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Design and Optimization of a Mars Rover's Rocker-Bogie Mechanism

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Abstract: *The need to develop a highly stable suspension system capable of operating in multi terrain surfaces while keeping all the wheels in contact with the ground. The design has a mechanism that can traverse terrains where the left and right rockers individually climb different obstacles. It is also done to sustain a tilt of over 50deg without tipping over the sideways. In order to go over an obstacle, the front wheels are forced against the obstacle by the rear wheels. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle.*

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I. Introduction

The Rocker bogie system is the suspension arrangement used in Mars rovers introduced for Mars Pathfinder and also used on Mars Exploration Rover (MER) and Mars Science Laboratory (MSL) missions. This bogie can resist mechanical failures caused by the harsh environment on MARS. The primary mechanical feature of the Rocker Bogie design is its drive train simplicity, which is accomplished by two rocker arms. In order to go over an obstacle, the front wheels are forced against the obstacle by the rear wheels. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle. The middle wheel is pressed against the obstacle by the rear wheel and pulled against the obstacle by the front, until it is lifted up and over. Finally, the rear wheel is pulled over the obstacle by the front two wheels. During each wheel's traversal of the obstacle, forward progress of the vehicle is slowed or completely halted. These rovers move slowly and climb over the obstacles by having wheels lift each piece of the suspension over the obstacle one portion at a time.

II. Selection Of Mechanical And Electrical Components

A. Mechanical Components:

1) Shaft
2) Link
3) Bearing
4) Wheel
5) Motor
6) Bogie
7) Cleaning brush

B. Electrical and Electronic Components:

1) Power cables
2) On / off switch
3) Reverse switch

C. Design and Optimization of a Mars Rover's Rocker-Bogie Mechanism:

The rocker bogie suspension system, which was specifically designed for space exploration vehicles have deep history embedded in its development. The term "rocker" describes the rocking aspect of the larger links present each side of the suspension system and balance the bogie as these rockers are connected to each other and the vehicle chassis through a selectively modified differential. As accordance with the motion to maintain Centre of gravity of entire vehicle, when one rocker moves up-word, the other goes down. The chassis plays vital role to maintain the average pitch angle of both rockers by allowing both rockers to move as per the situation. As per the acute design, one end of a rocker is fitted with a drive wheel and the other end is pivoted to a bogie which provides required motion and degree of freedom. Encounter area of rocker bogie suspension system is shown in the figure.

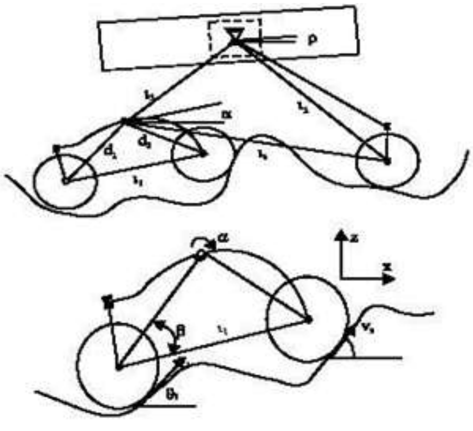


Fig: Encounter area of rocker bogie suspension system is shown in the figure.

D. Working of Mars Rover's rocker-Bogie Mechanism:

The initiation of rocker bogie suspension system can be traced to the development of planetary rover which is mobile robots, especially designed to move on a planet surface. Early rovers were tele-operated ,while recent ones are fully autonomous, such as FIDO, Discovery and recently developed Curiosity mars exploration rover. The rovers needed to be very robust and reliable, as it has to withstand dust, strong winds, corrosion and large temperature changes under mysterious conditions. Maximum rovers remain powered by batteries which are recharged by solar panels during the day installed over there surface. The locomotion system of rovers remains crucial to enable it to reach objective sites, conduct research, and collect data and to position itself according to the demand. There are three main types of rover locomotion developed so far i.e. wheeled, legged and caterpillar locomotion.

The main difference between the miscellaneous designs of planetary robots lies in the type of locomotion system. Even after developing many legged and hybrid robots, most researchers still focus on wheeled locomotion for rovers because of its locomotive ease and advantages and among wheeled locomotion design, the rocker bogie suspension system based design remain most favored. The ancient FIDO rover and the Sojourner contain 6 independently steered and driven wheels suspended from a rocker-bogie mechanism for maximum suspension and ground clearance. Rocky Seven Rover has a similar suspension system just differ in front wheels. The Nano rover & Nomad Rovers have four steered wheels suspended from two bogies & CRAB Rover utilizes two parallel bogie mechanisms on each side to overcome obstacles and large holes.

As far as the initial research is concerned, the software optimization seeks for an optimum in the constrained solution space given an initial solution and Dr. Li et al. derive a mathematical model to generalize rover suspension parameters which define the geometry of the rocker-bogie system. The objective behind evolution of rocker bogie suspension system is to develop a system which minimizes the energy consumption, the vertical displacement of the rover's Centre of mass and its pitch angle. In this research, our endeavor is to transfer these major advantages embedded with the rocker bogie system into conventional vehicles in order to remove discomfort and complexities present in conventional suspension system in general and suspension system of heavy vehicles in particular.

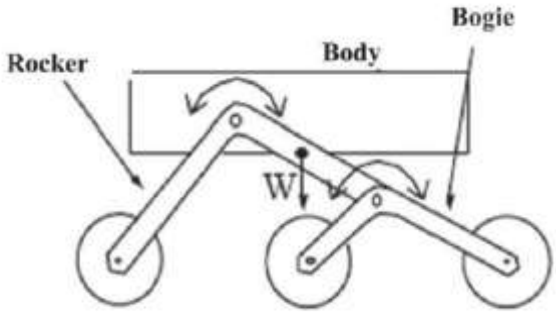


Fig: 2D View of Mars Rocker-Bogie Mechanism

E. Principle:

The rocker-bogie design consisting of no springs and stub axles in each wheel which allows the chassis to climb over any obstacles, such as rocks, ditches, sand, etc. that are up to double the wheel's diameter in size while keeping all wheels on the ground maximum time. As compared to any suspension system, the tilt stability is limited by the height of the Centre of gravity and the proposed system has the same. Systems employing springs tend to tip more easily as the loaded side yields during obstacle course. Dependent upon the Centre of overall weight, any vehicle developed on the basis of Rocker bogie suspension can withstand a tilt of at least 50 degrees in any direction without overturning which is the biggest advantage for any heavy loading vehicle. The system is designed to be implemented in low speed working vehicles such as heavy trucks, Bulldozers which works at slow speed of around 10 centimeters per second (3.9 in/s) so as to minimize dynamic shocks and consequential damage to the vehicle when surmounting sizable obstacles.

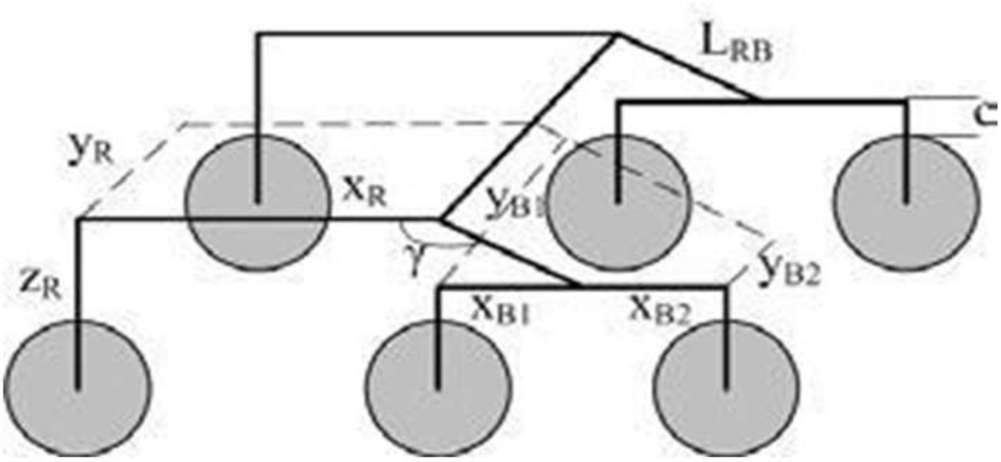


Fig: Geometry of Rocker Bogie.

As accordance with the motion to maintain Centre of gravity of entire vehicle, when one rocker moves up-word, the other goes down. The chassis plays vital role to maintain the average pitch angle of both rockers by allowing both rockers to move as per the situation. As per the acute design, one end of a rocker is fitted with a drive wheel and the other end is pivoted to a bogie which provides required motion and degree of freedom.

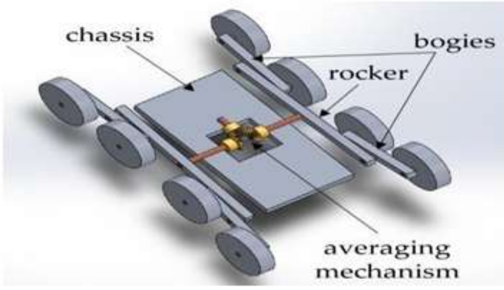
III. Experimental Procedure

As per the research it is find that the rocker bogie system reduces the motion by half compared to other suspension systems because each of the bogie's six wheels has an independent mechanism for motion and in which the two front and two rear wheels have individual steering systems which allow the vehicle to turn in place as 0 degree turning ratio. Every wheel also has thick cleats which provides grip for climbing in soft sand and scrambling over rocks with ease.

In order to overcome vertical obstacle faces, the front wheels are forced against the obstacle by the Centre and rear wheels which generate maximum required torque. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle and obstacle overtaken. Those wheels which remain in the middle, is then pressed against the obstacle by the rear wheels and pulled against the obstacle by the front till the time it is lifted up and over. At last, the rear wheel is pulled over the obstacle by the front two wheels due to applying pull force. During each wheel's traversal of the obstacle, forward progress of the vehicle is slowed or completely halted which finally maintain vehicles Centre of gravity.

The above said methodology is being practically proved by implementing it on eight wheel drive ATV system in order to gain maximum advantage by rocker bogie system.'

IV. Mars Rover's Rocker-Bogie Mechanism



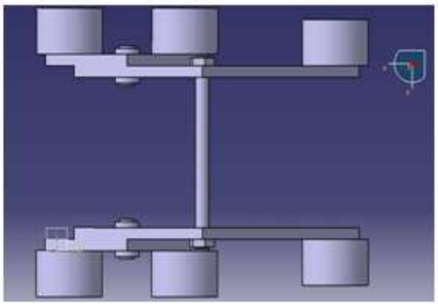


Fig: Top View

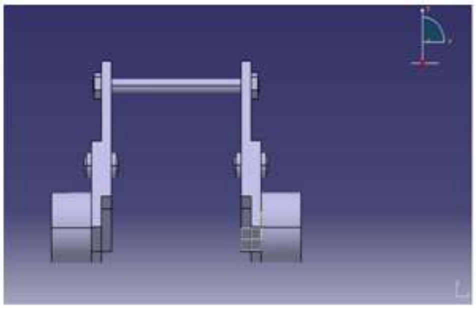


Fig: Front View

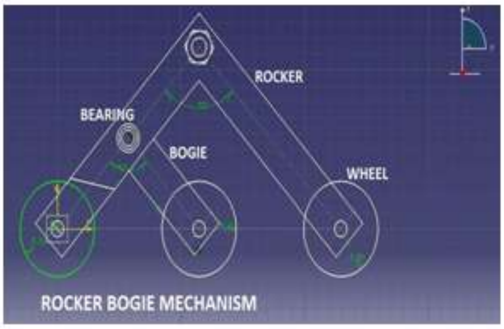


Fig: SOLIDWORKS 3D and **2D** Models of Rocker Bogie system

V. Result And Discussion

After the realized simulation, the results has been generated and analyzed which comparing the disturbances in the ATV's Centre of Gravity position in each of the two operating modes, contrasting the response of these two distinctive configurations of the rocker-bogie suspension against upcoming obstacles that can be present along the system generated obstacles and roadblocks. The test track used for these experiments is a 10 square meters platform with one cylindrical bumper. The simulated rover has a total mass of 260 Kg.

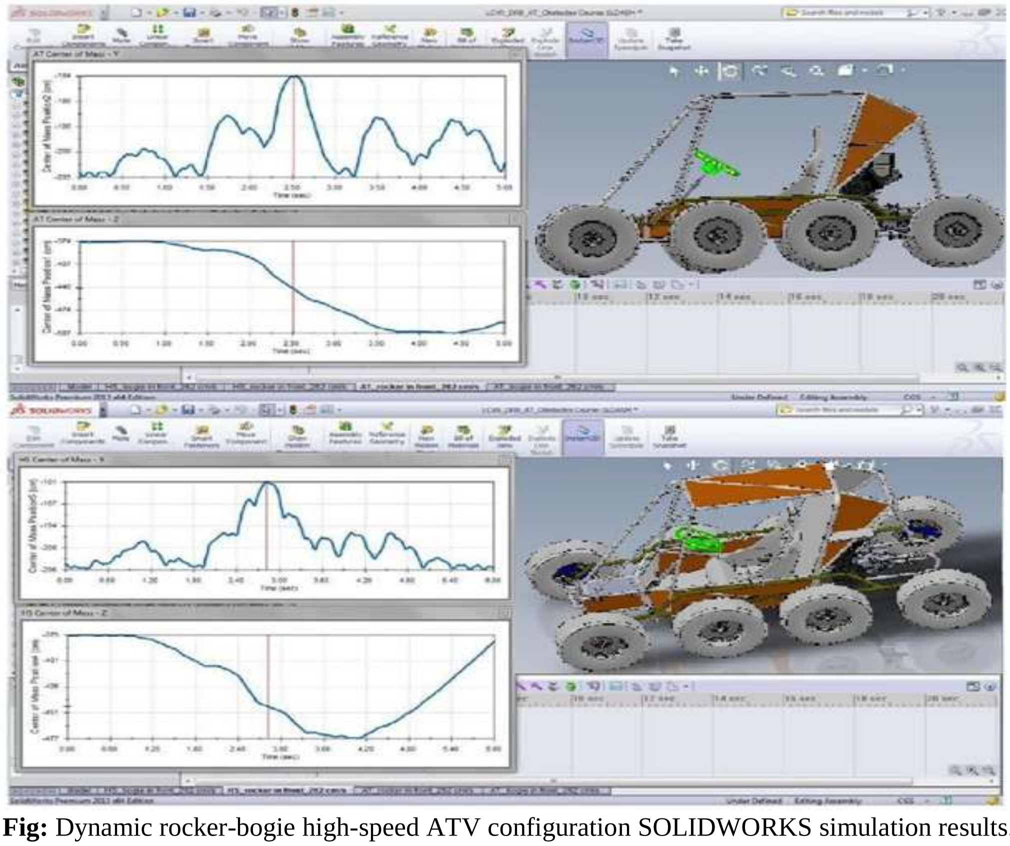


Fig: Dynamic rocker-bogie high-speed ATV configuration SOLIDWORKS simulation results.

A. *Wheel Design:*
From the table below, We have chosen 30rpm motor. From the table for 10cm/s; the wheel diameter is 63.6mm (**70mm** approx.)

B. Calculation of Tilt Angle & Wheel Base:

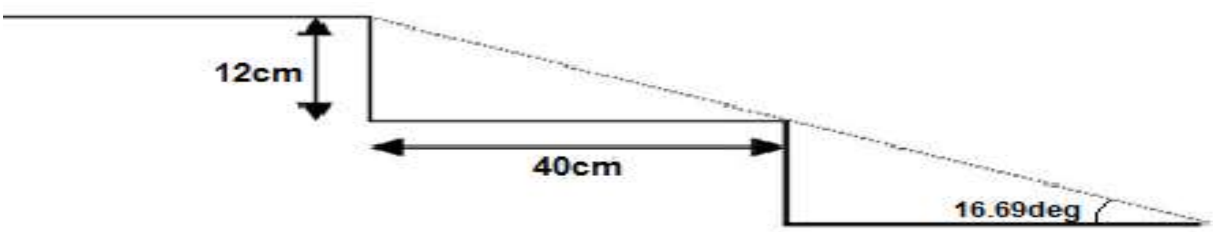
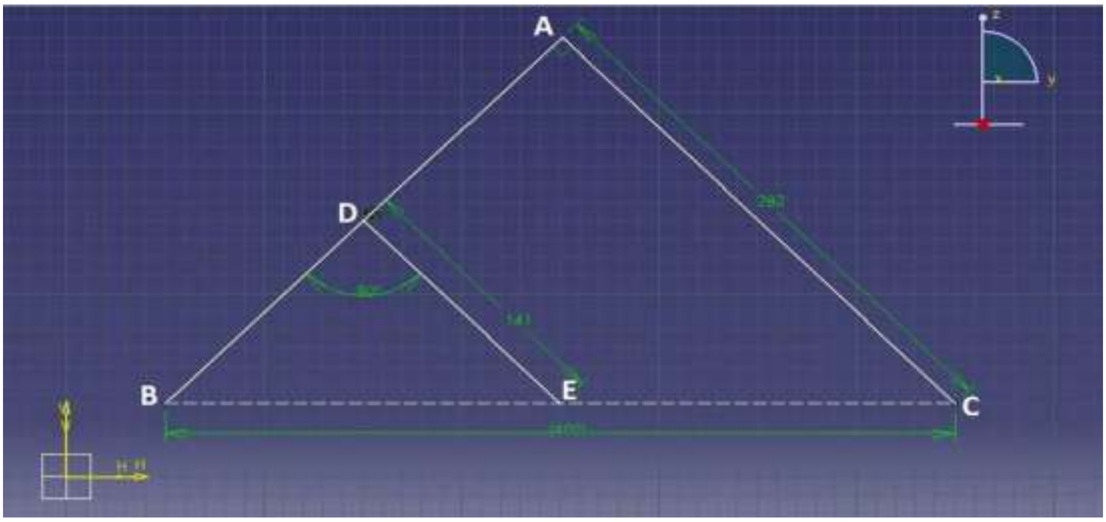


Fig: Tilt Angle & Wheel Base

For Tilt Angle:
$\Theta = \tan^{-1}(y/x)$
$\Theta = \tan^{-1}(12/40) = \mathbf{16.69^0}$

For Wheel base:
Deduce the wheel base,
Wheel base=Total length - (radius of front wheel + radius of rear wheel)
b=40-(3+3)
b=**34cm**

C. Calculation of Length of Links:



Length of link AC:
$BC^2 = AB^2 + AC^2$
$40^2 = 2(AB^2)$
AB=AC=28.2cm (**28cm** approx.)

Length of link DB:
$BE^2 = DB^2 + ED^2$
$20^2 = 2(DB^2)$
DB=DE=14.1cm (**14cm** approx.)

VI. Conclusion

The proposed paper produces a novel design in pursue of increasing the rocker-bogie mobility system in conventional heavy loading vehicle behavior when high-speed traversal is required. Presented situation was faced presenting two modes of operation within same working principle which is a rocker-bogie system with a robust obstacles traverse features and another is an expanded support hexagon achieved by rotating the bogies of each side of the vehicle. The proposed modification increases in the stability margin and proved with valuable and profitable contrasting the SSF metric with the 3D model simulations done in SOLIDWORKS. In future, if the system installed in heavy vehicles and conventional off road vehicles, it will definitely decreases the complexity as well as power requirements to retain bumping within it. This is a wide field of study and is very less explored. So this gave us the motivation for the development of this rocker bogie suspension system in a cost effective manner. Our concern during the development of the rover will be to optimize the speed such that the rover do not flip and may travel a little faster too and make it cost effective with maximum possible rigidity and ruggedness. With certain developments the bogie system can be used for defense related operations and also in wheelchairs for climbing stairs.

A. Advantages:

- This mechanism allows climbing obstacles twice the size of wheel diameter
- Does not employ springs and stub axles
- Equal distribution of load on all wheels
- Independent movement of rocker on either sides of the bogie
- The front and back wheels have individual drives for climbing, enabling the rover to traverse obstacle without slip.
- The design is simple and reliable

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