Design and Kinematic Analysis of the Car Jack

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Abstract **– Car jack is the basic equipment of every car. To replace the tires or to repair a specific defect on the car it is necessary to have a car jack. A modern way of creating the complex mechanical structures is described in this paper, which allows for rapid change of parameters and therefore of the whole design, i.e. the parameterized car jack model was developed.**

Also, the goal of this research is to carry out kinematic analysis of a car jack design. Parametric model is developed in such a way that all parameters of design are in correlations to one main parameter. The angle of thread spindle is chosen for main parameter. Usually, main parameter should be chosen as one of the parameters from power input elements.

Car jack has a human hand power which is applied on car jack handle and because of that, the angle of rotation of thread spindle is the best for main parameter.

Keywords **– complex mechanisms, car jack, kinematic analysis, 3D parametric modelling, parametrization**

1. Introduction

A car lift is a device used to lift a car and keep it at a certain height. The lifting force of car jacks is usually achieved via a threaded spindle or hydraulic cylinder. Only by using manual force, the car jack allows us to lift the vehicle to a certain height. [1], [2].

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To choose the right car jack, the most important parameters are lifting height and maximum load capacity which it can carry. Also, experience has shown that stability of car jack is very important parameter. The stability of the car jack mostly depends on the construction design [3], [4], [5].

Figure 1. "Scissor" car jack

There are many designs of car jacks that are mostly manually operated. Of course, there are car jacks that use electric lifting power, but they are much more expensive and not accessible to every car owner. This research is carried out to develop a parameterized CAD model and to carry out a kinematic analysis. Today, most commonly used car jack is known as "Scissor" car jack (Figure 1.). The parametric model was developed for this car jack on which kinematic analysis was performed. A lot of different research is done regarding car jacks [6], [7], [8], [9].

2. Design and Development of Parametric 3D Model

Goal of 3D modelling is not only to get visual representation of design. 3D model can be developed as functional 3D model with all kinematics functionalities like the real one. Using this 3D parametric model, it is possible to change positions of some parts on design by editing some of the parameters [10], [11], [12]. This type of 3D parametric modelling is used in this research to model the car jack. Simulation of the car lifting can be carried out using this CAD model.

Parametrization of car jack is very important, not only to make parametrization of some dimensions of individual parts, it is more important to make parametrization of positions of some points on car jack.

Another feature which needs to be implemented is to use links to connect all individual parts in one functional assembly [13], [14]. Using links, it is enabled that all changes on individual parts will automatically be updated in all assemblies where that part is copied.

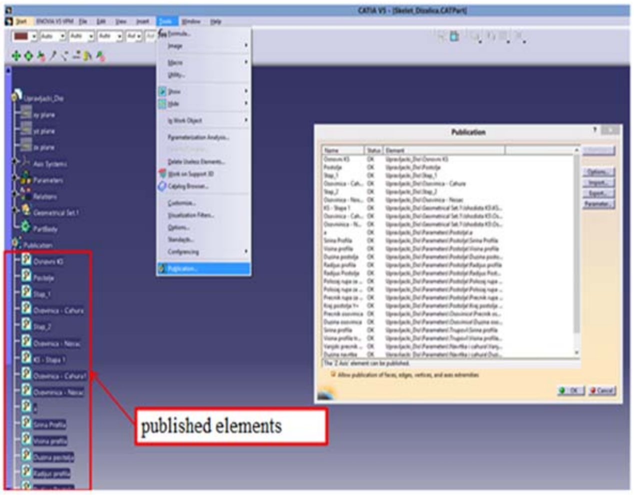

Figure 2. Published elements

The first step in publishing process is to make all elements as public (Figure 2.). Before that, the names of all parts need to be checked, two or more parts can't have the same name. After publishing of all parts, they can be copied easily.

Links are also important to show threads inside the software in real form and to enable positioning and parametrization of parts. Every assembly model has a control model. This model is a main part of the whole assembly model which is parametric controlled.

All information about the assembly, like coordinate systems, sketches, parameters, planes, etc., are stored inside control model. All other parts of assembly are also stored inside this control model (Figure 3.).

Coordinate systems have very important role in parametric controlled models. They determine positions of all parts inside assembly. By changing some parameters in the control part, parameters which influence the position of a car jack, the coordinate systems will move and according to them appropriate parts will move also.

To get accurate results from kinematics analysis it is important to model thread spindle and thread nut as real as possible. Problem with threads is how to establish real connection between thread toots. Standard constrains can not be used for this. The only option is to use links. By using standard constrains it is impossible to move thread nut along the thread spindle.

Without links, using standard constrains, there will be a problem because thread nut will have penetration to thread spindle during moving.

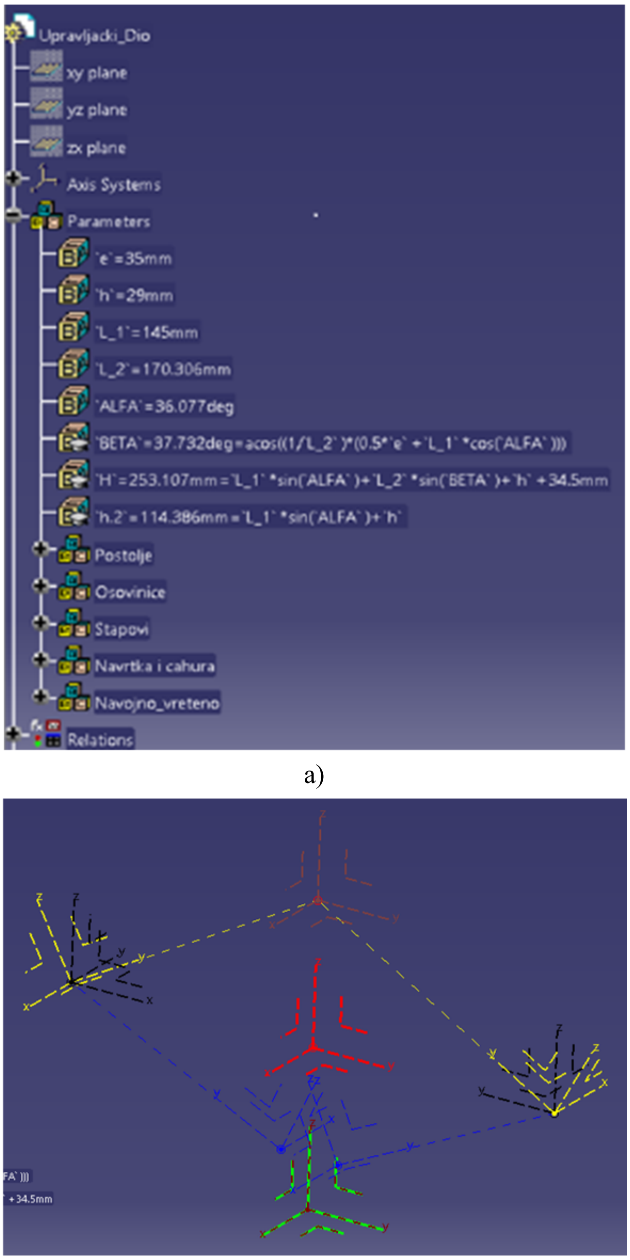

Figure 3. Control model; a) parameters, b) coordinate systems

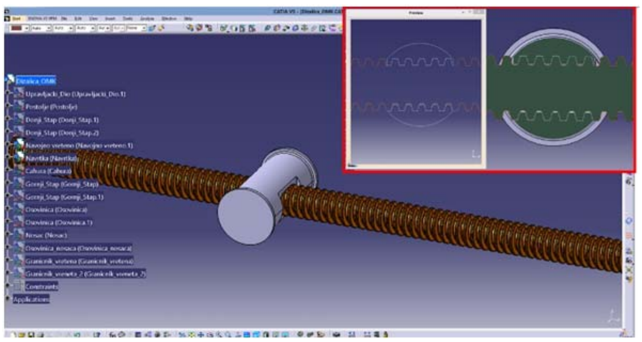

Figure 4. Connection of thread nut and thread spindle

Figure 4. shows a connection between thread spindle and thread nut. It is important to notice that there is not any material penetration between thread spindle and thread nut.

3. Analytical Kinematic Calculations of the Car Jacks

For kinematics analysis of a car jack design, schematic drawing from Figure 5. can be used. All parameters will be given in correlation to the angle of rotation of thread spindle φ. When thread spindle is turned around for one full circle, nut will be moved for the value of one step *P*. In the case of a car jack (Figure 5.), points C and D will move for the value of one step *P* for one full circle of thread spindle. Point C is the nut and point D is thread spindle support, which moves in the same way as the nut.

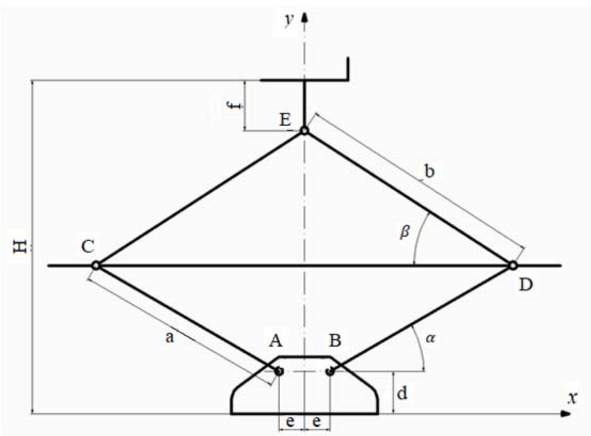

Figure 5. Schematic drawing of car jack

Movement of point D in function of thread spindle angle can be given as:

$$x_D = -p \cdot \frac{\varphi}{2\pi} = -\frac{p}{2\pi}\varphi \tag{1}$$

Lifting height, H in Figure 5., can be given as:

$$H = d + f + a\sin\alpha + b\sin\beta \tag{2}$$

Total movement of point D from Figure 5. can be given as:

$$x_D = -a\cos\alpha_0 + a\cos\alpha \tag{3}$$

Where α_0, is the value of angle α in lowest position. From equations (1) and (3) it is possible to get the equations which describe how angle α is dependent on rotation angle of thread spindle φ:

$$\cos\alpha = \cos\alpha_0 - \frac{p}{2a\pi}\varphi \tag{4}$$

$$a = \arccos\left(\cos\alpha_0 - \frac{p}{2a\pi}\varphi\right) \tag{5}$$

Similar process can be carried out to get the equation for how angle β is dependent on rotation angle of thread spindle φ. Position of point D from Figure 5. can be given as a function of angle α and β:

$$x_D = e + a\cos\alpha \tag{6}$$

$$x_D = b\cos\beta \tag{7}$$

From (6) and (7), the following equation can be formulated:

$$\cos\beta = \frac{a}{b}\cos\alpha + \frac{e}{b} \tag{8}$$

If equation (4) is included in equation (8), then following equations can be written:

$$\cos\beta = \frac{1}{b}\left(a\cos\alpha_0 - \frac{p}{2\pi}\varphi + e\right) \tag{9}$$

$$\beta = \arccos\left[\frac{1}{b}\left(a\cos\alpha_0 - \frac{p}{2\pi}\varphi + e\right)\right] \tag{10}$$

Using already known trigonometric identities $\sin\alpha = \sqrt{1-\cos^2\alpha}$ and $\sin\beta = \sqrt{1-\cos^2\beta}$, equations (4) and (9) can be given as

$$\sin\alpha = \sqrt{1-\left(\cos\alpha_0 - \frac{p}{2\pi}\varphi\right)^2} \tag{11}$$

$$\sin\beta = \sqrt{1-\left[\frac{1}{b}\left(a\cos\alpha_0 - \frac{p}{2\pi}\varphi + e\right)\right]^2} \tag{12}$$

Adding equations (11) and (12) in equation (2), the equation for lifting height *H* of a car jack in dependence of rotation angle of thread spindle can be given as:

$$H = d + f + a\sqrt{1-\left(\cos\alpha_0 - \frac{p}{2\pi}\varphi\right)^2} + b\sqrt{1-\left[\frac{1}{b}\left(a\cos\alpha_0 - \frac{p}{2\pi}\varphi + e\right)\right]^2} \tag{13}$$

Differencing equations (13) in accordance to the time, speed of lifting v_d in dependence of rotation angle of thread spindle can be calculated as:

$$v_d = \frac{\left(\cos\alpha_0 - \frac{p}{2\pi}\varphi\right)\cdot\frac{p}{2\pi}\dot{\varphi}}{\sqrt{1-\left(\cos\alpha_0 - \frac{p}{2\pi}\varphi\right)^2}} + \frac{\left(a\cos\alpha_0 - \frac{p}{2\pi}\varphi + e\right)\cdot\frac{p}{2\pi}\dot{\varphi}}{b\sqrt{1-\left[\frac{1}{b}\left(a\cos\alpha_0 - \frac{p}{2\pi}\varphi + e\right)\right]^2}}$$

4. Numerical Kinematic Analysis of Car Jacks

Kinematics analysis, which includes calculation of speed and acceleration of elements and points on kinematic system can be carried out not only analytically, but numerical methods can be used also. Numerical analysis is usually carried out using advanced numerical computer applications for wide type of use [15]. In this research, for numerical kinematics analysis of car jack, software package CATIA is used. More precisely, its module DMU Kinematics. This module enables to simulate the moving of car jack parts and to input additional laws of movement.

Analysing the car jack it can be concluded that it has only one degree of movement, that movement is rotation of thread spindle. If thread spindle is not moving all other parts of assembly are stationary. That is the reason why thread spindle angle is chosen as main parameter.

Simulation in DMU Kinematics module is carried out by adding additional connections between car jack parts and by adding mathematical laws from chapter 2. Simulation is started by manually putting car jack in lowest possible position (Figure 6.).

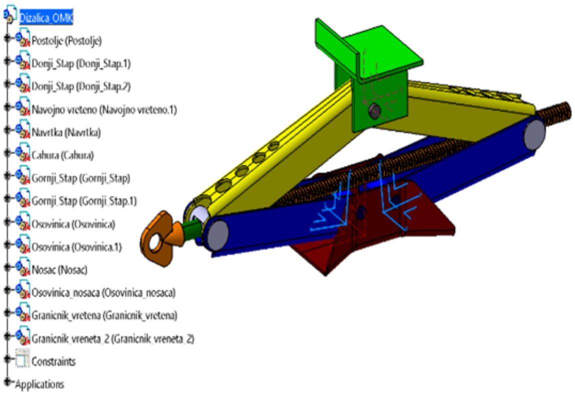

Figure 6. Lowest possible position of car jack and tree prepared for simulation

All connections, which are applied to the parts of car jack added some geometrical conditions between parts. After definition of connection, it is necessary to add law of motion by adding main parameter (angle of thread spindle). Also, it is necessary to add parameters which will be used to measure lifting height, lifting speed and angle α (Figure 7.).

After definition of all the above-mentioned parameters and laws, car jack is ready for kinematics simulation. It is necessary to wait for car jack to come to the most possible upper position and after that, the results are ready to be obtained.

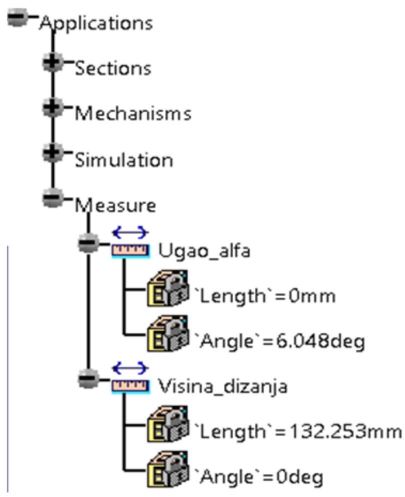

Figure 7. Display of measured parameters in CATIA tree

5. Results

Results of analytical and numerical kinematics analysis of car jack are shown in Figures 8., 9. and 10.

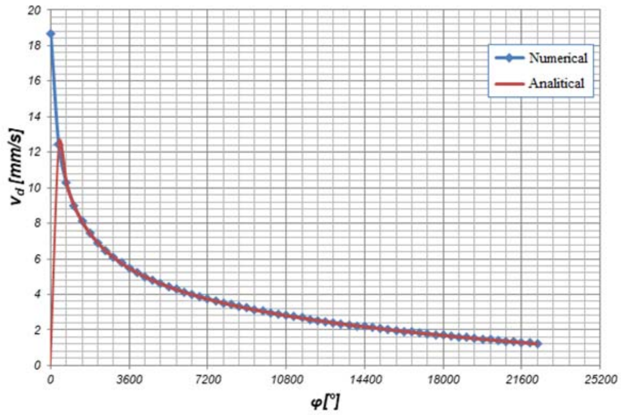

Figure 8. Lifting speed in correlation to the thread spindle angle of rotation

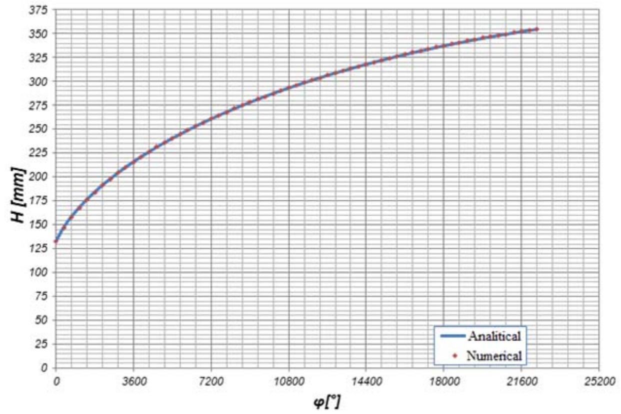

Figure 9. Lifting height in correlation to the thread spindle angle of rotation

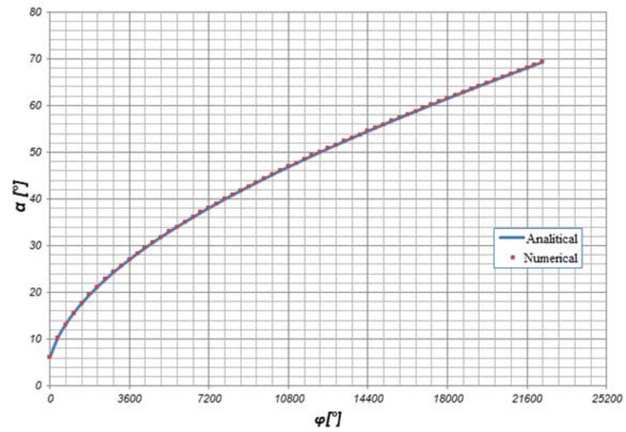

Figure 10. Change of angle α in correlation to the thread spindle angle of rotation

6. Conclusion

The goal of this paper was to carry out the design and kinematics analysis of the car jack.

Developed CAD parametric model is fully functional parametric CAD model. This was achieved using the method for 3D modelling explained in the paper. The model was developed in such a way that it is possible to change the position of all moving parts of a car jack by changing only one parameter (angle of rotation of thread spindle). This parametric is used for kinematics analysis of a car jack.

Kinematics analysis is carried out using analytical and numerical methods. From Figures 9. and 10. it can be seen that the results of the two analysis are almost identical, without any deviations. In Figure 8., it can be noticed that only one difference between results of analytical and numerical analysis exist only at the beginning. The reason for that is the fact that analytical calculations at the beginning of rotation for speed of rotation take the value zero and numerical analysis takes the value few moments after beginning of rotation (numerical analysis do not take in consideration stationary status at the beginning of lifting). If first value (initial position) from Figure 8. is not taken in consideration, then the diagrams of numerical and analytical analysis will be the same. The second way to get the same diagrams is to set value of 2π rad/s for initial value of angular speed of thread spindle and to set the value of initial angle of thread spindle to about zero.

It can be concluded that development of fully functional CAD model has big advantage, because it enables to put parts of 3D model in any position and to easy change any dimensions of the assembly. In addition, it represents great 3D model for future optimization of car jack design.

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