Regeneration of the Particulate Filter by Using Navigation Data

Increasing connectivity is having a major effect on the driving experience as well as on the car's inner workings; for instance, connected software functions have the potential to further reduce fuel consumption and CO_2 emissions. For the diesel engine, Bosch has developed a new system for controlling the regeneration of the diesel particulate filter. This system links engine management to the data provided by the electronic horizon about the route ahead.

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OPTIMAL REGENERATION TIME

Since the Euro 1 emissions standard was introduced in 1992, particulate emissions from diesel vehicles have been cut by some 97 %, with any remaining particulates removed almost completely by a diesel particulate filter (DPF). The latest filters work at over 95 % efficiency, and can efficiently filter out even the smallest of nanoparticles. Once the DPF is full, the deposited particulates are burned off, regenerating the filter so that it is once again fully functional. To trigger the regeneration process, the engine management system increases the exhaust temperature – for example, by means of post-injection and adjusting the throttle valve. The result of these measures is a massive rise in exhaust gas temperature which burns off the particulates. Other action can be taken additionally, such as adjusting the exhaust gas recirculation control. However, intervening in engine management moves the engine away from its optimum operating point, making it function less efficiently. This has particularly negative consequences when the regeneration takes place on unsuitable segments of the route, such as in city traffic or traffic jams. If DPF regeneration is carried out predictively with the help of a route preview, then it happens only on those sections of the route conducive to such an operation. This not only reduces fuel consumption and pollutant emissions, but also lessens the thermal load on the components during the regeneration process.

CONVENTIONAL REGENERATION STRATEGY

Today's DPFs are already optimised by engine management and sensors, **FIGURE 1**. The engine management system monitors the DPF loading conditions using a differential pressure sensor, which measures the pressure of the exhaust gas before and after filtering. Software functions in the engine management system evaluate the sensor information and set the intervals for regeneration depending on need. Compared to periodic regeneration, in which the particulate matter is burned off in preset intervals, demand-based regeneration takes place at longer intervals, which in turn reduces fuel consumption. As the central control unit, the engine management system decides

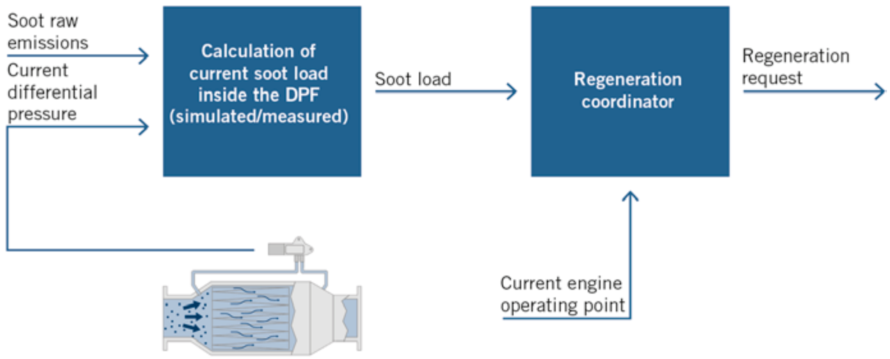

FIGURE 1 Conventional regeneration strategy (© Bosch)

FIGURE 2 Signal flow and processing of navigation data (© Bosch)

when to regenerate the DPF depending on its loading condition and on the engine's operating point. Once the optimum operating point has been reached, the engine management system launches the regeneration, which can take up to 20 min. In determining the point at which to start regeneration, however, current systems do not take the route ahead of the vehicle into account. In other words, if the regeneration process kicks off and the engine leaves optimum operation point during DPF regeneration, the soot is not burned completely off the filter, more fuel is consumed, and a greater thermal load is put on the exhaust gas treatment components. This scenario can occur when the car leaves the highway, arrives home, sits in traffic, or in other situations.

ELECTRONIC HORIZON

Today's navigation systems provide an electronic horizon that expands the route preview far beyond what the driver can see. It draws on three-dimensional navigation data to deliver detailed, far-sighted information about road layout, inclines, speed limits, and traffic on the road ahead. This map data plus the vehicle's current position is forwarded via standardised interfaces to other control units, such as engine management, which can use this predictive information for their own functions. The ECU receives the navigation data, processes it, and provides it as physical values with the help of an interface, **FIGURE 2**. The form, resolution, and scope in which this information must be available depends on the use case. For shorter drives, it is irrelevant whether the navigation system's route guidance function has been activated or not: without active route guidance, the control unit continuously calculates the vehicle's most probable path. Yet the longer the route, the less precise the most probable path is, making predictions of the upcoming road no longer reliable. This is why active route guidance is preferred for longer-term use cases, a function that in this case corresponds to the electronic horizon. To this end, the driver inputs the planned destination and the engine control unit receives information about the entire route to be driven. The unit can determine, for example, when the car will be on the highway and how much of the route remains before the car reaches its destination. Connecting to the highly dynamic information from the navigation system also helps the unit recognise where on the route there may be traffic. The engine management system can use this data to help it choose the optimum section of the route for performing complex operations such as diagnostics, adjustments, or exhaust gas treatment functions.

PREDICTIVE STRATEGY

The newly developed DPF regeneration control system is based on the electronic horizon with active route guidance. Using the route preview, the engine manage-

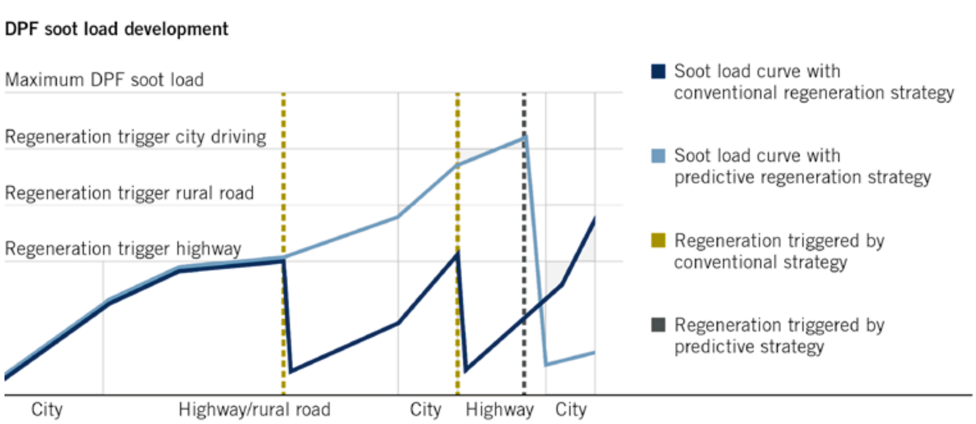

FIGURE 3 Comparing conventional and predictive regeneration strategies (© Bosch)

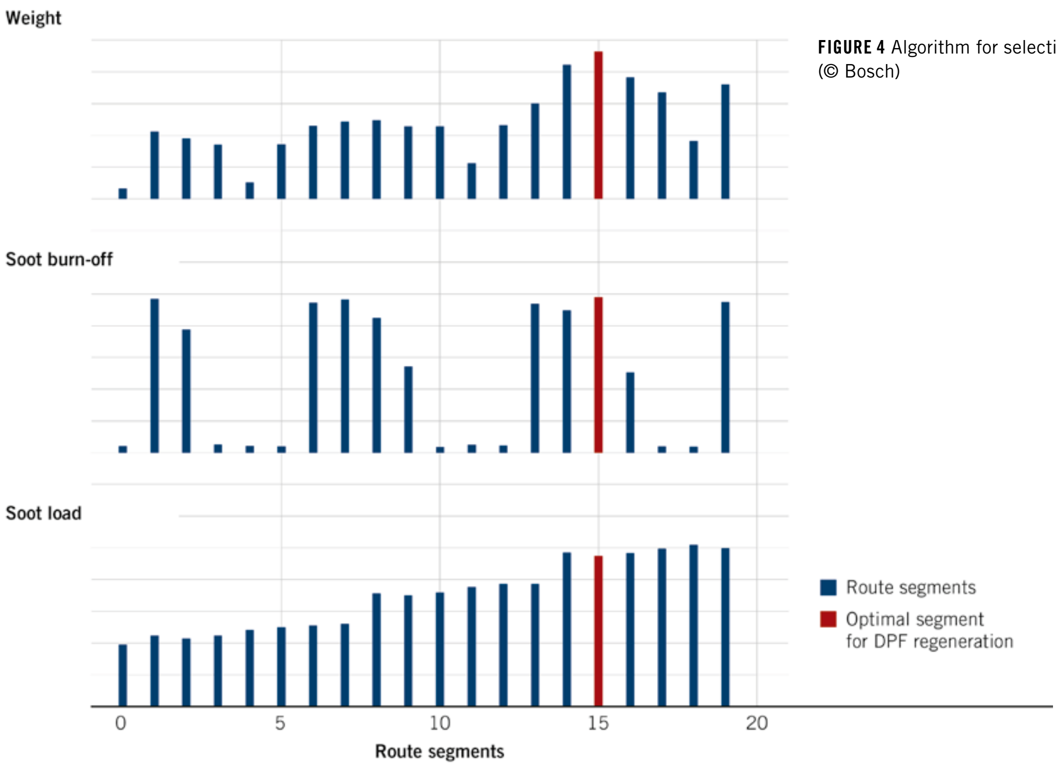

FIGURE 4 Algorithm for selecting regeneration segments (© Bosch)

ment system dynamically calculates the state of the DPF and evaluates the route characteristics to determine where the engine operating points will be optimum for regeneration. Based on this information – and by weighing up further factors – the regeneration process is planned and carried out in consideration of the following:

- Regeneration is carried out as frequently as needed, but as seldom as possible.
- Regeneration is carried out only when the DPF can be cleared completely in one regeneration interval.
- Regeneration is carried out only on optimum sections of the route, for example highway, cross-country routes.
- Before entering a city the DPF should be empty to avoid a regeneration in urban area, **FIGURE 3**.

This predictive control system makes it possible to reduce fuel consumption and pollutant emissions as well as the thermal load on the DPF during regeneration, thereby protecting the components.

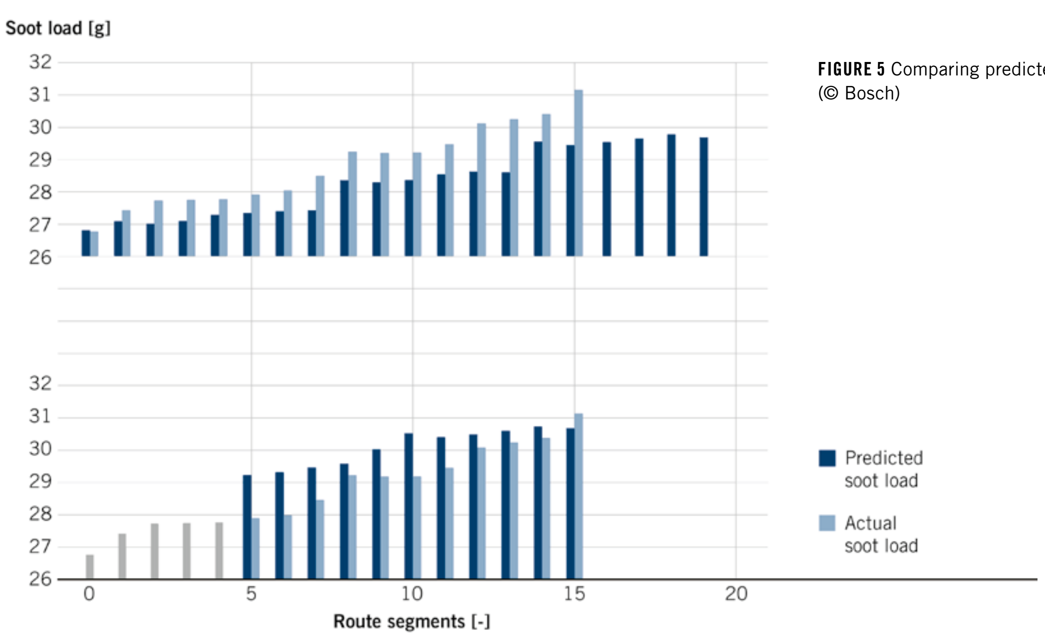

FIGURE 5 Comparing predicted and actual soot load (© Bosch)

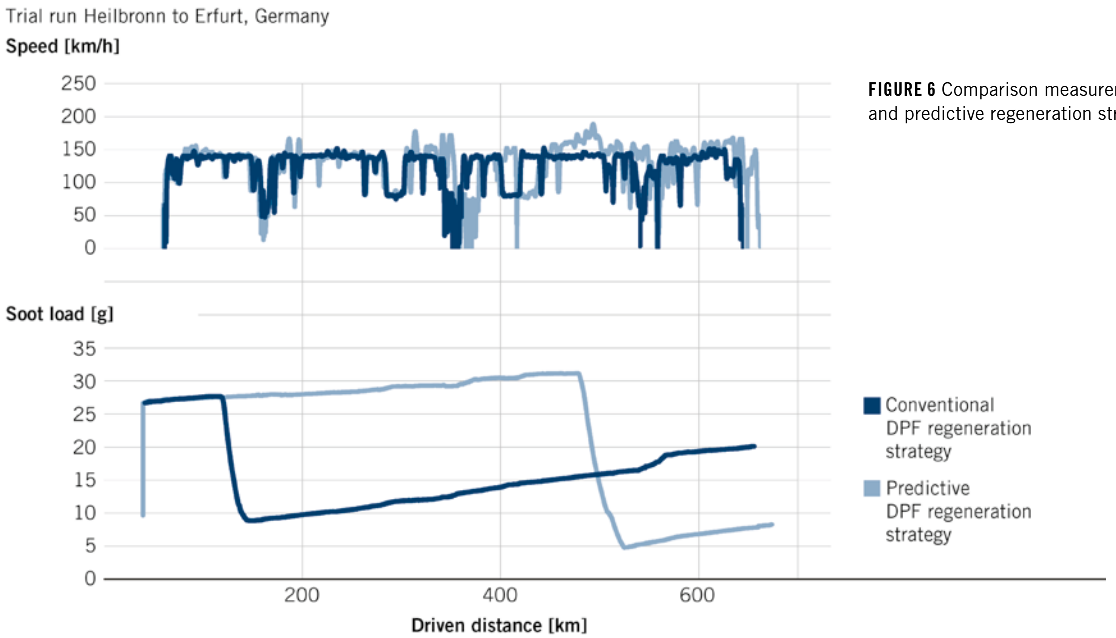

FIGURE 6 Comparison measurements of the conventional and predictive regeneration strategies (© Bosch)

Supplementing this predictive control of DPF regeneration with further operating strategies, such as a hybrid control system in a diesel hybrid, serves to strengthen the positive effects. It avoids unintentional activation of the internal-combustion engine in electric drive mode, while artificially generated higher loads, for example to charge the batteries, increase the efficiency of the regeneration. Driving becomes more comfortable when the engine management system takes more account of the driver's wishes.

PREDICTIVE SOOT LOAD MODEL

With a conventional DPF regeneration strategy, the filter's soot load is either estimated depending on the engine's operating point (load and speed) or measured in a stationary state by a differential pressure sensor. Furthermore, the increase in the soot load depends on the fact that the particulate filter works more efficiently as the soot load increases. The ratio of nitric oxide (NO) to nitrogen dioxide (NO_2) in the exhaust gas also serves to reduce the soot load at certain speeds, a phenomenon referred to as "passive" regeneration (CRT effect – continuously regenerating trap). When developing the new regeneration strategy, these effects were factored into the predictive soot load model. Using the navigation data makes it possible to determine the expected loading condition of the particulate filter on every section along the planned route. This means that three questions can be settled right at the start of the drive. One: should regeneration happen at all along the planned route? Two: will the soot load on the DPF surpass a critical threshold and therefore make regeneration necessary? And three: can the regeneration be delayed until the vehicle reaches an optimum section of the route?

SELECTING THE OPTIMUM ROUTE SEGMENT

Ideally, once DPF regeneration has begun it should be carried out completely. This means that the regeneration has to last long enough to clear a minimal threshold value of the soot load so that the engine management system recognises the particulate filter as "clear." That is why the prediction of the soot load within the new control strategy was expanded to include determining possible soot burn-off for each segment of the route. In this way, planning DPF regeneration takes into account whether the chosen route is long enough for regeneration or if the regeneration process will take several route segments. The new management system takes other factors into consideration as well. For example, it can postpone DPF regeneration to the latest possible route segment, so that the vehicle can park at its destination with a clear filter. Similarly, the system can avoid executing two regenerations in too short a space of time.

To determine which section of the route is ideally suited for regeneration, multiple factors are weighed against each other for each section to produce a "favourability value": the higher this value is, the more favourable the route segment is for DPF regeneration, **FIGURE 4**. The most favourable segment is calculated using an efficient search algorithm. No approval is given for the DPF regeneration until the vehicle reaches this segment on the planned route. The predictive models, the weighting, and the determination of the regeneration segments are updated cyclically. With each update, the accuracy of the soot load prediction increases, **FIGURE 5**. What is more, any change made to the planned route – when the driver makes a wrong turn, has to follow a detour, or inputs a new destination – is immediately incorporated dynamically into the prediction to reflect the new conditions.

Comparing conventional (demand-based) and predictive DPF regeneration showed that the former took place much earlier on than in the comparison drive, **FIGURE 6**. Regeneration using a predictive strategy took place in plenty of time before the vehicle reached its destination and at an optimum engine operating point. When this result is extrapolated, it confirms the assumption that the new regeneration strategy lengthens the intervals between regenerations, thereby reducing fuel consumption, emissions, and the thermal load on the components.

SUMMARY AND OUTLOOK

Connecting the powertrain to data from the electronic horizon opens up a host of new functions that make driving a car more efficient, safer, and more convenient. In addition to those described here, Bosch Engineering is developing further functions that process, provide, and in some cases use navigation data. Predictive cruise control, cornering assistance, and braking assistance are just a few areas where a route preview can be applied. If a far-sighted route preview is available, hybrid vehicles can use predictive battery management thus optimising energy recuperation. In addition, predictive exhaust gas treatment that is adapted to the road ahead can reduce fuel consumption, emissions, and wear and tear on the components. In the future, further development of this function will focus on weaning it off of its reliance on active route guidance. The goal is to expand the predictive management of DPF regeneration to include standard routes as well, on which route guidance has not been activated. Once the engine management system gets to know the profiles of frequently driven routes, it can file them away for future reference. Then it can plan operating points on the daily commute, for example, without accessing navigation data. The advantage of this solution is that it can be integrated into existing systems without needing any additional hardware. In addition, the predictive information is also to be used for other exhaust gas treatment functions and components; these can have a negative impact on fuel consumption and emissions thanks to their long lifetimes and complex interventions in engine management. A similar plan foresees coordinating the processes of these new, as-yet undeveloped functions.