Wheelmotor by Machine Dynamics

See Figure 1

Photographs of the wheelmotor were in the last issue of *Current Events*. It is shown in the diagram here. It is an electric motor built into a road wheel, in the space normally occupied by spokes or a metal wheel. The tire is mounted on the rotor. Electric wires go to the stators, which do not rotate. The net result is a propulsion system with the wheels being the only moving parts. This particular wheelmotor built into a 26-inch-diameter automobile tire has been under development for two years. It is presently undergoing dynamometer testing. Road testing will be next, then preproduction prototypes. This version was designed to be a commercial product with high-volume manufacturing incorporated into the design. Manufacturing, marketing, and capital partners are being sought. The preliminary technical specifics are:

Configuration	Dual axial gap brushless motor
Maximum voltage	600V DC
Peak Torque	800 Ft-Lb_f at 300 amps
Continuous torque	250 Ft-Lb_f at 100 amps
Maximum speed	60 mph
Controllers	Two separate IGBT pulse-width modulated controllers One for each separate stator winding
Magnets	Neodymium iron boron rare earth
Total weight (with tire)	120 Lb_m
Tire size	26-inch outside diameter
Airgap	.100 inch per side
Bearings	Tapered rollers (two) 32210
Seal	Labrynth seal between rotor and stators (2)
Cooling	Air-cooled stator
Estimated production cost	$4,500 per wheel which includes IGBT controller
Braking	Integral band brake
Mounting	Stainless-steel adapter plate for bolting to existing rear trailing arm
Cores	Sintered iron, powder metal

The initial market for wheelmotors will be add-on rear wheelmotors to existing front-wheel drive cars. This will transform the car into a plug-in hybrid while retaining the original engine, transmission, and fuel tank. It will become a dual-fuel and dual-propulsion vehicle. The driver (and passengers) will have the peace of mind of never being stranded because of engine problems, and always having the ability to use it, even if gas is not available. The decision to convert is reversible. If the owner is unsatisfied, then the rear wheelmotors and batteries can be removed, restoring it to gas-only operation.

Why?

Why go to all the trouble of redesigning the wheel when we have reliable vehicles that work well? There are at least four good reasons.

First, the wheelmotor eliminates the weight and manufacturing complexity of the engine, transmission, coupling (clutch or torque converter), drive shaft, and differential. These are all precision-machined components. The propulsion system will consist of three major components:

- A wheelmotor
- Controller
- Batteries, or other energy storage

The net result will be a vehicle that costs less to produce and more reliable because of less numbers of complex parts.

Second, DC motors produce their maximum torque at zero speed, where it is needed most to accelerate from a stop. The DC motor torque curve matches the vehicle load profile well. An internal- combustion engine produces no torque at zero speed. It must have a clutch, or fluid coupling, to “ease” the load to the engine without stalling it. Therefore, electric motors have better performance and efficiency at low speed, where the majority of city driving is done.

Third, the energy source is electricity and not gasoline. Electricity is available almost anywhere on the planet, and can certainly be generated anywhere, even in space. Electric propulsion is the prime mover of the future. The depletion of a specific fossil fuel source will not kill the wheelmotor.

Fourth, it makes sense to place the torque production as close as possible to the point of use. Ferdinand Porsche recognized this in 1900, but became sidetracked by the lure of the internal- combustion engine for racing. Placing the motor in the wheel gives the vehicle designer more flexibility in chassis layout and functionality.

Unsprung weight

One objection to the wheelmotor is placing all that iron, copper, and magnet weight below the chassis springs contributing to “unsprung weight.” Unsprung weight is actually two physical phenomena—one is the actual mass and the other is rotational inertia. The official definition of “unsprung weight” is the mass between the road surface and the bottom of the spring. A wheel with a high mass below the spring will transfer more force to the chassis when hitting a pothole or road bump. This is important for motorcycle racing cross country, or for any vehicle operating on a rough surface at high speed. For normal speeds on smooth road surfaces, it’s a “don't care.” On the contrary side, too little unsprung weight could be detrimental to steering stability. This is because the tire will lose contact with the road surface a greater percentage of the time.

The second factor of rotational inertia refers to the torque required to accelerate a wheel from a stop. Larger tires (or rotating tire plus wheel plus brake disc) require more torque, therefore more energy. The rotating inertia of a wheelmotor should be only slightly more (maybe 10% more) than a standard wheel of the same size, due to the added magnets. Reducing rotating inertia is important for very high speed vehicles (>100 mph) that make quick turns. For normal speed vehicles, the rotating inertia provides some gyroscopic stability and is desirable.

See Figure 2

The Dual Axial Gap Brushless Design

This configuration, sometimes called a pancake motor, has a large diameter and narrow width. It is a natural geometric shape to fit inside a wheel. The large diameter delivers more torque for the same electromagnetic force at the airgap, and provides more room for magnets and coils.

The dual axial gap means that both poles of the magnet are exposed to an airgap, so it utilizes the magnets better. There is no rotor iron, so the rotor weight is reduced. There are two stator windings, which means that there are, effectively, two motors in each wheel. This delivers twice the torque of one motor, and also provides for redundancy. If one motor fails, then the vehicle can get home on the other functioning stator. To capitalize on this, we have integrated two IGBT power switches into the controller also, each one powering a separate stator.

The external stators are exposed directly to the relative wind for effective air cooling at no extra energy penalty.

The brushless feature means that there are no brushes to maintain, or to arc. The brushless design allows the motor to operate to much higher voltages—600 VDC for common magnet wire winding. The brushless design also allows for electronic phase shifting "on the fly," to maximize torque at low speed, or efficiency at high speed. This is software controllable, with some manual inputting (if desired) by the driver.

The coils are individually wound as salient poles. This means that they can be wound on standard high-speed coil-winding machines for low-cost manufacturing. There is no hand winding. A shorted winding can be easily repaired without stripping out all the wire. This makes it field repairable by cutting and unbolting the "bad" coil and installing a replacement.

Finally, an axial gap can be adjusted with shims. The adjustable air gap means that the torque output is variable for enhanced performance and to compensate for bearing wear.

Why Now?

Some features of electric vehicles have always been desirable such as:

1. No need for shifting
2. Mobile auxiliary electric power source on wheels
3. Military stealthiness (no heat, no noise)
4. No air pollution
5. No disposing of liquid wastes, i.e., oil
6. Reliability
7. Easy and fun to drive

Why they have not been reintroduced sooner will be debated for centuries. The timing is now right for returning to electric propulsion because of the following recent developments.

1. Powerful rare earth magnets are now available. Neodymium iron boron magnets were invented in the 1980's. The cost has since decreased substantially.

2. Reliable pulse-width modulated controls are now common with sufficient protection circuitry to remain in the safe operating envelope and not smoke themselves.

3. Semiconductor power switches (IGBT's) have recently become available in high power ratings to handle more than 1,000 amps and over 1,500 volts.

4. Batteries have steadily improved since the 1970's with better chemistries. More energy storage options are available.

5. Costs are rapidly increasing for hydrocarbon fuels, and future supply is uncertain.

6. Local governments are mandating zero-emission vehicles in cities and restricting internal- combustion engine usage in the form of emission inspections and restrictions to idling truck engines.

7. Environmental issues just might overshadow everything else above with public awareness, and a desire to change.

The present wheelmotor design has evolved through six prototypes over the past twelve years. Just four years ago I had doubts that we could ever build a controller. The Electric Auto Association has been the driving impetus that energized this project to fulfill a college dream. It has been wonderful doing the experimenting. Now it is time to step up to some real work in making it go commercial. Feedback is welcome to victor@machinedyn.com or (505) 884-9005.

Figure 1

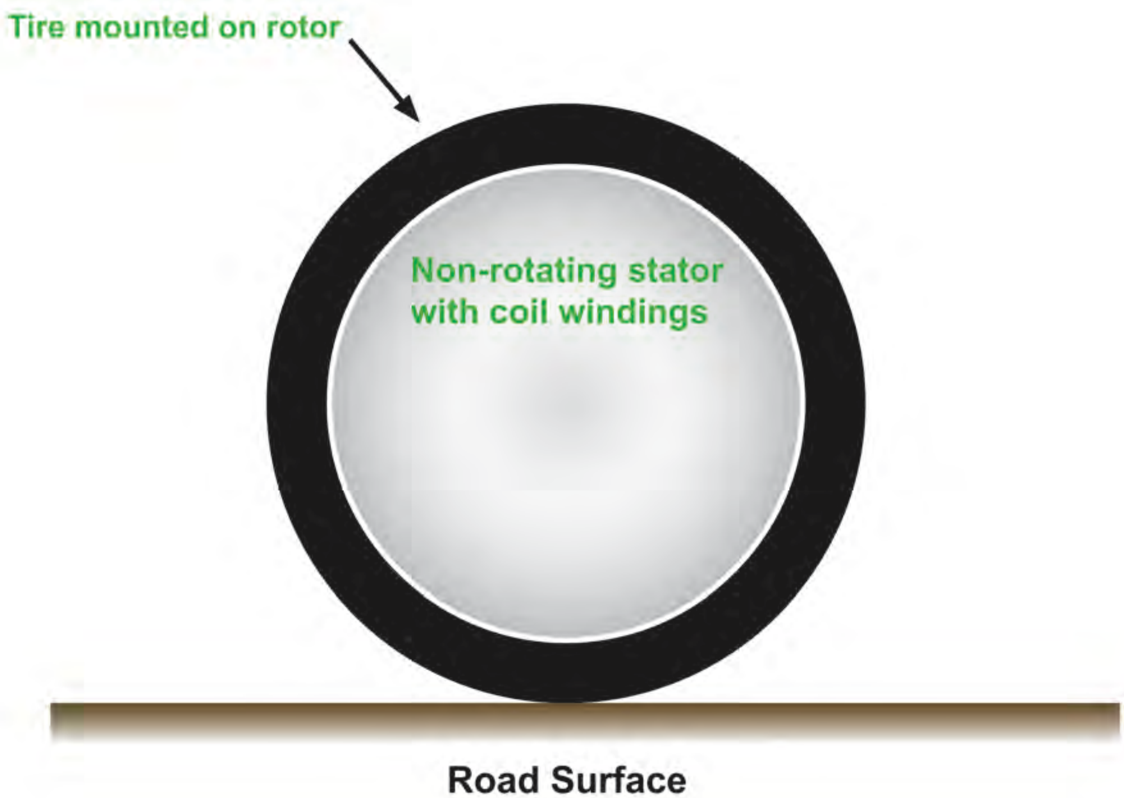
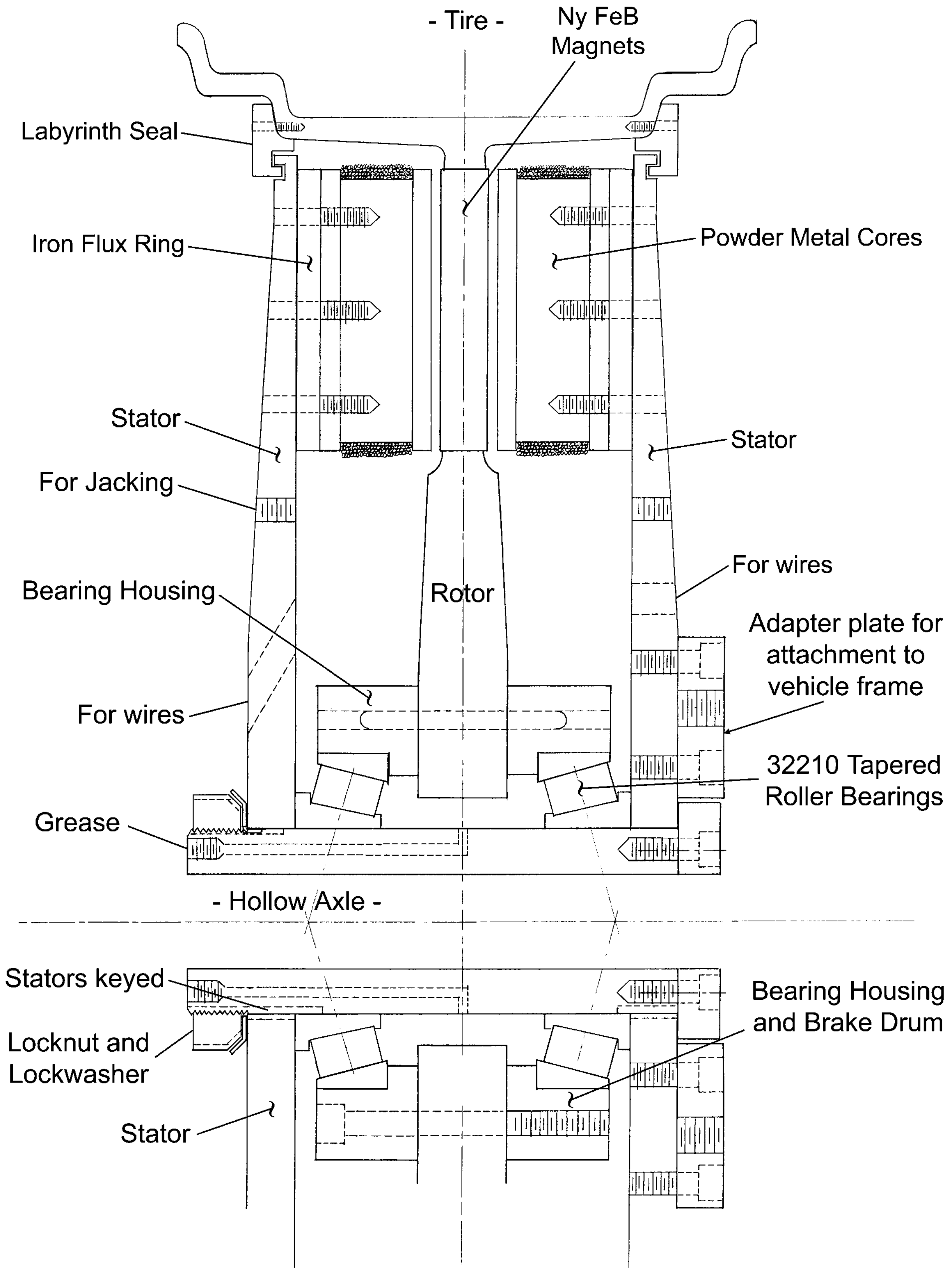

Tire mounted on rotor
Non-rotating stator
with coil windings
Road Surface

Figure 2



- Tire -
Ny FeB
Magnets
Labyrinth Seal
Iron Flux Ring
Powder Metal Cores
Stator
Stator
For Jacking
For wires
Bearing Housing
Rotor
Adapter plate for
attachment to
vehicle frame
For wires
32210 Tapered
Roller Bearings
Grease
- Hollow Axle -
Stators keyed
Bearing Housing
and Brake Drum
Locknut and
Lockwasher
Stator