THE ELECTRIC BICYCLE PROJECT INCLUDING AN INVESTIGATION OF HUMAN CYCLING PERFORMANCE

Deleted: Electrical Machines Committee¶
Industrial Power Conversion Systems Department

Deleted: Investigation of Interior Permanent Magnet Offset-Coupled Automotive Integrated Starter/GeneratorAlte

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Abstract

Lightweight Electric Vehicles offer cheap and clean alternatives to conventional vehicles for commuter and recreational applications.

This paper examines an alternative design for a front wheel, direct drive, 3-phase brushless d.c. hub motor. The motor, controller and battery systems were optimised using cyclist output power data from experimental results.

Peak power (for short bursts) as well as sustainable power data was collected from dynamometer and mobile tests. On board torque and speed sensors, interfaced to a computer data acquisition system displayed and logged the results.

The brushless dc motor is driven from a 3-phase mosfet bridge inverter and controlled by a PIC based microcontroller. Hall effect, brake and throttle position sensors provide rotor position and set speed information to the processor. Pulse Width Modulation is used to control power to the motor and regenerative braking improves overall efficiency.

This project is a culmination of final year student project work and post-graduate research.

The paper describes how to build a low cost electric bicycle using a washing machine motor core and an inexpensive PIC based micro-control system. It describes the data logging techniques and results, hub motor construction, as well as battery selection.

Introduction

Many modern cars are powered by 100 horsepower or greater, internal combustion engines with an efficiency of around 30%. These vehicles are consuming our fossil fuel reserves at an alarming rate and are the major contributor to urban congestion and atmospheric pollution.

One alternative to the car for commuter and recreational use is the electric bicycle.

Electric bicycles have been around for as long as automobiles (Humber electric bicycle 1898) [1]. Currently, the electric bicycle is experiencing a “coming of age” due to the development of lighter battery systems and efficient electric motors and drives.
Many new designs for electric bikes are emerging with a variety of different drive systems, including friction roller drive onto the tyre, separate chain and sprocket drives, toothed belt and pulley drives and gearboxes. Some direct drive and planetary gear hub motors were also reported [2].

Bicycle Power Requirements

An understanding of the power requirements of the motor and the battery capacity for the electric bicycle was gained by analyzing data logged on a bicycle dynamometer as well as from a mobile data acquisition system attached to the bicycle.

Dynamometer Test Bed

The dynamometer test bed shown in figure 1 used friction drive rollers beneath the bicycle tyres. These rollers drive a separately excited, 800 watt d.c. generator through a toothed belt and pulleys. Power from the d.c. generator is fed to a resistive load.

Figure 1. Dynamometer Test Bed

Figure 2. Torque Transducer

The strain gauge torque transducer shown in figure 2 runs on top of the bicycle chain and measures vertical force on the chain, giving pedaling torque data. Speed is given as a d.c. voltage from a tacho-generator at the wheel. Output power from the dynamometer is measured at the load using voltage and current sensors. Input power from the cyclist was measured from the wheel speed and pedal torque sensors.

Human input power and dynamometer output power information is displayed and recorded using a data acquisition system and desk-top computer.

Mobile Data Logging

Mobile data logging using a laptop computer and three channels of a data acquisition system logged pedaling torque, wheel speed and gear ratio to give cyclist input power.

Data Logging Test Results

Pedaling the dynamometer indoors introduced limitations for body heat dissipation and did not allow for the wind resistance losses. It therefore could not provide an accurate estimation for the bicycles power needs under varying terrain and wind conditions.

The stationary tests did however provide useful data on peak power capacity for various cyclists and also provided a platform to evaluate and test the bicycle, signal conditioning devices and data logging.

The mobile data logging system provided power input data for the bicycle under varying conditions and riders.

A comparison between an average cyclist using the dynamometer and an elite athlete competing in a one kilometre time trial [3] is shown in figure 3.

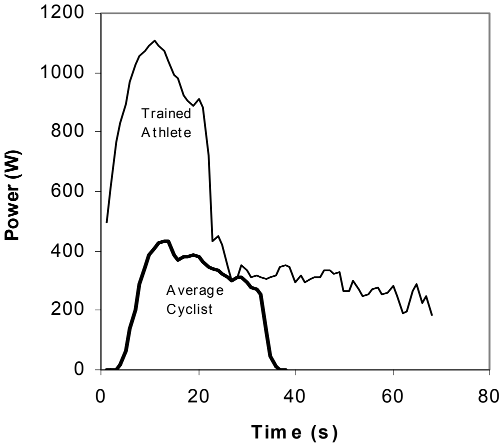

Figure 3. Peak output power of an athlete and an average cyclist.

The output power of a human cyclist for a short burst (less than 1 minute) as shown in

figure 3 is far greater than what is possible during a more sustained effort.
Other examples of human power capacity:

1. An athlete competing in a 25-kilometre bicycle race can sustain an average cycling power output of approximately 300 watts [3].
2. An average human's output power for a full day of cycling is less than 100 watts.

Hub Motor Development

A 3 phase, brushless d.c. direct drive motor was mounted into the front wheel of a bicycle. A custom-built wheel hub was produced from a single piece of large diameter aluminium alloy rod and spoked into a standard 26-inch bicycle rim. Figure 4 shows the machining of the aluminium hub.
The motor core is from a direct drive washing machine (Fisher and Paykel) and was fitted into the custom built hub. It has proved to be quite suitable for this application as the speed ranges and power ratings were very similar for both applications.

Figure 4. Machining Aluminium Billet

Figure 5. Front Wheel Hub Motor Components

Motor Control

Brushless d.c. motor commutation is achieved by sequentially switching pairs of semi-conductor power switching devices to control current to the motor windings. By using these switching devices instead of the traditional carbon brushes and copper commutators, greater efficiency is achieved as well as potential for far superior motor control.

A three phase "H-Bridge" inverter circuit was developed that uses 6 high efficiency power mosfet switching devices. These switches control the electrical current from the batteries to the 3 motor phases. The motor phases are "star connected", that is, one end of each winding is connected to a common point. Each of the free ends of the windings have two mosfet switches, one connected to ground, the other connected to positive power rail, see figure 7. It is essential that both high and low switches on any one phase must never be on at the same time, as a dead short would result.

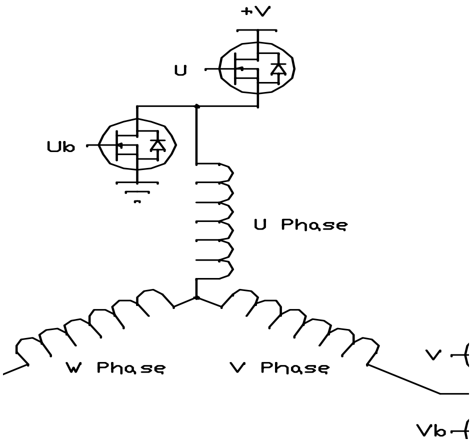

Figure 7. Motor Phases with Mosfets

The six semiconductor switches are controlled by a

microprocessor via optical isolation devices (for protection) and utilising a single chip for gating the high and low sides of the inverter.
Timing information is necessary to ensure that the three phase power applied to the stator windings is synchronized with the permanent magnet rotor position. This timing information is provided by three “hall effect” position sensors. The sensors are set either high or low (5V or 0V) depending on which magnetic pole is adjacent it at the time. Thus a 3-bit signal from the 3 sensors provides rotor position information to the controller.

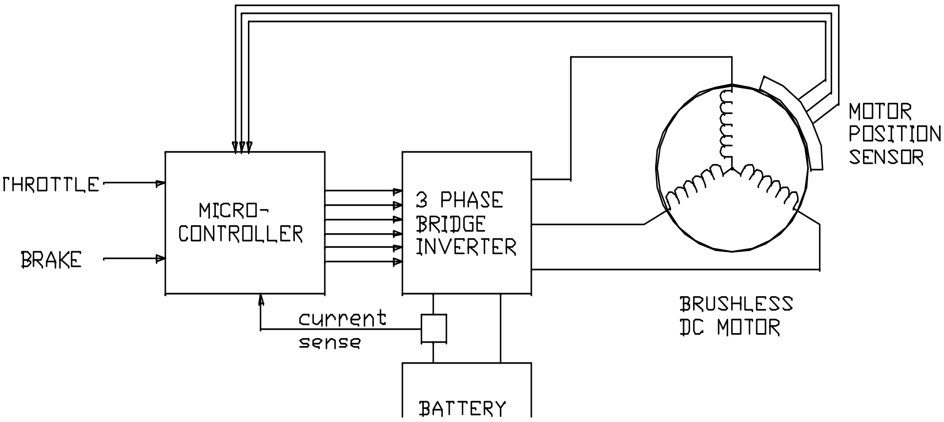

Figure 8. Complete Motor Control System

Microprocessor

A Microchip PIC16F877A, 8-bit (14-bit Core), 20 MHz microcontroller is at the heart of the controller. This 40-pin chip has 33 input/output pins including 8 analog-to-digital inputs [4]. Three of the pins are used as inputs for the hall effect motor position sensors, 6 of the pins are configured as outputs to drive the 6 power switching devices. Throttle position, braking level and a supply current sensor occupy 3 of the analog inputs. This chip has plenty of spare pins and unused memory space that can be used for future expansion of the controller capabilities to include more features and options.

Programming the PIC

The necessary programming tools are all freely available from the Microchip web site along with some useful application notes. Third party compilers, many with free evaluation versions can be found on the web and allow code development in other programming languages including C.

Battery Selection

Sealed Lead Acid, Nickel Cadmium, Nickel Metal Hydride and Lithium Ion batteries were all considered for the electric bicycle.

Cost, capacity, energy density, discharge rates, charge rates, self-discharge rates, life expectancy, charging efficiency and toxicity are all factors in the selection process.
It is important that the battery capacity (Amp-Hour rating) needs to be high enough to allow for a reasonable driving range as well as supply enough current under peak loads.

Lithium Ion Cells have the highest energy density but are more expensive and require precise battery management to avoid damage.

Sealed Lead Acid Batteries are the least expensive and offer high charging efficiency but have lower energy density, longer recharge times and suffer when deep discharges occur.

Nickel Cadmium Cells offer fast charging and discharging, are very robust and have a high energy density but contain toxic material and suffer a moderate self-discharge over time.

Nickel Metal Hydride Cells have a higher energy density than Nickel Cadmium and are not toxic but the self-discharge rate is higher and maximum discharge rate lower.

The actual riding conditions (gradients, range etc.) also affect the final choice of battery type and capacity.

Conclusions

The initial measurements indicate that the power requirements for the electric bicycle to perform as well as a healthy non-athlete over a short commute are in the order of 200 watts continuous and 450 watts peak.

For an average commute of 20 minutes each way in light to moderate conditions approximately 160 watt-hours of usable battery capacity is required. The required capacity can be reduced or the range extended when the rider input is added.

The direct drive, front wheel, brushless d.c. hub motor offers a simple, efficient and quiet means of propulsion that can easily be fitted to a conventional bicycle.

Finally, the electric bicycle project has shown a viable, low cost alternative to the automobile for errands, daily commutes and recreational purposes.

References

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[2]. E. M. Odom and D. Gerbus, Optimal Design of Hybrid Electric-Human Powered Lightweight Transportation, Final Report (KLK320, KLK321, NIATT, No. 1 – 12), National Institute of Advanced Transportation Technology, University of Idaho, July 2001.
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[4]. Microchip PIC16F877 Data Sheets.

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School of Civil and Environmental Engineering, University of Adelaide:
- Data Logging System

Volunteer Cyclists:
- Cycling Performance Data

Student Project Work:
- Development of Dynamometer Sensors and Signal Conditioning Devices
- Development and Calibration of Torque and Speed Transducers
- 3 Phase Bridge Inverter and Interface Development