All Terrain Automated Carriage for Howitzer Guns

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Abstract - *Most of the inventions you use in your daily life were first developed for the defenses. The epitome of technology of a country is usually based on its defense systems. Therefore, we would be highly honored if we could step into this field. In this paper our aim was to develop a vehicle which could give the Bofors gun mobility, in course versatility in discharging of the weapon. We designed the vehicle using the rocker bogie suspension system while improving its capabilities to suit our purpose. The problem which we have tried to solve was that Bofors guns were very tedious to be carried to different places and rocky terrain. The guns are also unable to fire while in a rocky terrain. This improved movement of the guns will help the gunmen to fire while being in extreme geographical conditions. Our design also can be adapted into an unmanned vehicle, which the world is trying to pursue in the future.*

Key words – Bofors Guns, Defense System, Rocker Bogie Suspension Systems, Rocky Terrain, Unmanned Vehicle

1. INTRODUCTION

The system used in the designing of this vehicle is based on the rocker bogie mechanism. The rocker-bogie system is the suspension arrangement developed in 1988 for use in NASA's Mars rover Sojourner and which has since become NASA's favored design for rovers. The "rocker" part of the term comes from the rocking aspect of the larger, forward leg on each side of the suspension system. These rockers are connected to each other and the vehicle chassis through a differential. Relative to the chassis, when one rocker goes up, the other goes down. The chassis maintains the average pitch angle of both rockers. One end of a rocker is fitted with a drive wheel, and the other end is pivoted to the bogie. The "bogie" part of the term refers to the smaller, rearward leg that pivots to the rocker in the middle and which has 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, and were also quite commonly used in trailers of semi-trailer trucks. Both tanks and semi-trailers now prefer trailing arm suspensions.

The rocker-bogie design has no springs or stub axles for each wheel, allowing the rover to climb over obstacles (such as rocks) that are up to twice the wheel's diameter in size while keeping all six wheels on the ground. As with any suspension system, the tilt stability is limited by the height of the center of gravity. Systems using springs tend to tip more easily as the loaded side yields. In order to go over a vertical obstacle face, the front wheels are forced against the obstacle by the center and rear wheels. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle. The middle wheel is then pressed against the obstacle by the rear wheels 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. This is not an issue for the operational speeds at which these vehicles have been operated to date.

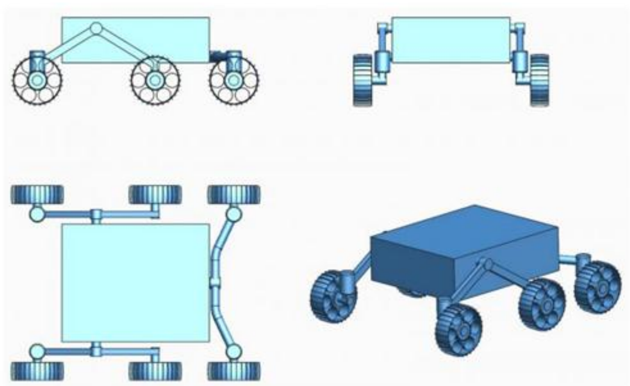

Fig 1: A simple rocker bogie mechanism

2. LITERATURE REVIEW

The authors of this paper did extensive research work of both the rocker bogie mechanism and Artillery Weapon System (AWS) before finalizing the design. The howitzer 777 gun was taken into consideration for this design. The muzzle disturbance simulation of 122 mm caliber truck-mounted howitzer during firing is carried out in different calculation methods in terms of rigid and flexible components. Different element types are employed to build the best flexible model for such weapon system. Sensitivity analyses for different design variables which affect the firing angle are examined and then the final design was thought of. There are a lot of studies that deal with launch vibration reduction to decrease the Muzzle Disturbances (MD).

Most of them can be summarized in two basic trends; firstly, improving the MD through evolving the performance of the recoiling system, and the other trend is to improve the MD by adding some structure to AWS to increase its rigidity or by applying optimization techniques to ameliorate the system layout. Actually, most of these studies simulate the MD from the point of view of cannon structure flexibility modeling but there are few studies that deal with the MD simulations from the point of view of carrier structure flexibility modeling. All the above points were researched and based on these designing was carries out.

In this paper, we investigate and review the different technologies and approaches, and demonstrate their capability to improve the performance of the vehicle in a rocky terrain or uneven surface. The main aim was the ease of movement in uneven terrain and the firing of gun on uneven surface in the mountainous region or the rocky region. Various technologies in which different configurations, component combinations and mechanical designs are used to improve the performance of the suspension are also discussed in this paper. For the vehicle design, a brief description is first presented and then by reviewing the previous studies, the performance of the suspension of the vehicle is investigated. Issues like flexibility that is to create a flexible model to absorb the recoil from the gun and to keep the flexibility the desired material selection was extensively researched upon by the authors of this paper. Retention of stability of the vehicle was also looked after from the point of view of design. The different positioning of wheels of the vehicle when it is stationary in order to achieve the desired stability was looked into. After all the extensive research the authors of this paper reached the final design of the vehicle with rocker bogie suspension which is presented in this paper.

3. METHODOLOGY

The authors of the paper thought of some theoretical design which they would be able to apply later practically. The theoretical design is explained in brief. After the theoretical design the analysis using Ansys Software has been explained.

3.1 Components

A. Mechanical Components
Bolts and nuts, 60*60 steel box section pipes, 100*100 steel hollow box section pipes with 40 mm thickness, ball bearings, caster wheels, bearing housing, motor coupling, bevel gears and wheels.

B. Electronic components
Motors, battery, micro-controllers, motor drivers, encoders, Gyroscope

3.2 Theoretical Design

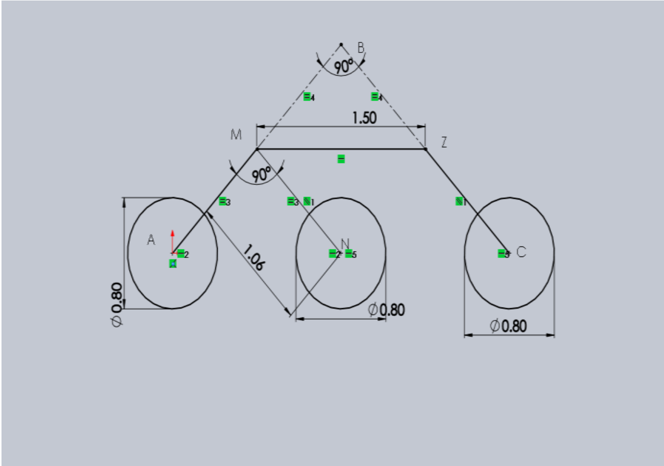

Fig 1 - Kinematic Diagram of the Design

The angle ABC is 90° and M is the midpoint of AB. This is the basic design constraint considered in most of the rocker-bogie systems which we have studied.

A.MODELLING OF THE BASE

The dimensions of the gun were found to be approximately 2m*2m. Therefore, we considered a base of the same dimensions.
M Z are the pivot points on this base 1.5 m apart from each other.

Angle between ABC and AMN:

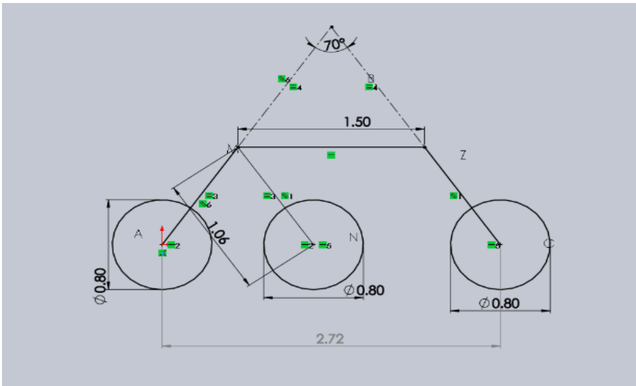

Fig 2A - (Angle less than 90°) - Angle 70°

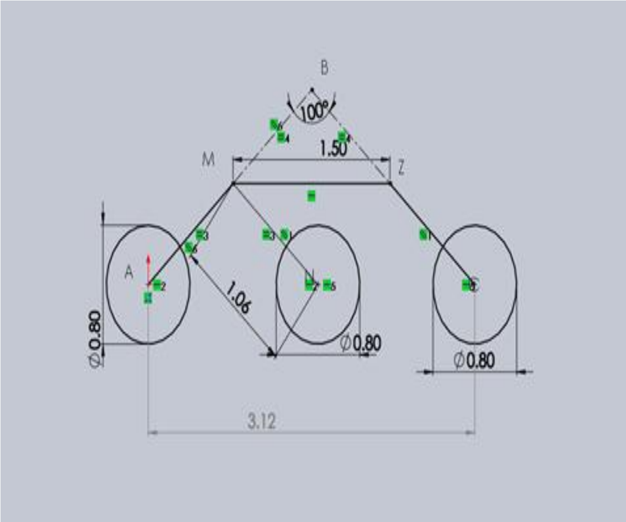

Fig 3B - (Angle More Than 90°) - Angle 100°

Case 1 -
Angle less than 90° (Fig 3A)
For angle less than 90°, the length AC decreases. The lesser the distance between AC, lesser will be the climb height.

Case 2 -
Angle more than 90° (Fig 3B)
For angle more than 90°, the stresses induced on the links AM, MN, and ZC will be more and therefore has a higher chance of failure. To counter the weight of the gun, vertical reaction forces are induced by the wheels.

As the angle goes on increasing, the vertical forces by the wheels decreases and hence the links have to bear more stress and might fail easily.

B.DESIGN OF THE LINKS

AM= MZ/ √2 = 1.5/√2 = 1.06m

AM=MN=ZC=1.06m

3.3 Actual Model

Fig 3A - Actual Model

This is the actual model on Rocker Boogie mechanism that has been used.

A. Wheel Assembly

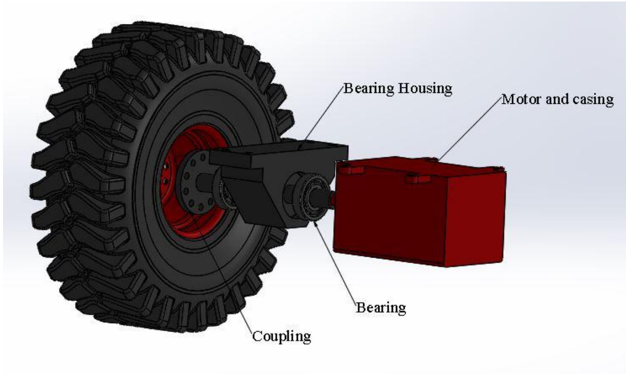

Fig 4B - Wheel Assembly

The motor shaft is connected to the wheel through the coupling. A bearing housing is used to bear the radial load on the shaft. Two radial ball bearings have been placed in the groove provided inside the bearing housing. The dimensions of the tyres are based on the MRF tyre data.

The calculations for the motor torque are as follows (for a single motor):
The motor torque has to overcome three resistive forces-
1. Rolling resistance force,
2. Acceleration force, and
3. Gradient Force.

Mass of the gun= 4400kg
Mass of the chassis= 1600 kg
Total mass=Mass of gun+ Mass of chassis
Total mass =6000 kg
Number of tyres= 6
Mass on each tyre=6000/6=1000 kg
Radius of the wheel = 45 cm 450 mm

1. Rolling resistance force
μ_r = Coefficient of rolling friction=0.015
N= Weight acting on single tyre=1000*9.8 N
rolling resistance= μ_r * N =147 N

2. Acceleration force
The average acceleration value for army tanks was found out to be 1 m/s^2 =a
M=mass of each tyre=1000kg
Acceleration force=m*a=1000N

3. Gradient force
Maximum angle of climb=30° (θ)
Gradient force=mg sinθ=4900 N

Total resistive force (TRF)=6047 N
Motor torque=TRF * Wheel radius=2205 Nm
This is the minimum torque required by a motor to drive a wheel.

B. Rotating Base Assembly

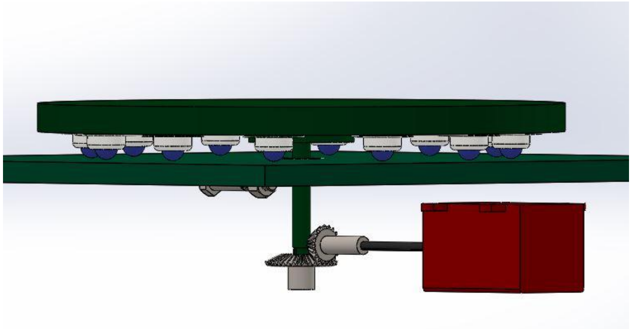

Fig 4B - Rotating Base Assembly

This is the rotating base assembly, which is used to rotate the gun in all directions. The rotating base attached with the caster wheels is placed on the fixed base. The rotating base assembly is connected to the bevel gear assembly through a coupling.

The torque required for the motor can be calculated by:
$\tau = I\alpha$
Where τ= Torque required to rotate the base
I=Combined moment of inertia of the base and the gun.
α= Desired angular acceleration.

4. ANSYS ANALYSIS

Static structural Analysis is a branch of ANSYS that deals with numerical simulation methods and makes use of different algorithms to solve and analyze the problems that involves various kinds of forces.

Static structural requires various settings like pressure, force, and various other factors.

4.1 Material Properties

Table - 1

Material	Structural steel
Youngs modulus	215gpa
Poisson's Ratio	0.265
Density	7850 kg/m3
Coefficient of thermal expansion	7.2e-06
Yield strength	2.5e+08

A. Meshing

The partial differential equations that govern fluid flow and heat transfer are not usually amenable to analytical solutions, except for very simple cases. Therefore, in order to analyze fluid flows, flow domains are split into smaller subdomains (made up of geometric primitives like hexahedra and tetrahedra in 3D and quadrilaterals and triangles in in 2D).

4.2 Ansys Mesh of Hex Bolt

The bolt used for pivoting the rocker and the boogie has been analyzed. This is an ISO standard bolt of dimensions M42 x 200

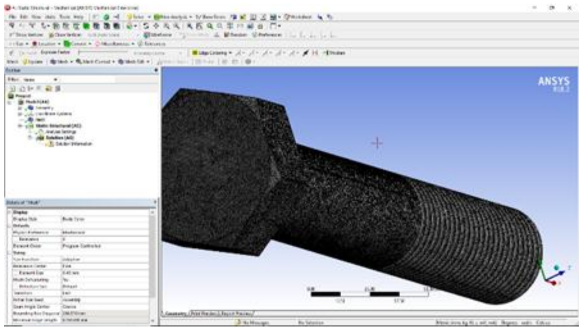

Figure 5A - Ansys mesh of bolt (View 1)

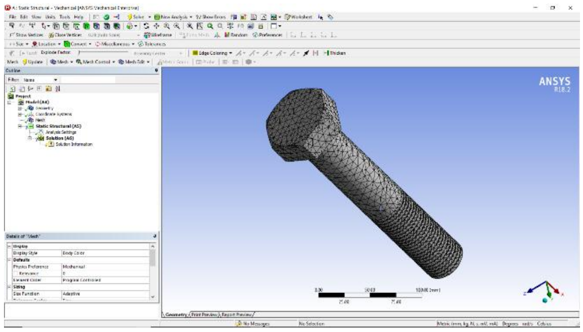

Fig 5B - Ansys mesh of bolt (View 2)

A.ANSYS MESH OF ROCKER

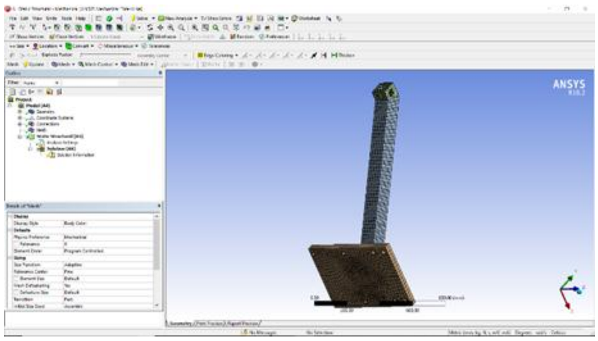

Fig 6A: - Ansys Mesh of Rocker (View 1)

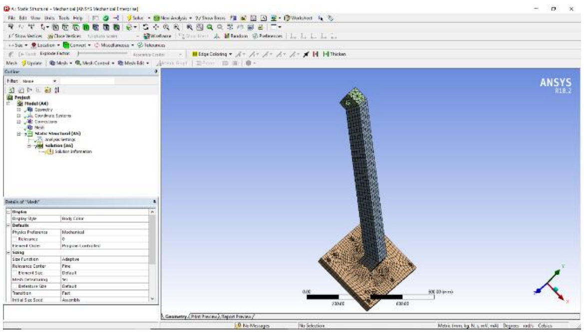

Fig 6B - Ansys Mesh of Rocker (View 2)

Table - 2 : Properties (meshing) of hex bolts

Property	Description
Display Style	Body Colour
Physics Preference	Mechanical
Size Function	Adaptive
Relevance Center	Fine
Max Face Size	6.69640mm
Defacture Size	3.482e-002mm
Nodes	37559
Elements	20308

Table - 3 : Properties (meshing) of rocker

Property	Description
Display Style	Body Colour
Physics Preference	Mechanical
Size Function	Adaptive
Relevance Center	Fine
Max Face Size	6.7890mm
Defacture Size	2.732e-002
Nodes	19365
Elements	3309

B.APPLICATION OF FORCE AND SUPPORT

Table - 4 : Hex Bolts

Property	Description
Force	12000 N On The Side Wall of Bolt
Fixed Support	Upper & Lower Part Of Bolt

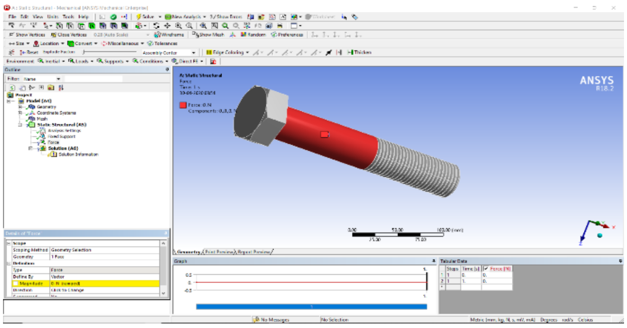

Fig 7A - Application of force on shank

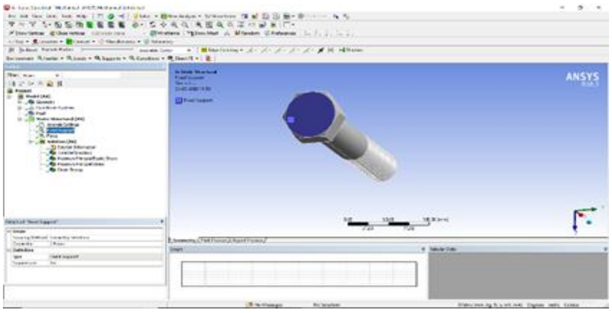

Fig 7B - Fixed support

Table - 5 - Rocker

Property	Description
Force	12000 N On The Upper Part Of Rocker
Fixed Support	Lower Part Of Rocker

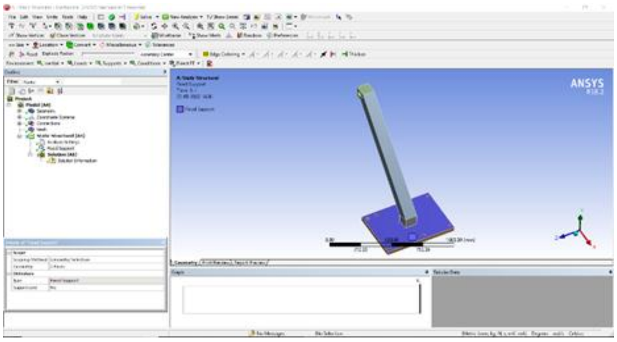

Figure 8: Force on Rocker

Table – 6: Results [Hex Bolts]

NAME OF PROPERTY	VALUE
TOTAL DEFORMATION	0.0267 mm
MAX.PRINCIPLE ELASTIC STRAIN	0.000287mm/mm
MAX.PRINCIPLE STRESS	69.49MPa
STRAIN ENERGY	0.219mJ

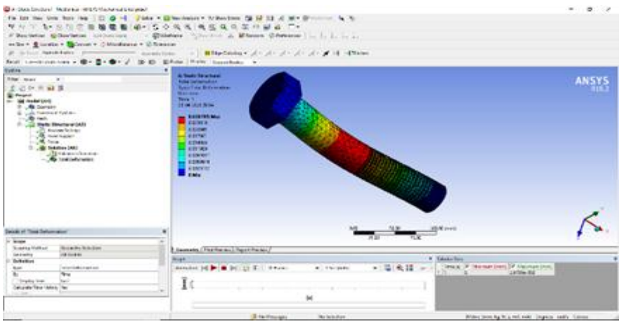

Fig 9A - Deformation seen on bolt (View 1)

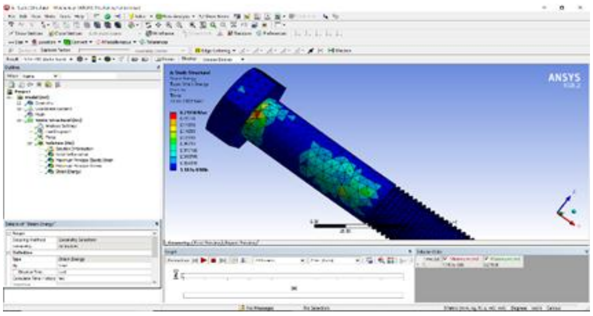

Figure 9 B: Deformation seen on bolt (View 1)

Table – 7 : Results [Rocker]

NAME OF PROPERTY	VALUE
TOTAL DEFORMATION	3.467 mm
MAX.PRINCIPLE ELASTIC STRAIN	0.000487mm/mm
MAX.PRINCIPLE STRESS	90.39MPa
STRAIN ENERGY	100.58mJ

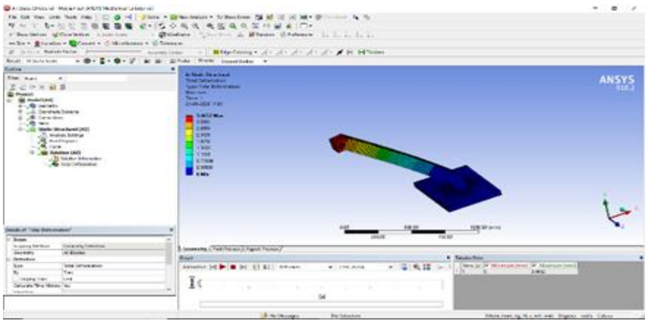

Fig 10A - Deformation seen on Rocker (View 1)

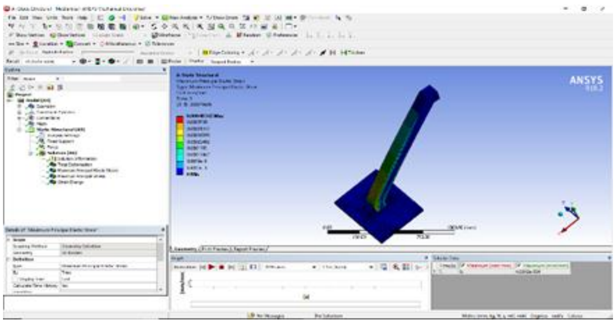

Fig 10B - Deformation seen on Rocker (View 1)

4.3 Hypermesh Analysis

HYPERMESH software provides more accurate results in less time for large components. Hence for analysis of the base of the carriage this software has been used.

Table – 8 : Material

Material	Structural steel
Youngs modulus	215gpa
Poisson's Ratio	0.265
Density	7850 kg/m3
Coefficient of thermal expansion	7.2e-06
Yield strength	2.5e+08

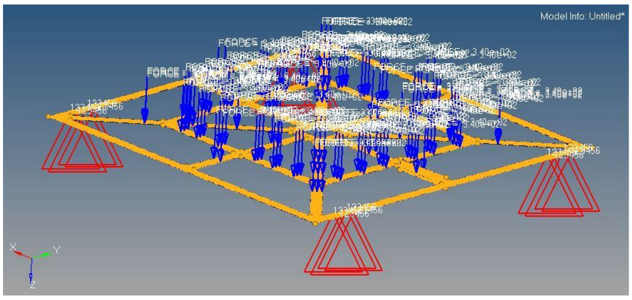

Fig 11 - Force and Support

Blue arrows indicate the distributed force applied and the red triangles represent the support. Total force of 60000 N has been applied.

HYPERMESH indicates the total deformation that might take place. Initial design of the base which was considered deformed up to 3mm.

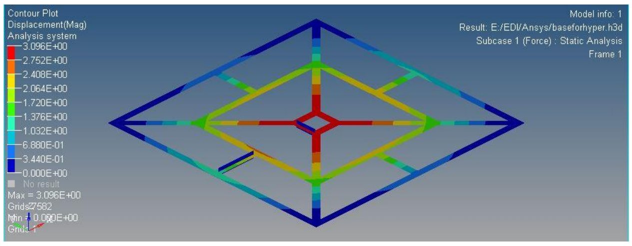

Fig 12 A - Initial base design

Based on the results obtained in this analysis, some changes were made in the base structure to reduce the deformation. This result indicated that more stress needs to be distributed near the center. Taking this into consideration some extra links have been added near to the center. The modified structure yielded up to 2.3 mm, which is considerable.

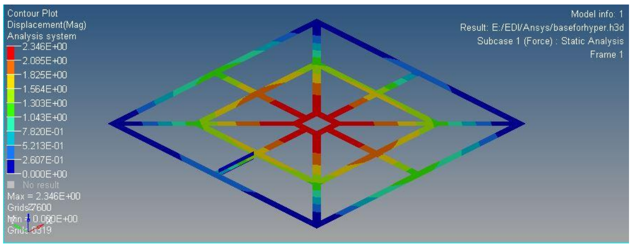

Fig 12B - Modified base design

5. PROCEDURE

5.1 Working of the All Terrain Vehicle

Our designed vehicle when deployed helps the mounted Bofors gun move from the site of deployment to the shooting site faster than the conventional vehicles. The six wheels benefit the distribution of the heavy gun and the increased stability allows the chassis to be elevated so to overcome the terrain obstacles. The vehicle can overcome obstacles twice the height of its wheel diameter. While overcoming the hurdle ideally all the six wheels are in contact with the ground.

5.2 Locomotion

This is a motor operated and battery powered locomotion system. This is an all wheel drive, which means power is supplied individually to all the wheels rather than supplying to any common shaft. In this case we cannot have a common shaft as all the wheels have independent motion with respect to each other. The electric servo motors power the wheels of the vehicle; six servo motors power six wheels each. For steering the vehicle, the speed of the wheels has to be changed. If the carriage has to take a right turn, the speed of the wheels on the right side can be decreased and the speed of the wheels on the left side can be increased. The steering of the vehicle is only possible on plain terrain. Changing the speed of the wheels can be done by varying the power supply to the motor. This can be effectively done by using various electronic controllers and motor drivers. Motors along with encoders are used where there is a need to monitor and change the speed of the motor shaft. In this case there is no place for installing the encoders, so servo motors have been used which are the motors with integrated encoders.

5.3 Rotation of the base

If a gun is located in a particular terrain, it should be able to shoot in all the directions. One way is to do it is to revolve the carriage about its center. But this way is quite complicated and will need special kind of wheels like Mecanum wheels. Also, to do so, some restrictions in the geometry have to be introduced. To overcome this, a system of rotating base has been implemented. This rotating base will work just like an axial bearing, whose one side remains fixed and other side can rotate. A fixed base will be attached to the base of the carriage. A base attached with caster wheels is placed on this fixed base. This base is connected to coupling passing through the center of the fixed base. The coupling constraints the position of the rotating base and it can rotate freely without translating. Caster wheels act as load bearers and uniformly distribute the load over the entire base of the carriage. The coupling is fixed with the bevel gear arrangement. A very high torque is required to turn the entire gun and bevel gear arrangement serves the purpose by multiplying the output torque of the motor.

6. FUTURE SCOPE

It is public knowledge that 75% of Indian militaries' artillery and machines are bought from other countries like USA, Sweden, France and more and thus, we stay dependant on other countries technologies to keep our land and people safe. Therefore, we feel that we are stepping into a industry which is not evolved to best of its abilities and there is a lot of potential for Indian manufacturers.

Our design is better equipped to adopt the self-driving vehicle technology and embrace its ever-increasing advantages. Our design currently helps reduce manpower and adopting the new technology can eliminate the need of a person to operate the machine and therefore reduce the human risk factor which is of major concern in a field like that of the military. The transition into a self-drive vehicle will be seamless than the conventional Bofors guns as proven by the rovers used to explore the terrain of Mars and the Moon which use roughly the same mechanism for mobility.

Adoption and integrating the high-speed transversal stability enhancement method will be a huge advantage to the vehicle. The modification could not be completed by us while working on the design and but simulation done by researchers show promising results[4].

The current method of steering exploits a lot of power, much more efficient methods can be developed in the future which will be reduce power consumption while also enhancing the flexibility of the vehicle.

A private defense designer and manufacturer do not exist in Indian market. It would be expensive to manufacture the product, but the change in Government policies of privatization of the defense industry will eventually create an industry which many people could benefit from including us.

7. ADVANTAGES

7.1 Very high ground clearance

The vehicle can climb over and obstacle twice it's wheel diameter. Suspensions are what matter when you are off the road. The huge clearance in the mechanism is the most advantageous for our purpose. Guns have always been very low towards the ground. India's borders are surrounded with hilly rocky regions. Our design will help the guns to travel into the rocky regions of the Himalayas and the highlands and give us the upper hand in the battle.

7.2 No Axel or springs

Suspensions are what matter when you are off the road. Eliminating the axel eliminates breakdowns. The guns are very heavy ranging from 4 ton to 12 tons and manufacturing an axel to withstand this weight as well as have a greater factor of safety because of its off-road utility is difficult. Springs do give a comfortable passage through the bumpy roads but they increase the pitch of the vehicle. And increase in pitch is not desirable. The absence of spring also helps traction of the wheels.

7.3 Traction

Having six wheels improves the traction of the vehicle. The mechanism also allows the weight to be distributed between the six wheels equally. While climbing over an obstacle all the six wheels are grounded and provide traction, thus obstacles twice the size of the wheel and be overcome seamlessly.

7.4 Versatility

Our designed vehicle can climb obstacles twice the size of the wheels and have very high traction to pass through loose gravel patches. The vehicle also has very high clearance which helps it to pass through sufficient depth rivers.

7.5 Lighter than trucks

When it comes to higher mobility of the guns are mounted on trucks with high weight compacity or tanks like panzers are used. The trucks do very well off-road transportation but their low clearance limits their versatility. The trucks are extremely heavy to be picked up by the helicopters. The tanks can climb over obstacles but the manufacturing cost is very high than our vehicle.

7.6 Reduced manpower

Current Bofors gun needs a crew of 5 people to operate the machinery. This number will soon reduce as the automation technologies in reloading will improve. The vehicle which we designed is to be operated by a single operator and the reloading by a second operator. But with as the automated vehicles increase soon the military will find it beneficial for their purpose as no man will be harmed on the field. Our vehicle is capable of operation from a distant operator as proved by the rovers which we have been using to roam on other planets. Reducing manpower helps reduce the human risk factor which is one of the major concerns of this industry.

7.7 Low Centre of mass

The six wheels contribute to the lower centre of mass. The chassis is mounted on the rocker. And the chassis has the maximum pitching angle of average of the pitching angle of the two rockers. Thus, the chassis has lower centre of mass. The High-Speed transversal configuration increases the stability polygon of the vehicle and the enlarged area lowers the centre of gravity.

7.8 Lower Pitch, Yaw and Roll

The rotation about the front to back axis (roll) is reduced in the high-speed transversal configuration as shown in the data [add data here].The rotation about the side to side axis (Pitch) is lesser as discussed in the Low Centre of mass point (4th point). The rotation about the vertical axis (Yaw) is negligible as the resistance provided by the tyres towards the perpendicular direction is very high.

8. LIMITATIONS

8.1 Poor recoil management

Currently we do not have recoil system which could seamlessly transfer all the recoil energy out of the vehicle. The extrusions currently being used in guns are very effective when it comes to planar ground surface. But our vehicle is well suited for the “off-road” kind of surfaces in which the topography is unpredictable. We can accommodate the weight of these extrusions in our vehicle but its ability to execute does not suit our utility.

8.2 Weight

The vehicle is heavier than the previous arrangement of the two wheels and two turning wheels. But our vehicle does have increased versatility than the previous generation. The manufacturing cost does also increase as the utility increases. The added weight will be difficult for the helicopters or the artillery planes.

9. CHALLENGES

A. An identified improvement to our vehicle was a subtle change in the orientation of the boogie so as to achieve a better stability while the vehicle is at higher speeds. One study proved that by titling the boogie laterally inwards we can increase the stability polygon of the vehicle which will allow higher velocity while lowering the centre of mass of the vehicle. Unfortunately, after hours of brainstorming we were unable to design a 2 axis (2 DOF) pivoting joint that could also support the weight of the gun. Overcoming this challenge will certainly maximize the functionality.

B. Currently in our design the motors driving the wheels are directly connected to the drive shaft without a power transmission system. Our design does not allow any loss of power because the wheels cannot have a delayed torque from the motor or else the traction at high surface gradients. The motor just beside the wheel will cause some restrictions to our functionalities like the clearance. This can be eliminated my having a reliable power train between the wheel and the motor. By moving the motor into the upper part, the vehicle would be able to travel through sufficient depth rivers.

C. The steering currently is done by reversing one side (set) of wheels and forward biasing the other side, thus generating the turning moment. This method helps turning on plane ground but it does not work efficiently on rocky terrain. Improved design will help change the direction while in the rocky terrain and will also be much more efficient.

10. ACKNOWLEDGMENT

The objective of this project is to provide clear and thorough presentation of theory and practical knowledge of All Terrain Automated Carriage for Howitzer Gun. To achieve this objective, the group members by no means have worked alone as these ideas have been shaped by comments, suggestions and acceptance given by Prof. Pradeep K Khaire (Department of Mechanical Engineering).We are thankful to Prof Pradeep K Khaire for his guidance, support and inputs in this course project without which it wouldn’t have been a success. We are thankful to Prof (Dr) Mangesh Chaudhari [Head of Department Mechanical Engineering] for his support and for addition of such kind of projects in our curriculum. We express our sincere thanks to the management of Vishwakarma Institute of Technology, Pune for allowing us to carry out such educational projects. We express our feelings and respect towards our parents, without their blessings, help and motivation this project could not have been completed and would have been just a dream for us. We are thankful to all those whom we might have inadvertently failed to mention here but have a positive contribution in successful completion of this project.

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