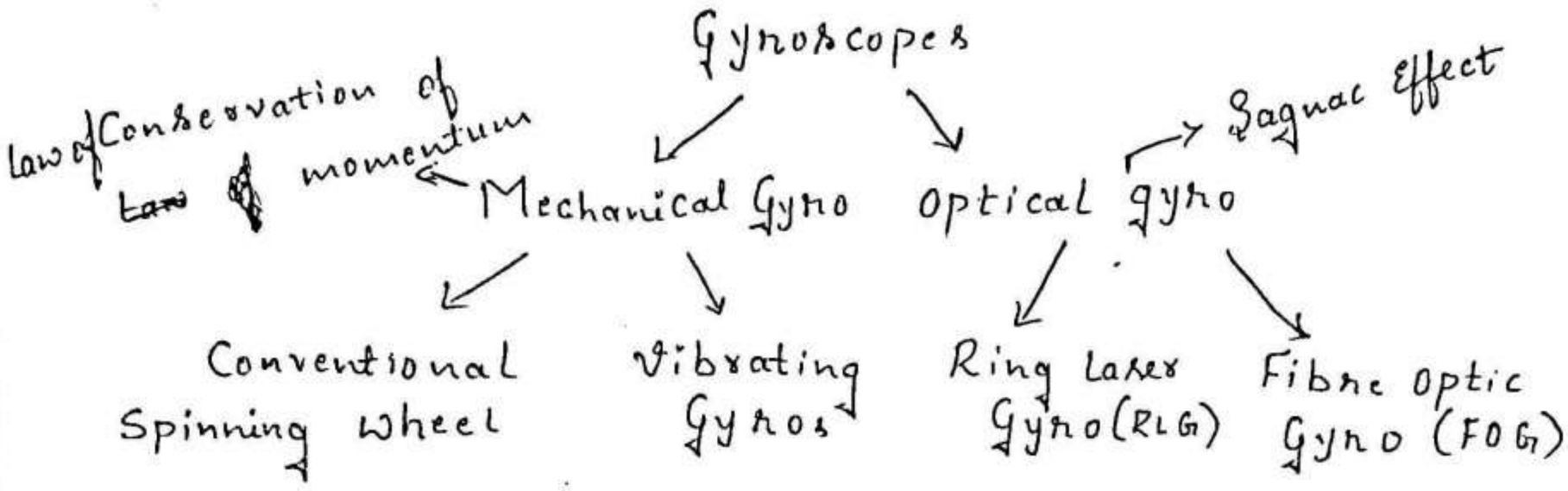
UNIT 3 : Gyroscope

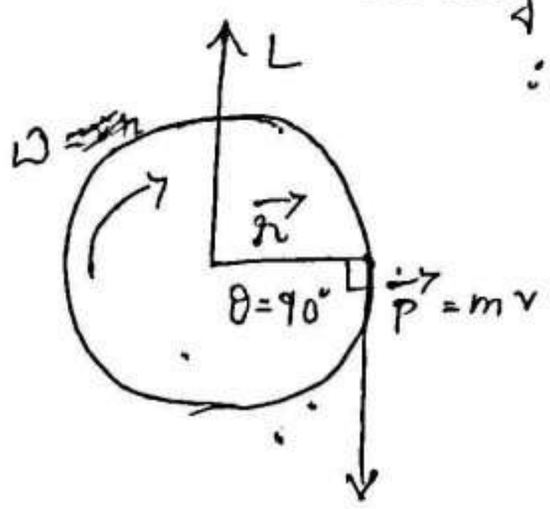
* A Gyroscope is basically an angular motion sensor.
  [Gyro → Rotation , Scope → Sensor]



Conventional Mechanical Gyroscope :

* Mechanical Gyro uses law of Conservation of angular momentum
* Law of Conservation of angular Momentum States that, for a rotating body, the total angular momentum is Conserved ($L = \Omega I$). The total angular momentum of rotating body remains Constant, unless disturbed by External torque.

Example: Aircraft carrying freely spinning rotor, is flying straight & level.



∴ Angular momentum of high speed rotor is given by $L = I\Omega$

I → Moment of Inertia of rotating mass

Ω → angular velocity in radians per second.

$\vec{P}$ = Linear momentum vector

$= mv = m\Omega r$

$\vec{r}$ = position vector ; $L = pr\sin\theta$

$\theta = 90° = m\Omega r \cdot r = m\Omega r^2$

$= I\Omega$

I → Moment of Inertia of rotor

∴ Accuracy

Direct Reading Compass

Two types of Compass

- Direct Reading Compass
- Remote Indicating Compass (flux gate)

* Impact of torque as the rotor is minimised by using Low friction bearings & gimballs., the angular momentum remains unaltered before & after change in altitude of aircraft.
  i.e plane of rotating disc is unaltered. even altitude of Aircraft changes.
* Pitch, roll & yaw angles of aircraft are measured using angular displacement sensor such as Potentiometer or Rotating Variable Different Tranformer
* Vertical axis gyro measures pitch & roll of aircraft
* Horizontal axis gyro (Directional Gyro) is used to sense yaw.
* TBI uses another property of Gyro Called precession.
* Precession is angular change of plane of rotation due to an applied torque.

2

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Precision It is the angular change of the plane of rotation due to applied torque.

It occurs at 90° away from applied torque

* Frictional forces reduces resisting relation of spinning rotors.

* Friction Causes bias errors in gyro which need to be Corrected periodically.

Ex:- Electro-Static forces are used to float a 1cm diameter beryllium Spiere Spinning at 1,50,000 rpm. Chambers will be enclosed & is evacuated to 10^{-7} torr.

* Gyro is free-Spinning rotor, Capable of measuring large angular displacement. [Used in Strapdown Navigation S/m].

* In Dynamically Tuned Gyro(DTG), dynamic Spring torques are created using gimbal S/m which balances torque from Support flexures.

* It is free runing with Reduced friction.

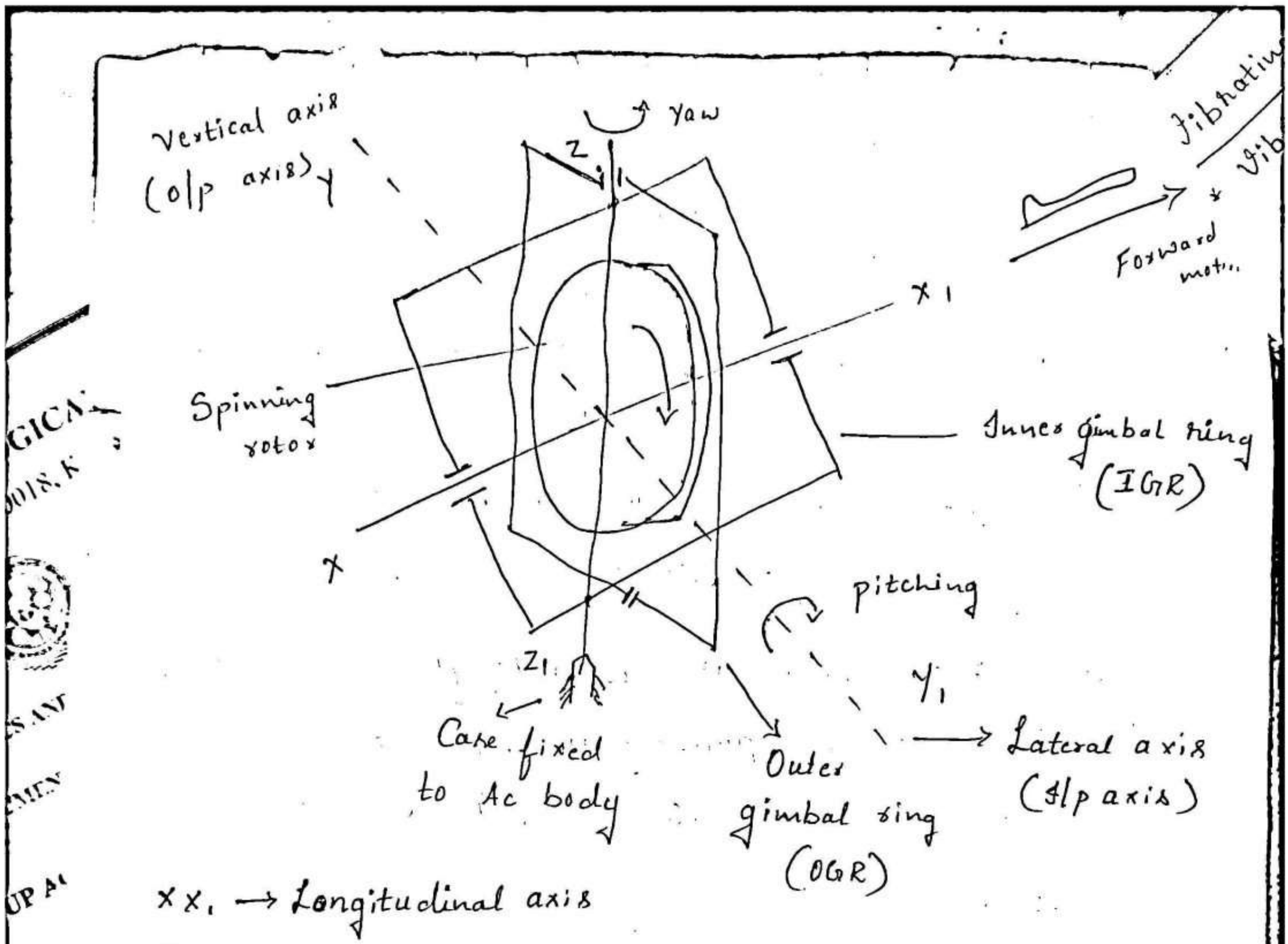
* Two axis DTG used in inertial measurement units(IMU) gimbal & platform Stabilisation, tactical missile guidance, gyro Compass, Camera Stabilisation, Radas antenna Stabilisation Etc.

Advantages of rib & optic

1. Reliability
2. Accuracy

3

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XX₁ → Longitudinal axis

→ Rotor spins about XX₁, High quality bearing mounted on IGR.

→ OGR free to rotate is ZZ, axis

* IGR ⊥ˡᵃʳ to pivot axis of OGR.

* Mechanical Gyro consists primarily of high-speed spinning rotor.

4

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Vibrating Gyros

Gyro - rotation

* Vibrating mechanism keeps vibrating in same plane as the aircraft changes its attitude.
* Advantages over Conventional Spinning rotor gyro.
  - → Higher simplicity
  - → Low cost
  - → Greater accuracy.

Apparent force related to earth's surface that causes deflection of the object.

* When Ac is in pitch motion, the response of vibrating gyro is caused by Coriolis Effect.
* Coriolis force accelerates proof masses in vibrating gyros
* Accelerometer used to sense acceleration. → Refer back page
* Vibrating gyro consists of 2 proof masses in vibrating ~~gyro~~ in plane at frequency ω_m.
* The acceleration due to Coriolis force,

$$a_c = -2(v \times \Omega)$$

Vector cross product of v & Ω.

$v \rightarrow$ velocity of object in rotating s/m

$\Omega \rightarrow$ angular velocity vector, directed along the axis of rotation ($\perp^{lar}$ to plane of rotation).

* The Out of plane displacement γ_{op} induced ~~the~~ by aircraft rotation is given by,

$$\gamma_{op} = k \Omega x_{ip} \omega_R \cos \omega_R t$$

* γ_{op} gives signal proportional to angular velocity, Ω.

level declinding Descent

5

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* Coriolis Effect is a fictitious force. Causing appar deflection of moving objects, when they are observ from rotating frame of reference.

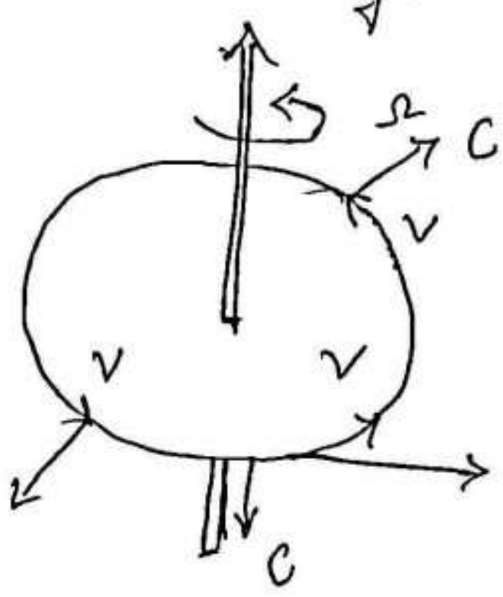
* Fictitious / pseudo force as disappears in a non-accelerating (inertial) frame of reference.

* $a_c = -2\vec{\Omega} \times \vec{v}$

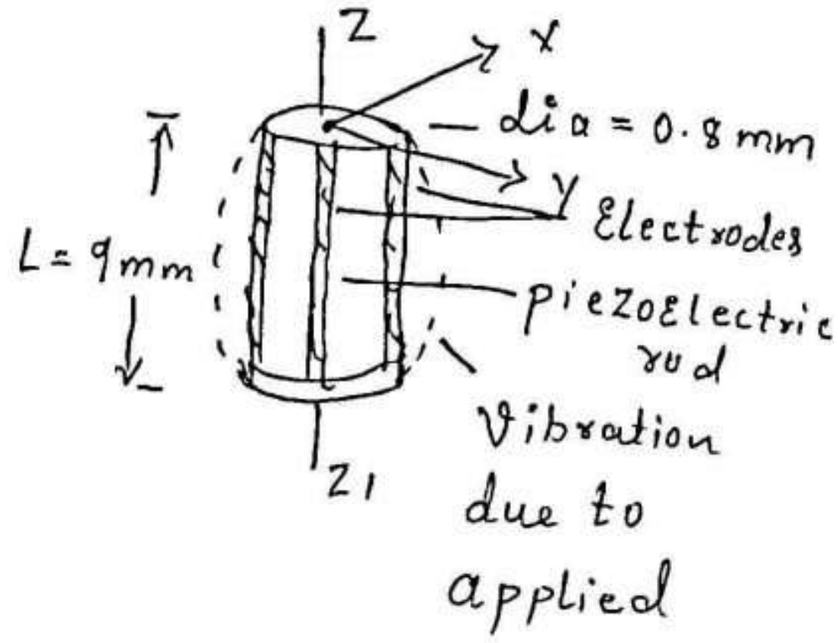
* Coriolis force $F_c = m a_c$

$= -2m\vec{\Omega} \times \vec{v}$

* F_c acts in a direction $\perp^{lar}$ to axis of rotation & velocity of the body.

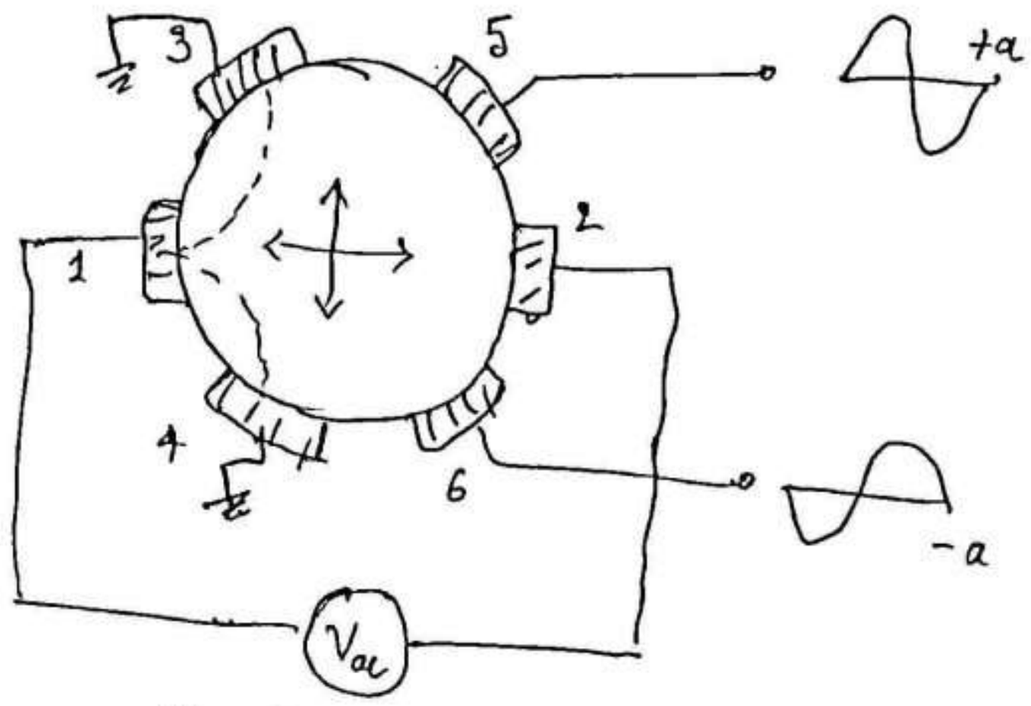


Ω → rate of rotation
v → velocity of object
C → Coriolis force



Vibration due to applied Voltage

a) Front view



b) Top view

6

Part A Review

A vibrating gyro uses piezoElectric Effect or turning fork to vibrate proof mass.

* Piezoelectric rod are vibrated.

* Basic principle of piezoElectric gyroscope is, Vibrating mechanism keeps vibrating is same plane as the attitude of its supports rotates with angular velocity, ω Ω.

* piezoElectric Element is vibrated by the application of alternating excitation voltage V_{ac}.

* When Ac attitude changes, the resulting Coriolis force is extracted after it is Converted into voltage by same piezoElectric transducer.

Construction :

* Vibrating Element Consists of Cylindrical piezoElectric Ceramic rod, on which Six Electrodes are placed & polarised.

* 3 piezoElectric rods are Considered.

Working :

* The voltage is applied as shown in figure b/n 1-2, 1-3 & 1-4 (Torsional Vibrations are setup in rod)

* Torsional vibrations produce displacements due to Coriolis force $\perp^{lar}$ to velocity vector.

* Coriolis displacement, produces o/p vltg proportional to angular velocity Ω, across Electrodes

5-2 Inphase Component

6-2 Outphase Component

Level right turn Descending left Level descending Descending Right

7

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* Ceramic gyros

- Highly sensitive can detect angular velocity as low as 0.1 degree per second.

→ High speed rotations 1500 degrees per second.

→ used as transducer to measure angular velocity in digital Camera for image stabilisation.

→ used in Altitude Control S/ms.

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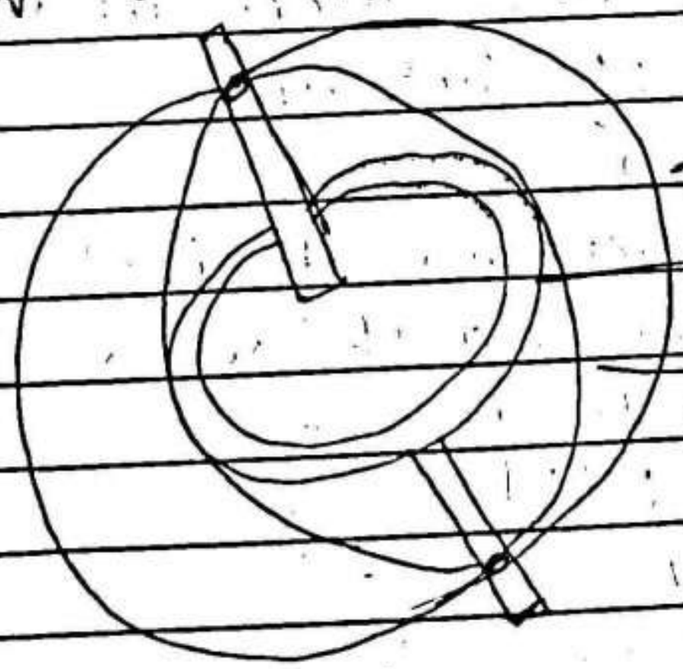
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Basics of Mechanical Gyroscope

* It contains heavy metal wheel or rotor
It has 3 degree of freedom:-

i) Spining freedom (xx1) perpendicular to centre.
ii) Tilting freedom (yy1) horizontal axis at 1^le to spin axis.
iii) Veering freedom (zz1) Vertical axis 1^lar to tilt & spin

* Rotor is mounted by 2 concentrically pivoted rings called inner & outer gimball rings.
The whole s/m is called gimball s/m.
* All the axis are mutually at right angles to one another & intersect at centre of gravity of rotor



* When motor is rotating, if weight is hung to inner gimbal ring, it will support the weight which shows the rigidity of system.

9

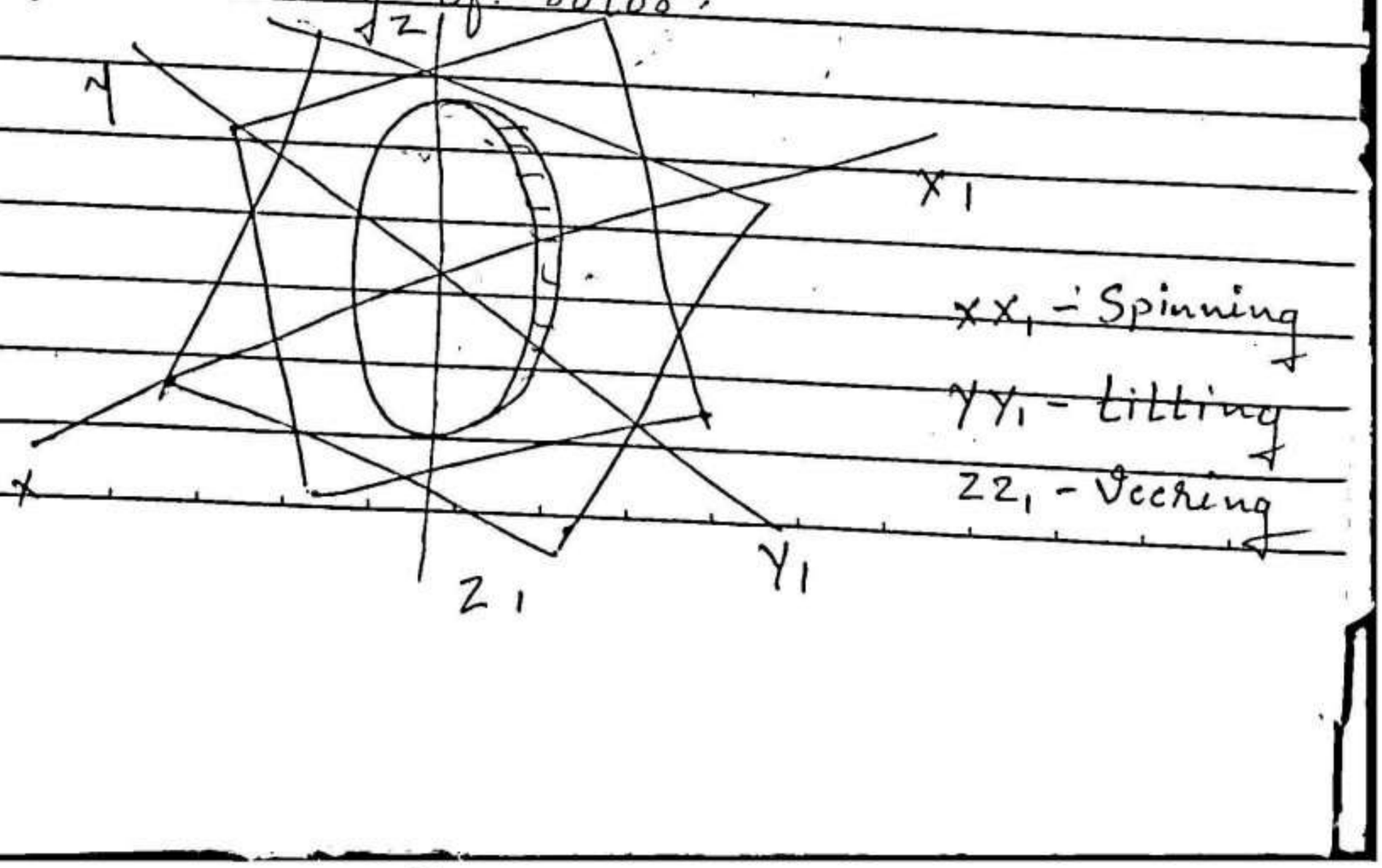
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about
f Complete gimbal s/m start rotating ZZ, axis which shows precession.

Two properties of Gyroscope

1. Rigidity:
   It resists force tending to change plane of rotation of its rotor.
   It depends on
   i) Mass of the rotor
   ii) Speed of rotation
   iii) Distance at which mass acts from centre i.e. radius of gyration.

2. Precession:
   The angular change in direction of plane of rotation under the influence of applied force.
   The changes takes place at 90° away in the direction of rotation.
   It depends on
   i) Strength & direction of applied force.
   ii) Moment of Inertia of rotor
   iii) Angular velocity of rotor.



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* Directional gyro Consists of Electric motor driven high Speed (24000 Rpm) rotor with large moment of Inertia to enhance Spacial Rigidity.
* Rotor Rotates freely in inner ring using high quality, low friction bearing.
* The outer ring Carries Compass Card 0°-360° Rotates in ZZ1 axis using precession bearing.
* Compass Card will be Stationary with Rotating Lubber Line.
* DG uses Compass Card for direction & desired heading Can be adjusted by adjustable bug.
* Action of DG is based on Spatial ~~Gyro~~. Reference provided by Rotor. [i.e Directional change measured by Spatial reference].

Errors in Directional Gyroscope :-

1. Friction in bearing used [Real drift]
2. Earth's Rotation : Ω_E (15°/hour) [Apparent drift]
3. Aircraft's movement [Transport wander] :

1. Real drift :-

In DG many mechanical bearings & gimbals are used. If friction is present, it will Cause drift w.r.t time in Compass Card. Such unwanted precessional torque Can be reduced during design & Construction. The assembly of DG should be done in clean environment to Eliminate dust partical which Can Cause drift.

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2. Apparent drift :-

- Earth rotates at 15°/hour
- The Spatially Stabilised gyro does not change with the rotation of earth. Causing apparent drift in DG ~~Causes apparent drift~~, & so DG
- DG should be reset periodically referring to Magnetic heading manually or automatically
- That is done by Gyro-Stabilised direction Indicator

Apparent drift = $\Omega_E \sin\lambda$

Drift is max at poles

λ → Latitude at which Ac flying

Ω_E → angular velocity of earth

3. Transport Wander :-

Caused due to Ac movement. adding / Subtrating angular Velocity of Earth

- Consider DG aligned to North pole

At N-pole, ZZ_1 axis is aligned to axis of earth

Apparent drift = Ω_E (15°/h)

- When Ac travels to point A, at Latitude of λ XX, will have apparent tilt in vertical plane.

That apparent tilt is Called Transport Wander.

When Apparent drift = $\Omega_E \sin\lambda$

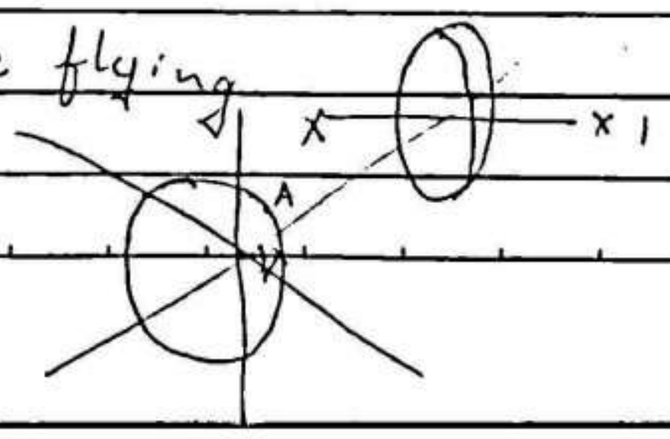
$$\text{Transport Wander} = \frac{U}{R} \tan\lambda$$

U → east-west Component of Ac velocity

R → Earth radius

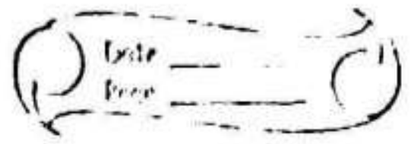
λ → Latitude at which Ac flying

- Transport Wander detected by gravity-detection device & apply precession torque to Cancel it.



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Limitations of Directional Gyros :-

There are 2 limitations:-

i) Gimbal lock

* When XX, becomes same as that of YY, & ZZ,
* So no useful data is available along spin axis.
* DG turns as whole, Causing precession & toppling.

ii) Gimbal error:-

* When Orthogonality of XX,, YY, & ZZ, are no longer maintained.
* Usually all 3 should be mutually orthogonal.

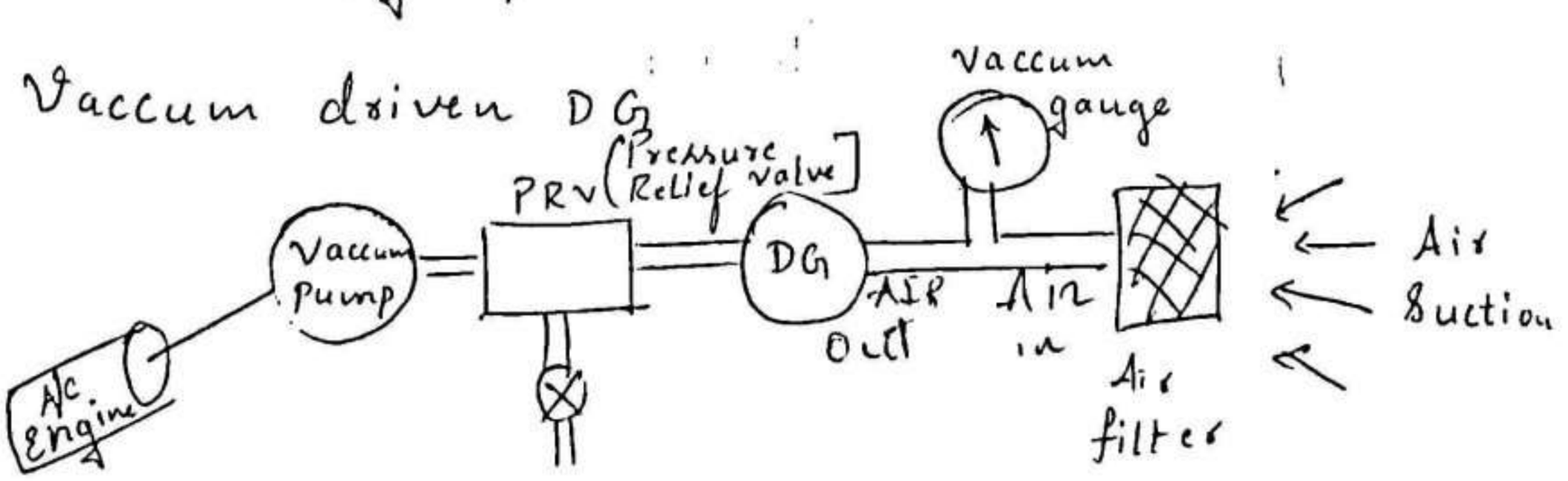
Gyroscopic Drives :-

1. Pneumatic Drive
2. Electric Drive

Pneumatic Drive

* Pneumatic motors are realised using either Vaccum or High pressure

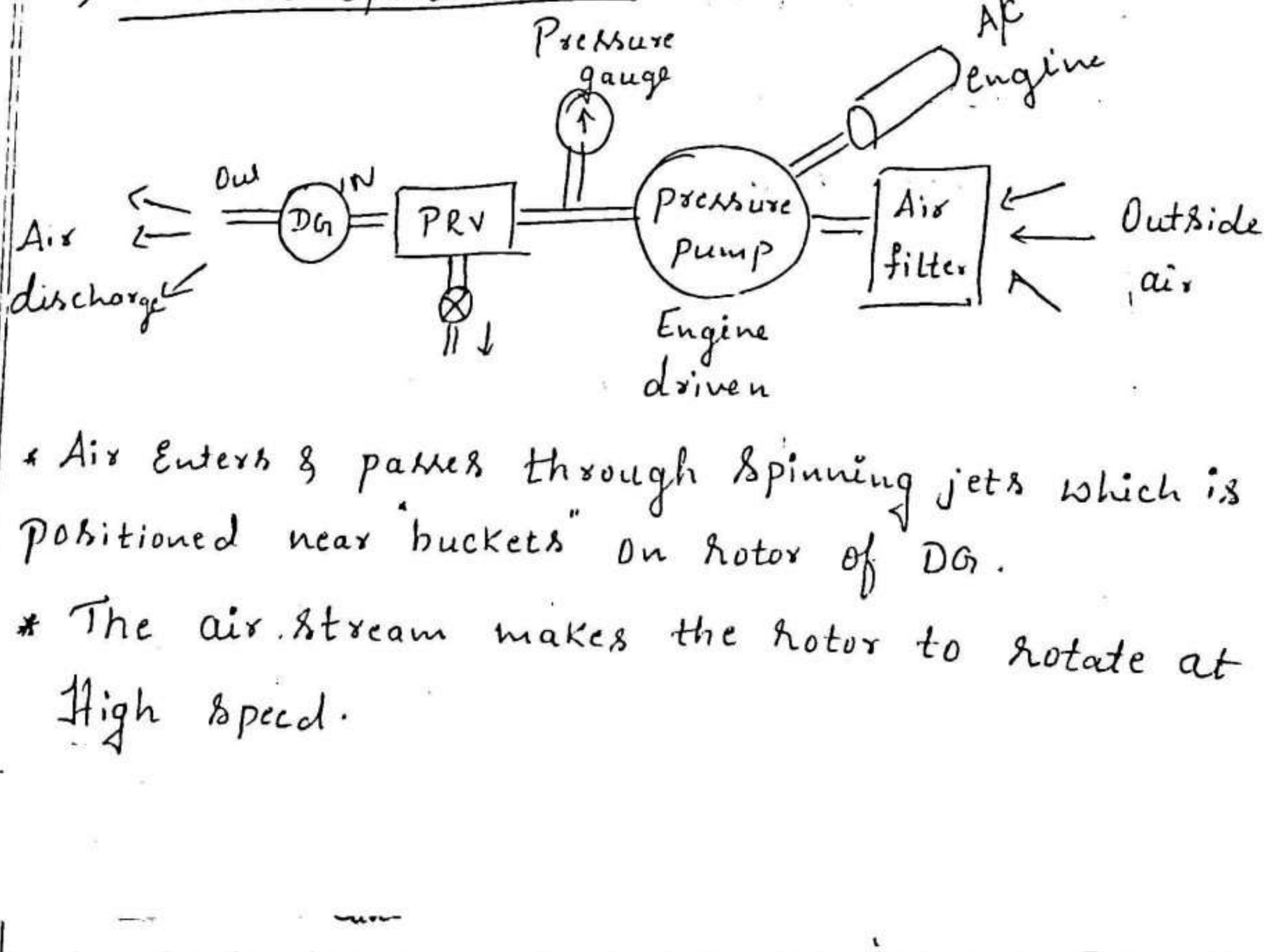
1. Vaccum driven DG



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* Vaccum pump is ~~d~~riven by A/C engine using appropriate gearing.
* Air is sucked by vaccum created (4 Hg or about 1000Pa vaccum pressure)
* Air filter Reduces dust Content & ensure Clean air Supply.
* DG is Connected to AF & PRV.
* PRV has Spring to Create prespecified vaccum pressure.
* If excess vaccum is Created the valve open against Spring tension to allow outside air which Reduces vaccum level.

2) Pressure operated DG :-



* Air Enters & passes through Spinning jets which is positioned near "buckets" on Rotor of DG.
* The air stream makes the Rotor to Rotate at High Speed.

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Electric Drive

- DG's rotor is driven by Ac / Dc motor.
  - Ac motor → Gyro-Horizon
    DC motor → TBI

DG → 3ϕ 115V 400Hz Induction motor

* DG's rotor have Large moment of Inertia.
  Increase radius of gyration, $I_{xx} = MR^2$
* Motor is inside → Inner ring
  Motor Casing Supported by Outer ring.

Speed; $N = \frac{120f}{p} = \frac{(120)(400)}{2} = 24000 \text{ rpm}$

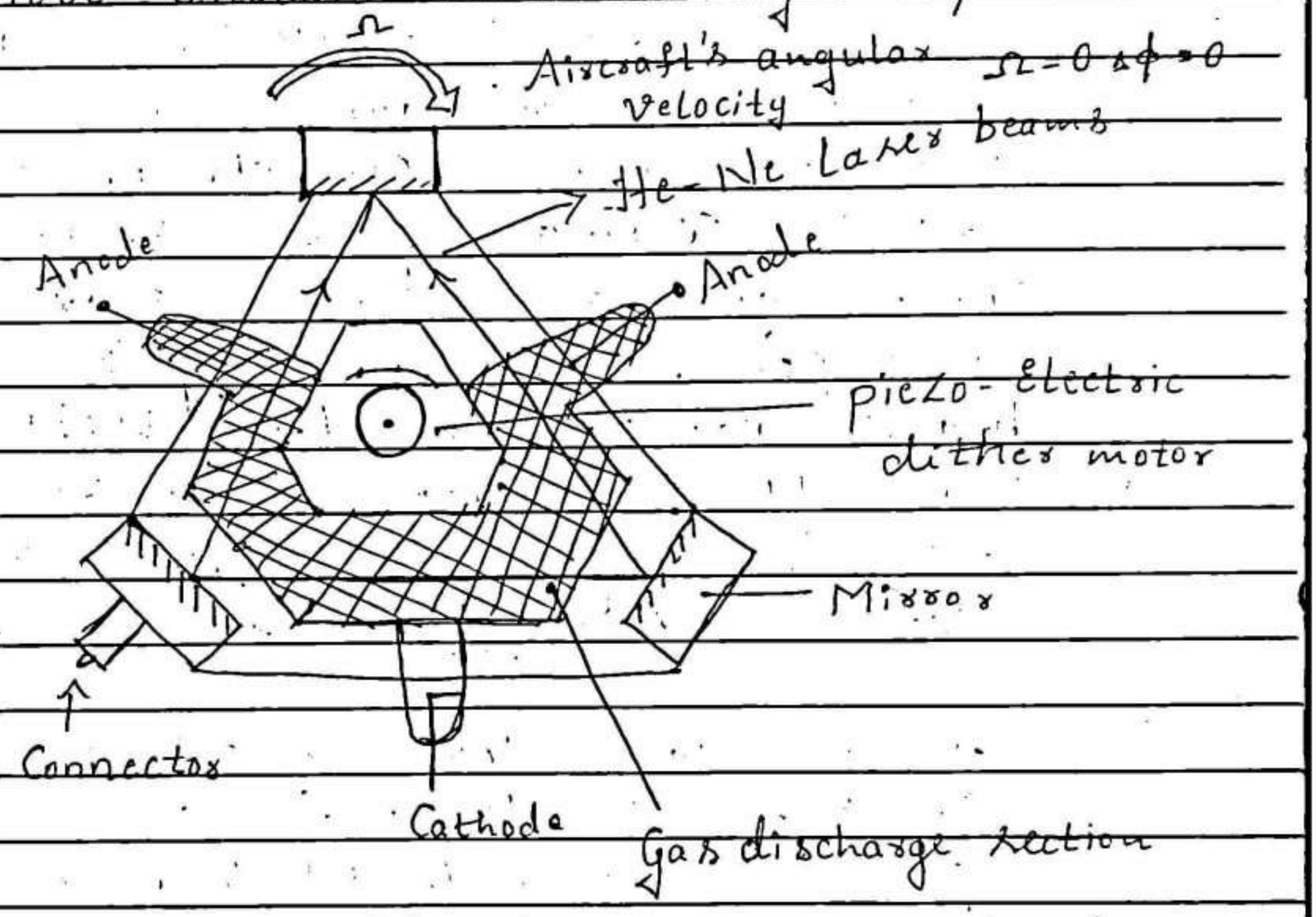
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Ring Laser Gyroscope:

* Basic principle of RLG is SAGNAC Effect
* Sagnac Effect is phase induced b/n 2 Opposing light beams moving around a ring of optical path; When ring rotates at angular velocity (Ω)
* Many mirrors used to make laser light beam to move around in a triangular path.



* RLG body is a Solid glass block, made of fabricated glass.
  Fabricated also called Cervit glass.
  1) Very Hard
  2) Low thermal Co-efficient expansion
  3) When temp ↑ or ↓, the glass will not expand or Contract.

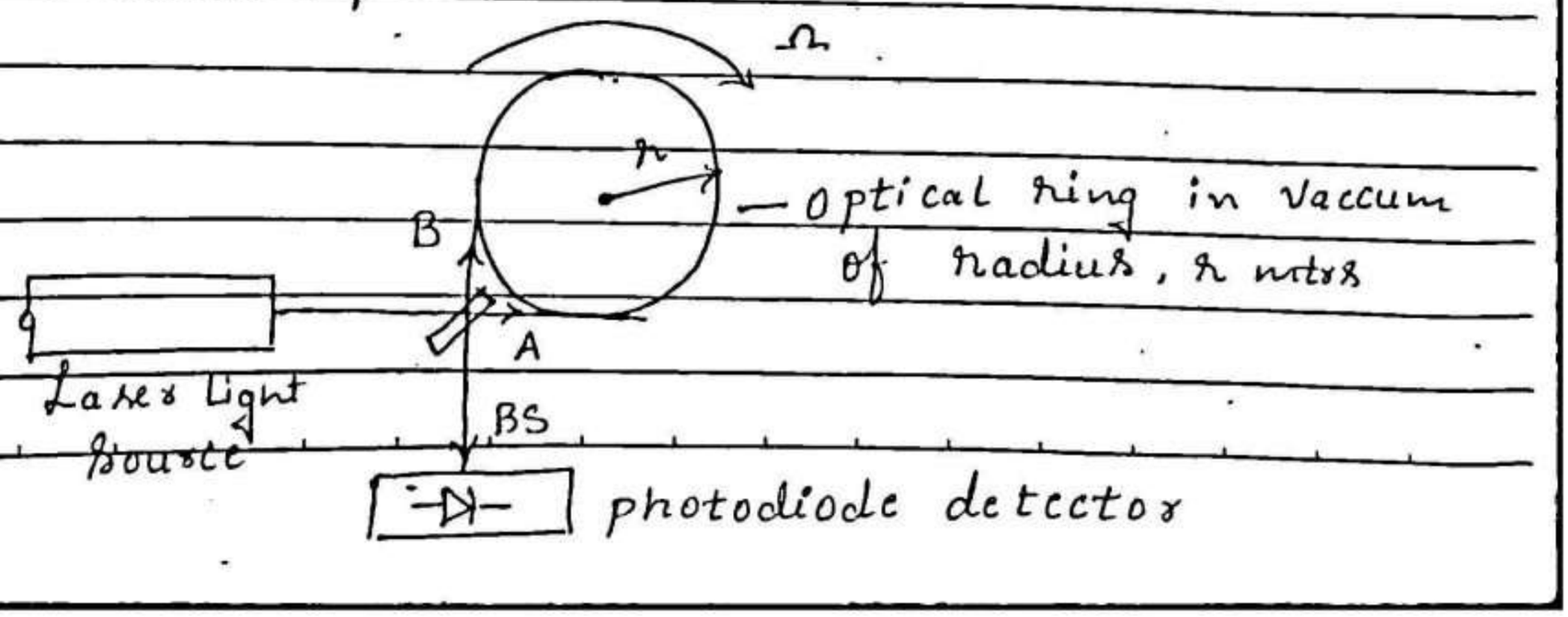
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* An Optical Cavity is formed in Solid triangular block using ultrasonic diamond drilling.
* A mirror is placed at each corner to form a triangular optical-resonator.
* Discharge section is filled with mixture of helium & neon gases at low ~~temperature~~ pressure to form part of He-Ne laser.
* High voltage of 2-4KV is applied to Cathode & anode; which discharges laser light.
* Two lasers beams, One clockwise(CW) & Counter clockwise (CCW) are formed in Corner assembly.
* When gyro not rotating at axis ⊥ar to plane of paper, the 2 perfectly Symmetric laser beams Cause Zero phase shift (i.e $\Delta\phi = 0$)
* When block rotates, the phase shift b/n 2 laser beams is directly proportional to Ω of RLG, $\Delta\phi = \left(\frac{8\pi A}{\lambda_0 C}\right)\Omega$

A → Area enclosed by optical path
λ_0 → WL of He-Ne Laser (=633nm)
C → Speed of Light ($=3\times10^8$ m/s)

To Derive $\Delta\phi$:-



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Assumptions:

1. Single Circular turn having radius, R
2. Ring is strapped at its COG.
3. Light path in Vaccum, so $C = 3 \times 10^8 m/s$
4. BS acts both as beam Splitter & beam Combiner
5. A & B have identical path length
6. Coil rotates in CW direction

* When $\Omega = 0$, Coil not rotating
A & B go through length $2\pi r$ arrive at detector at same time. Thus, $\Delta\phi = 0$

* When Coil rotating at Ω, Beam A → CCW Slightly faster than beam B.

Time taken by beam A to arrive at detector

$$t_A = \frac{2\pi r}{C + r\Omega}$$

$r\Omega$ → Linear velocity around ring

for Beam B, $t_B = \frac{2\pi r}{C - r\Omega}$

Time difference, $\Delta t_d = t_A - t_B$

$$= 2\pi r \left[\frac{1}{C + r\Omega} - \frac{1}{C + r\Omega} \right]$$

$$= \frac{4\pi r^2 \Omega}{C^2 - r^2\Omega^2}$$

$$= \frac{4\pi r^2 \Omega}{C^2} \quad \because C^2 >> r^2\Omega^2$$

Area of ring, $A = \pi r^2$

$$\Delta t_d = \frac{4A\Omega}{C^2}$$

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$\therefore$ phase difference, $\Delta\phi = \frac{2\pi \Delta t_d}{t}$

Where $t \rightarrow$ period of laser light $= 1/\nu$

$\nu \rightarrow$ freq. of laser beam $= c/\lambda_0$

$\lambda_0 \rightarrow$ Wavelength of laser

$\Delta\phi = 2\pi \Delta t_d \cdot \nu$

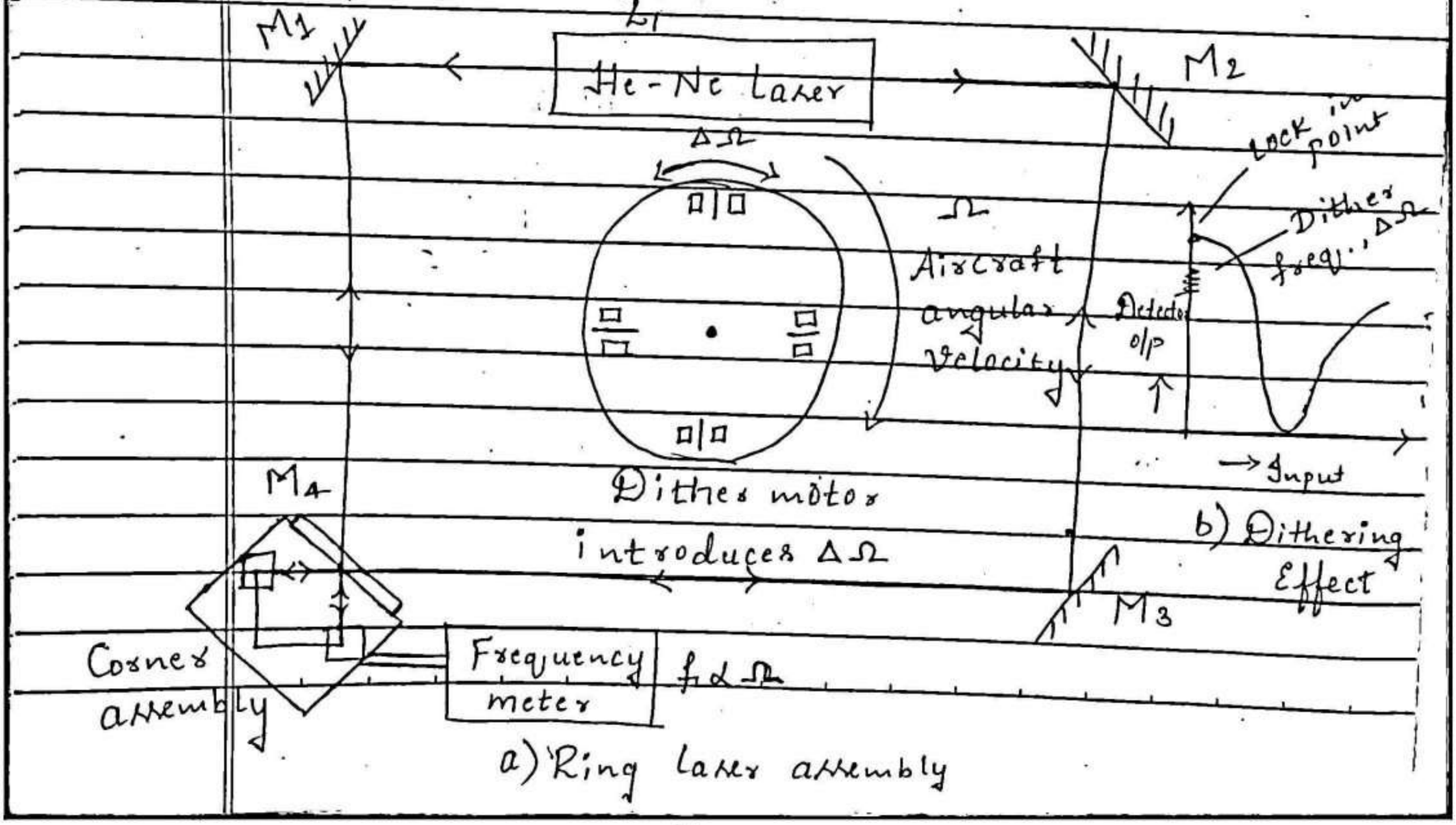
$= 2\pi \Delta t_d \cdot \frac{c}{\lambda_0}$

W.K.T ; $\Delta t_d = \frac{4A\Omega}{c^2}$

i.e $\Delta\phi = 2\pi \left(\frac{4A\Omega}{c^2}\right) \cdot \frac{c}{\lambda_0}$

$\Delta\phi = \frac{8\pi A\Omega}{c\lambda_0}$

$\Delta\phi$, phase shift directly proportional to angular velocity, ν.



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Corner assembly Consists of,

1. Corner prism
2. Beam Splitter
3. Readout detector (a sensor)

RLG primarily used for Angular Velocity measure-ment.

Best used in Strap-down mode

Commonly used in Inertial Reference S/m (IRS)

Advantages :-

1. Wide dynamic range
2. Short alignment duration
3. High Reliability.

* RLG Consists of rectangular (or triangular) block of glass.
* A Cavity to Carry Laser light is made within the glass block using precise Computer-Controlled ultrasonic drill. ~~M_1, M_2, M_3~~
* M_1, M_2 & M_3 are 3 high quality mirrors mounted at 3 Corners.
* M_4 partial mirror which partially transmits & reflects Light.
* L_1 is He-Ne Laser which emits 2 Counter-rotating light in beams, moving within optical Cavity.
* Assembly is rigidly fixed to Aircraft.

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Beam A → Rotating opposite to direction of RL.
Beam B → Direction is along the direction of rotation of RLG.

* phase shift, $\Delta\phi$ at partial mirror M_4 is sensed by photodetector, using interferometric principle
- 2 beams produce interference fringe resulting in dark & bright fringes when destructive & Constructive interference occurs respectively.
when $\Omega = 0$, fringe pattern is stationary.
→ The frequency of detector o/p is proportional to angular velocity, Ω.

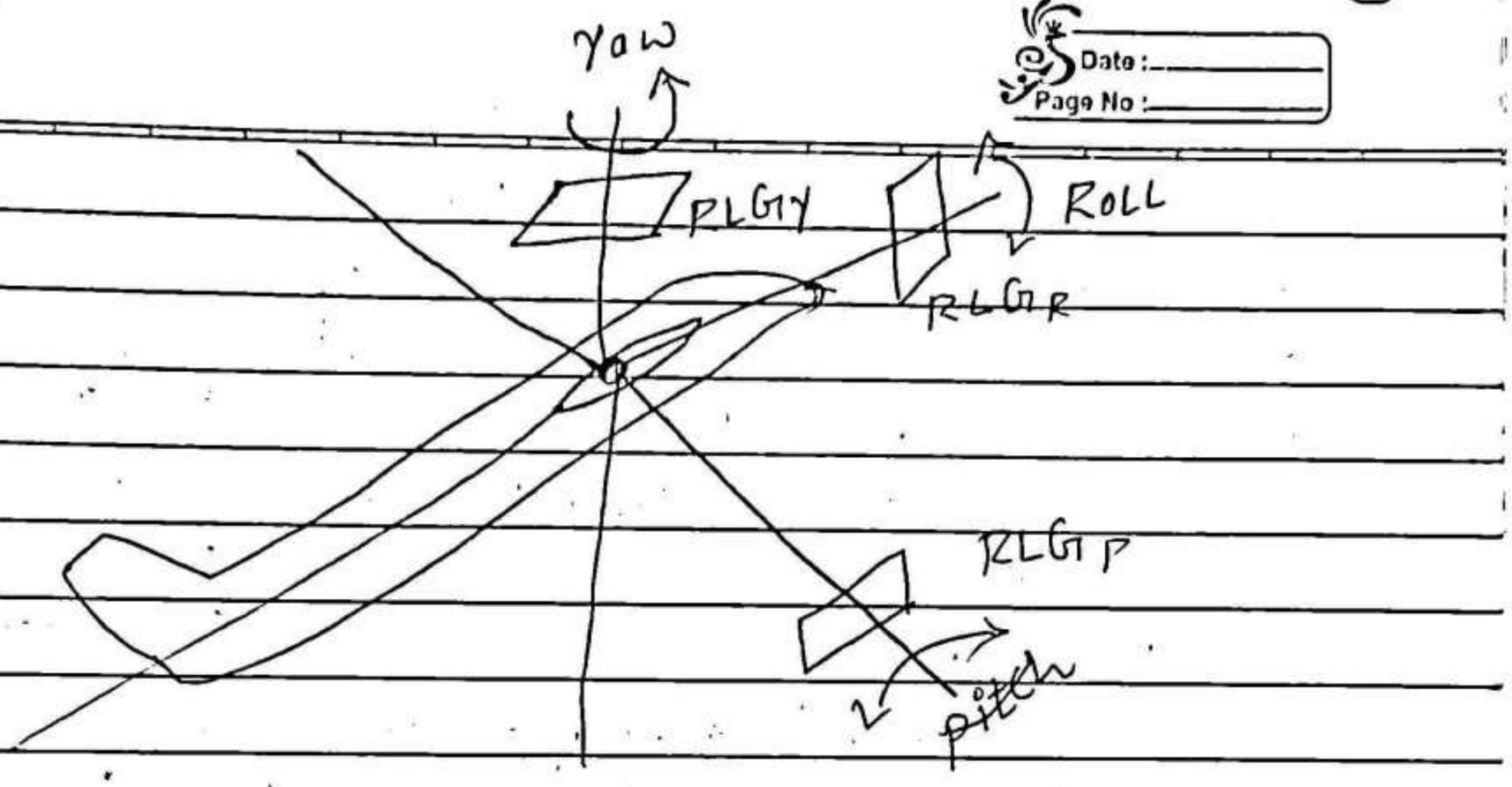
* When rate of rotation is low ($> 0.001°$/hour), the detector o/p is non-linear.
* At Certain threshold value, the 2 beams are locked & detector o/p is Zero..
Lock Effect is minimized by dithering
* Dithering - a low frequency, low oscillations intentionally introduced by piezo-Electric Crystal.
Dithering vibrate entire glass block to unlock & remove the restriction.
* Dithering is introduced to vibrate the entire glass assembly about input axis which is ⊥ar to plane of Laser ring path.
* Such oscillation move the operating point away from lock-in position, thus sensor is enabled to detect minute movement in fringe pattern.
* $\Delta\Omega$ is removed from photo detector o/p.

Ω → angular velocity

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RLG used to sense the angle of pitch, roll & yaw.

* When Ac is not rotating, fringe Spacing will be Constant.
* When Ac is rotating, fringe Spacing $\propto \Omega$.

Advantages :-

1. RLG has no rotating parts, hence reliability increases.
2. No gimbal s/m, mechanical Complexity reduced
3. Strap-down direct mounting on Aircraft
4. No Complex platform & levelling mechanism
5. Easy & quick alignment.

Disadvantages :

1. Expensive
2. poor sensitivity, due to limited path length.
3. Lock in at low frequency.

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Fibre Optic Gyros (FOG)

* FOG also uses SAGNAC Effect
* It increases ~~Attenb~~ Sensitivity by using no of turns of optical fibre.
* Cost & mechanical Complexity is minimised.
*

Disadvantage:
Drift due to temperature Change
Drift with time
Bias instabilities has Overcome.

* FOG will give very precise rate of rotation information & large reduction in cross-sensitivity due to vibration, acceleration & shock.
* FOG have no moving parts & no inertial resistance to movement.
* Most used & reliable technology.

Before 2000,
* FOG had higher resolution than RLG
* FOG Suffered bias Stability & worst scale factor performance.
* Now it has Overcome all the instabilities.

* FOG use an external laser diode Source together with optical beam Splitters to Launch the laser light so that 2 rotating beams one in clkwise & anticlkwise rotating are produced.

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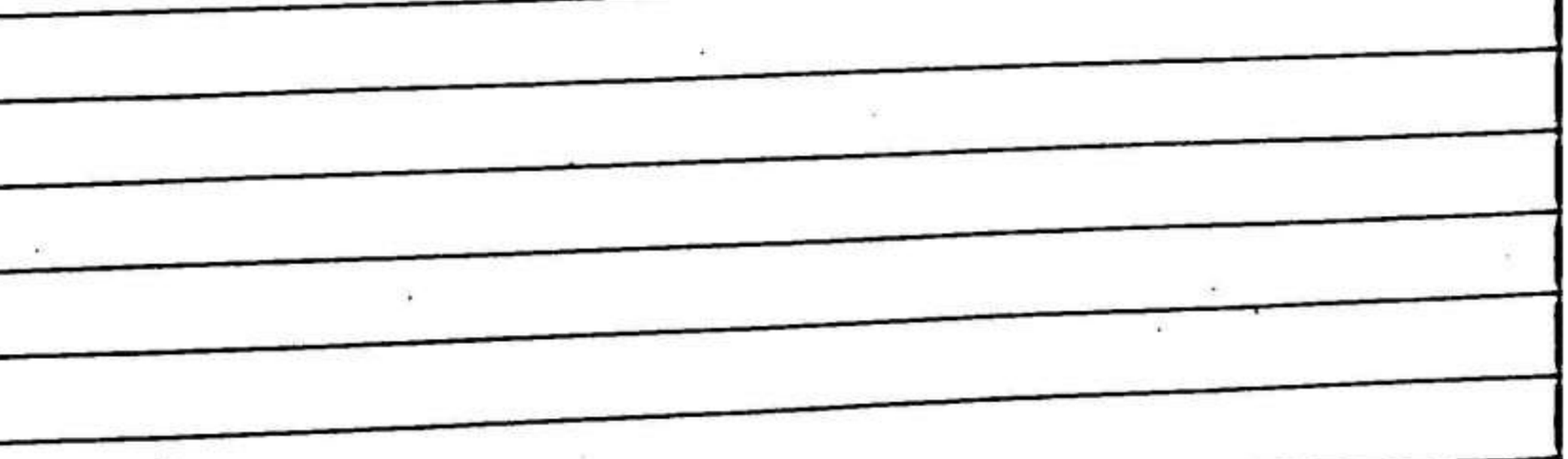
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* There are N turns of high quality, low loss, single-mode fibre whose axis decides the aircraft attitude which FOG will sense.
* 3 seperate FOGs required to sense pitch, roll & yaw of aircraft.

$$\Delta\phi = \frac{8\pi A \Omega N}{C \lambda_0}$$

N → Number of turns of optical fibre.



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Attitude

Gyro - Horizon

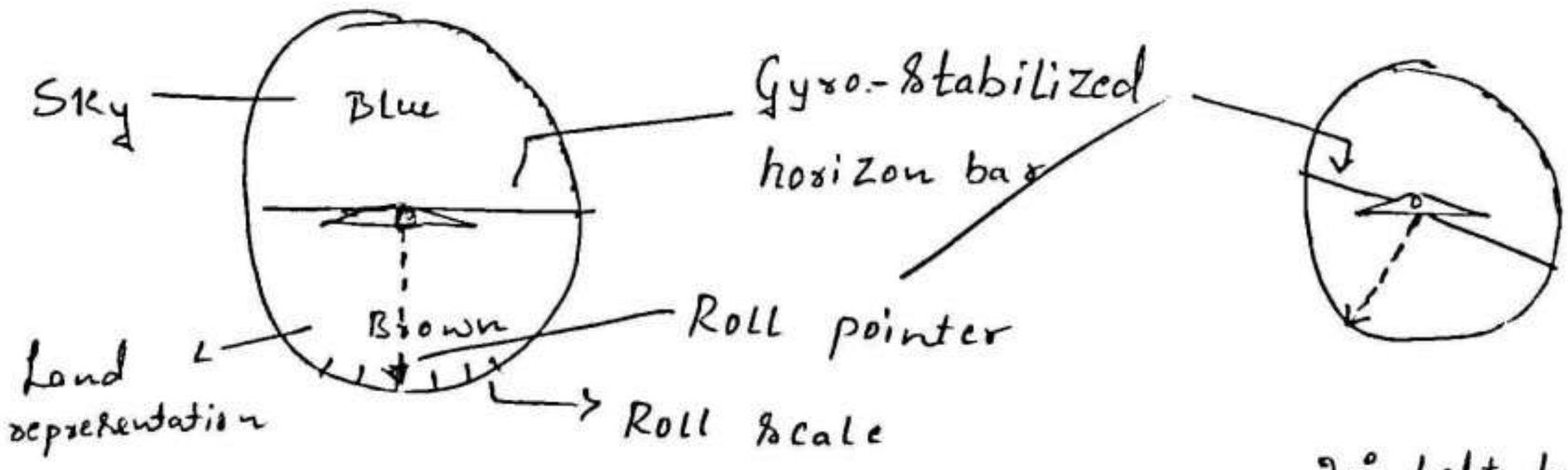
(14)

* It is also called ADI, Artificial horizon etc.
* Instrument which displays simulated horizon for pilot.
* It displays line on FD (flight Director) within horizontal plane where pitching & Rolling of aircraft are shown.
* It establish Inertial Spatial reference based on gyroscopic rigidity.
* GH uses vertical axis to indicate pitch & roll attitude of aircraft.
* The display has

↙ Aircraft Symbol

↘ Gyro-Stabilised Horizontal bar Symbolizing natural horizon.

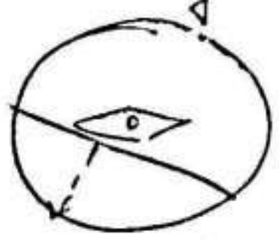
* The Needle will be perpendicular to horizon bar.



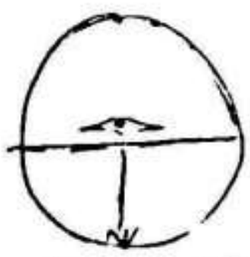
Straight & Level

30° left bank

Climbing left



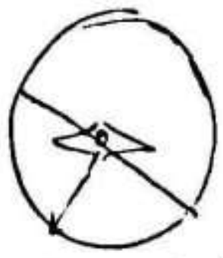
Climbing left turn



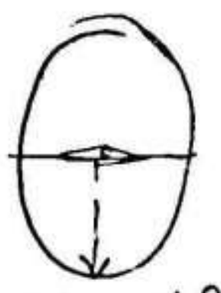
Level climb



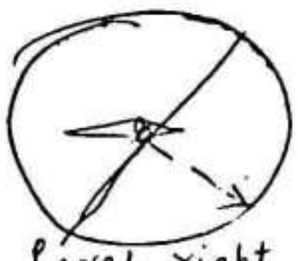
climbRight turn



Level left turn



Straight & Level



Level right turn



Descending left



Level descending



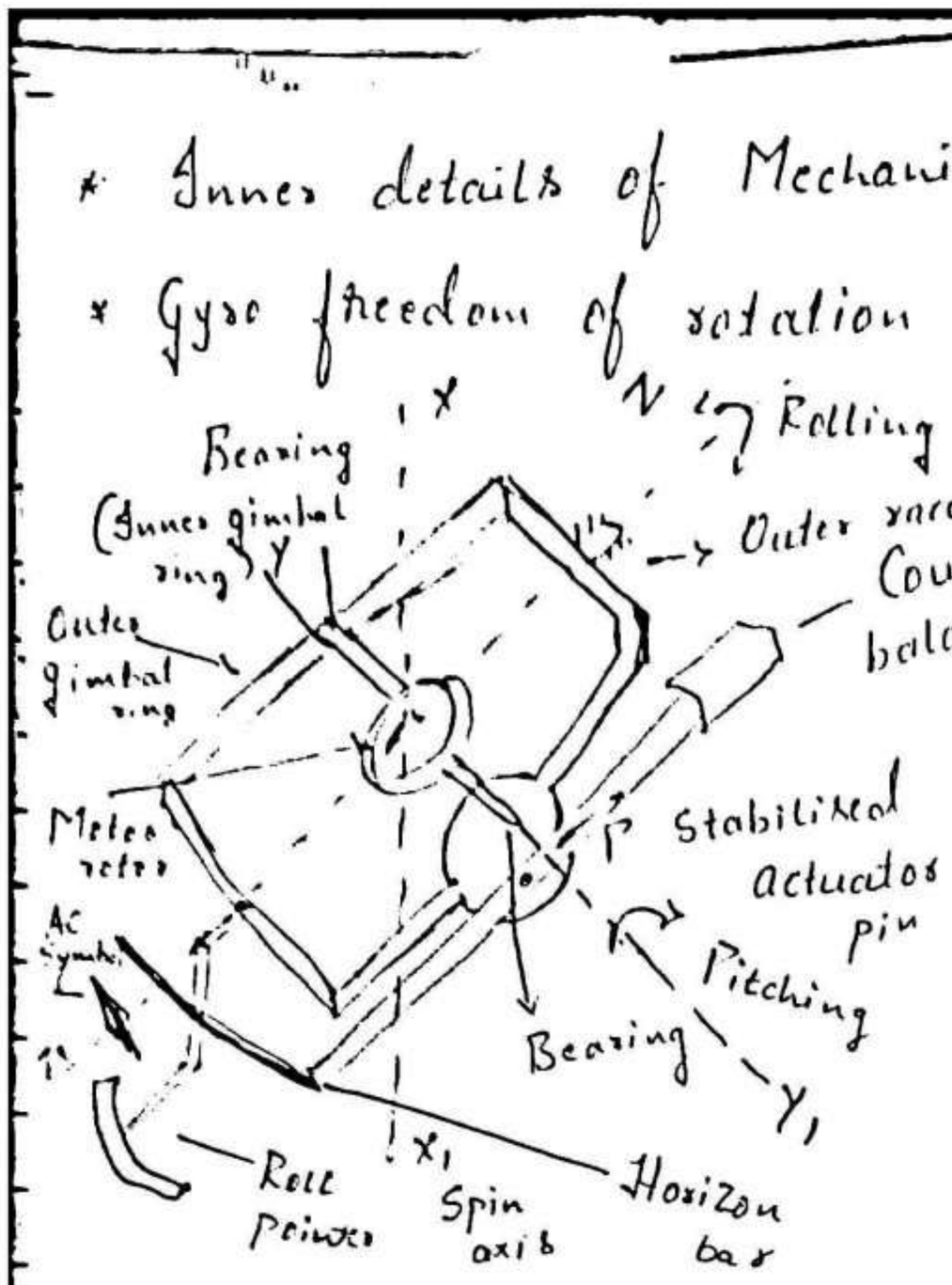
Descending Right

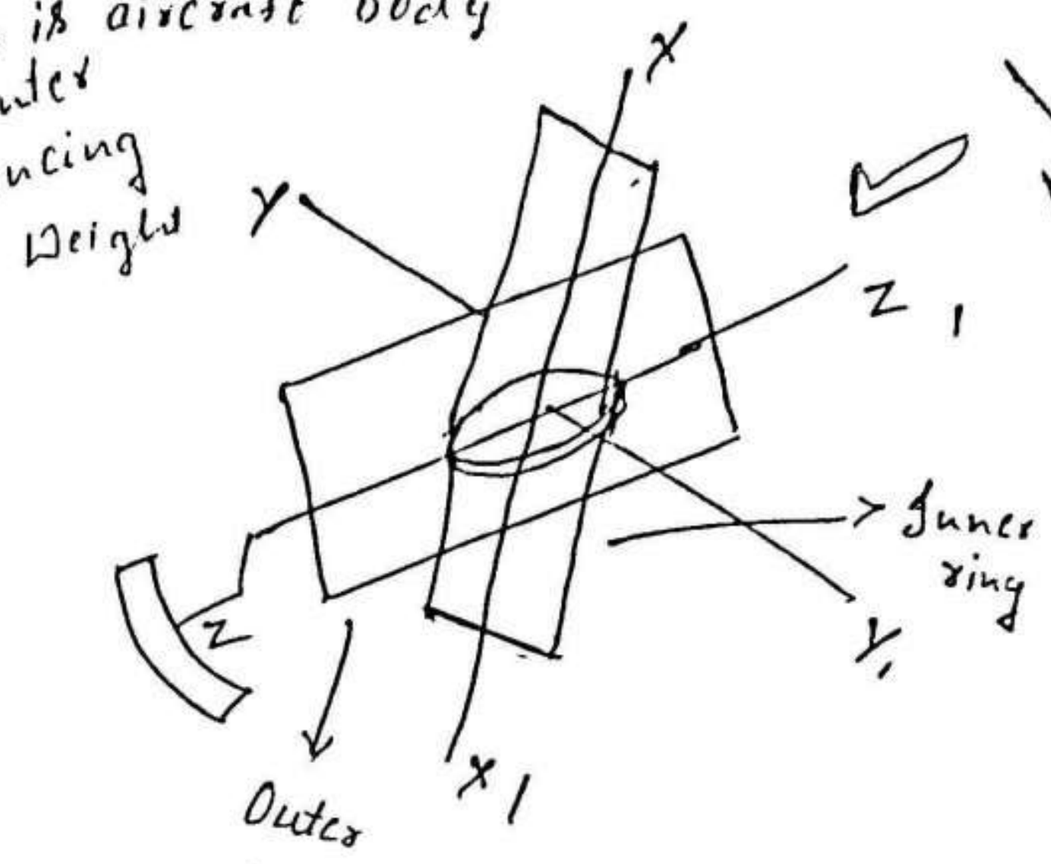
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* Inner details of Mechanical Gyro - Horizon

* Gyro freedom of rotation on all 3-axis XX_1, YY_1 & ZZ_1





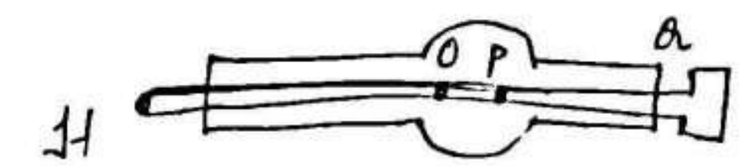
XX_1 → Spin axis

YY_1 → Lateral

ZZ_1 → Longitudinal

1. XX_1 ⟶ Have high speed rotor (Rotor is an induction motor squirrel cage runing outside stator) powered by 115V, 3φ, 400H_z Ac through 3 slip rings.
   * Casing of rotor forms inner ring.
2. YY_1 ⟶ Pivoting inner ring with high-quality bearing in Outer ring.
3. ZZ_1 → Pivoting Outer ring with bearing fixed to instrument case, which is placed rigidly to Aircraft airframe.

* When Ac is straight & level Outer ring remains horizontal in line with symbol.



Horizon bar

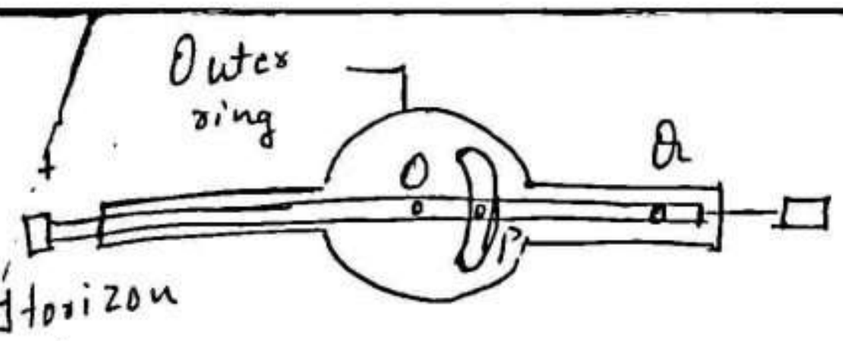
P → Actuating pin

R → pivot point

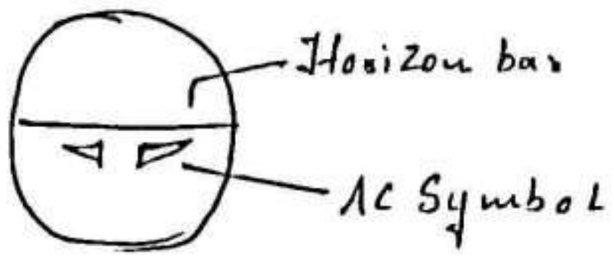
O - Origin

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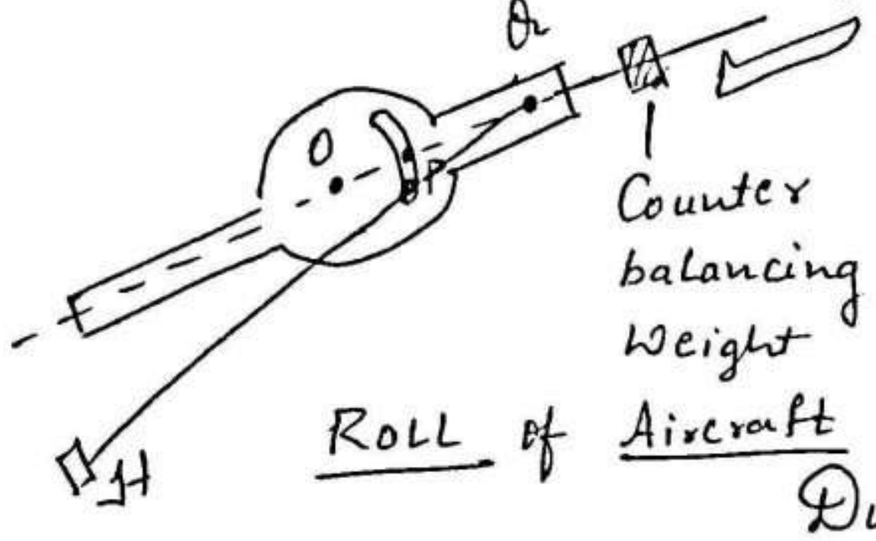
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Side view during Straight & level flight



Dial Indication



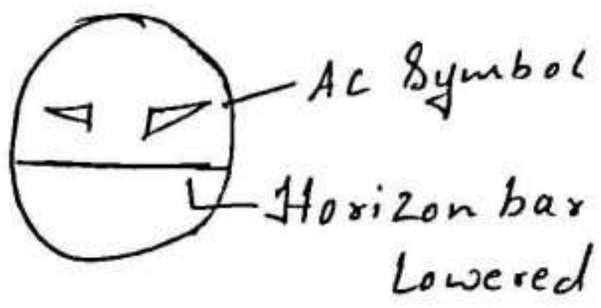
ROLL of Aircraft — ZZ'

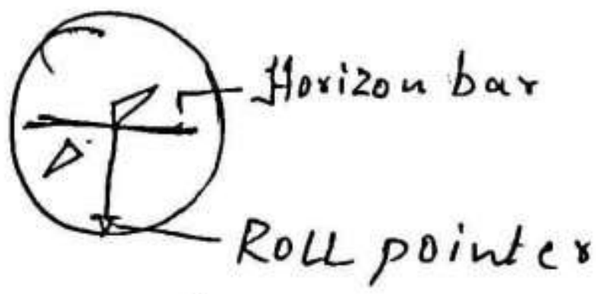
During climb

HP/PQ → Ratio of lengths, reduces load on Stabilised actuating pin P.

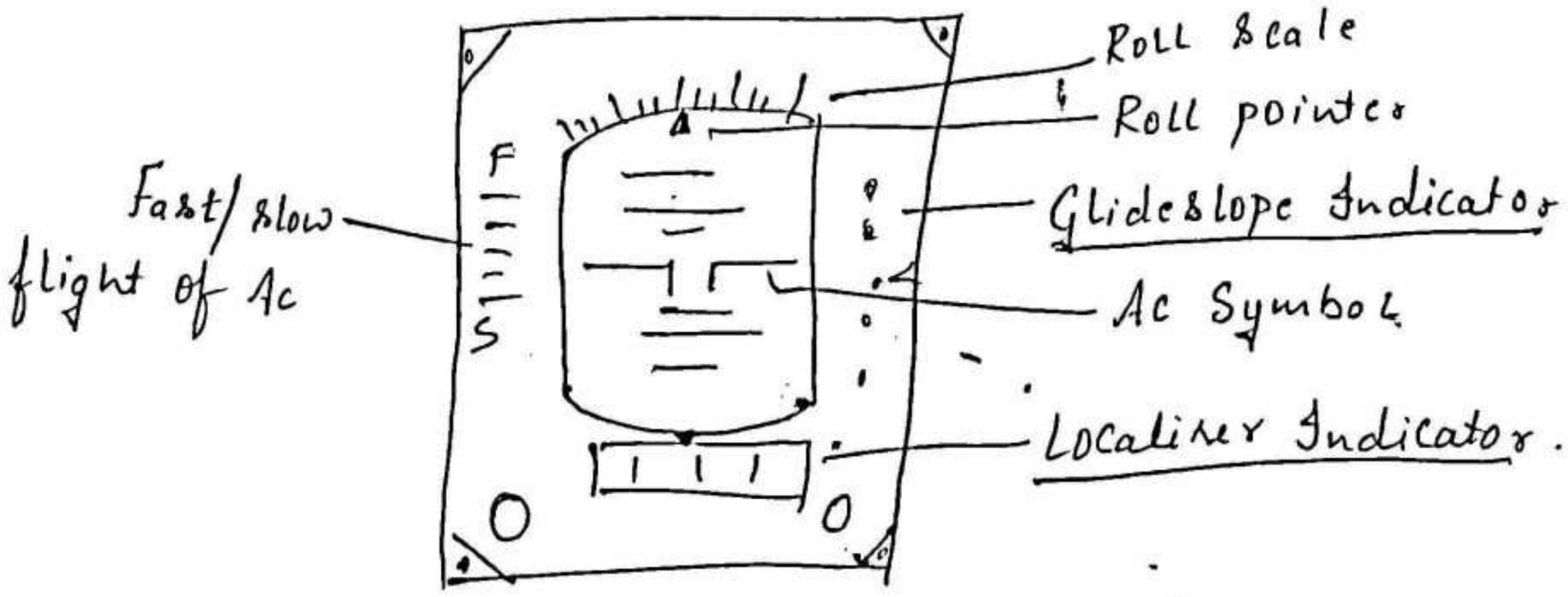
During roll of Aircraft

Dial Indication





* Roll angle ranges from 0°- 360°
* Pitch angle range 0-60° in order to prevent gimball lock which occurs whenever Spin axis Coincide with other 2 axis.



Modern gyro Horizon

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* Mechanical gyro are replaced by AHRS (Attitude & Head Electric Reference System) which has RLG / FOG / Micro-Electro Mechanism based gyros → Stabilised by FDU.

* AHRS Outputs attitude to devices such as PFD, FCS or Autopilots (AP) in glass Cockpit (Flight Control S/m)

* AHRS → Excellent Reliability

* Mechanical gyros used in B-747 type Ac as Standby instrument when EFIS has malfunction.

Erection S/m of Gyro-Horizon:.

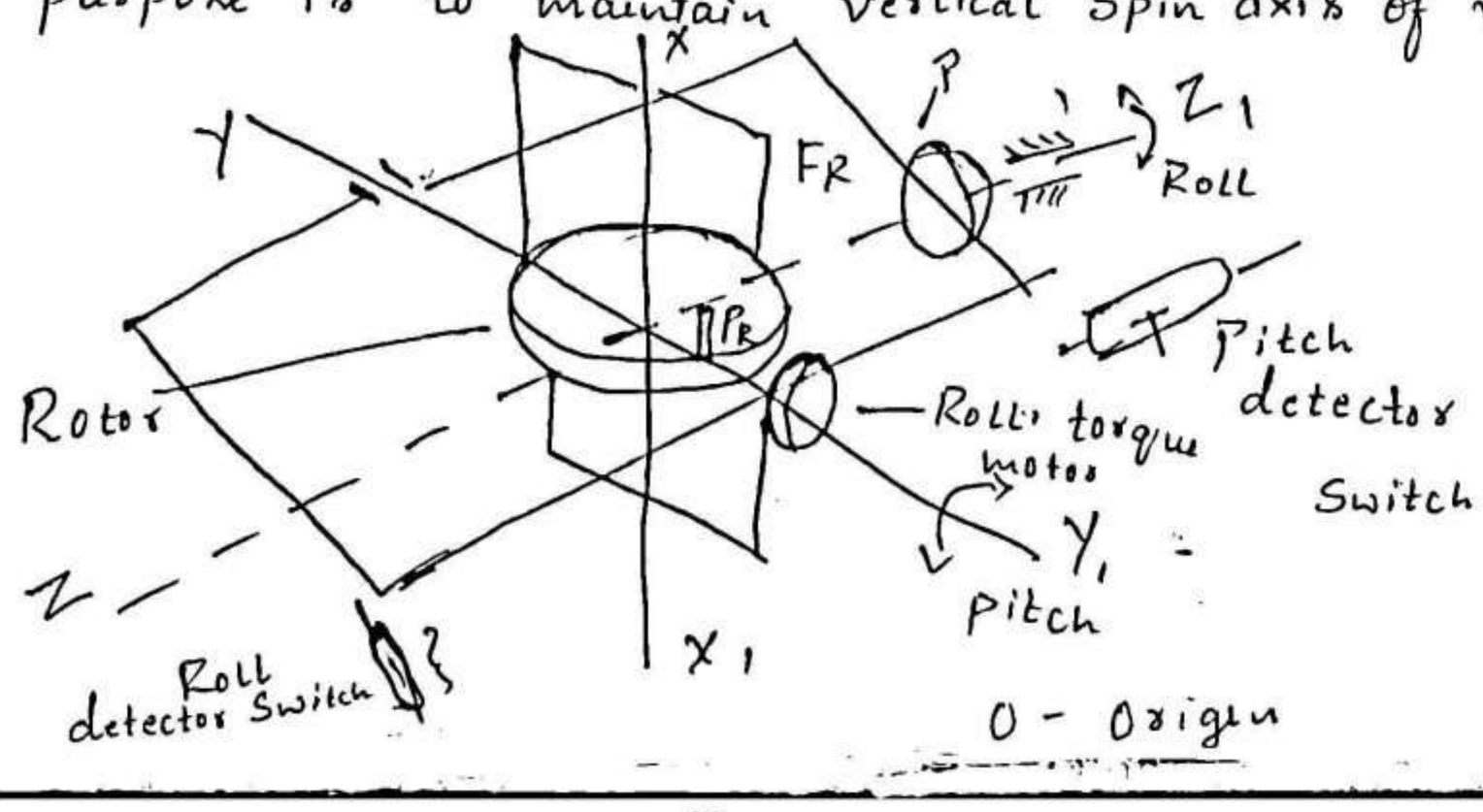
* Objective is to ensure that the Spin axis is in Vertical position & to maintain Verticality.

There are Several types of erection S/m:.

1. Gravity assured vane used in pneumatic gyro
2. Ball type for Electrical gyro
3. Levelling Switches to detect deviation & apply precisional torque to maintain Verticality.

Torque Motor Erection S/m:.

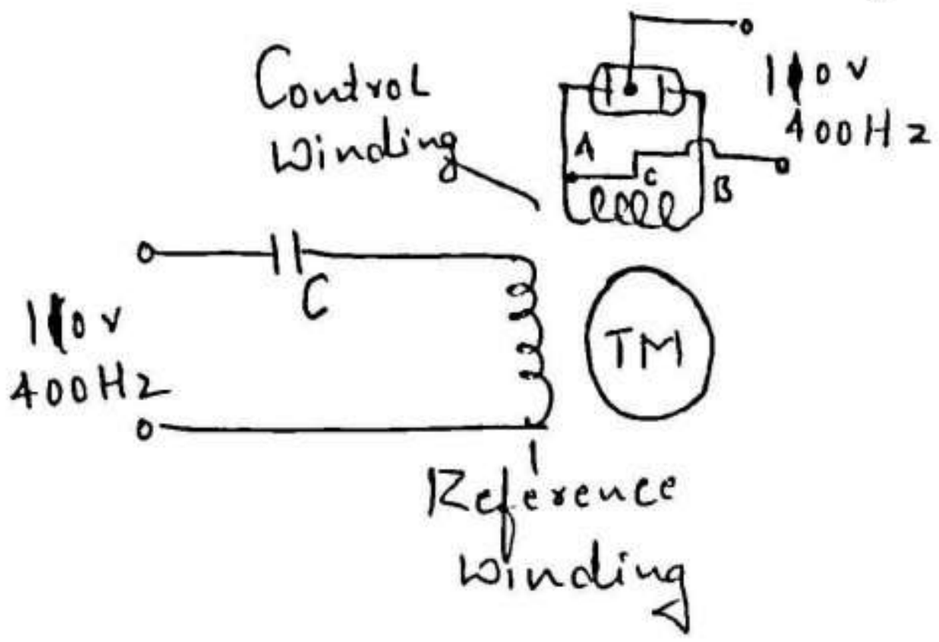
* Main purpose is to maintain Vertical Spin axis of vertical gyro.



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Electrical Connections to torque motor



* Roll detector mercury switch detects proper phase (i.e rolling right / left) & applies Control voltage to Roll torque motor.

→ When motor rotates with force F_R, resulting in precession force P_R acts 90° away in direction of rotation.

→ P_R is applied to Outer gimbal ring to make straight & level flight (If left roll → P_R right & vice-versa).

→ Similarly for pitch of Aircraft.

Electrical Connection

→ Torque motor is bidirectional

→ Reference winding, Connected to 110V, 400Hz Supply having phase-Splitter Capacitor to produce Starting torque.

→ Control winding Connected to 110V, 400Hz Ac Supply. Other 2 ends Connected to Ac Supply via Mercury Level Switch.

→ Electric Supply is given to either A or B depending on Orientation of Ac.

→ If A energizes in one direction, B energizes in opposite direction.

* Possible to erect gyro-horizon using Fast-Erection S/m by applying high power to Correction torque motors — Pitch motor
— Roll motor

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TURN & BANK Indicator

Turn & Bank Indicator in Single instrument display

① Turn rate (degree/second) using precession torque

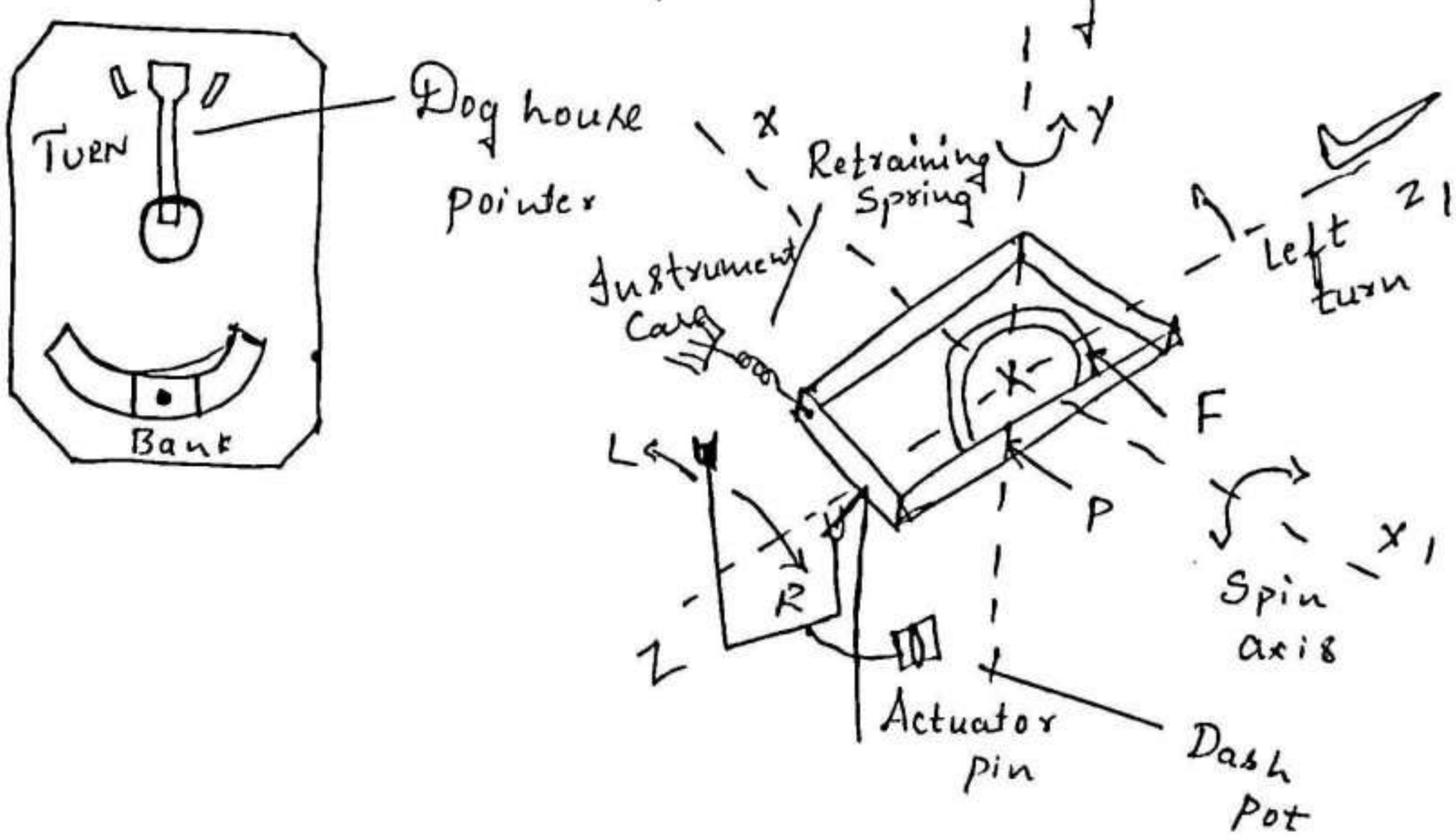
② Bank and/or Slip using ball in Curved glass tube.

Turn Indicator.

* It uses Rate gyroscope to sense number of turns.

It will be having

1. Only one gimbal ring, free to rotate in ZZ,
2. A Rotor whose Spin axis is alligned to lateral axis xx, Rotor Speed is 5000rpm.
3. A Calibrated Spring b/w gimbal & Casing.



* If Ac is flying Straight & level, Rotor axis xx, is made horizontal by Retraining Spring & Dog house pointer will be at Zero position.
* When Ac turns left, (F) a force is applied to rim of Rotor Resulting precession force P make actuator pin & pointer to point to left.

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the pointer moves against Calibrated spring to indicate turn rate in degree per second.

* F & P acts 90° away in direction of rotation.
* P Causes gimbal to tilt about ZZ, axis which is restrained by Calibrated spring.
* Tilting occurs till 'P' balances the spring force

Spring force $\propto$ Spring displacement, x

Precession of rate Gyroscope is given by

$$P = L \cdot \frac{d\theta}{dt}$$

$L \rightarrow$ angular momentum $= \Omega I_{xx_1}$

$I_{xx_1} \rightarrow$ Moment of Interia

$\frac{d\theta}{dt} \rightarrow$ rate of turn - yaw rate

If L is Constant, rotor speed Constant

$$P \propto \frac{d\theta}{dt} \propto x$$

The pointer reaches new null

When $P = Kx$ $K \rightarrow$ Spring Constant

Thus gimbal ring rotation indicates rate of turn.

Gimbal ring deflection is not more than 5°

Graduation on scale from 1 – 4

Turn rate → 180°/m to 720°/m in steps of 180°/m.

* Damping dash pot will damp out oscillation during faster turns.

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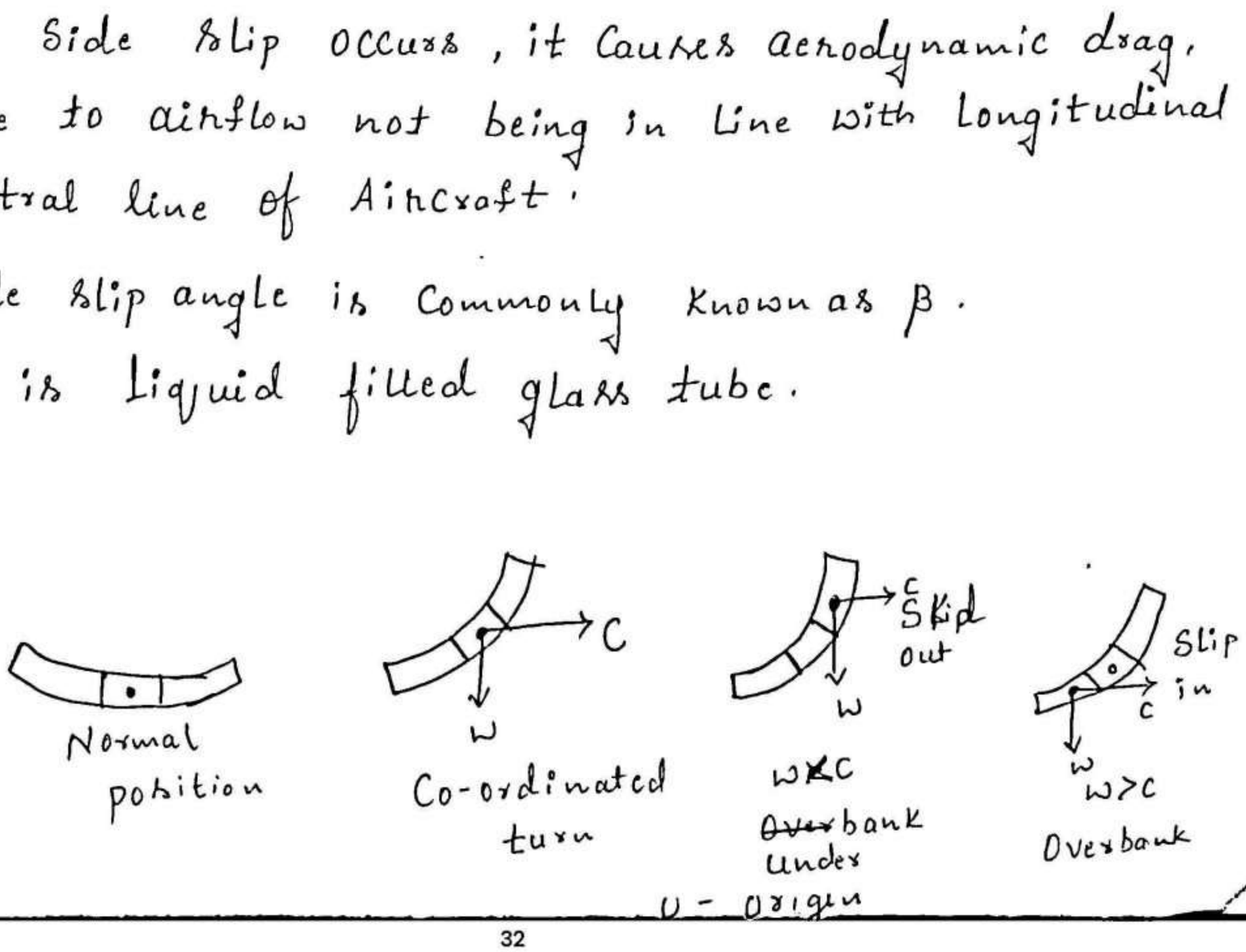
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* Speed must be Controlled within narrow tolerance range.

$$T \propto \omega I \propto \frac{d\theta}{dt}$$

Bank Indicator :-

* A Coordinated turn occurs when there is no Skidding Out or Slipping into a turn.
* Two forces acts on Bank Indicator one is due to weight & another Centrifugal force.
* When both forces are equal the heavy ball mounted in indicator will be in between the Lines.
* If $W < C$ the Condition is under banked & it is Skidding out of turn.
* If $W > C$ the Condition is over banked & it is Slipping into turn.
* If Side Slip occurs, it Causes aerodynamic drag, due to airflow not being in Line with Longitudinal Central line of Aircraft.
* Side Slip angle is Commonly Known as β.
* It is liquid filled glass tube.



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