

## KINEMATIC SIMULATION AND NUMERICAL ANALYSIS OF THE SUSPENSION SYSTEM OF LIGHT WHEELED VEHICLE

**Patryk Różyło**

*Department of Machine Design, Faculty of Mechanical Engineering  
Lublin University of Technology  
Nadbystrzycka Street 36, 20-618 Lublin, Poland  
e-mail: p.rozylo@pollub.pl*

### **Abstract**

*The paper presents the process of kinematic simulation and FEM numerical analysis of the suspension system of the light-wheeled vehicle. Fragment of the suspension system is a set of simple vibration damping mechanisms occurring in light-wheeled vehicles. The materials used for analysis is aluminum, steel and rubber characterized by properties hyperplastic. The suspension system has been subjected to the force generated from the substrate, resulting from the prevailing inequality terrain. Kinematic simulation made using CAD software enabled the mapping of the actual behaviour of the suspension with a simple steering mechanism, while passing at the characteristic curvilinear track. Numerical investigations have enabled the analysis of stress distribution in the structural elements while pointing out areas with the highest levels of stress reduced, designated by HMM hypothesis (Huber-Mises-Hencky). The FEM analysis used local and global density of the mesh through which highlighted the level of maximum stress concentration. Result of reduced stress distribution shown exactly on the complete form of the test model of a wheeled vehicle suspension. In the analysis of numerical models have been used elasto-plastic materials and hyperplastic available in the Abaqus. Calculations were carried out taking into account the issues of using geometrically non-linear Newton-Raphson method.*

**Keywords:** *Finite element method, kinematic simulation, suspension, light wheeled vehicles, numerical analysis*

### **1. Introduction**

The vehicle suspension is a set of elements connecting the wheel to the rest of the vehicle. The primary task of the suspension is to move all forces generated at the contact with the ground on the body. The forces and vibrations occurring in the suspension system while the vehicle is moving on the road, are effectively eliminated by the elastic elements and damping. Easing any shocks caused by uneven road surfaces, directly affects the ride comfort and vehicle.

Analyses associated with a suspension system, often need to determine the mutual position of the elements, which cooperate closely with each other in complex loading conditions. Knowledge of the stress distribution appearing in the system components can influence the improvement of the construction work and to reduce wear.

The modern environment of CAD / CAE supports both the design process, simulation, testing and numerical optimization. Virtual kinematic analysis provides a range of information relating to study the mechanism, e.g.: description of trajectory points of the structure, determination of speed or acceleration test points, and the scope of the mobility of the mechanism. Kinematic simulation also allows you to show information about the collision between the mating components and present the assumed process kinematics in the form of a computer, before making mechanism in reality.

Additional capabilities provide numerical tests, which are currently the most developed form of stress analysis of materials. Advanced computational packages using the finite element method allows for a detailed study design, in terms of deformation, stress or movements. Knowledge of the stress distribution in the individual components of mechanisms allows us to optimize both the geometrical parameters and physical components designed at the stage of design.

The paper presents the use of CAD and CAE in generating kinematic simulation and numerical FEM using the following programs used for commercial purposes Catia V5 – design and kinematic simulation, Abaqus – numerical analysis.

## 2. Object of study

The subject of the research work is a fragment of the suspension system of light-wheeled vehicle. A suspension system designed in CATIA V5R19 environment in which the sequence was also carried out a kinematic simulation. The mechanism consists of several components, the construction of which was based on a relatively simple piece of suspension system and steering system. Kinematic simulation used a complete systems design fragments, while the numerical studies used only a fragment of the suspension system.

Most of the elements were tested mechanism components made of aluminum alloy with a nominal value of 1016, which defined a model for elastic-plastic material with characteristics bilinear. The spring suspension system made of structural steel of designation ST3/S215.

Tab. 1. The material properties of steel and aluminum

	Young's modulus [MPa]	Poisson's ratio	Yield strength [MPa]	Tensile strength [MPa]
Steel St3/S215	210000	0.3	215	375
Aluminum 1060	70000	0.33	103	110

Material tires were modelled based on the adoption of a model hyperplastic material whose characteristics determined by the equation Marlow in Abaqus, the curve describing the relationship between stress and strain. The curve with the values characterizing the material tires shown in the figure below.

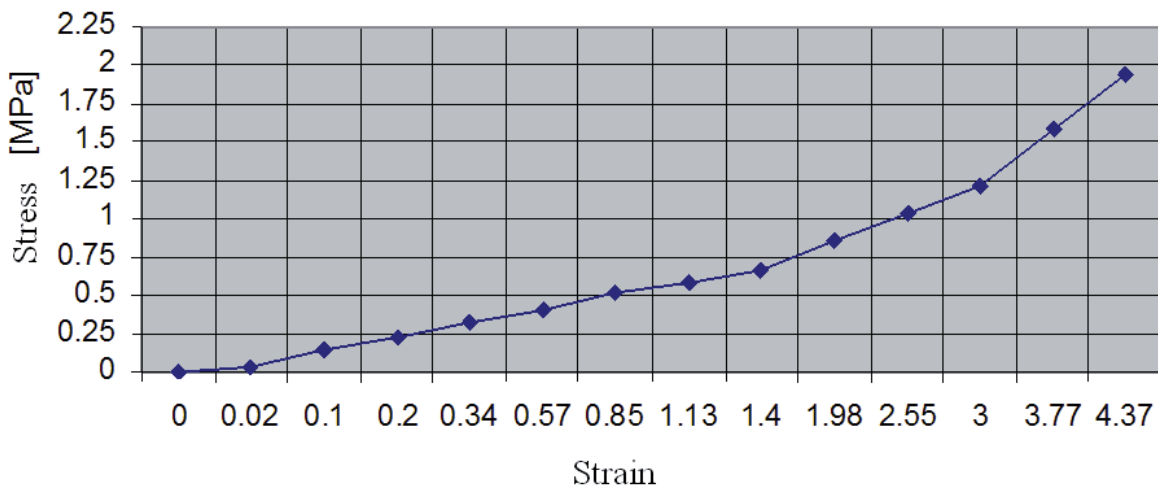


Fig. 1. Characteristics of rubber material [4]

The study of numerical simulation and kinematic were prepared appropriate spatial models. Model prepared for kinematics simulation, consists of both a fragment of the suspension system and the steering mechanism, and the mechanism for numerical analysis, only the suspension. Both examples intended test models shown below.

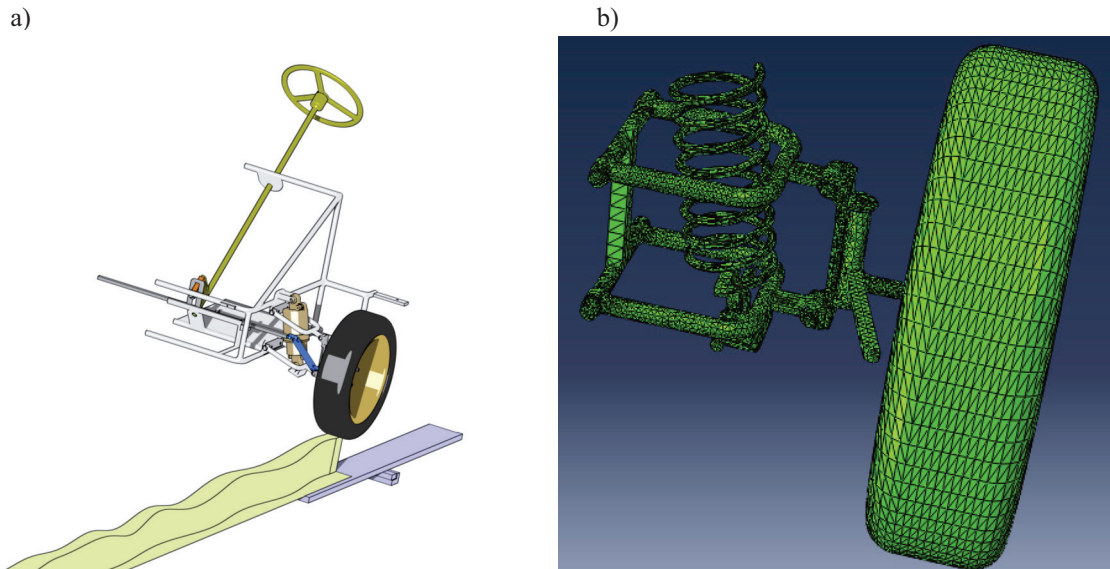


Fig. 2. The suspension system prepared for analysis: a) kinematic, b) numerical

### 3. Kinematic simulation

Kinematic Simulation allowed us to control and check the status of the correctness of the movement mechanism on a curvilinear track. Generate a kinematic simulation allowed us to show a comparable behaviour mechanism in Catia environment, to maintain in fact. This step is required to define the individual components of the test system, the necessary kinematic constraints. Imposed boundary conditions allow inter alia, reducing the required degrees of freedom, as well as determining the motion parameters between tire and track driving. During the simulation, it was possible to observe the behaviour of the mechanism, the encountered irregularities on the running track. In this type of analysis is possible registration parameters such as velocity and acceleration of moving data points on the components, determine the extent of motility of the entire system, or the analysis of a collision occurring between the elements. The following figure shows a system subjected to simulation.

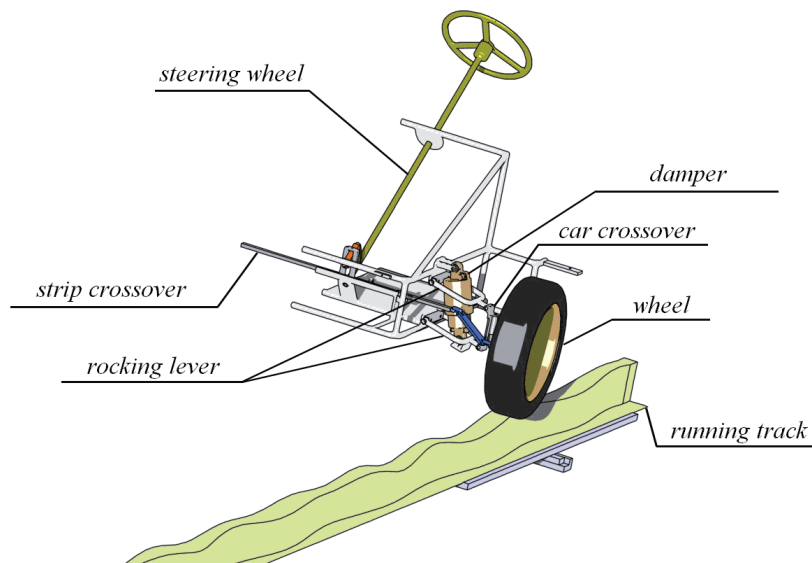


Fig. 3. The mechanism subjected to a kinematic simulation

Kinematic simulations are precisely based on the movement of the suspension system and interdependent with the steering mechanism. The process generated by subjecting the constant

cooperation of both systems. Simulation of the mechanism, takes place after the curvilinear track, designed in the appropriate module, so that presents realistic motion mechanism. The simulation was carried out in the DMU Kinematics module, which is one of the modules Catia V5R19 environment. In order to run the simulation used the necessary relationships and ties between all the elements and the process is shown 3 stages for the initial, middle and final phase of the traffic below.

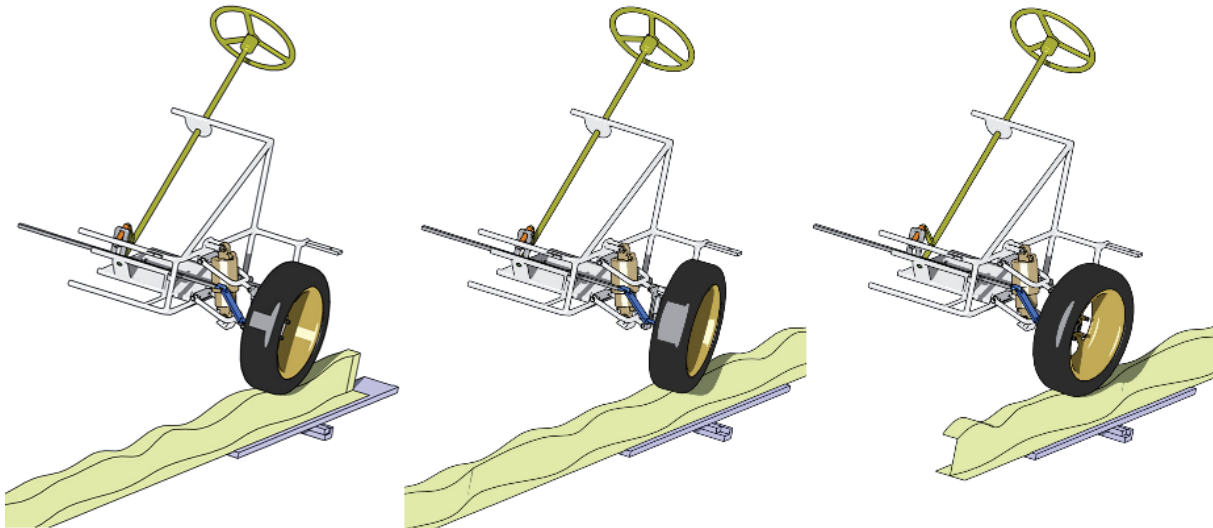


Fig. 4. Mileage kinematic simulation

In order to correctly generated, the simulation properly restraining the bottom guide and frame in the space, assigned for over twenty kinematic constraints, received free degrees of freedom. The drive mechanism was a correlation attributed between the crossover and the wheel. Ride on the designated track is in accordance with the behaviour of Ackerman's compensation system. While the vehicle is moving straight, extension arm crossover converge in one point with the rear axle, while the twisting manoeuvre, the extension axis of crossover converge at a single point with the extension of the rear axle.

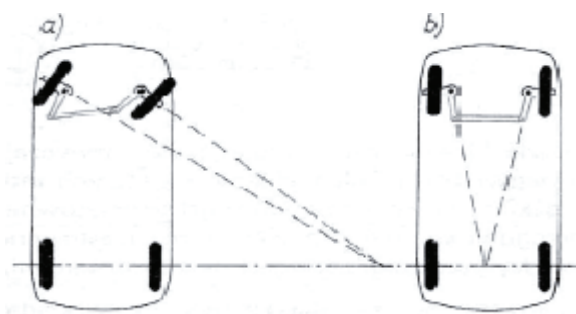


Fig. 5. Switchman mechanism calling the appropriate wheels turns [3]

Properly designed suspension system will allow ride without undesirable slip during a turn. The essence of a kinematic simulation was to determine the appropriate correlation between the two systems used in the motion simulation.

#### 4. Numerical analysis

Numerical analysis was performed for the case load, which corresponds to the interaction of the substrate with the wheel, where the tire presses on the front surface of the curvilinear track.

The value of the applied force acting on the wheel is calculated in theory, by analysing cooperation wheels with the ground, according to the following scheme.

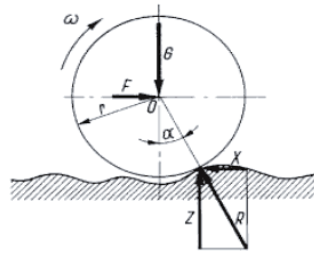


Fig. 6. The forces acting on the wheel rolling on uneven surfaces [1]

The average value of the angle between Z and R reactions, that is the vertical reaction of the substrate and a second reaction directly acting a wheel, is approximately  $10^\circ$ . Value G corresponds to the load, which would interact on the test piece of the suspension system. Taking into account the prevailing conditions, determined the value of the average force acting on the wheel suspension system. The calculated force is represented by the following formula (1) [1].

$$R = \frac{G}{\cos 10} = \frac{500}{0.98} \approx 510N . \quad (1)$$

Construction of a numerical model based on geometric imported from CATIA to Abaqus 6.10. The discretization operation used four nodal elements solid type Tet-4 with linear shape functions. Discrete model structure had exactly 333649 elements and 110678 nodes in the generated grid. Any interactions that occurred in the system are connected with a contact between the components on the tangential and normal directions. Initial conditions that applied in the program were associated with finding a suitable test object in space and applying a point load. Elements that are fully fixed: the rocker axis and the upper region of the spring. The force acting on the system, according to the calculations is 510N. Established places and applying a concentrated force at the point in the system shown below.

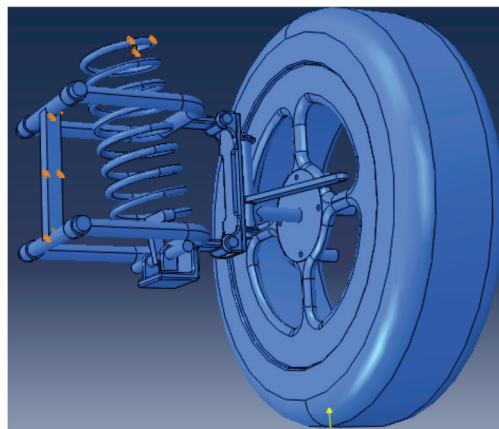


Fig. 7. Figure shows the direction of the force acting from the ground and place of restraint in the suspension system

FEM calculations were based on static analysis, thus the mass of the test system was not taken into account. In order to obtain accurate results, there were increased breakdown of individual increments. Significant impact on improving the quality of the calculations was also to establish contact control associated with the stabilization of the calculation.

Discretization process model is a key step of numerical analysis. The grid is composed of nodes that describe the geometry of the object, and storing the specific values of the studied property (strain, temperature, etc.). The work was been done on the basis of increasing density



values associated with global and local mesh, which gave the accurate calculation, at the expense of long computation time. Discretization was based only on elements such as the Tet-4 as those with complex structure and Hex-8 at the axisymmetric components. The model FEM with assigned a grid is shown below.

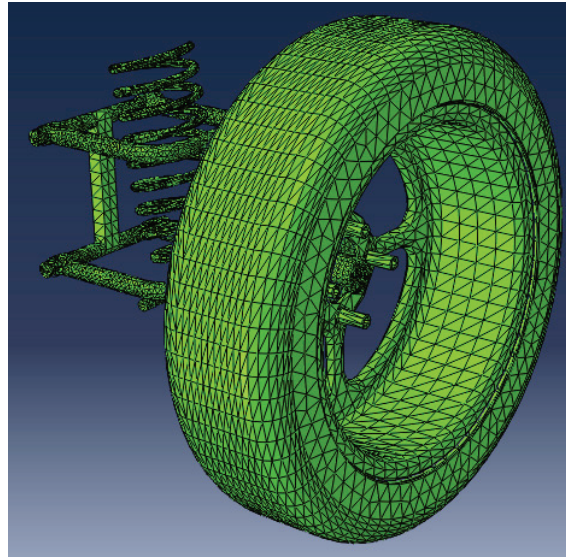


Fig. 8. Fragment of the suspension system after discretization

The scope of the research included an analysis of the steady state, so the description of the system behaved independent of the variable of time. FEM analysis allowed us to obtain a reduced HMH stress distribution in the test structure. The most loaded part of the system was a car crossover, which gave the symmetrical distribution of the stresses resulting from the bending moment.

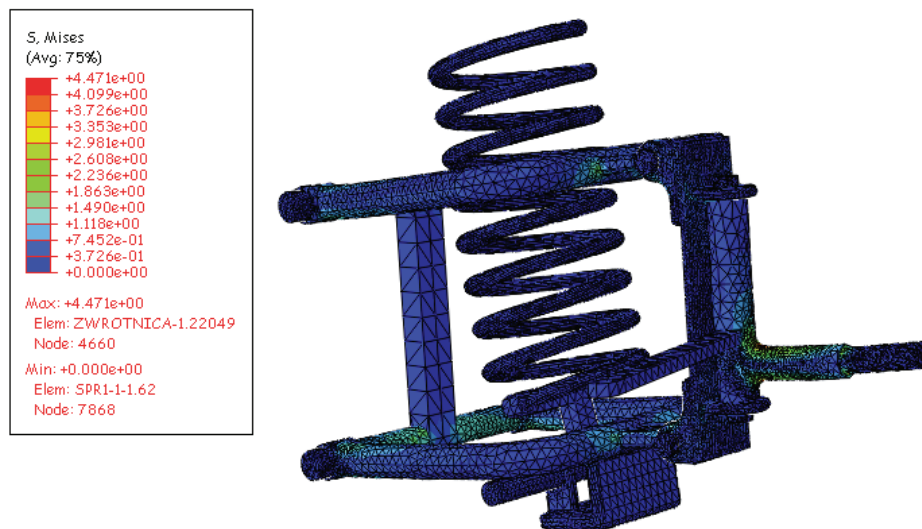


Fig. 9. Stress distribution in the suspension system

The symmetric stress distribution level is present at the connection of car crossover with wheel axis. Maximum stresses are less than 4.5 MPa, as shown in the following figure.

Reduced stress distribution clearly shows the location of maximum stress concentration. The level of stress is relatively low due to the low weight of the vehicle, because it is intended for young users. The suspension is made of aluminum, which data are summarized earlier in the work. Low level of stress that occurs in the suspension system, does not exceed the yield strength of the material, so that even with a constant load, does not adversely affect the operation of the system.

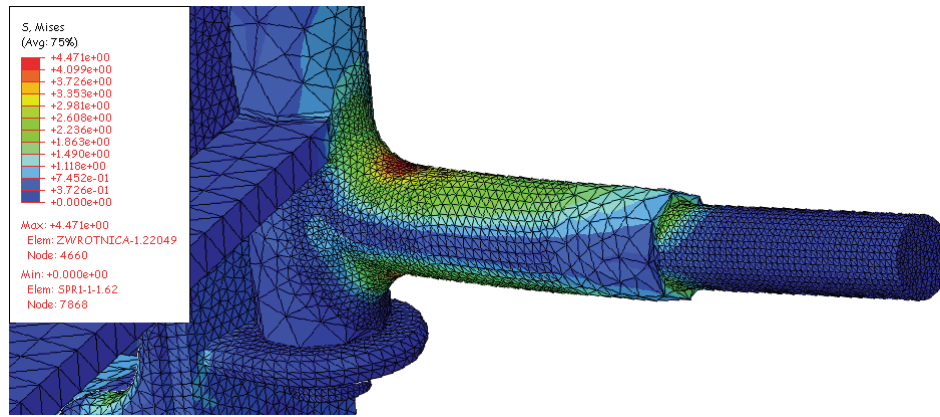


Fig. 10. Stress distribution on the element crossover

## 5. Conclusion

The results of numerical calculations have provided the necessary information concerning the degree of effort the individual elements of the test mechanism. Using the FEM analysis can identify sensitive zones in the studied mechanism. The results of numerical analysis show the distributions of stress in terms of concentrations in the most exposed places, where in the case of the system studied the highest level of stress was associated with a crossover.

Kinematic Simulation allowed us to perform a virtual analysis of collision-free motion of mechanism. Through visualization, we observe not only the behaviour of the same mechanism, but we can also define parameters such as velocity and acceleration points, or generate a collision between the components.

Maximum stress level was less than 4.5 MPa; therefore, the car crossover will not be threatened during use. The yield strength of the material crossover has not been exceeded, while taking into account the changing nature of the load, the suspension may be long-term properly exploited.

## References

- [1] Orzełowski, S., *Budowa podwozi i nadwozi samochodowych*, Wydawnictwo WSiP, Warszawa 2010.
- [2] Reimpell, J., Betzler, J., *Podwozia samochodów – Podstawy konstrukcji*, Wydawnictwo Komunikacji i Łączności, Warszawa 2004.
- [3] Rychter, T., *Budowa Pojazdów Samochodowych*, WSIP, Warszawa 1999.
- [4] Szczegółowy proces generowania materiałów hipersprężystych wraz z charakterystyką, <http://www.axelproducts.com/downloads/CurveFitCAE.pdf>, 2013.