Design and simulation of a Mine Proof Mechanism

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Abstract. The issue of security is very paramount in every organization. The traditional mine proof vehicles with a solid plate hull provide protection against very small IED (improvised explosive devices) & MINES. This led to lives being lost more due to physical injuries by shock produced and a large change in momentum in very small time, that made organs over pressured and fatality. The present analysis deals with the application of a mechanism filled with Nitrogen gas to provide the cushioning effect of damper and using that pressure and Kinetic energy of gases to be utilized in acting against the mechanism forcing the compressed gases to break the safety valve and move into a reserve container which has various attachments and the pipes of steel take that heavily pressurized air into the compartment. The compartment having an inserted airbag type structure will be filled with air and it will make the compartment a big air stuffed structure to damp shockwaves. The designing and the strength analysis of the structure is done with the help of CATIA & ANSYS. The result was not very different except we achieved a reduced chance of physical and secondary deaths. The flat hull was then replaced by a V shaped hull which shown a reduction in 66% of pressure concentration on the vehicle hull. By using the combination of damping container system and a V monocoque hull the blast force was mainly diverted and the overall casualties can be reduced.

Keywords: Mine Proof Mechanism, CATIA, Ko- SST model, CATIA, Nitrogen gas, V monocoque hull, IED, Damper etc.

1. Introduction:

Mine proof vehicles are basically armoured vehicles having a hardened and stuffed chassis and a reinforced body to protect the occupants from the blasts of an explosion such as from a Mine and an
IED. The use of MPV’s started just after the Second World War. Its capability was very high according to then situations. It used to even adapt and counter anti-tank mines. With changing situations the capabilities also changed and the use of powerful explosives started undermining it which leads to lives being lost even in a protected vehicle. The use of MPV’s and their advancement in technology has become a necessity to counter the threats.

India, a developing country, becoming an economic hub and preparing to go into the next phase as a destination of investment in major sector by various MNC’s from different countries is facing a frequent and indispensible problem of insurgency along with Naxal areas, posing high threat to country and its assets that leads to encounters between forces and the terrorists. This led the government to turn to MPV’s for better security of its forces and to transport the forces directly to the site without having any casualty in between. The productions of “ADITYA” MPV also provided strength to security forces and thus were ordered in large quantities by CRPF and the Indian Army. Moreover the major problem with the existing vehicles is the shockwave generation during blast and the only solution is damping the shockwave rather than to oppose it and shield the occupants only. This will lead to fewer fatalities and better operational capabilities. The objective of this study is to stop or minimize the shockwave of the Mine or IED explosions from reaching the occupants and thus mitigating the secondary deaths. This can be achieved by utilizing and pairing this concept with a existing concept, V monocoque hull. This leads to a better diversion of explosive gases and even after the Mine or IED is detonated just below the vehicle, the effect is mitigated to an extent allowing the concept to work on lower pressure than what could have been.

The basic concept of this study is Newton’s third law i.e. “Every action has an equal and opposite reaction”. The energy generated by the explosions needs to be dissipated otherwise such a large amount of pressure when transferred through chassis and body imparts a very high change in body inertia.

The prototype includes a damper system (container filled with Nitrogen gas at 4 bar pressure) and under insulated conditions just above the hull i.e. the acting face. The explosion would lead to create a high pressure system which would impact the front face of solid plate and push it vertically upward via a slider mechanism against the gas pressure of nitrogen stored in the container, a part of energy would be damped and the pressure transfer would take place. The safety valve in the container would break and allow passing of Nitrogen into a centralized chamber which would basically divide and give path for the gases to move into the pipe attached to it.

The whole interior and the seats would have a web of airbags made of Kevlar that would be filled with the rushing Nitrogen gas and would completely pack the hard body and impact points. The occupants would also be held and a cushioning effect will be produced against the large change in momentum.
thus stopping pressure overflow.

The numerical simulation of the gas flow was done in ANSYS FLUENT and taking “K-omega” turbulence model. The temperature analysis used for plate was done by Transient thermal analysis (change in temperature conduction with respect to time). The pressure and temperature for this study are taken as 100 psi (70.3 kg/cm²) and 1400 degree Celsius respectively.

Tong Chang et al. [1] performed experiments using a blast calorimeter in which the bomb had a cylindrical internal volume of 5 L and could support a pressure of 200 Mpa. N. Heider et al. [2] optimize forces those transferred through the whole vehicle structure including possible damping mechanisms, the seat construction and the connection between seat and vehicle structure. Z. Q. Xue et al. [3] modelled the complete process of shock wave overpressure of free field air explosion. V. Denefeld et al. [4] studied the global effect due to IED detonation near or below the military vehicle and minimized the global effect by optimizing the vehicle shape and dynamic impulse compensation technique. David Havel, P.E. Columbia Steel Casting Co [5] produce austenite manganese steel with high toughness for very harsh application. Many other researchers like Verma et al. [10], Singh et al. [11], Rathore et al. [12], Gupta et al. [13], Kumar et al. [14] and Sharma et al. [15] also work in the same area to increase the strength of structure.

All the Previous study indicates that IED is a very heavy explosive and can be quite deadly if used in a high quantity. The pressure curves also show that there is a very high change in momentum in a very short time leading to a shock wave generation. The V-monocoque hull is definitely used and works well against a greater quantity of explosion. The experimental value showed a power produced of up to 5MJ/kg by using just 50 gm of TNT. The buried mine produces three wave structures that are peak, negative and oscillating pressure.

The present analysis and study would definitely help in reducing the peak pressure as well as in the damping of the oscillating pressure to a great extent.

2. Design, Modelling & Analysis

The design and modelling for the present study was developed on CATIA V5 R20 using its various modules such as part modelling, generative shape design, wireframe, surface modelling, sheet metal design, drafting 2D & 3D, CATIA simulation. The analysis was done on ANSYS with the help of various modules like ANSYS Workbench, ANSYS Fluent, ANSYS Transient thermal analysis, ANSYS Structural analysis.

The next design is moved from a hydraulic to a pneumatic system for the mechanism to work effectively. It consisted of better design features such as a V shaped hull with V shaped grooves all over the face to help in transferability and reducing stress concentration. The design is also equipped
with a centralized compartment that will work as a divider for gas flow and the pipes attached to it would lead to a floated airbag as shown in Fig. 1.

**Fig. 1** – Improvised design with centralized compartment

Fig. 2 shows the lower plate section and will be used for analysis and it is the acting face which will have direct contact with the explosive gases. The gases would strike at an angle apart from 90 degrees because of the groove and will have thus a reduction in intensity.

**Fig. 2** – Grooves of the acting face

Firstly the structural analysis for the acting face plate was done and the results were simulated according to real life scenario. The pressure assumed was 1000 psi and it was assumed to be equally
distributed on the surface. All sides were constrained and only the acting face was allowed to move, the results came in visual format as shown in Fig.3.

Fig. 3. Analysis of structural strength of acting face of plate

Analysis of flow of gases in a pipe shows that the gas will also get heat in the whole experiment thus a need for proper gas was necessary. Choosing Nitrogen as it was abundant, very cool, and also non toxic. The gas is lighter and is stable at higher temperature and pressure. The pressure relief will allow it to make a cover to douse off fire. Table 1 shows the density variation of nitrogen gas during the flow with pressure and temperature variation. Fig. 4 shows the pressure analysis through the pipe for the present study.

Table 1 – Density-pressure relation w.r.t variation in temperature

| DENSITY OF NITROGEN GAS (kg/m³) | At 0°C | At 400°C | At 1200°C |
|---------------------------------|--------|----------|-----------|
| 1 BAR pressure                  | 2      | 0.45     | 0         |
| 10 BAR pressure                 | 13     | 4.97     | 3         |
| 30 BAR pressure                 | 37     | 15       | 12        |
3. Mathematical Calculation

Apart from the analysis of the mechanism on software, a small set of calculations were also done on paper such as:

i. Strength and properties of metal used
ii. Centre of gravity of chassis
iii. Mass of the gas
iv. Mass of the container
v. Revised C.G taking mechanism into account

The value and dimensions of the chassis and mechanism is shown in Table 2, TATA 1615’s chassis is taken as reference chassis.

Table 2 – Specifications of vehicle and mechanism

|                | Total length | Total width | Front weight | Rear weight | Gross weight |
|----------------|--------------|-------------|--------------|-------------|--------------|
| TATA 1615      | 6184mm       | 2440mm      | 10200kg      | 6000kg      | 16200kg      |
| MECHANISM      | 6000mm       | 2400mm      | 7500kg       | 7500kg      | 15000kg      |

3.1 Strength and properties of metal used

The metal that this project uses is Austenite steel which has a very high corrosion resistance and high impact toughness also required to cope up with the blast pressure. The properties of the Austenite steel are shown in Table 3.
Table 3. – Properties of Austenite steel

| Property                      | Value               |
|-------------------------------|---------------------|
| Density                       | 7.96 g/cm$^3$       |
| Melting point                 | 1370-1400°C         |
| Coefficient of expansion      | 16-18*10$^{-6}$     |
| Thermal conductivity @rtp     | 16.3 W/m-K          |
| Brinell hardness              | 160-190             |
| Elongation                    | < 60%               |
| Tensile strength              | 460-480 Mpa         |
| Modulus of elasticity         | 190-120 Gpa         |

3.2 Centre of gravity of chassis

The centre of gravity of chassis is taken simply taking 1 mass as 10,200 kg and other mass as 6000 kg as shown in Fig. 5. The CG is derived below

M1=10200 kg
M2=600 kg

![Fig 5. C.G of chassis](image)

Let’s assume length=6200mm=620cm
6000×x=10200× (620-x)
6324000=16200x
X=390 cm
3.3 Mass of gas

The mass of nitrogen gas that can be filled in damping compartment as shown in Fig. 6(a) and 6(b), has been derived below

At 5 bar, 0°C
Density of nitrogen gas is 7 kg/cm²

The volume of container is taken out as
Volume of container = length × breadth × height

\[ V = 240 \times 40 \times 600 = 5760000 \] 

Density of Nitrogen = 7 kg/m³

Mass of gas = density × volume = \( 7 \times 5760000 \times \frac{1}{1000000} \) = 40.32 kg

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3.4 Mass of container

The mass of container for nitrogen gas can be calculated by treating as hollow cuboids of given dimension as shown in fig. 7 (a) and 7 (b) having thickness 50 mm on all sides.
Fig. 7(a) Side dimensions of compartment with thickness 50 mm

Fig. 7(b) Front dimensions of compartment with thickness 50 mm

Volume of inner cuboid $V_1 = 5,760,000$
Volume of outer cuboid $V_2 = 7,625,000$
The total volume is $(V_2-V_1) = 7,625,000 - 5,760,000 = 1,865,000$
Mass of container = density of metal $\times$ volume $(V_2-V_1)$
Mass of container = $7.96 \times 0.0010 \times 1,865,000$
Mass of container = 14,845 kg
Revised CG will just be in between the chassis CG and container middle point as the weight is almost equal and thus a lowering in CG will provide better stability and better manoeuvrability.

4. Result and Analysis
The present study use pneumatic compressed Nitrogen as a working fluid which is a very cold gas and whose density is approx 1.2506 gm/L. This gas was compressed and filled into a container of volume $= 5760000 \text{ cm}^3$. The total weight came out to be 40.53 kg of the gas which was not much compared to the vehicle weight. The gas one of the coldest available would not be affected much by explosion heat and flow would be with very less friction through the pipes to the airbags and provide cooling effect to the interior of the MPV also. The property of it being non flammable and non toxic was another good
point of choosing it as the fluid and after the explosion and all process; the release of it through the safety valves surrounding the vehicle will displace oxygen and control fire. The overall damping was increased and constant deceleration in pressure reduction was observed.

Use of V-monocoque hull is experimentally proven to divert the action of expanding gases of the explosion and makes an overall reduction in the height achieved from the explosion directly under hull at 90 degrees by a huge reduction of 2/3rd i.e. 66% of the total height. The use of monocoque hull seems very effective in directing the gas flow away from main body of the military vehicle, thus reduces the pressure rise by approximately 65%.

5. Conclusion

The present simulation, analysis and calculation show that in front of 50 kg and above TNT the pressure produced by it exceeds 100 psi of air pressure. That pressure at an instant works like a solid and even the total weight of vehicle i.e. 31 ton cannot be able to handle 1 % of the total power and would thus be lifted. But applying the mechanism would give an extra resistance to the vehicle and also the time taken by the gases to act would increase which means that there will be lesser instant change in linear momentum. Moreover the flow of air would provide resistance to the total pressure applied by explosion which would help fill the air bag instantly and the stuffed person under the airbag cover would be safe from external injuries as well as leading to less fatality.

The present study shows that the V-monocoque hull is very effective in directing the gases away from the main body and lowering the overall damage. It reduces the total explosion pressure by up to 65% by changing the angle at which the gases will act. It also leads to a change in the overall vertical movement of the vehicle by 1/3rd of the total value. New V shaped grooves are introduced on the already V-monocoque hull for better and equal transferability of gases.

The spring damper system was replaced with a gas damper system that made damping more effective and very less recoil was observed even in case of similar working equipments. The compressed gas was then made to flow through a series of interconnected tubes which led to the in time floatation of the airbags ultimately leading to providing a full protection cover for the occupants. Use of Nitrogen gas will provide another duty that the release of nitrogen from airbags will move out from side valves making a protecting cover of gas which will also be able to put off fire.
Now an experimental testing should be conducted on this concept to get the physical feasibility. The scope is very high as the need to safeguard vital investments is increasing day by day. The idea of spring damping method was absorb the explosion pressure and was needed to be replaced with something robust which not only protected the vehicle but also the occupants and led to several design changes.

With growing uncertainty, the market is also increasing for a robust mechanism that can handle and survive much greater explosion. A wide range of applications and necessity is open for this mechanism to be used for such as VIP transportation requires a large money capital to make the place secure, this mechanism can help remove some of their burden. Better protection and transportation of Security forces can be done directly to the warzone.

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