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COMPARATIVE ANALYSIS OF VIBRATION MODES FOR A VENTILATED BRAKE DISC30

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Abstract: *This paper presents an analysis of vibration modes for a ventilated brake disc made of materials with different properties. It was analysed the brake disc made of two different materials, and the discs made with the same type of material, differing only in its density. The analysis was conducted using FEM (Finite Element Method) and CATIA V5.*

Keywords: ventilated brake disc, vibration modes, FEM, CATIA V5.

INTRODUCTION

During an analysis of vibration modes it is supposed that the piece vibrates under the influence of initial impulse; in this case, we are interested by the vibration mode and the frequency of vibration mode of the piece. Practically, the vibration mode is one of the many ways in which the piece deforms when vibrating.
The determined frequencies of the vibration mode can be used for:

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

By exciting the system at a frequency close to its own frequencies, the system will vibrate with an increasingly amplitude and the resonance phenomenon occurs. The risk of this phenomenon is to overpass the elastic limit of the system and to damage it or producing noise over the limit. The eigenmodes can be analyzed taking into account the amortization or taking not.
In this paper, the amortization it was not taken into consideration because it is considered to be less than 15%, which is a typical value for similar parts in the automotive industry.

CALCULATION OF EIGENMODES

FEM is a technique based on numerical analysis to obtain approximate solutions used to determine the variation of parameters that characterize the continuous media such as the fields of displacements, strains or stresses.
This involves achieving a finer meshing together with increasing the frequency of study, because the wavelength decreases while the frequency increases.
The mesh used for the dynamic study of the frequency bands analyzed for components of automotive axles is generally the same as that used for the static studies.
Two main types of analysis can be performed for the boundary conditions:
- free frequence analysis, when the constraints (the boundary conditions) are not taken into account;
- with imposed conditions (frequence analysis), when the constraints are taken into account.
In the free frequence analysis, the structure is considered suspended and thus is not subject to any effort or constraint. This type of analysis allows to obtain the pure characteristics of a

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structure, without influences imposed by constraints or by the external environment (forces, moments, etc.)
A piece decomposed into finite elements (discretized) will have a vibration number equal to the sum of the degrees of freedom minus the number of degrees of freedom overturned by constraints.
Solving the equation of motion for the vibration modes written in the matrix form is [1]:

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

where [M] is the matrix of mass, [K] is the stiffness matrix and {u} the displacement vector.

A harmonic solution adopted is of the form:

$$\{u\} = \{\Phi\}\sin\omega t \tag{2}$$

where Φ is the vector and ω is the pulsation.

Replacing the solution in the equation of motion and simplifying we obtain:

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

The solution to the eigenmodes problem is reduced in terms of modal analysis to:

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

The equation (3) is reduced to:

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

with i=1,2,3,....

Each value $\lambda_i = \omega_i^2$ and vector Φ_i define a free vibration mode of the structure. The relationship between the eigenvalues λ_i, frequencies f_i and pulsations ω_i is:

$$f_i = \frac{\omega_i}{2\pi}; \quad \omega_i = \sqrt{\lambda_i} \tag{6}$$

The 3D model of the brake disc analysed is shown in Figure 1.

Figure 1. The 3D model of the brake disc analysed.

For the calculation there were used three kinds of materials whose properties are shown in Table 1 [2].

Table 1. The properties of the materials used.

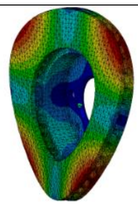
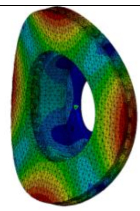
Cast iron	Hardness [HB]	Resistance	Young's Modulus [MPa]	Density [kg/m^3]	Poisson coefficient
GL 09 (standard)	197-241	>200	121000	7200	0,29
GL 09 (modified)	197-241	>200	121000	7300	0,29
GL 11	170-217	>150	101000	7100	0,29

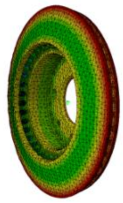
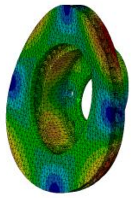
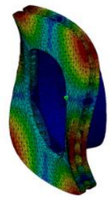
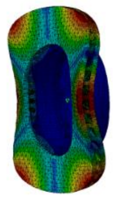
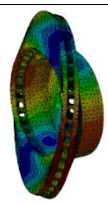
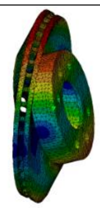
The meshed model contained a number of 33604 nodes and 133365 items. The calculation was done for free frequence analysis case of the Generative Analysis Structural module, part of CATIA V5 [3].

THE RESULTS OBTAINED

Table 2 presents the eigenmodes obtained for the three cases studied and the images of each mode. It is noted that each of the first six vibration modes has zero value, which is normal for this type of analysis which corresponds to rigid body motion.

Table 2. The eigenmodes obtained by calculation.

Mode no.	GL09 cast iron (standard)	GL09 cast iron (modified)	GL11 cast iron	Image (standard mode)
Frequency [Hz]				
1	0.0000e+000	0.0000e+000	0.0000e+000	
2	0.0000e+000	0.0000e+000	0.0000e+000	
3	0.0000e+000	2.1855e-004	0.0000e+000	
4	6.3473e-004	3.5385e-004	8.2524e-005	
5	7.1592e-004	8.4636e-004	1.7128e-004	
6	8.3715e-004	9.5881e-004	5.4668e-004	
7	1.6324e+003	1.6211e+003	1.5018e+003	
8	1.6393e+003	1.6281e+003	1.5082e+003	

Mode no.	GL09 cast iron (standard)	GL09 cast iron (modified)	GL11 cast iron	Image (standard mode)
Frequency [Hz]				
9	3.1743e+003	3.1525e+003	2.9205e+003	
10	3.4085e+003	3.3850e+003	3.1359e+003	
11	3.4653e+003	3.4415e+003	3.1882e+003	
12	3.6417e+003	3.6167e+003	3.3505e+003	
13	3.6435e+003	3.6185e+003	3.3522e+003	
14	4.0276e+003	4.0000e+003	3.7056e+003	
15	4.0345e+003	4.0068e+003	3.7119e+003	

There were analyzed the frequencies up to approximately 4000 Hz, which corresponded to the first 15 modes of vibration.

Table 3 shows their values started with the vibration mode no. 7, calculating the frequencies deviations from the GL09 cast iron -standard material.

Table 3. The vibration modes and their deviations.

Mode no.	GL09 cast iron standard	GL09 cast iron modified		GL11 cast iron	
	Frequency [Hz]	Frequency [Hz]	Average deviation	Frequency [Hz]	Average deviation
7	1632	1621	1[%]	1502	8[%]
8	1639	1628		1508	
9	3174	3153		2921	
10	3409	3385		3136	
11	3465	3442		3188	
12	3642	3617		3351	
13	3644	3619		3352	
14	4028	4000		3706	
15	4035	4007		3712	

CONCLUSIONS

It is noticed that when using the same type of cast iron, differing only the density of the material (GL09-standard cast iron / GL09-modified cast iron), the deviation is low (1%). The usual rules states that the frequencies of a piece with deviations in geometry or material characteristics does not differ by more than 5% from those obtained at its homologation.
In the situation of using a different type of cast iron (GL11), the deviations are 8%, greater than 5%, as shown in Table 3.
At the homologation of the brake discs could be imposed additional measurements of the vibration modes, and when a defect of failure occure the frequencies measurements will be compared, thereby achieving rapid and with minimum costs information about possible changes in material or shape. Shape changes can occur when changing the molds, in particular to the inner walls of the ventilated brake disc.

REFERENCES

[1] Cheung, Y. K., *Finite Element Methods in Dynamics*, Kluwer, 1991.

[2] * * * *Renault standards for cast iron parts*.

[3] * * * *CATIA V5 DOCUMENTATION*.