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MODELING OF STRESS IN THE CAR HALF AXLE

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Preface

One of the most important parts of the vehicle is axle. The axle of the vehicle while driving is dynamically loaded. Determination of operating load with respect to different operating conditions (driving on terrain/road, the speed of the vehicle, acceleration/ braking, straight ride/cornering of vehicle, etc.), which can occur while driving is very difficult. Stresses arising in components of the axle during operation have a particular impact mostly on fatigue damage of the axle parts [2]. Fatigue damage is a long process, which in components during inspection might not be apparent, in contrast to the emergence of fatigue fracture, which is a rapid process. For vehicles while driving can have catastrophic consequences:

- Loss of vehicle stability,
- loss of vehicle control,
- treat of vehicle crew,
- treat of other traffic participants,
- damage of other parts of vehicle.

Modern CAE, (computer-aided engineering), systems allow a combination of several numerical methods such as finite element method (FEM), multibody simulation (MBS), programs for determining the loading, stress and calculation of the fatigue life [1].

In the case of a vehicle axle is the best to use MBS (a model of the axle with flexible parts, determine the spectrum of the load while driving on virtual ground). In the case of numerical analysis using MBS with flexible parts, are inputs for the computer analysis the material properties, stresses of individual load cases and developments of these loads. In the MBS with flexible parts, the number of loading cases is equal to modal shapes of flexible part used for computation. The results of calculation are courses of stresses in every single node of the car axle parts [1].

In he article are used several CAE programs, in particular from the company MSC. Their proposed interaction between programs is shown in Fig. 2. Dashed lines indicated possible linkage to programs allowing the fatigue life prediction. Using these programs have been especially selected to ensure easy exchange of data between different software. In Fig.1 is displayed double wishbone axle of off-road vehicle, in which the courses of stresses were modeled in its individual components [4].

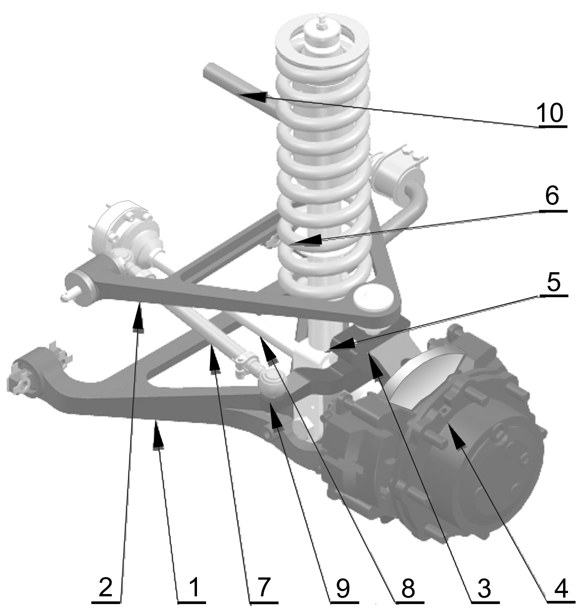


Fig.1 Half axle arrangement.

1 - lower arm, 2 - upper arm, 3 - hub carrier, 4 - wheel hub, 5 - telescopic damper, 6 - helical spring, 7 - control rod, 8 - cardan shaft, 9 - control lever, 10 – transverse stabilizer

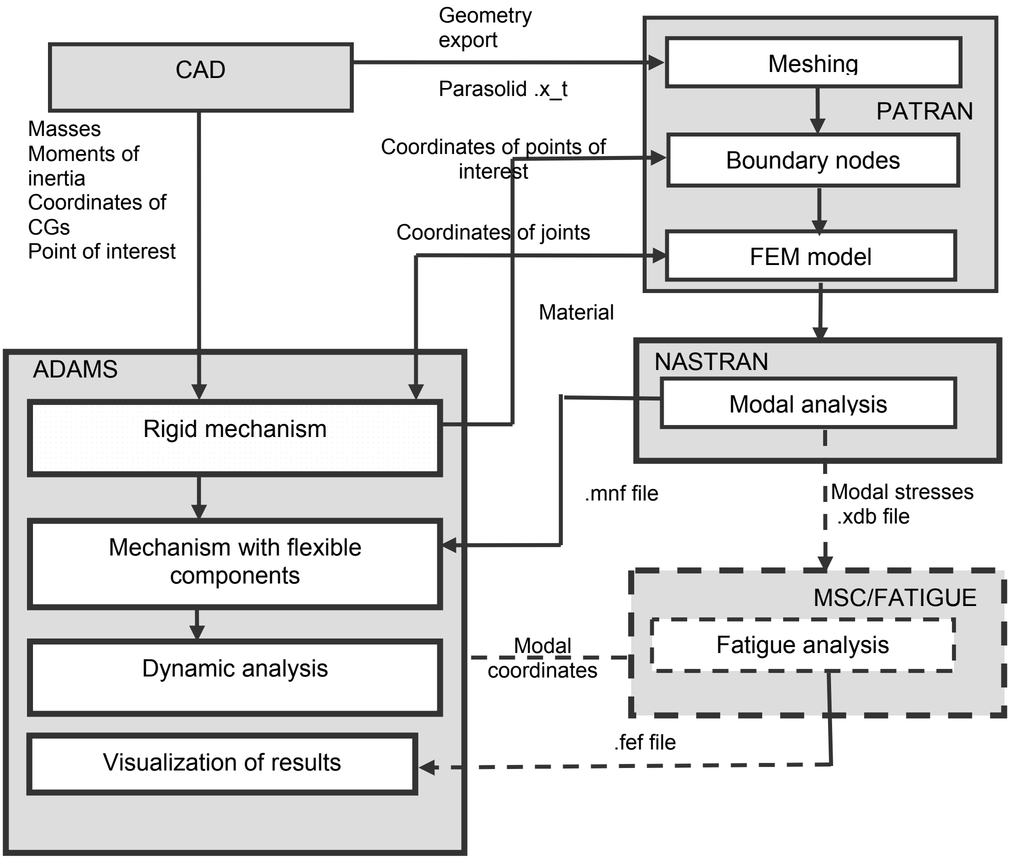


Fig.2 Mutual interaction between selected CAE software

1. Mathematical – physical model of vehicle

Mathematical - physical model of the vehicle was created by using Adams/Car. Block diagram of the virtual vehicle is displayed in Fig3 [3].

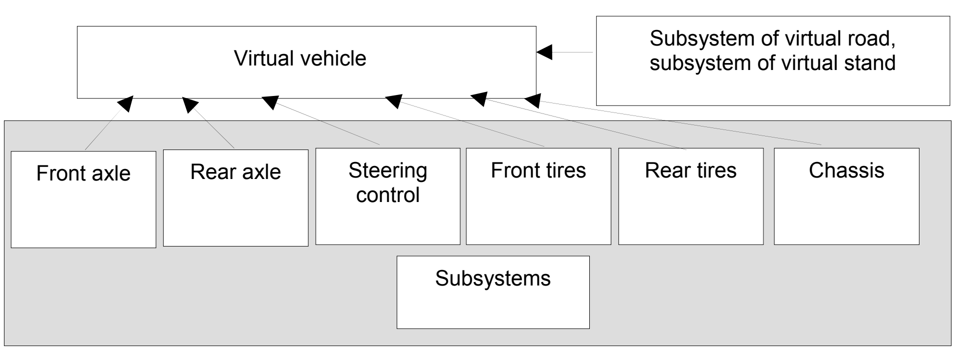
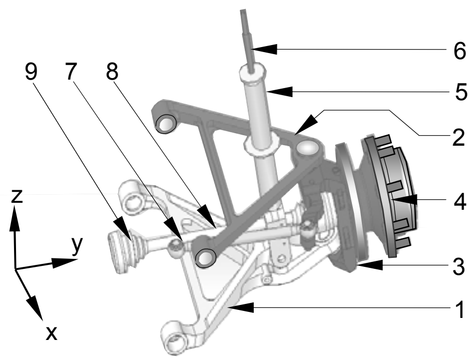
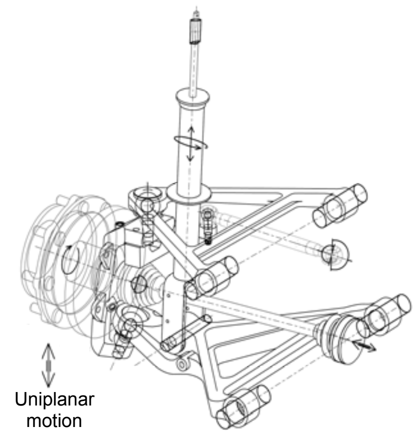


Fig.3 Block diagram of virtual vehicle

In Fig.4a) are depicted axle components used in the subsystem of the front and rear axles. In Fig.4b) are depicted the joints used in the model. The model is built using flexible joints for the upper arm, lower arm and the damper of axle. In tab. 1 is calculated resulting degree of freedom of the half axle [3].





a) parts used in axle b) joints used in axle

Fig.4 Model of half axle

1 – lower arm, 2 – upper arm, 3 – hub carrier, 4 – wheel hub, 5 – body of damper, 6 – piston of damper, 7 – control rod, 8 – cardan shaft, 9 – shaft tripod

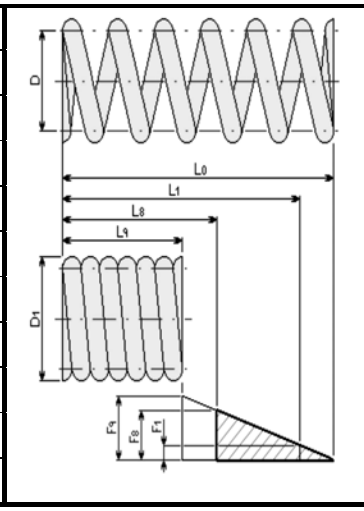
Tab.1 DOF of the half axle [2]

	Model with flexible joints		
	Num	**DOF**	**ΣDOF**
Parts	10	6	60
Sliding	2	-5	-10
Cylindrical	1	-4	-4
Revolution	1	-5	-5
Universal	3	-4	-12
Spherical	3	-3	-9
In plane	1	-1	-1
Imposed motion	1	-1	-1
Resulting DOF			18 °

The model includes two axle force components: a spring and damper. Characteristics of spring is shown in Tab. 2, characteristics of damper is shown in Fig.5..

Tab.2 Parameters of spring

d [mm]	25
D [mm]	135
D_1 [mm]	160
D_2 [mm]	110
L_0 [mm]	525
L_1 [mm]	403
L_8 [mm]	302
L_9 [mm]	294
F_1 [kN]	18,78
F_8 [kN]	34,3
F_9 [kN]	35,9



Suppose the stiffness of front axle spring:

$$c = \frac{F_8 - F_1}{L_1 - L_8} = 154 \;\left[N.mm^{-1}\right]. \qquad (1)$$

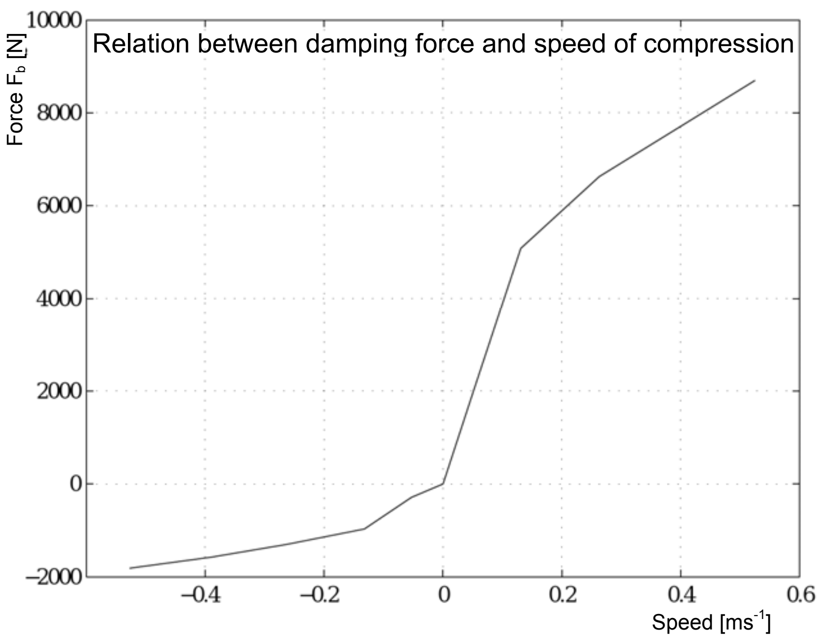
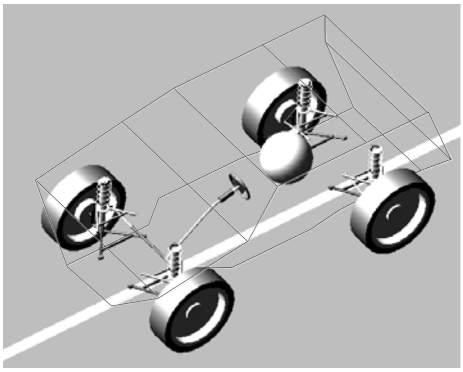
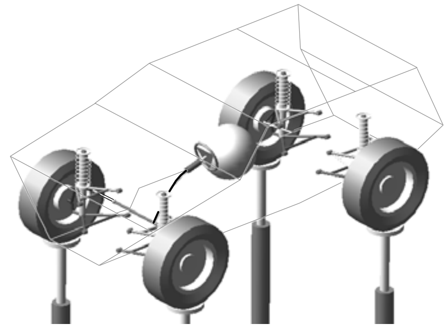


Fig.5 Characteristics of damper

Complete mathematical physical model of the vehicle created according the scheme depicted in Fig.3 is shown in Fig. 6.



a) on virtual road



b) on virtual stand

Fig.6 Mathematical – physical model of vehicle

To determine the loads of individual parts of axle, solid bodies were replaced with flexible bodies. Properties of flexible bodies in an external FEM program are contained in a MNF file (Modal Neutral File) which contains all relevant information about the inertia and elastic properties of flexible bodies, as well as information required for flexible bodies insertion in to Adams program. To determine the minimum number of its mode shapes is modified Craig-Bampton method used (Component mode synthesis, CMS) [8].

This method reduces the size of finite element model. It allows selection of a subset of degrees of freedom which are not subject to modal superposition - boundary degrees of freedom. The advantage of modal superposition is that the modal flexible body, even after reducing the number of modal shapes replaces deformations of the flexible body, which has a large number of nodal degrees of freedom with a much smaller number of modal degrees of freedom [8].

To create flexible bodies was used a combination of preprocessor and postprocessor Patran and Nastran solver.

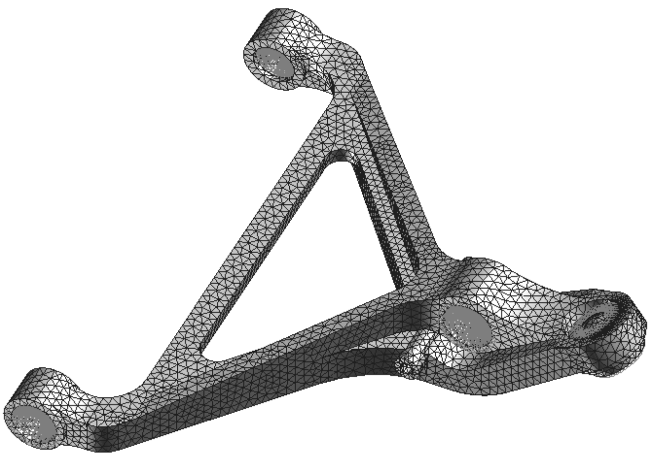
The processes of replacing rigid bodies with flexible bodies consist of the following steps:

1. Creation of flexible body in Patran.
2. Creation of boundary nodes.
3. Generation of .mnf file – modal analysis.
4. Replacing rigid body with flexible one in Adams.

In Tab.3 are depicted properties of rigid bodies, which were used in the model of the vehicle axle. In Fig. 7 shows the lower arm ready for modal analysis. In Tab. 4 are depicted results of modal analysis of the lower arm.

Tab.3 Flexible bodies used in model

Name of part	Number of nodes	Number of elements	Number of boundary nodes
Upper arm	9321	4882	3
Lower arm	58392	36502	4
Hub carrier	59583	37676	4
Control rod	55959	35550	2
Body of damper	26044	13887	3
Piston of damper	12646	7499	2



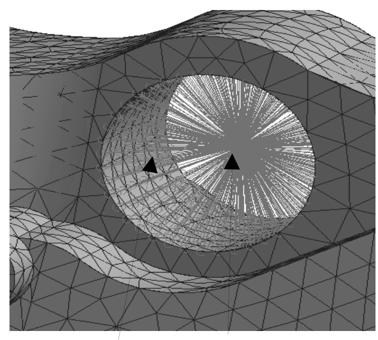


Fig.7 Lower arm ready for modal analyze (mnf generation)

Tab.4 Mode shapes of lower arm

Mode shape	1	2	3	4	5	6	7	8	9	10	11	12	13
Freq. [Hz]	0	0	0	0	0	0	519	566	639	695	722	926	1190
Mode shape	14	15	16	17	18	19	20	21	22	23	24	25	26
Freq. [Hz]	1329	1420	1687	1767	2036	2183	2398	2645	2807	3048	3431	3644	3688
Mode shape	27	28	29	30	31	32	33	34	35	36	37	38	39
Freq. [Hz]	4375	4980	5398	6891	7994	8213	8437	9991	11070	11109	14624	17402	17434

2 Static analysis of half axle

The half axle is fixed in places of connection to hull, then the axle is loaded with force at the wheel contact with the ground. Static simulations of axles in the automotive industry are mainly used in the design phase (e.g. method 321g - three times load in the vertical direction, two times in the lateral direction, one times in the longitudinal direction), static testing of driving situations, but also in forecasting the fatigue life of the axle. The disadvantage of static simulation is neglecting the dynamic components of loads and the impact of the axle damping [3].

In Fig.8 is depicted the stress distribution when the vehicle weight 6500 kg.

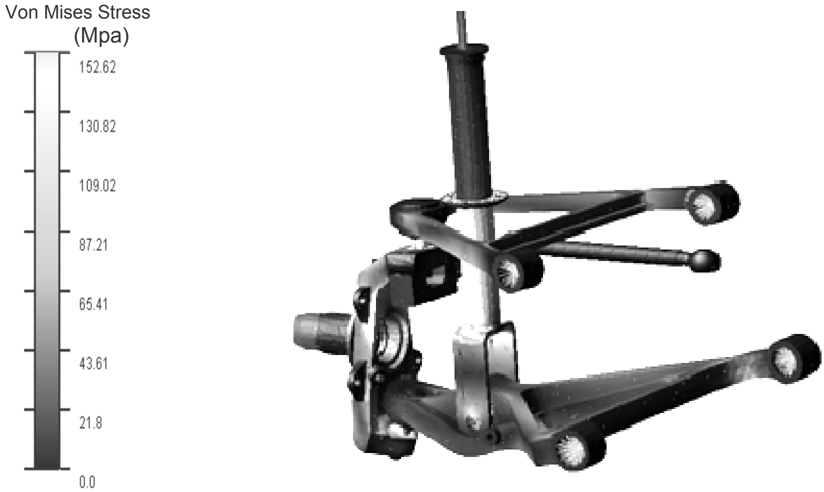


Fig.8 Static analysis of half axle

The most critical place of the axle is inside side of the lower pivot ball. Detail of the critical place is shown in Fig. 9.

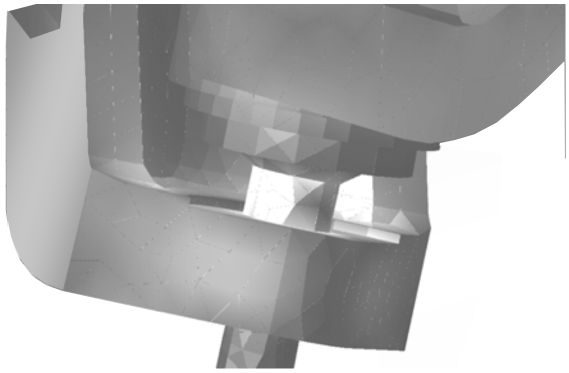


Fig.9 Critical place of lower pivot ball

In Fig.10 is depicted stress distribution in the lower arm of the half axle.

Fig.10 Stress distribution in lower arm

3 Dynamic analysis of the half axle

The statistical properties of height inequalities of the road surface in the longitudinal direction in a single track can clearly describe the random function h(l) where l is the distance in the direction of vehicle movement. Inequalities of the longitudinal profile of the road according to the measurements can be considered as a stationary ergodic random function with zero mean value and normal probability density distribution. For statistical description of the inequalities of the road surface is currently used mostly power spectral density (PSD). Power spectral density of height inequality reflects the frequency distribution of total power of random process [6].

The experimental measured courses of PSD elevation of the road surface imperfections shows that they can be approximated with sufficient accuracy in the logarithmic coordinates a straight line. PSD can be written in the general form

$$S_h(\Omega)=S_h(\Omega_0)\cdot\left(\frac{\Omega}{\Omega_0}\right)^{-k} \qquad (2)$$

where

Ω_0 – referential angular frequency,

k – waveness coefficient.

From the relation (2), taking into account constant parameter $k=2$ for all wave lengths is based the standard STN ISO 8608, in the creation of classes characterizing the normative quality of roads in terms of height inequality of the longitudinal profile [6].

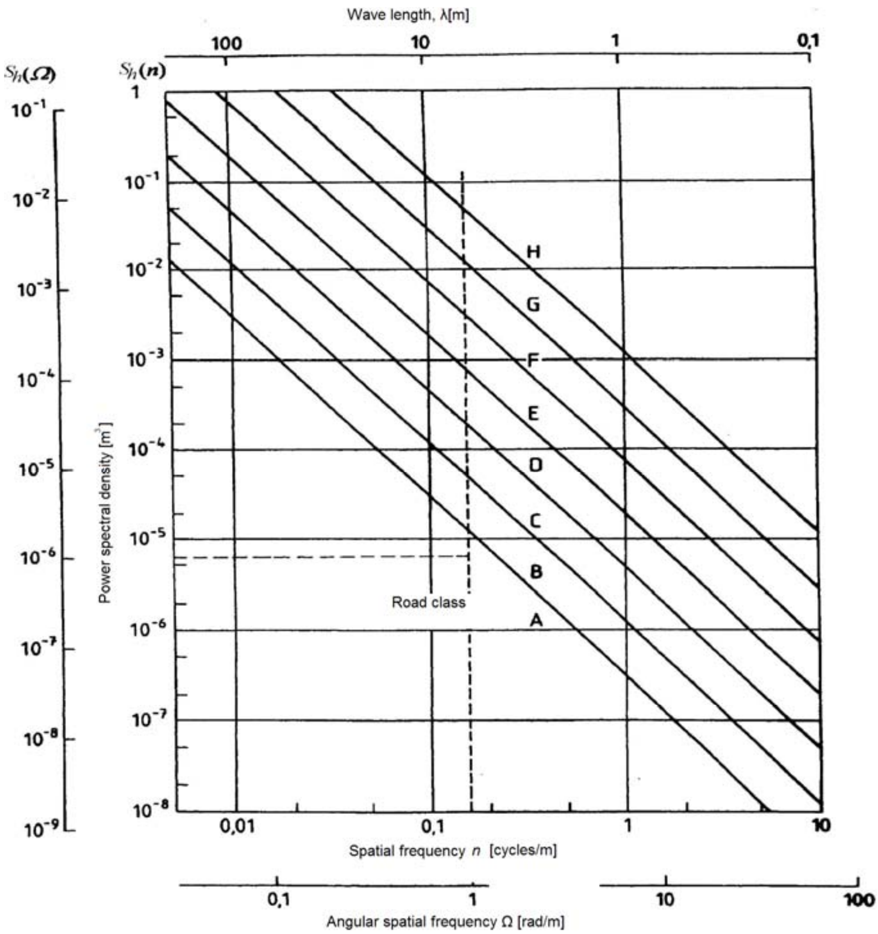


Fig.11 Classification of roads according STN ISO 8608

The value of parameter *k=2* corresponds to a balanced share of band inequalities from short and long waves in the power spectra. This approach is often used to simulate the vibration of the vehicle [6].

Based on STN ISO 8608 [9], to generate a random road profile from power spectral density of profile was used modified Matlab m-file. The author of the original program is Ing. Peter Múčka, PhD. of SAS.

In Fig. 12 and Fig. 14 are depicted generated inequalities of the road in the program Matlab, which are used as a car excitation on a virtual stand (Fig. 6b). In Fig. 13 and Fig. 15 are depicted courses of stress at a critical point of lower spherical pivot (Fig. 9) when the vehicle speed is 15 $m \cdot s^{-1}$ [3].

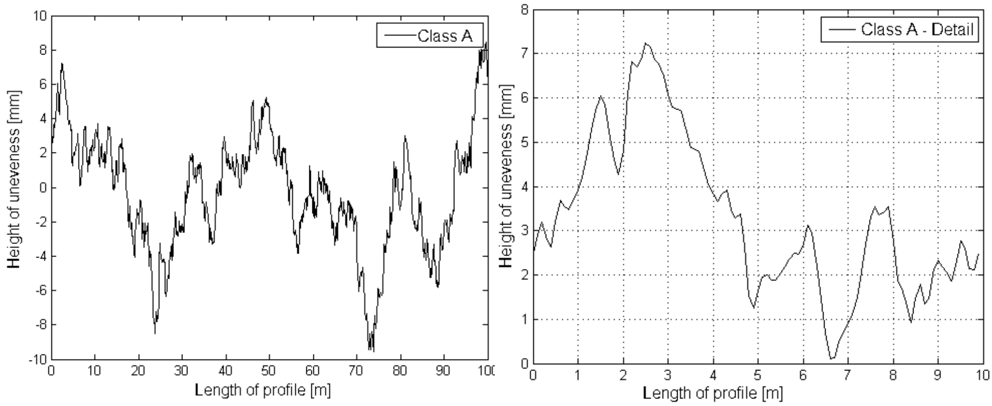


Fig.12 Profile of road class A

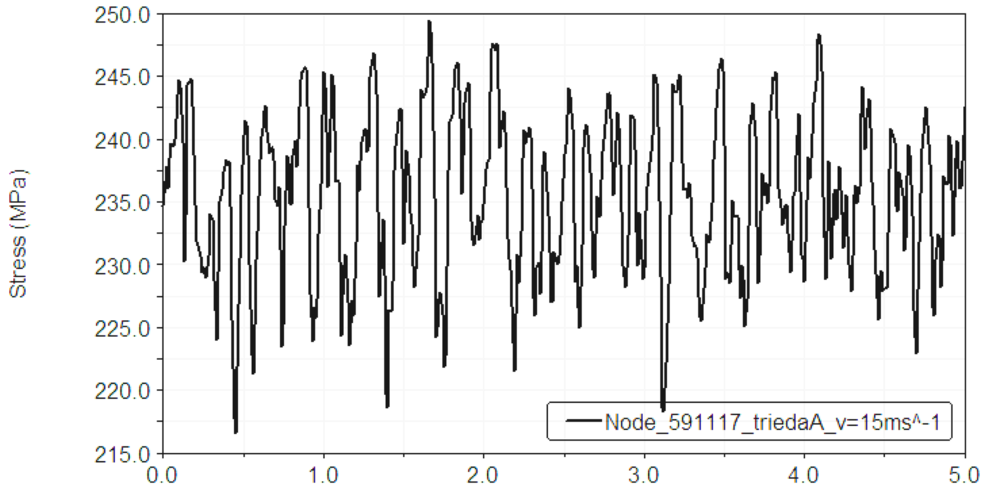


Fig.13 Lower spherical pivot, Class A

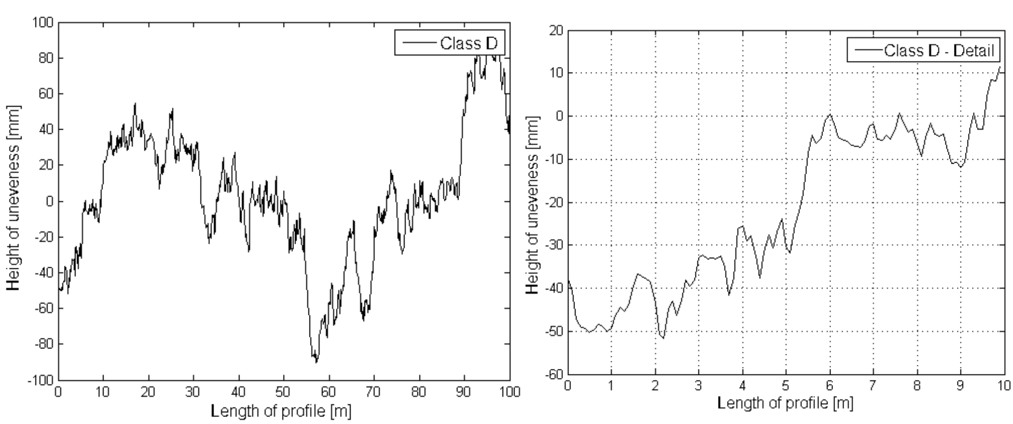


Fig.14 Profile of road class D

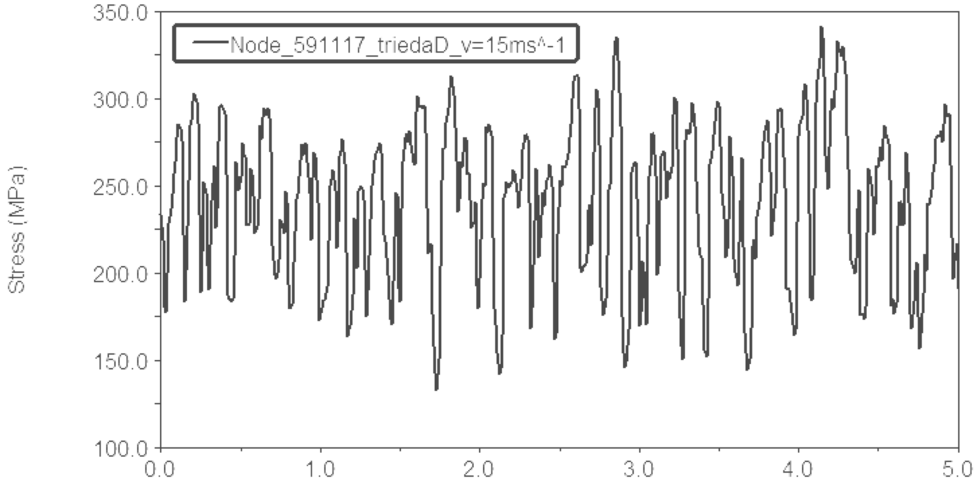


Fig.15 Lower spherical pivot, Class D

Conclusion

The article describes the method of determining the distribution of stress in the vehicle half axle using a combination of several advanced CAE programs. Described methodology is particularly suitable for the automotive industry. Where after construction of a virtual car can be easily monitored the impact of various factors (vehicle speed, unequal terrain, crossing the artificial barriers, etc.) stress in various parts of the car axle. Created a virtual model of car is suitable not only determine stress distribution in the construction, but is also suitable for predicting the life of components and simulation of vehicle dynamics. The methodology described in Fig. 2 is not tied only to vehicles, but with use of Adams/View can also be used in other fields of mechanical engineering, for example design of conveyor belt [8].

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Bibliography and Information Resources

1. BOCKO, P.: *Posudzovanie životnosti nosných konštrukcií dopravných strojov a zariadení s využitím numerických a experimentálnych metód*, dizertačná práca, Technická univerzita v Košiciach, Košice, 2006
2. BLUNDELL, M., HARTY, D.: *The multibody system approach to vehicle dynamics*, Elsevier Butterworth-Heinemann, ISBN 0 7506 5112 1, 2004
3. BUCHA, J.: *Modelovanie prognózovania zostatkovej životnosti vybraných súčiastok špeciálnej techniky*, Dizertačná práca, Trenčín, 2009
4. BUCHA, J., CHOVANEC, A., LEITNER, B.: *Modeling of half axle using Simulink*, In: Transport means 2008: Proceedings of 12th international conference, 2008, Kaunas, ISSN 1822-296X
5. HRUŽÍK, L., VAŠINA, M., SIKORA, R.: *Diagnostics of Drive Dynamics with Hydraulic Motor and Inertial Mass*, In:Acta Technica Corviniensis,Bulletin of Engineering, Romania,2009
6. KROPÁČ, O., MÚČKA, P.: *Relations between characteristic of longitudinal unevenness of roads: a review*, In: Strojnícky časopis 54, 2003 č.1
7. *SAE Fatigue Design Handbook*, third editition, AE-22, Society of automotive engineers, 2001
8. SAPIETOVÁ, A., ŽMINDÁK, M., MELICHER, R.: *Dynamická analýza dopravníka s poddajným členom, In: Výpočty konstrukcií metodou konečných prvku,* Ústav mechaniky, biomechaniky a mechatroniky, Fakulta strojní, ČVUT, Praha, 2007, ISBN 978-80-01-03942-7
9. STN ISO 8608: *Mechanické kmitanie, profily povrchu cesty, Zaznamenávanie nameraných údajov,* SÚTN, Bratislava

Resumé

Modelovanie priebehov napätí v polonáprave automobilu

Jozef BUCHA & Jozef TURZA

V článku je popísaný postup na určovanie napätí v súčiastkach nápravy automobilu. Je navrhnutý a popísaný model, ktorý pomocou viacerých moderných programov a metód výpočtu umožňuje sledovať veľkosť a rozloženie napätí v komponentoch nápravy pri jazde vozidla po terénnych nerovnostiach rozličnými rýchlosťami. Priebehy nerovností sú generované podľa normy STN ISO 8608, čo umožňuje jednoduchú kvantifikáciu vozoviek. Navrhnutý model je univerzálny. Môže byť použitý aj v iných oblastiach strojárstva.

Summary

Modeling of stress in the car axle

Jozef BUCHA & Jozef TURZA

The article describes the procedure for stress determining in the parts of car axle. It is designed and described model, where used modern programs and methods of calculation, which allows monitoring the size and distribution of stress in the components of the vehicle axle when the vehicle ride through road bumps with different speeds. Road unevenness is generated according to ISO 8608, allowing easy quantification of quality of roads. The proposed model is universal. It can be used in other mechanical engineering fields.

Zusammenfassung

Modeling Spannung im Auto Achse

Jozef BUCHA & Jozef TURZA

Der Artikel beschreibt das Verfahren für die Bestimmung der Spannungen in der Auto Achsteile. Es wurde so konstruiert und beschrieben Modells mit fortgeschrittenen Programme und Methoden zur Berechnung erlaubt es, die Größe und Verteilung der Belastung Komponenten in der Achse zu überwachen, wenn das Fahrzeug ausgeschaltet ist Unebenheiten der Straße mit unterschiedlichen Geschwindigkeiten. Wellenformen werden von Ungleichheiten nach ISO 8608 erstellt, was eine einfache Quantifizierung der Straßen. Das vorgeschlagene Modell ist universell. Kann in anderen technischen Bereichen eingesetzt werden.