Prospects for the application of fuel cells in electric vehicles

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Abstract

For a hybrid vehicle the use pattern has large effect on the vehicle design. If the vehicle is to be used extensively on the motorway then a continuous high power is required. For the case of a fuel cell battery hybrid vehicle this would require a large fuel cell (>30 kW) to meet the sustained high power demand. The current high materials and fabrication cost of most fuel cells prohibits the commercial development of such a system. Consequently if fuel cell vehicles are to enter a 'clean car' market, earlier rather than later, alternative configurations must be sought and compromises in terms of performance are inevitable.

Introduction

A low power fuel cell (3 → 10 kW) coupled with methanol fuel processing equipment and batteries weighing between 150 and 200 kg can satisfy most urban driving patterns and provide a similar level of performance to a conventional vehicle. Limitations are experienced with high speed driving (>100 kph) when the distance travelled is greater than about 100 km.

The work presented here describes a relatively low cost solid polymer fuel cell (SPFC)/battery hybrid which will serve as a commuter car. The design utilises the fuel cell as an onboard recharging system. The range of such a vehicle is determined by the configuration of fuel cell power and battery 'size' to a point where the quantity of primary fuel carried becomes the limiting factor. The hydrogen demand for the fuel cell can be met by either the reformation of methanol or direct from hydride storage. For example with a 45 l capacity methanol tank (and reformer operating at 70% efficiency) the range would be 300–400 km on mixed town and country driving. For the ECE 1504 drive cycle the range would be over 500 km. The emissions for such a vehicle would be about a 50% reduction in CO_2 compared to an IC engine vehicle; with less than 0.002 g/km of HC and less than 0.004 g/km NO_x [1]. The emission of CO is dependent on the reformer design but projected targets are around 100 ppm [2].

If hydrogen, stored as metal hydride, were to be used then emissions of CO_2 for the vehicle would be zero but the range, assuming a 280 kg hydride storage vessel,

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would be reduced to 50% of the 45 l methanol system. The hydride vehicle would weigh approximately 200 kg more than the methanol vehicle and would have a range of about 250 km, around the ECE 1504 cycle, compared to 500 km for the methanol fueled vehicle. The refueling process would be of the order of 8 min [3]. This consequently offers virtually a 'zero emission vehicle'.

Fuel cell

The design is based on a 60 cell stack with a 140 cm^2 per cell working area. With a working potential of 0.75 V per cell at 0.6 A a stack efficiency of approximately 50% sould be obtained. Figure 1 shows an example of a single cell capable of producing 20 A. These figures are based on previous work at Loughborough [4, 5] using stack and reformer weights estimated at 10 kg/kW. This value includes all associated component parts. Current densities in excess of 0.6 A/cm^2 at 0.75 V have been demonstrated using Nafion™ 117 with platinum loadings of 0.45 mg/cm^2 using oxygen and hydrogen [6]. It is assumed therefore that 0.6 A/cm^2 at 0.75 V should be obtainable, with 3 mg/cm^2 on reformate and air. As better membranes become available [7] then higher voltage operation will be obtained resulting in improved efficiency (i.e. $>50\%$).

Reformer

Exact figures on the reformer are difficult to estimate but providing some use can be made of waste heat an efficiency of $60 \rightarrow 90\%$ [8] should be achieved. For this design of hybrid a figure of 70% was taken as an appropriate value. The reformer would use a partial oxidation and shift reaction method to produce the carbon dioxide/hydrogen gas stream [9]. Any carbon monoxide in the stream will be removed by the introduction of a small amount of air into the hydrogen side of the fuel cell causing preferential oxidation of the CO [10].

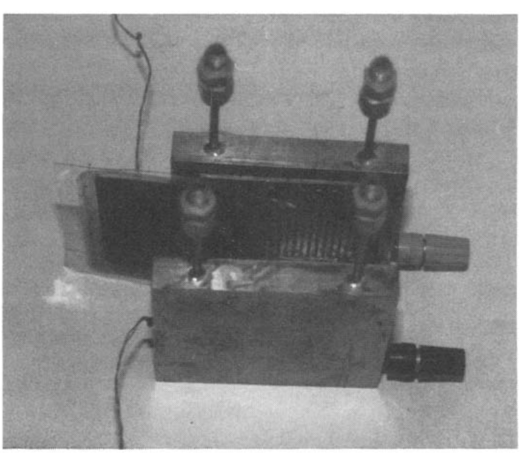

Fig. 1. Single cell.

Hydride hydrogen storage

A titanium–ferro–vanadium–manganese hydride storage system weighing 280 kg [3] has been assumed in this study. This will store approximately 90 kW h of energy (320 W h/kg) whereas 45 l of methanol provides 178 kW h of hydrogen energy when taking reformer efficiency into account. The hydrogen can be supplied to the refuelling stations in many forms. For example reformers could be installed at the stations to convert natural gas or bio gas to hydrogen or electrolysers could be employed which are powered by any available electrical supply.

Vehicle design

In selection of the components for the proposed vehicle we have, as far as possible, used those which are readily available. The battery specification, for example, is taken from SAFT STM 6V monoblock (STM 5.200). The quoted specific energy for this is 56 W h/kg for a 3 h discharge. This figure has been derated to 50 W h/kg to allow for aging.

The specifications of the components parts are:

Battery

SAFT nickel–cadmium accumulator
STM 5.200 (50)* 56 W h/kg (3 h discharge)
200 W/kg for 15 s, 50% discharge
Efficiency 70%
Life span cycles 1600 to 80% DOD
(should give life of > 5 years on test routes studied)

Motor and Controller

Data taken for unique mobility motor and controller 50 kW peak power [11]
Motor efficiency taken from contour plots typical values 90% at 1000 rpm and 2 kW and 95% at > 4000 rpm and 25 kW
Controller efficiency calculated from contour plots [11] typical values
@ 3750 rpm and 60% load the efficiency is 96.5%
@ 7500 rpm and full load the efficiency is 98%

The primary characteristics used for the simulation study are:

Bare vehicle weight	670 kg
Controller weight	20 kg
Motor weight	16 kg
Pay load	80 kg
Cd	0.34

Trade off study

From a study carried out in the USA [12] the average range requirement per day is less than 100 miles (161 km) for 90% of drivers who live in metropolitan areas for 95% of the time. These figures may not be particularly accurate for the European

*Values used in simulation.

situation but for the purpose of this study the vehicle target market would be a privately owned, second vehicle.

The fuel cell on this vehicle would not require a fast start-up and would run at almost constant load. During any particular day the fuel must provide all of the energy used by the vehicle. As a minimum requirement a low power cell can be used to replenish the batteries over a relatively long time period. For example if in a particular day the car is used for 2 h with an average power requirement of 7 kW (typical mixed driving average power demand) then 14 kW h must be generated within a 24 h period requiring a fuel cell power output of less than 600 W.

However, this means that during a particular journey virtually all of the energy has to be provided by the battery and that the recharge time may be many hours. Increasing the fuel cell size reduces the recharge time and the continuous driving range is increased; a point is reached when there is no significant advantage in increasing the fuel cell size further.

Vehicle simulation

The data for the simulation program was obtained by instrumenting an IC engine vehicle and measuring the speed and distance travelled. For this simulation study no regenerative braking was included. The data was collected at 6 Hz but averaged every 2 s during the time when the ignition was turned on.

This method results in a simulation vehicle which closely matches the performance of the IC engined test vehicle; in this case a 1300 cc Ford Escort. Figure 2 shows the general layout used for the vehicle simulation study.

Results

Figure 3 shows the range that can be achieved at constant speed on flat ground. At low speed the range is limited by the low efficiency of the motor and controller (a fixed gear ratio has been assumed). When a point is reached where more power

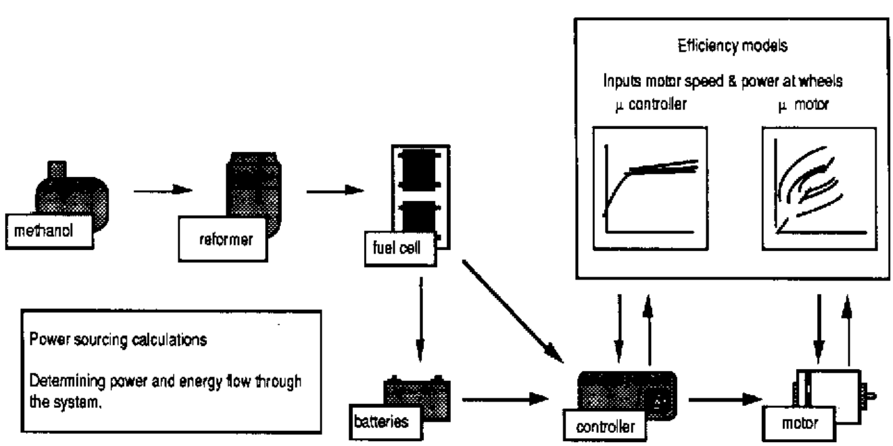

Fig. 2. Basic layouts used in simulation.

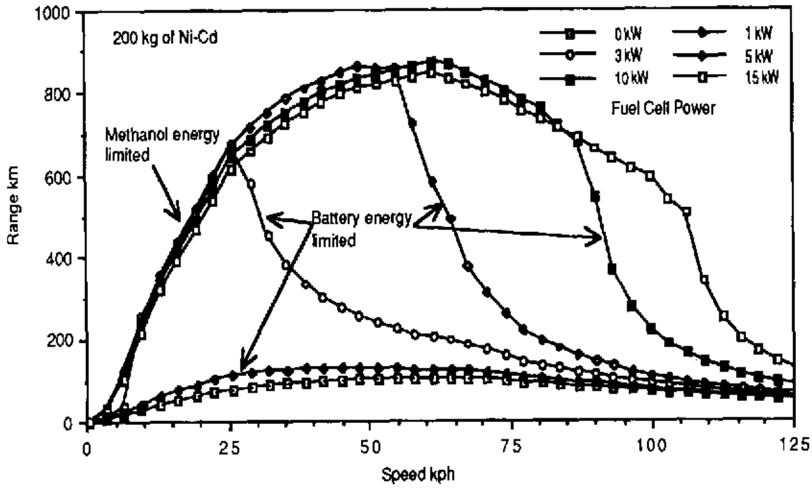

Fig. 3. Range at constant speed.

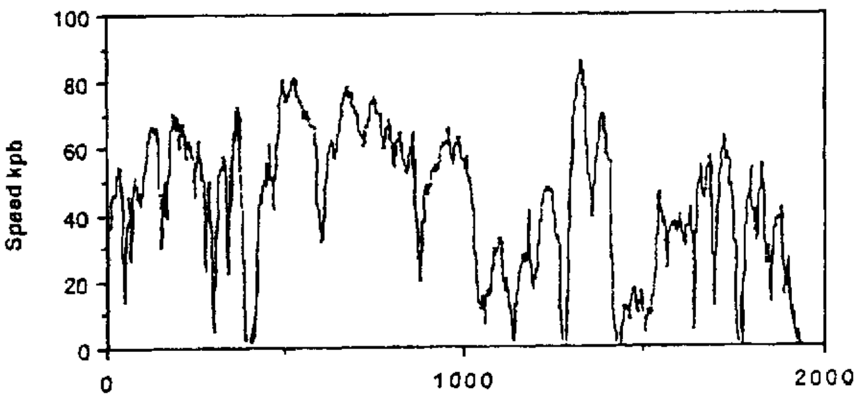

Fig. 4. Portion of drive profile (Loughborough to Nottingham).

is required than the fuel cell can provide the range begins to reduce because the batteries are being used to supplement the power demand.

For normal driving patterns the results are presented as a range based on the performance on a single journey. The characteristics of the journey were not based on any statistical driving pattern, but were chosen to represent typical speeds and distances.

The characteristics of the journeys are:

Loughborough to Nottingham	start at 07:30
Average speed	43.55 kph
Maximum speed	88.0 kph
Journey time	1936.0 s
Distance	23.42 km

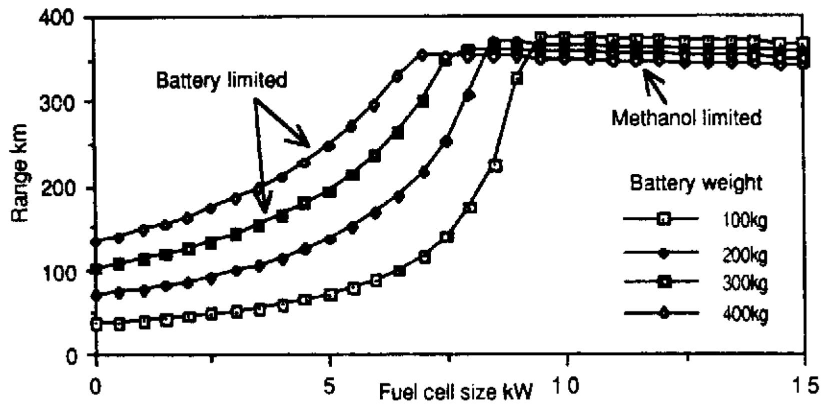

Fig. 5. Range for continuous driving.

The results (Fig. 5) represent the range of the hybrid vehicle, running on methanol, during continuous driving, for mixed town/country (as in Fig. 4). It is clear that significant range extension is achieved for fuel cell powers above 3 kW and range is only limited by the amount of methanol for fuel cell power above about 8 kW.

For actual daily use a smaller sized fuel cell is acceptable, i.e. the batteries partly discharge during driving and only are fully recharged when the vehicle is parked. For ranges on hydride stored hydrogen the range is reduced by a factor of approximately 0.5.

Conclusions

The combination of a small sized solid polymer fuel cell (8 kW) and 200 kg of nickel–cadmium batteries, will power a vehicle capable of seating four passengers, with a range in excess of 400 km at 65 kph. During normal town and country driving the range will be reduced to about 200 km. The 200 km drive can be repeated after a stationary period of about 5 h. The emissions of NO_x, HC and CO are extremely low and CO_2 emissions are about half that of a IC engine powered vehicle. If hydrogen is used as the primary fuel then the range is reduced to 50% of that of methanol but emissions of HC, CO, NO_x and CO_2 are virtually zero.

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