### A Wheelmotor is Not a New Idea

- Internal Combustion Engine Driven Wheel
- Hydraulic Motors on Farm Machinery
- Lohner-Porsche Electric Wheel c.a. 1903
- Gear Motors on Mine Trucks
- Diesel Locomotives



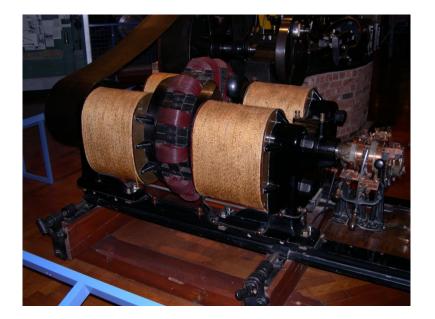






### Dual-Axial Gap Motor is Not a New Idea

- Promoted by Motor Designers in Textbooks
  - Hanselman
  - Hendershot
  - Gieras
- Brushed Motor at Henry Ford Musem, Dearborn Michigan
- Naval Propulsion Motors for Submarines



292 AXIAL FLUX PERMANENT MAGNET BRUSHLESS MACHINES

*Figure 9.12.* Large power double disc AFPM brushless motor. 1 — PMs, 2 — stator assembly, 3 — housing, 4 — shock snubber, 5 — shock mount, 6 — rotor shaft, 7 — rotor disc clamp, 8 — shaft seal assembly, 9 — bearing retainer, 10 — stator segment, 11 — centre frame housing, 12 — spacer housing, 13 — rotor disc, 14 — bearing assembly, 15 — rotor seal runner, 16 — rotor seal assembly. Courtesy of *Kaman Aerospace*, EDC, Hudson, MA, U.S.A.

### Dual – Axial Gap designs



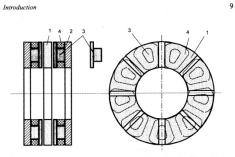
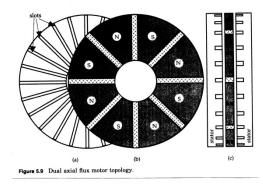


Figure 1.6. Double-sided AFPM brushless machine with three-phase, 9-coil external salientpole stator and 8-pole internal rotor. 1 — PM, 2 — stator backing ferromagnetic dise, 3 — stator pole, 4 — stator coil.

#### Hanselman

Design Variations 123



#### Hendershot

38 DESIGN OF BRUSHLESS PERMANENT-MAGNET MACHINES

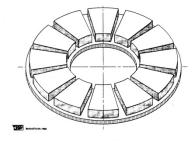


Fig. 2.7 Rotor magnet plate with 12 magnet poles

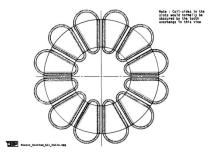


Fig. 2.8 Array of stator coils (one phase only)

## Wheel History

- Potter's Wheel c.a. 6,000 B.C.
- Cart wheel unearthed in Eastern Europe c.a. 3,500 B.C.
- The need to move heavy Loads over rough terrain
- Many variations today Road Wheels
  Fans
  Pumps
  Electric Motors
  Generators
  Machine Tools
  Rolls
  Turrets
  Bearings
  Couplings
  Pulleys
  Shafts
  Gears

## **Conventional vs Pancake**

- Conventional motor is long and smaller in diameter
  - Coupled to driven machine via belts, chains, couplings, or gears
- Pancake motor is narrow and larger in diameter
  - Eliminates drive components
  - Takes up less space
  - In hub of driven machine
  - Delivers more torque at slow speed



### **Benefits of Dual-axial gap**

- Both sides of magnet are used
- No rotor iron less rotor weight
- Two stator windings more copper
- Two motors/Two controllers for redundancy
- Better heat removal with shorter path to outside
- Adjustable air gap
- Individually wound salient coils for manufacturing and reparability
- Modular design



# Why Wheelmotors?

- Less parts
  - Lower overall cost to make
  - More reliable
- Maximum torque at zero speed
- Reliable energy source i.e. electricity
- Operates without oxygen underwater and in vacuum
- Consumes almost no energy when stopped
- Torque production is close to the point of use
- Frees up space in the vehicle for other purposes
- One wheel vehicle is possible

### Ryno Motors



## Counterarguments

### Range

- As a city vehicle only, present battery capacity is sufficient
- Trips need to be managed (give up some flexibility)

### • Unsprung weight

- Not relevant for normal driving
- More is better for stability
- Slightly more energy use during acceleration

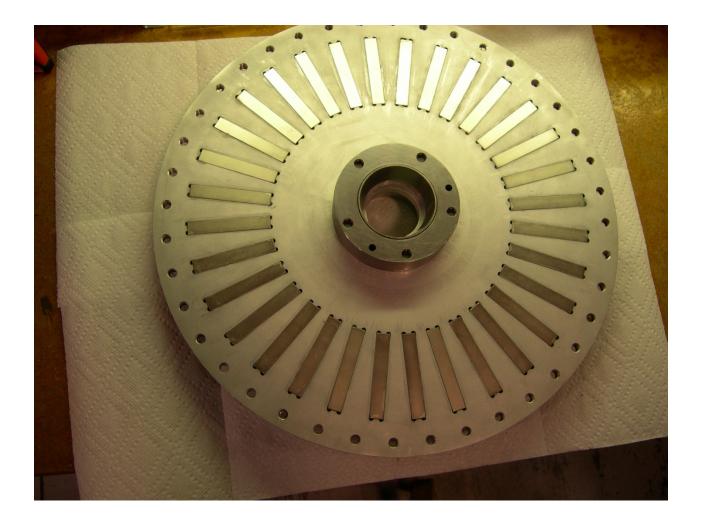
# Why Now?

- High energy magnets NdFeB since 1985
- Reliable pulse width modulated (PWM) controllers
- High power semiconductor switches (IGBT'S)
- Battery chemistry continues to improve
- Hydrocarbon fuel costs increasing and supply uncertain
- I.C. engines are complex and costly to maintain
- Zero-emission vehicles are being mandated by some local governments
- Environmental regulations

## Problems

- Wear at axle from high torque
- Controller reliability long-term
  - Capacitors
  - Free-wheeling diodes
- Tire replacement
- Hall sensor failures
- Disassembly in the field
- Handling of high energy magnets in production

### Rotor with Magnets



### Rotor in Wheel with Bearing Block – Inside View



### Inside Stator Prior to Vacuum Impregnating



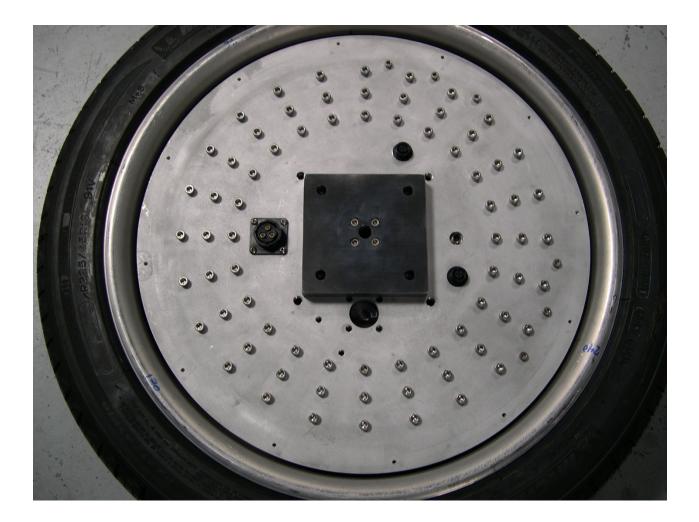
### **Disassembly Fixture**



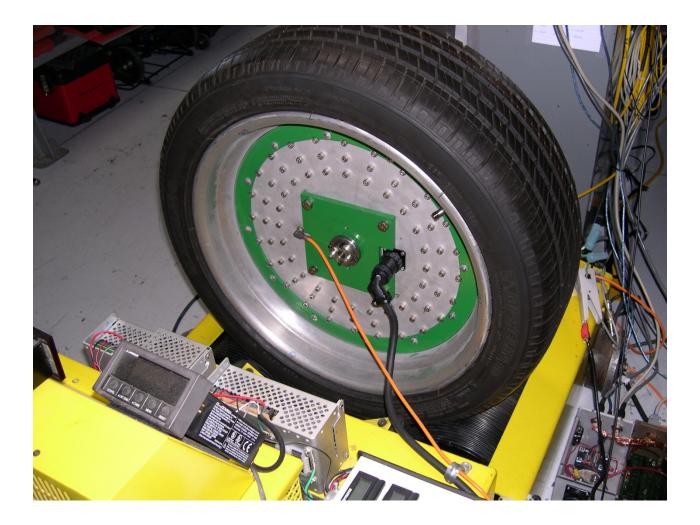
### Rotor in Wheel with Axle – Outside View



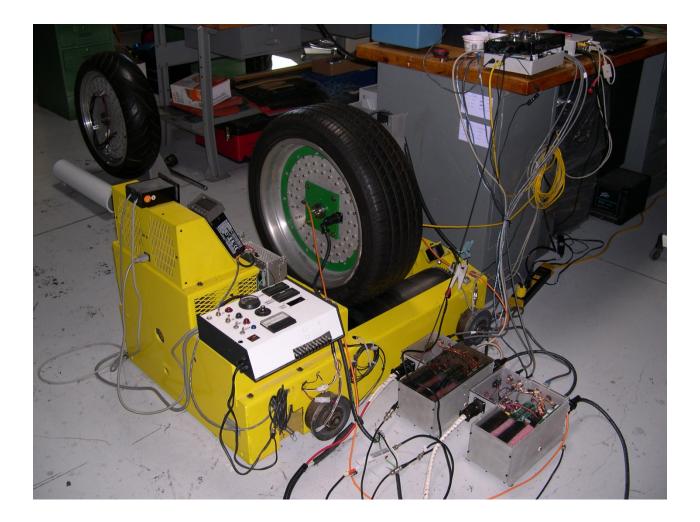
### Inside View with Adapter Plate



### On Dynamometer with Seals and Torque Plate



### Prototype Controllers



### Inside View Attachment to Vehicle

