Towards A Specialist System To Support The Calibration Process Of Engine Management Systems Over Upcoming Technologies To Reduce Overall Exhaust Emissions

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Abstract: Each year new strict regulations and homologations cycles have been released and in order to fulfill these rules, new technologies appeared as a solution for better engine efficiency and reduction of overall emissions; however, only cost efficient technologies are applied on large scale production, those technologies have to be studied because it represents most of the world fleet. New technologies in tandem with more restrictive regulations increase the complexity over the engine calibration process. Calibration is the key to engine control and mistakes can lead to consequences that represent safety risks, environmental treats and enormous costs for vehicle manufactures. As the companies thrive for a shorter development time to compete on the automotive market, the calibration process complexity demands time, being more expensive and challenging over time. Arguments are given in order to explain the necessity for an engine calibration specialist system capable of fully representing the knowledge e cross domains evolved on the process while dealing with cross requirements and necessary interoperability to help the addition of new technologies.

Keywords: Emissions regulamentation, homologation cycles, engine calibration, upcoming technologies.

1. Introduction

Engine technologies have been evolving in steps with the promulgation of emission standards for new engines and new vehicles [1]. Emissions can be treated basically in three different brunches, engine and exhaust controls, evaporative controls, and diagnostic controls [2]. Engine control consists of the hardware and software developed to provide a better engine control, for example the electronic fuel injection system itself. Evaporative emissions control the amount of hydrocarbons (HC) that do not come from the exhaust but from the evaporation on the fuel tank, therefore devices such as a canister serve as a storage unit, during the right conditions, the gases are release at the intake and burned. Exhaust control devices for emissions consist of catalytic converters, air injection systems and other types of after treatment devices. Diagnostic controls are related to OBD (On Board Diagnostics) which has the capability to self-diagnostic and report a fault that leads to deviations on the emission's level. All previous methods to reduce overall emission are linked to an Engine Management System (EMS) that become an essential system for engines in order to achieve high performance, low fuel consumption and low emissions [3]. An EMS is a mixed-signal embedded system that interacts with the engine by several sensor and actuators which are managed by software present at the main control unit. The software is a general basis capable of controlling a range of engines, the software deal with this variety by enabling or inhibiting strategies. The fine adjustment and how well an EMS works depend on the hardware, software and mainly on the calibration work [4]. Calibration is a fine process of tuning, molding the engine according to specifications, making sure that the final result attends emissions regulation and the overall project requirements. The calibration process has become more complex, time consuming and challenging due to the appearance of new technologies and new strict homologation norms. This research expose new homologation cycles and upcoming technologies to enhance engine control with focus on solutions that have been adopted in large scale production. At the final section, it is presented the necessity for a specialist model to deal with difficulties found on the calibration process.

2. Light-Duty Regulations

Current and future regulations implemented in Europe, China, USA, Brazil and India showed a concern for overall emissions by tightening emission`s limits for NMOG, NOx, and CO_2. In 2017 started the Tier 3 standards in USA which is going to be one of the stricter in the world by the end of 2020 with a limit of NMOG + NOx at 30 mg per mile [5]. On Europe the Euro 6 started on September of 2017 and brought important changes with the new World Harmonized Light Vehicle Test Procedure (WLTP) in addition of Real Driving Emission (RDE) defining a Particle Number (PM) limit of 6 × 1011per km applied to Gasoline Direct Injection (GDI) vehicles with a margin of 0.5% due to the uncertainties of the Portable Emissions Monitoring System (PEMS) [6]. On China regulations will be implemented in two stages, China 6a starting in 2020 with RDE and China 6b to be implemented in 2023 with more strict limits, in contrast with the European the Chinese regulations have no distinction over GDI or Port Fuel Injection (PFI), this is a very important aspect since PFI have more PN emissions during cold start and in cold ambient conditions making it more restrictive specially by the 6b stage with factor of 2 for CO and HC, a reduction in 40% for NOx and 33% for PM, furthermore, a limit of 20 mg per km on N2O emissions which is not even present on European regulations [7]. On Brazil, it still in Proconve phase L6 which started on January of 2013; however, it is going to be implanted the L7 phase by 2022, this new phase have NMHC + NOx levels of 80 mg per Km and PM of 6 mg/ Km to be measured by RDE [8]. Most of the countries are evolving in regular steps; however, India is going to skip one step, today the Bharat Stage 4 is the current regulation which will be changed for the Bharat Stage 6 which is going to be based on Euro 6 by 2020, nowadays RDE still in study in order to define a test procedure that represent most of the actual driving conditions on the country, it is expected to be fully defined and ready to be applied by 2023 [9].

3. Homologation Cycle

The New European Driving Cycle (NEDC) had it last update on 1997 and used a chassis dynamometer under well-defined ambient conditions for temperate and humidity to give approval on the emissions certification process [10]. This cycle should represent the typical usage of a car in Europe; however, it is criticized for giving fuel economy estimations which are unachievable in reality, not only that, but the vehicles were specially prepared to pass this test and since the publication of reports highlighting the discrepancies between laboratory and on road emissions [11], a new homologation cycle has been created to test RDE. The RDE was complemented with a test procedure that would be able to represent normal use under a representative range of driving conditions [12], under RDE, a car is driven on public roads and exposed to a wide range of different conditions. The test includes low and high altitudes, additional vehicle payload, up and down hill driving, urban roads, rural roads and highways. An on road test procedure based on the application of a portable emissions measurement system (PEMS) has been put at work for heavy duty vehicles since 2014 [13], but for cars and light commercial vehicles, it become a standard only in 2016 after (EC) 2016/427 and (EC) 2016/646 were published. As the new cycles become necessary for emissions approval, the complexity of the procedure affected the calibration process, since it must develop calibrations to attend all the proposed conditions, making necessary the development of new testing rigs and instrumentations. The RDE test must be performed on public roads under real traffic, also the information is analyzed by tools that check the trip in order to validate the collected data during the percuss.

4. Technologies to Reduce Overall Emissions

Increasing stringency on emission standards has gradually forced the appearance of new sophisticated engine management systems in tandem with hardware development and calibration strategies [14]. Some solutions already existed; however due to cost reduction strategies, they were not developed for large scale production. As the engines become more efficient, a downsizing trend took lead. Engines with smaller volumetric capability could reach the same power levels of bigger old engines, thus also reducing weight and contributing for fuel economy.

4.1 Three-way Catalytic Converter and Integrated Exhaust Manifold/Catalytic Converters

A three-way catalytic converter (TWC) is a common and largely used after-treatment unit used in gasoline engines to treat exhaust gases. Its main function is to convert harmful exhaust gases such as CO, HC and NOx in less harmful gases such as CO2, H2O and N2 [15]. The TWC work depends on the calibration of a catalyst monitor system that have a set point to maintain the exhaust gases into the catalyst window. New homologation cycles requires catalysts that can guarantee emissions over 160K Km, this reacquires changes on calibration cycles that include tests with much more aged engines and catalysts. Later emission regulations are much more stricter and any advantage to reduce emission during the cold phase of the engines are welcome, therefore the Integrated Exhaust Manifold/Catalytic Converters appeared as a solution to decrease the light off time for the catalytic converter while enhancing packaging. By changing the location of the catalyst it also changed the location of the O2 sensor which became closer to the engine also improving the O2 sensor warm up. Looking for the calibration point of view, this changes allowed for an early control technique which could sense and control overall emission on early stages of engine operation.

4.2 Selective Catalytic Reduction (SCR)

The fuel economy regulations for light-duty vehicles will require the corporate average fuel economy (CAFE) to increase to 19.3 km per liter by 2025, which is more than 50% higher than the current regulations [16]. Most of actual vehicles have gasoline engines operating at stoichiometric air-to-fuel ratios (AFR), which are suitable for TWC to control NOX, CO, and HC emissions; however, in order to attend the necessity to reduce fuel consumption, engines have been designed to work at lean operation which can increase fuel economy by 10–20% over stoichiometric operating engines; nevertheless, it comes with a cost since the conventional TWC are unable to reduce NOx in the presence of excess oxygen [17]. For Gasoline engines the most common approach is the passive SCR method which generates NH3 under slightly rich conditions, which is stored on the downstream converter. The stored NH3is then used to reduce NOx emissions when the engine switches to lean operation, this system is extremely dependent of the calibration of AFR [18]. For diesel engines, it is applied two types of SCR systems, Diesel Oxidation Catalyst (DOC) and Ammonia Oxidation Catalyst (AMOX). DOC is primarily intended to burn off the residual hydrocarbons and CO in the exhausts, but also can be used to change the exhaust gas temperature, while AMOX is used to increase NOx conversion efficiency is an advanced active emissions control technology system that injects a liquid-reductant agent (automotive-grade urea) through a special catalyst into the exhaust stream. Calibration is based on bench testes and it is challenging because it depends on the engine exhaust gas composition that is difficult to control, any neglected reactions may influence the SCR reaction [19].

4.3 Gasoline Direct Injection (GDI)

As a solution for new emissions regulations, GDI gave new possibilities to optimize engine performance, improve fuel economy and in tandem with after treatment methods, reduce overall emissions [20]. Compared to port fuel injection (PFI), GDI alone can reach 1.5% increase on fuel economy and following the global tendency for downsizing, it can achieve 8% using a turbocharging system [21]. The improvement in the fuel economy, the possibility to run on higher compression ratio, the possibility to enhance AFR control and reduction of problems during cold start is some of the advantages of this technology. Latest increases on fuel economy for internal combustion engines alone is a reflex of the volumetric yield rise; however it comes with a trade-off, first with extra costs since this system is more expensive, secondly with emission of NOx and particulate matter (PM) which also require more expensive after treatment devices and largely increases the calibration complexity. According to [22], the emissions on GDI engines are directly related to the initial fuel spray, evaporation, mixture preparation and distribution inside the combustion chamber, all related parameters to the combustion process itself. As characteristic of this system we also have disadvantages, such as the complexity of the control and injection technologies required for seamless load changes, elevated fuel system pressure and fuel pump parasitic loss.

4.4 Exhaust gas recirculation (EGR)

Emissions pushed the development of small and more efficient engines, small displacement engines that can reach high levels of power, providing fuel economy and reductions on GHG emissions, specially CO2 [23, 24]; however it comes with a drawback since high temperature on the combustion chamber increases NOx emissions, and also this kind of engine is susceptible to higher knock risks compared with naturally aspirated engines [25]. As a partial solution for lowering the temperature on the combustion chamber, the EGR provided a dilution of fresh air with exhaust gases, improving knock resistance without strong reductions on overall efficiency [26], temporarily reducing pumping losses at partial load and also reducing the inlet temperature of exhaust turbines, serving as a protection during high loads [27]. For diesel powered vehicles, the EGR reacquires fuel of specification, with low sulfur levels, otherwise in can produce sulfuric acid during the recirculation processes, causing corrosion to the intake header, valves and seals, compromising the overall engine integrity [28]. The EGR must work with the entire engine management system, since it affects the AFR in respect to the concentration of oxygen. New devices were added in order to control the system, i.e., the amount of recirculated gas is controlled by an electromechanically operated valve, also sensors measure both exhaust and intake pressure, in many cases a variable geometry turbo (VGT) is also applied to increase the control possibilities. Calibration has become more challenging due to the addition of interconnected systems and requirements for NOx, PM, fuel consumption and vehicle performance that meets consumer expectations.

4.5 Turbocharging

The better way to increase engine efficiency is recovering lost energy. Turbocompounding is a heat recovery technique that has been successfully used in medium and large scale engines, since the exhaust heat utilization improve fuel efficiency, reduce carbon emissions, provide a fast warm up and optimize head temperatures on conventional internal combustion engines [29]. Turbo is necessary especially for diesel engines which operate with lean mixtures and to provide extra flow of the exhaust gases in order to perform EGR, thus new arrangements were developed, such as two stage and parallel turbocharging in tandem with new controlling technologies such as Variable Geometry Turbo (VGT) [30]. Regular turbo presents problems regarding its limited volumetric efficiency which in general causes a turbo to work properly just on high engine speeds, variable nozzle turbo (VNT) also known as VGT, can adapt its geometry in order to increase turbo performance at low engine speeds, reducing turbo legging and improving overall engine efficiency [31]. This technology is more common on diesel engines due to its low exhaust temperatures; however, new materials have improved their resistance to high temperatures, increasing the use on gasoline engines [32]. For every new added controllable device, extra variables are also added to the calibration process, making the search for optimal conditions highly complex and time consuming [33]. Calibration takes place over static and dynamic test benches, depending on judgment based on professional`s expertise, it becomes more challenging due to the rising number of variables to be tuned under reduced time and a very competitive ambient.

4.6 Hybridization

Hybridization has been presented as a promising approach to reduce overall emissions. This kind of technology is based in two powertrains: an internal combustion engine combined with an electric motor which is supplied with an energy storage system that is recharged by regenerative system that recovers energy while braking or in specific regimes of engine work. Nowadays, there are three main configurations regarding the arrangement of electric motors and internal combustion engines: parallel, series and parallel/series. Regardless of their powertrain architecture the internal combustion engine is reduced compared to an equivalent conventional engine. [34] tested the emissions for HEV (Hybrid Electric Vehicles) over real-world simulation driving cycles and the results showed low overall emissions and a higher fuel efficiency specially for urban cycles. With the results, it is expected that HEV applications should expand towards urban areas and can play an important role reducing CO2 emissions. Calibration becomes more challenging since hybrid vehicles have to deal with intermediary engine regimes in tandem with a smart energy management system.

5. Discussion

More strict emission regulations in tandem with new complex homologation cycles and a modern powertrain create significant challenges regarding the engine calibration process. Basic calibration requirements of performance, dynamics, fuel consumption and emissions depend on an optimized tuning; however, those calibration tasks are becoming more complex, time consuming and costly while the industry demands optimal results in a shorter amount of time. A current state of art engine capable to attend to the more strict regulation have about 50,000 calibration variables, much of those labels need a complex treatment with automated tools that transform engineering requirements into a calibration. Even though technological advances can automatize part of the process, it still depending on specialist`s judgment which does not totally eliminate human error, furthermore, with new technologies it becomes more challenging to understand the connection and even the interference of new calibration blocks with the already existent ones. Engine calibration itself is a complex process since it evolves heterogeneous domains of knowledge that must change information and merge concepts in order to attend project requirements, safety and emissions regulations. Misinterpretations, misleads or mistakes can be made and if an error passes through the validation phase, it can reach enormous proportions and consequences, risking personal safety, contributing to climate changes with greenhouse gases emissions and even affecting health with respiratory diseases related to exhaust gases. From the business point of view, a recall due to a calibration mistake represents a huge brand loss due that is very difficult to estimate due to spread of the bad marketing and a huge cost to amend customer`s vehicle to conformity. This paper points to the necessity for a specialist system capable to fully represent the knowledge and multiple domains while dealing with cross requirements and interoperability over the calibration process front new strict emission regulations, new homologation cycles and increasing complexity of system to reduce emissions and increase engine efficiency.

6. Conclusion

Strict regulations and new homologation cycles forced the appearance of new technology in behalf of better engine control and increase on engine efficiency. The authors looked into current regulations and homologation cycles for countries with large fleet of vehicles. A literature review showed technologies that have been applied for automakers in large scale production and also the impact over the calibration process. Calibration still is constant development along the evolution of hardware, software and control techniques for internal combustion engines. Arguments were presented pointing to the complexity on engine calibration process and the increasing demands for better results in reduced time, fact that could lead to mistakes which can have global effects over safety, environmental changes, economics and health. This paper points to the necessity for a specialist system capable of the fully representation of the knowledge and multiple domains evolved on the calibration process, not only that, but system must be capable to deal with cross requirements over the appearance of new calibration labels as a result of the addition of new technology while promoting better communications through interoperability by means of new standardization and common language.

7. Other recommendations

In order to give continuity to this research, several subjects are proposed for future works. Research knowledge representation and interoperability methods that best suit the calibration process in order to create a specialist system.

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