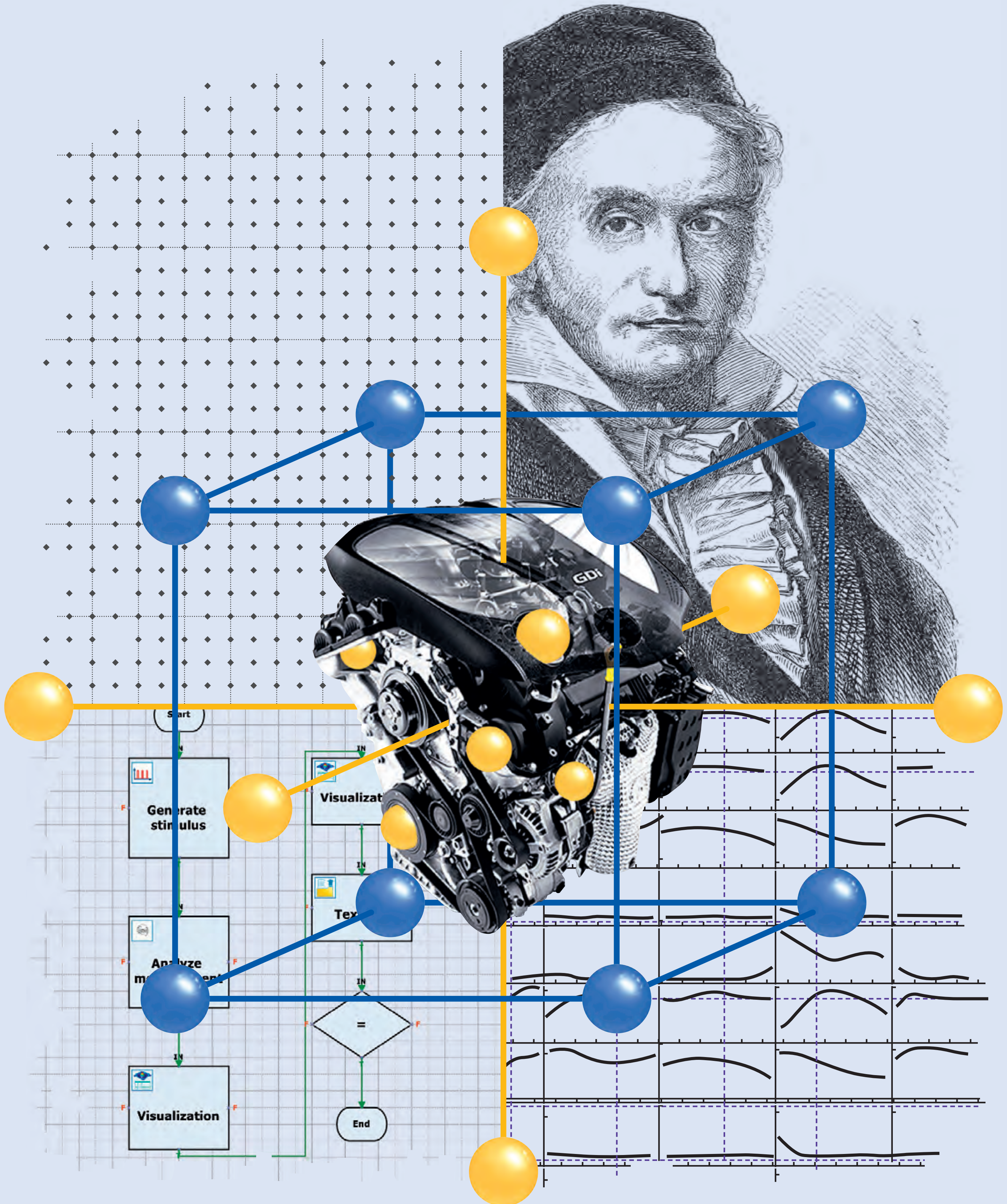

Optimization of Gasoline Engines

Model-based calibration at Hyundai

Increasingly efficient engines and systems are being developed by Hyundai Motor Company (HMC) in order to meet the demanding requirements with respect to performance, fuel consumption, and pollutant emissions. The many degrees of freedom afforded by the large number of systems are reflected in the wide range of parameters that must be adjusted and optimized in the course of calibration.

AUTHORS

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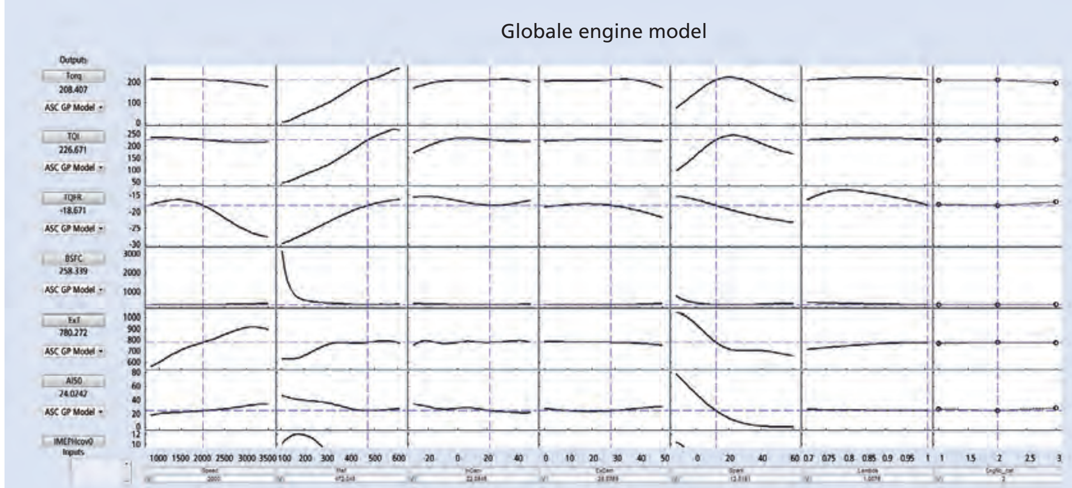
The Hyundai Motor Company (HMC) research and development center, located in Namyang, Korea, introduced a new, model-based calibration process that efficiently calibrates the engine's entire operating range. This new calibration process is based on advanced modeling and automation methods which are supported by ETAS ASCMO and ETAS INCA-FLOW software tools. Hyundai achieved time savings of seventy-five percent in the measurement effort and a concurrent quality improvement with the new process as compared to the prior standard calibration processes for gasoline engines.

Project scenario

Hyundai determined the measurement effort saved compared to the previous process and the quality of the results based on standard calibration packages for gasoline engines. The engine was a naturally-aspirated V6 3.0L GDI engine with a three-stage intake system, dual



Torq (Nm) = Torque (Nm)
BSFC (g/kWh) = Brake-specific fuel consumption (g/kWh)
ExT (°C) = Exhaust temperature (°C)
IMEPHcov0 (%) = Coefficient of variation of indicated mean effective pressure in combustion chamber (%)

Figure 1: Graphs showing the dependencies between output and input variables. The ETAS ASCMO model simulates the dependencies very well across the entire parameter space.

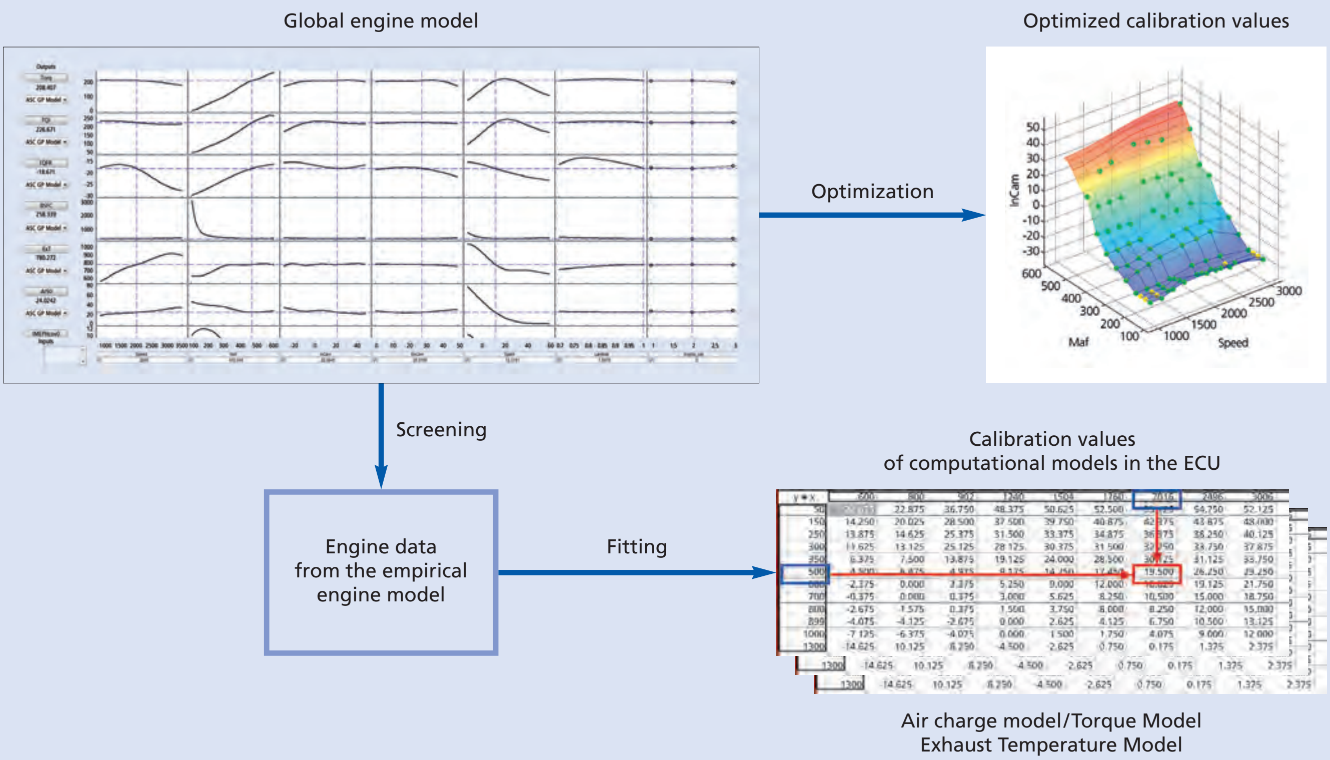


Figure 2: Optimization of parameter values of models in ECU ("optimization function") by adjusting ("fitting") the output of these models to data derived from the empirical engine model using ASCMO ("screening").

continuously variable valve timing, and a Continental engine control unit. Intake and exhaust camshaft timing, injection timing, and ignition angle calibrations were optimized. Additionally, ECU models for air charge, torque, and exhaust temperature were calibrated.

New calibration process

While redesigning the calibration process, Hyundai implemented two new methods, namely Design of Experiments (DoE) and fully automated measurements at the engine dynamometer. Highly accurate computer-generated models which simulate the behavior of the engine were developed using machine learning techniques and measurement results. The DoE test plans and the models were generated using the ETAS ASCMO tool. The DoE test point measurement plan was automated at the dynamometer test cell with the aid of a newly developed measurement control system based on the INCA-FLOW tool.

Calibration based on engine model

The engine model created from the test bed measurements simulates the behavior of the engine with high accuracy across the entire parameter space (see figure 1). On the basis of the model, both the fuel consumption and the full-load torque were optimized (see Figure 2). At the same time, the knocking limit and the exhaust temperature limit were observed. Typically, calibration of the air charge, torque, and exhaust temperature ECU models required large volumes of data. Unlike standard practice with conventional methods, this data was not laboriously measured at the engine dynamometer, but derived by ASCMO from the empirical engine model ("screening"). ASCMO generated models resulted in less than 5% error for the air charge model, less than 5% (or a maximum of 5 Nm) error for the torque model, and less than 15°C error for the exhaust temperature model as compared to validation measurements.

Conclusion and summary

Hyundai achieved a dramatic increase in engine calibration efficiency after implementing a global, model-based process. The company reduced the engine dynamometer testing measurement effort by 75% with the new process as compared to the conventional method. In summary, we conclude that the global, model-based process enables engineers to efficiently calibrate complex engines and achieve the project defined goals with high-quality results.