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Design development analysis and crash simulation of gimball integrated vehicle

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Abstract: -- The gimbal is a mechanism having degrees of freedom in both elevation and azimuth axis similar to gyroscope which has 3 axial freedom. Gimball assembly consists of a) box ,where the required components are fixed b) motors, for the rotation of gimball in required direction c) beam support, for holding the structure d) base plate to connect two beam structural beams e) base plate, for support of entire structure.

The following points are considered for design of gimbal assembly:

- **Mechanical configuration has a minimum value of MI about all the axes.**
- **The mechanical design is optimized for stiffness so that the natural frequencies are well above the natural frequency to avoid resonance.**
- **Machining accuracy of various surfaces is to be maintained so the geometric cross coupling & friction are minimized.**

Torque calculations are done for required loading conditions and a motor is selected. The gimball and gimball installed truck are designed analysed and simulated.

Keywords: design calculations, gimball, hypermesh, simulation

I. INTRODUCTION

To develop, calculate, select, design, assemble, analyse, simulate a mechanism to track an object in air and then lock the target and launch high intensity laser beam onto it. To achieve this objective two axis (elevation and azimuth) rotary mechanism, Gimball has been developed and individually all components of gimball are analysed and assembled to truck, TATA LPTA. Truck is individually designed and crash analysis has been done on few components to know the energy transfer and deformations.

DESIGN CONSIDERATIONS AND APPROACH

The following points are important for design of gimbal assembly:

- Electro-mechanical configuration must have minimum value of MI about all the axes.
- The mechanical design is optimized for stiffness so that the natural frequencies are well above the control-bandwidth to avoid resonance.
- Machining accuracy of various surfaces is to be maintained so the geometric cross coupling & friction are minimized.

The mechanical design of a gimball is the most critical activity having a direct impact on the performance in terms of accuracy, durability, reliability, speed, size, weight and cost. The geometry of a gimball refers to the overall design of the system. "U" designs allow the payload to be hung between two supports. The U design allows for good balancing of a payload to reduce the amount of torque required. However, U designs are not amenable to multi-part payloads and limit the size of the payload that can fit within the U brackets. U-shaped systems also tend to be larger and heavier gimball units, and often more expensive. U-shaped designs can also be less stiff with more torsion that can affect overall pointing accuracy. Pedestal designs are more compact and allow payloads to be mounted on side.

The designed gimball will have two axis i.e., elevation and azimuth. The elevation axis will be on top and azimuth is on the bottom. The material for gimball will be of high strength Al. Alloy. IS 7075–T6 condition and approximately the gimball block is around 40 kg.

II. TORQUE CALCULATIONS

Inner Elevation of Mass = 40 kg

Inner Elevation of Inertia

jei X - 0.8-along roll axis
jei Y - 0.88-along Elevation axis
jei Z - 0.81-along azimuth axis

CG Offsets

Oei X - 1.5mm

Oei Y - 6.95mm

Oei Z - 6.28mm

Static Friction

0.369N-m (4Bearings+20%misalig(3inch,.035x4x1.2N-m=0.168N-m) +motor breakaway.

(0.2N-m)

Platform Disturbance

3deg/sec [00.5Hz(Aerostat)]

Damping Friction Coefficient

Max . frequency is about 40 HZ In friction curve, 0 HZ stiction clominates for very low frequencies, cloumb friction and for higher frequencies damping friction dominates.

It can be taken double of elastic friction so the value is 0.258 x 2 =0.588N-m

Co-efficient = (0.588/2x Pi x 40) =0.00294N-m/rad/sec

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Mass Imbalance Coefficient

Inner Elevation Mass x Inner Elevation Offeset x CG = 40 x 0.003 x 9.8

=1.89 N-m/G.

(A s per the discussion with mech dept, CG Offset Will not Be More than 3mm after balancing .so max CG Offset Taken is 3mm)

Slew Torque

Acceleration due to slew Profile = 60 x pi/180

= 1.047 rad/sec

Frictional Acceleration Due to Slew Rate

=(DampingFriction Coefficient x Slew rate)/EI inertia

= (0.00294 x 60 x pi /180)/0.8

= 0.00385 rad/sec.

RMS Estimate of Slew Induced Acc

= Sqrt(1.047^2 + 0.00385^2)

= 1.05rad /sec^2.

Slew Torque

= 1.047 x 0.8

= 0.837 N-m.

Disturbance Torque

External Disturbance Acceleration

= 3deg/sec x pi/180 x pi x 0.5Hz

= 0.165 rad/sec^2.

Torque due to external disturbance

= 0.165 x 0.8

= 0.132 N-m.

G effect Due To Imbalance

Due To Plat Form Linear Motion

Assumed 1.5GRMS

Due To Vibration

Assumed G is 1GRMS

Total G = Sqrt (1.5^2 + 1^2)

= 1.8 G

Imbalance Torque Due To Mass Imbalance

= Mass Imbalance Coeff x G

= 1.8 x 1.8 G

= 3.24 N-m.

Gross Product

Max - Angular velocity specified as

Wei X = 60/180 x pi

= 1.047 rad/sec

Wei Z = 60/180 x pi

= 1.047 rad/sec.

Disturbance Due To Cross Product

= (jei X- jei Z) Wei X . Wei Z

= (0.77-0.76) x 1.047 rad/sec x1.047 red/sec

= 0.011 N-m.

Cable Restraints = Cable Restraint Constant x Deviation Angle

Cable Restraint Constant = 0.012 N-m/deg (Assumed)

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Worst Case Angle = 4s Deg (No Slip Ring For Inner Elevation)

= 0.012 x 4s

= 0.54 N-m.

Viscous Friction

= Viscous friction coefficient X disturbance rate

= 0.00294 x 2x pi x 40

= 0.738 N-m.

Stiction

Due To Bearing And Seals And estimate based on their diameter significant for rate polarity changes and worst case condition case condition of stab loop BW

Stiction torque = 0.369 N-m (4 Bearings +motor breakaway).

Total Disturbance torque.

= External Stiction Torque + Cable restraint + Sqrt(imbalance^2+crossproduct^2 +viscous co eff^2)

= 0.369 + 0.54 + sqrt(2.454^2+0.011^2 +0.738^2)

= 4.1 N-m.

Total torque.

= Slew torque + Disturbance torque

= 0.837 + 3.56

= 5.2 N-m.

With 50% margin, torque of the motor is

= 5.1+ 1.5

= 7.1 N-m.

III. MOTOR SELECTION AND DESIGN

For the torque obtained a standard motor according to the specifications is selected from AEROTECH motors. A brushless motor is selected, S 130-102.

Motor Model	Units	S-130-39		S-130-68		S-130-81		S-130-102		S-130-123	
Winding Designation		A	B	A	B	A	B	A	B	A	B
Performance Specifications[1,2]											
Stall Torque, Continuous[3]	N-m	2.36		4.18		5.89		7.69		8.65	
Peak Torque[4]	N-m	9.42		16.73		23.55		30.75		34.61	
Rated Speed	rpm	2,000	4,000	1,000	2,000	750	1,500	500	1,000	375	750
Power Output, Continuous	W	493.4	986.9	437.9	875.9	462.4	924.8	402.5	805.1	339.8	679.5

Fig no.1 Motor selection on required torque.

Then the required motor according to the dimensions is designed.

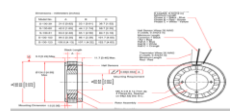

Fig no.2 Selected motor dimensions

Fig no.3 Motor design

IV. DESIGN OF GIMBALL AND TRUCK

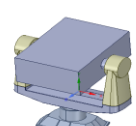

Fig no.4 design of gimball assembly

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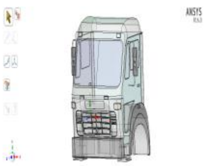

Fig no.5 Design of truck frontal cabin

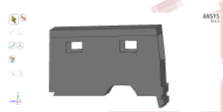

Fig no.6 design of truck back cabin

V. MESHED COMPONENTS

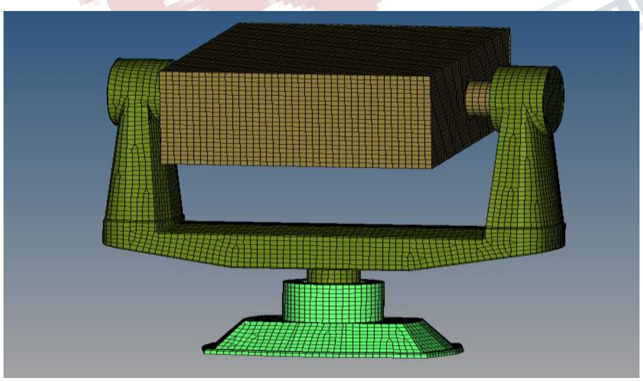

Fig no. 7 Gimball assembly meshed

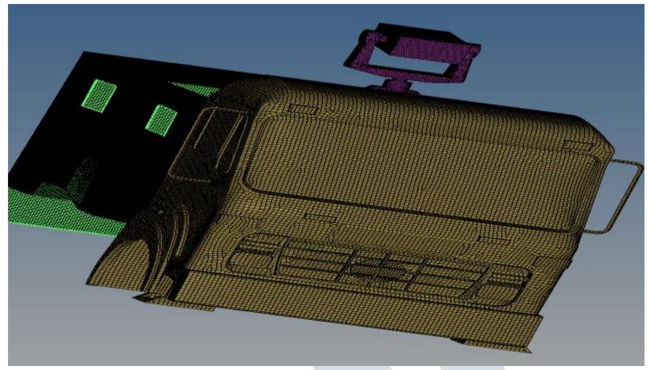

Fig no.8 Gimball installed truck meshed

VI. PROPERTIES AND SIMULATION

I. Gimball material properties

GIMBALL ASSEMBLY	Properties
Material	Aluminum Alloy 7075-T6
Model type	Linear Elastic Isotropic
Yield strength	5.05e+008 N/m^2
Tensile strength	5.7e+008 N/m^2
Compressive strength	4.25e+008 N/m2
Elastic modulus	7.2e+010 N/m^2
Poisson's ratio	0.33
Mass density	2810 kg/m^3
Shear modulus	2.69e+010 N/m^2
Thermal expansion coefficient	2.4e-005 /Kelvin

II. Gimball mesh properties

Mesh type	Shell Mesh
Mesher Used	Curvature based mesh
Maximum element size	27.8378 mm
Minimum element size	5.6
Total Elements	10473
Total Nodes	28405
Mesh Quality	High

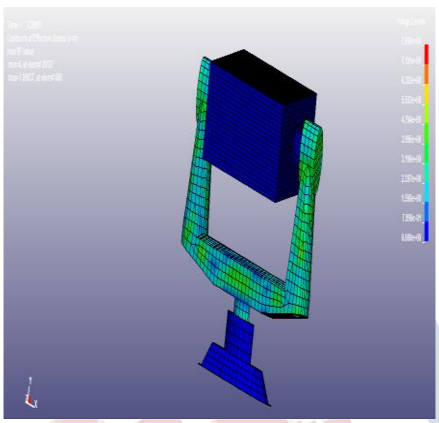

Fig no.9 Simulation of gimball with all other components as rigid.

VII. GIMBALL INSTALLED VECHICLE SIMULATION

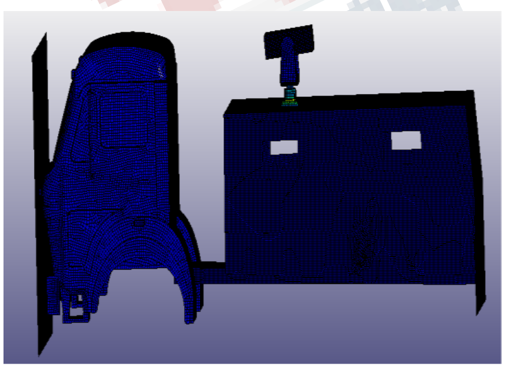

Fig no.10 Simulation of gimball installed truck

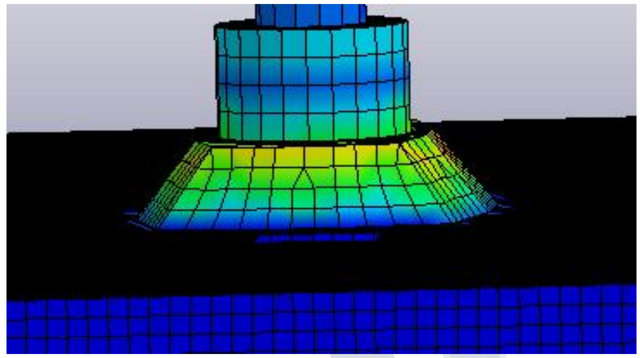

Fig no.11 Magnified view of gimball installed truck

The maximum displacement is 12.4mm in gimball base at 100km per hour.

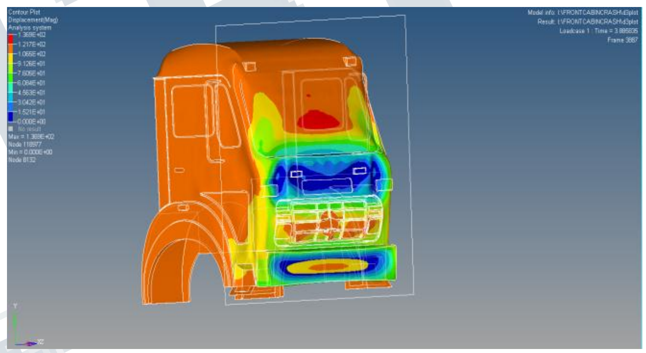

Fig no.12 Simulation of truck frontal cabin

Maximum displacement is 15.7mm at 3.5 milli seconds in front region at 100km per hour.

CONCLUSION

The gimball , the two axial rotary equipment is designed and analysed and is safe for its operation.
Crash and Impact analysis is done for different components and is safe for operation.

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