Vibration analysis of the F-segment car exhaust system

V S Popov¹, S S Gavryushin², G G Nadareishvili¹ and S I Yudin ¹

¹ FSUE "NAMI", 2, Avtomotornaya Str., Moscow 125438, Russian Federation, 
² Bauman Moscow state technical University, Moscow

E-mail: vladislav.popov@nami.ru

Abstract. The paper considers the problem of improving the comfort and environmental friendliness of a modern f-segment car with an internal combustion engine by reducing the noise and vibration levels of the exhaust system. Gas-dynamic and mechanical excitations from the car engine and road surface cause vibrations in the exhaust system, which are transmitted through the body and the bracket structure to the body causing discomfort of the driver and passengers. To reduce the negative impact, when designing the exhaust system, it is necessary to ensure such a location of the exhaust system suspension elements that will meet the maximum operation requirements for the vibration comfort. An important task is to build a numerical experiment for the entire assembly structure to determine the nature of the similar systems loading. The solution of the above tasks is aimed at the insurance of specific strength and durability of both the entire system as a whole and the most important support elastic elements. This calculated study is of practical importance not only for reducing the vibration load of car exhaust systems and the car body, but also for improving the vibro-acoustic comfort of passengers.

1. Introduction
In cities, the problem of increased noise and vibration of vehicles is becoming more and more actual. Vibrations are the cause of discomfort for residents, drivers and passengers of vehicles. The most dangerous is considered to be the impact on a person of general and combined vibration in the low-frequency range of 4-30 Hz.

All modern vehicles must meet the requirements of increased comfort and environmental friendliness. It is achieved mostly by increasing the protection against noise and vibrations of the power plant, namely, by improving the exhaust systems of any purpose cars. The solution of the problem lies in the study of natural oscillation frequencies of this system and differentiation of their values from the resonant frequencies values of the car structure elements. The main features of these systems and occurring processes in them are the aggressiveness of the exhaust gas environment, high temperature, gas flow rate, etc. [1].

2. Main part
The car's exhaust system consists of pipelines, the main purpose of which is to transfer engine exhaust gases into the atmosphere and prevent them from entering the car cabin. Baffles and chambers are designed for partial treatment of exhaust gases and reduction of noise and vibration which are caused by the gas flow. The exhaust system consists of a muffler, resonator, and connecting pipes. An example of the exhaust system under study is shown in figure 1.
Figure 1. General view of the exhaust system.

Studying the dynamics of the exhaust system design will reduce vibration and noise. The exhaust system should not be rigidly attached to the car body, because this will transmit vibrations to the cab of the vehicle. Therefore, the exhaust system must be installed through elastic elements. One of the parameters that can be effective in reducing the noise and vibration of the exhaust system is the choice of the elastic elements stiffness.

A high-performance exhaust system becomes unusable because of its insufficient durability caused by excessive vibration levels. This excessive level of vibration resulting from the engine exciting forces and road surfaces is transferred to the suspension brackets, reducing their service life. Therefore, the participation of NVH (noise, vibration, harshness) engineers when selecting the elastic elements location becomes necessary to ensure their minimal loads and increase the durability of the elements.

For the calculation analysis, a finite element model divided into 389 thousand shell elements has been created. The elastic suspension elements of the exhaust system were modeled as springs with corresponding stiffness. The exhaust system is made of stainless steel with a Young's modulus $E = 2,3 \times 10^{11}$ Pa, a Poisson's ratio $\mu = 0.3$ and a density $\rho = 7800$ kg/m$^3$.

The calculation was performed with preloading of the exhaust system by gravitational forces and thermal boundary conditions of the 2nd kind. Dissipative basalt packing was modeled by concentrated masses at the corresponding points of the structure [2]. The sagging of the exhaust system was 3 mm. Setting the boundary conditions for the calculation is shown in figure 2.
Figure 2. Boundary condition.

Modal analysis is performed using the ANSYS software package to determine the frequencies and mode shapes of the system. The results of calculations of the first ten natural frequencies of the exhaust system are shown in table 1.

| Mode | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Frequency [Hz] | 3.8 | 7.9 | 8.4 | 10.1| 14.3| 15.8| 17.8| 18.4| 26.6| 38.8|

For example, figure 3 shows the mode shapes of the exhaust system at a frequency of 18.4 Hz.

Figure 3. Sixth form of oscillation of the exhaust system.

The quality of the exhaust system suspension points can be estimated by the vibrations amplitude of the exhaust system at resonance frequencies [3]. The harmonic response of the system with an amplitude
of 1.8 g was estimated. Figure 4 shows a dependency graph of the vertical axis movements amplitude on the oscillations frequency for the four points of suspension of the exhaust system.

The results of the analysis showed that the amplitudes of oscillations at different points of suspension differ significantly. The oscillation amplitude at the second suspension point is two times greater than at the third and fourth points. When optimizing the design, the output parameters will be a reduction in the vibration amplitudes of the suspension points, followed by the further comparison of the amplitudes.

![Dependency graph of amplitude of vertical axis movements on the frequency for four points of the exhaust system suspension.](image)

**Figure 4.** Dependency graph of amplitude of vertical axis movements on the frequency for four points of the exhaust system suspension.

3. Conclusions

Thus, Finite Element Modeling allows to determine location of the vibration nodes at different frequencies. The results obtained for the considered exhaust system showed that the location of the suspension points can be optimized by calculations.

References

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