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-long roll axis
jei Y - 0.88-long Elevation axis
jei Z - 0.81-long azimuth axis
CG Offsets
Oei X - 1.5mm
Oei Y - 6.95mm
Oei Z - 6.28mm

Static Friction
0.369N-m

(4 Bearings + 20% misalignment (3 inch, .035x4x1.2N-m = 0.168N-m) + motor breakaway.
(0.2N-m)

Platform Disturbance
3deg/sec [0.5Hz (Aerostat)]

Damping Friction Coefficient
Max. frequency is about 40 HZ. In friction curve, 0 HZ stiction dominates for very low frequencies, Coulomb friction and for higher frequencies damping friction dominates. It can be taken double of elastic friction so the value is

\[ \text{Co-efficient} = \frac{(0.588/2 \times \pi \times 40)}{0.00294 \text{N-m/rad/sec}} \]

Mass Imbalance Coefficient
Inner Elevation Mass \times Inner Elevation Offset \times CG = 40 \times 0.003 \times 9.8
= 1.89 N-m/G.

(Assumed)

(Slew Torque)
Acceleration due to slew Profile = 60 \times \pi/180
= 1.047 rad/sec

Frictional Acceleration Due to Slew Rate
= (Damping Friction Coefficient \times \text{Slew rate}) / EI inertia
= (0.00294 \times 60)
x pi /180)/0.8
= 0.00385 rad/sec.

RMS Estimate of Slew Induced Acc
= \sqrt{(1.047^2 + 0.00385^2)}

Slew Torque
= 0.837 N-m.

Disturbance Torque
External Disturbance Acceleration
\[ = \frac{(\pi/180 \times \pi \times 0.5Hz)}{0.165 \text{ rad/sec}^2} \]

Torque due to external disturbance
= 0.165 x 0.8
= 0.132 N-m.

G effect due to imbalance
Due to platform 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
= \text{Mass Imbalance Coeff} \times G
= 1.8 \times 1.8 G
= 3.24 N-m.

Gross Product
Max - Angular velocity specified as
Wei X = 60/180 \times \pi
= 1.047 rad/sec
Wei Z = 60/180 \times \pi
= 1.047 rad/sec.

Disturbance due to cross product
= (jej X - jej Z) \times Wei X . Wei Z
= (0.77-0.76) \times 1.047 rad/sec x 1.047 rad/sec
= 0.011 N-m.

Cable Restraints
\text{Cable Restraint Constant} \times \text{Deviation Angle}
\text{Cable Restraint Constant} = 0.012 \text{ N-m/deg}
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.

IV. DESIGN OF GIMBALL AND TRUCK
Fig no.5 Design of truck frontal cabin

V. MESHED COMPONENTS

Fig no.6 design of truck back cabin

VI. PROPERTIES AND SIMULATION

I. Gimball material properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Aluminum Alloy 7075-T6</th>
</tr>
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<tbody>
<tr>
<td>Material type</td>
<td>Linear Elastic Isotropic</td>
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<tr>
<td>Yield strength</td>
<td>5.05e+008 N/m²</td>
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<tr>
<td>Tensile strength</td>
<td>5.7e+008 N/m²</td>
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<tr>
<td>Compressive strength</td>
<td>4.25e+008 N/m²</td>
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<tr>
<td>Elastic modulus</td>
<td>7.2e+010 N/m²</td>
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<tr>
<td>Poisson's ratio</td>
<td>0.33</td>
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<tr>
<td>Mass density</td>
<td>2810 kg/m³</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>2.69e+010 N/m²</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>2.4e-005 /Kelvin</td>
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</tbody>
</table>
II. **Gimball mesh properties**

<table>
<thead>
<tr>
<th>Mesh type</th>
<th>Shell Mesh</th>
</tr>
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<tbody>
<tr>
<td>Mesher Used</td>
<td>Curvature based mesh</td>
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<tr>
<td>Maximum element size</td>
<td>27.8378 mm</td>
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<tr>
<td>Minimum element size</td>
<td>5.6</td>
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<tr>
<td>Total Elements</td>
<td>10473</td>
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<tr>
<td>Total Nodes</td>
<td>28405</td>
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<tr>
<td>Mesh Quality</td>
<td>High</td>
</tr>
</tbody>
</table>

![Fig no.9 Simulation of gimball with all other components as rigid.](image1)

**Fig no.10 Simulation of gimball installed truck**

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

**Fig no.11 Magnified view of gimball installed truck**

![Fig no.11 Magnified view of gimball installed truck](image2)

**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.

**REFERENCES**


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[15].D Friedman, CE Nash (2010) - Advanced Roof Design For Rollover Protection