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Improvement of dynamic characteristics of the car in the light of technological evolution

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Abstract The Member States of European Union are required to enact the Vibration Directive [4] into national legislation. This paper describes the development of car technology aiming to reduce the impact of unwanted forced vibration on a change of position of the chassis when car is passing over bumpy road. It is about the transition from the preset (passive) mechanical suspension to the adaptive (active) mechatronic suspension. The new breakthrough solution without compromises uses the rules, procedures and tools of the TRIZ approach. Adaptive car provides the best ride comfort and driving safety at the same time.

Key words: dynamics, ride comfort, driving safety, TRIZ approach

1 Effect of vibration on the car driver

Despite constant improvements to passenger and commercial vehicles, the number of accidents caused by driver drowsiness is increasing, even though the requirement for enforced resting time has been complied with. The reason that the driver gets tired while driving and while waiting at the border with the engine idling may also be that the low-frequency forced vibration from the road (below 8 Hz) and high frequency forced vibration of the engine at idle speed (above 20 Hz) acts on him adversely.

If forced vibration were located in the spectrum of natural frequencies of the internal organs (eyes 20-25 Hz, stomach: 3-8 Hz, ...), even though the driver is unaware of the internal organs attempt to reduce their amplitudes, a few hours of vibration exposure results in fatigue and a reduction of the driver's attention sufficient enough to cause a crash. The driver is most sensitive to vibration in the band 4-8 Hz, therefore, an essential requirement for car dynamic characteristics in terms of ride comfort is that vibration frequency should be outside this area.

Vertical ride comfort describes the ability of the vehicle to absorb road excitation so, that car body vibration is minimized. The basic evaluation measure for ride comfort criteria in ISO 2631 [4] is the root-mean-square value $RMS\left(a_w\right)$ of weighted acceleration a_w:

$$RMS(a_w) = \sqrt{\frac{1}{N}\sum_{1}^{N} a_w^2(n)} \quad (1)$$

where N denotes the total length of the signal of segments n ,

$$a_w{}^2 = \sum_i k_i^2 a_{wi}^2 \quad (2)$$

k_i is the weighting factor for different position

$$a_{wi} = \sqrt{\int_0^\infty \phi_i(\omega) d\omega} \quad (3)$$

where

$$\phi_i = C_i^2 W_i^2(\omega) \left|H_i(\omega)\right|^2 G_u(\omega) \quad (4)$$

is modified PSD, C_i is the factor for the stochastic excitation, W_i is frequency weighting function, H_i is the transfer function from the tire patch to the i position and G_u is the power spectral density of the excitation from the road. The accepted ride comfort has a value $RMS(a_w) < 0.315(m/s^{-2})$ according to British Standard (BS) 6841. In the Fig.1a the ride comfort is denoted as normalized body acceleration $A = a_w/g$.

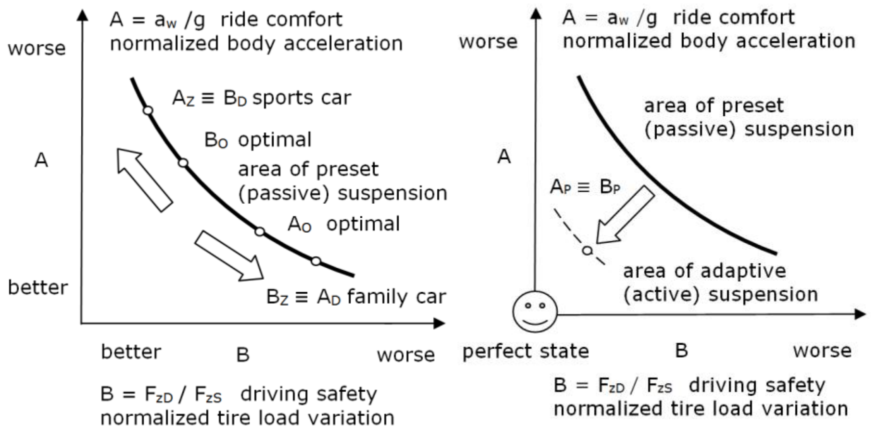

Fig.1 Target conflict between ride comfort A and driving safety B for a) passive suspension, and for b) active suspension.

Driving safety, denoted on Fig.1b as $B = F_{zD}/F_{zS}$, depends on the normalized tire load variation is F_{zD}/F_{zS} , where F_{zD} is dynamic normal tire force, and F_{zS} is static tire force. The normal tire force F_{zD} is calculated using the formula:

$$F_{zD} = m_{wh}g + c\left(l_f\varphi_y - u_z\right) + d\left(l_f\dot{\varphi}_y - \dot{u}_z\right) \tag{5}$$

where m_{wh} is the wheel mass, g is the acceleration of gravity, l_f is the distance from the center of mass to the front axle, c is the suspension spring constant, and d is the suspension damping constant, u_z, resp. $\dot{u}_z$ is the vertical displacement, resp. velocity of the center of gravity of the car body, φ_y is pitch angle and $\dot{\varphi}_y$ is pitch angular velocity.

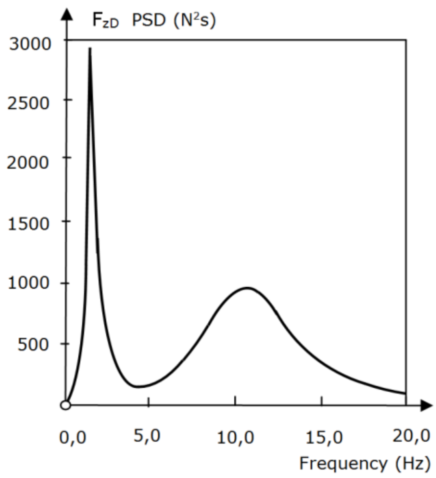

Fig. 2. PSD of the normalized tire load.

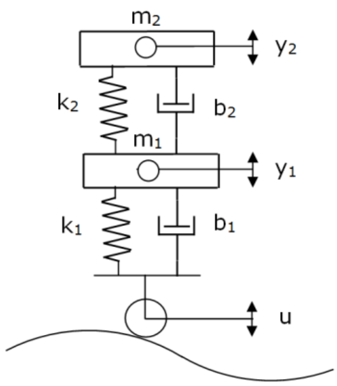

Fig. 3. The two mass passive suspension.

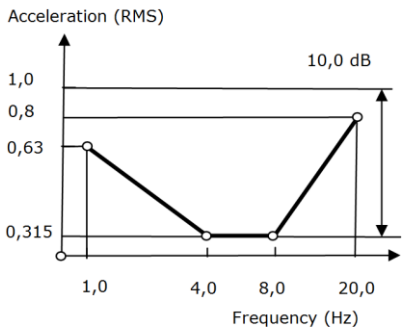

Fig.4 Vertical vibration exposure curve.

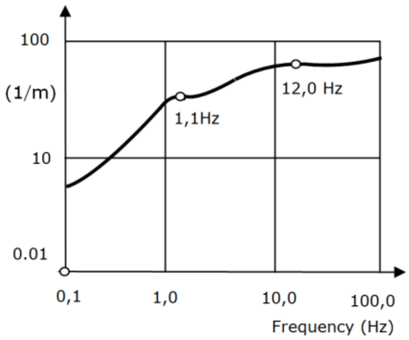

Fig.5 Car frequency response function.

The driver is most sensitive in the bandwidth 1-2 Hz (eigenfrequency of car body-sprung mass) and about 6-8 Hz (eigenfrequency of wheel suspension-unsprung mass), so this low ride comfort is in contradiction with high driving safety due to the highest values of PSD of normal tire force [3]. Peaks in frequency response PSD of normal tire force are unwanted, because they cause discomfort to the driver. The damping of the main shock-absorber has the main influence on the ride comfort (70%), while for driving safety the tire stiffness is actually the most sensitive parameter (70%) [2].

Vehicle suspension system performance is typically rated by its ability to provide improved road handling (driving safety) and improved passenger ride comfort. The fixed setting of passive suspension properties is always a compromise between ride comfort and driving safety for given road conditions on the one hand and payload suspension parameters on the other. When developers attempt to improve car driving comfort (A) so that no sudden changes in the position of the car body (under minimum acceleration), this deteriorate driving safety (B) in the form of undesirable jumps of the wheels. Thus arose the concept of family car that has good ride comfort (A_D) on Fig.1a, but bad driving safety (B_Z) and sports car that has good driving safety (B_D), because it maintains the wheels in constant contact with the road (without jumps), but it has poor ride comfort (A_Z).

The only possible solution for improving the dynamic properties of a car has long been regarded the optimization, but it results in compromise: either optimal family car (A_O), or optimal sports car (B_O). The main objective of suspension systems is to reduce movement of the car body (sprung mass). Then the challenge for breakthrough perfectioning of driving performance of a car is to overcome the contradiction (opposing ride comfort and driving safety) and to achieve the best possible ride comfort and driving safety ($A_P \equiv B_P$) in Fig.1b simultaneously.

2 Laws and procedures of the TRIZ approach

The acronym TRIZ means Theory of the resolution of invention-related tasks. Altshuller developed the TRIZ approach after study of patterns of invention in the global patent literature [1], and today a lot of problem-solving, analysis and forecasting tools is derived from it. An important mission of the TRIZ approach is to reveal patterns of evolution expressed on the Law of least action. Thus, everything in nature has an innate desire to get as close to the unreachable goal, which is perfect efficiency as a result of perfect purposefulness and perfect economy (Fig.6). TRIZ approach allows to drive the problem solving process with higher effectiveness and efficiency, because of its logic oriented towards the overcoming of conflicts rather than accepting trade-offs among requirements. In the TRIZ approach the essence of the generic steps (need, benefits, procedure, and use) for systematic perfection of creations is to recognize and remove contradictions:

- The managerial-administrative contradiction on the level of intention for a change: the director will invite developers to enhance the driving characteristics of the car to be successful in the market. This is contradiction between the requirements to improve the car and the absence of the conditions to do so (need to identify the targets, acquire knowledge of the process and ensure proper resources). The principle for overcoming the managerial-administrative contradiction is to seek out and remove the global-technical contradiction.

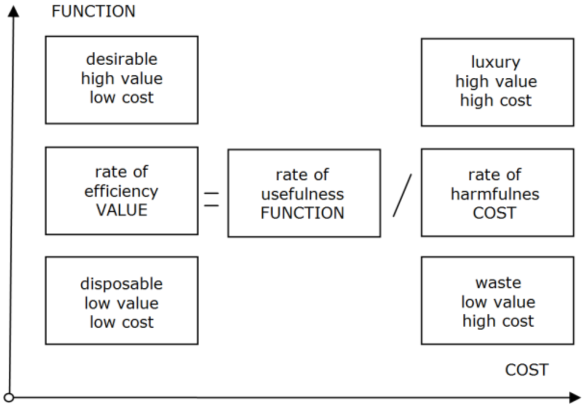

Fig. 6. The value of creations is a measure of cost effectiveness for the fulfillment of their function.

- The global-technical contradiction on the system level of creation is the conflicting relationship between the features of the parts of the whole creation when improving one part (driving comfort A on the level of car body) worsens the second part (driving safety B on the level of wheel). The overall principle for overcoming global contradiction is to search and remove the local-physical contradiction when one part satisfies conflicting properties simultaneously.
- The local-physical contradiction on the single part level: the suspension of the car body has to ensure zero change in the force transmitted to the car body for its desirable zero heave, and at the same time to ensure non-zero change in the force which pushes the wheel onto the road. Then the car provides the best possible ride comfort and driving safety ($A_P \equiv B_P$) on Fig.1b simultaneously.

An expert on cars, who works without knowledge of the TRIZ approach, uses only his area of knowledge, therefore he tries to remove a local conflict through new resources (additional equipment to produce force). The result is of high value but high costs (Fig.6) Magic Body Control system [5] with a camera which scans irregularities of the road ahead. Then the Active Body Control system uses a hydraulic piston to act on each steel coil spring to quickly and independently adjust the suspension on each wheel and provide the best possible ride comfort and driving safety ($A_P \equiv B_P$) on Fig.1b simultaneously. The Master of the TRIZ approach has the mission to guide the car expert how to intentionally search for initiatives in successful patents from all areas of knowledge and warns that the removal of local conflict has to be to take advantage of local resources (drive and braking torque) which makes it possible to achieve high value at low cost (Fig.6).

Fig.7 shows the transition from preset (passive) features of a mechanical suspension to a hydraulic suspension with self-adaptable change of a magneto rheological fluid properties, to a hydro-pneumatic suspension, to the adaptable (active) suspension with electronic management of features, toward the recent removal of unwanted movements of the car body (vertical heave, yaw, roll and pitch) for desirable ride comfort by quick control of the drive and braking torque acting on the wheel motors (LEAF [6]) and ensuring necessary wheel load simultaneously.

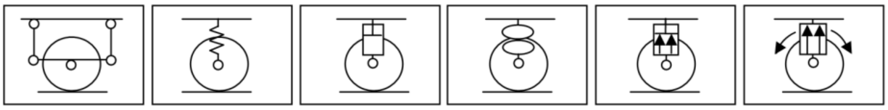

Fig. 7. The individual steps for breakthrough improvement of car suspension.

6 Conclusions

The example of the use of the TRIZ approach for improving the dynamic of the car in this paper explains why successful universities and companies have already integrated Computer Aided Innovation (CAI) based on the TRIZ approach into education and research. The benefit of the TRIZ approach is that it leads to the creation a necessary interdisciplinary overview, and to better systemization and exploitation of existing knowledge. The cooperation of company experts with Masters of the TRIZ approach results in a breakthrough and patentable innovations.

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