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NVH ANALYSIS OF OFFROAD VEHICLE FRAME. EVALUATION OF MUTUAL INFLUENCE OF BODY-FRAME SYSTEM COMPONENTS

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Abstract. The article focuses on the basic NVH characteristics of a vehicle such as global static stiffness, eigenfrequencies and local dynamic stiffness. We built the Smart Digital Twin of serial SUV that allow reduce the time and costs of the design stage by reducing the number of real tests. The optimal target values of static stiffness for the Frame and BIW were selected to achieve the target static stiffness of the Trimmed body.
Keywords: finite element, frame, frequency, stiffness, vehicle.

1. Introduction

In the modern world people spend a lot of time in a vehicle, so vibro-acoustic comfort in a car plays a very important role, influencing the customer product satisfaction and, although not directly, on safety, reducing driver tiredness. Term NVH unites a complex of characteristics related to behavior of the vehicle structure under the operating loads and responsible for vibro-acoustic perception by human senses. During the development of new vehicles, it is always required to work out the tasks of improving the design effectiveness, i.e. to find the best compromise between high level of safety, light weight, fuel efficiency, reliability and such customer demands as perfect handling, vibro-acoustic comfort, load carrying capacity etc.

In body-on-frame vehicles much attention is paid to the frame as the main load-bearing part, which is a support for the powertrain, suspension and body. In the case of body-on-frame SUV, there are two separate subsystems, the frame and the body, which are designed usually by separate departments. Each system has its own individual characteristics, which change when the systems become the parts of an assembly.

In this paper we present the results of our work for the new body-on-frame SUV. Its predecessor, the serial SUV, was used as the basis for analysis. In order to completely switch to digital design in the new paradigm of Digital factories, we built the Smart Digital Twin of serial SUV, that will allow reduce the time and costs of the design stage in future, by reducing the number of real tests. The final purpose of the work is: having the target levels for selected characteristics on a trimmed body, to cascade them down to the lowest levels and to issue target values for individual subsystems, the Frame and the Body, with the purpose of using in the respective departments. The analyzed objects, Smart Digital Twins of the Frame, the Body and the Trimmed body are shown in Figure 1. The new vehicle design based on the Smart Digital Twin validated by results of our work; make us convinced the digital design will give us the results that will match the acceptance tests.

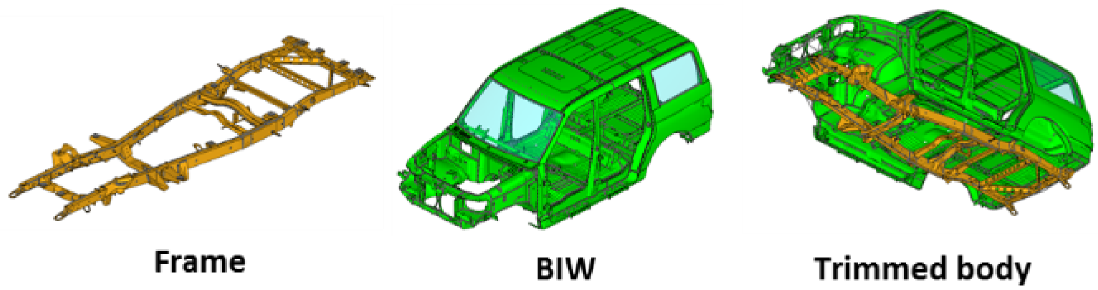


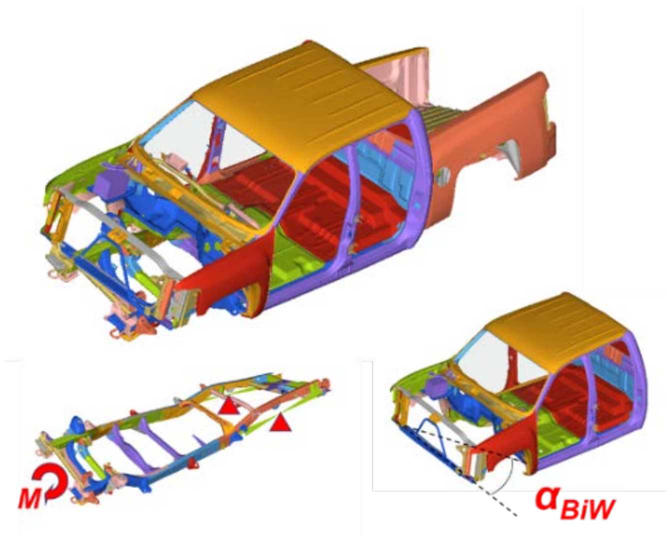
Fig. 1. Analysis objects.

2. Static and dynamic stiffness analysis of body-on-frame SUV

One of the design effectiveness key indicators is the static and dynamic stiffness. Static stiffness of the frame is mainly defined by its global torsional, vertical and lateral stiffness. The torsional and vertical stiffness of the frame plays big role in isolating PWT and road vibrations and load carrying capacity of a vehicle. The lateral stiffness of the frame is very important for appropriate handling and cornering ability of the vehicle.

Dynamic stiffness of the frame is mainly defined by its global eigenfrequencies and local dynamic stiffness (LDS), and also plays major role in isolating main sources of noise and vibrations. The eigenfrequencies of the frame should be as high as possible and be decoupled with frequencies of harmonic excitations of such systems as PWT, chassis, fans etc. The local dynamic stiffness should be high enough to provide good filtration of rubber mounts. Because of the similarity of approaches, static stiffness is represented by the example of torsional stiffness, modal analysis by the example of torsional mode, local dynamic stiffness by the example of powertrain mounts only.

Static stiffness. To define the torsional static stiffness of the trimmed body, the frame is loaded with a twisting moment, and twisting angle of the BIW is evaluated (Fig. 2). To define the torsional static stiffness of the trimmed body, the frame is loaded with a twisting moment, and twisting angle of the BIW is evaluated (Fig. 2).



$$C_{tor.fr+BiW} = \frac{M}{\alpha_{BiW}}$$

Fig. 2. Torsional stiffness of the trimmed body evaluation test scheme.

Torsional static stiffness of the yrimmed body is the ratio of twisting moment (applied to the frame) to twisting angle of the BIW. This characteristic is included in the vehicle technical requirement list. It is useful for the structure analysis to make a plot of twisting angles along the BIW length as shown in Figure 3.

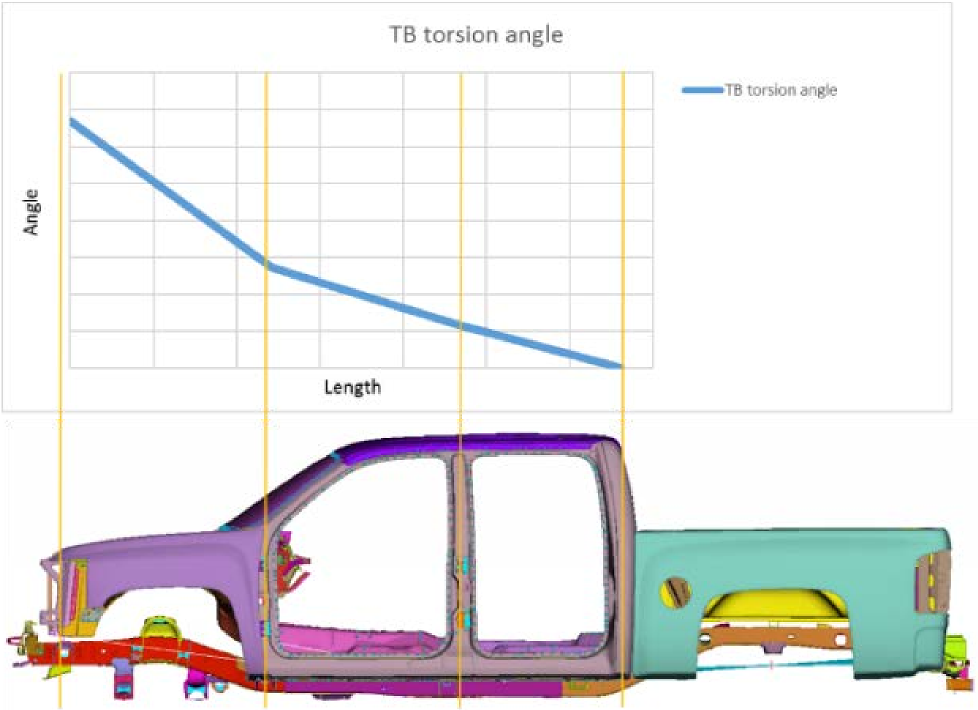


Fig. 3. Example of the plot of twisting angles along the BIW length.

Modal analysis. The lowest eigenfrequencies of the trimmed body are defined to decouple them with the eigenfrequencies of unsprung masses and the frequencies of engine idle vibrations (Fig. 4).

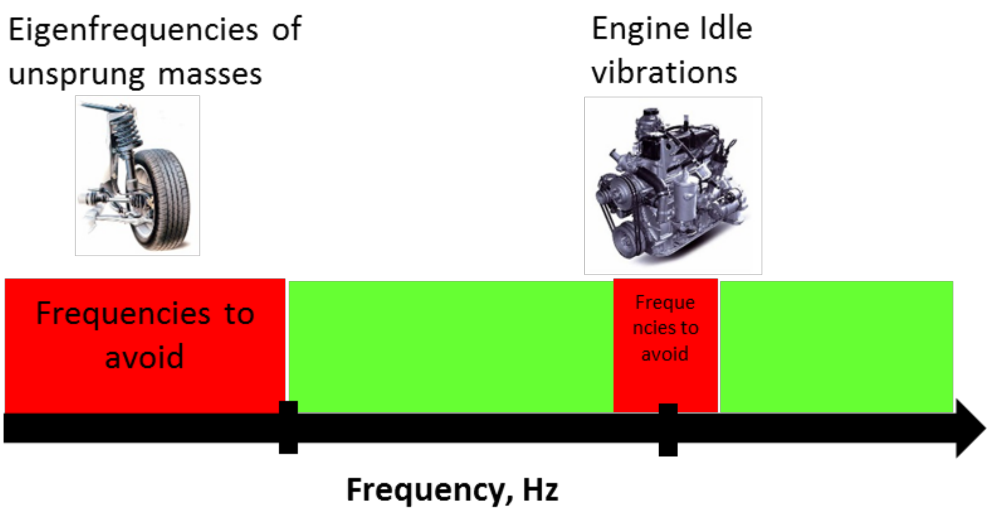


Fig. 4. Global eigenfrequencies to avoid scheme.

Local dynamic stiffness of the rubber mounts installation zones is evaluated to ensure good filtration. Local dynamic stiffness of Frame/BIW in the rubber mounts installation zones should be several times higher of the respective rubber stiffness (Fig. 5).

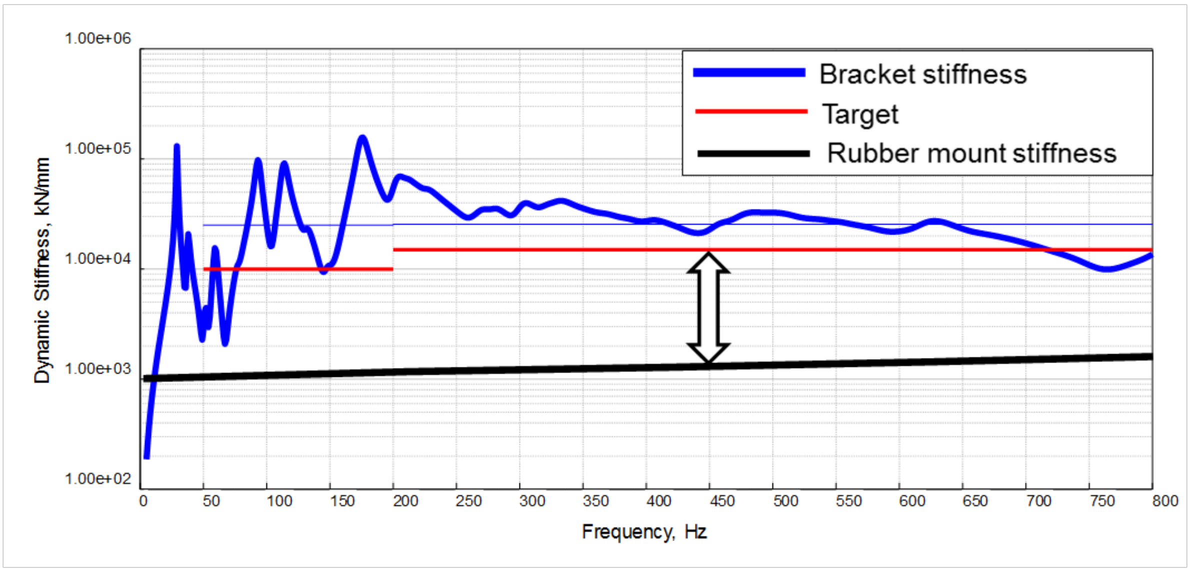


Fig. 5. Example of the local dynamic stiffness targeting.

3. Simulations results

Static stiffness results. Plot of twisting angles of the BIW (as part of the trimmed body) of the Serial SUV Smart Digital Twin is presented in Figure 6. The point marks the twisting angle corresponding to the target stiffness. The dotted line is the relative level below which all the twisting angles of the BIW as part of trimmed body must be. The continuous line demonstrates the simulation results. It is seen from the plot that the part corresponding to twisting the front end does not meet the target level. This is due to the concept of body-on-frame construction; the frame receives all the main loads, so the body needs no power elements such as longerons in the front end. This should be taken into account assigning target stiffness for the frame and the body individually.

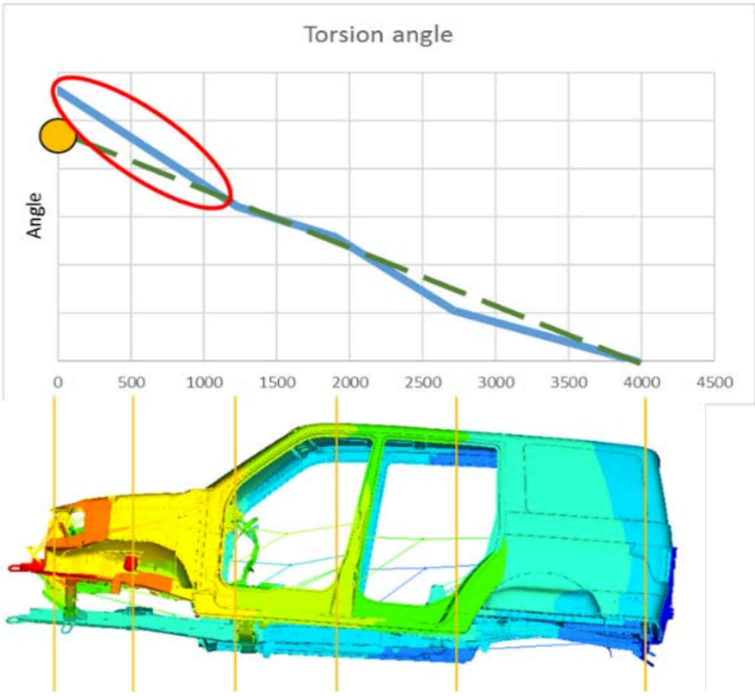


Fig. 6. Plot of twisting angle of the serial SUV Smart Digital Twin.

Modal analysis results show the following dynamics.
The lowest eigenfrequencies of the frame as part of trimmed body are higher in comparison with those of the individual frame by 10 Hz. This is explained by the change of boundary conditions (elastic contact with “heavy” body) at slight change in mass.

The lowest eigenfrequencies of the BIW as part of trimmed body are lower in comparison with those of the individual BIW by 7 Hz. This is explained by a minor change of boundary conditions (elastic contact with “light” frame) at significant increase in mass, because the mass of such components as openings and trims is included in the trimmed body.

The dynamic changes schematically are shown in Figure 7. The changes should be taken into account, when assigning target values of the lowest eigenfrequencies for the frame and the body individually, in order to eliminate the coupling between the frequencies of the frame and BIW with each other as well as with engine idle vibrations on the trimmed body.

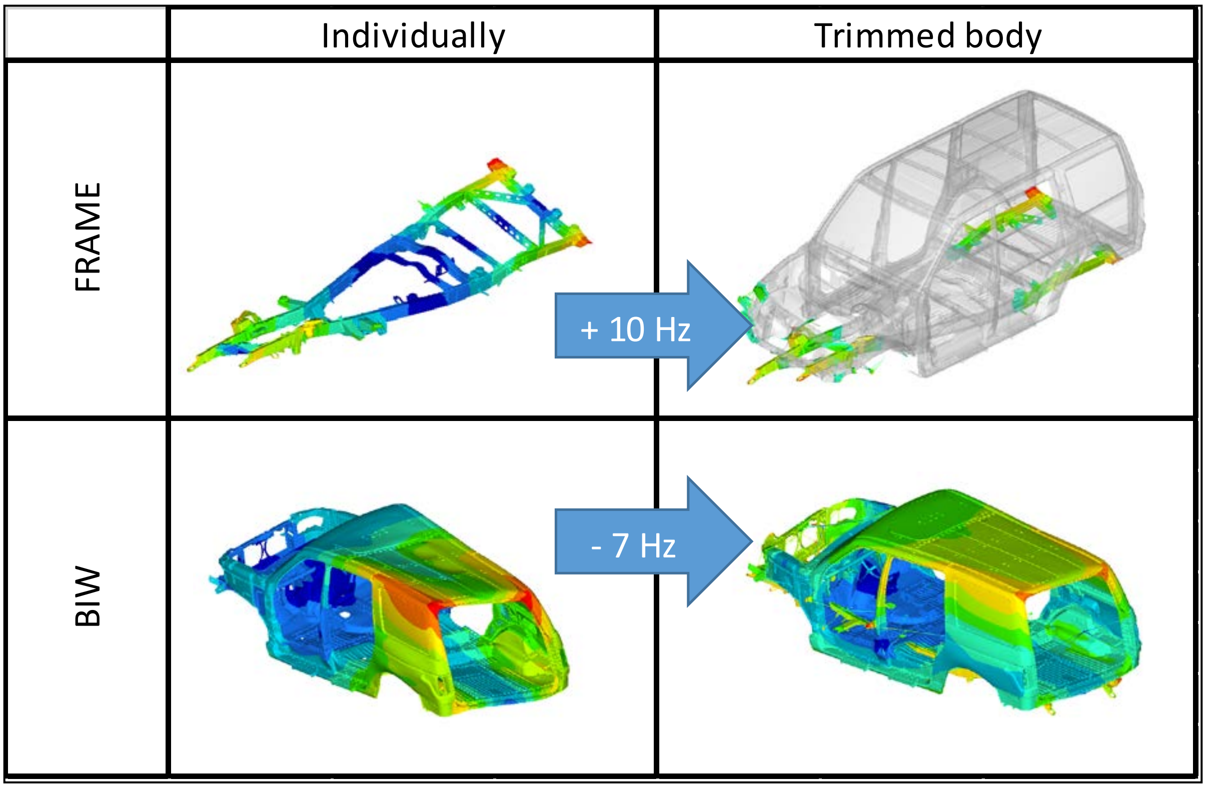


Fig. 7. Dynamics of eigenfrequency change at switching from the individual frame and BIW to the trimmed body.

Local dynamic stiffness of the powertrain mounts was calculated in the frequency range from 0 to 800 Hz. The calculations were done for the frame and the trimmed body. The results were averaged for low and medium frequency ranges. The difference between averaged results for frame and trimmed body is shown in Table 1. We see that differences are:
- maximum 3.8 % for the low frequency, that is significant;
- maximum 0.5 % for the medium frequency, that is insignificant.

The reason is that with increasing frequency the wavenumber (the number of waves in a specified distance) increases too; thus mode shapes become more localized and the frame boundary conditions have less influence on the results.

Table 1. Local dynamic stiffness on the Frame and on the Trimmed body comparison.

Point	Units	Dir.	Difference between component in separately and in assembly, %	
			Low freq.	Mid. Freq.
Engine left mount	N/mm	x	-3.8	0.0
		y	2.6	0.2
		z	-0.7	0.2
Engine right mount	N/mm	x	-3.5	0.1
		y	1.4	0.0
		z	1.2	0.1
Gearbox mount	N/mm	x	1.4	-0.1
		y	-1.5	-0.5
		z	0.5	-0.2

4. Conclusion

The optimal target values of static stiffness for the Frame and BIW were selected to achieve the target static stiffness of the Trimmed body. The optimal target values of lowest eigenfrequencies of the Frame and BIW were selected to eliminate the coupling between the frequencies of the frame and the body with each other and with engine idle vibrations on the trimmed body. From the results of LDS analysis we can conclude that in the absence of full Trimmed body model it is possible to make first estimations of LDS on the Frame. However, when the Trimmed body model is available it is necessary to update the results for the low frequency range.

Acknowlegements

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