

A Unique Application of Gasoline Particulate Filter Pressure Sensing Diagnostics

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Abstract

Gasoline particulate filters (GPFs) are important aftertreatment components that enable gasoline direct injection (GDI) engines to meet European Union (EU) 6 and China 6 particulate number emissions regulations for nonvolatile particles greater than 23 nm in diameter. GPFs are rapidly becoming an integral part of the modern GDI aftertreatment system.

The Active Exhaust Tuning (EXTUN) Valve is a butterfly valve placed in the tailpipe of an exhaust system that can be electronically positioned to control exhaust noise levels (decibels) under various vehicle operating conditions. This device is positioned downstream of the GPF, and variations in the tuning valve position can impact exhaust backpressures, making it difficult to monitor soot/ash accumulation or detect damage/removal of the GPF substrate.

The purpose of this work is to present a unique example of subsystem control and diagnostic architecture for an exhaust system combining GPF and EXTUN. In particular, the On-Board Diagnostics (OBD) controls are required to detect a disconnected/plugged downstream hose when combining a differential pressure (dP) sensor and an electronically controlled EXTUN valve in an exhaust system containing a GPF. The regulatory implications related to failing to detect a disconnected/plugged downstream hose are also discussed. Validation data from the control strategy under different operating conditions is reviewed.

History

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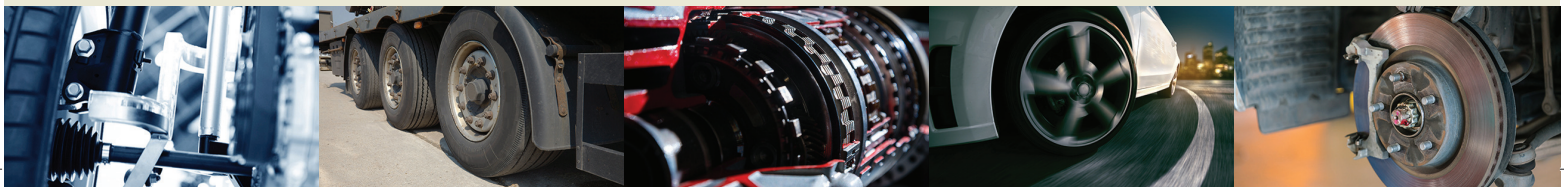
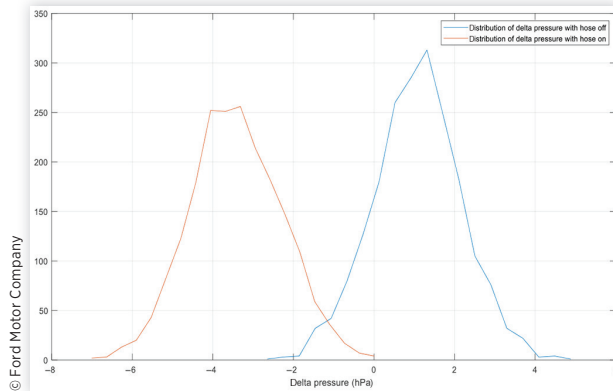


FIGURE 10 Histogram of the monitor metric (pressure difference in hPa) for a set of drive cycles with hose off and hose on.



When the downstream hose is connected, we expect a negative distance from the threshold.

The results of a Monte Carlo simulation with the above noise factors over 40,000 samples are shown in Figure 10. We can define the separation between the intact and failed systems as the difference in means over the geometric sum of the standard deviations.

$$S = \frac{\mu_{\text{hose off}} - \mu_{\text{hose on}}}{\sqrt{0.5 \cdot (\sigma_{\text{hose off}}^2 + \sigma_{\text{hose on}}^2)}}$$

And find the value $S = 4.05$ for this analysis.

Summary/Conclusions

This study focused on using an EXTUN valve to diagnose a disconnected downstream hose on a dP sensor using a 5.0L Ford Mustang as a test vehicle, and the following conclusions emerged.

- A novel method that utilizes an EXTUN valve to conduct an intrusive dP sensor with downstream hose disconnected diagnostic with a GPF was developed.
- The dP sensor with downstream hose disconnected diagnostic method proved robust and showed considerable separation between faulted and non-faulted conditions.
- The diagnostic method developed allows the manufacturer to meet regulatory requirements for the detection of a missing downstream hose off and robustly diagnose a missing or damaged GPF substrate.

Contact Information

Definitions/Abbreviations

- CMS** - Catalyst monitor sensor
dP - Differential pressure sensor
DPF - Diesel particulate filter
EXTUN - Exhaust tuning valve
GDI - Gasoline direct injection
GPF - Gasoline particulate filter
PCM - Powertrain control module
T - Temperature sensor
UEGO - Universal exhaust gas O₂ sensor

References

1. Joshi, A., "Review of Vehicle Engine Efficiency and Emissions," SAE Technical Paper 2020-01-0352, 2020, <https://doi.org/10.4271/2020-01-0352>.
2. Giechaskiel, B., Joshi, A., Ntziachristos, L., and Dilara, P., "European Regulatory Framework and Particulate Matter Emissions of Gasoline Light-Duty Vehicles: A Review," *Catalysts* 9 (2019): 586, <https://doi.org/10.3390/catal9070586>.
3. van Nieuwstadt, M.J., Pressure sensor diagnosis via a computer. US Patent US6947831B2, September 20, 2005.
4. Lambert, C., Bumbaroska, M., Dobson, D., Hangas, J. et al., "Analysis of High Mileage Gasoline Exhaust Particle Filters," *SAE Int. J. Engines* 9, no. 2 (2016): 1296-1304, <https://doi.org/10.4271/2016-01-0941>.
5. Van Nieuwstadt, M. and Ulrey, J., "Control Strategies for Gasoline Particulate Filters," SAE Technical Paper 2017-01-0931, 2017, <https://doi.org/10.4271/2017-01-0931>.
6. Richter, J., Klingmann, R., Spiess, S., and Wong, K., "Application of Catalyzed Gasoline Particulate Filters to GDI Vehicles," *SAE Int. J. Engines* 5, no. 3 (2012): 1361-1370, <https://doi.org/10.4271/2012-01-1244>.
7. Chan, T., Meloche, E., Kubsh, J., Rosenblatt, D. et al., "Evaluation of a Gasoline Particulate Filter to Reduce Particle Emissions from a Gasoline Direct Injection Vehicle," *SAE Int. J. Fuels Lubr.* 5, no. 3 (2012): 1277-1290, <https://doi.org/10.4271/2012-01-1727>.
8. Sappok, A., Wang, Y., Wang, R., Kamp, C. et al., "Theoretical and Experimental Analysis of Ash Accumulation and Mobility in Ceramic Exhaust Particulate Filters and Potential for Improved Ash Management," *SAE Int. J. Fuels Lubr.* 7, no. 2 (2014): 511-524, <https://doi.org/10.4271/2014-01-1517>.
9. Dadam, S., Sharma, S., and Jentz, R., Method for variable position exhaust tuning valve diagnostics. US Patent 10844762, April 25, 2019.

10. Dadam, S., Jentz, R., Lenzen, T., and Meissner, H., "Diagnostic Evaluation of Exhaust Gas Recirculation (EGR) System on Gasoline Electric Hybrid Vehicle," SAE Technical Paper 2020-01-0902, 2020, <https://doi.org/10.4271/2020-01-0902>.
11. Van Nieuwstadt, M.J., Lehmen, A., Martin, D.R., Rollinger, J.E. et al., Gasoline particulate filter diagnostics. US Patent 10323562, February 14, 2019.
12. Jentz, R., Lenzen, T., Dadam, S., Meissner, H. et al., Method and system for exhaust gas recirculation system diagnostics. US Patent 10632988, December 12, 2019.
13. Jentz, R.R., Sharma, S., and Dadam, S., Heat exchanger for exhaust tuning systems. US Patent 10436087, April 25, 2019.
14. Van Nieuwstadt, M., Shah, A., Serban, E., and Martin, D., "Regeneration Strategies for Gasoline Particulate Filters," SAE Technical Paper 2019-01-0969, 2019, <https://doi.org/10.4271/2019-01-0969>.
15. Dadam, S., GPF downstream hose EGHR diagnostic on hybrids, US Patent 10928275.
16. Liu, X., Szente, J., Pakko, J., Lambert, C. et al., "Using Artificial Ash to Improve GPF Performance at Zero Mileage," SAE Technical Paper 2019-01-0974, 2019, <https://doi.org/10.4271/2019-01-0974>.
17. Zhu, D., Pritchard, E., Dadam, S.R. et al., "Optimization of Rule-Based Energy Management Strategies for Hybrid Vehicles Using Dynamic Programming," *Combustion Engines* 184 (2021): 3-10, <https://doi.org/10.19206/CE-131967>.
18. Dadam, S., Ravi, V., Jentz, R., Kumar, V. et al., "Assessment of Exhaust Actuator Control at Low Ambient Temperature Conditions," SAE Technical Paper 2021-01-0681, 2021, <https://doi.org/10.4271/2021-01-0681>.
19. Snyder, K. and Ku, J., "Plug-In Hybrid Electric Vehicle Reengineering of a Conventional Sedan for EcoCAR2," SAE Technical Paper 2015-01-1235, 2015, <https://doi.org/10.4271/2015-01-1235>.
20. Snyder, K. and Ku, J., "Advancement and Validation of a Plug-In Hybrid Electric Vehicle Plant Model," SAE Technical Paper 2016-01-1247, 2016, <https://doi.org/10.4271/2016-01-1247>.
21. Ravi, V.K. and Dadam, S.R., Methods and systems for an active exhaust valve. US Patent 11,002,166, November 19, 2020.
22. Ravi, V.K., Dadam, S., and Jentz, R.R., Methods and system for diagnosing active exhaust valves based on temperature and thermal image data. US Patent 11,015,511, October 8, 2020.
23. Vedula, R., Men, Y., Atis, C., Stuecken, T. et al., "Soot Observations and Exhaust Soot Comparisons from Ethanol-Blended and Methanol-Blended Gasoline Combustion in a Direct-Injected Engine," *SAE Int. J. Fuels Lubr.* 11, no. 2 (2018): 163-180, <https://doi.org/10.4271/04-11-02-0008>.
24. Dadam, S.R., Zhu, D., Kumar, V., Ravi, V. et al., "Detection Method for Cybersecurity Attack on Connected Vehicles," SAE Technical Paper 2021-01-1249, 2021, <https://doi.org/10.4271/2021-01-1249>.
25. Kumar, V., Zhu, D., and Dadam, S.R., "Intelligent Auxiliary Battery Control-A Connected Approach," SAE Technical Paper 2021-01-1248, 2021, <https://doi.org/10.4271/2021-01-1248>.