USER STORY

Integral Powertrain Helps Bentley Motors Increase Horsepower, Reduce Emissions, and Improve Driveability

Integral Powertrain (IP) engineers knew that they faced a substantial challenge when they worked with Bentley Motors to boost the performance of the Bentley Arnage while reducing emissions and improving driveability.

"With today's complicated engine management strategies, it's not always intuitive which changes will achieve the desired calibration result," says John McLean, IP's Director of Powertrain Systems. Clearly, IP engineers would need to investigate a wide range of hardware and software concepts. However, they had limited access to prototype vehicles.

IP solved the problem by simulating and testing multiple engine and calibration improvements using MathWorks™ tools for Model-Based Design.

"With Simulink®, we created a very sophisticated scratchpad that lets us investigate options, rapidly devise new solutions, and test ideas that we would otherwise be unable to try in an appropriate timeframe and with only a limited number of test vehicles available," McLean says.

THE CHALLENGE

The previous Arnage model, powered by a 450 horsepower (HP) 6.75-liter twin-turbo V-8, complied with California Air Resources Board (CARB) LEV-1 and Euro Stage 3 emissions standards. Integral Powertrain had to bring the engine up to LEV-2 and Euro Stage 4 standards, increase power output to 500 HP, and improve the vehicle's effortless responsiveness.

The 2007 Bentley Arnage.

"It's difficult to improve in all three areas at once because they mutually conflict," explains McLean. "For example, you can put larger turbochargers on a car to help increase the power output, but that makes it harder to achieve the required level of driveability. Similarly, you can increase power by increasing valve lift, using more overlap, or lowering the compression ratio, but these changes tend to boost emissions, degrade the idle quality, or increase stresses."

IP needed a way to test new ideas quickly and while using only a small number of prototypes.

THE SOLUTION

IP engineers specified new catalysts, to reduce emissions, and designed and specified new turbochargers and valve train, to increase performance and response. They worked with Bentley and the engine management supplier to develop a new engine control unit (ECU), which they calibrated using MATLAB®, Simulink, and Model-Based Calibration Toolbox™.

THE CHALLENGE

To test multiple engine improvement strategies with reduced use of costly physical prototypes

THE SOLUTION

Use MathWorks™ tools for Model-Based Design to redesign, model, and simulate the engine's valve train and to calibrate the powertrain

THE RESULTS

- Horsepower increased, strict emissions standards met
- Design iterations accelerated
- Test times reduced by 80%

> *Simulating the dynamic valve train in Simulink® enabled rapid development of a more powerful and responsive version of the engine that meets strict emissions regulations.*
>
> **John McLean, Integral Powertrain**

Working in Simulink, IP engineers created a dynamic model of the engine's entire valve train. They used a combustion model to simulate the forces exerted on the valves by cylinder pressure.

They validated the model by using MATLAB to process data gathered from an existing engine fitted with strain-gauged pushrods. They first compared results visually. Later, they performed a more detailed verification, using MATLAB to compare Simulink results with the measured data.

The IP team used the model to evaluate several camshaft profiles over a range of speed-load conditions. The redesigned camshaft based on these simulations delivered immediate emissions and power-output improvements the first time it was installed.

Next, the team re-optimized the calibration. Using Simulink and Model-Based Calibration Toolbox, they developed statistical models of key engine responses from spark-sweep mapping data. They used those models with a Simulink implementation of the ECU strategy to calibrate the torque, exhaust gas temperature, and air-charge models.

Once they had mapped the ECU, the team could optimize the engine behavior to reduce emissions during the catalyst light-off period. They focused on optimizing the engine running during the first 30 seconds after a cold start. They used parameterized Simulink models of the inlet manifold "lost fuel" characteristics and "wall wetting" dynamics, together with data from actual tests, to tune the cold start and drive-away calibration. A design of experiments was performed using Model-Based Calibration Toolbox to optimize the pre-light-off emissions from the engine.

The design changes developed by IP are currently in production in the 2007 Bentley Arnage.

THE RESULTS

- **Horsepower increased, strict emissions standards met.** Integral Powertrain helped Bentley improve the responsiveness and increase the power output of the Arnage engine from 450 HP to 500 HP while reducing engine emissions by up to 50%. The Arnage now meets both CARB LEV-2 and Euro Stage 4 emissions standards.

- **Design iterations accelerated.** "We used our Simulink model to evaluate different camshaft profiles quickly," says Roger Duckworth, IP's head of Engine Development. "Instead of the three-week process of grinding a camshaft, installing it in the engine, and testing it, we used Simulink to get the results in one or two days. Over ten iterations, that's a substantial time saving."

- **Test times reduced by 80%.** "Cold start or transient fueling tests can be done only once every eight hours because you have to wait for the engine to cool down each time," says McLean. "Based on the results from a morning test, we evaluate potential changes in Simulink iteratively and then test them when the car has cooled. We can run five simulated tests a day because we use Simulink to model our strategy."

To learn more about Integral Powertrain, visit *www.integralp.com*
To learn more about Bentley Motors, visit *www.bentleymotors.com*

APPLICATION AREAS

- Automotive
- Model-Based Design
- Data analysis
- Powertrain calibration

PRODUCTS USED

- MATLAB®
- Simulink®
- Model-Based Calibration Toolbox™

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