THE DYNAMIC ANALYSIS OF CATALYTIC CONVERTER

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Abstract: *The paper shows the modal analysis of analytic converter used in the engine exhaust system. For calculus is used a catalytic converter modeled by surfaces, using CATIA V5 application. On computes comparatively the vibration eigenmodes for the catalytic converter housing, with and without taking into consideration the ceramic monolith influence. The results obtained by numerical calculus are compared with experimental data achieved at the University of Pitesti.*

Keywords: catalytic converter, ceramic monolith, dynamic analysis, FEM

INTRODUCTION

Out of the engine noise sources ordered by loudness, the most important are the evacuation of combustion gases and the fresh fluid intake. The effects of these two sources is attenuated with silencers. The role of the exhaust is to evacuate the exhaust gases in the atmosphere in a form tolerable by human
Starting with the first cars with significant power, it was highlighted the lighting danger of the exhaust and the psychological disorders caused by its noise. Recent studies on the quality of our vital ambience draw attention to the part of responsibility of the engines for atmospheric pollution [1-4].
The converter designed and presented in this paper is used for a car equipped with spark ignition engine, with the cylinder capacity up to 2000 cm3.

THE 3D CONVERTER MODEL

The digital 3D model of the converter analyzed in this paper was done using the CATIA V5. The model is shown in Figure 1. The housing unit of the converter is made of stainless steel of 1.5 mm thickness.

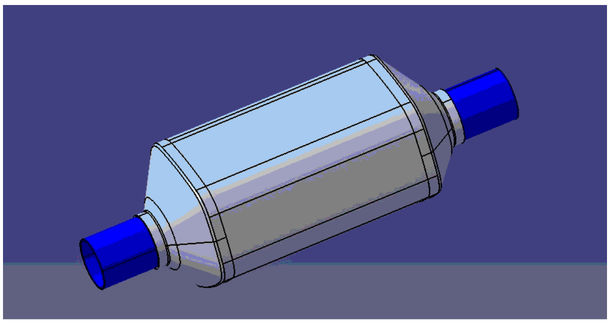

Figure 1. The 3D model of the catalytic converter.

Generally, for the construction of the housing it is used the ferrite sheet that has good mechanical strength and a good sound absorption coefficient, a good elongation and a proper workability. There are used the stainless materials because the reactions in the converter occur at high temperatures, with

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water disposal. In these conditions, the ordinary steel materials would damage (peel), and they may block or damage the ceramic monolith presented in Figure 2.

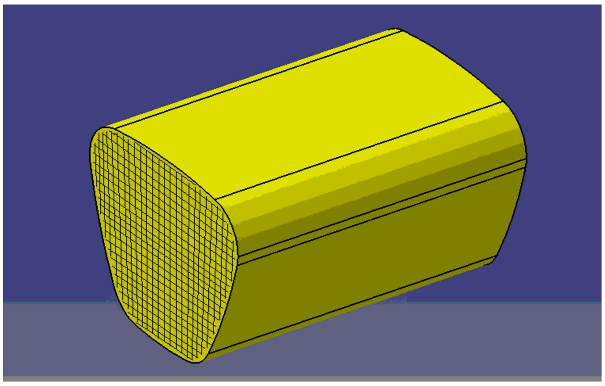

Figure 2. The ceramic monolith.

THE DYNAMIC CALCULUS

CONSIDERATIONS REGARDING THE MODAL ANALYSIS

The modal analysis consists in determination of the dynamic characteristics of structures and may include both analytical and experimental processes. The description of the dynamic characteristics of the structure is done by determining the vibration eigenmodes. Each mode of vibration is associated with certain modal properties, such as frequency, damping, amplitude, mass, etc. These characteristics of the structure may be determined at any point thereof.
The advantages of using modal analysis in the study of a system consist in the evaluation of the dynamic characteristic of the structure and the determination of their frequencies [5, 6, 7, 8].

MODAL ANALYSIS USING THE FINITE ELEMENT METHOD (FEM)

Based on its modal characteristics, a structure is more or less sensitive to vibrations. This sensitivity to vibrations is characterized by a number of extreme behaviors to some frequencies called vibration eigenmode. The numerical modal analysis determines the modal characteristics of a structure.
The basic concept in the numerical modeling with finite element is the concept of approximating the mesh. The approximation is an essential feature of the process of knowledge, representing one of the main forms of achieving it.
It is important that the mesh is sufficiently fine so that the modal deformations to be represented correctly, being necessary to have at least four elements per wavelength.
It may be carried out two types of modal analysis:
- "free - free" (free frequency analysis) - when is not taken into account the constraints (the boundary conditions);
- the conditions imposed (the frequency analysis) - when the constraints are taken into account.

During the "free - free" modal analysis, the studied structure is considered suspended and thus is not subject to any effort and any constraints. This type of analysis allows obtaining the pure characteristics of a structure, without influences imposed by the constraints or the external environment (forces, moments, etc.).
A modal analysis can be carried out also with the particular boundary conditions; these constraints are met in most cases in the operating conditions.
Solving the equation of motion for the eigenmodes matrix is written as:

$$[M]\left\{\ddot{u}\right\} + C\left\{\dot{u}\right\} + [K]\{u\} = 0 \tag{1}$$

where *[M]* is the mass matrix, *[C]* is the damping matrix, *[K]* is the stiffness matrix and u is the displacement vector [9, 10, 11, 12].

A harmonic solution adopted is:

$$\{u\} = \{\Phi\}\sin \omega t \qquad (2)$$

where Φ is the eigenvector and ω is the own pulsation.
Substituting the solution into the equation of motion and simplifying we get:

$$([K] - \omega^2 [M])\{\Phi\} = 0 \qquad (3)$$

The non-trivial eigenmode solution of the problem is reduced in terms of modal analysis to:

$$\det([K] - \omega^2 [M]) = 0 \qquad (4)$$

The equation (4) is reduced to :

$$[K - \omega_i^2 M]\{\Phi_i\} = 0 \qquad (5)$$

with i = 1, 2, 3, ...
Each eigenvalue $\lambda_i = \omega_i^2$ and eigenvector Φ_i define a free vibration of the structure. The relationship between eigenvalue λ_i, frequency f_i and own pulsation ω_i is:

$$f_i = \frac{\omega_i}{2\pi};\ \omega_i = \sqrt{\lambda_i} \qquad (6)$$

MAKING THE CALCULUS MODEL

We choose a catalyst model generated by surfaces, which is shown in figure 3. For the calculation of the vibration eigenmodes it has been used the module "Generative Structural Analysis" of CATIA V5 for the case of hanging bodies, respective the "free frequency analysis". The mesh was made of plate-shaped elements predominantly quadrilateral, as shown in Figure 4 [13].
There were analyzed to compare two ways of computing, namely:

1) there were calculated the vibration eigenmodes for the catalytic converter housing without taking into account the influence of the ceramic monolith;
2) there were calculated the vibration eigenmodes for the catalytic converter housing by taking into account the influence of the ceramic monolith.

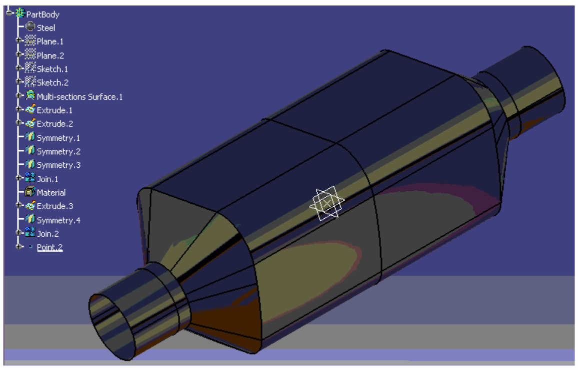

Figure 3. The calculus model generated by surfaces.

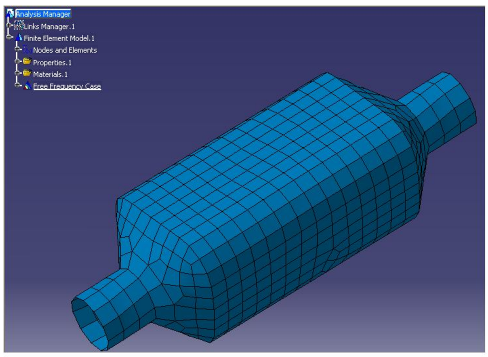

Figure 4. The mesh created without the influence of the ceramic monolith mass.

The number of elements used in the two cases is shown in Table 1. The mass of the ceramic monolith (1.9 Kg) was located at a point in the center of the converter housing using the option "mass distribution" of the calculation module as shown in Figure 5.
Table 2 presents the properties of the materials used for calculation.

Table 1. The number of elements used for each model.

Entity	Without ceramic element	With ceramic element
Nodes	663	664
Elements	653	654

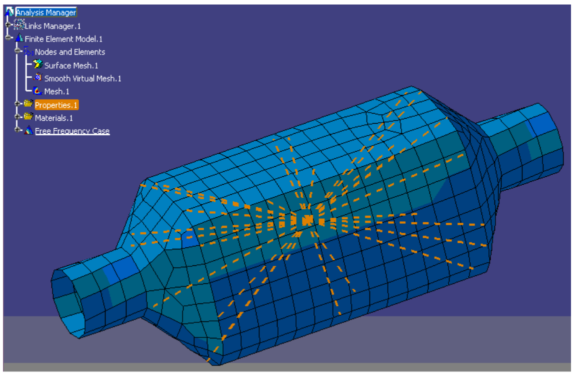

Figure 5. The mesh created simulating the influence of the ceramic monolith mass.

Table 2. The properties of the materials used for calculation.

Material	Steel
Young's modulus	2e+011N_m2
Poisson's ratio	0.266
Density	7860kg_m3
Coefficient of thermal expansion	1.17e-005_Kdeg
Yield strength	2.5e+008N_m2

In both cases there were analyzed the first 30 vibration modes. The results are presented in Table 3 for the first 30 modes of vibration in both cases (the rigid body modes are excluded from the list).

Table 3. The calculated vibration modes.

Mode number	Without ceramic element	With ceramic element	Mode number	Without ceramic element	With ceramic element
	Frequency [Hz]	Frequency [Hz]		Frequency [Hz]	Frequency [Hz]
7	6.1363e+002	6.0994e+002	19	1.8578e+003	1.8561e+003
8	8.5315e+002	8.5115e+002	20	1.8823e+003	1.8756e+003
9	9.2511e+002	9.2365e+002	21	1.9141e+003	1.9093e+003
10	9.7754e+002	9.6970e+002	22	1.9451e+003	1.9402e+003
11	1.2139e+003	1.2092e+003	23	1.9532e+003	1.9491e+003
12	1.3010e+003	1.2942e+003	24	2.0182e+003	2.0150e+003
13	1.3513e+003	1.3479e+003	25	2.3757e+003	2.3702e+003
14	1.5141e+003	1.5087e+003	26	2.4027e+003	2.3966e+003
15	1.6422e+003	1.6385e+003	27	2.4835e+003	2.4644e+003
16	1.6822e+003	1.6789e+003	28	2.5400e+003	2.5310e+003
17	1.7636e+003	1.7514e+003	29	2.6032e+003	2.5985e+003
18	1.8562e+003	1.8547e+003	30	2.6248e+003	2.6074e+003

In both cases the first six modes of vibration are equal to 0, which was expected given the case analysis used (free frequency analysis). Also, the eigenmode frequencies for the analysis taking into account the influence of the mass of the ceramic monolith have lower values than the analysis without the influence of the mass of the ceramic monolith. The visual analysis of the eigenmodes found that in the 30 vibration modes calculated appear both torsion and bending global deformation modes and local modes. The higher frequency the mode shape becomes more complex. Figure 6 and Figure 7 illustrate the vibration mode shape no. 21 (1909 Hz) for the second case.

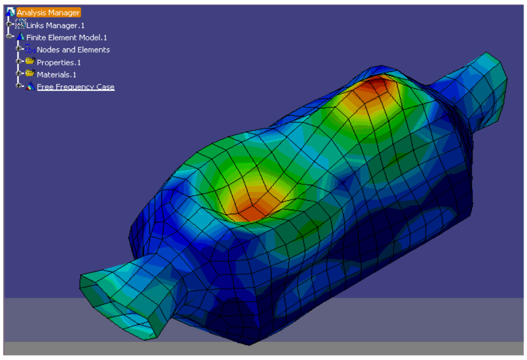

Figure 6. The deformation of the housing with monolith for the vibration mode no. 21 - the upper face

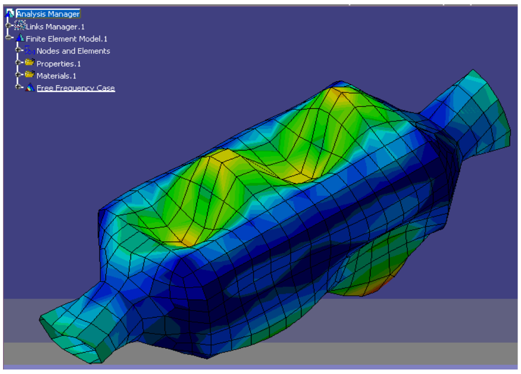

Figure 7. The deformation of the housing with monolith for the vibration mode no.21-the bottom face

MEASURING THE NATURAL FREQUENCIES OF THE CATALYTIC CONVERTER

THE MEASURING INSTRUMENTS USED

The experimental measurements were done using a measuring chain consists of the following elements:

- accelerometer type PCB, 353B04 model, sensitivity 1,011 mv/m/s^2;
- measuring amplifier;
- hammer for measurements.

Software settings:

- accelerometer, 1 Hz high-pass filter, FFT analysis up to 10,000 Hz;
- the FFT analysis was set to 3200 points of calculation.

These elements are shown in Figure 8. We used the integrated Soudbook system with SAMURAI (SINUS Messtechnik GmbH) software specialized in measurement and analysis of vibration and noise. This software is dedicated to data acquisition, signal analysis and control of various devices and external equipment. The hammer used to strike the piece in order to achieve the vibration is specifically for measurement of vibrations and incorporated therein a power transducer that is used in some measurements.

Figure 8. The device used for measurements.

Multiple measurements were made mainly in two cases, namely: with the converter suspended (Figure 9) and with the converter mounted in the overall exhaust assembly (Figure 10).

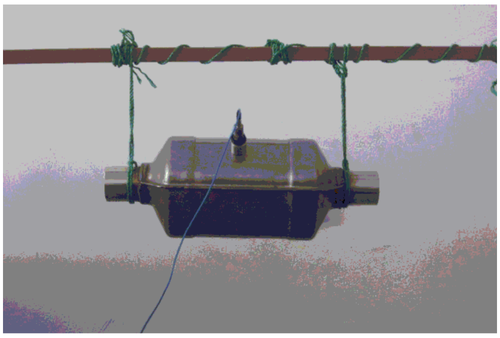

Figure 9. The converter suspended.

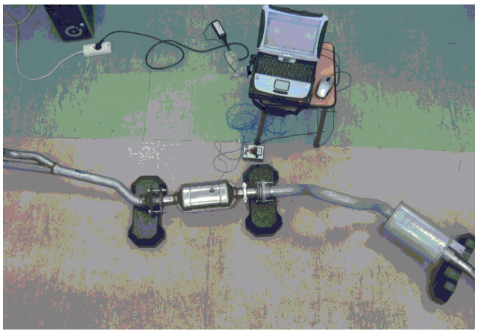

Figure 10. The converter mounted in the overall exhaust assembly.

THE EXPERIMENTAL RESULTS

The determinations were performed by several experiments in which the accelerometer was mounted in various positions on the catalyst, and it was excited in different directions. Figure 11 shows the results obtained with the suspended converter, the accelerometer mounted centrally disposed and the transverse excitation, and Figure 12 shows the results when the accelerometer is centrally disposed and the excitation is longitudinal.

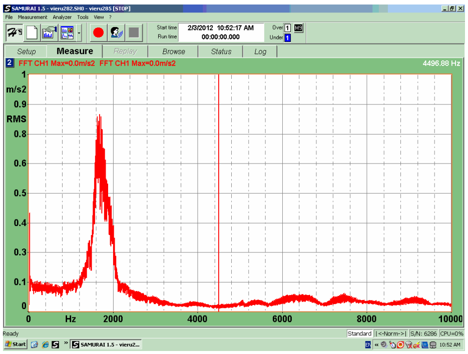

Figure 11. The results with the accelerometer centrally disposed and transverse excitation.

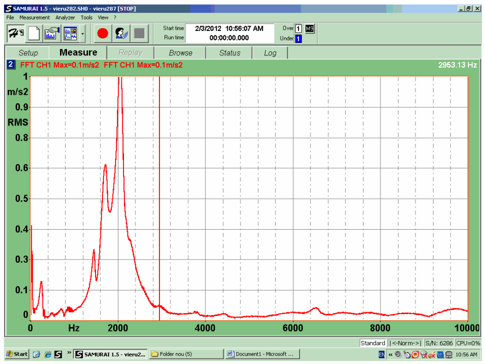

Figure 12. The results with the accelerometer centrally disposed and longitudinal excitation.

It could be observed that in both cases the maximum values of vibration amplitude is around 2000 Hz, so close to the vibration mode no. 21. For the values greater than 2000 Hz, the analyzed signal amplitude decreases. The results of the experimental measurements for the exhaust assembly are shown in Figure 13.

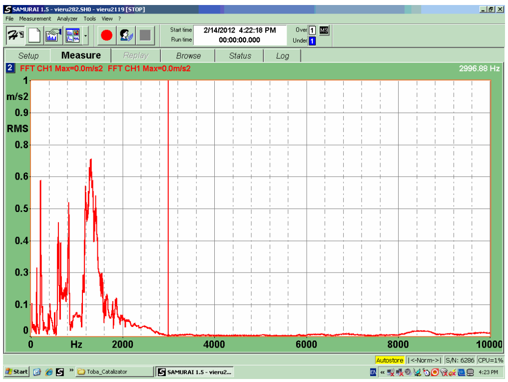

Figure 13. The results of the experimental measurements for the exhaust assembly.

CONCLUSIONS

For the measurements done with the converter mounted in the exhaust assembly, it was observed that the signal keeps generally the same shape but the maximum values of the amplitudes are obtained for frequencies below 2000 Hz.

Once determined, the eigenfrequencies can be used for:

- frequency analysis and transient analysis;
- experimental analysis;
- optimize the dynamic behavior of structures.

In the modal analysis, the dynamic response of the structure is the sum of the individual eigenmodes of vibration. By determining the characteristics of the vibration modes using experimental and / or analytical means, it is possible to determine what undesirable responses (noise, vibration, great efforts) are created and to formulate the corrective action.

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