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> Dr.-Ing. Sven Christian Fritz, MTU

Virtual test environment for large engine development

Virtual test bench at MTU Friedrichshafen

Developers at MTU Friedrichshafen GmbH in Germany have now solved a design dilemma they faced with large engines up to 10,000 kW that are used to power luxury yachts, mining trucks, and rail vehicles. The engines must comply with the respective exhaust emission standards applied in different parts of the world. Access to real test benches, however, is restricted, which limits the extent to which developers can create non-standard conditions. The solution? Virtualization.

In the American sports world, MVP stands for Most Valuable Player. In a similar spirit, the virtual test bench at MTU Friedrichshafen is referred as MVP, which stands for "MTU Virtueller Prüfstand" in German. This is certainly a fitting name for the highly efficient tool that plays such an important role in the company's development and validation of advanced diesel engines for large applications. The fully virtualized, automated test environment enables developers to engage in effective, interdisciplinary teamwork – and the advantages do not end there. Simulation also overcomes restrictions the developers faced with physical test benches due to the power range of the MTU generator sets.

Dr. Sven Fritz, Methodology Specialist at MTU, explains the dilemma they faced with the 4000 series generator sets. Weighing up to 15 metric tons and with a power range of 2,040 to 4,300 kW, they are used in applications such as luxury yachts, gigantic mining trucks, rail vehicles, and pump drives for oil and gas extraction. Such powerful engines burn up to a ton of fuel an hour which, for test purposes, required a system capable of supplying up to 25 tons of conditioned air to the test bench. Climate chambers used to condition air to a specific temperature and humidity, however, are not available for such large volumes of air. A further problem is that different regulations in place around the world mean the engines are subject to a dozen different exhaust emission standards – and these stipulate the exact environmental conditions for compliance with the respective limits.

Virtualization is the key

"For anything that lies beyond the capabilities of our test benches we have to turn to simulation," Dr. Fritz says. Virtual tests can plug the gaps left by physical test benches and help developers tackle tough assignments. Recently, for example, developers were called upon to reduce nitrogen oxide (NO_x) from 6.4 to 3.5 g and particle emissions from 0.2 to 0.1 g per kilowatt hour (kWh) for engines in the over 560 kW power range for the U.S. market (EPA Tier 4). Then, in a second stage, they had to reduce NO_x and particle emissions to 3.5 g/kW and 0.04 g/kWh, respectively, by the middle of this decade. Carbon monoxide and hydrocarbon emissions obviously had to be cut, too. No mean feat, given that the developers had no access to the drive trains in the overall system. "It's simply not feasible for us to bring a super yacht or gas extraction pump into our yard for testing," says the MTU expert, pointing out one of the major hurdles they faced.

To make sure the engines and their control systems comply with emissions standards, the developers therefore have to incorporate an extra degree of freedom, something that inevitably involves exponentially increasing levels of parametrization work. At the same time, they have ever shorter development times and shrinking budgets to contend with. This calls for highly efficient collaboration among the teams involved, which cover a range of different disciplines including thermodynamics, electronics development, and testing. The idea is to elaborate the operating strategies and optimize the parametrization data to the greatest extent possible in the simulation stage with a view to minimizing the number of Hardware-in-the-Loop tests in the real test environment. This is especially important given that the tests are a significant cost factor: depending on their series and power output, MTU engines burn anywhere between 200 and 2,000 kg of fuel an hour. To complicate things further, the number of test benches is limited and not every test bench can accommodate every engine. Taking all this into account, one thing became clear: "The test bench should only be used for fine-tuning the values parameters we assign in the simulations," Dr. Fritz says.

Combining expertise from all disciplines

The MVP developers faced the challenge of providing their colleagues from engine and ECU development, testing, and calibration with a virtual test environment that would enable them to execute test programs with minimal start-up times. Their solution also needed to be intuitive for calibration engineers to use. "First of all, we looked at the expertise and tools we had access to in our own ranks, and on that basis we set about pooling our knowledge and incorporating it into our virtual test environment," Dr. Fritz says. The idea was that engine, ECU, and ECU software developers and the calibration engineers could continue to use their tried-and-true tools without having to learn the ropes of new instrumentation and software routines. After all, engine parametrization is complex enough already when you consider the wide variety of charging and fuel-injection strategies involved, not to mention exhaust-gas recirculation and exhaust-gas treatment.

Since some sub-components were already available with MATLAB®/Simulink®, or could easily be transferred to the platform, it was clear from the outset that Simulink® should form the backbone of the virtual test environment. The central engine and ECU model is based on this platform, which caters to the integration of further load, cooling system, and exhaust-gas treatment models. The same applies to interfaces to ETAS INCA and AVL Puma Open.

Unlike those responsible for developing the methods, the calibration experts on the team were accustomed to working with INCA. This is where the ETAS strategy of relying on standardized interfaces came into its own. This proved to be the only way of ensuring that all developers could continue to use their established tools with updated toolchains – tools that may differ from team to team and from discipline to discipline. "We need solutions that can be easily tailored to our business requirements to avoid us having to constantly adapt the tools we use," Dr. Fritz explains.

In the case of the virtual test environment, the method developers connected INCA to the MATLAB® environment via INCA-SIP V7.2. It has been possible to link INCA to MATLAB®/Simulink® in the INCA Experimental Target Integration Package (INCA-EIP) in this way since the roll-out of INCA V7.2. Developers can also use the measurement and calibration functionality of INCA for the direct calibration of Simulink® ECU function models. This way, users at MTU do not need to familiarize themselves with the complex MATLAB® environment. Instead, they can continue working in their usual environment, where they can experiment with speed and load requirements, for example, or adjust the ECU or environmental parameters. "This is a key feature for us," Dr. Fritz says. "INCA gives our calibration experts a user-friendly, intuitive interface with which to navigate the complex simulation environment." Thanks to MTU's highly constructive collaboration with ETAS, implementation of the necessary system adjustments was a mostly smooth and seamless process. "Despite the complexity of the project, both partners were able to adapt relatively easily, not least thanks to the effective way we worked together to find solutions," Dr. Fritz says, praising efforts on both sides.

A bright future for the automated test bench

In addition to the setup described above, MTU Friedrichshafen has integrated an end-to-end automation system that converts the solution into a fully virtualized test bench. Offering simulated measurement technology and virtual driving programs under a wide range of load requirements, the virtual test bench works exactly the same way as a real test bench. Tests initially carried out in the virtual environment can be subsequently reproduced and verified on the real test bench at any time. The benefits extend way beyond cost reduction and a solution to the climate-chamber dilemma: "The simulated environment lets us experiment and gives us the freedom to try out unconventional approaches and operating strategies that time and cost restrictions would otherwise make impossible on the real test bench. We've already had a few of those light-bulb moments and greatly expanded our know-how in this area," Dr. Fritz says. And, unlike with the real test bench, time spent using the simulator no longer causes bottlenecks. Once fed with all the right data, the computer does everything on its own – and the running costs are barely more than the electricity it uses. The hourly operating costs of a real test bench, by comparison, lie in the four-figure range. Virtualization also reduces the CO_2 and emissions footprint.

Another major advantage, according to Dr. Fritz, is that – at the simulation stage – an approximation to reality is sufficient in two thirds of all cases. "It's not necessarily the accuracy but the quality of the tests that counts. Often, the second decimal place isn't even relevant," he says. "As long as the ECU and engine model are on the same time cycle, real-time processing takes a back seat." As things stand, the physical model for large engines is very CPU-intensive and still too slow to run the simulations in real time. But the developers are continuing to work on this aspect. Dr. Fritz is also considering another possibility: if they worked with the ETAS INTECRIO rapid prototyping tool, they could conceivably use the overall simulation for function prototyping. He also envisages using the virtual test environment for Hardware-in-the-Loop tests where appropriate – for instance as a means of testing, validating, and verifying real MTU ECUs and their software. One thing is clear: virtualization paves the way for truly effective collaboration on the large and efficient engines of the future.

Interviewee

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