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# Development of a high-performance lead–acid battery for new-generation vehicles

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**Abstract**

The ultimate objective of this project is to demonstrate that a valve-regulated lead–acid battery of dual-tab design can be successfully substituted for the nickel−metal hydride battery pack in a Honda *Insight* hybrid electric vehicle. While the realization of the construction of the battery modules, the battery management system and the associated software has been more complex and time-consuming than was originally envisaged, the battery has now been fitted into the vehicle. With the initial system integration work now complete, the project plan is to test the vehicle with its lead–acid battery for up to 50,000 miles over a combination of the high speed, hill and urban circuits at the Millbrook Proving Grounds in the UK, as well as in general road driving. Prior to this, the developmental battery will have new cells fitted because of the uncertain cycling history of the original cells during the prolonged development period.


*Keywords:* Dual-tab; Honda *Insight*; Hybrid electric vehicle; Lead–acid battery; Valve-regulated

## 1. Introduction

The Honda *Insight* is a very fuel-efficient hybrid electric vehicle (HEV) but is currently powered by an expensive 144-V, 6.5-Ah nickel−metal hydride (Ni−MH) battery. The purpose of the RHOLAB Project [1] is to develop a much cheaper lead–acid battery to replace the Ni−MH battery in the demonstration vehicle and thus make this type of vehicle more affordable in the market place. As well as demonstrating the ability to meet the power requirements of the HEV application, it is also necessary to achieve an acceptable life under this demanding duty cycle. The first stages of the project have been reported in an earlier paper [1].

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## 2. Project progress

### 2.1. Preparation of vehicle for the lead–acid battery

The Honda *Insight* that was acquired as a test-bed for the lead–acid battery has been benchmark tested with its Ni−MH pack over 5000 miles at the Millbrook Proving Grounds in the UK [1]. The Ni–MH battery was then removed and tested for comparison with the RHOLAB cell pack. Meanwhile, the rear of the car was prepared for installation of the lead–acid battery. The dual-tab lead-acid module is slightly longer than that of the original-equipment battery and this required a modification to the battery support frame in the Honda. The various stages in the preparation of the car are shown in Figs. 1–4. The four modules sit side-by-side in the same location as occupied by the Ni−MH battery. At the rear of each module can be seen (Fig. 4), the cooling fans that draw air from the passenger cabin through the component cells, as in the original vehicle.

Fig. 1. Rear of *Insight* with Ni–MH battery and motor control module removed.

Fig. 2. Support frame for the lead–acid battery.

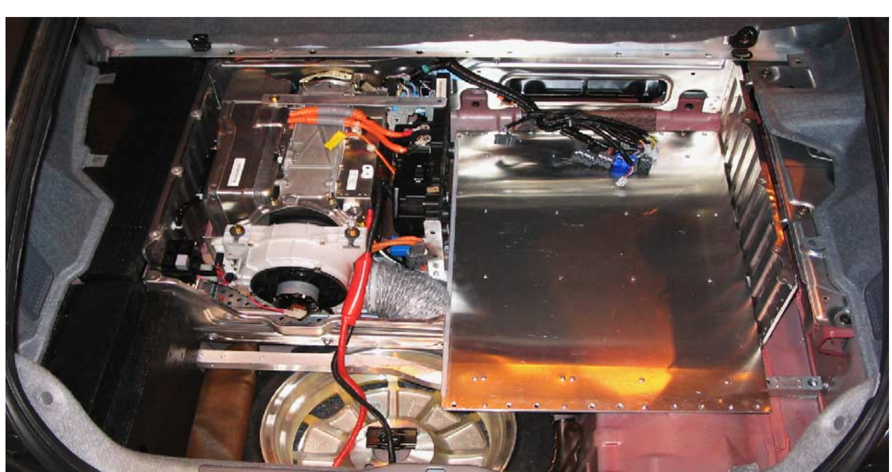

Fig. 3. Motor control module re-fitted with the new battery tray.

Fig. 4. RHOLAB lead–acid battery in position.

### 2.2. In-vehicle testing of RHOLAB battery pack

After fitting the battery, the data-logger was installed above the battery and, for convenience during testing, the electrical control unit and battery management system were placed above the Honda motor control unit on the left-hand side, as is seen in Fig. 5. The protective covers will be re-fitted once the initial proving trials are complete.

The RHOLAB *Insight* under test in the UK is shown in Fig. 6. These latter stages of the project have been subject to lengthy delays due to various software issues with the battery management system and, subsequently, to issues with integrating the battery with the vehicle. Typical of such problems is illustrated by the data presented in Fig. 7.

After installing the lead–acid battery, it was found that a diagnostic trouble code was issued by the Honda motor control module (MCM) in response to an unspecified voltage problem. This caused the integrated motor assist (IMA) to cut out and prevented any significant driving as it occurred very early after start-up. The reasons were very difficult to track down as there is limited information available from the Honda documentation. Some software modifications

Fig. 5. Data logger and system controls in position.


Fig. 6. RHOLAB *Insight* under road test with its lead–acid battery.

were made and it was then possible to run the car using the IMA system for 3 min without a single MCM fault, as illustrated in Fig. 8. The car was then driven using both the power-assist and the regenerative-braking modes with the levels being increased until the same voltage error was reached. Following an extensive number of trials, the whole system has become much more robust as demonstrated by data collected from a 30-min road test (Figs. 9–13). It is interesting to note that two stop−start events are recorded, i.e., the two zero-speed occurrences in Fig. 11. These can be equated with the zero engine rpm recorded in Fig. 13. This shows that the Honda systems are operating normally and that the new battery is capable of providing the instant starts required under such circumstances. Other information

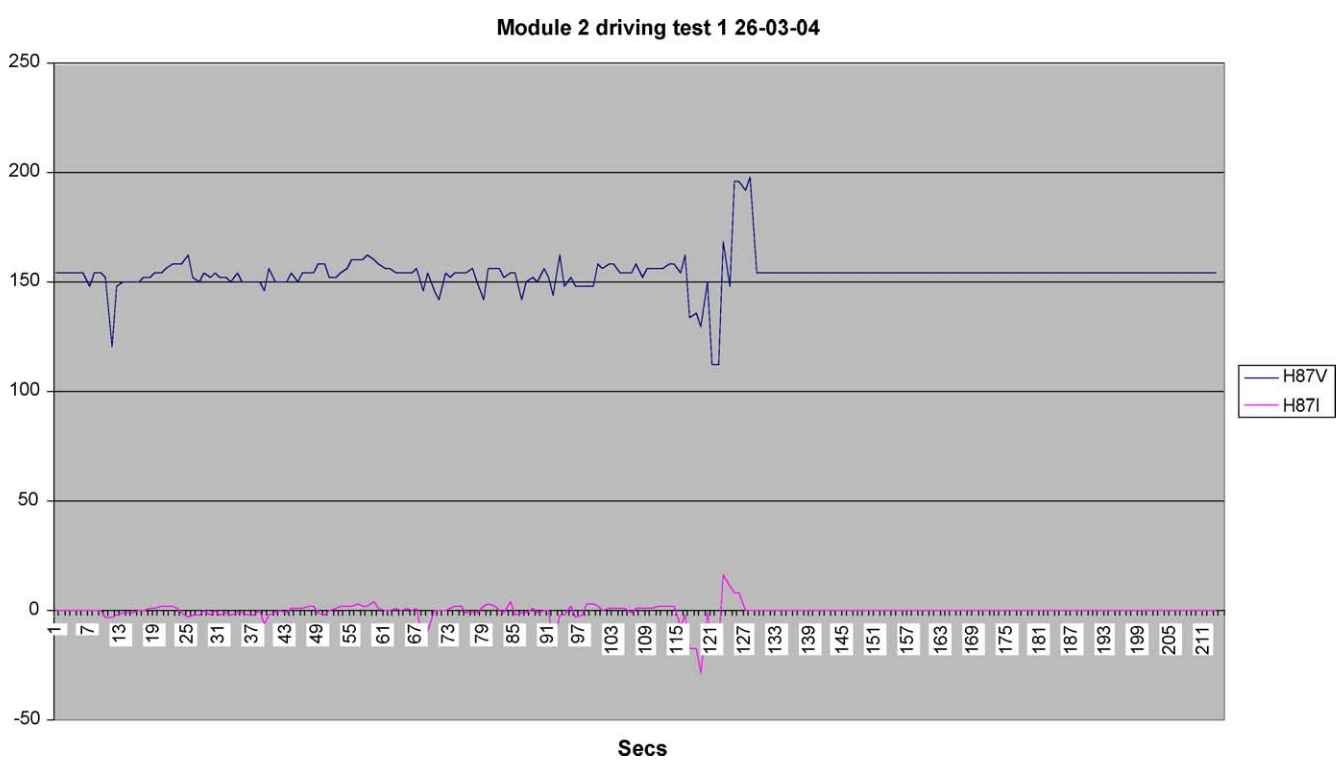


Fig. 7. Voltage-related problem causing the IMA to cut out.

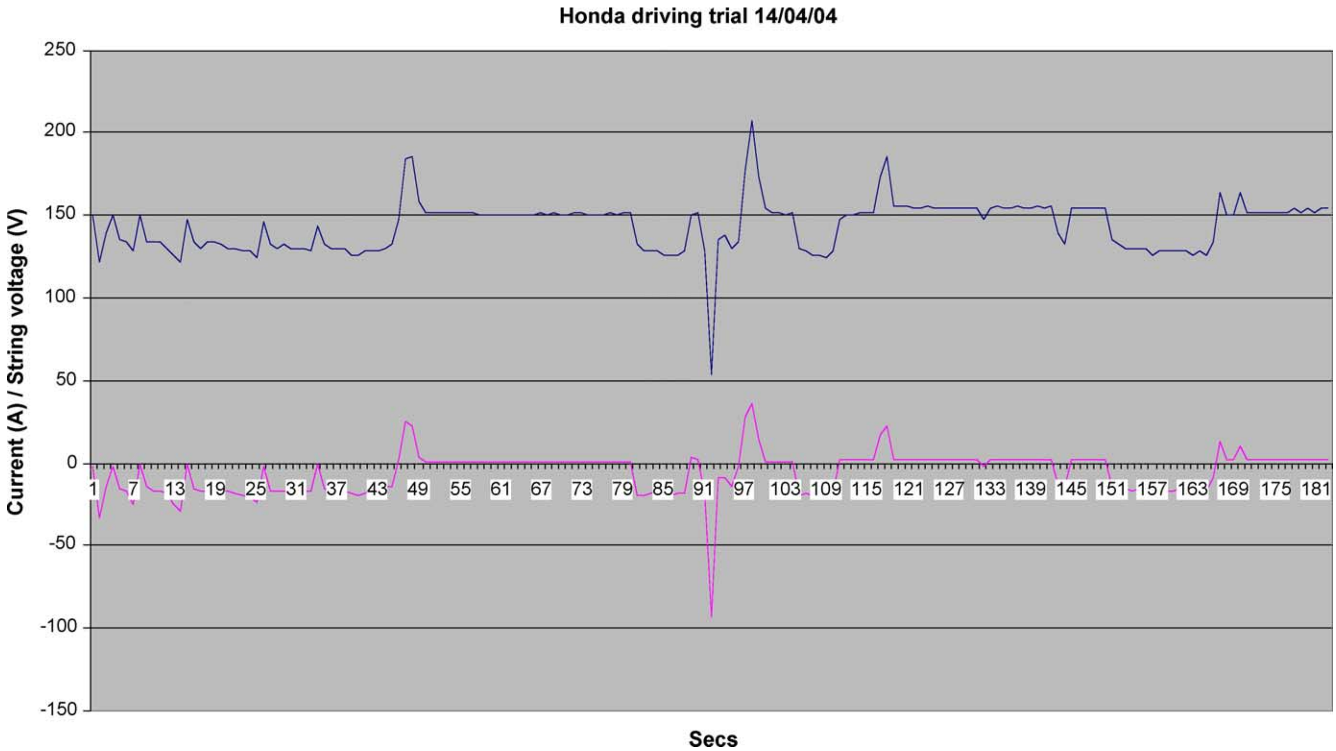


Fig. 8. Three-minute driving trial without IMA problems.

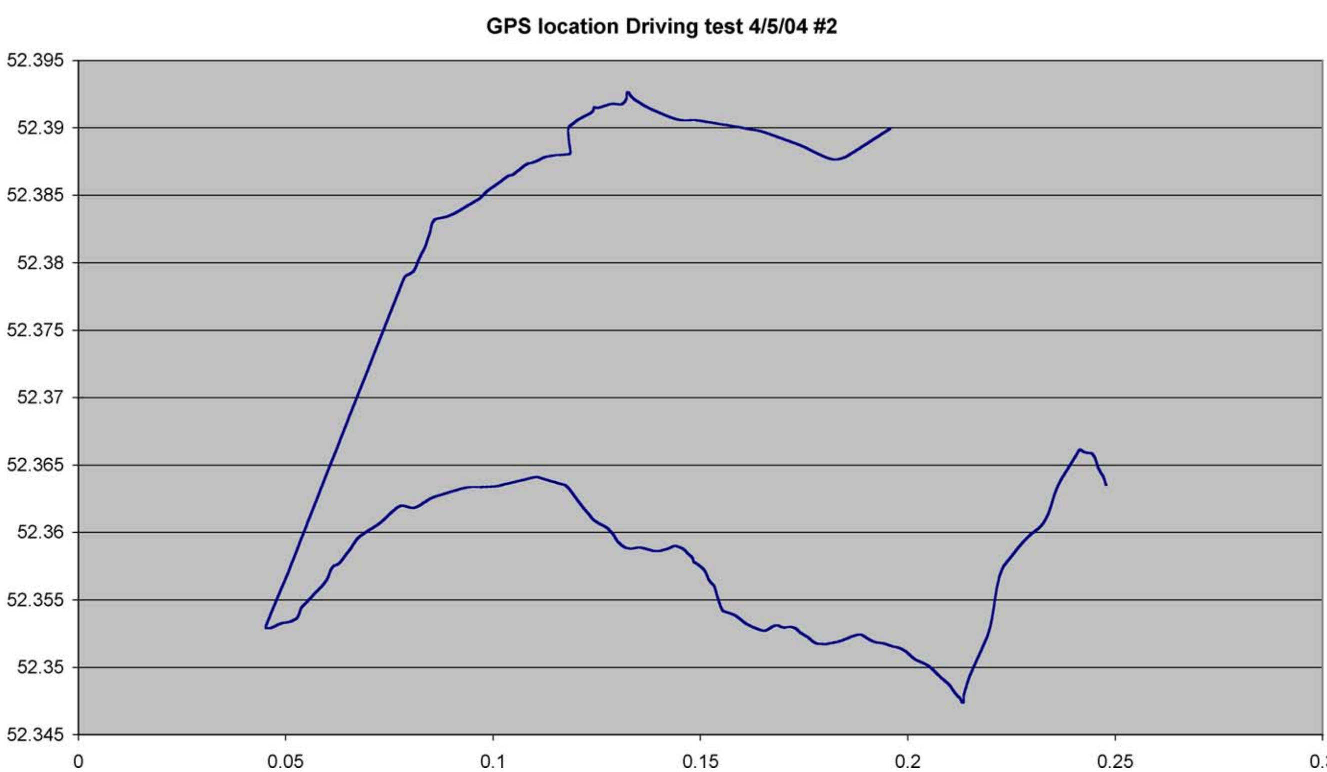


Fig. 9. GPS plot of road test with lead–acid battery.

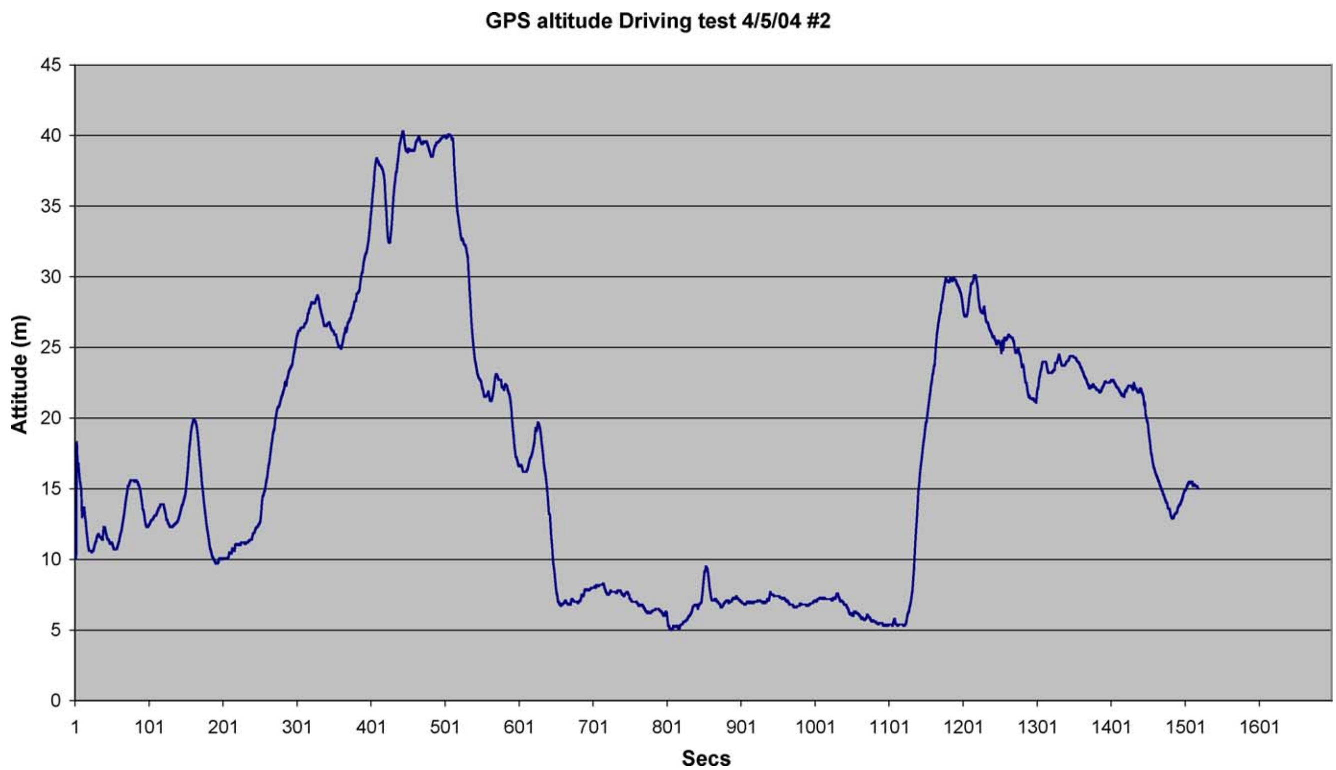


Fig. 10. GPS plot showing altitude during road test.

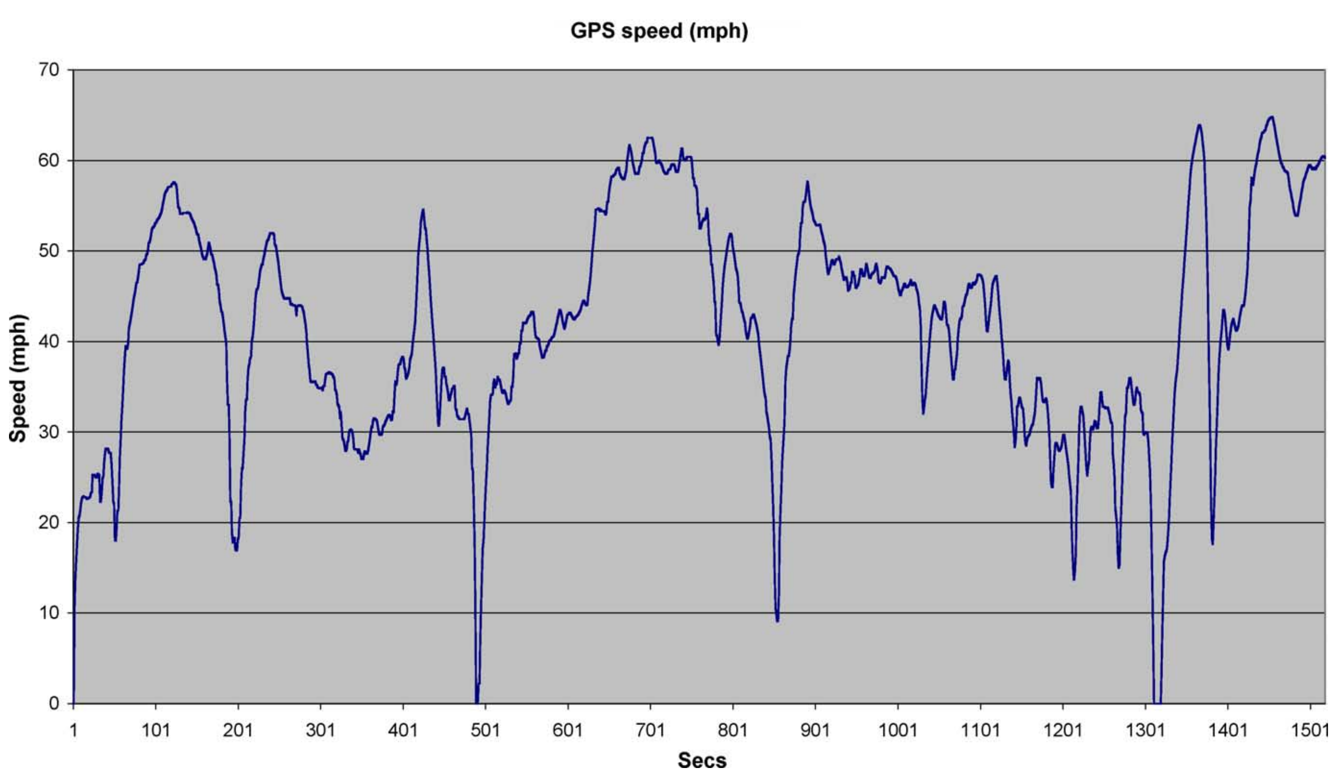


Fig. 11. GPS record of speed data during road test.

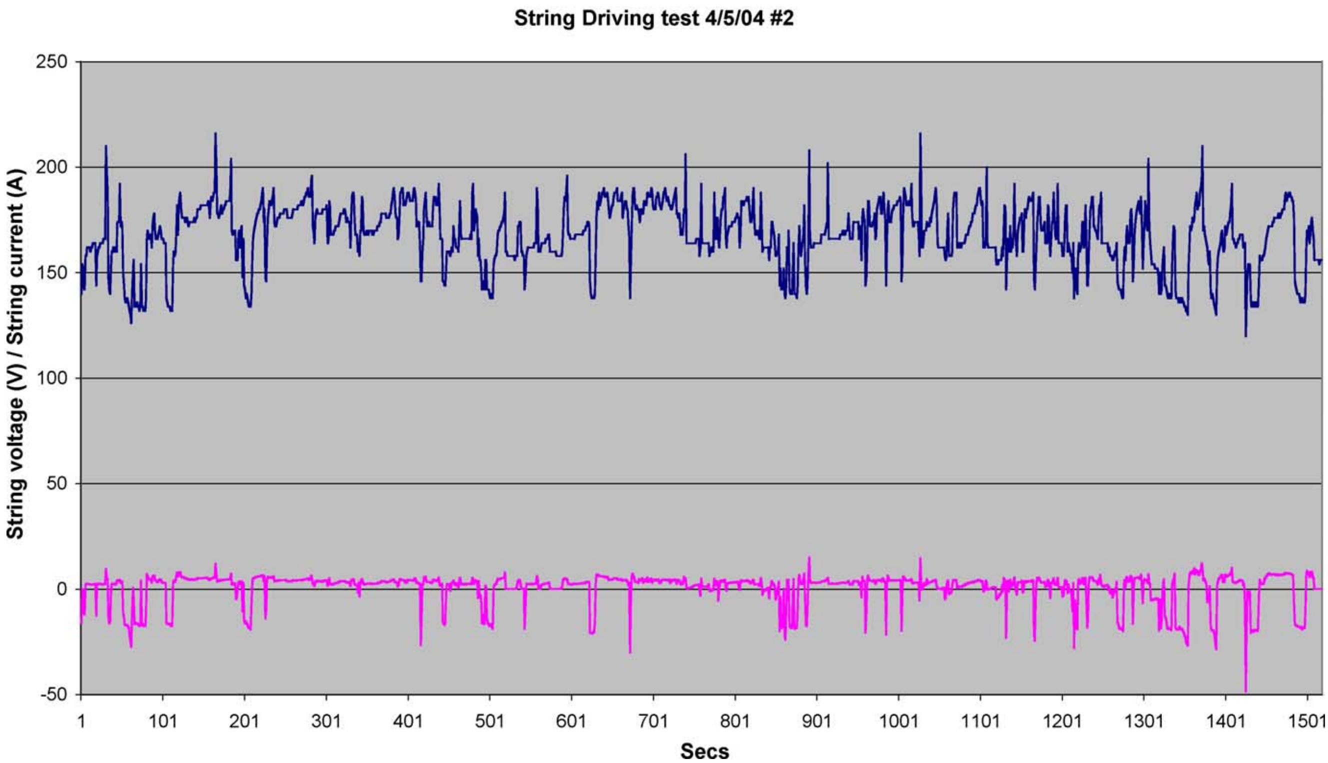


Fig. 12. Battery voltage and current recorded during test.

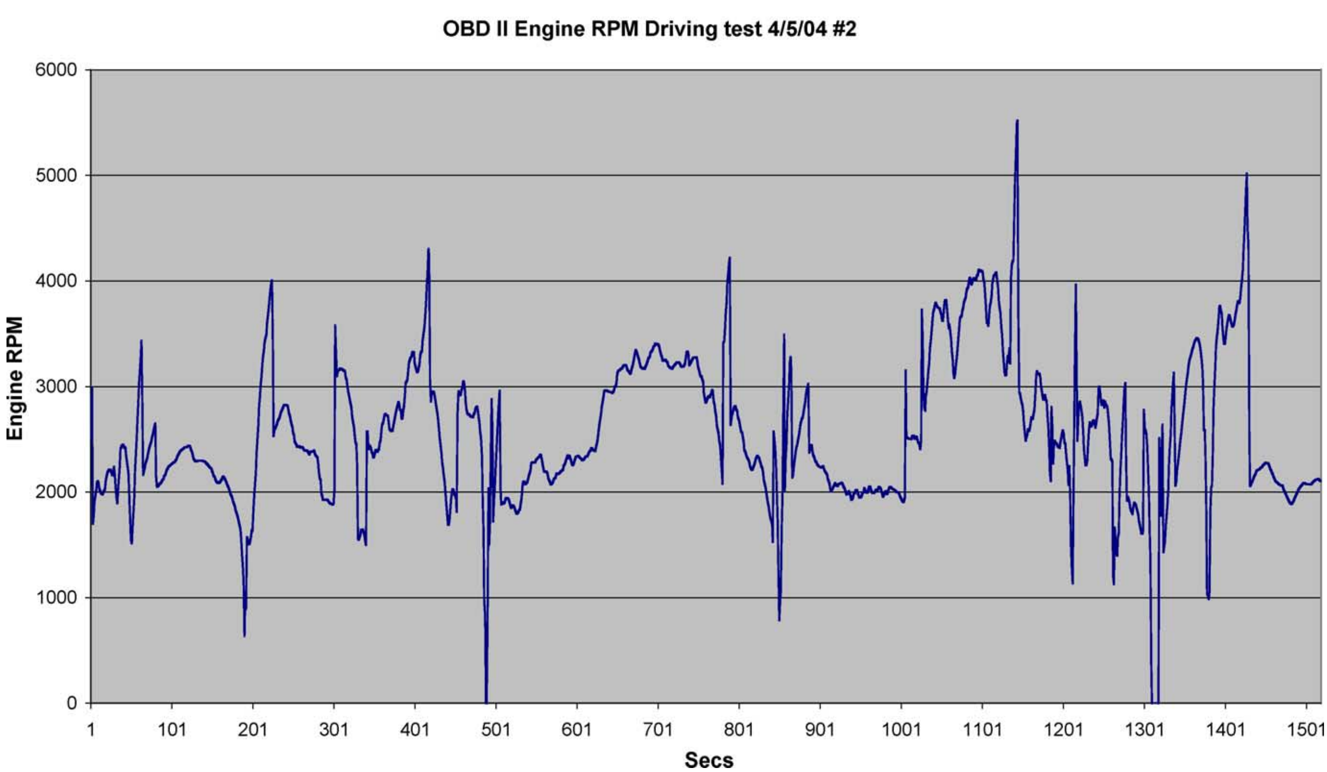


Fig. 13. Engine rpm logged from OBD II port.

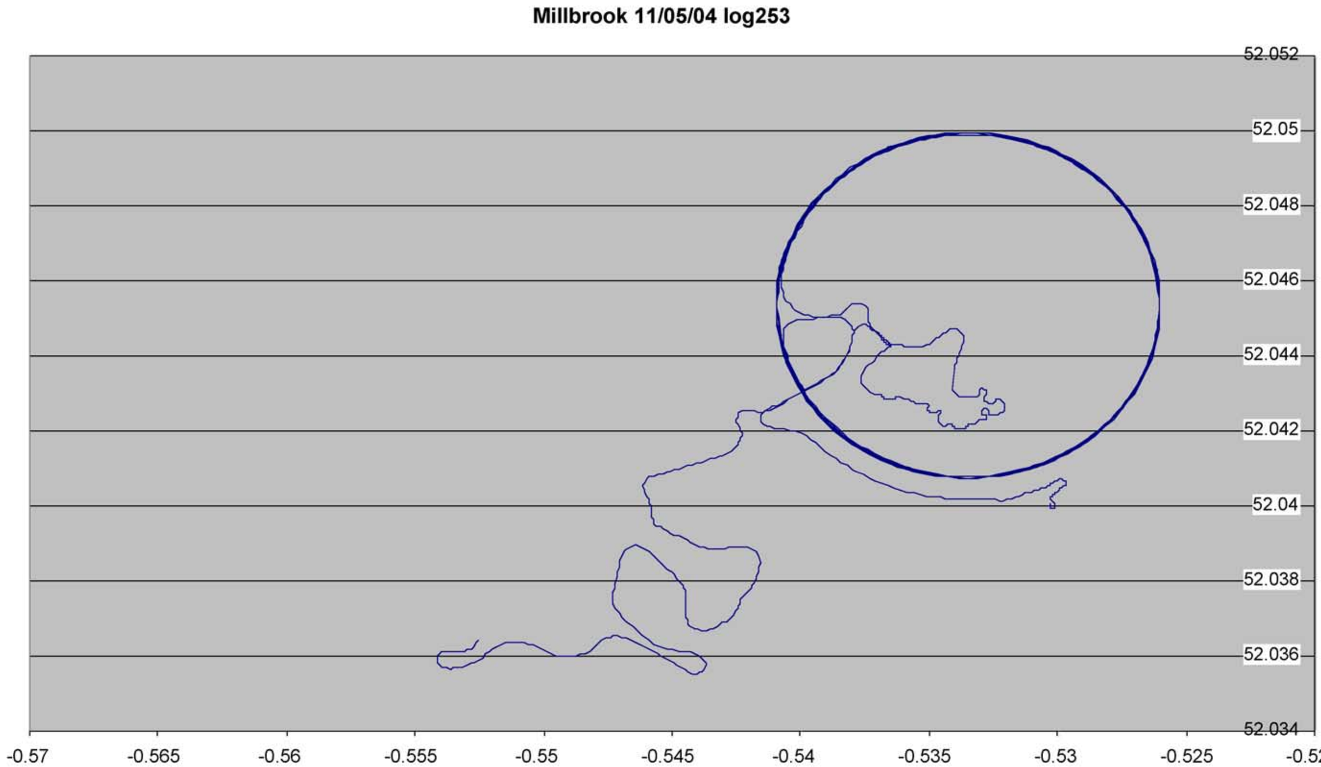


Fig. 14. GPS plot of trial run on various Millbrook circuits.

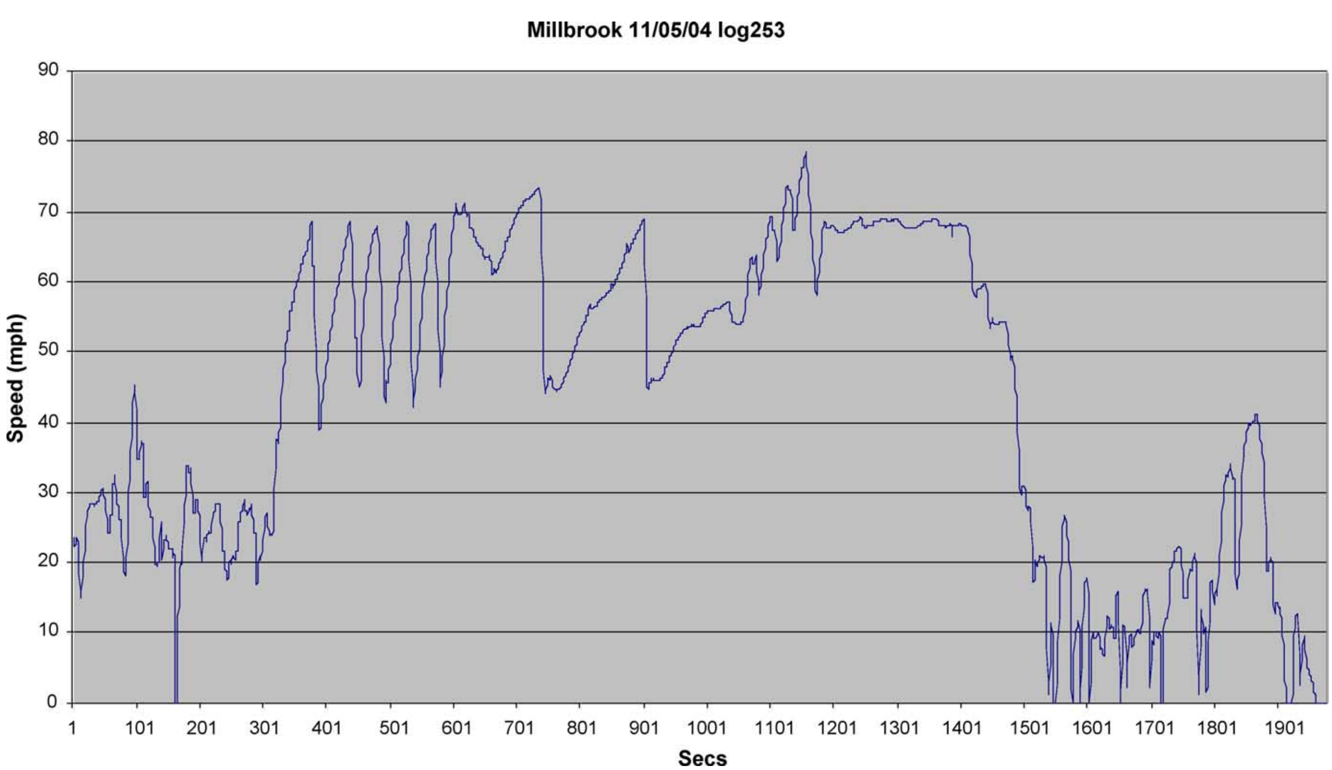


Fig. 15. GPS speed data from Millbrook test.

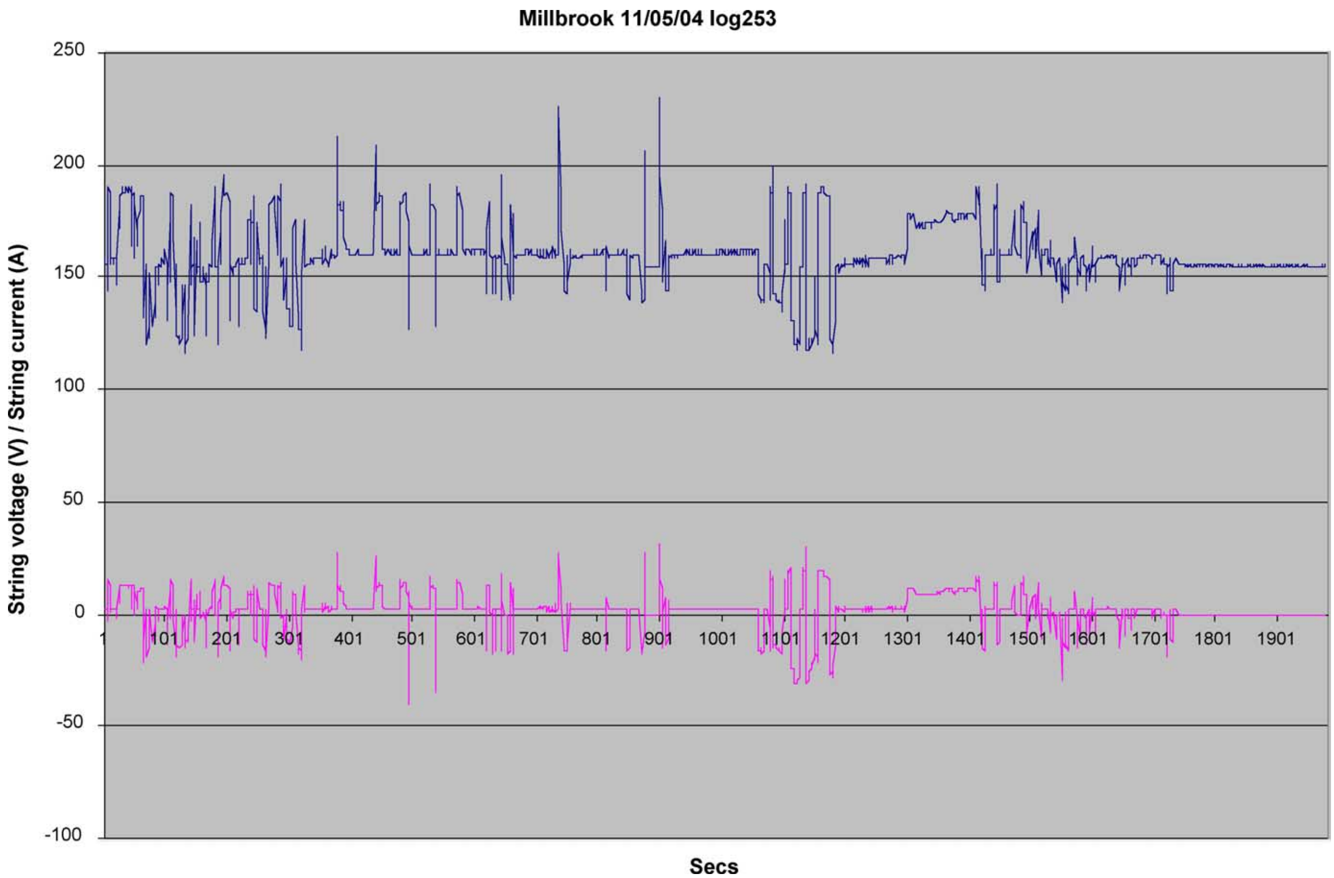


Fig. 16. Battery current and voltage recorded during the Millbrook test.

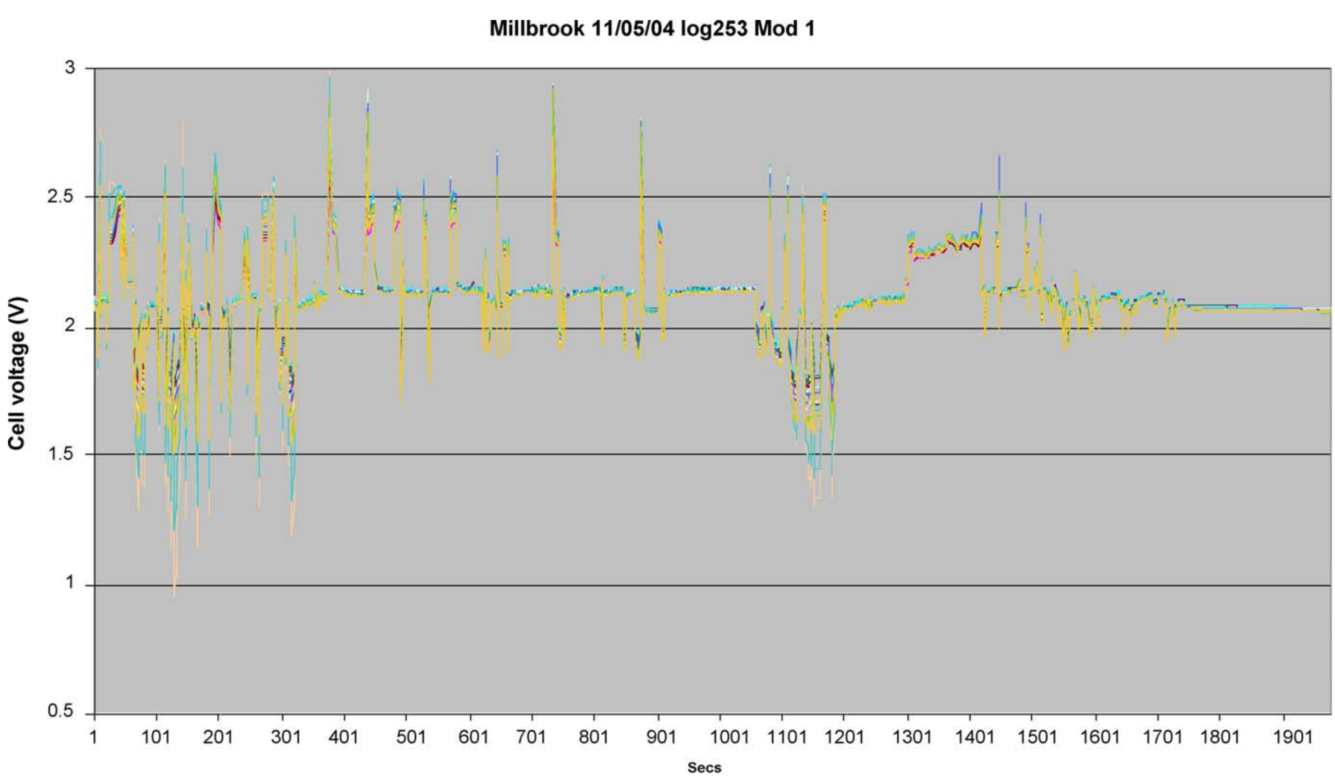


Fig. 17. Module 1 cell voltages recorded during test showing good cell balance.

(e.g., throttle position) can be collected, and thus with all this data, it is possible to relate battery performance, or any unusual event, to either road conditions or the driving of the vehicle.

Having confirmed that the vehicle was operating reliably, it was taken for trials around the three test circuits at the Millbrook Proving Grounds in the UK. In the GPS plot, shown in Fig. 14, the car started at the top of the hill circuit and then completed, successively, several laps of the high-speed circuit that increased the battery state-of-charge by utilizing a driving cycle of gentle acceleration and hard braking, four laps at a steady 70 mph, and finally a lap on the urban circuit before returning to base. The speed data on the various parts of the test are presented in Fig. 15, and the equivalent battery voltage and current in Fig. 16. The individual battery voltages plotted over each other for battery module 1 (Fig. 17) clearly demonstrate that the individual cells have remained in good balance.

The above are very encouraging results after the frustrations of resolving the various software and integration issues. At the time of writing, the car has probably completed around 2000 miles of relatively trouble-free testing under road conditions. The Advanced Lead–Acid Battery Consortium (ALABC) is trying to secure additional funding to complete a 50,000 mile durability test of the lead–acid battery in the RHOLAB *Insight*. Prior to this, it is the intention to fit new cells to the battery modules. This is because the present cells are over 3 years old and have had a very uncertain cycling history during the integration period.

## 3. Conclusions

During the initial phase of then RHOLAB Project, the design of the dual-tab cell was completed and the cells built and delivered. Subsequent testing of these cells under 'real vehicle' cycling regimes has shown that the cells are capable of meeting the high input and output currents demanded by the application and that conditioning routines extend battery life.

Complex design work on the battery modules and the battery management system has been completed and construction of these items finished. Bench testing of a module with its battery management system should start shortly. Whilst it would obviously have been preferable to do this ahead of the road tests, project delays with complex software issues have made this impossible.

The benchmark testing of the *Insight* with its Ni–MH batteries has been completed and the vehicle is now fitted with the RHOLAB lead–acid battery pack. Initial testing has shown that the latter battery is capable of meeting the power requirements of the vehicle under real driving conditions. This pack is scheduled to be fitted with new cells during the last quarter of 2004 and will then be subjected to an extended life test using a combination of testing at Millbrook and on the open road.

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## Reference

[1] A. Cooper, J. Power Sources 133 (2004) 116–125.