SSRG International Journal of Mechanical Engineering
ISSN: 2348 – 8360 / https://doi.org/10.14445/23488360/IJME-V9I5P101

Volume 9 Issue 5, 1-8, May 2022

Original Article

Development of an Exhaust Throttle Valve with Electronic Controller for Heavy Duty Truck's Exhaust Brake Application

R. Ajith Surendar[1], M. Senthilkumar[2]

[1,2] *Department of Automobile Engineering, MIT Campus, Anna University. Chrompet, Chennai, Tamilnadu, India.*

Received: 03 March 2022 Revised: 25 April 2022 Accepted: 30 April 2022 Published:21 May 2022

Abstract *- Exhaust brakes are used in conventional heavy-duty trucks to slow down the vehicle speed. An exhaust brake slows a diesel engine by closing off the exhaust path from the engine, causing the exhaust gases to be compressed in the exhaust manifold and the cylinder. Since the exhaust is compressed and no fuel is being applied, the engine slows down the vehicle. Since it is a mechanically operated baffle plate, it closes fully 90 degrees to restrict the flow. So that backpressure is created and sent back to the exhaust manifold.*

In some cases, the backpressure level is huge, harming the engine operation. Since it is a mechanical brake, we cannot control the movement of the baffle plate. The baffle plate is controlled via E-Motor and controller systems to automate this. So that we can control the amount of backpressure creation and operate the baffle plate at any angle, it increases the exhaust gas temperature to a certain level. These two automotive ideas are implemented in this project.

Keywords *- CREO 4.0, ANSYS, LabVIEW, Vibration Shaker, Thermal Analysis, Virtual Instrumentation.*

1. Introduction

The exhaust braking system closes the exhaust path, stopping the gases from being eliminated from the exhaust pipe. As a result, backpressure is built in the manifold and the cylinders, making the engine work backward and slowing down the vehicle. Especially if the vehicle doesn't have a very high speed, drivers can use only the exhaust brakes for slowing down and stopping their cars, reducing the wear and tear on the regular brakes. One of the biggest advantages of exhaust brakes is that they can take some stress off the regular brakes and prevent overheating, especially when going downhill. Similarly, suppose a driver transports a fifth wheeler, a caravan, or a loaded trailer, and he needs to go downhill. The exhaust brake can prevent the vehicle from going too fast, reducing the likelihood of an accident. The engine brake can also slow down and stop a vehicle, yet it has a big disadvantage: it is quite loud when applied. On the other hand, exhaust brakes are completely silent and convenient to use regularly.

Even though it has a lot of advantages, it is still a mechanical brake. I will change this brake to automate the exhaust brake with an electronic controller. We could not stop the baffle plate at any angle in the conventional exhaust brake. But in a proposed model, this feature is added. We can operate a baffle blade at any angle, even under vehicle running conditions, without creating back pressure on theengine. On the other case, for after-treatment process in the BS6 vehicles normally takes a high temperature of exhaust gases. So, placing the baffle plate at an angle restricts the exhaust gas flow and automatically increases the gas temperature.

2. Methodology

A literature review aims to understand the existing research and debates relevant to a topic or area of study and present that knowledge in a written report. Conducting a literature review helps you build your knowledge in your field.

Design calculation for torsion spring, gear tooth calculation for pinion gear, compound gear and sector gear, gear ratio calculation, motor specifications, power requirements, and Backpressure calculation for this project.

With Model-Based Design, virtual models are at the center of your development process to improve how you deliver complex systems. Use Model-Based Design with CREO software and ANSYS for FEA analysis and temperature analysis in the body.

Since this part takes the high temperature of the air, thermal analysis of a part should be conducted. So the material chosen for the proposed part could be better, and it could withstand the temperature of 500-degree exhaust air. It is chassis mounted component vibration analysis also done for this part.

After collecting all these documents, choosing the right materials, and building up the actual proto-model.

After developing the proto-model, the basic performance test should be conducted. So that we know whether our product is working fine or not. Also, list tests like the Position control test, Backpressure measurement test, sensor signal vs. throttle angle tests, and some environmental aging tests to be conducted on the sample.

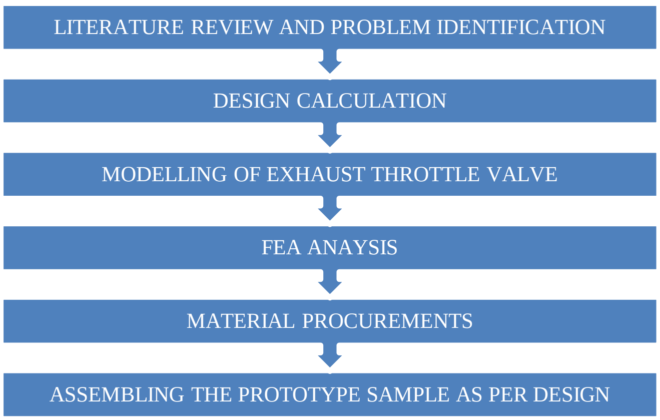


Fig. 1 Methodology flow chart

2.1. Existing System

The existing part has an exhaust brake switch, 3/2 solenoid valve, Exhaust throttle valve, and air cylinder. Whenever the need for an exhaust brake driver, press the exhaust switch, and it will connect the DC power to the 3/2 solenoid valve. It releases the air to the air cylinder, and the air cylinder stroke extends. This is what currently exhaust brake is working.

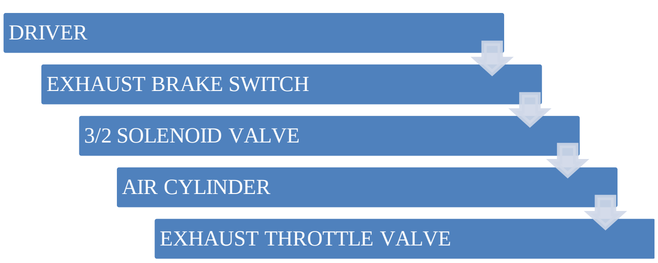


Fig. 2 Block diagram – Existing system

If the driver switches off the exhaust brake switch, sometimes the exhaust baffle plate cannot return to its actual position. Because sometimes the solenoid valve itself does not exhaust the air from delivery, that baffle plate remains closed, and it blocks the exhaust air from the engine, so back pressure is created. The created back pressure went through the engine exhaust port. It will slow down the piston movement and reduce the engine speed.

2.2. Proposed System

This system eliminates the exhaust brake switch, 3/2 solenoid valve, and air cylinder. Instead of this actuating unit along with a DC motor takes place. The exhaust air from the IC engine passes through the baffle plate.

One throttle position sensor is placed inside the controller unit, which monitors the baffle plate angle. The motor shaft is connected to the baffle plate shaft. The plate remains partially closed whenever the air passes through the baffle plate. So that the exhaust gas temperature will be high at the same time back pressure creation also less

3. Analysis

3.1. *Thermal Analysis*

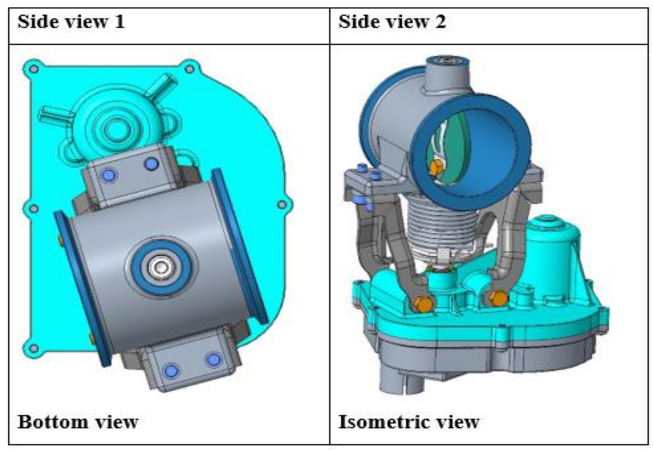


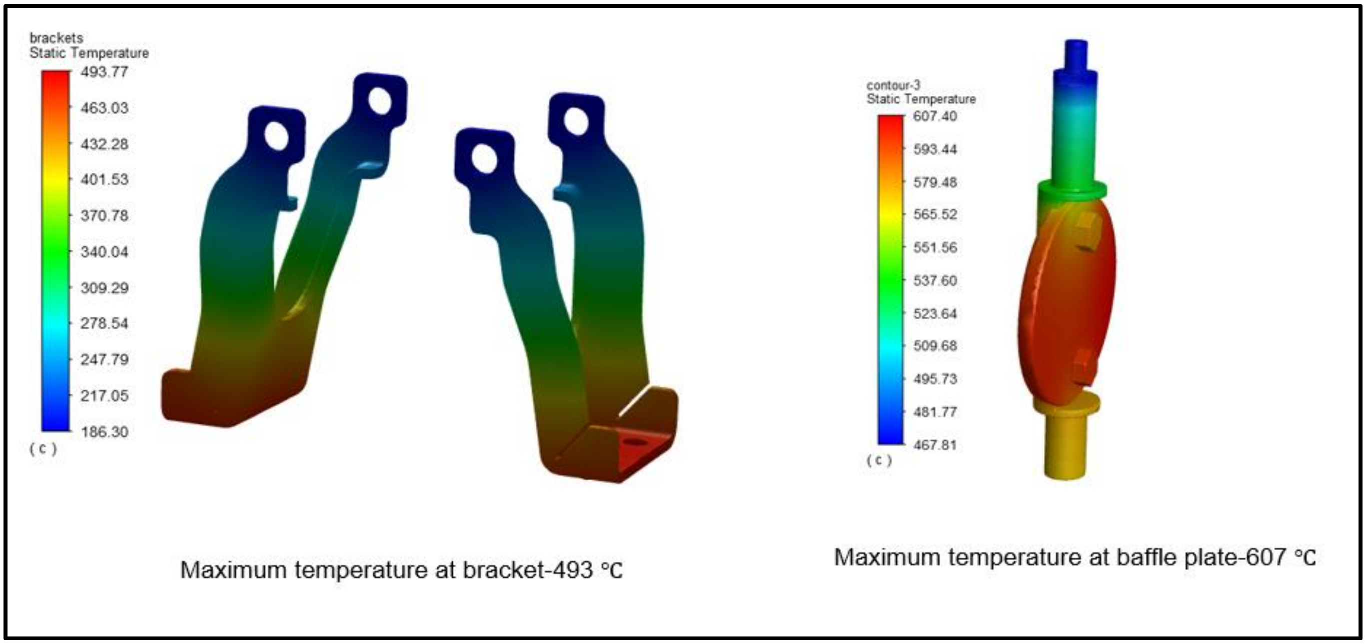
Fig. 3 3D Models

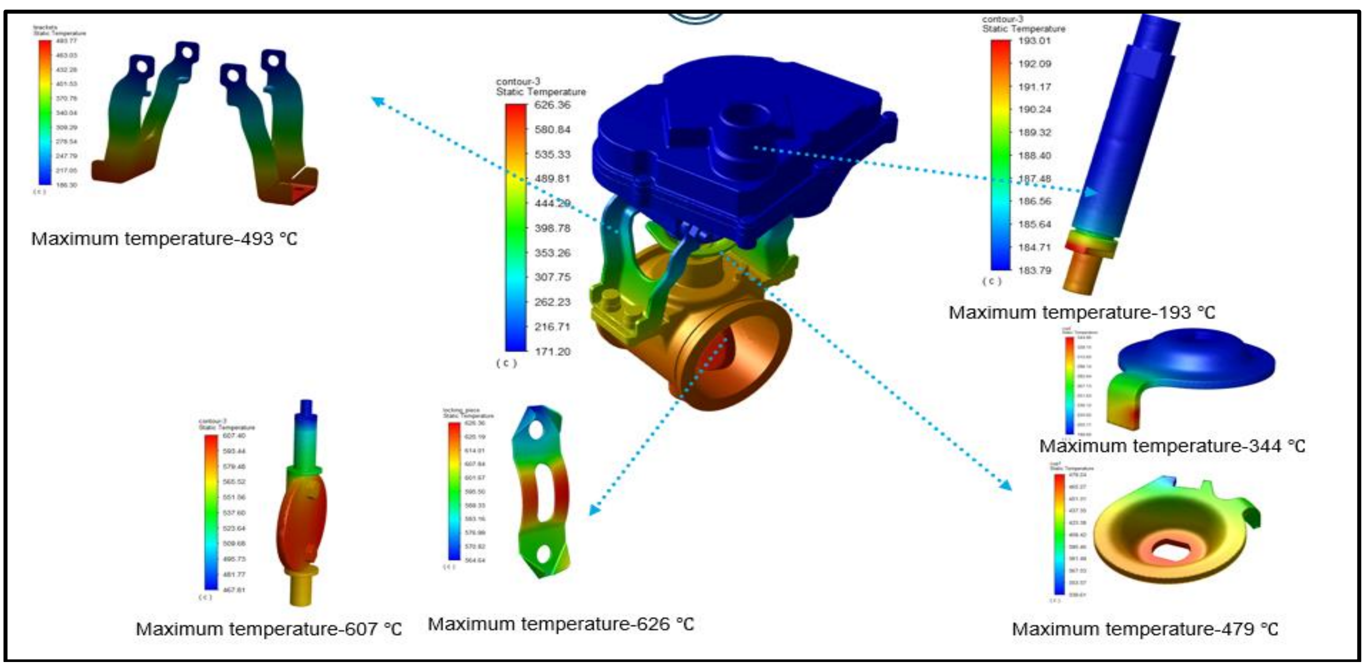
The exhaust throttle valve receives a high air temperature from the engine exhaust, and the part must be withstanding the temperature. So that temperature analysis on the part could be done.

Boundary Conditions:

Table 1. Boundary conditions – CFD

Requirements	Specifications
Exhaust gas temperature	650 °C
Atmosphere temperature	90 °C
Outlet	To atmospheric
The mass flow rate of air	100 lpm (Assumed)


brackets
Static Temperature
493.77
463.03
432.28
401.53
370.78
340.04
309.29
278.54
247.79
217.05
186.30
contour-3
Static Temperature
607.40
593.44
579.48
565.52
551.56
537.60
523.64
509.68
495.73
481.77
467.81
Maximum temperature at bracket-493 °C
Maximum temperature at baffle plate-607 °C


contour-3
Static Temperature
626.36
580.84
535.33
489.81
444.29
398.78
353.26
307.75
262.23
216.71
171.20
contour-3
Static Temperature
193.01
192.09
191.17
190.24
189.32
188.40
187.48
186.56
185.64
184.71
183.79
Maximum temperature-493 °C
Maximum temperature-193 °C
Maximum temperature-344 °C
Maximum temperature-607 °C
Maximum temperature-626 °C
Maximum temperature-479 °C

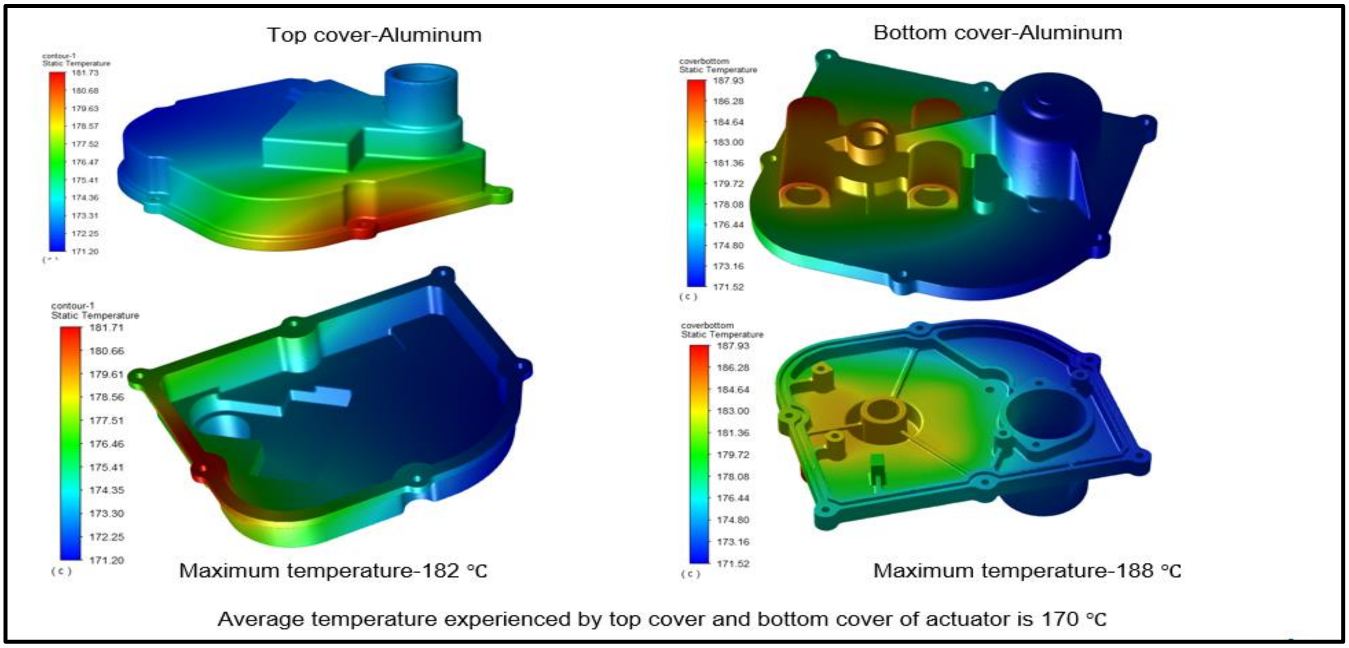


Fig. 4 Thermal analysis study

Summary:

1) The average temperature experienced by the actuator box is 170 ℃ for the given input and atmospheric conditions.
2) The maximum temperature in the actuator box is 188 ℃.
3) Surrounding atmospheric airflow velocity, the shape of obstruction, and temperature.
4) The flow velocity of air is based on the vehicle speed.
5) Material properties of the parts.
6) Location of fitment.
7) Any other additional heating source is fitted nearby the turbocharger and engine.

3.2. VIBRATION ANALYSIS

The exhaust valve was subjected to the chassis-mounted component, and a vibration study was performed on the sample. Boundary conditions:

- Two points in the exhaust valve taken as fixed points
- Not a forced vibration. It is free vibration. Rough mesh can be assumed.

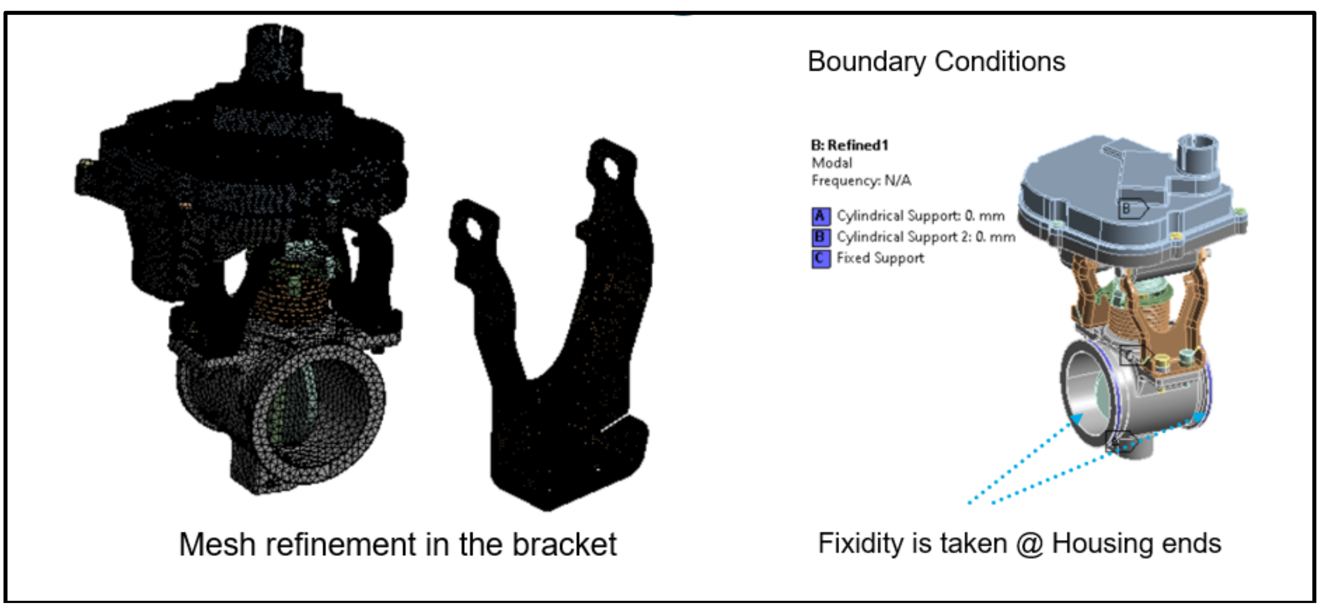


Fig. 5 Boundary conditions – vibration

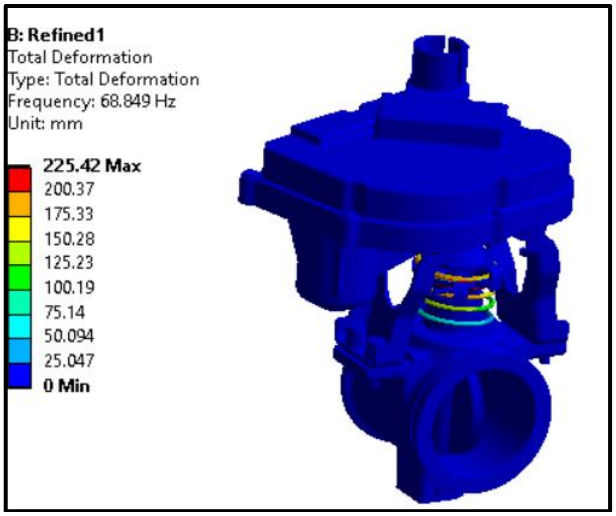


Fig. 6 First Natural frequency =69 Hz

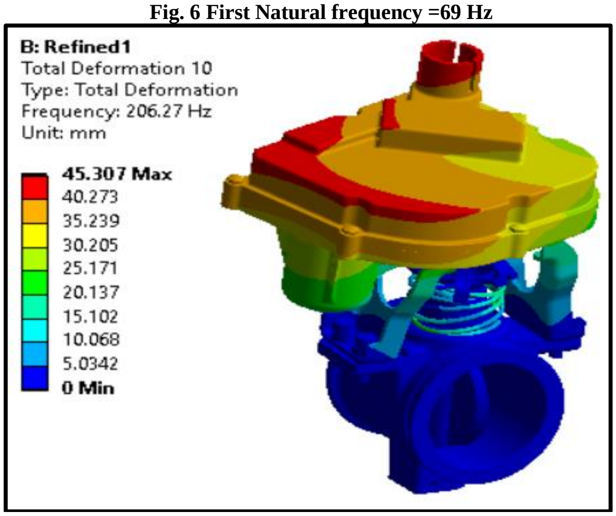


Fig. 7 Seco nd Natural frequency =76 Hz

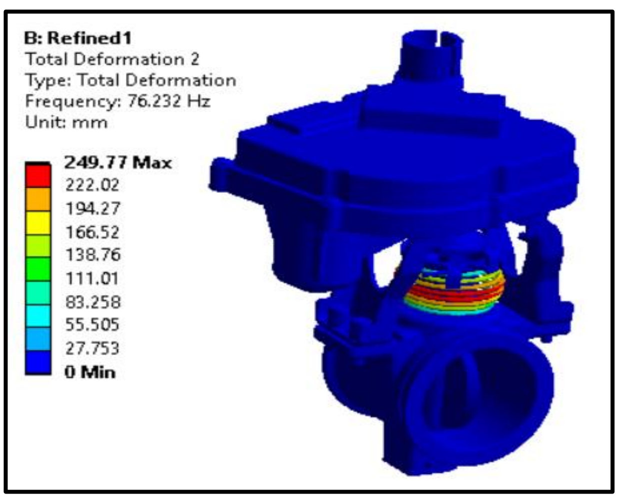


Fig. 8 Third Natural frequency =206 Hz

Observations:

- All three natural frequencies are far away from the operating frequency.
- The first natural frequency is observed in torsion springs.
- At 206 Hz itself, whole product displacement takes place.
- Hence the product looks safe.

4. Results

4.1. Back Pressure Measurement Test:

Input parameters:

- The voltage supplied to the motor: 24 V

Measurement method: Baffle plate was closed, the air was supplied at different flow rates, and backpressure values were plotted.

Table 2. Test results

Flow rate (LPM)	Backpressure (bar)
0	0
1000	1.22
2000	2.2
3000	3.14
4000	3.86
5000	4.42

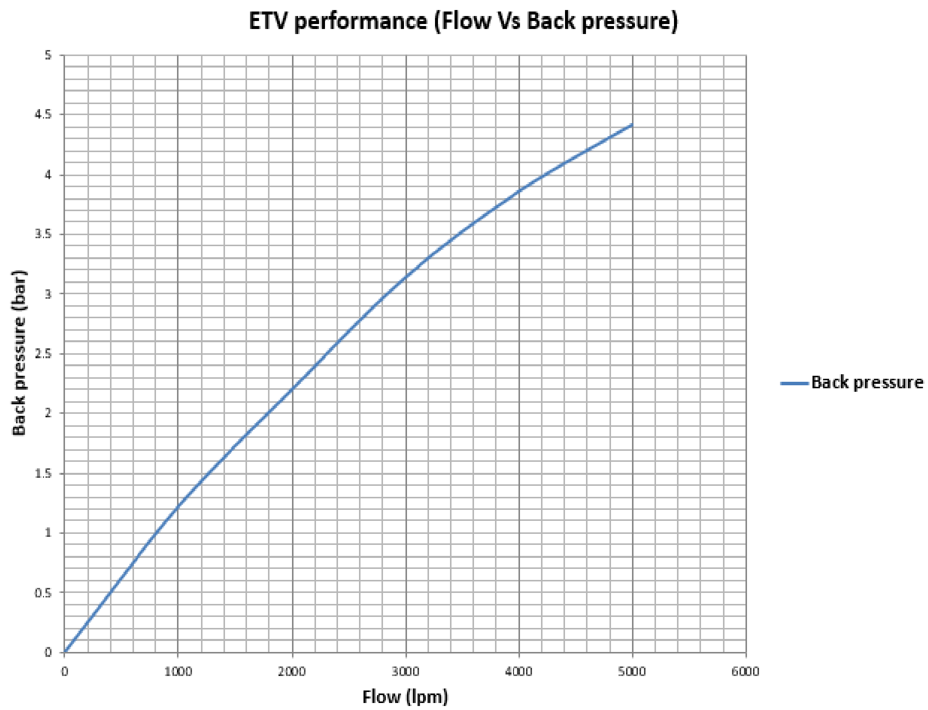


Fig. 9 Graphical Data

Measurement method: Air was supplied in controlled flow after that, the baffle was closed, and measure backpressure was.

Table 3. Test results

Flow rate (LPM)	Backpressure (bar)
0	0
1000	0.93
2000	1.70
3000	2.46
4000	3.10
5000	3.70

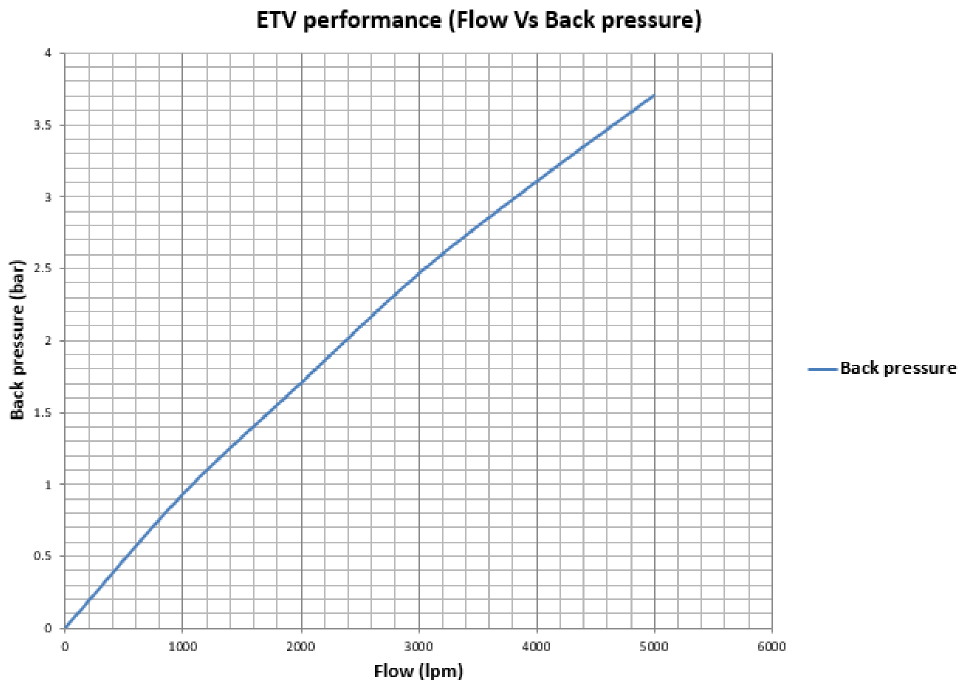


Fig. 10 Graphical Data

4.2. Angle Vs. Backpressure measurement at 5000 lpm:

Table 4. Test results

Angle (Degree)	Backpressure (bar)
0	0
15	0
30	0
45	0
60	0.05
62.5	0.1
71.27	3.70

This result shows that even in the vehicle running condition baffle plate will be in open condition. No issues occur due to this.

5. Conclusion

This proto-model has been developed to test the exhaust brake system. The construction and working of exhaust throttle valves have been studied from the start. Study on what are all the merits and demerits that occurred in the conventional system. Next, many literature papers have been studied to improvise the electronic throttle valve features. To compare the present and proposed system, 3-D modeling is developed using CREO software which is very useful for CFD and vibration analysis. Based on the simulation results, the developed part is safer in the aspect of temperature analysis. Since it is the chassis-mounted component, vibration analysis is also done. From the result, the product is safer in mechanical load study. From the literature and simulation results, the Proto model has been developed for testing the output parameters.

6. Future Work

Proving the proto-model development, testing is the only way of approach. So below works are planned for the next phase of the project.

- Constructing the proto-model, various performance tests to be carried out in the test lab
- Position control test, backpressure measurement test, sensor signal vs. throttle angle tests and some environmental aging tests, etc.,
- Compare the existing throttle valve and proposed system test results and enhance the efficiency of the output product
- If possible, vehicle level performance check to be done in heavy-duty vehicles

Acknowledgement

Author pieces of knowledge to Dr.M. Senthil Kumar, Head of the Department, Department of automobile engineering, Madras institute of technology, Anna university-Chennai for his valuable guidance, suggestion, and immense support for the smooth progress of the project.

References

[1] Jinyoung Jang, Effects of Exhaust Throttling on Engine Performance and Residual Gas in an SI Engine. (2004).
[2] David Chalet, Analysis of Unsteady Flow Through a Throttle Valve Using CFD. (2010).
[3] Thanom, Electronic Throttle Control System: Modeling, Identification and Model-Based Control Designs. (2013).
[4] Yadav, Design and Control of an Intelligent Electronic Throttle Control System. (2015).
[5] Akash Pathak, Improved Exhaust Emission Control by Using Cu-Zeolite Catalyst Based Catalytic Converter, International Journal of Trend in Scientific Research and Development. (2018).
[6] Amjad & Akram, Design and Comparative Study of Advanced Adaptive Control Schemes of Electronic Throttle Valve. (2019).
[7] DICV, Case Study – Exhaust Valve Failure. (2020).
[8] W. Huber, B. Lieberot H-Leden, W. Maisch and A. Reppich, Electronic Throttle Control, Automotive Engineering. 99(6) (1991) 15-18.
[9] C. Rossi, A. Tilli and A. Tonelli, Robust Control of a Throttle Body for Drive by Wire Operation of Automotive Engines, IEEE Transactions on Control System Technology. 8(6) (2000) 993– 1002.
[10] R. Conatsera, J. Wagner, S. Gantab and I. Walker, Diagnosis of the Automotive Electronic Throttle Control System, Control Engineering Practice. 12(1) (2004) 23–30.
[11] J. Deur, D. Pavkovic, N. Peric, M. Jansz, and D. Hrovat, An Electronic Throttle Control Strategy Including Compensation of Friction and Limp-Home Effects, IEEE Transactions on Industry Applications. 40(3) (2004) 821–834.
[12] Y. Pan, U. Ozguner and O. H. Dagci, Variable-Structure Control of Electronic Throttle Valve, IEEE Transactions on Industrial Electronics. 55(11) (2008) 3899-3907.
[13] Yuan Xiaofang, Wang Yaonan, Sun Wei and Wu Lianghong, RBF Networks-Based Adaptive Inverse Model Control System for Electronic Throttle, IEEE Transactions on Control System Technology. 18(3) (2010) 750-756.
[14] C. H. Wang and D. Y. Huang, A New Intelligent Fuzzy Controller for Nonlinear Hysteretic Electronic Throttle in Modern Intelligent Automobiles, IEEE Transactions on Industrial Electronics. 60(6) (2013) 2332–2345.
[15] Xiaohong Jiao, Jiangyan Zhang and Tielong Shen, An Adaptive Servo Control Strategy for Automotive Electronic Throttle and Experimental Validation, IEEE Transactions on Industrial Electronics. 61(11) (2014) 6275-6284.
[16] A. K. Yadav, Prerna Gaur, Shyama Kant Jha, J.R.P. Gupta, and A.P. Mittal, Optimal Speed Control of Hybrid Electric Vehicles, Journal of Power Electronics. 11(4) (2011) 393-400.
[17] Anil Kumar Yadav and Prerna Gaur, Robust Adaptive Speed Control of Uncertain Hybrid Electric Vehicle using Electronic Throttle Control with Varying Road Grade, Nonlinear Dynamics. 76(1) (2014) 305-321.
[18] Anil Kumar Yadav and Prerna Gaur, AI based Adaptive Control and Design of Autopilot System for Nonlinear UAV, Sadhana - Academy Proceedings in Engineering Science. 39(4) (2014) 765- 783.
[19] Anil Kumar Yadav and Prerna Gaur, Intelligent Modified Internal Model Control for Speed Control of Nonlinear Uncertain Heavy Duty Vehicles, ISA Transactions. (2014). http://dx.doi.org/10.1016/ j.isatra.2014.12.001.
[20] Michael J. Neath, Akshaya K. Swain, Udaya K. Madawala, and Duleepa J. Thrimawithana, An Optimal PID Controller for a Bidirectional Inductive Power Transfer System Using Multiobjective Genetic Algorithm, IEEE Transactions on Power Electronics. 29(3) (2014) 1523-1531.
[21] Anil Kumar Yadav, Prerna Gaur, A.P. Mittal, and Masood Anzar, Comparative Analysis of Various Control Techniques for Inverted Pendulum, In proceeding of IICPE, New Delhi. (2011).
[22] V. I. Utkin, Variable Structure Systems with Sliding Modes, IEEE Transactions on Automatic Control. 22(2) (1977) 212–222.
[23] V. I. Utkin, Sliding Modes in Control and Optimization, Springer, Berlin. (1992).
[24] Yangmin Li and Qingsong Xu, Adaptive Sliding Mode Control With Perturbation Estimation and PID Sliding Surface for Motion Tracking of a Piezo-Driven Micromanipulator, IEEE Transactions on Control Systems Technology. 18(4) (2010) 798- 810.
[25] Bidyadhar Subudhi and Shuzhi Sam Ge, Sliding-Mode-Observer Based Adaptive Slip Ratio Control for Electric and Hybrid Vehicles, IEEE Transactions on Intelligent Transportation Systems. 13(4) (2012) 1617-1626.
[26] Kurihara N, Yamaguchi H, Adaptive Back-Stepping Control of Automotive Electronic Control Throttle. J. Softw. Eng. Appl. (2017).
[27] Jiao X, Li G, Wang H, Adaptive Finite Time Servo Control for Automotive Electronic Throttle with Experimental Analysis, Mechatronics. 53 (2018) 192–201.
[28] Rui B, Yang Y, Wei W, Nonlinear Backstepping Tracking Control for a Vehicular Electronic Throttle with Input Saturation and External Disturbance, IEEE Access. 6 (2018) 10878–10885.