The Fastest Hydrogen Powered Vehicle in the World

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On September 25th, 2009, the Venturi Buckeye Bullet 2(BB2) became the first hydrogen fuel-cell vehicle to eclipse the 300 MPH mark, setting an international speed record of 302.877 MPH. This makes the BB2 the fastest hydrogen powered vehicle in the world, including vehicles powered by hydrogen combustion engines. The BB2 program included over 2 years of initial conceptual design, followed by 3 years of testing, development, and racing by Ohio State University students.

2009 marks the 15th anniversary of OSU's involvement in electric racing. Beginning in 1994 with the Formula Lightning series and continuing through 2002, OSU raced their vehicle, The Smokin' Buckeye. As the Formula Lightning series was being phased out, the team set its sights on breaking the all-out electric land speed record, which stood at 248 MPH, and built the Buckeye Bullet 1 (BB1), a battery-electric land-speed vehicle. After 3 years of racing at the Bonneville Salt Flats in Utah (home to the Bonneville Speedway for high-speed race cars), the BB1 set a U.S. record of 314.958 mph.

U.S. and international speed records differ by the time allowed between two speed-averaged runs. The US record, certified by the SCTA-BNI, allows four hours to service and requires the vehicle to travel the same direction down the course, with the average of two runs defining the record. The international record, certified by the FIA, requires the vehicle to travel across the same mile, in opposite directions within one hour, with the average speed of those two runs defining the record.


At the time, we were limited in how quickly we could recharge the battery because the battery technology used for the BB1 took more than 1 hour to fully recharge. Thus, it was impossible for the BB1 to set a International record over 300 MPH because we had to go easier on the batteries. However, we knew that fuel cells provide an ideal solution, as the vehicle can quickly be refueled between runs and this concept prompted the team to begin design of a fuel cell powered vehicle, the BB2. The BB2 would use the same 3-phase traction motor from the BB1, but required an all new design to package the fuel cells. To predict speeds and required power levels for an all new car, a new Simulink vehicle simulator was first created. Simulink is The MathWorks software environment for multidomain simulation and Model-Based Design.

Ballard Power Systems provided two fuel cell modules from their successful city-bus program. The two fuel cell modules were originally designed to create a combined peak power of 250kW, but more than 500kW would be required for the BB2. OSU students worked with engineers from Ballard and Ford to design the systems that would supply the fuel cell, and allow high power operation.

In a fuel cell, an electrochemical reaction occurs that combines hydrogen and oxygen (normally taken from air) to create electricity. The byproducts of the reaction are water and heat. Although fuel cells vehicles can be refueled quickly, they require the careful design of systems that can supply the hydrogen and oxygen, and a cooling system that can remove the heat.

One kg hydrogen is stored at 5000 psi, providing just enough hydrogen for a single run. For the oxidant, an enriched mixture of 40% oxygen and 60% helium is stored at 2400 psi. The enriched oxygen content (compared to 21% in air) allows the fuel cells to create more power, and eliminates the accessory load of an air compressor.

A normal radiator could not be considered for cooling because it would cause a sever penalty in the aerodynamics of the vehicle. Instead, approximately 350 lbs of ice is stored in two separate tanks, and melted through a two-loop liquid cooling system using a heat exchanger provided by Modine.

Supervisory control of the complex interactions between the fuel-cells, motor/inverter, cooling, and gas-delivery systems was all coordinated through a Simulink based controller provided by Motohawk. This provided the team with quick user-interface to make rapid control changes.

The vehicle is piloted by Roger Schroer, a professional driving instructor from Ohio's Transportation Research Center. The driver is surrounded by a carbon fiber safety tub and a steel roll cage, and secured with a 7 point harness. Two parachutes are the primary braking mechanism, but in the event of a parachute failure, Lear-Jet aircraft brakes provided by Goodrich allow a safe stop from full speed.

In August 2007, the BB2 ran for the first time, and achieved a peak speed of 201 MPH. In October of 2007, the BB2 achieved 223 MPH. Between 2007 and 2008 the team focused on increasing the power available from the fuel cells, and returned in August of 2008, achieving 286 MPH, but ran into severe reliability problems due to oxidant pressure control. Before the 2009 race season, much effort was put into the pressure control of the fuel cells.

Due to the properties of the fuel cell reaction, a fuel cell will inherently make more power when run at the highest possible pressure. At the fuel cell stack the pressure cannot exceed approximately 45 psi. The vehicle is driven through a manual transmission, which causes extreme pressure spikes when the electrical load is momentarily cut on each shift because the flow of the gases changes rapidly.

To allow operation near the pressure limitations of the stack without exceeding design pressures, pressure relief valves were installed on the oxidant and hydrogen supply systems. Extensive system pressure modeling using Simulink and physical testing was conducted so that the pressure spikes during shifts remained below the design limits, while maximizing operating pressure. Consistent test-to-test comparative data analysis with Matlab was invaluable in pushing the system performance to its limits.

The end result of 3 years of design, modeling, and testing was a fuel cell system that could reliably provide up to 600 kW of power. This provided more power than the 3 phase motor could draw, and ultimately allowed the vehicle to break the 300 MPH barrier.

In the future, the team will continue to push electric-traction technology to its limits. Since the 2004 BB1 battery record, much progress has been made in Lithium-Ion batteries. The team hopes to capitalize on this technological advancement to continue to safely push the limits of electric-traction drive technology. Currently, extensive data analysis from the BB2 using MATLAB is being used to improve and validate the Simulink vehicle model to see what speeds will be attainable for future programs.

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