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KINEMATIC ANALYSIS OF TRAPEZOIDAL SUSPENSION

Summary. This article deals with the kinematic analysis of trapezoidal suspension. Specifically, it focuses on the behaviour of the chassis when obstacle crossing was monitored. Our team is developing an autonomous mountain vehicle that will be equipped with different working adapters such as a cutter bar and a picker. The device was designed for work on slopes, hence, must be able to overcome certain natural obstacles. This implies the need to analyse the wheel suspension kinematics. The vehicle was built on a trapezoidal suspension, which has proven to be the most suitable option with respect to operating conditions. From the results obtained, it was possible to analyse the driving characteristics of the obstacle, track the rollover limits and overall safety of operation.
Keywords: mountain mower, trapezoidal suspension, obstacle

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1. INTRODUCTION

The comfort of driving a car depends on the road surface, road condition and the construction of the car itself [14,18,19,21]. The last of these factors can reduce the adverse effects of the other two. There are many types of constructions. The axles are the vehicle structural elements, which connects the vehicle frame and the wheel [1,3]. The axle consists of the wheels, wheel suspension system, wheel bearing system and optional systems: suspension, steering, drive and wheel braking [5,8,15,16].

Division of the axles:

1. Solid axles
2. Swinging (independent hanging) axles

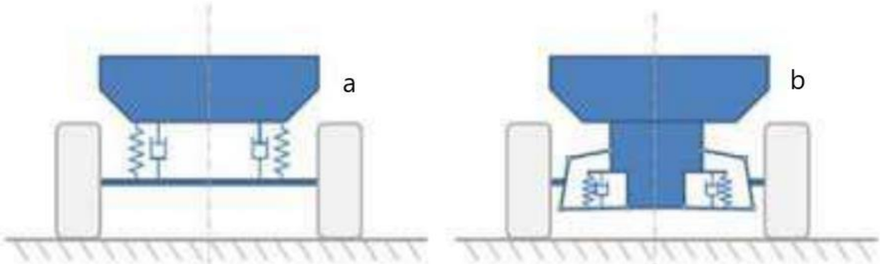

Fig. 1. a) solid axle, b) independent hanging axle [1]

The dependent suspensions consist of a rigid element - a beam at the end of which the wheels are attached. Hence, the movement of the wheels is dependent as the movement of one wheel is transmitted through the beam to the other. Thus, they are mainly used on the rear axles of trucks and on the axles of vehicles designed to work in tough terrains and difficult conditions [2,4,6,20]. The vertical movement of the wheel with independent suspension does not affect the direct movement of the opposite wheel. The advantages of independent suspension are vibration resistance and simpler influence of vehicle properties by changing geometry, smaller space requirements and lower weight of unspring parts [10].

Kinematic analysis was used to calculate the positions, velocities and acceleration points of the mechanism, regardless of the load. The design and calculation works were done with the use of the Creo Parametric CAD system and the ADAMS system.

2. BASIC REQUIREMENTS

The proposed axle is based on the following requirements:

- forwards / backwards
- turning wheels
- turn around the centre of the mower
- walk in

The following requirements were observed as well:

- work on slopes with a slope of up to 45°
- overcome terrain inequalities and obstacles
- correct positioning of the mowing device
- maintaining agrotechnical requirements

- dampening dynamic effects from wheel drive
- use of suitable tires for a given use
- use of passive suspension
- points of attachment of the arms on the chassis

Based on these requirements, the trapezoid axle type (two-armed) was selected. The advantages of this type of suspension are mainly the variability in the choice of geometric parameters, the possibility of attaching the shock absorbers and the load distribution on the two arms. The rotating unit was above the wheel, allowing the wheel to rotate by 90°. The advantage of the position of the servomotor [9,10] above the wheel was to reduce the load on rotation. This "relieving" of the servomotor was ensured by moving the axis of the servomotor through the centre of gravity of the wheel. We tried to distribute axle weight to the centre of gravity of the wheel, which helped to use full tires. Other components and construction were significantly easier, making the axle centre position in the direction of the horizontal axis y approaching the centre of gravity of the wheel. In the direction of the axis z, from the position of the centre of gravity, the servomotor with the gearbox was affected. A schematic sketch of the axle can be seen in Fig. 2 [11,12,17].

2.1. Elements of the mechanism

The main axle parts (Fig. 2) are the chassis attachment (1), upper suspension arm (2), lower suspension arm (3), suspension body (4), wheel attachment (5), air damper (6) and a servomotor (8).

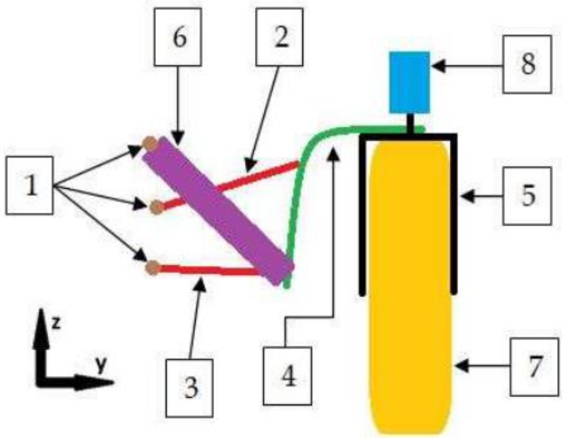

Fig. 2. Schematic sketch of the axle [17]

To suspend the axles, the air suspension was selected as it is more suitable for the needed application because it has adjustable stiffness. We were able to adjust the stiffness of the dampers by the means of the pressure in the rolls. These shock absorbers have the possibility of complete shutdown and a choice of jump in the event of an obstacle. Communications between the shoulders and the brick, as well as the shoulders and the frame, are pivotable. Therefore, each joint had one degree of freedom, which was ensured by the roller bearings [7,8].

The choice of the geometric dimensions of the trapezoidal suspension was based on the concept of the mower, the size of the reaction forces at the pivots of the suspension pins and the kinematic analysis of the suspension mechanism.

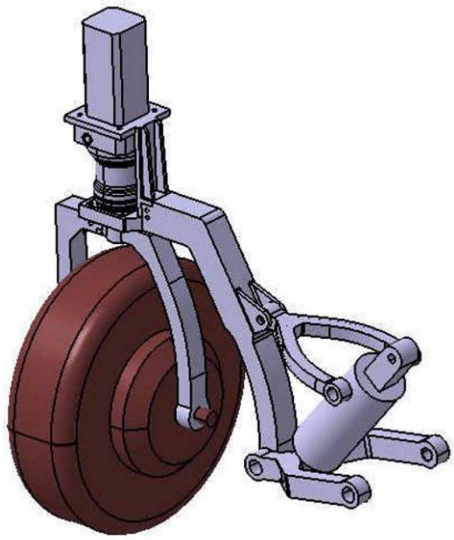

Fig. 3. Geometrical 3D model of the axle [17]

3. KINEMATIC ANALYSIS OF THE TASK

Before performing the analysis, it was necessary to define the mechanism itself, create a kinematic scheme, determine the number of degrees of freedom of the mechanism, the correctness of the mechanism, as well as the number and type of links in order to create a mathematical model. The input parameters of the model were the geometric coordinates of the significant points and the suspension parameters, which formed a set of all permissible solutions. The created kinematic model of the mechanism has one degree of freedom. The remaining degree of freedom was taken by defining the displacement of the DB (wheel / terrain) contact point in the z-axis direction (Fig. 4) [17].

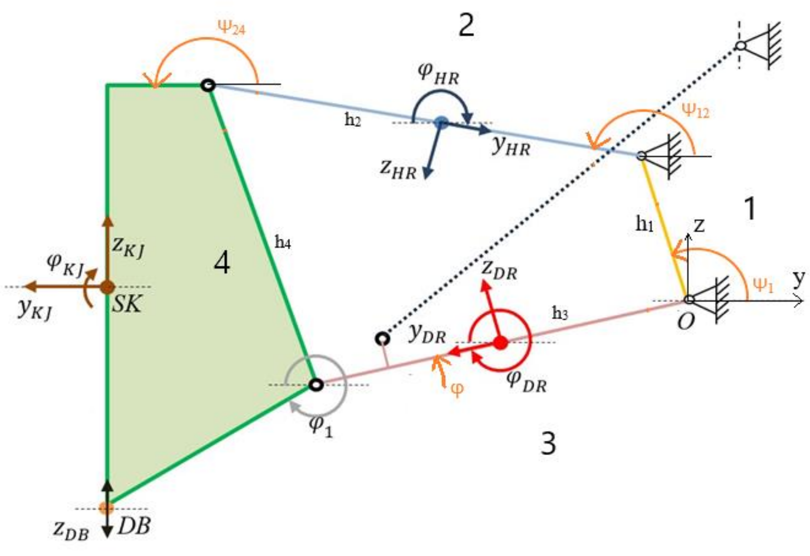

Fig. 4. Kinematic scheme with reference points [17]

This kind of mechanism has been analysed by different authors in various publications [3,4,13]. However, it is obvious that the mechanism of this suspension is four-element, closed and single-loop. The Gruber's rule determines that real mobility is the same as the theoretical one, consequently, the system is correct.

3.1. Mathematical model

Mathematically, the motion of a mechanism is described by nonlinear algebraic equations (NAE). Fig. 5 demonstrates that it is a closed-loop mechanism. We determined the number of vector loops from the formula [5]

$$k = s - u + 1 = 1. \tag{1}$$

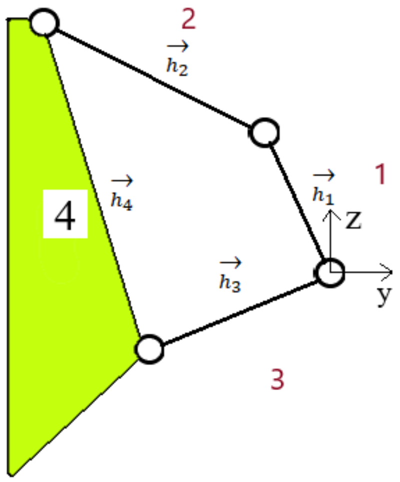

Fig. 5. Single loop mechanism

The vector loop is then written as the equation

$$\vec{h}_1 + \vec{h}_2 + \vec{h}_3 + \vec{h}_4 = \vec{0}. \tag{2}$$

The input values were based on the dimension requirements of a customer. The formulas derived for the mechanism kinematic loop are defined as

$$\text{y axis: } a\sin\psi_1 + h_2\sin\psi_{12} + c\sin\psi_{24} + b\sin\varphi = 0, \tag{3}$$

$$\text{z axis: } a\cos\psi_1 + h_2\cos\psi_{12} + c\cos\psi_{24} + b\cos\varphi = 0. \tag{4}$$

3.2. Solution in ADAMS

The model used for ADAMS simulations has been adapted to suit the optimised number of moving parts, hence, the inertia of the mechanism itself. The simplified model of a mountain mower was developed in the Adams MSC software (Fig. 6). The input parameters of the model were the geometric coordinates of the significant points and the hanging axle parameters that created the set of all acceptable solutions.

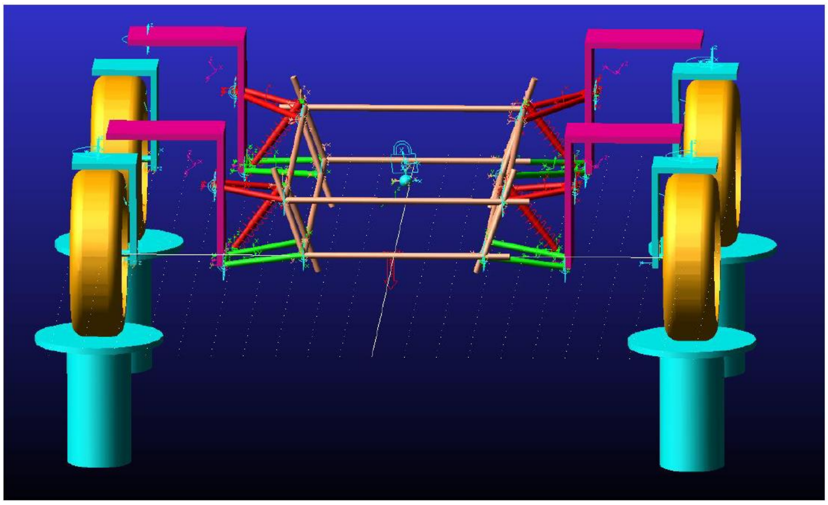

Fig. 6. Model in Adams view environment

As mentioned above, the remaining degree of freedom was removed by defining the displacement of the wheel contact point and the ground in the z-direction. Simulations that represented the crossing of the mower over the obstacle were performed. The simulation consisted of a displacement of 100 mm in the z-direction, that is, 50 mm in the positive direction and 50 mm in the negative axis direction (Fig. 7).

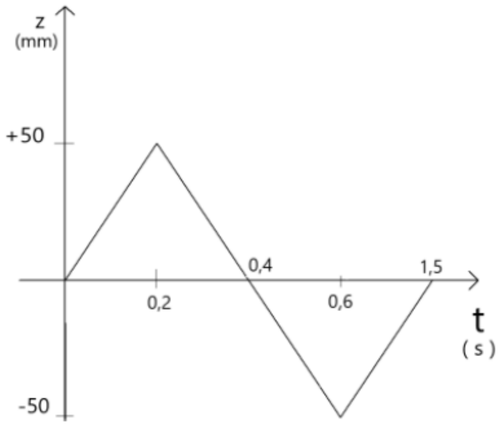

Fig. 7. Graph of actuating process (right side)

4. RESULTS

The actual implementation of input variables was evaluated by monitored parameters / outputs from the simulation. The outputs were specific characteristics or features of the model that delimited a set of permissible solutions. Many outputs were monitored for simulations. We have selected the following outputs for this article.

The following selected graphs reflect the behaviour of a specific point on the frame, depending on the change of path, speed and acceleration when crossing the obstacle.

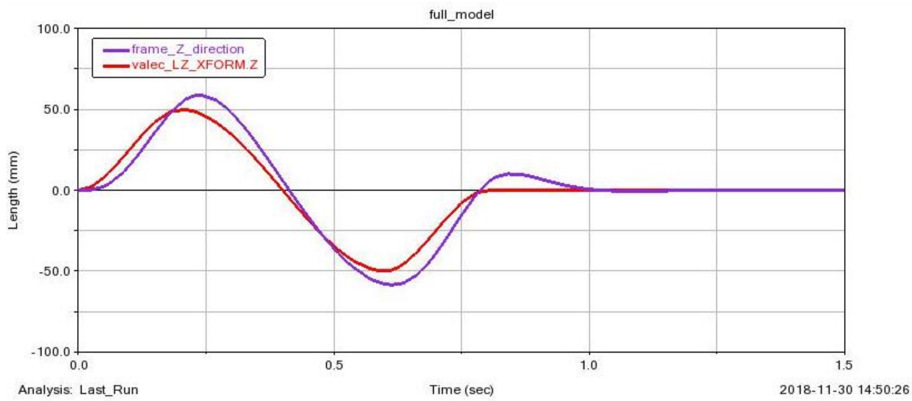

Fig. 8. Graph of track dependence on time

The red colour curve in Fig. 8 shows dynamic excitation (by displacement). The total displacement was 100 mm in the z-axis direction, 50 mm in a positive and 50 mm in a negative direction.

The purple colour illustrates the response of the vehicle gauge in the direction of z-axis.

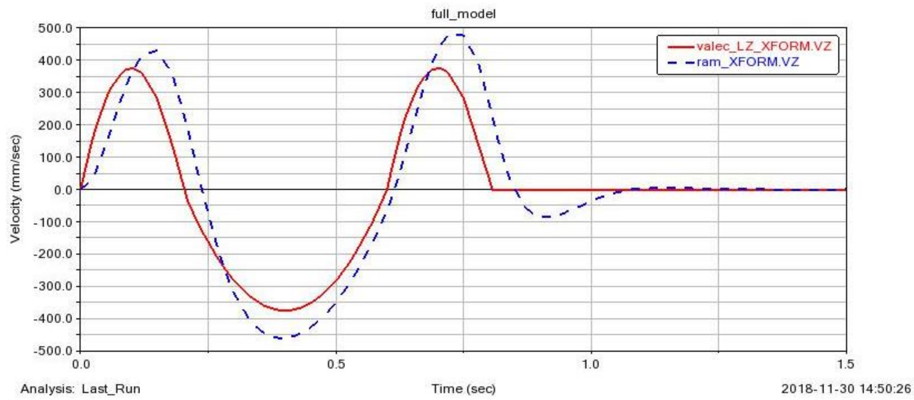

Fig. 9. Time - velocity dependence

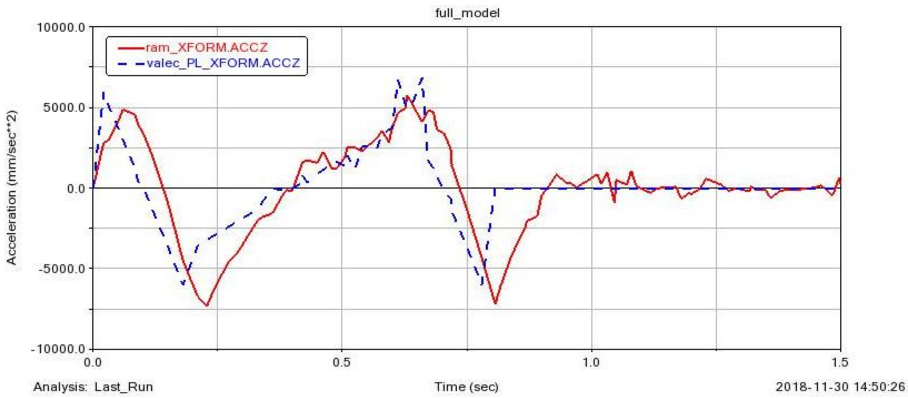

Fig. 10. Time - acceleration dependence

Figure 11 shows the maximum compression or stretching of the spring. During the passage of the wheel through the obstacle, the force effects on the springs were monitored.

Fig. 11. Spring force during simulation

5. SUMMARY

The kinematic analysis in MSC Adams demonstrates the possibilities of applying different types of suspension. Extreme conditions for safe operation when crossing obstacles were identified. Solution results were verified on a second mower prototype (MM2). All tests were successful. Furthermore, other tests are ongoing at the time of preparation of this article.

The first part of this article provides information on axle types and the choice of the appropriate axle type. The selected axle appears to be the most appropriate for (MM2) as confirmed by tests. The initial conditions that influenced the formation of the suspension were defined. In the next section, the principle of creating a mathematical model was presented. Thereafter, an overview of some test results.

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