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Comparison of Natural Frequencies of a MacPherson Suspension Arm using Different Bushings

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Abstract. **The main function of the suspension system and its components is to absorb vibrations when the vehicle moves over bumps and to provide its stability in the different operating modes. Some of the vibration parameters are natural frequencies and mode shapes. This paper presents the results of the natural frequencies of an arm of the MacPherson front independent suspension using different bushings. For this purpose, three-dimensional geometric model of the arm was created and its frequency analysis was performed by Finite Element Analysis (FEA) using SolidWorks software. The obtained results of the natural frequencies of the arm with different bushings by FEA were presented and compared with those obtained experimentally.**

Keywords: experimental study, FEA, mode shape, natural frequency, polyurethane bushing, rubber bushing.

I. Introduction

The suspension system serves to transmit the forces acting on the wheel to the frame and ensure the smooth movement of the car. In the case of independent suspensions, the smoothness is improved by reducing unsprung mass, which also reduces the natural frequency of vertical vibrations.

It is well known that optimal ride comfort is achieved when the natural frequency is in the range of 1-1.5 Hz. The range of the natural frequency and vibration amplitude must be taken into account during the design process of the suspension and its components. Study [1] presents an investigation of the vibrational behavior of a car suspension in the frequency range from 50 to 200 Hz.

The suspension arm has been studied in various references [2]-[9] using Finite Element Analysis (FEA) software and experimentally. Studies [4], [6]-[8] provide results on the modal analysis of the suspension arm using FEA. In [2], [3], [9] the results of dynamic analysis of the suspension arm by FEA and experiment are presented. In most of the papers [3]-[5], [8], [9] in the study of the suspension arm, in the mounting locations of the bushings, their stiffness is not considered, and usually the constraints are set by using fixed supports. It is known that the elastic (stiffness) and damping characteristics of suspension components affect the ride comfort and must be selected appropriately. Therefore, it is correct to consider the stiffness characteristics of bushings when performing various analyses of the suspension and its components, which affects the natural frequencies of metal parts [10].

The purpose of this study is to determine and compare the natural frequencies of a front arm of a MacPherson type suspension using different bushings. The simulation results of the natural frequencies were confirmed by experiment, which is also part of the current study.

II. Materials and Methods

The MacPherson type is widely used in the front suspension of modern passenger cars and its advantages are simpler design and structure, small mass, low cost and good comfort.

The natural frequencies of the arm are most often determined by performing a physical experiment, analytically determined or by using FEA.

A control arm is one of the main suspension elements that connects the wheel hub to the vehicle frame. A connection between the arm and the frame is made by using various bushings, and between the wheel and the arm by using ball joints.

The object of the study is an arm of the MacPherson front independent suspension on the passenger car Skoda Octavia. Figure 1 shows 3D model of an arm and the place 1 and 2, where the bushings are mounted.

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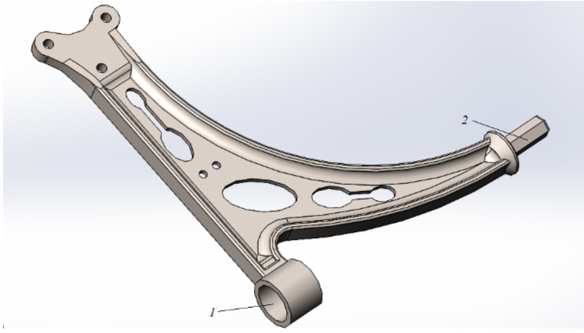


Fig. 1. The three-dimensional geometric model of an arm.

The correct setting of the supports is critical in determining the natural frequencies and mode shapes of the suspension and the arm, respectively.

Bushings were used as elastic supports of the arm and their stiffnesses were calculated by different methods and presented in another publication by the authors.

Recently, rubber bushings have been increasingly replaced by polyurethane bushings because the polyurethane material has many advantages, some of which are high strength, high elasticity, and the ability to suppress vibrations [11], [12]. The comparison of the natural frequencies of the arm was performed using two bushings of different materials. In the Case I, a rubber bushing was used as an elastic support at mounting location 1, and in the Case II, a polyurethane bushing was used. In both cases, the rubber bushing was mounted at position 2 of the arm.

Table 1 shows the bushing stiffness results needed to perform the arm frequency analysis using FEA.

TABLE 1 FEA STATIC STIFFNESS OF THE BUSHINGS.

Stiffness	**Values**		
	Rubber bushing 1	***Rubber bushing 2***	***Polyurethane bushing 1***
Axial stiffness (N/mm)	107	147.1	1407
Radial stiffness (N/mm)	3505	594	2923

Natural frequencies and mode shapes were determined by frequency analysis in SolidWorks Simulation. The arm is made of cast steel, according to EN10293 and its mechanical properties are presented in [13], [14].

Figure 2 shows the fixation of the arm by elastic supports at the mounting locations of the rubber bushing surfaces.

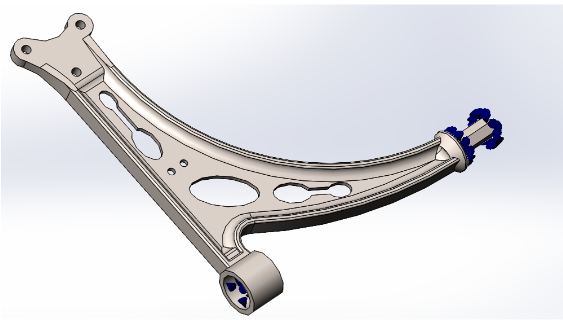


Fig. 2. Elastic supports.

A three-dimensional curvilinear mesh was generated (fig. 3). It includes 206 546 nodes and 129 397 elements.

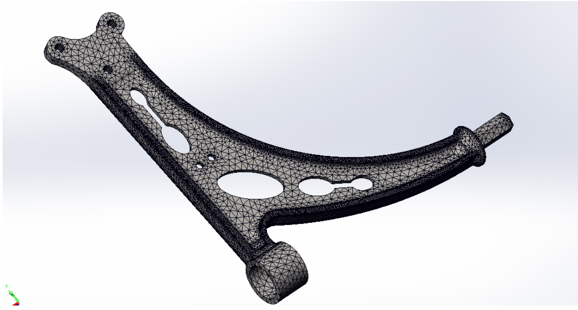


Fig. 3. FEA mesh.

The natural frequencies of the arm were also determined by a physical test. It was carried out by measuring and recording the accelerations along the three axes x, y and z. The experimental study was carried out using a developed system for determining the natural frequencies presented in [13],[14]. Each test was performed ten times for accuracy and reliability.

Fig. 4 shows the object and the measuring equipment for the experiment, which is consisted of the following components: 1 - arm, 2 - accelerometer ADXL335, 3 - multifunction I/O Device NI USB-6343, 4 - power supply and 5 - PC. Fig. 4a shows the experiments using rubber bushings 1 and 2, and Fig. 4b shows the experiments using polyurethane bushing 1 and rubber bushing 2.

a) Case I

b) Case II

Fig. 4. Experimental determination of natural frequencies.

The accelerometer was attached to the suspension arm. The mass of the accelerometer is very small and this has a negligible effect on the measurement. The FFT method in MATLAB software was used.

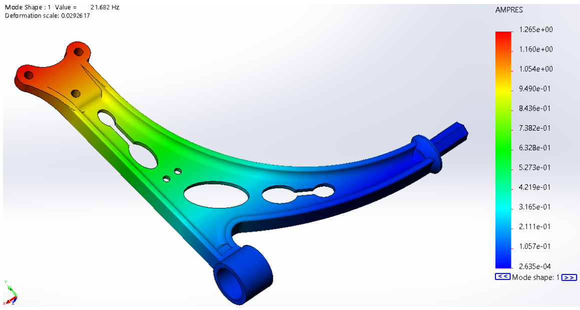
III. RESULTS AND DISCUSSION

Table 2 shows the results of the six natural frequencies of the arm obtained by FEA for both cases.

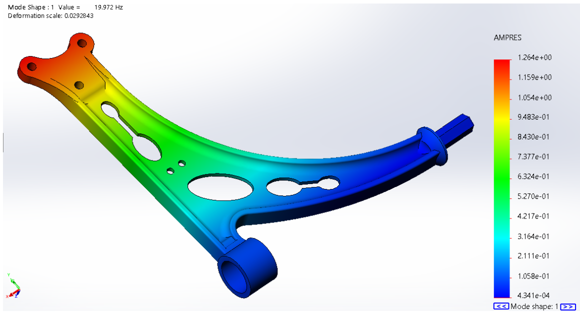
TABLE 2 THE NATURAL FREQUENCY FROM FEA.

Mode number	Natural Frequency, Hz	
	Case I	***Case II***
1	21.68	19.97
2	78.16	76.77
3	128.34	122.89
4	134.38	127.32
5	232.71	217.5
6	250.31	231.19

The first mode shape in the Case I and Case II are shown in Fig. 5a and Fig. 5b. Fig. 6a and Fig. 6b present the second mode shape in both cases.

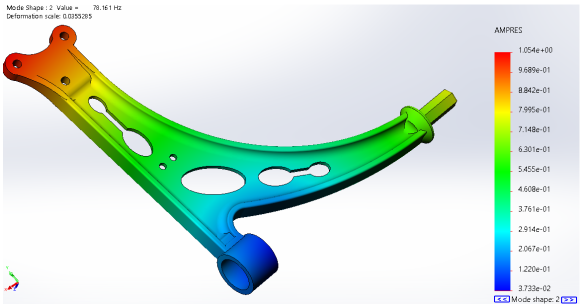


a) Case I

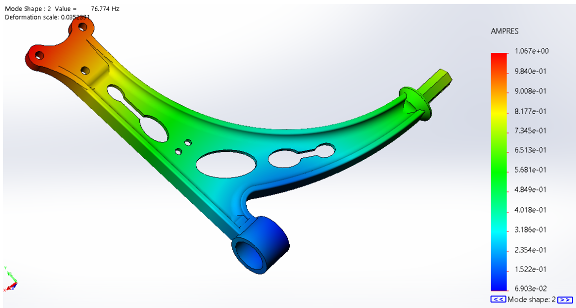


b) Case II

Fig. 5. The first mode shape.



a) Case I

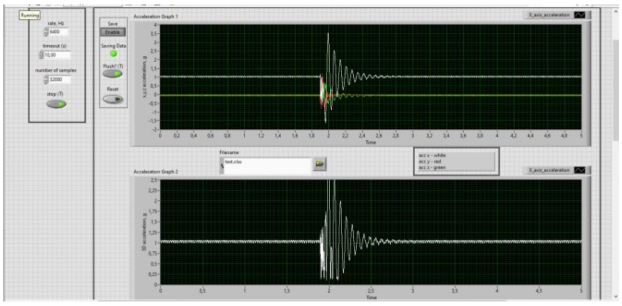


b) Case II

Fig. 6. The second mode shape.

Fig. 7 illustrates the obtained experimental results for acceleration in raw format along the three axes - x, y, and z. The electrical signal received from the accelerometer was processed without software filtering.

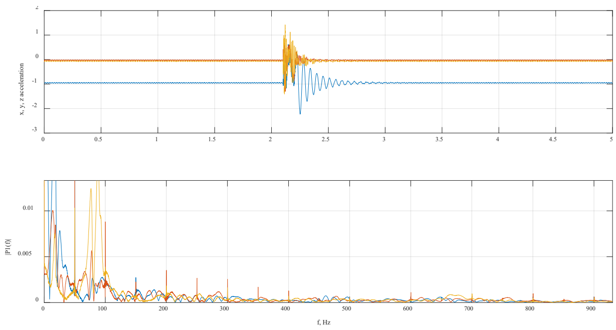
a) Case I



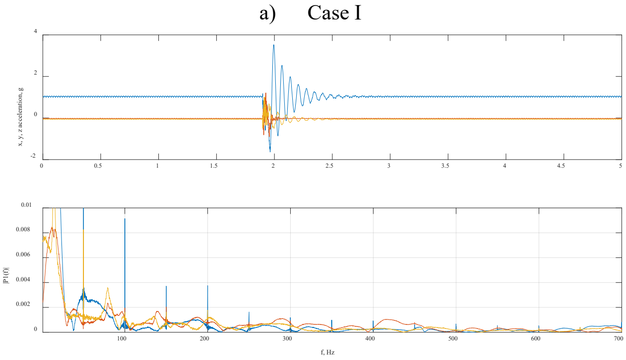
b) Case II

Fig. 7. Experimental acceleration results.

FFT analysis of the experimental data was performed and the results for the natural frequencies for each axis are shown in Fig. 8.



a) Case I



b) Case II

Fig. 8. FFT analysis.

Table 3 presents the experimental results obtained for the both cases.

TABLE 3 THE NATURAL FREQUENCY FROM EXPERIMENTS.

Mode number	Natural frequency, Hz	
	Case I	*Case II*
1	22.4	21.6
2	92.8	79.2
3	134.8	108
4	149	116
5	233.6	208
6	247.6	226

The natural frequency results obtained by FEA are comparable to those obtained experimentally.

It can be seen that the relative errors between simulation and experimental results does not exceed 15.78%.

IV. CONCLUSIONS

On the basis of the results of the study, the following conclusions can be drawn:

The overall results (based on both cases) regarding the natural frequencies of the arm obtained by FEA show that the lowest value is 19.97 Hz (Table 2, Mode number 1, Case II) while the lowest value obtained by the experiment is 21.6 Hz (Table 3, Mode number 1, Case II). The next value of natural frequencies is significantly higher than the frequency of excitation forces generated by road surface irregularities [2].

The results of natural frequencies of the arm with rubber and polyurethane bushings obtained by FEA (Case I and Case II) are close and the most significant difference is about 8%.

Corresponding values of the natural frequencies obtained by FEA are close to experimentally registered once, e.g. Table 2 Case I versus Table 3 Case I.

The results obtained for the natural frequencies from the numerical study by FEA and the experimental study show that the first six natural frequencies when the original rubber bushing is used are higher in value compared to the variant where the polyurethane bushing is used. This is due to the different characteristics of the two materials.

From the obtained experimental results of natural frequencies when using different bushings, it can be seen that the significant difference is in the fourth natural frequency - 28.4%, and in the results of numerical simulation with FEA, in the first - 7.89%. The significant difference in the experimental study may also be due to the fact that the rubber bushing, unlike the polyurethane one, is not new, which to some extent may be related to the change in the material properties.

The obtained results of natural frequencies can be used as a basis for solving various problems of suspension system and its components.

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