

A Dissertation

On

**Designing of Turret Assembly on Light Bullet Proof
Vehicle**

Submitted in partial fulfilment of requirements for the degree of

Master of Engineering

in

CAD / CAM Engineering

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DECLARATION

I hereby declare that the work done in this report entitled, "Designing of Turret Assembly on Light Bullet Proof Vehicle" submitted towards partial fulfilment of award of Master of Engineering degree in CAD/CAM Engineering in Mechanical Engineering Department of Thapar Institute of Engineering and Technology, Patiala is an authentic record of work carried out by me under the supervision and guidance of Dr. Gagandeep Bhardwaj, Assistant Professor and Dr. Neeraj Grover, Assistant Professor, Mechanical Engineering Department of Thapar Institute of Engineering and Technology, Patiala and Mr. Praveen Laad, Deputy General Manager, Vehicle Integration-Defence, Engineering Research Centre, Tata Motors Ltd., Pune, India. The contents of this thesis report, in full or in parts have not been submitted to any other institute or university for the award of any degree.

Date: 15-07-2019


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This is to certify that above declaration made by the student concerned is correct to the best of my knowledge and belief.


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ABSTRACT

The requirement of Light Specialist Vehicles is of great concern because of increasing terrorist activities in different regions of India over the past years. Indian Government approved high budget for upgradation of Armoured vehicles having capabilities of fighting in night and weapon accuracies. Therefore, a need of Bullet Proof Vehicle (LBPV) from Ministry of Defence (MOD) raised to focus on safety of Indian army troops engaged in counter insurgency, to provide them protected mobility.

The present study undertakes a designing of armoured turret assembly on Light Bullet Proof Vehicle 4x4 (LBPV). The model analysis and experimental tests were carried out to study the behaviour of turret assembly on vehicle. The analytical and experiment evaluation of the turret assembly on vehicle was carried out in accordance with the various level of testing done in Tata Motors Limited and Gujrat Forensic Sciences University (GFSU) on the basis of requirement by MOD. However, in order to achieve the robust design, the simulation results were validated with the experimental testing in order to gain confidence. Further the results obtained from analytical and experimental evaluation were studied and design improvisation was carried out to manufacture turret assembly that has to assembled on the roof of the vehicle before submission to MOD. As the turret design is totally a new concept for Original Equipment Manufacturers (OEM), therefore this thesis addresses the design and development of turret assembly on LBPV which include design modelling, analysis, design improvisation, manufacturing of turret and finally fitment on the vehicle.

Keywords: Light Bullet Proof Vehicle, Ministry of Defence, Turret Assembly, Design Modelling, Robust Design

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LIST OF ABBREVIATIONS

3D	Three Dimensional
LBPV	Light Bullet Proof Vehicle
MOD	Ministry of Defence
GFSU	Gujrat Forensic Sciences University
OEM	Original Equipment Manufacturers
GDLS	General Dynamics Land Systems
GOI	Government of India
INSAS	Indian Small Arms Systems
LMG	Light Machine Gun
RFP	Request for Technical and Commercial Proposal
FOS	Factor of Safety
EPDM	Ethylene Propylene Diene Monomer
SLR	Self-Loading Rifle
ISO	International Organisation for Standardization
HBW	Hardness, Brinell, Tungsten (wolfram) Carbide
MPa	Mega Pascal
CAD	Computer Aided Design
2D	Two Dimensional
IS	Indian Standards
DFME	Design Failure Mode and Effect Analysis
DVP	Design Validation Plan
RPM	Revolutions Per Minute
RPS	Rotation Per Second
LSUV	Light Support Utility Vehicle
JIS	Japanese Industrial Standards
Hz	Hertz

Chapter 1

Introduction

1.1 Background and Motivation

The requirement of Light Specialist Combat vehicle is a great consent because of increasing terrorist activities in different regions of the India over the past years. Indian Government is investing on upgradation of armoured vehicles with its night fighting capabilities and weapon accuracies. The procurement of these armoured vehicles will come under Buy Indian category which states that vehicle will be designed, developed and manufactured in India. Different Indian companies which include Tata Motors, Bharat Forge Ltd, General Dynamics Land Systems (GDLS), L&T, Mahindra, several other companies ranging through Tata Power SED, Reliance Defence, Rolta, Punj Lloyd, Ashok Layland and the public sector Ordnance Factory Board (OFB) have formed consortia to compete for the supply of 2610 specialist combat vehicles. The requirement of Light Bullet Proof Vehicles came from Ministry of Defence (MOD), Government of India (GOI) to different Original Equipment Manufacturing Companies (OEM) under Buy Indian category.

The project came into existence due to requirement of Gunner's hatch/ Turret having 360° traversing motion with foldable perimeter protection with suitable detachable mount to mount and effectively fire the in-service 5.56 mm Indian Small Arms Systems (INSAS) and 7.62 mm Light Machine Gun (LMG) which can enable firing at an elevation of 60° or more and depression of 10° or more from the roof of LBPV as shown in Fig.1 (a) & (b).



(a)



(b)

Fig.1.1 (a) CAD design of armoured vehicle and (b) Manufactured armoured vehicle
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Organisation designed the vehicle and manufactured proto vehicle as per the Request for Technical and Commercial Proposal (RFP) issued by MOD, GOI.

1.2 Problem Statement

Present study deals with the designing of turret assembly from scratch on vehicle including analytical and experimental evaluation of that turret assembly which was carried out in accordance with the various level of testing done in Tata Motors Limited and Gujrat Forensic Science University (GFSU). Final turret assembly was manufactured and assembled on the proto vehicle after incorporations of the test results came from analytical and experimental evaluation. For designing the turret assembly on vehicle, the design constraints were taken from request for technical and commercial proposal (RFP) issued by Ministry of Defence (MOD), Government of India (GOI).

Until recent times, design of turret assembly was incorporated only with gun-mounted assembly in Indian Light Specialist Combat vehicle in Tata Motors but in present time for the safety of the crew members, turret assembly was designed with the perimeter protection assembly in specification as requested by MOD. This has led to the simultaneous change and refinement in design in addition to the research in manufacturing of turret assembly and fitment on the vehicle by keeping in mind the requirement of the customer.

Additionally, this project came with the following studies

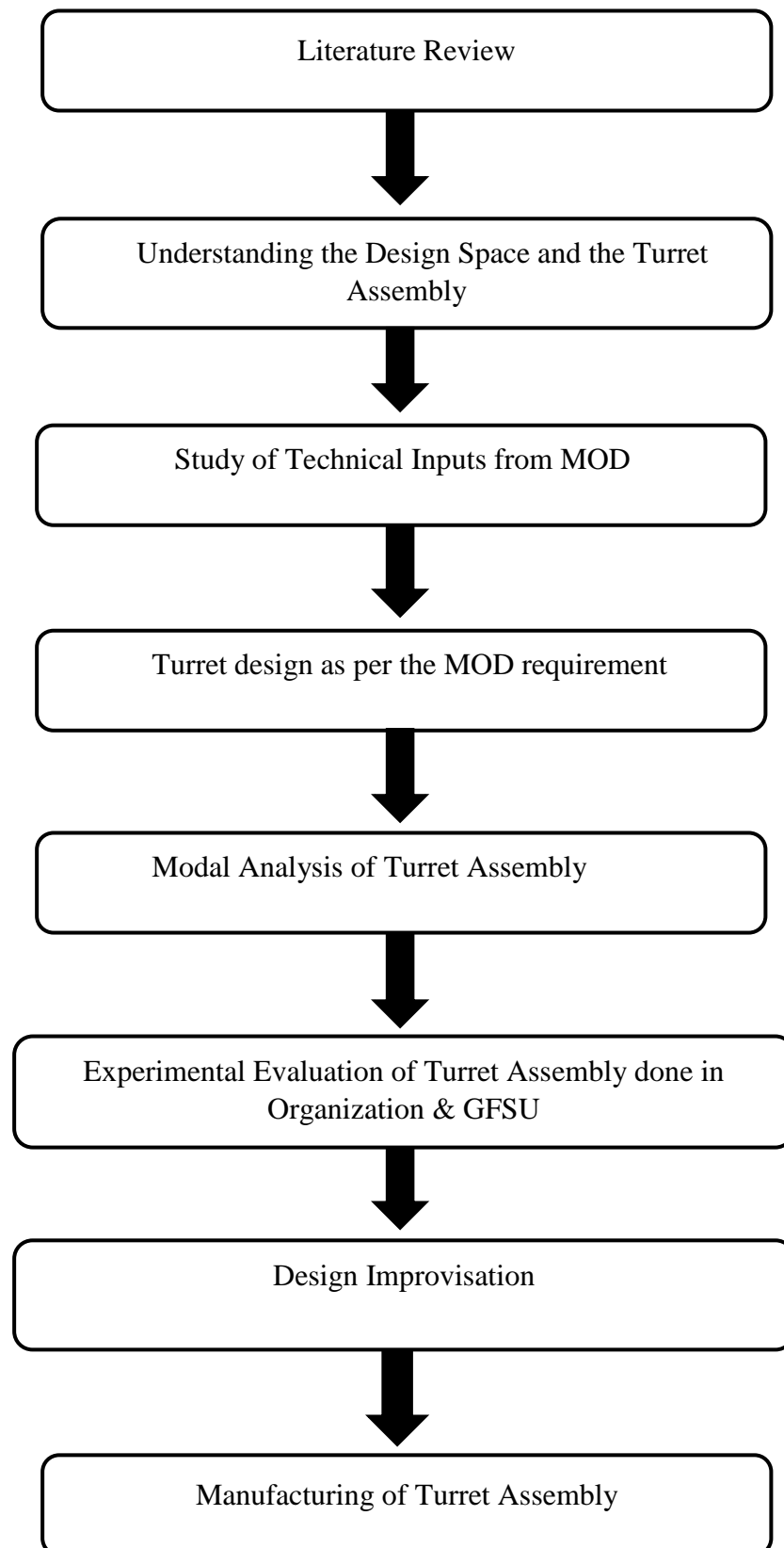
- Design of perimeter protection assembly in such a way that time required for folding and unfolding should be minimum.
- Minimum torque required for 360° traversing motion of detachable mount assembly along with perimeter protection assembly.

1.3 Expected Rewards of the Proposed Research

- The design passes the analytical and experimental evaluation tests will be manufactured and will be fitted on the armoured proto vehicles before submission to MOD. The design made would be tested as for the maximum and minimum limits set by the company and MOD requirement. If the design found well inside the threshold limits, the designs may be implemented for the upcoming vehicles.

- The same turret assembly will be used for other armoured vehicles.
- The safety of troops engaged in counter insurgency with the addition of perimeter protection assembly
- Within weight limits and easy assembly: as weight of vehicle was the major constraint.
- Customer Satisfaction.

1.4 Overview of the Methodology



1.5 Design Validation Plan

Sr. No.	Task Name	Duration(Days)	July'18	Aug'18	Sept'18	Oct'18	Nov'18	Dec'18	Jan'19	Feb'19	Mar'19	Apr'19	May'19	June'19
1	Understanding of Industrial/Define Project	6	█											
2	Literature Survey	30	█	█										
3	Use to PLM (Data storage Software)	7		█	█									
4	Finalization of Objective and Methodology	5		█	█	█								
5	Basic learning in Creo	15		█	█	█	█							
6	Data collection of existing vehicle	5		█	█	█								
7	Understanding the requirement of MDD	4		█	█	█								
8	Understanding the Design space and the Turret Assembly	2		█	█									
9	Study of different sub assemblies used in Turret Assembly	10		█	█	█	█							
10	Designing of Turret Assembly	30		█	█	█	█	█						
11	Basic learning of Modal Analysis software (Hyperworks; Nastran & Hyperview)	20		█	█	█	█	█						
12	Modal analysis of Turret Assembly	4		█	█	█								
13	Drawings creation of Turret Assembly	15		█	█	█	█	█						
14	Design release in PLM	30		█	█	█	█	█	█					
15	Manufacturing of Turret Assembly	15		█	█	█	█	█	█					
16	Fimnet of turret assembly on vehicle	3		█	█	█								
17	Experimental tests on vehicle with Turret Assembly in Tata Motors & CPFSU	30		█	█	█	█	█	█	█				
18	Study of feedbacks came from analytical and experimental evaluation	5		█	█	█	█	█	█	█				
19	Improvisation in Turret Design	10		█	█	█	█	█	█	█	█			
20	Final design proposal of Turret	2		█	█	█								
21	Drawings creation of Turret Assembly	5		█	█	█	█	█	█	█	█			
22	Manufacturing of final Turret Design	10		█	█	█	█	█	█	█	█	█		
23	Fimnet of final Turret Assembly on vehicle	3		█	█	█								
24	Vehicle submitted to MDD	2		█	█	█								
25	Formation of draft with detail work	20		█	█	█	█	█	█	█	█	█		
26	Submission of draft report to Industrial Guide	5		█	█	█	█	█	█	█	█	█	█	
27	submission of modified report to Industrial Guide	5		█	█	█	█	█	█	█	█	█	█	█

Chapter 2

Literature and Patent Review

2.1 Literature Survey

The use of armoured vehicle become necessity for the safety of defence troops engaged in counter insurgency, providing them protected mobility and for movement of small independent team operations in different regions of India due to increase in terrorist activities. Turret is one of the requirements from MOD on the LBPV. Thus, for designing and developing the turret assembly design parameters, material selection, manufacturing process and its application plays a significant role. Literature and patent review were done by keeping in mind the above points.

The inventors patented a turret assembly in which inventors described about the different parts used for designing the same. Study described about the sub-assembly of mounting plate and ring in which mounting plate is fixed to roof and ring is engaged and having rotary motion. He included the study of the turret assembly further comprising a support block coupled to the mounting plate, wherein the plurality of vertically disposed bearing wheels includes a first wheel coupled to the support block, and wherein the plurality of horizontally disposed bearing wheels includes a second wheel coupled to the support block. further comprising a plurality of support blocks arranged concentrically with an opening of the mounting plate [1].

Berkovich and Chachamiam patented the turret assembly without deck penetration for minimizing exposure of combatants to enemy forces when accessing above deck equipment, comprising a base plate on top of which is mounted at least one fireable and remotely operable combatant interfaceable implement, said base plate being rotatable about a substantially vertical axis and supported for rotation by bearing means mounted within a deck of a military facility. A hatch displaceable connected to said base plate, for normally covering a hatchway formed in said base plate and for exposing said hatchway when displaced and a rotatable disc of a slip ring unit carried by said hatch. In their study they also described about the hatch which is displaceable connected to the base plate by means of four arm assemblies which allow the hatch to be lowered and displaced laterally from the base plate and then to be returnable displaceable so as

to cover the hatchway. the hatch displacement initiator comprises a handle connected to an interior facing end of an axle assembly rotatably mounted within the hatch for applying a displacement initiating force to the hatch, and a locking bar, e.g. a flexible locking bar, connected to an exterior facing end of the axle assembly and having Substantially the same angular disposition as the handle, rotation of the handle in a first rotational direction causing the locking bar to be positioned in abutting relation with an upper Surface of the base plate whereby to prevent the hatch from opening, and Subsequent rotation of the handle in a second rotational direction opposite to said first rotational direction causing said locking bar to be disengaged from the base plate [2].

Kiel *et al.* patented the gunner protection of the turret on vehicle in closed position. Their invention described the ornamental design of the gunner protection with different perspective views [3]. Frank patented the collapsible camper shell turret system in which a turret base is mounted to a surface around an opening on the surface, at least two pivotally connected arms, including a first arm having a first end and a second end, the first end connected pivotally to a turret ring on the turret base, the turret ring rotating 360° , a second arm having a first end and a second end, the second end of the first arm connected pivotally to the first end of the second arm and a mounting means connected to a distal end of the second arm and configured to support a shooting device. In a stowed position under the surface, the second arm is collapsible against the first arm such that the second arm and first arm are parallel. In a deployed position, the first arm pivots approximately 270° out from under the surface and through the opening, surrounded by the turret ring, to extend above the surface and the second arm pivots approximately 270° about the first arm. The first arm and second arm are reversibly retractable back to the stowed position. The gasketed turret hatch protects the user and cargo inside the camper shell from damage by the elements. The camper shell has at least one muzzle depression stop removably attached to the top exterior of the camper shell. When the doors of the gasketed turret hatch are open, the movable two-part arm having a second arm connected to the first arm by the lock hinge swings up and out of the turret and locks into place, thus allowing the user to fasten accessories to the mount [4].

Greenwood and Hartmann studied the combination of sling seat and waist belt assembly upon which a turret gunner can be seated on military vehicle having a rotatable turret

ring. The invention claimed the dimensions and fabrication of seat in such a way that turret gunner can be seated comfortably [5]. Adorni and Chiappini claimed the invention of armoured vehicle provided with revolving overhead turret with armament which connect with the vehicle interior with the armoured rectangular hatch. Their study described about the overhead turret comprising a base and being connected to the armour-plated cockpit by said circumferential bearing to allow revolving of the overhead turret around a substantially vertical axis passing through a centre of said bearing, said base comprising a floor located completely external to the cockpit and a hatch attached to the floor by a pair of opposed hinges, wherein the hatch pivots about the hinges toward the interior space of the cockpit from a first position closing a passage in the floor to a second position providing communication between the overhead turret and the cockpit [6].

Patry and Berejnoi purposed the study of turret for a military vehicle which supports the oscillating mass comprised of medium calibre cannon having elevated orientation. The turret was designed and manufactured in such a way that insulation of turret with respect to the exterior was done so as to avoid any contamination and to ensure the evacuation of the combustion gases produced when the ammunition is fired. This study also claims the air tightness of the turret was by the oscillating mass and boundary friction kept low so as to reduce the disturbances in the aiming of the oscillating mass [7]. Armoured vehicle and tank with unmanned turret pivotable in azimuth via a turntable disposed on a roof plate containing a weapon which is pivotable in elevation was patented by Jilg *et al.* Their study also includes a panoramic viewing device, embodied as a glass optical direct viewing device, includes a viewing head disposed above the roof plate on the azimuthal axis of rotation of the turret. An optical viewing channel is guided through the passageway connecting the Viewing head with a viewing part in the crew compartment [8].

Wilson patented rotatable turret having gear box assembly for rotation of the turret assembly. Their study claimed the gear assembly which is fitted onto the pre-existing housing mounting brackets. The designing was done in a such a way that the input shaft extends through the gear assembly housing and includes an input shaft gear that meshes with a drive shaft gear. The size of drive shaft gear was maximised for fitment inside the gear housing. The sprocket is connected to the end of the drive shaft gear which is

mechanically linked to the turret assembly for controlling the rotation of the turret assembly [9]. Arrighi patented the turret assembly which includes hollow casing with the addition of cannon also named as firearm. The turret assembly was divided into front portion and rear portion in which front assembly includes firearm and the rear portion or tail defines a rear cavity, which houses at least one between a projectile magazine and a mechanism to load the projectiles into the breech of the firearm. Both the portion are different from each other and assembled in such a way that they can partially communicate with one another [10].

Carter designed the armoured vehicle gunner's protection cupola which provide protection from bullets and ballistic threats. This study claims the use of disposition of high-performance fibres in a shell of pliable material enclosed in the outer shell having flame resistance pliable materials which provide protection from fire and thermo acoustic threats. The outer shell or carrier is provided with a plurality of straps and fasteners for positioning and securing the pliable materials to the rigid frame containing the rigid or semi-rigid ballistic materials and thus providing rear and side skeletal and muscular protection from bullets and ballistic projectiles, flame, and thermo-acoustical threats [11]. Another study of ballistic protection of turret was patented by Squires and Gardiner, which claimed the addition of ceramics tiles which was reinforced resin polymer with nanoparticles. Nonwoven material and multiple nanotextile layers were added with the ceramic layers for the increase in ballistic protection [12]. Alter et al. patented the study of structural components for armoured vehicles in which additional detachable armour plate was provided on the side of troops for additional safety. The study comprises of composite layered structure having honeycomb core in addition to the covering layers. Study also focused on the use of fixture elements which were used to fix the detachable armour plate to the fixed core plate [13].

Cazalieres *et al.* patented light retractable turret having active system which was oriented in vertical extendable elevation and also in azimuth. This retractable turret is also having a protective cowling for active systems and used for closing the caisson. The active system constituted of first and second arm forming a deformable parallelogram arranged on either side of the active system and elevation and azimuth aiming means for said active system, the deployment being controlled by a first manual

means activating the first arm, the orientation in elevation and in azimuth of the active system being controlled by a second manual means activating the second arm [14].

In another patent Kiel *et al.* claimed the study of blast shield on armoured vehicle which includes a turret having flat base plate which constitute all view panels including a ballistic glass windows and having front and rear lifting eye. The mounting of flat base plate was done on the turret which was fixed with the armour plate [15]. Ohnstad patented the dome shaped turret including the turret shroud with annular base and open upper margin. Optically clear dome structure built with anti-shock, anti-ballistic and anti-blast shockwave and came with the conclusion of less overall weight of the turret shroud, dome structure and gun shield than that of a conventional, metallic turret shroud, thus provided enhanced functionality of the turret system. The turret shroud was manufactured with multiple layers of a contour woven, fibre-reinforced, anti-ballistic, anti-shockwave material fabricated with the Kevlar material with certain degree of flexibility on impact by a striking the projectile for the purpose of dissipating projectile energy [16]. Johnson *et al.* patented the armoured cab for the vehicle in which three layers of armouring was done for providing the extra protection for the troops. Plastic material was sandwiched between the two layers of armoured material which was used in the walls of the cab. For angled section only two layers of armoured material was used. Material used for the manufacturing was kevlar sold by E.I. du Pont de Nemours and Company. Preferably, layers of an aramid material or other suitable plastic or synthetic material having the requisite strength and ballistic and explosion protection characteristics, are layered over the interior of all of the wall surfaces of the armoured cab with the exception of windows. The thickness of the aramid layer material may be approximately from 1/4 inch to 2 inches in thickness, and preferably is 3/4 inch in thickness [17].

The study of addition of auxiliary plate having through holes and smaller cross-sectional area in front of main armour plate was patented by Ravid and Hirschberg. The designing of additional plate was done in irregular and staggered shape to shatter projectiles of ballistic on the main armour plate. The study claimed the use of different material of auxiliary plate in front of main armour plate which thermoplastic and thermosetting material. The study was done on the ceramic material, metal and a backing layer behind main armour plate. Backing layer may include aluminium,

fibreglass, aramid fibre, material or combination [18]. Barenyi studied the effect of degradation of mechanical properties in heat affected zone by thermal cutting process. The study was carried out in TTSteel software by using sample of steel Armox 440, 500 and 600 after their cutting by plasma and laser cutting process. They came with the conclusion that degradation of 20-30% mechanical properties in heat affected zone occurred after cutting of armoured material by thermal cutting process [19]. Robledo *et. al* designed the welding procedure of Gas metal arc welding process (GMAW) on MIL A46100 armour steel and came with the conclusion that designed WPS is a better option because of formation of narrow heat affected zone and increase in impact energy test as compared to the shielded metal arc welding (SMAW) [20].

The effect of hardness on the ballistic behaviour of AISI 4340 and DIN 100Cr6 armour steel was studied by Demir *et al.* and came out with the result that AISI 4340 was having the better ballistic performance and 29% lighter in weight than DIN 100Cr6 [21]. Senthil *et al.* investigated the evaluation of ballistic resistance of Armox 500T steel plates having thickness 8mm against 7.62 API projectile with the velocity of approx. 850 m/s at 5 different angle of incidence which was varied as 0°, 15°, 20°, 25° and 30°. The simulation results showed the perforation of 7.62 API projectile up to 25° and at 30° the bullet rebound of a surface after deforming the armour plate [22]. Microstructural analysis of ballistic tests was done by Balakrishnan *et al.* on welded joints of AISI 4340 armour steel because of ballistic performance in comparison to base metal [23].

2.2 Observations from the Literature

- It has been observed from the literature that the shape of perimeter protection assembly has been modelled freely without any constraints for the particular application
- No literature shows the specification of the bearing in bearing assembly for the particular application of the special armoured vehicle
- Design of gun mount was not specified in any of the literature

2.3 Objectives of the Project

- To design the turret assembly on light bullet proof vehicle
- Analytical and theoretical validation of turret assembly on vehicle

Chapter 3

Case Study of Turret Assembly

In this section, literature review for understanding the turret and turret assembly is presented. Turret is a rotating weapon platform that is mounted on the roof of the vehicle having protective structure and weapon mechanism to protect the crew and allowing the weapon to be directed and fired. Usually, turret is used to mount machine guns, autocannons or large calibre guns which can be monitored remotely or manned. It is also known as self-contained protective position which is situated on the top of the vehicle as a defensive wall which provide protection against battle damage and in the counter insurgency environment of operation, for the safety of the crew members. The mounting of guns can be in a fixed position on the turret assembly, allowing crew member to access the weapon through an opening in the vehicle's ceiling. Turret are known as mechanisms that are usually suitable for supporting a weapon and are capable of protecting the people onboard or the mechanism that enable the firearm related projectile to be fired enabling the firearm to be directed and fired in distinct directions at the same moment. To overcome the difficulty in transportation of armoured vehicle because of overall height, the turret assembly may be fastened to the roof of the vehicle. Sub-assemblies are further fastened to complete the turret assembly. Base plate, bearing assembly, hatch assembly, gun mount assembly and perimeter protection assembly as the sub-assemblies together form a combined turret assembly.

3.1 Bearing

A bearing is a commonly used machine element that constraints relative motion to the desired motion. The basis of the functionality of a bearing relies upon reducing surface friction by maintaining point and line contact. This is achieved by introducing spherical and cylindrical components between two surfaces. Thus, by restricting the motion in one degree of freedom, the motion in the desired direction is greatly enhanced. Used in wide variety of applications, which includes profound use in turreted vehicles, the bearings are being used from quite a while. The initial designs of armoured fighting vehicles incorporated the use of rotary bearings and since then the design has not changed much. Even in modern turret vehicles, the same concept is being utilised. The

maintenance of the bearings is also cost efficient as compared to other machine elements. The design of the bearings is quite modular and offers easy replacements. Because of these advantages, the use of bearings is preferred. There are different types of bearings to meet application requirements in terms of efficiency, reliability, durability and maximum performance. Radial Rotation, linear motion, spherical rotation and hinge motion are some common motion that permitted by the bearing. Basically, two different types of bearing namely radial and thrust bearing are used for wide range of applications which usually based on load direction. Each bearing is having its unique characteristics and designed for certain purposes. In this section relevant literature review is done for the different types of bearing used in different applications.



Fig. 3.1 Bearings [24]

3.1.1 Selection of Bearing

a.) Installation space

Installation space of bearing depend upon the space available which further decide the selection of width, outer, diameter and bore size of bearing.

b.) Load rating

Depending upon the installation space, bearing selection is done with different load ratings. According to studies roller bearing can bear higher loads and absorb shock loads better than ball bearing. The load rating also depends upon the performance of the bearing.

c.) Speed

Speed depends on various factors which includes type of bearing, caging style, size and lubrication method. Deep groove ball bearing has the highest permissible speed with the use of conventional grease lubrication.

d.) Skewing of the inner/outer rings (mis-alignment)

Inner and outer rings should not be tilted, but they are always slightly askew. This happens when the shaft is deformed due to loading or when compensation is needed for dimensional errors in the structure. The permissible level of skewing depends on the bearing type and operating conditions. This allowable angle is usually very small. If more skewing is required, options such as self-aligning ball bearings, self-aligning spherical roller bearings or special bearing units are recommended.

e.) Rigidity

Applied loads deform the bearing, starting with the areas of contact between the rolling elements and the raceway. Bearing rigidity is the term used to describe the relationship between the bearing load and the elastic deformation of the inner and outer rings and the rolling elements. Roller bearings are suitable in cases where high rigidity is needed. Rigidity can also be increased by preloading angular-contact ball bearings or tapered roller bearings.

f.) Running noise and torque

Rolling bearings generate minimal running noise and torque. If required, deep-groove ball bearings and cylindrical roller bearings can be made to run even more quietly. Deep-groove ball bearings are recommended for use in electric motors and measuring instruments where low levels of noise and friction are key considerations.

g.) Running accuracy

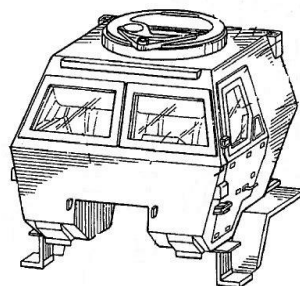
There are different ways of determining how accurately bearings run. Precision classes depend on the bearing type. If precision running is required, deep-groove ball bearings, angular-contact ball bearings and cylindrical roller bearings are the best choice.

h.) Installation and removal

Installation and removal methods vary by bearing type. If the bearing can be taken apart, it is easier to install and remove. Cylindrical roller bearings, tapered roller bearings and needle roller bearings generally fall into this category. They are the best choice if regular inspections are made. Self-aligning ball bearings and self-aligning roller bearings with tapered bores (with or without sleeves) require more skill to mount because the internal clearance is adjusted during the installation process.

3.2 Hatch

Hatch assembly is one of the sub-assemblies of turret assembly, involve a circular plate that defines an opening which is mounted on the vehicles by virtue of bearings so that it can be rotated relative to the vehicle. The hatch cover is mounted onto the circular plate by hinges and can be rotated between the position where the hatch opening is closed and an open position where the top of the hatch cover lays down on the top of the vehicle. Armoured vehicle consisting of turret assembly which includes hatch assembly that must be lifted, navigated and finally raised to the resting position during opening cycle. The closing cycle would be opposite. Opening and closing mechanism performed manually using a single handle. The hatch permits access to the turret not only from outside and from the top of the vehicle, as traditionally happens but also by the crew member from inside the vehicle.



(a)

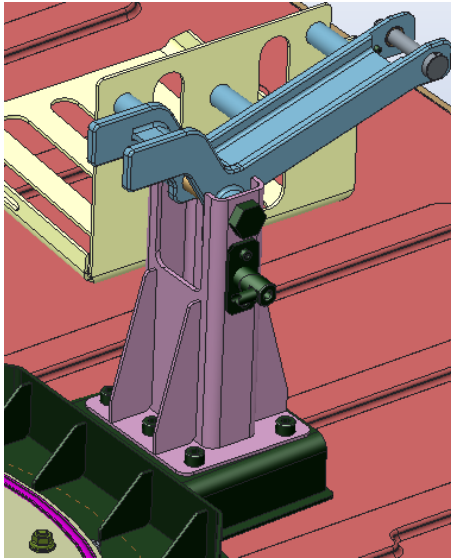


(b)

Fig.3.2 (a)Schematic drawing of hatch assembly [17] and (b) Hatch assembly on vehicle [25]

3.3 Gun Mount

Fig.3.3 shows the structure used for supporting a weapon mainly guns is termed as gun mount assembly. Gun Mount assembly is also one of the sub-assemblies of turret assembly in which guns are positioned on the mount which is fastened to the rotating ring enabling a gunner to point at the target.



(a)



(b)

Fig.3.3 (a) CAD design of gun mount assembled on the roof of the vehicle and (b) CAD design of gun mount assembly on vehicle

Chapter 4

Methodology

This chapter summarizes the method or steps followed to achieve the desired results. It starts with presenting the earlier studies done for the design strategy and further depicts that what steps were taken to fulfil the objectives of the study using a flow diagram. After this, the steps taken are elaborated so as to give an insight to what each step was made for and what were done in the particular step.

As the required vehicles with turret assembly will be deployed across the country and remote locations in all type of terrain and inhospitable climate condition, protected mobility and to provide work services during war scenario, the dynamic response on turret assembly from road excitations and ammunition firing would be considered as major concern which may lead to various failures in sub-assemblies and parts of turret assembly. As the turret is designed for special armoured combat vehicle which has a role of movement and operation of small independent team, a protected platform for troops engaged in counter insurgency, conveyance of Commanders in counter insurgency environment and providing protected mobility. Weight and cost are also the concerns for the development of turret assembly. Therefore, to improve the durability and ballistic protection one should be familiar with the sub-assemblies of turret and its manufacturability. Further, welding and bending of armoured material might result in degradation of ballistic resistance. Therefore, the design of turret assembly should be optimized by minimizing the welding and bending process, but it only has an advantage if the design of turret assembly is proper. Therefore, turret design must be analytically validated using the HyperMesh as a pre-processor, Nastran as a solver and HyperView as a postprocessor whereas experimentally through in-house testing in Tata Motors and Gujrat Forensic Sciences University. Lastly, the turret assembly is to be fitted on the roof of the vehicle that are to be submitted to MOD thus meeting their requirements.

The Fig.4.1 shows the work flow process for achieving all the objectives that were achieved in this project.

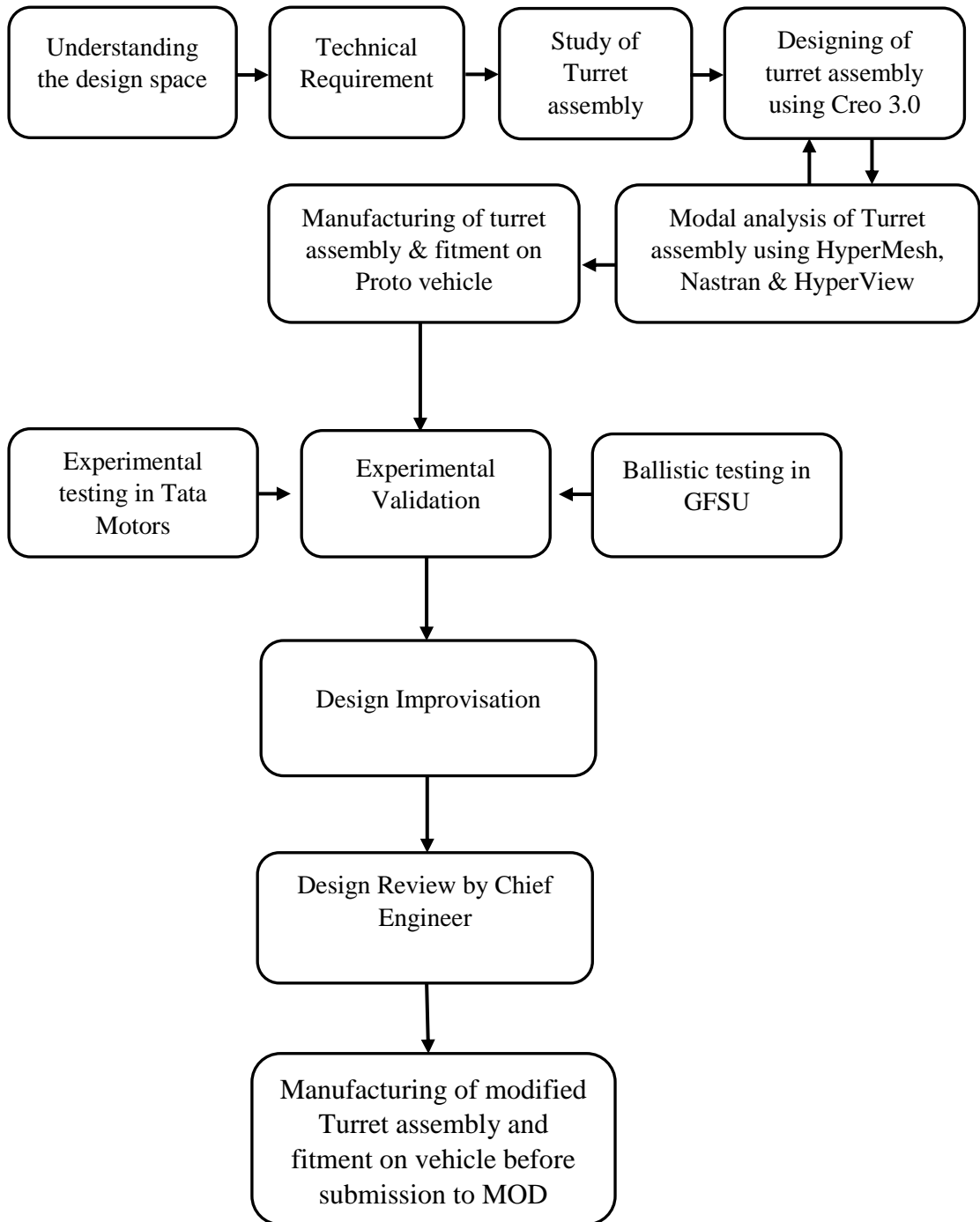


Fig.4.1 Work flow Process opted for achieving each objective

4.1 Understanding the Design Space and Turret Assembly

The study was done to understand the constraints in which the work has to be done. As the proto vehicle is already developed according to the requirement of the customer, the constraint would be the space for modelling of the turret assembly on the roof of the vehicle which cannot be changed. The literature survey, documented in Chapter 2 of this report was done for gaining the knowledge of previous work done for the cited subject and forming base for the study by understanding the attributes of the turret assembly on LBPV and acquiring knowledge in the field of turret design and the various challenges that are to be overcome for a perfect design which are presented in the Chapter 3 and Chapter 4 of the report.

4.2 Technical Requirement

In defence sector, technical requirements are totally depending upon the requirement from the MOD. Designing and development of vehicle along with turret assembly was done as per the technical requirement from customer which cannot be altered. Design space and customer are the main constraints while designing.

Setting up the Base Model of the Turret Assembly and making 3D model of the same using Creo

Development of light armoured vehicle with turret assembly in defence sector was the challenging task for this industry in which designing and development of turret assembly was totally the new concept. 3D model was created as per the requirement given by the customer and the constraints set for designing the turret assembly on the roof of the armoured vehicle. Weight was the major constraint while development of the armoured turret assembly on special armoured vehicle. Now this step inflicted a challenge to design the turret assembly by keeping the design space same, keeping the requirement of the customer in mind and not increasing the overall weight of the vehicle. So, for doing the needful several combinations were researched for maintaining the desired parameters and the model which fitted the space and the requirement was chosen to move forward with. 3D modelling of base plate, bearing assembly, hatch assembly, gun mount assembly and perimeter protection assembly was done using the Creo 3.0 software.

4.2.1 Base Plate

The turret assembly includes a mounting plate having a fixed orientation relative to the roof. It was designed to support the bearing assembly which is fastened to the roof of the vehicle. The 3D model of the base plate was designed according to the design space and requirement of the customer with minimum 600 mm diameter. Gas welding was done for joining the armoured base plate and armoured side ring.

4.2.2 Bearing Assembly

Bearing was selected on the basis of application of turret assembly on the armoured vehicle. As per the requirement of the customer.

- The roof mounted Gunner's Hatch/ Turret should be 360° traversing
- Bearing should be designed with minimum 600 mm diameter
- Bearing assembly should bear a minimum static load and dynamic load as per the loading condition on bearing assembly
- Dust seal protection should be given to the raceway system
- Slew ring turning torque should be between 5 to 7 kgm
- Proper surface protection should be provided to prevent rusting
- Lock holes should be provided so that gunner can lock the gun mount assembly at desired position in 360° traversing
- Locking arrangement should be provided so that bearing cannot rotate the turret assembly in dynamic condition of the vehicle

On the basis of above requirements bearing of C-45 medium strength steel having ball bearing with double raceway having steel balls was developed with the minimum inner diameter of 634 mm and outer diameter of 765 mm with same number of through holes on the bearing as given on the base plate so that it can be fastened with the base plate.

- Bearing assembly was designed in such a way that it can bear dynamic load of 600 kg and static radial load of 800 kg, considering the Factor of Safety (FOS) as the loading condition on the bearing was coming 200 kg
- Grease lubrication is given to the raceway system
- Dust seal protection having class IP 50 of nitrile/vitron given to the raceway system as these special armoured vehicles will be deployed in various areas of India

- Slew ring turning torque kept between 5 to 7 kgm
- Shot Blasting SA 2.5 with CED coating of 20-25 micron with powder coating of type 10 to 50 microns surface protection provided on the bearing
- Locking hole was provided in the bearing so that it can lock the gun mount assembly
- Two Grease nipple was given in the bearing at 180° apart for providing lubrication to the raceway system
- Ball feeder plug with O ring sealing provision is also given in the bearing



Fig.4.2 Bearing with base plate

4.2.3 Hatch Assembly

As discussed in Chapter 3, hatch assembly involves a circular plate that defines an opening which is mounted on the vehicles by virtue of bearings so that it can be rotated relative to the vehicle. With the help of hatch crew members can be access the gun on gun mounting on the top of the armoured vehicle. Hatch assembly includes hatch plate, left-hand and right-hand sided hinge assembly, ribs, spindle with lever assembly, bracket for adjusting the lock mechanism, bush, ribs, hatch plate locking mechanism on rear perimeter protection plate which consist of plate plunger hatch lock. In hatch assembly, ribs are firstly bolted with the hatch plate with allen bolts in such a manner that head facing inside of the cockpit and not exposing to the surface of the ribs from environment as shown in Fig.4.3 (c). As from the previous industrial studies and

experimentation results, bolts tail should not be exposed to the free end as bullets can be penetrated inside the cabin while designing the armoured vehicle which is strictly not acceptable for the customer. Bolt shearing take place if bolt is exposed to the free end after hitting the bullet on the bolt. Hinges height as shown in fig.4.3 (b) are designed in such a manner that hatch assembly can perfectly rest on the lip seal which is made to rest on the surface of the perimeter side surface of the base plate. Lip seal is designed according to the diameter of the base plate to avoid metal to metal contact which will occur between the hatch plate and the perimeter of the base plate. Ethylene Propylene Diene Monomer (EPDM), a synthetic rubber used as the material of the lip seal. According to the experimentation results on existing vehicles, 30% compression of rubber lip seal take place after placing the hatch assembly on lip seal in close position. With the help of single handle, opening and closing cycle of hatch mechanism can be performed manually. During opening of the hatch mechanism firstly hatch is lifted by 50 mm and then traversed by 120° and rest on the rear perimeter protection plate with the single locking mechanism as shown in Fig.4.3 (c). For closing the hatch plunger type lock made to force backward manually which rest on the lip seal. After that handle is rotated in clockwise direction as shown in Fig.4.3 (a).

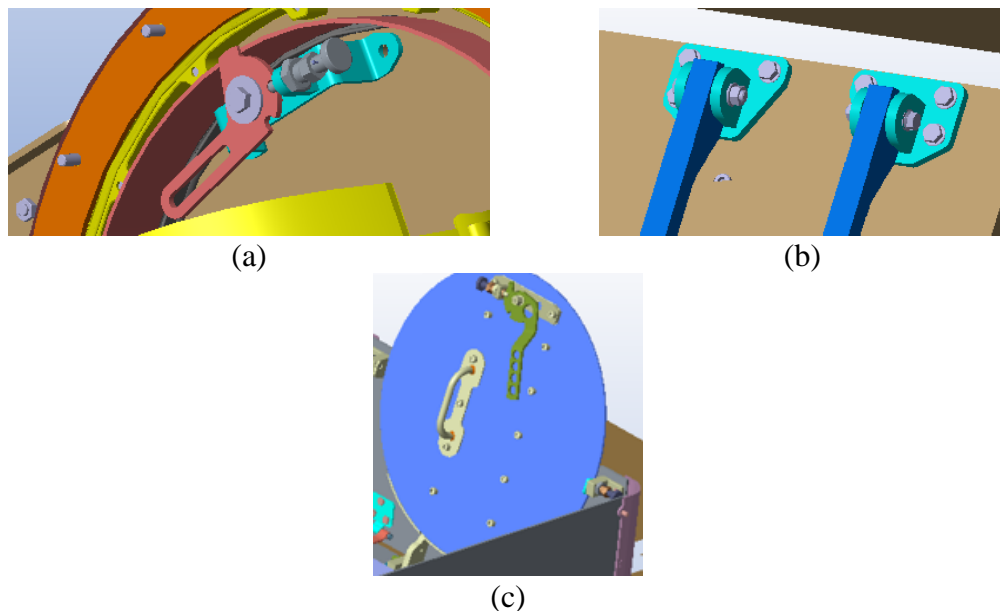


Fig. 4.3 (a) Locking mechnism from inside the cockpit, (b) Hinges mechsimsim with ribs and (c) Hatch plate rest on the perimeter protection with the single plunger lock

4.2.4 Gun Mounting Assembly

Cad model of gun mounting assembly was designed after the bearing assembly and hatch assembly. Gun mounting assembly consist of gun mount bracket which can be able to mount 7.62 mm light machine gun and 5.56 mm Indian small arm system light machine gun. It was designed in such a way that it can enable firing at the elevation of 60° or more and depression of 10° or more as per the requirement of MOD as shown in Fig.4.4 (c). This become possible with the help of pin mechanism which can be locked at the desired position. Pin is fitted between the gun mounting bracket and supporting bracket as shown in the Fig.4.4 (a) which is based upon the torque hinge mechanism. Gun mount tray was modelled based upon the gun dimensions which was provided by the army after the visit to their headquarters. Many research works were done on the height of gun mount tray which was decided upon the ergonomics and requirement of the customer. Provision for locking the gun on gun mount as shown in Fig.4.4 (a) was also designed as per the gun shown by the MOD. Before analysis supporting bracket was designed in tapered section so that minimum stresses should be produced and bending should not occur. Clearance fit was given to the bush assembly in gun mount assembly for local play of the gun so that gun can rotate small distance without rotating the whole turret assembly. This mechanism is useful for the crew members engaged in the counter insurgency environment. Interference fits are given to the fixed parts of the gun mounting assembly. Front protection plate is fastened with the supporting bracket of the gun mount. Whole gun mount assembly is also fastened with the base protection plate as shown in Fig.4.4 (b).

Gun mounting assembly was designed by keeping in mind the following points.

- As per the requirement of the customer the firing rate of gun will be 650 rpm which cause high gun recoil frequency which will transfer to the whole turret assembly. Therefore, to overcome high gun recoil frequency the gun mounting design should be as stiff as possible. Weight is also the major constraint while designing the turret assembly

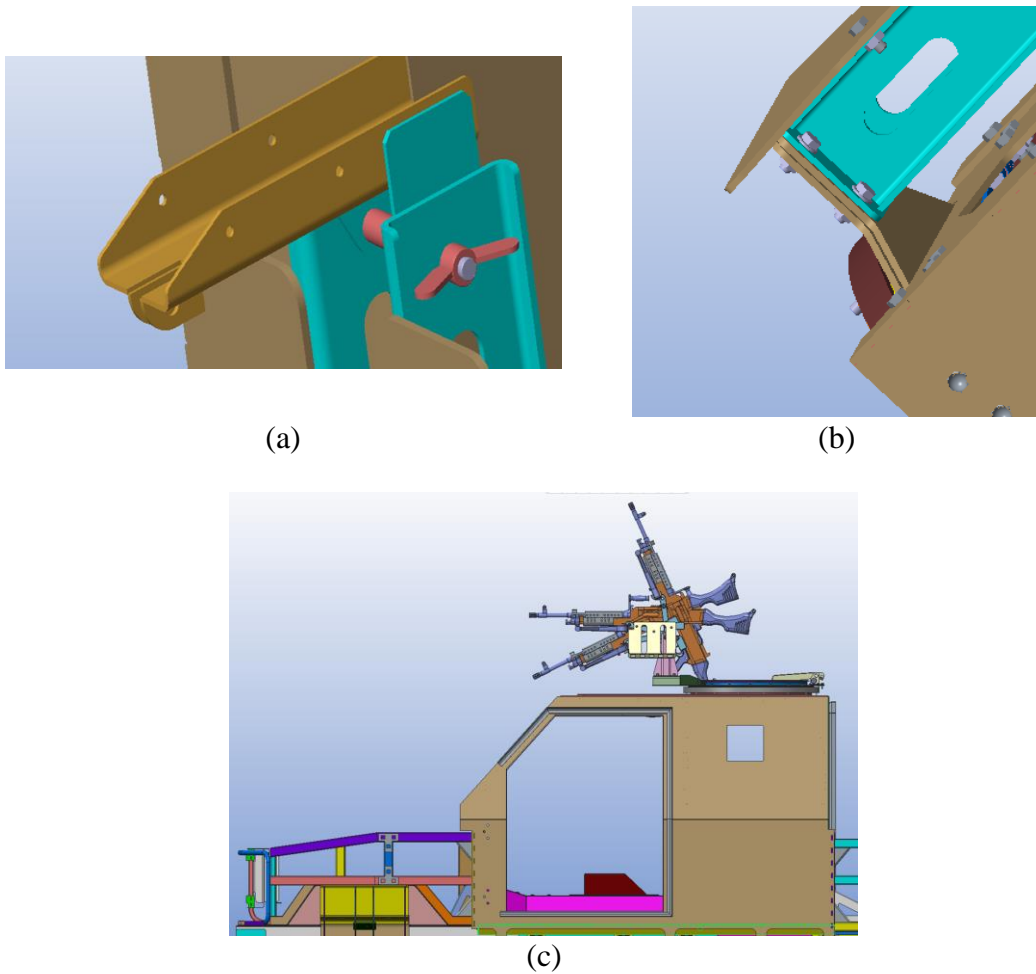


Fig.4.4 (a) Gun mount tray and (b) Gun mount assembly fastened with the base protection plate (c) Elevation and depression of gun mount with gun

- Supporting bracket should not bend because of recoiling of the gun. Therefore, taper design was given to the supporting bracket for minimum stress formation and to avoid the bending of the supporting bracket
- Designing of gun mount tray width, elevation and depression of gun mount should be as per the requirement of the customer

4.2.5 Perimeter Protection Assembly

Perimeter protection is given for the safety of the crew members in turret assembly. Before designing the perimeter protection assembly, research work was done for fulfilling the requirement of the customer which were as follow

- Perimeter protection should be designed with armoured steel that can withstand multiple hits i.e. two pair each of 5.56 mm INSAS and 7.62 mm self-loading

rifle (SLR) and one pair of 7.62 mm AK-47 at a distance of 10 meters at angle of $45^\circ \pm 5^\circ$ from the top and same number of shots at an angle of $90^\circ \pm 5^\circ$ from front and all sides

- Perimeter protection height should be 450 mm from the roof of the vehicle
- Perimeter protection should be in foldable and un-foldable condition provided with proper fasteners
- Folding and unfolding time of perimeter protection should be minimum

Based on the above inputs from customer, many research works were done for fulfilling the requirement of the customer. Firstly, time was taken to decide the shape of the perimeter protection. Benchmarking of hexagonal, circular and rectangular shape was done to get the best suitable design to fulfil all the requirements, out of which rectangular shape was finalised because in rectangular shape, time taken for folding and unfolding the turret perimeter protection came out less than 30 minutes after development of the whole turret assembly with the use of the fasteners. Then armoured material of required ballistic resistance is selected. The development of perimeter protection assembly is done with the armoured material whose properties are stated in the next section. The material was already tested for ballistic resistance by supplier end and the industry itself against required protection level. Armoured material used in the perimeter protection is already used in the development of armoured vehicles in the industry. The height of perimeter protection is taken as per the requirement of the customer.

4.3 Material Properties

The major portion of the turret assembly was developed with ballistic protection steel which is having an extra hardness, available in cut length sheets. The hardened steel is delivered in quenched condition which is not recommended for further heat treatment because it can reduce the ballistic resistance. The process of grain refinement is done for the steel. The armoured material sheets are available in the thickness of 3-6 mm and in plates it came with the thickness of 6-15 mm. The tolerance values of thickness depend upon the armoured sheet and plate thickness which varies from 0.36-1.0 mm. The Brinell hardness test is used in the mechanical testing of the armoured material which is done on the basis of International standards ISO-6506-1 on the 0.3-2.0 mm

milled surface. The hardness value of armoured material varies from 540 to 600 HBW. The chemical composition of the armoured material is shown in the Table 4.1.

Table 4.1 Chemical composition of an armoured material

Ni	Cr	Mo	Si	C	P	S	B
2.50	1.50	0.8	0.70	0.36	0.015	0.010	0.005

These compositions are in maximum percentage

Other materials used in the turret assembly is developed with the high strength alloy steels. These materials are fabricated by incorporating trace alloying additions of niobium, titanium and vanadium, which is regulated by cooling after hot rolling. The ultimate tensile strength varies between 500 to 640 MPa and yield strength varies between 460 to 560 MPa having 21 % of elongation. The chemical composition of the armoured material is shown in the Table 4.2.

Table 4.2 Chemical composition of steel other than armoured steel

Mo+Ni	Cr	Mn	Si	C	Cu	S	Al
0.4	0.2	0.8-1.4	0.25	0.41	0.2	0.01- 0.025	0.02

These compositions are in maximum percentage

4.4 Fasteners

Bending and welding are maximum avoided while development of the whole turret assemblies due to the reason of decrease in ballistic resistance. Maximum sub-assemblies are joined with the help of fasteners as per the organisational standards. Turret base assembly fastened with the bearing assembly and perimeter protection assembly. The perimeter protection plates are also bolted with the joinery plates. The bearing assembly is also bolted with the roof of the vehicle. Hexagonal weld nuts inside the roof of the vehicle were provided as per the Bureau of Indian standard IS 8856. Gun mount is bolted with the turret base assembly. The fasteners grades were chosen in such a manner that it cannot shear off with the impact of the bullet. Proper torqueing of fasteners is done as per the organisational standards to avoid loosening of sub-assemblies during dynamic condition of the vehicle.

4.5 Modal Analysis of Turret Assembly

The modal analysis of turret was done with the help of HyperWorks software and Nastran as solver. In organisation, HyperMesh and HyperView are used as the pre-processor and post-processor respectively. The CAD Model of armoured turret assembly was modelled in the Creo 3.0 which was exported to the HyperMesh in which meshing of the whole turret assembly and connections between the sub-assemblies were done as shown in the Fig.4.5. Material properties and thickness was provided as per the requirement of the design.

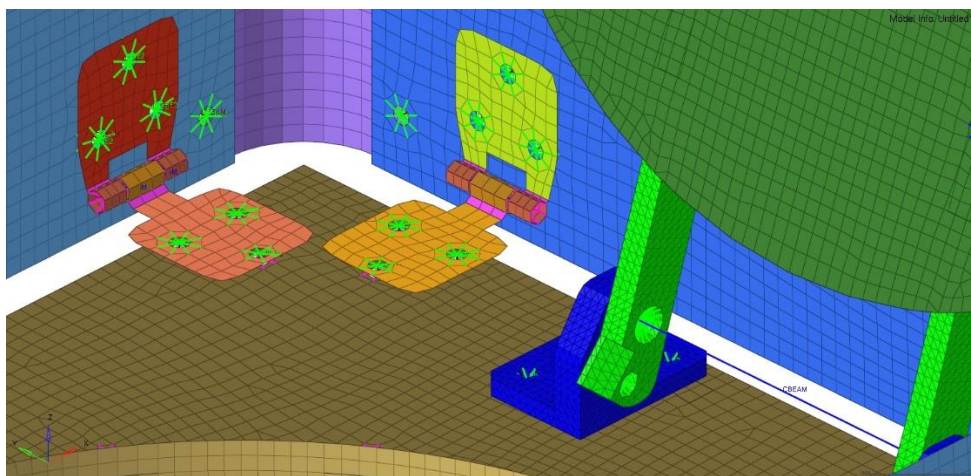


Fig.4.5 Meshing and connections

During modal analysis, the following assumptions were taken in account.

- Loads are transferred through bolts and weld connections mainly
- Weld modelling is approximate and assumed to be sufficient strong
- Material properties are assumed as linear and stress beyond yield is linearly extrapolated
- For uniform thickness parts and for bolt connections the meshing was considered as 2D meshing
- For non-uniform thickness parts, cylindrical parts and welding of materials the meshing was considered as 3D meshing
- Passenger load was considered as the point load

The Fig.4.6 shows the constraints given to the turret assembly while performing the modal analysis of turret assembly. Turret assembly was bolted with the roof of the

armoured vehicle in which hexagonal weld as per the Bureau of Indian standard IS 8856 nuts were provided. All degree of freedom was arrested as shown in the triangular form in the Fig.4.6. Modal analysis of turret seat hanger which is provided for the crew member considering the mass of 90 kg was also done which is considered as the point load as shown in the Fig.4.6.

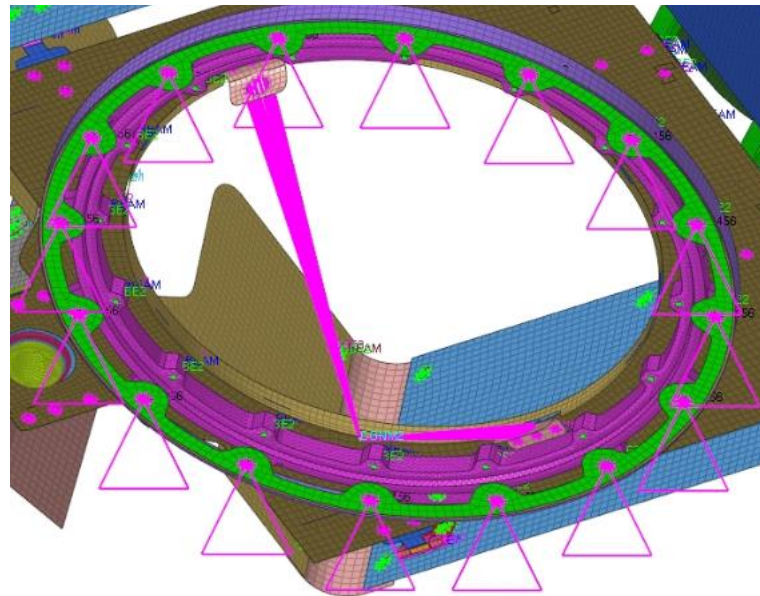


Fig.4.6 Constraints given to the turret assembly while performing modal analysis

4.6 Challenges

After the turret assembly has taken place on the armoured vehicle, a difficulty was found in the 360° traversing rotation of turret assembly. While the initial torque requirements were calculated to be 5 kgm, the first practical assessment of torque requirements showed an increase of 5-8 kgm. Research work was done for finding the root cause for the major challenge that was faced after the turret assembly fitment on the vehicle. After proper studies, these points were observed.

- The roof of the vehicle is manufactured in the single sheet of armoured steel which is welded with the perimeter of the vehicle. Although the roof of the vehicle was considered as the flat surface during 3D modelling but during practical inspection irregularities in the surface flatness was observed
- Due to manual fastening of the bolts on the base plate with perimeter protection assembly, irregularities in surface flatness of turret base plate was observed.

This causes interference with the turret ring bearings, which results in increased torque requirements and reduction in turret rotation speed

To rectify the particular issues, the structural support was introduced in the form of machined ring which was specifically fabricated to mitigate the irregularities in the turret base plate. This was achieved by varying the thickness of the machined ring to accommodate the discrepancies in the flatness of the turret base plate. The welded structural support proved to be highly efficient in reducing the interference with the turret ring and significantly improved the turret rotation speed.

4.7 DFME and DVP

The design failure mode and effect analysis (DFME) technique was carried out for current study to identify, prioritize and eliminate potential failure from the system, design or process before they reach the customer as it provides a discipline for documenting the analysis for future use and continues process improvement. Generalised failure modes can occur while testing the component by the organisation and the other testing agencies. Further, design validation plan is (DVP) is a tool that document the plan that will be used to confirm that a product, system or component meets its design specification and performance requirement. These both techniques are used in the organisation for the development of any component from the concept to the final product.

Chapter 5

Results and Discussion

In this research project, a methodology was followed to design the armoured turret assembly on the armoured vehicle as per the requirement from the MOD. This involved the 3D modelling of turret assembly, modal analysis, experimental validations so that final manufactured armoured turret assembly can be assembled on the armoured vehicle before submission to the MOD. This chapter of research shows the results obtained after analytical and experimental validation at every step in the design process as per the followed methodology. The analytical results were obtained by using the HyperMesh as the pre-processor, Nastran as the solver and HyperView as the post-processor by doing the modal analysis of the turret assembly on the vehicle. Proto of turret assembly was manufactured and assembled on the vehicle for the experimental validation. The experimental validations were done based on the results obtained on the vehicle level testing done in organisation and the ballistic testing in Gujrat Forensic Sciences University. Based on the analytical and experimental results, design improvisation was done for the final manufacturing of turret assembly on the vehicle.

5.1 Analytical Results

Modal analysis of armoured turret assembly on LBPV which is a new vehicle under development was done to validate the turret assembly of LBPV. The assumptions made during modal analysis were mentioned in the previous chapter of this project report. Modal analysis of turret assembly was done under the two conditions which are mentioned as below.

5.1.1 Gun Firing Condition

During counter insurgency environment, firing will occur from the gun mounted on the gun mount which will cause excitation on the turret assembly due to the recoil of the gun. In this condition, hatch was in open condition and person is sitting on the turret seat belt. No movement of vehicle was considered during the firing condition. Modal analysis was done in hatch open condition and crew member sitting on the turret seat belt. The firing rate of gun input came from MOD in the requirement in which modal

analysis was done by considering the mass of the gun as 10 kg at the pivot point of the gun mount. Gun mount loading condition was considered as shown in the Table 5.1.

Firing rate of gun = 650 RPM
 Firing rate of gun = 650/60 = 10.83 RPS or 10.83 Hz
 Acceptable frequency > 15.3 Hz (1.414 x 10.83)

Table 5.1 Gun mount loading condition

Type of Gun	Self-Weight with filled magazine (fully loaded)	Ammunition details	Velocity of bullet at target	Target distance
5.56 INSAS LMG	6.73 kg	Cart SA ball 5.56 mm MK1A	890±10 m/sec	25 m
7.62 LMG	9.5 kg	Cart 7.62 mm ball A-7 MK-II (7.62 mm x 39 mm hard steel core)	700±20 m/sec	20 m

5.1.2 Vehicle Running Condition

On the basis of various testing done on existing armoured vehicle manufactured in the organisation, the acceptable frequency was considered as 20 Hz during dynamic condition of the vehicle. This acceptance frequency was resulted from the light support utility vehicle (LSUV) which is a base vehicle of LBPV. The vehicle was tested as per the Japanese Standards JIS 1601-D which define the vibrational testing methods for the automobile parts and the experimental testing done on the different Indian road conditions. **The vehicle input parameters and results are strictly confidential and shall not be considered in any form for further validations.** Table 5.2 shows the results for modal analysis results in hatch open condition and person sitting on the turret hanger seat. Frequency on the 4 no. modes were resulted on the basis of mentioned conditions and the critical assumptions.

Table 5.2 Modal analysis results of turret assembly in hatch open condition and person sitting on the turret hanger seat

Modes	Frequency (Hz)	Location
Mode-1	16.1	Gun Mounting Assembly
Mode-2	13.8	Hatch in rest position on the rear perimeter protection
Mode-3	16.78	Turret Seat Hanger
Mode-4	21.4	Perimeter protection of turret assembly

As per the above results Mode 2 (Hatch in resting position on the rear perimeter protection) is falling below acceptance criteria of 15.3 Hz which is not acceptable. Two design proposals were made after the modal analysis as mentioned below.

- Additional plate of armoured material having the same thickness of perimeter protection assembly were added for the better results in modal analysis and gun mounting to the base plate will become more rigid

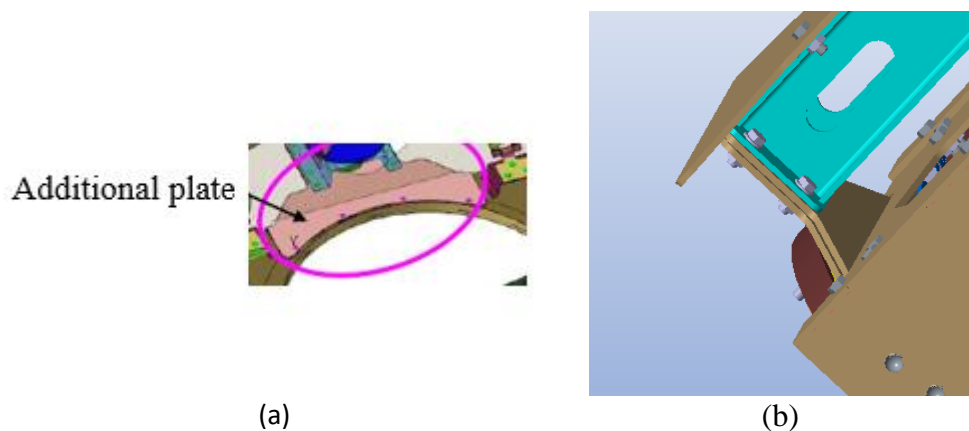


Fig.5.1 (a) Position of addition of armoured plate and (b) View showing the addition of armoured plate bolted with the gun mount

- Locking mechanism changed after the results of modal analysis. Before modal analysis, the locking mechanism was given on the ribs which rest on the resting pipe provided on the perimeter protection. After model analysis the locking mechanism was provided from inside the rear perimeter protection as shown in the Fig.5.2. This improvisation was done to improve the locking mechanism of the hatch assembly for the safety of the crew member sitting on turret hanger seat

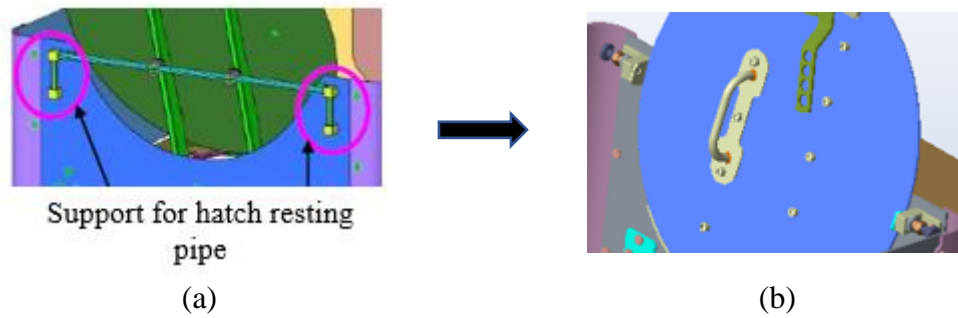


Fig.5.2 (a) Design before modal analysis and (b) Improvisation in locking mechanism after modal analysis

Further the rear plate of perimeter protection was changed for the better structural stability as shown in the Fig.5.3 (b). With the change in locking mechanism and change in design of armoured rear perimetric protection plate, no failure was observed during the experimental validation.

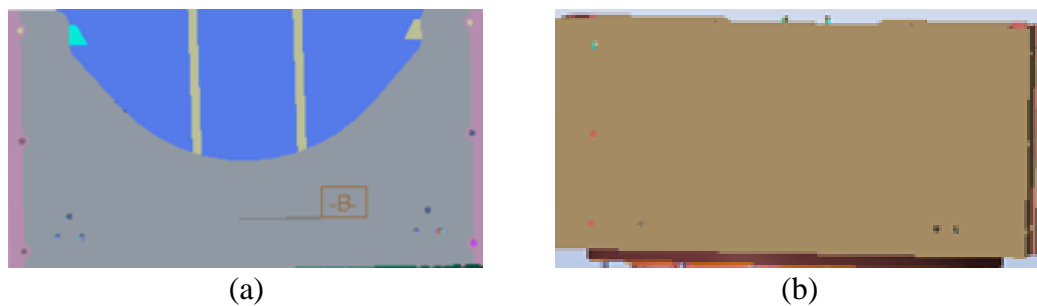


Fig.5.3 (a) Design of rear perimeter protection plate before modal analysis and (b) Design improvisation of rear perimeter protection plate after modal analysis

Table 5.3 shows the results for modal analysis results in hatch close position and vehicle in dynamic condition. Frequency on the 2 no. modes were resulted on the basis of mentioned conditions and the critical assumptions. In other 2 no. modes, the modal analysis was not required because during vehicle running condition the turret seat hanger will be not used and hatch will be in rest position.

Table 5.3 Modal analysis results of turret assembly in vehicle dynamic condition where hatch is in closed position

Modes	Frequency (Hz)	Location
Mode-1	22	Perimeter protection of turret assembly
Mode-2	23.9	Gun mounting assembly

As per the above results both the modes are above the acceptance frequency of 20 Hz which is acceptable in dynamic condition of the vehicle.

Hence the design validation was done analytically with all the conditions and as per the requirement of the customer. To validate the analytical results, experimental validation was carried out by manufacturing the proto turret and performing the various tests in organisation itself and by other testing agencies after fitment of turret assembly on the vehicle.

5.2 Experimental Results of the Turret Assembly

The LBPV with turret assembly are validated with the modal analysis and compared with the experimental testing. Further, the base vehicle is analysed experimentally to determine the improvement in design of turret assembly before submission to the customer. The experimental testing was done in two places, vehicle level testing in the organisation and other ballistic testing in Gujrat Sciences forensic University.

5.2.1 Durability Testing

Light Bullet Proof Vehicle is designed for off road condition, so field test was carried out on base vehicle with turret assembly moving on off road conditions and on highways with fully laden condition with the speed of 40-60 kmph in off road conditions and 80-100 kmph on highways covering the 3500 to 4000 kms.

As per the design validation plan, the vehicle along with turret assembly completed 100 cycles of torture track with the speed of 10-40 kmph depending upon the type of terrain. 100 cycles of torture track are more than enough for the component durability validation. Out of 100 cycles, vehicle covered 20 cycles in unladen condition and 80 cycles in laden condition. The torture track in organisation is based upon the different road conditions of India. The vehicle run on the torture track to withstand extreme conditions. This test has been conducted for the validation of durability of component on vehicle. The vehicle has been driven on the most torturous terrains which is tested for the endurance of the component. The testing was done in hatch open condition where 90 kg dummy made to sit on the turret hanger seat. The testing was also done in hatch closed position. After the completion of the 100 cycles, each and every part of turret assembly was visually inspected and no failure was observed. Analytical results were validated with the experimental results as no failure occurred.

5.2.2 Ballistic Testing

After the completion of durability testing, vehicle was sent to the GFSU for ballistic testing. Different points were marked on the turret assembly on which bullet has to be fired. The whole setup was done as per the procedure suggested in the request for technical and commercial proposal. The gunner's hatch door was tested by firing of one pair (2 shots) of 7.62 mm SLR at a distance of 10 m at an angle of $45^\circ \pm 5^\circ$ from the top and perimeter protection assembly with gun mount assembly with same number of shots at an angle of $90^\circ \pm 5^\circ$ from front and all sides. After the completion of ballistic testing bullets were found to be penetrated through the bend portion of the perimeter protection assembly as shown in the Fig.5.4 (a) and no penetration was observed in the straight portion of the perimeter protection assembly as shown in the Fig.5.4 (b). This was tested by firing of one pair (2 shots) of 7.62 mm SLR at a distance of 10 m at an angle of $90^\circ \pm 5^\circ$ from front and all sides.

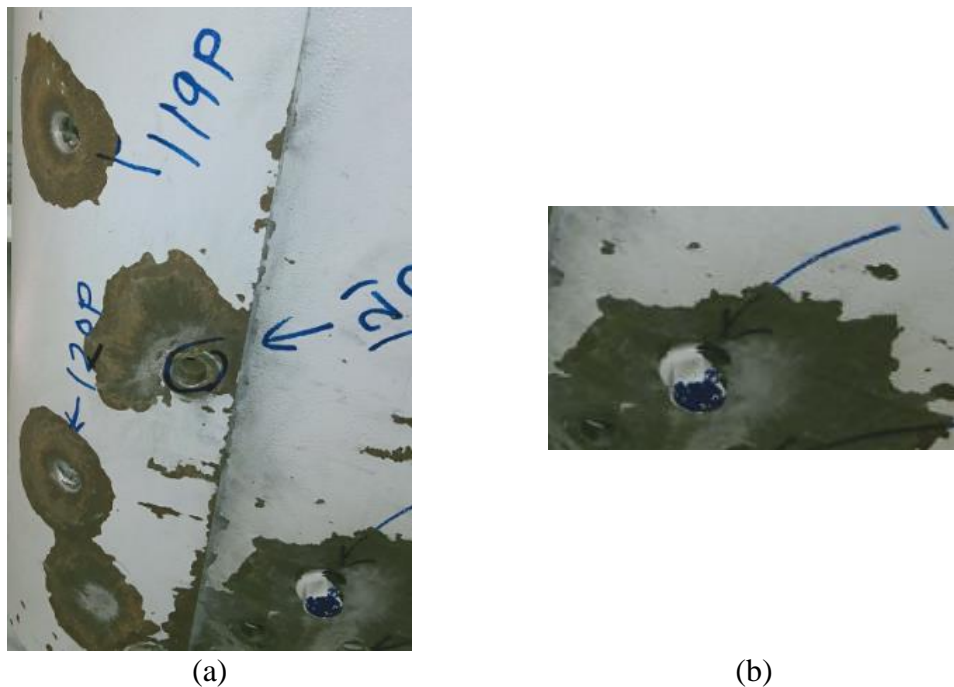


Fig.5.4 (a) Bend portion of the perimeter protection assembly and (b) Flat portion of the perimeter protection assembly

The preliminary root cause of the of these perforations was the decrease in the hardness of the armoured material because of manual multiple hits on straight armoured plate for bending into the desired shape. As discussed earlier in Chapter 2, the armoured material hardness decreases while bending the armoured plate. This was confirmed by the

metallurgy reports of the bend plate of the perimeter protection assembly for metallurgy observations of the armoured material in which bullet was penetrated. Pre-examination of hardness of plate was conducted by the material engineering department. The hardness measurement was taken in-line with the guidelines shared by the armoured material supplier. Polishing was undertaken for the bend specimen as the pre-preparation for testing. Lower hardness value was obtained against the specification of the armoured material. The percentage decrease in the hardness values of bend plate are shown in the Table 5.4.

Table 5.4 The percentage decrease in the hardness values in bend plate

Hardness	1	2	3	4	5	6	7	8	9	10
Traverse (BHN)	11.2	16.3	20.8	27.2	27.2	27.2	27.2	23.1	13.7	11.2

As per the observation from the above table maximum reduction of hardness took place in between the bend plate i.e. in between 3rd to 8th point. The sample of bullet penetrated bend plate was tested as shown in the Fig 5.5 (a) and points where hardness was measured are shown in the Fig.5.5 (b).



Fig.5.5 (a) Test specimen of bullet penetrated bend plate and (b) Hardness measurement points on bullet penetrated bend plate

Another observation was observed of the falling of allen bolt head inside the cabin. This was due to the gunner's hatch door which was tested by firing of one pair (2 shots) of 7.62 mm SLR at a distance of 10 m at an angle of $90^\circ \pm 5^\circ$ as shown in the Fig 5.6. As the bullet strike on the hatch plate, the stress transferred on the given size of allen bolt due to dynamic deformation of plate resulting in sharing of the bolt head and falling into the cabin.

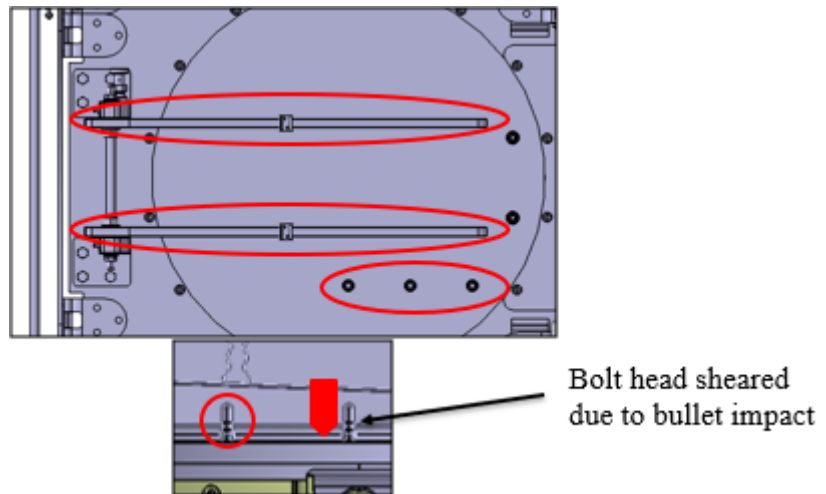


Fig.5.6 Bullet fired at highlighted portions

Lastly, the bullet penetrated through the front portion of the base plate of the bearing assembly as shown red colour dots in the Fig.5.7. The root cause of penetration was the full welding of bottom and perimetral part of the base plate of bearing assembly. Due to the full welding, the heat affected zone was created resulting in the reduction of hardness of the armoured base plate of the bearing assembly.

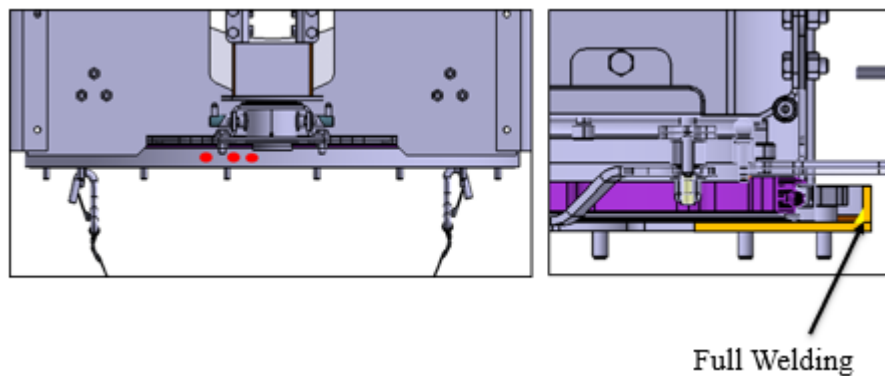


Fig.5.7 Penetration of bullet in base plate

Corrective actions were taken against all the observations found under ballistic testing. The design improvisation was done to overcome the drawbacks came in ballistic testing. For the bullet penetration in bend plate, the corner joint design changed where no bending was used. Joints made same as existing proven joineries as shown in the Fig.5.8. As these two plates are join by welding, hence decreases the hardness of the armoured material used. To overcome that, trap was given in the final design to restrict the bullet penetration as shown in the Fig.5.8.

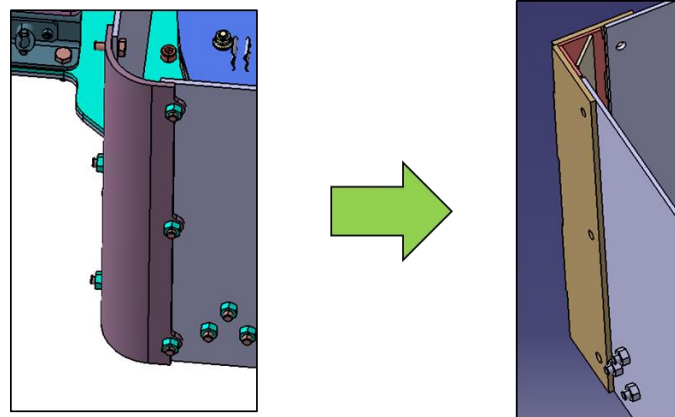


Fig.5.8 Corner joint design

For the falling of bolt head into the cabin, the additional armoured cover plate added over the ribs of the hatch assembly and higher bolt size with higher grade was given for the better stability. Hatch handle and hatch lock bolts were kept common with the rib mounting bolts as shown in the Fig.5.9. With this addition armoured plate, the impact of bullets on the allen bolts will decrease. These hatch plates are tack welded with the ribs of the hatch assembly. Hence resulted in the better design as compared to the earlier one.

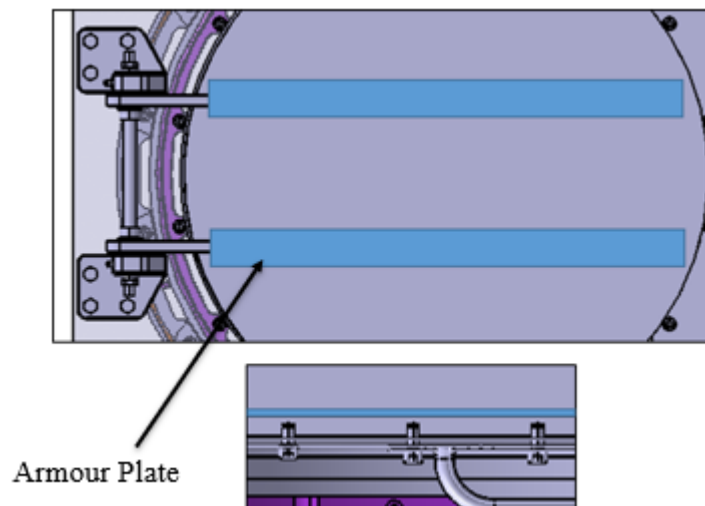


Fig.5.9 Addition of armoured plate on ribs of hatch assembly

For the last observation, tack welding was used for joining the two portions of the base plate of bearing assembly instead of full welding result in the decrease of creation of heat affected zone (HAZ) as shown in the Fig.5.10. Armour circular plate was designed in rear of the front protection circular plate of base plate of bearing assembly for providing extra protection against the impact of bullets. Tack welding was done for joining front protection circular plate and base portion of the base plate as per the

guidelines provided by the supplier for welding the armoured steel. With the proper welding procedure, the ballistic resistance of the armoured steel slightly decreases rather than the drastic decrease of ballistic resistance due to full welding.

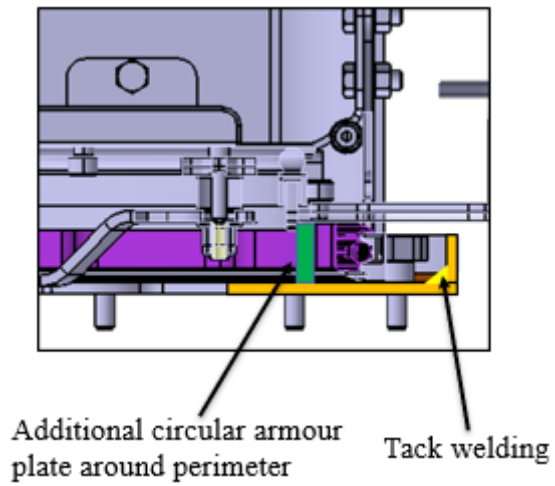


Fig.5.10 Addition of circular armour plate

Chapter 6

Conclusions and Scope for Future Work

6.1 Conclusions

This thesis aimed at the design of the turret assembly on light bullet proof 4x4 vehicle which is designed for off road conditions as per the requirement of the customer. The result summary in this thesis report is discussed as per the observations made while designing the turret assembly. Some conclusions that can be drawn from the study are

- The 3D modelling of the turret assembly was designed in the space available on the roof of the vehicle. As the turret is designed for special armoured combat vehicle which has a role of movement and operation of small independent team, a protected platform for troops engaged in counter insurgency, conveyance of Commanders in counter insurgency environment and providing protected mobility
- The modal analysis of turret was done with the help of HyperWorks software and Nastran as solver. In organisation, HyperMesh and HyperView are used as the pre-processor and post-processor respectively. Modal analysis was done in two conditions, firstly in hatch open condition and crew member sitting on turret seat belt and secondly in hatch close condition and in dynamic condition of vehicle
- In hatch open condition and crew member sitting on turret seat belt condition, hatch in rest position on the rear perimeter protection is falling below the acceptance criteria of 15.3 Hz which was not acceptable. This was improved by changing the locking mechanism and designing the new rear plate of perimeter protection assembly. In hatch close condition and in dynamic condition of vehicle, as per the results all the modes frequency were resulted above the acceptance frequency of 20 Hz which is acceptable
- The experimental validations were done based on the results obtained on the vehicle level testing done in organisation and the ballistic testing in GFSU. Based on the analytical and experimental results, design improvisation was done for the final manufacturing of turret assembly on the vehicle

- After incorporation of new design ideas as mentioned in Chapter 5 for improving the ballistic resistance, the final turret was manufactured under the given weight target of 200 kg. This was the challenging task for an organisation to manufacture the armoured vehicle with turret assembly under 4000 kg, which was achieved remarkably with the margin
- The cost incurred by developing the turret assembly in-house is much below the quotation given by the supplier for manufacturing the whole turret assembly

6.2 Scope for Future Work

Based on the present work, the following points can be implemented as the future scope in the manufactured turret assembly.

- Gear mechanism can be implemented for the rotation of turret assembly having the controls within the hands of the crew member
- Dome shape armoured turret can be designed with the ballistic resistance glasses for more safety of the crew members
- Gun mount can be re-design for mounting of heavy machine guns on the present turret assembly
- Lighter turret assembly can be manufactured with the use of ballistic resistant composite materials based upon the requirement of the customer

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