

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 7, Issue 7, July 2018

Design of Stair-Climbing Rocker-Bogie Mechanism

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ABSTRACT: In planetary exploration, Rocker-Bogie Mechanism will continue to play a significant role. Present mobility designs are complicated, using number of wheels or legs. They are not built up to mechanical failure initiated by the tough environment on Mars. Four-Wheeled rovers are capable of navigating rough terrain using an effective high degree of mobility suspension system. Drive train ease is the fundamental mechanical feature of the rocker-bogie design, which is accomplished using only two motors for mobility. Inside the body where thermal deviation is kept to a lowest, both motors are located that is responsible for increasing reliability and efficiency. Since there are few hindrances on natural terrain that need both front wheels of the rover to climb simultaneously, six wheels are used. Analytical models of how the rover interacts with its environment are essential to design and control these. Models are too needed for rover action planning. A series of mobility experiments in the uneven roads, agricultural land, inclined stairs and difficult surfaces established that rocker bogie can accomplish some distance traverses on the field.

KEYWORDS: Rocker bogie; Stair climbing; Rover; Wheel type mobile robot

I. INTRODUCTION

Over the past decade, the rocker-bogie suspension design has become a verified mobility application known for its greater vehicle stability and obstacle-climbing capability. Following numerous technology and research rover implementations, the system was successfully flown as part of Mars Pathfinder's Sojourner rover. When the Mars Exploration Rover (MER) Project was first proposed, the use of a rocker-bogie suspension was the obvious choice due to its extensive heritage. The challenge posed by MER was to design a lightweight rocker-bogie suspension that would permit the mobility to stow within the limited space available and install into a configuration that they could then safely use to egress from the lander and explore the Martian surface [4].

Simplicity is something you need when you build a robot. There were numerous cases when a suspension system could not be evaded even though in maximum cases you'd never require a suspension system. 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 improved differential. And the term "bogie" refers to the links that have a drive wheel at each end. Bogies were commonly used as load wheels in the tracks of army tanks as idlers distributing the load over the terrain. Both applications now select trailing arm suspensions. The design of rocker-bogie has no springs or stub axles for each wheel, permitting the rover to climb over hurdles, such as rocks, that is up to twice the wheel's diameter in size while keeping all six wheels on the ground. Tilt stability is limited by the height of the centre of gravity with any suspension system.

II. LITERATURE REVIEW

The concept of our research work is to create a rocker-bogie suspension system based on those of NASA. It established the rocker-bogie suspension system for their rovers and was applied in the Mars Pathfinders and Sojourner rover. The latest planetary exploration rovers being created by NASA employ a rocker-bogie system, which is a six-wheel-drive

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configuration (three wheels on either side) for best stability and control over rough terrain. Each side of the robot has both a rocker and a bogie as suggested by the name itself. The rocker consists of two wheels connected by a linkage to a pivot on the main chassis, while the bogie consists of a single front wheel connected to a pivot on the rocker linkage. The rocker-bogie suspension system passively keeps all six wheels on the robot in contact with the ground even on uneven surfaces. This creates for great grip and manoeuvrability (Harrington & Voorhees). The rocker-bogie suspension mechanism which was presently NASA's approved design for wheeled mobile robots, primarily because it had study or strong abilities to deal with hurdles and because it uniformly distributes the payload over its six wheels at all times. It also can be used for other purposes to operate on rough roads and to climb the steps. It was having lots of advantages, but one of the main disadvantages is the rotation of the mechanism when and where is required. The rotation can be possible by providing individual motors to individual wheels which sources arise in cost and complicacy in design. Here an effort was made to transform the existing design by integrating a mechanism of gear type steering which is single motor operated that simplifies the design as well as the total cost and operating cost of the mechanism.

In this work, the proposed steering mechanism was designed, and CATIA V5 was used for the modelling and in ANSYS the same was analyzed for static analysis for the proposed torque condition of the motor. In the analysis, all the results were analyzed for static analysis [1]. The researchers deliberate the concept and parameter design of a Robust Stair Climbing Compliant Modular Robot, capable of tackling stairs with projections. The periphery of the wheels of our robot helps in tackling overhangs by modifying the geometry. Vigorous design parameters were set to minimize performance variation along with establishing a concept design. The Taguchi Method based on Grey was adopted for providing the best setting for the design parameters of the robot. The robot prototype was shown to have successfully scaled stairs of varying dimensions, with overhang, thus validating the analysis performed [2].

In work, an analysis method to make the rocker-bogie suspension system climb up a stair was attained. The east coast of Malaysia faced a massive flood from the heavy downpour, leading to huge flood damage and caused severe loss of life and property. The flood carries the remains, trees and soil along their path, damaging the road and building structure, leaving the road getting uneven. This situation makes challenging to task force bearing aids during the post-disaster management. The research paper proposed an intelligent inclined motion control of an amphibious vehicle while moving on uneven terrain surface [3].

The research paper deals with the designing and modelling of stair climbing robot which is based on the famous rocker bogie mechanism in ANSYS rigid body dynamics module. While climbing steps and stairs, the robots often undergo from undesired phenomenon slip, sticking and floating which may cause instability of the mobile robot. The Taguchi method was chosen as an optimization tool to make the path of the centre of mass close to a straight line while all wheels keep in contact with the ground during climbing stairs. Due to its easiness and cost effectiveness both in formulating the objective function and satisfying multiple constraints simultaneously, Taguchi method was adopted. In the Optimization, enhancement of Seven kinematic parameters of rocker bogie mechanism was done that also included four link lengths, i.e. Y1, Y2, Y3 and three-wheel radius, i.e. X1, X2, X3. The kinematic Model of proposed mechanism was built, and its simulation was carried out in ANSYS Rigid body dynamics. Three different shapes of typical stairs were selected as user conditions to determine a robust optimal solution. The result obtained shows the variation of the centre of mass position with time, variation of the velocity of joint with time, variation of force with time [5].

It was a suspension arrangement used in mechanical robotic vehicles which were used specifically for space exploration. The rocker-bogie suspension based rovers have been successfully introduced for the Mars Pathfinder and Mars Exploration Rover (MER) and Mars Science Laboratory (MSL) missions conducted by apex space exploration agencies throughout the world. Presently the most favoured design for every space exploration company indulge in the business of space research was the proposed suspension system. The research origination's motive was to understand mechanical design and its advantages of Rocker-bogie suspension system to find suitability to implement it in conventional loading vehicles to improve their efficiency and also to cut down the maintenance related costs of conventional suspension systems [6].

The world market for mobile robotics was estimated to increase substantially in the next twenty years, exceeding the market of industrial robotics regarding units and sales. Important fields of application are homeland security,

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surveillance, demining, reconnaissance in dangerous situations, and agriculture. For unstructured environments, the design of the locomotion systems of mobile robots was generally complex, particularly when they were required to move on rough or soft terrains or to climb obstacles. The three main categories of locomotion systems (wheeled – W, tracked – T and legged – L) and the four hybrid categories that can be derived by combining these main locomotion systems were discussed with reference to maximum speed, obstacle-crossing capability, step/stair climbing capability, slope climbing capability, walking ability on soft terrains, walking ability on rough terrains, energy efficiency, mechanical complexity, control complexity and technology readiness. The current and future trends of mobile robotics were discussed [7].

The “rocker-bogie” for our Mars Rover is known as the optimization of a particular suspension system. This type of mechanism has been used on most of the rovers on Mars. It has proved to be a simple and elegant design. A Genetic Algorithm was implemented and used to optimize the geometry and kinematics of the rover’s wheel suspension system subjected to the well-defined performance metrics. This work shows the effectiveness of the optimization of a rocker-bogie suspension system using a Genetic Algorithm. It also discloses that the resulting system meets all constraints and that considerably reduces the error of individual performance metrics and the overall system. It was shown that the overall fitness of the rover suspension system could be increased by an average of 28% after 100 iterations compared to an initial guess. All performance metrics defined were improved significantly throughout the optimization. The method can be applied to different types of rovers to optimize the wheel suspension mechanism’s geometry [8].

III. DESIGN OF STAIR CLIMBING ROCKER BOGIE

To determine the dimensions of rocker and bogie linkages and angles between them is the important aspect in the manufacturing of rocker bogie mechanism. In this mechanism, the lengths and angles can be changed as per requirement. The main aim of the work is to manufacture the rocker-bogie mechanism which can overcome the hindrances of 150 mm height (like stones, wooden blocks) and can climb over stairs of height 150 mm. Another objective is to hike any surface at an angle of 45° . We had designed the rocker-bogie model by assuming stair height 150 mm and length 370 mm to achieve the above targets. Find the dimensions of the model with the Pythagoras theorem. Both angles of linkages are 90° .

1. Design calculation

Under this section, we will discuss our complete rover design and discuss how our key design decisions were made to meet the requirements and goals presented in the previous sections. Each one of these is related to meeting fundamental requirements. The objective of the research work is for stair climbing. The dimensions of linkages should be correct to attain proper stair climbing. Assume the stair height and length to be 150 mm and 370 mm respectively. To climb stairs with higher constancy, it is required that only one pair of the wheel should be in a rising position at a time. Therefore, to find the dimension of bogie linkages, the first pair of wheels should be placed at horizontal position, i.e. at the end of the rising as shown in Figure 1 and second pair should be placed just before the start of rising. There should be some distance between the vertical edge of stair and second pair of the wheel to prevent striking of wheels of the rocker bogie.

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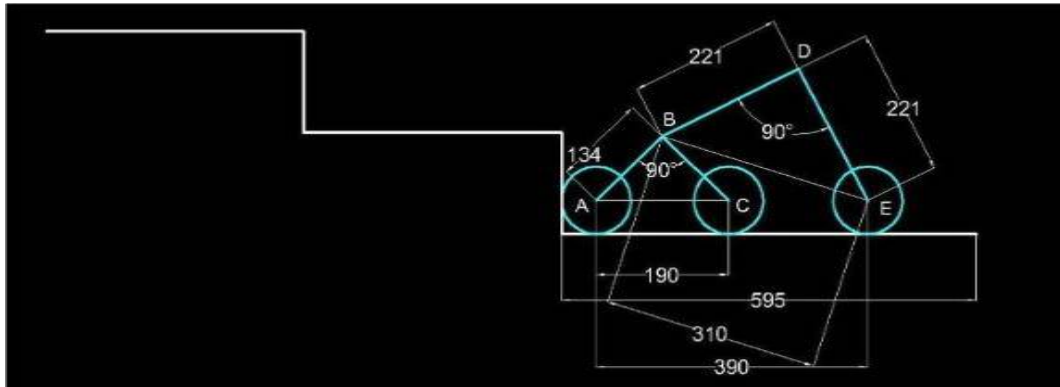


Fig. 1. CAD Drawing for 1st Triangle

Then, the distance between first and second wheel using CAD software (190 mm) is to be calculated.

In the right-angled triangle ABC, assume lengths AB and BC as x.

Now, using Pythagoras in triangle ABC (Figure 2.)

$$AC^2 = AB^2 + BC^2$$

$$190^2 = x^2 + x^2$$

$$190^2 = 2x^2$$

$$x = 134 \text{ mm}$$

Therefore, AB = BC = 134 mm (Figure 2)

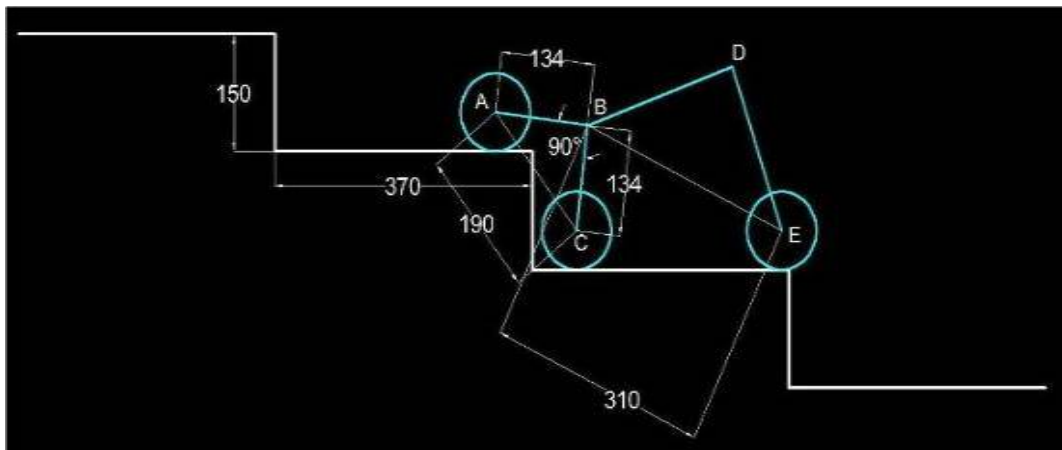


Fig. 2. CAD Drawing for 2nd Triangle

Correspondingly, for finding dimensions for rocker linkages, first, two wheel pairs should be placed at the horizontal position while third wheel pair should almost complete its rising before rising of the first pair of wheel starts. Placing wheel in this manner obtained the dimension of link BC (311mm).

Now consider $\triangle BDE$ (Figure 3),

$$BE^2 = BD^2 + DE^2$$

$$311^2 = 2y^2$$

$$y = 221 \text{ mm}$$

Therefore, BD = DE = 221 mm (Figure 3.)

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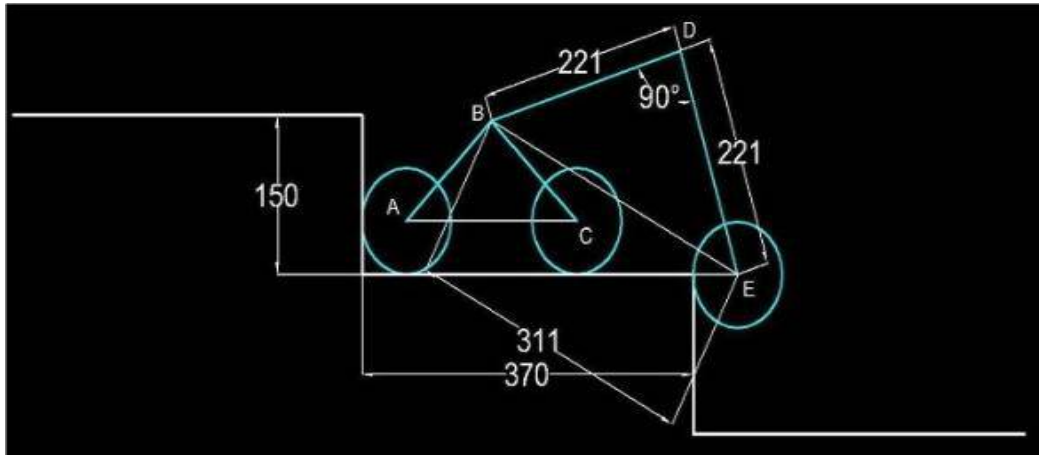


Fig. 3. CAD Drawing of both Triangles

The whole mechanism has been drawn considering all these lengths and angles. Figure 3 above, displays all the dimensions of the robot. For drilling 15 mm diameter holes, acrylic of width 40 mm is appropriate.

2. Drawing in Computer Aided Design (CAD) software

After calculating the dimensions of a triangle using CAD software, a 2D drawing is prepared with calculated dimension, and drawing views for the same are shown in Figure 4.

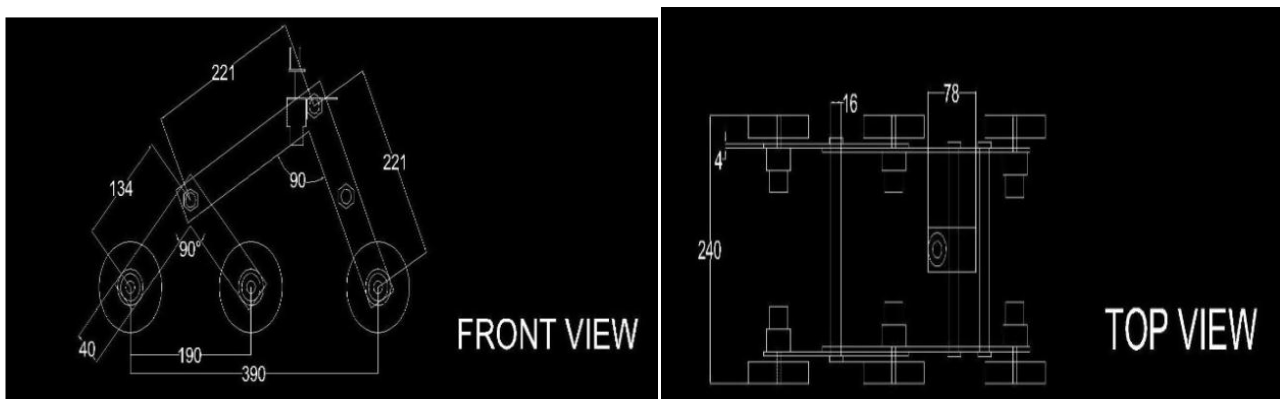


Fig. 4. 2D Drawing of Rocker Bogie Mechanism

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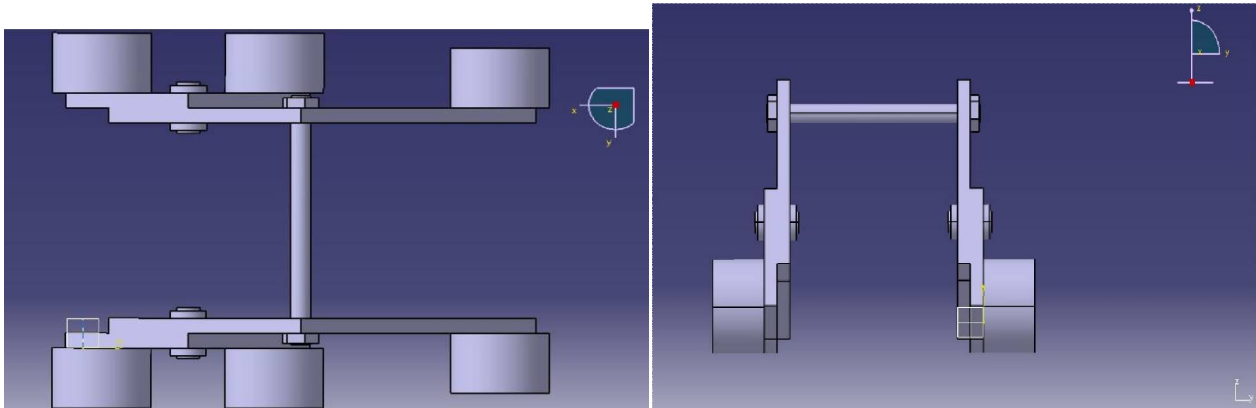


Fig. 5. 3D Drawing of Rocker Bogie Mechanism (Top and Front views on left and right respectively)

3. Selection and Design of Wheel

The wheels are desired to be wider for increasing the traction to traverse upon the obstacles. And their diameter depends upon the availability and amount of speed required. The actual rover uses billet wheels, and machine the wheel and tread from one piece of round aluminium stock. The main problem during the selection of the wheels is lightweight consideration and the distribution of load on the wheels. Designing of the wheel is to do such that it can run at a velocity up to 0.5 m/s. Speed 60 - 100 rpm of motor is assumed. Using velocity relation, velocity is calculated for assumed speed and using calculated velocity we can find out the diameter of the wheel, i.e. 95.35 mm. Therefore, we select the wheel of 120 mm diameter.

For the light weight and cost effectiveness of the rover, we will choose plastic wheels with rubber treads available in the market depending upon the calculations. The plastic wheels (as shown in Figure 6) offer a low-cost solution that is durable enough for a combat robot which is still light enough to be practical. Here six wheels are used for the robot. Wheel Diameter: 120 mm, Wheel Width: 20 mm, Shaft Diameter: 6mm



Fig. 6. Photo Image of Rubber Wheel

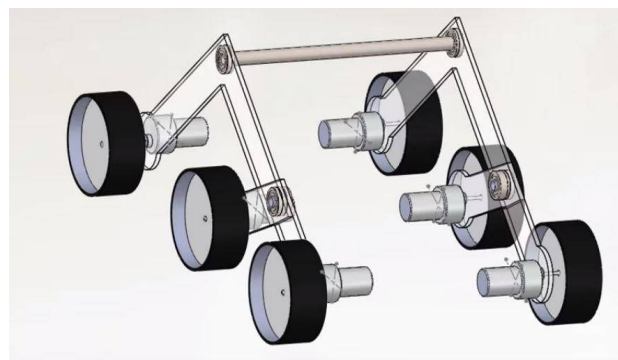


Fig. 7 Final 3D model of Rocker Bogie

4. Calculation of acceleration for robot

It's desired to take an acceleration of about half of the maximum velocity for a typical robot to run on flat terrain. The maximum velocity of the robot is 0.5 m/s therefore; the acceleration of robot will be 0.5/2 means 0.25 m per second square. This means it would take 2 seconds to reach maximum speed. If the robot is moving up inclines (as per Equation. No.1) or through rough terrain, you will need a higher acceleration due to the counter of gravity. We required to climb the angle of up to 45°. Hence,

$$\text{Acceleration of inclines} = \{9.81 * \sin(\text{angle of inclination}) * \pi\} \setminus 180 \text{ ----- (1)}$$

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Vol. 7, Issue 7, July 2018

$$= 0.121 \text{ m/s}^2$$

$$\text{Total Acceleration} = 0.25 + 0.121 = 0.371 \text{ m/s}^2$$

IV. EXPERIMENTAL RESULTS

Rocker-bogie whose 3D design is finally designed (Figure 7) is manufactured for ground-level experimentation and tested. The outcomes were found to be satisfactory, and the performance was adequate. The final Rocker-bogie manufactured is shown below.



Fig. 11. Stair-climbing Rocker-Bogie

V. CONCLUSION

A simple and computationally efficient rocker-bogie rover model is presented. This work illustrates how rocker-bogie system works on different planes. Under reasonable assumptions, it is possible to determine the rover attitude and configuration, given its position and ground characteristics, and whether the rover will slide, tip over or maintain its balance. According to the different weight acting on the link, determines torque applied to it. Rocker-bogie can climb the stair with great steadiness by assuming accurate stair dimensions. The designed and manufactured model can climb the inclined surface up to an angle of 45° . We tested it for the wheelchair with certain modification in rocker-bogie system and found satisfactory performance obtained during mobility. When the stair climbing test was being carried out for length less than 375 mm (15 inch) we found that the system couldn't climb the stair. It can be possible to develop new models of rocker bogie which can climb the stairs having low measurements.

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Vol. 7, Issue 7, July 2018

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