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CLOUD-BASED SOLUTIONS

Measuring and Testing of Intake Air Temperature Control System

ETAS

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Cloud-based Design of the Intake Air Temperature Control System

With an eye to the forthcoming Euro 7 emissions standard, Hyundai Motor Company is working on an active intake air cooling system for turbocharged gasoline engines. The design process is very time-consuming, not least because intake air temperature has to be regulated across all of the engine's operating ranges. However, thanks to a cloud-based simulation from ETAS, Hyundai has been able to substantially accelerate this process and make it much more efficient.

How many kilometers can a test vehicle cover in 30 min? And how many test vehicles would it take to cover 22,000 km in the same time with a wide variety of routes and traffic conditions and at different speeds and gearing ratios? And what if these test drives were to be based on more than 1,000 different driving cycles and a driving distance of 2.2 million km? Increasingly, these are the kind of questions that automakers face when developing and designing complex vehicle systems as well as testing and validating the software that controls them. Such complexity results in concrete time and cost burdens that can easily blow a hole in development budgets and schedules.

PREPARING FOR THE NEXT CHAPTER OF EMISSIONS LEGISLATION

Hyundai Motor Company (HMC) is currently developing the technology that will enable its turbocharged gasoline engine family to comply with the forthcoming Euro 7 emissions standard. In this case, it will no longer be possible to practice the commonly used method of fuel enrichment in phases of high thermal load on the exhaust gas system. The aim is to achieve an air-fuel ratio of $\lambda=1$ across the engine's entire operating range and at ambient conditions stretching all the way from -7 to 35 °C. In order to ensure that the elimination of fuel enrichment does not result in overheating and thus, over the long term, in damage to the exhaust gas system, HMC is looking to optimize a range of parameters, including the temperature of the intake air. This is because a low intake air temperature results in a low exhaust gas temperature.

HMC is therefore developing a system to actively control the temperature of the intake air. Intake air can become too

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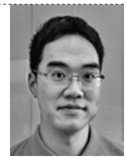

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warm as a result of high ambient temperatures or a prolonged operation of the engine at full load. When this happens, a chiller utilizing the vehicle's Air Conditioning (AC) unit is used in tandem with the engine's water-cooled intercooler. In such cases, however, it is important to ensure that this use of the AC chiller to actively control intake air temperature is strictly regulated according to need, **FIGURE 1**.

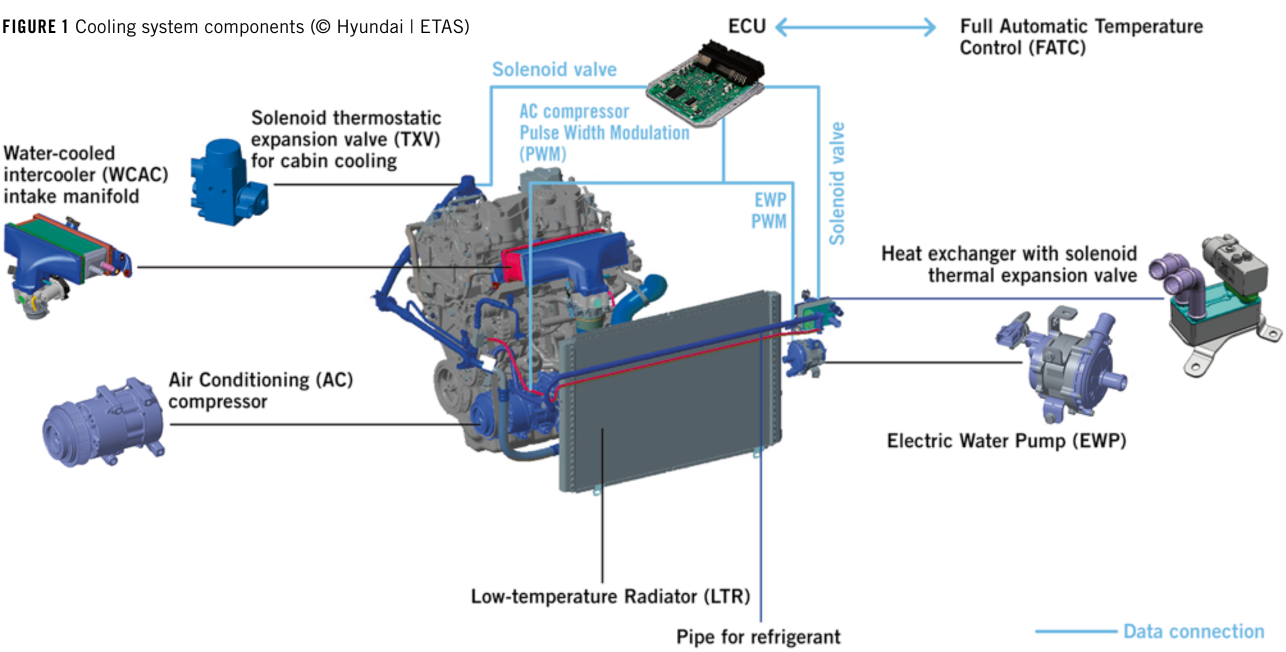
If the AC chiller on one hand runs too often or at a needlessly high power, this conflicts with the aim of achieving maximum fuel efficiency and minimum CO_2 emissions. If, on the other hand, cooling is too low, there is a risk of overheating and a noncompliance with legal emission limits. In order therefore to ensure that the active intake air cooling system consistently operates in a robust and compliant manner, the control system must be configured, tested, and validated for all possible driving profiles and environmental conditions. To efficiently manage system design and minimize the time and cost involved in testing and validating the control software, HMC uses modern simulation methods.

CO-SIMULATION PROVIDES THE PLATFORM FOR VIRTUAL TESTING

The goal was to hold exhaust gas temperatures below a predefined target value of 930 °C. To achieve this, HMC engineers opted for a simulation-based development process. The key tool here was COSYM, the co-simulation platform from ETAS. Since HMC had already built an ETAS tool chain with tools such as INCA, ETAS ASCMO, and ETAS ASCMO-MOCA, developers were confident they could use these tools to create the component models as well as calibrate and optimize them.

The first step was to model the engine and the main components for the active intake air cooling system – that is, an AC chiller, a water-cooled intercooler, a Low-temperature Radiator (LTR), and the ECU for the control system. The aim was to quantify the degree of heat exchange in the LTR, in the AC chiller, and in the intercooler, and to place this in relation to a model of the intercooler system, **FIGURE 2**. In this way, it was possible to deduce cooling performance on the basis of the operating point of the AC compressor. In addition, the developers used ETAS ASCMO employing the Gaussian process method in order to raise the complexity of the engine model to the requisite level for this project.

FIGURE 1 Cooling system components (© Hyundai | ETAS)



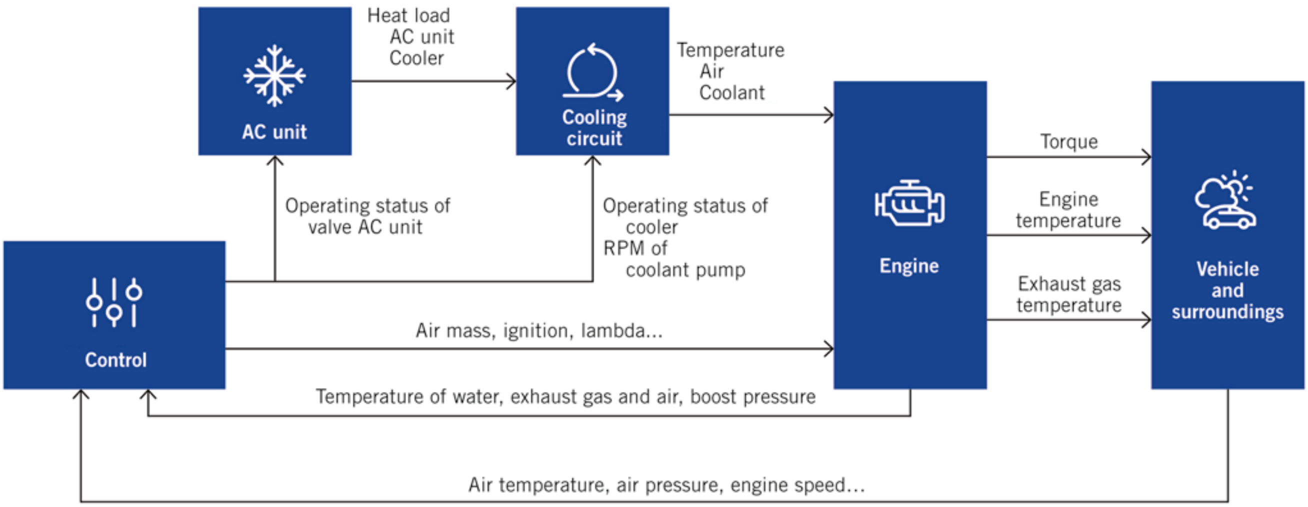


FIGURE 2 Interfaces between simulation and signal flow (© Hyundai I ETAS)

The team then used the ETAS COSYM co-simulation platform to combine the resulting cooling-circuit model – based on the modeled AC chillers – with a virtual vehicle, **FIGURE 3**. For the purposes of integration and simulation, the developers converted each of the component models into Functional Mock-up Units (FMU), thereby standardizing data exchange within the simulation. Moreover, thanks to COSYM's standardized interface, it was also possible to integrate models that were generated with other development tools such as ETAS ASCET, Simulink, or C code. Also helping to boost efficiency was the exceptionally high simulation speed – thanks to the use of existing compiled models – and the solution's structured workflows, which provide users with a rapid visualization of complex simulation results and assist them with parameter calibration.

Using the simulation, the team was rapidly able to gain an overview and then develop and promptly validate the relevant control logic. At this initial stage, they were also able to test and optimize the interaction between components by means of online calibration. This led, among other things, to a reconfiguration of the temperature-control system, which now features two separate cooling loops rather than just one – as in the original plan, which turned out to deliver a substantially inferior cooling performance.

PARALLELIZED TESTS ON CLOUD SERVERS

On the basis of this groundwork, HMC has laid the foundations for a much quicker testing and validation process. The developers have now seamlessly uploaded their integrated simulation environment to the ETAS CLOUD SERVICES and, with the help of a cloud-simulation solution ETAS MODEL-SIMULATOR, have created a high-performance and high-efficiency test and validation solution. Using this cloud-based simulation, it is possible to parallelize practically any number of tests and therefore substantially accelerate the process. In the case of this project, the HMC team was

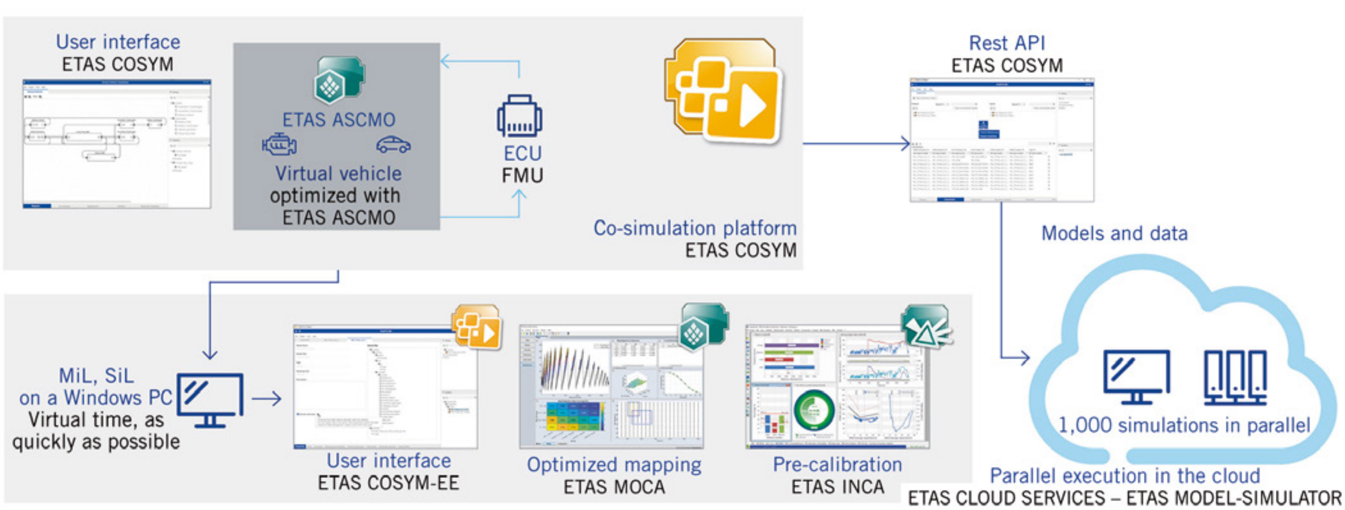


FIGURE 3 Schematic diagram of the simulation environment (© Hyundai I ETAS)

able to simulate the 22,000-km test drive referred to above in a time of just 30 min.

To be able to cover the widest possible range of operating scenarios, the team used a database from Bosch. This is based on 20 billion km driven in European traffic and has been broken down by Artificial Intelligence (AI) into 1,032 representative driving scenarios, each with different topographical and traffic conditions as well as different speeds and gearing ratios. These driving cycles cover over 30,000 h and a total of 2.2 million km of real traffic events, which are rendered in virtual space. In combination with parallelizable virtual testing, this largely eliminates the need for real tests with expensive test vehicles, complex transport logistics, and a high degree of coordination. It therefore provides the basis for a significant increase in the systematic quality of testing and validation while at the same time significantly reducing the time and costs involved.

In addition to speeding up test and validation procedures, cloud simulation also offers other advantages. For example, in view of limited budgets and time constraints, conventional methods often focus merely on a selection of worst-case scenarios. With virtual testing, however, it is possible to cover a much wider range of driving conditions. This therefore paves the way to a realistic, robust, and – as in the case of the active intake air cooling system – highly efficient system design. Thanks to the broad scope of testing options at their disposal, HMC engineers were able to optimize the power draw of the AC chiller across a whole range of operating phases and real road conditions. At the same time, in the course of comprehensive testing, they were able to demonstrate that even at an ambient temperature of 35 °C and a constantly high engine load, the exhaust gas temperature is almost continuously below the predefined target value of 930 °C and that the legally prescribed emission limits are complied with at all times.

SUMMARY AND OUTLOOK

In conjunction with an integrated co-simulation model that combines all the key components of an active cooling system in COSYM, the use of cloud simulation with the MODEL-SIMULATOR results in a significantly faster development process. At the same time, the control system developed in this way can be tested and validated to an unprecedented degree. As a result, the degree of calibration and, with it, the quality of the overall system increase significantly. At the same time, parallelized virtual testing helps minimize the use of costly and time-consuming experimentation and road tests. In the future, these will serve merely to verify – shortly before series production – control systems that have already matured in real driving scenarios generated in the cloud simulation and that have already been extensively calibrated.

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