OPTIMIZATION OF THE EXHAUST SYSTEM WITH PARTICULATE FILTER FOR BETTER BACK PRESSURE.

Kalyana Raman Subramanian  
General Motors Tech Center, Bangalore, India

Zakirul Haque  
General Motors Tech Center, Warren, Michigan, USA
Objective:

- To reduce the back pressure of the exhaust system with particulate filter (PF) without compromising noise performance.

- The addition of PF in the exhaust system increases the back pressure tremendously and at same time PF increases the noise performance of the system.

- In this work an attempt is made to reduce the back pressure of the system by utilizing the positive contribution of PF on noise performance.
Motivation:

- Almost all of the exhaust systems of current diesel engines include PF. Some of them have more than one PF.
- PF's contribution towards the exhaust backpressure is significant. For example, in a typical full size truck the estimated pressure drop across PF is about 16 kPa.
- PF generally contributes to the improvement of exhaust acoustic performance.
- Some of the gas engines also use PF to help reach the new strict emission regulations. Particle size present in the exhaust gas mixture needs to be reduced. In some region the requirement is mass based and some regions use particle size.
- The learning from this project will provide an excellent vehicle to optimize exhaust system systematically by considering lot more design parameters.
Optimization of Exhaust System with PF

**Background:**

Addition of an extra after treatment devices like PF becomes unavoidable for many vehicles due to the stringent emission regulations.

A PF is NOT a “flow-through” device, the gasses are forced through. Unlike a catalytic converter, the channels of the filter are blocked at alternate ends, forcing the gasses to flow through the cell walls in order to exit the filter. As the cell walls are porous, the clean gasses can pass through, but the holes are not large enough to particulate matter pass through.

The cell porous walls act as a restriction to the flow pressure pulses but at the same time it will increases the restriction of the system which in turn increases the back pressure of the exhaust system.
**Optimization of Exhaust System with PF**

*Project Overview:*

- It is common to remove a smaller tuner when a PF is used. PF is generally more restrictive than the smaller tuners. As a result, it contributes towards the increase of the exhaust backpressure and hence it causes the reduction of engine power.

- Because of the restriction, PF also helps in the attenuation of the engine noise. So it provides the opportunity to use less restrictive muffler and help regain some of the power lost.
Challenge:

- The important parameters that will have effects on the total exhaust backpressure and tailpipe noise are the PF design, location, pipe lengths, and pipe diameters.

- The main challenge was the lack of CAE tool to characterize the PF acoustically. Without any CAE tool it is hard to predict the effects of these parameters on the tailpipe noise.

- With the help of Gamma Technologies engineers we were able to develop a new procedure for this project to analyze the acoustic behavior of PF using GT-Power.

- The new procedure was used in this project to optimize the exhaust system with PF.
Optimization of Exhaust System with PF

**Define Requirements:**

- Initially the TL for PF and Middle Resonator were compared.
- Then the middle resonator was replaced by PF and the tailpipe SPL value is compared with the system with the resonator.

- Transmission Loss analysis shows that at the lower frequencies (0-600 Hz) PF is more effective than the mid muffler.
- Tailpipe noise analysis shows that the acoustic performance of the exhaust system with PF is better in general compared to the exhaust system with the mid-muffler. At higher RPMs it is more effective in attenuating the tailpipe noise.
Optimization of Exhaust System with PF

The back pressure of the system with PF is very high compared to the system with Resonator.

Middle Muffler replaced by Particulate Filter

Transmission Loss comparison

Back Pressure comparison

Each grid of the vertical axis represents 10 dB

Each grid of the vertical axis represents 10 kPa
Optimization of Exhaust System with PF

Resonator can be replaced by PF effectively for noise performance.

But the functional requirement will be bringing the back pressure of the PF system close down to the Resonator.
DEVELOP THE CONCEPT

P - DIAGRAM

Control Factors
1. Muffler Chamber Volume
2. Diameter of the muffler inner pipe
3. Diameter of the j.pipe

Exhaust System

Signal
Engine Output

Output
Back Pressure at different RPM

Noise Factors
1. Soot loading

Noise factor is not considered in the present project
Optimization of Exhaust System with PF

<table>
<thead>
<tr>
<th>Control Factors</th>
<th>LEVELS</th>
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<tbody>
<tr>
<td>Volume of the Muffler (L)</td>
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<tr>
<td>Diameter of the muffler inner pipe (mm)</td>
<td>52.6, 60</td>
</tr>
<tr>
<td>Diameter of the muffler i-pipe (mm)</td>
<td>52.6, 60</td>
</tr>
</tbody>
</table>

For the optimization the back pressure value at the maximum RPM – 6000 is considered.
Optimization of Exhaust System with PF

*Optimization Results:*

- L4 orthogonal array used to compare 4 models
- **Smaller the Better Optimization** – Reduce the back pressure
- Utilize S/N and Mean Chart Analysis to optimize the design

**Smaller-the-Better Optimization**

<table>
<thead>
<tr>
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<th>A</th>
<th>B</th>
<th>C</th>
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<th>N2</th>
<th>S/N</th>
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**Noise factor is not considered in the present Optimization**

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<td>Diameter of the Muffler inner pipe (mm)</td>
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<tr>
<td>C</td>
<td>Diameter of the I - Pipe (mm)</td>
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From the Mean Graphs, the smaller the better design is A2B2C2

A2 – 10 L Muffler Volume
B2 – 60mm Muffler Inner Diameter
C2 – 60mm I – Pipe Diameter
Optimization of Exhaust System with PF

**Verification of the final design:**

A verification simulation is carried out with the final design A2B2C2 and the back pressure and tailpipe SPL are compared with the Resonator model.

The back pressure value of the final design is almost equal to the Resonator model at 1000 RPM and we can observe at least 5kPa reduction for all the other RPM compared to the initial GPF design.

The Tail pipe SPL of the final design is almost matching with the Resonator model.
A procedure was developed using GT-Power to predict the acoustic performance of PF. The procedure was successfully used to optimize the exhaust system. In this study, an attempt is made to reduce the back pressure of the exhaust system by maintaining the noise performance. This study enables the scope of reducing the back pressure of the exhaust system while adding the PF. Since the flow phenomenon of the PF is similar in both diesel and gas cars, the procedure can be used for both diesel and gas engines. This gives the systematic approach for optimizing the exhaust system with PF.

Acknowledgement:

The authors gratefully acknowledge the contribution and insights provided by Mr. Matt Massaro of Gamma Technologies in developing the CAE procedure.