AC PROPULSION INC.

A C - 100 ELECTRIC VEHICLE DRIVE SYSTEM

POWER ELECTRONICS UNIT

Includes 100 kVA PWM inverter, battery charging circuitry, controls, auxiliary 12 VDC power supply, and interfaces for control pedals and dash instruments. Environmentally rugged forced air-cooled design.

INDUCTION MOTOR

High efficiency, 4-pole, forced air-cooled

KEY FEATURES

HIGH PERFORMANCE

* 120 shaft horsepower at 6,000 to 10,000 rpm
* 110 ft-lb. torque at zero to 5,000 rpm
* Up to 85 ft-lb regenerative braking torque
* 170 lb. total weight (motor and electronics)

HIGH RATE, INTEGRATED RECHARGE

* Charge from any power source between 100 and 250 VAC
* Charge rate controllable from 200 W up to 20 kW (with 240 VAC line)
* Unity power factor, sine wave current draw
* Automatic mode switching (recharge mode automatically activated when charge power is connected

HIGH ENERGY EFFICIENCY

* 93% (battery-to-shaft) at 40 hp, 8,500 rpm
* 90% (battery-to-shaft) at 10 hp, 8,500 rpm

COMPLETE SAFETY FEATURES

* No exposed high voltage surfaces
* All control wiring is grounded, 12 V, or less
* Protection against overcurrent, overvoltage, and overtemperature conditions
* Battery is floating with respect to vehicle chassis
* Double-insulated motor
* Interlocks to prevent "unsafe" conditions

ADVANCED CONTROL CIRCUITRY

* Provides "glass smooth" torque under all torque and speed conditions
* Provides natural and transparent driving feel

LOW MAINTENANCE DESIGN

* Electronics unit is plug-out removable
* Rugged induction motor requires no regular maintenance

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Orders are currently being accepted and delivered for drivetrains and demo vehicles.

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THE AC - 100 DRIVE SYSTEM

The AC-100 enables new levels of performance for electric vehicles. Its features include advanced state-of-the-art design, high performances combined with high energy efficiency, smooth controllability, regenerative braking, unity power factor recharging, up to 100 A. of 13.8 VDC power for vehicle accessories, and numerous safety features.

The entire system weighs only 170 lb., yet produces more than three times the power of typical systems having the same weight (see Fig. 1 for torque and power vs. rpm). The combination of high power and high efficiency (over wide ranges of torque and rpm) allows the use of fixed-ratio gearing in place of a conventional transmission. This eliminates the losses, weight, cost, and acceleration discontinuities associated with transmission type drives. It also eliminates the possibility of motor overspeeding due to inadvertent down-shifting.

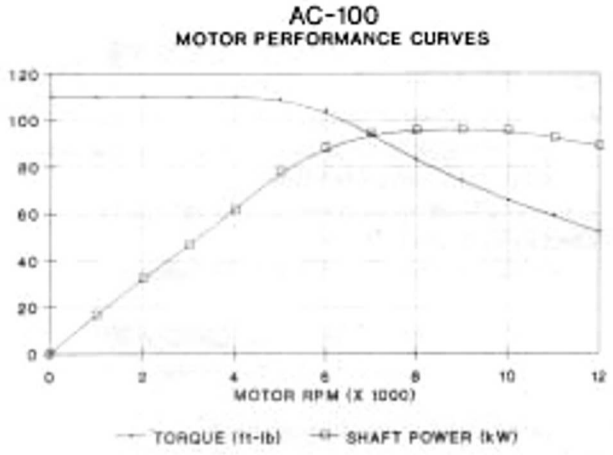

Fig. 1 - Torque and Power versus Speed

The AC-100, combined with presently available lead-acid batteries, allows exceptional acceleration, gradability, and range values to be obtained simultaneously for both conversion and "ground up" type vehicles (see Table 1).

Acceleration time to 60 mph:	**7.8 sec**
Range at 55 mph:	**131 mi**
Energy use at 60 mph:	**130 Wh/mi**
Gradability limit:	**45 %**
Recharge time for 50 miles at 60 mph:	**< 30 min**

Table 1 - Measured Performance Characteristics of a 1991 Honda CRX HF Powered by an AC-100, and using Lead-Acid Batteries

As well as being a high-performance drive system, the AC-100 is also a state-of-the-art battery charger. With a recharge capability up to 20 kW, the AC-100 eliminates the need for external chargers, typically weighing hundreds of pounds and costing thousands of dollars. Recharge can be obtained from virtually any 50 to 60 Hz power source between 100 and 250 VAC, while maintaining unity power factor. When installed in a vehicle such as the Honda CRX listed in Table 1, approximately 100 miles of driving range at 60 mph can be gained with a one-hour charge.

The AC-100 incorporates all the user interfaces. For example, brake lights are turned on during regenerative braking, back-up lights are turned on in reverse, a complete set of buffered, low voltage, ground-referenced signals are provided for vehicle dashboard instruments, and, there are various interlocks for operator safety.

Both the motor and electronics are designed to be environmentally rugged and easily maintained, and the controls are smooth and precise under all driving conditions.

RATIONALE BEHIND THE AC - 100 DESIGN

The AC-100 design builds on a combination of proprietary techniques enabling high power density, high energy efficiency, and inherent safety to be simultaneously achieved.

Induction Motor

While DC brushless and AC induction drives are both capable of achieving high power densities, the AC induction drive offers key advantages which are often overlooked.

Unlike the permanent magnet brushless approach, the induction drive allows motor magnetic flux to be controlled by the inverter. This "extra degree of freedom" enables the following benefits:

(1) Magnetic losses may be balanced against conduction losses. This enables improved part load efficiency, which is particularly important in high-performance systems with a large ratio between peak power and cruise load.

(2) Efficient operation above base speed is possible, as rpm are not constrained by voltage. The induction motor behaves like a variable ratio transmission, capable of delivering full power over a broad range of rpm; therefore, the need for a mechanical transmission is reduced while inverter utilization is increased.

The induction drive was also selected for improved ruggedness, lower material costs, and inherent safety: Motor emf goes to zero when excitation is removed, and disassembly is relatively hazard-free due to the lack of permanent magnets.

Fixed-Ratio Gearing

While the AC-100 can be used with a multi-ratio transmission for heavy vehicle applications, fixed-ratio gearing is appropriate for most applications below 4000 lb. gross vehicle weight. The advantages of fixed-ratio gearing include acceleration smoothness, enhanced regenerative braking utilization, substantially improved energy efficiency, and reduced gearbox cost, size and weight. Furthermore, with fixed-ratio gearing, two or more drive systems may be operated in tandem without problems of shift synchronization.

Integrated Battery Charger

The AC-100 utilizes a proprietary technique allowing drive system components to double as battery charger components. This saves cost and weight, while adding to system reliability.

Forced-Air Cooling

The AC-100 design implements forced-air cooling of both the electronics and motor using lightweight, low-cost components. A key point of the design is that environmental air does not flow past sensitive electronic and electrical components. For both safety and maintenance, the air-cooled design is superior to virtually any liquid-cooled approach.

Available Components and Processes

The AC-100 uses available, off-the-shelf components and standard fabrication techniques. As a result, volume production can be realized upon demand.

AC - 100 SPECIFICATIONS

SYSTEM (DRIVE MODE)

Nominal battery voltage:	336 V.
Minimum battery voltage:	240 V.
Maximum battery voltage:	420 V.
Maximum peak torque (< 5,000 rpm):	110 ft-lb.
Maximum shaft power (6,500 to 10,000 rpm):	120 hp
Maximum continuous shaft power (6,500 to 10,000 rpm):	60 hp
Maximum rpm:	12,000
Maximum regenerative torque*:	75 ft-lb

SYSTEM (RECHARGE MODE)

Minimum line voltage:	100 VAC
Maximum line voltage:	250 VAC
Maximum line draw:	100 A.
Recharge efficiency (240 VAC line, 10 kW):	> 90 %

POWER ELECTRONICS UNIT

Dimensions: (excluding blower, mounts, and connectors)	30.2" W. X 15.2" D. X 8.2" H.
Total weight:	70 lb.
Cooling:	Forced-air
Power terminations:	Aircraft style circular connectors
Control Connectors:	Miniature "D"
Inverter type:	Voltage-fed, MOSFET
Controls:	Current mode, sine-modulated
Control inputs:	Ground-referenced signals for key switch, accelerator pedal, regenerative sensitivity, forward, neutral, reverse, and recharge settings for line current and battery voltage
Instrumentation outputs:	Ground-referenced signals for battery voltage, battery current, motor temperature, line voltage, line current, and various LED status indicators
Maximum auxiliary supply current**:	100 A.

MOTOR

Dimensions:	12" dia. X 15" long (Max. dimension including cooling shroud, excluding blower)
Weight:	100 lb. (including shroud and blower)
Type:	Four-pole induction, high frequency design
Maximum rpm:	12,000
Insulation:	Class H, double-insulated
Cooling:	Forced-air
Sensors:	Winding temperature, tachometer

* May be adjusted to lower values by input command signal.
** Cooling fans share this power. Worst-case maximum current available is 60 A.

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AC PROPULSION
AUXILIARY PRODUCTS

PRECISION AMP-HOUR/WATT-HOUR METER

AC Propulsion has developed a compact, precision high-resolution amp-hour/watt-hour meter suitable as an in-vehicle engineering instrument. Included are four eight-digit displays corresponding to battery amp-hours charged and discharged and battery watt-hours charged and discharged. This instrument, designed for compatibility with the AC-100 instrumentation port, will enable amp-hour and watt-hour measurements which are typically accurate to within 1% and typically repeatable to within 0.1%. This product is particularly useful in determining battery coulombic and voltaic efficiencies, vehicle energy use and energy use sensitivity to drive system and road-load modifications.

BATTERY MONITOR AND CHARGE BALANCER

A second system is available which helps identify battery problems while enhancing battery "health". The system includes a compact LED dash display which identifies battery modules whose voltage is in excessive during recharge and defficient during discharge. The display also includes an analog meter which can suitably read any of the module voltages. All signals applied to the dash display are fully isolated from the battery to ensure safety.

A second function provided by the system is maintenance of charge-state equality between battery modules. During recharge, battery modules which are at higher charge states than the pack average may undergo over-charge and experience excessive terminal voltages. Under these conditions, the new system adds a discharge load to those (and only those) modules which are displaying excessive voltage. This, in turn, allows modules at lower states of charge to "catch up" as cycling continues. The net result is improved charge-state equality which in turn improves battery life and battery reliability.