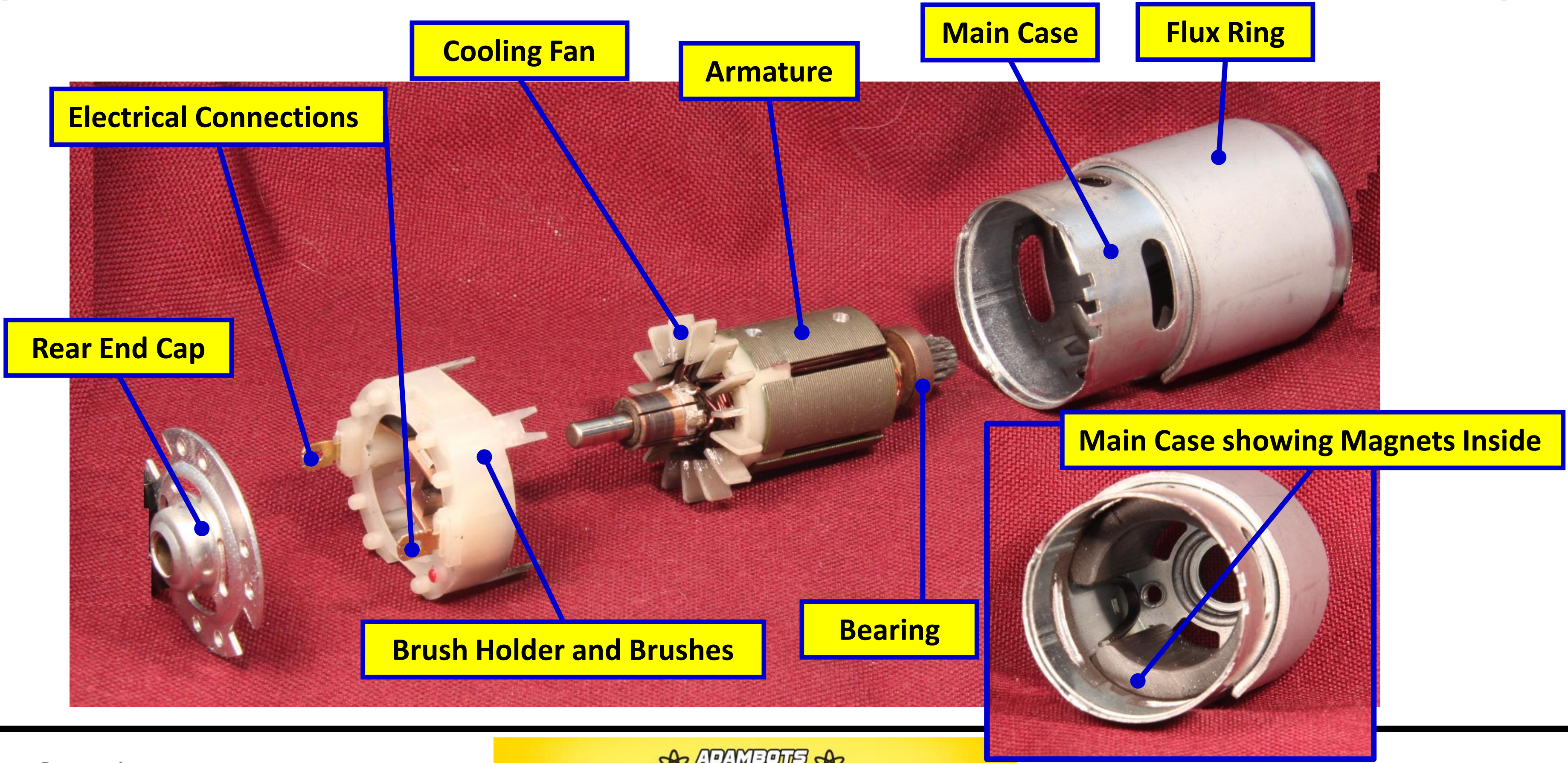
# Proper Applications for Different Motor Types

- 775 Motors can be used for intermittent duty cycle applications with higher torque requirements
  - 775 motors require much higher gear reduction ratios for use.
    - Speeds for 775 motors are 2 to 3x higher than CIM motors at similar working power levels
  - Good applications for these motors are:
    - Belt drive systems for game piece manipulation
    - Robot climbing application often using 2x motors driving same output shaft

# Proper Applications for Different Motor Types

- **BAG Motors can be used for intermittent duty cycle applications with lower torque requirements**
  - **BAG motors will also require high gear reduction ratios for use.**
    - **Best paired with Versa Planetary gear systems**
  - **Good applications for these motors are:**
    - **Lower torque drives for wheels used to input game pieces**

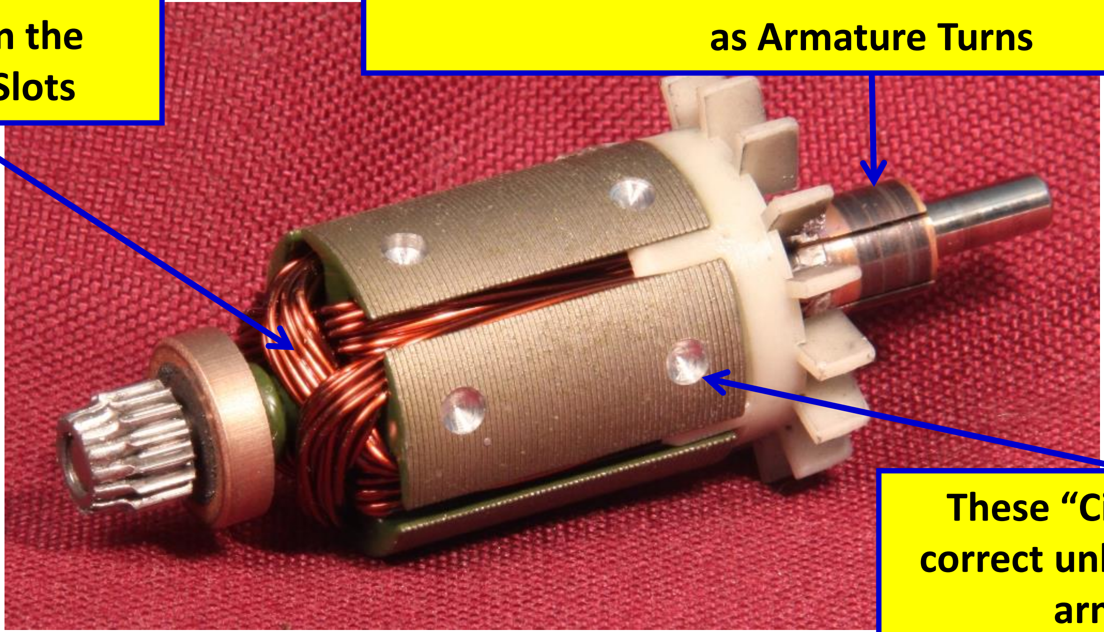
# Motor Internal Structure: 775 Motor Example



# Motor Internal Structure: 775 Motor Armature

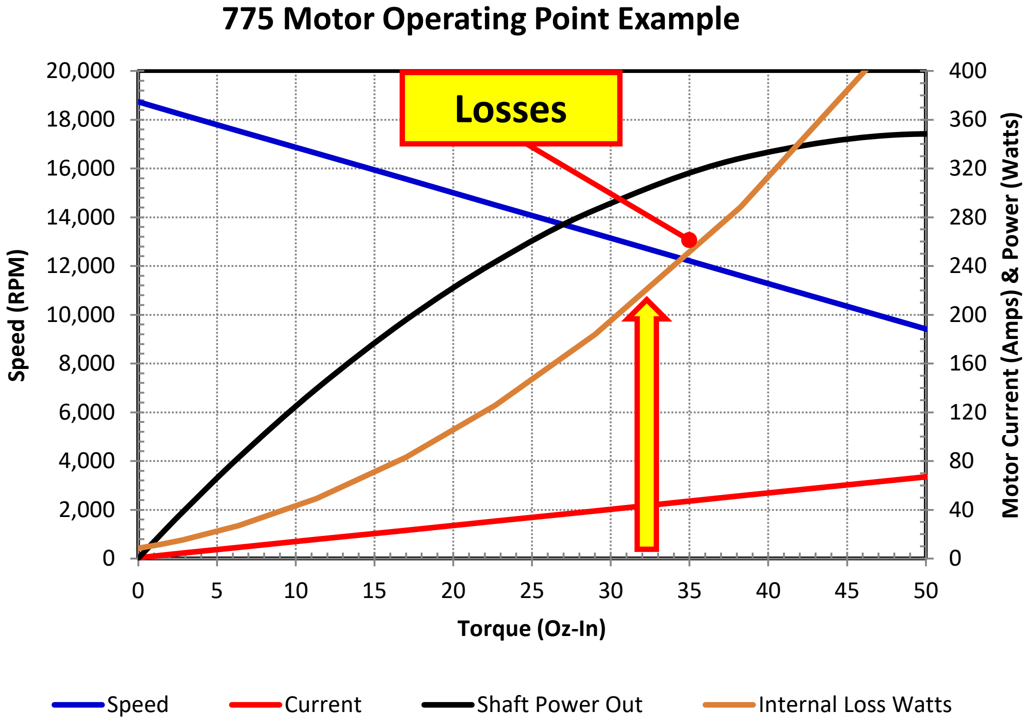
**Commutator Bars Connected to Each Wend of the Wire Coils Maintain Electrical Connection with the Brushes as Armature Turns**

**Multiple Individual Coils Within the Armature Slots**



**These “Circles” are to correct unbalance of the armature**

# Losses Within the Motor As Function of Operating Torque

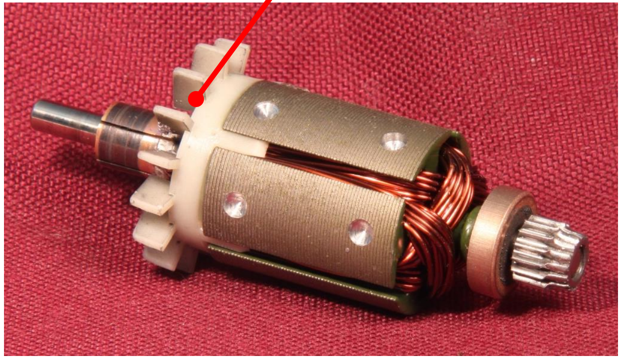



Losses within the motor increase with increasing motor torque and current levels

Majority of losses or temperature gain occur in armature coil wires and the commutator/brush interface

# Heat Rejection Paths from Motor Itself

- **Primary cooling method for 775 is cooling airflow drawn through motor by internal cooling fan**
  - **Higher motor speeds increases motor cooling airflow**
  - **Higher speeds also increases heat transfer within motor internal components**
- **Secondary cooling method is conductive heat transfer through motor case, end caps, and shaft**

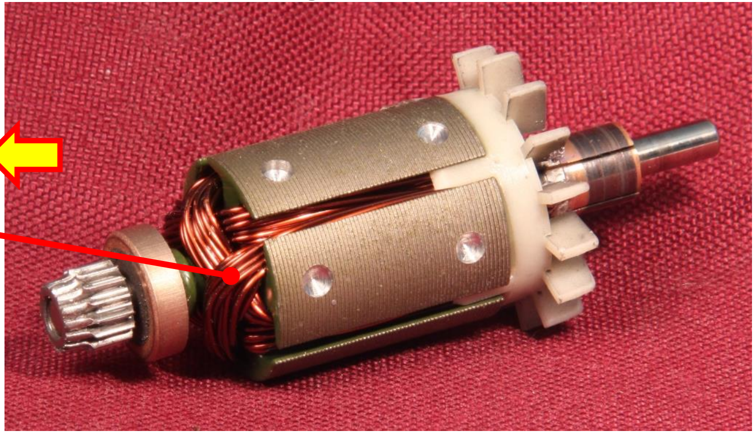



# Motor Overheating Failure Mode

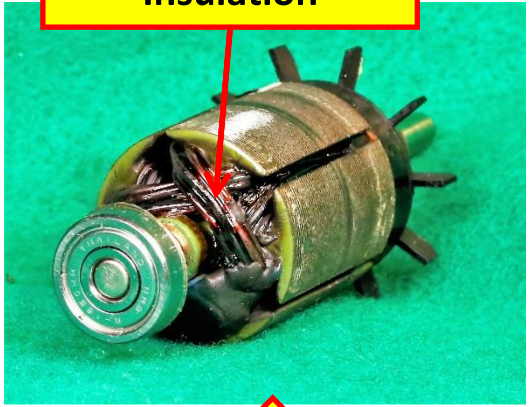
- Motor temperatures escalate when rate of heat generation within motor exceeds capacity for heat rejection from the motor
  - Varnish insulation on magnet wire coils is the initial failure point in the motor
    - Wire temperature exceeds temperature rating of varnish insulation causing it to soften and bubble allowing individual wire coils to make contact and short together causing motor to run slower, increase current draw, which further increases wire temperature that leads to progressive failure of entire motor
    - Smoke often seen from an overheated motor comes from overheated varnish
    - A Smoking motor is not always a Dead Motor. Varnish can smoke for some time before adjacent wire coils begin to short if power is removed before permanent damage
  - Any Non-Brushless motor will eventually overheat if subject to stall operation for a long period of time

# Key Failure Mode Related to Operating at Excessive Current/Torque Levels

Temperature within armature exceeds Max rating of varnish insulation coating used on wire coils



Blackened Wire Insulation



Failure of wire insulation results in Electrical shorts between adjacent coils that reduces speed, increases current draw, which further increases temperature that accelerates failure of motor

This temperature related failure releases the "Blue Smoke" often seen when motors fail

This is a motor that has experienced failure due to breakdown of wire insulation

# Limits of Motor Operating Torque

- Maximum operating torque or current draw for continuous or intermittent duty cycle is a function of motor design elements and overall sizing
  - Smaller diameter wire in armature coils has a lower maximum current density limit (Amps per Sq-Millimeter) than larger diameter wire
    - Larger diameter wire has higher surface are and can more easily reject heat from resistance related losses
    - Wire used in CIM motors is much larger diameter than BAG and 775 motors
  - Larger diameter motors also have larger external surface area that increases capability to reject heat
  - 775 Motor can achieve higher operating power levels due to internal cooling fan that is not present in larger, similar power motors

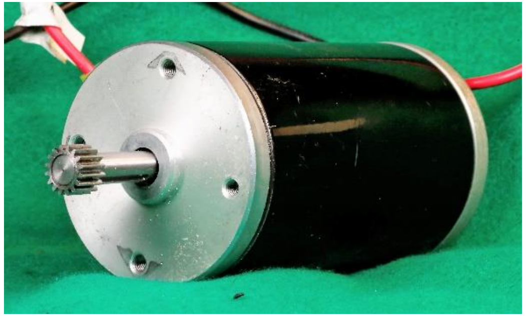
# Operating Current Levels for FIRST Motors

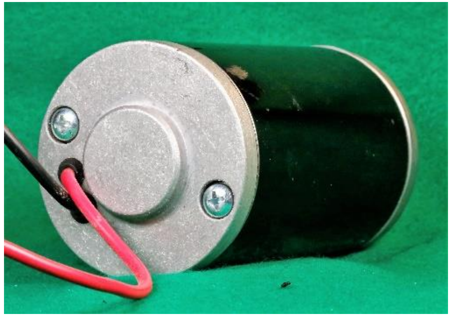
- Full Size CIM and Falcon 500 motors can run for full 2 ½ minute match time at 40 Amp Current without suffering damage from internal heating
  - Motors will get "Warm", and may loose some performance, but will generally not suffer permanent damage
    - Motor performance does decrease with higher motor temperature.  This is why FIRST allows 6 Minutes for motors to cool down between matches during the finals

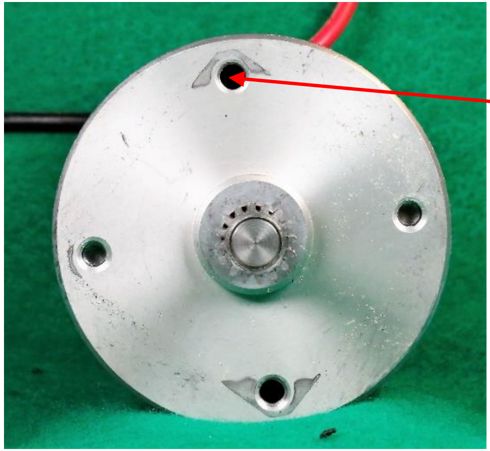
# Operating Current Levels for FIRST Motors

- 775 and Mini-CIM Motors can run intermittently at 40 Amp levels without suffering damage during 2 ½ minute match time
  - Short term 10 Second climb once per match is a good application for 40 Amp operating point with these motors
    - Design at 40 Amp operating point is not a good practice since this is too close to 40 Amp circuit limit
- Should use a longer term current draw limit of 25 Amps for 775 motors within 2 ½ minute match duration
- BAG Motors should use a 13 Amp limit for longer term current draw limit during a 2 ½ minute math duration

# Internal Structure of Full Size CIM Motor



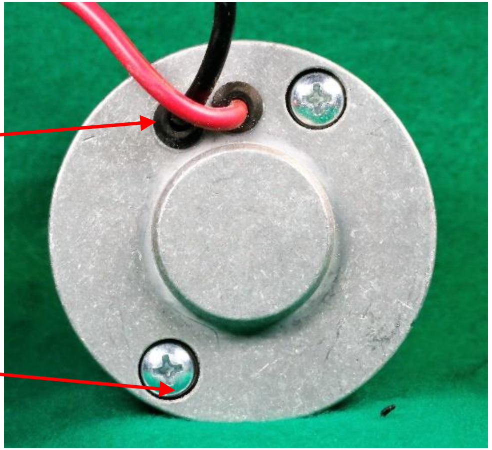





4x Mounting screw locations in front end cap

Rubber grommet sealing motor leads

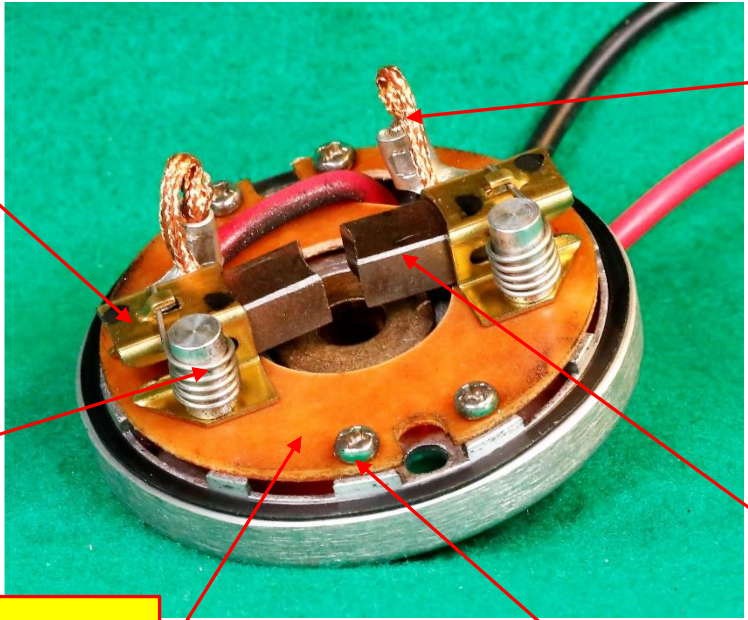
Through Bolts Holding Motor Together



# Details of Brush Card of Full Size CIM Motor

Brass Brush box keeps brush in position as brush wears away

Flexible Brush shunt conducts current from leads to brush as brush wears away



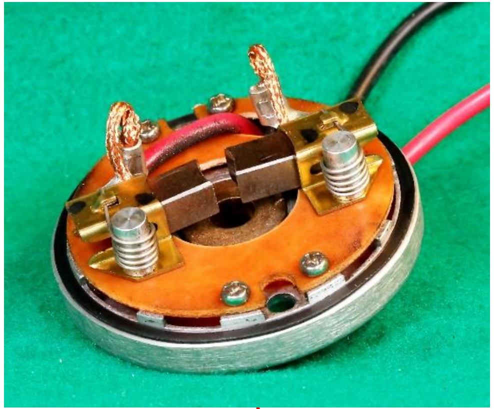
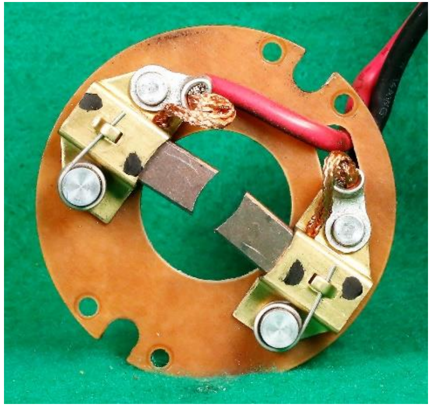
Brush Springs keep brush in contact with commutator as brush face wears away with use

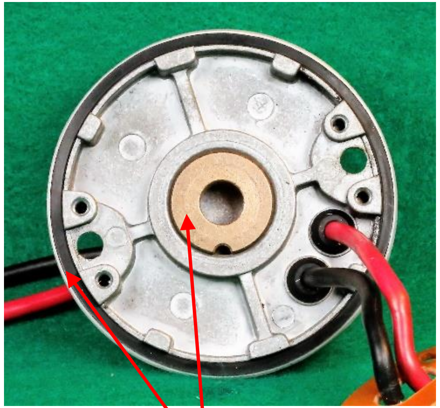
Non-Conductive base plate

Mounting Screws

Brushes conduct current to commutator bars. These wear away with use

# Brush Card and Rear End Cap: Full Size CIM

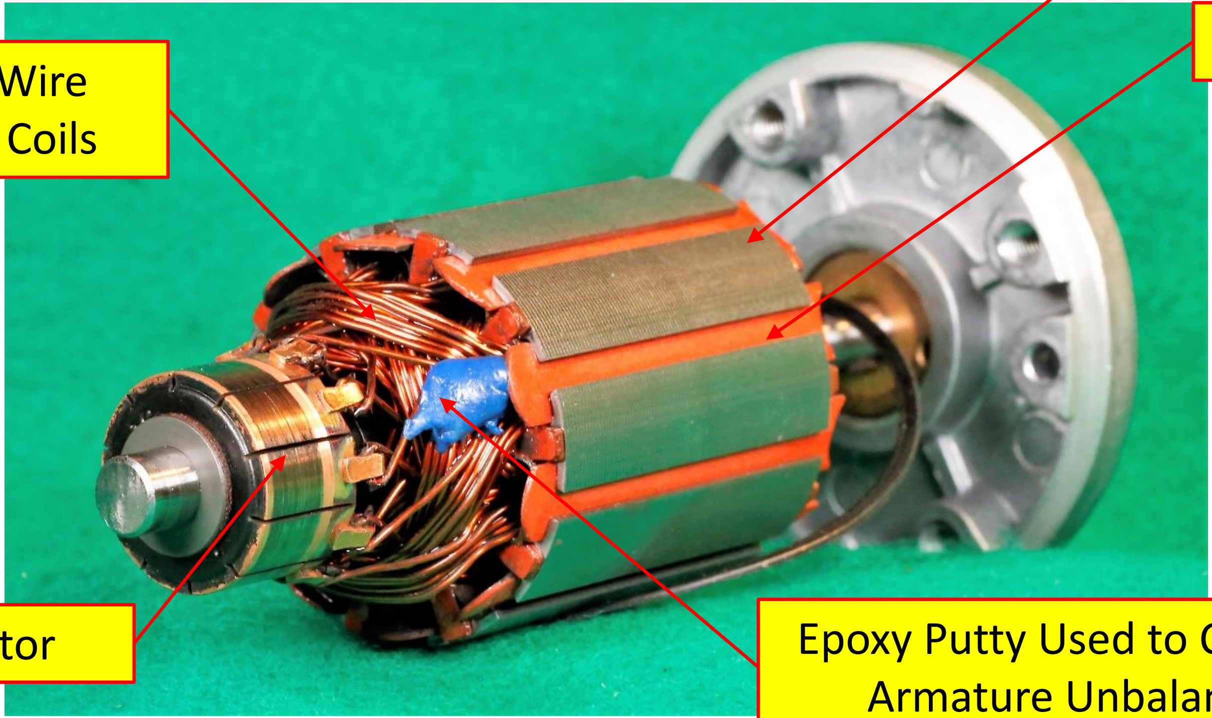


Brush Card fastened to rear end cap by 4x screws

Front & Back of Brush Card

Rear end cap with sintered bronze bushing and rubber sealing ring

# Armature Detail: Full Size CIM



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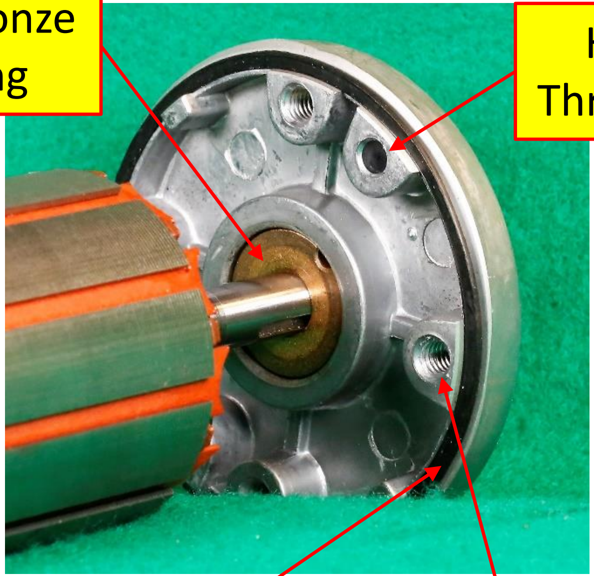
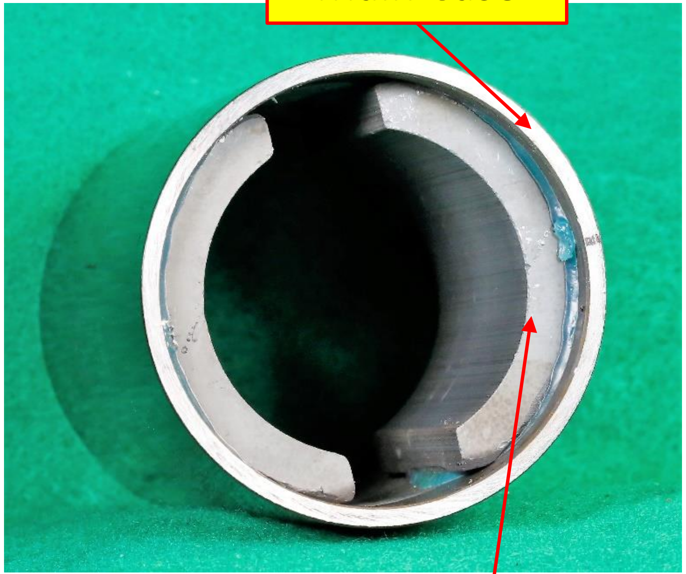
# Front End cap & Case/Magnet: Full Size CIM

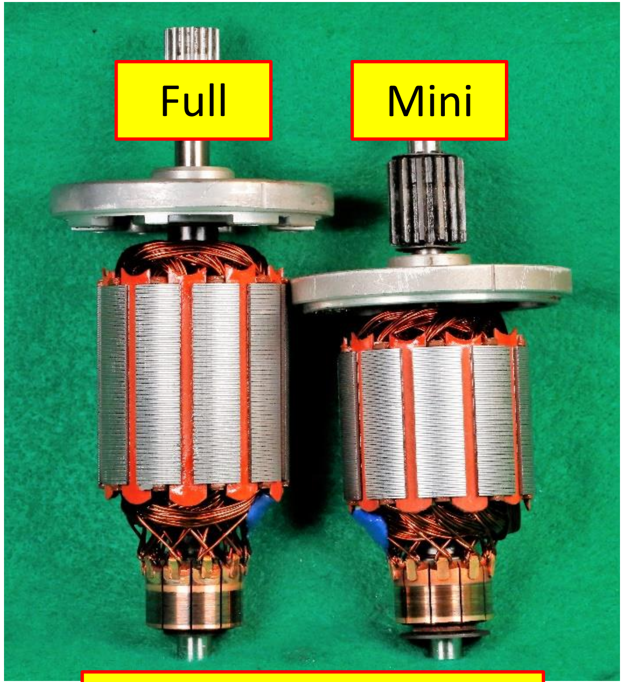


# Mini CIM Motor

Mini-CIM is a shorter version of Full Size CIM

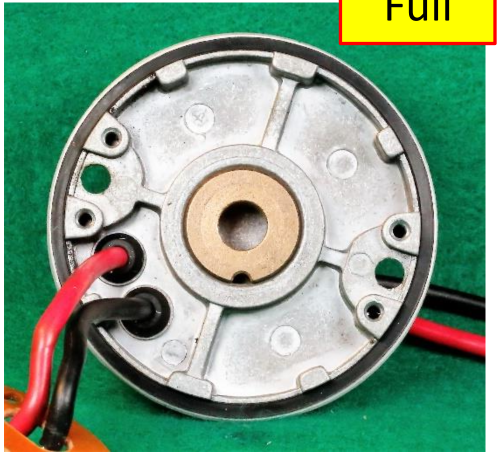
Different End Cap Design



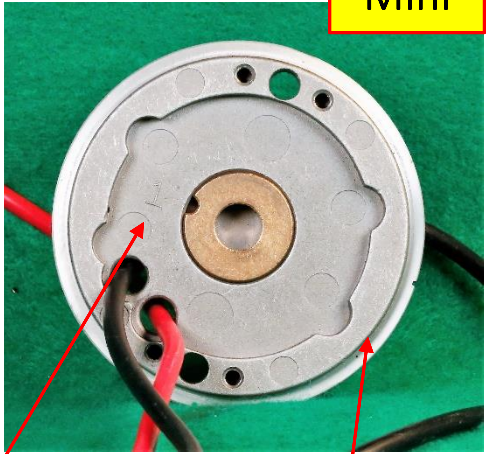
Full

Mini

Same Components Just Shorter



Full



Mini

No Structural Ribs

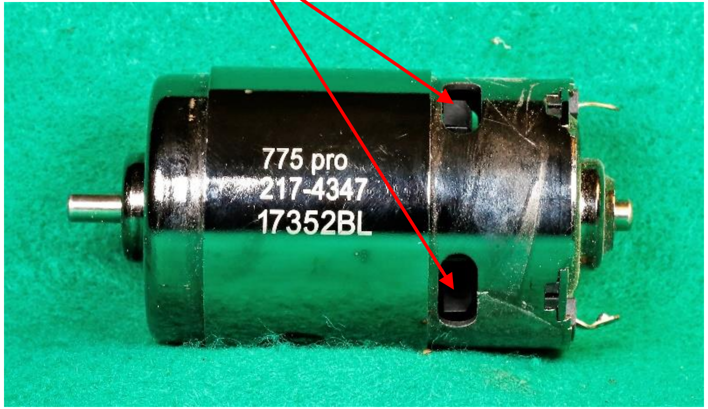
No Rubber Sealing Ring

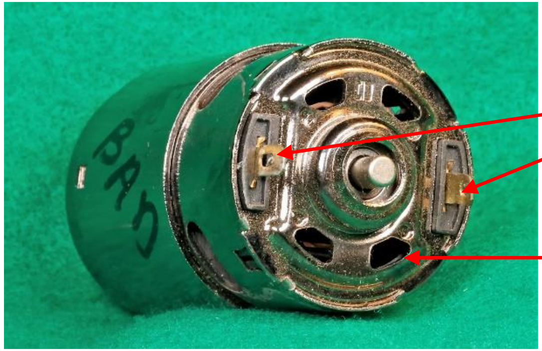
# 775 Motor

Back

Front

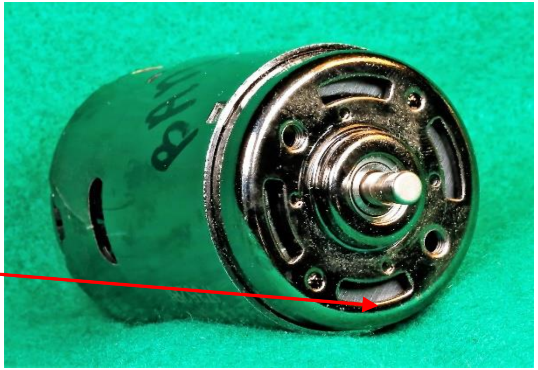
Cooling Airflow Outlet



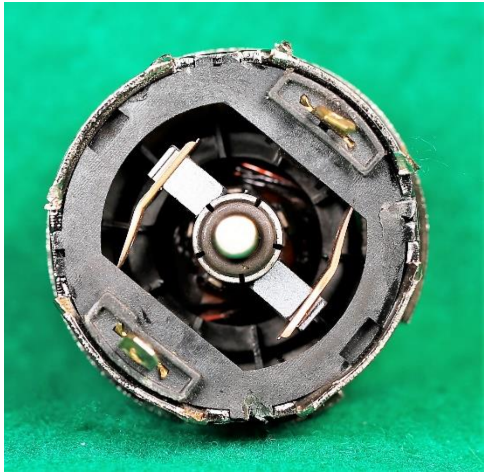



Motor Connectors are very small

Cooling Airflow Inlets on both Front and Back End caps

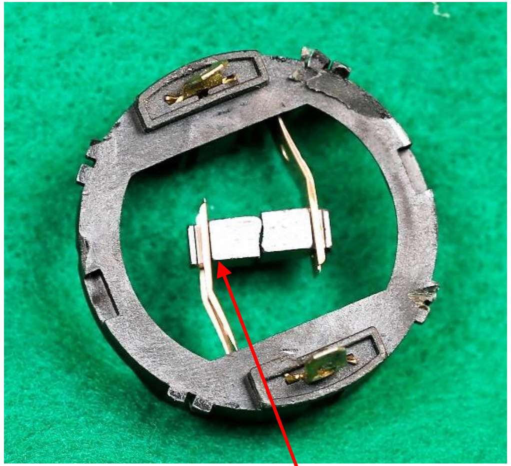


# Brush Assembly: 775 Motor



Brushes on Commutator

Connector and cantilever spring are one part

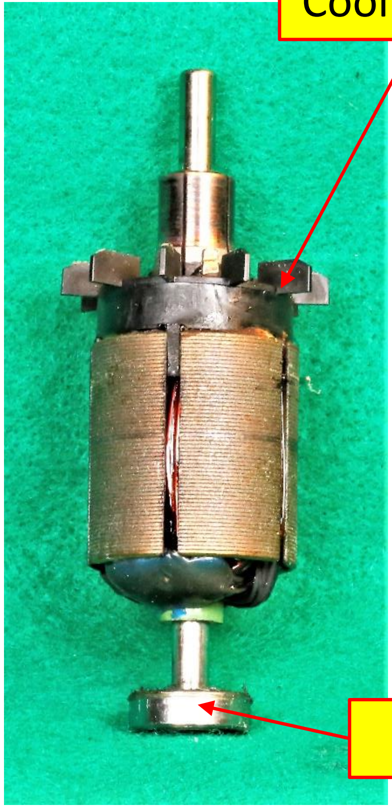


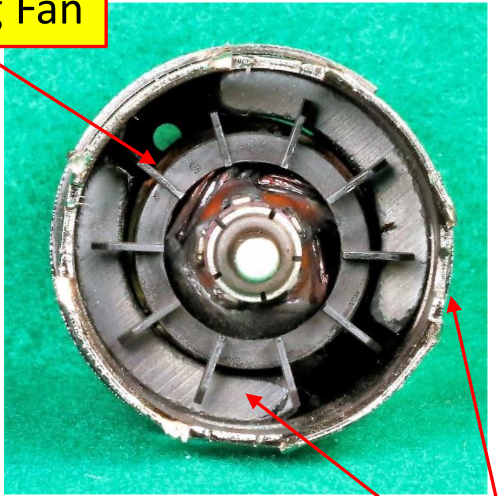
Brushes mounted directly on cantilever Springs

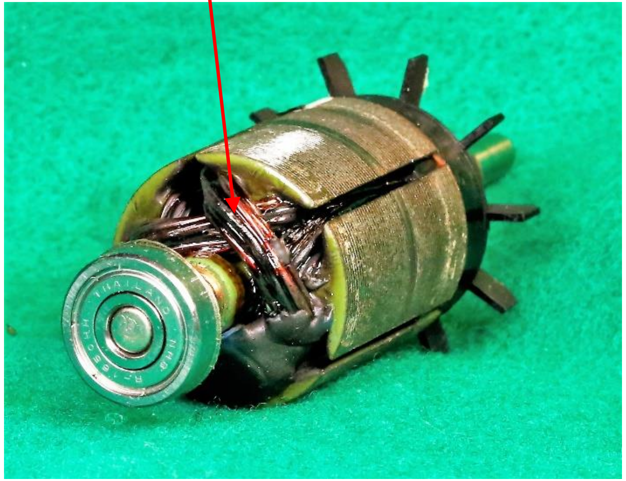
# Brush Assembly: 775 Motor

This motor has Burned Armature Windings

Cooling Fan







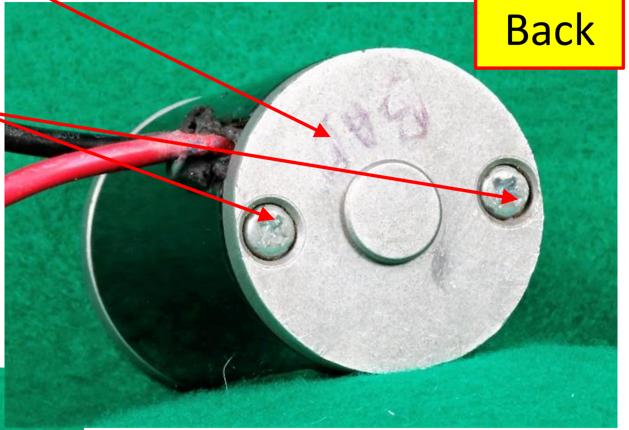
Ball Bearing

Case and Magnets

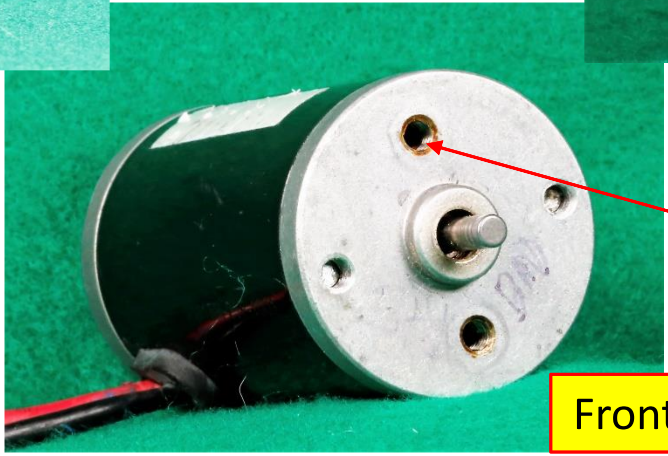
# BAG Motor

Case Construction Similar to CIM Motors


Through Bolts



Back

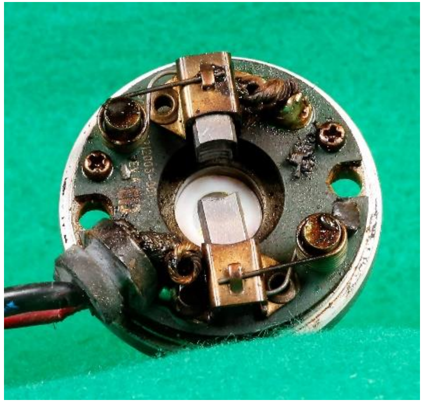
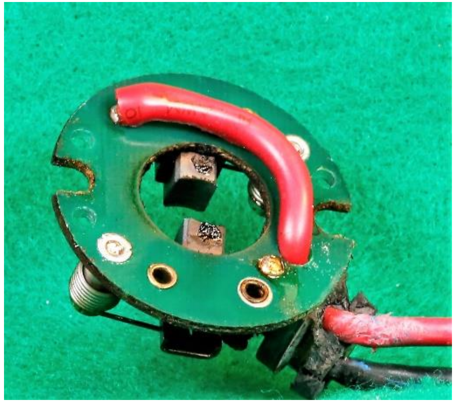


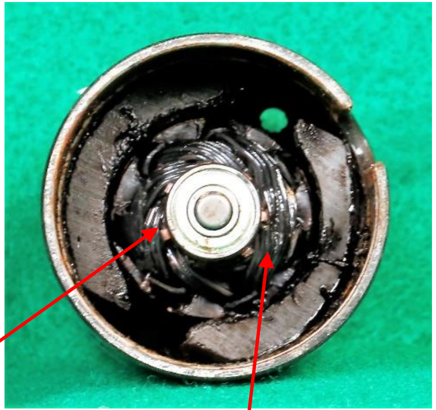
2x Mounting Screw Holes

Front

# BAG Motor

Photos From a Motor with a Burned Armature



Brush Card Construction Similar to CIM Motors

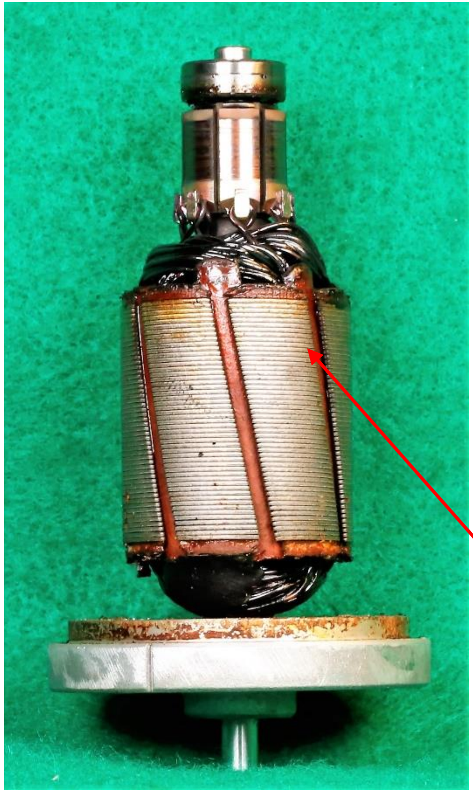
Ball Bearing

Burned Armature Winding Coils

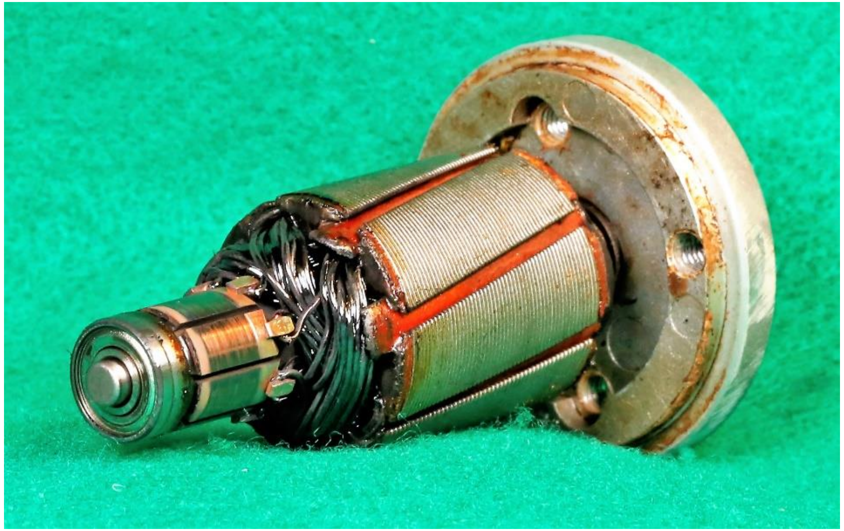
Condensed Residue from Overheated Winding Insulation

# BAG Motor Armature

Photos From a Motor with a Burned Armature



Armature Construction Similar to CIM Motors

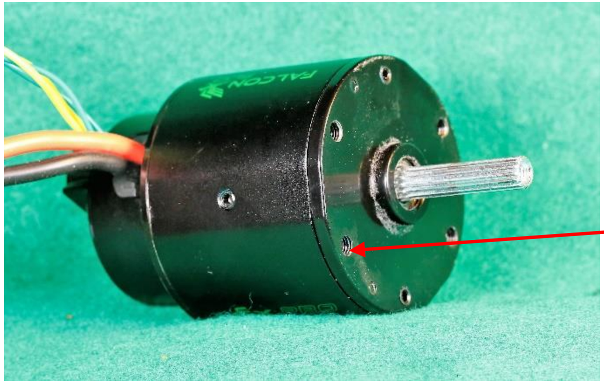


Laminations are Skewed as opposed to Straight as on CIM Motor in effort to reduce Vibration/Noise coming from interaction with magnetic field

# Falcon 500 Brushless Motor

Controller is Integrated with Motor


Spline Shaft Unique to Falcon

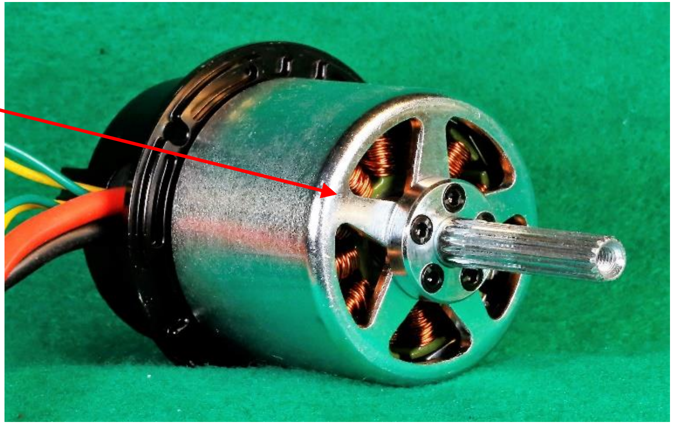



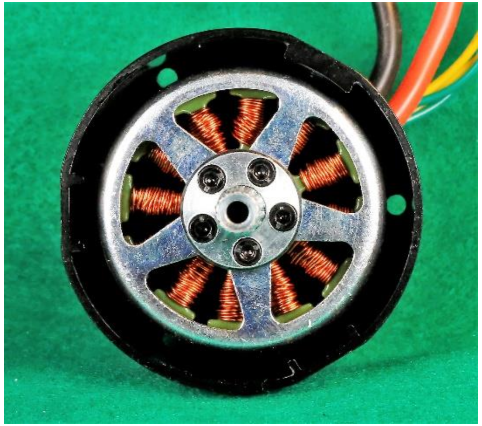
4x Mounting Screw Holes

# Falcon 500 Brushless Motor

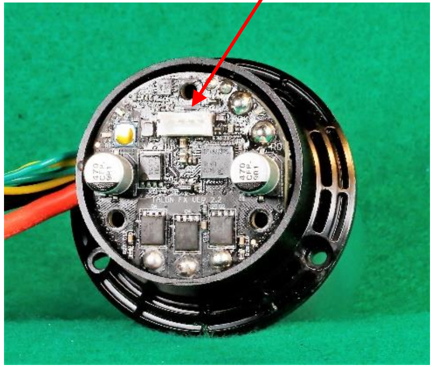
Plastic Cover Removed

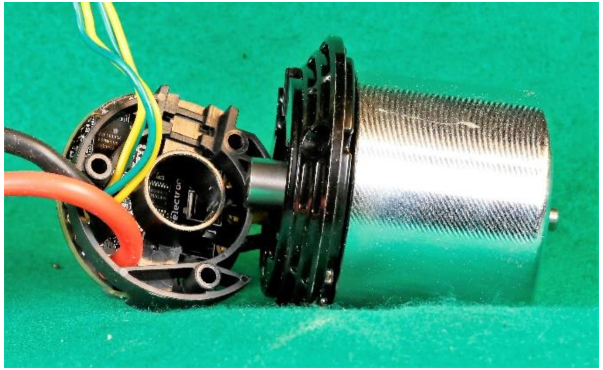
Rotor Cup with Shaft Attached





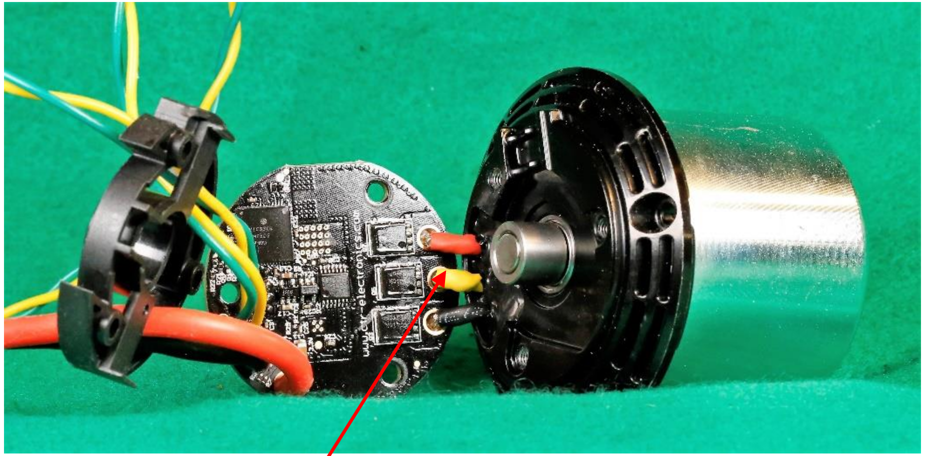
Power Electronics Located Inside Back Cover





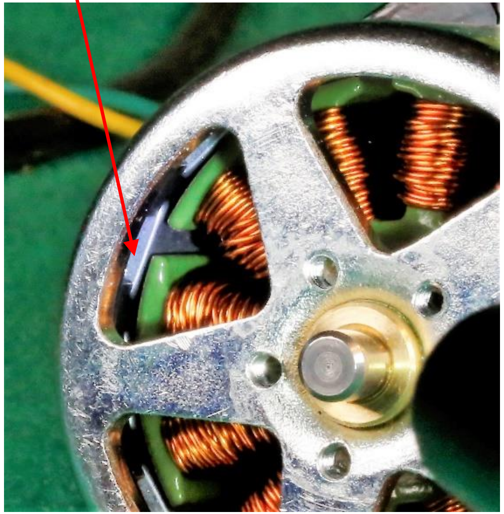
Motor has “Inside Out” Architecture. Windings and laminations are fixed and Magnet /Steel rotor rotate around fixed copper windings

# Falcon 500 Brushless Motor



High Energy Product Neodymium Magnets bonded to inside of rotor cup.  One reason for higher efficiency and lower weight

Power Leads for 3-Phase Winding from Electronic package to Fixed coils inside stator



# Benefits of Brushless Motors

- Significantly higher operating efficiency
  - CIM at 200 Watt power out is 63% Efficient
  - Falcon 500 at 200 Watt power out is 87% Efficient
  - Savings of 7 Amps at same output power level
- Lower Motor only Weight
  - CIM motor = 2.8 Lbm  Falcon = 1.1 Lbm  1.7 Lbm Savings
- Additional mass and weight savings
  - Motor controller is integrated inside brushless motor that saves packaging space on electronics board and provides additional 0.26 Lbm weight savings

# Benefits of Brushless Motors (Continued)

- Brushless motor controller offers stall protection
  - Motor will shut down if presented with a stall condition and will not overheat
- Lower rotating inertia provides quicker acceleration compared to CIM motors
- Brushless motor system provides feedback of rotor speed and can maintain exact command speed
  - No need for stand alone encoders
  - CIM Brush DC motor cannot achieve target command speed without external encoder bases sensor PID loop
  - Critical for control of shooter wheel speed to control shot distance

# Benefits of Brushless Motors (Continued)

- Can run longer without needing to cool motor due to higher efficiency
- Falcon brushless motors have advantage compared to Neo motors due to integrated power electronics which eliminates need for separate controller on electronics board
- Falcon 500 Motors proven after 2+ FIRST Seasons and have proven to be reliable