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Unit-IV
Spacecraft Control

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Contents

- Spacecraft Control
  - Control Requirements
    - Attitude Control
    - Station Keeping
      - Types of Control Maneuvers
- Stabilization Schemes:
  - Spin Stabilization
  - Gravity Gradient methods
  - 3 axis stabilization

Contents

- Commonly used control systems:
  - Mass Expulsion Systems
  - Momentum Exchange Systems
- Sensors:
  - Gyro & Magnetic Torque sensors
  - Star & Sun sensor
  - Earth Sensor
  - Magnetometers & Inertial Sensors

Spacecraft Control

- The attitude and orbit of a satellite must be controlled so that the satellite's antennas point towards earth and that the user knows where in the sky to look for the satellite.
- This is particularly important for GEO satellites since the earth station antennas that are used with GEO satellites are normally fixed and movement of the satellite away from its appointed position in the sky will cause a loss of signal.

Spacecraft Control

- There are several forces acting on an orbiting satellite that cause its attitude and orbit to change, as discussed in previous chapters.
- The most important forces for a GEO satellite are the gravitational fields of the sun and the moon, and solar pressure from the sun, meteorite impact.

Spacecraft Control

- A LEO satellite is less affected by the of the gravity of the sun and moon, but variations in the earth’s magnetic field and gravitational constant cause deviations in the orbit.
- Solar pressure acting on a satellite’s solar arrays and antennas, and the earth’s magnetic field generating eddy currents in the satellite’s metallic structure as it travels through the magnetic field, tend to cause rotation of the satellite body.

Spacecraft Control

- Careful design of the structure can minimize these effects, but the orbital period of the satellite makes many of the effects cyclic, which can cause nutation (wobble) of the satellite.
- The attitude control system must damp out nutation and counter any rotational torque or movement.

Spacecraft Control

- To maintain accurate station keeping, the satellite must be accelerated periodically in the opposite direction to the forces acting on it. This is done as a sequence of station keeping maneuvers, using small rocket motors called gas jets or thrusters that can be controlled from earth via the TTC&M system.

Attitude Control

- A spacecraft's attitude must typically be stabilized and controlled for a variety of reasons.
- It is often needed so that the spacecraft high-gain antenna may be accurately pointed to Earth for communications, so that onboard experiments may accomplish precise pointing for accurate collection and subsequent interpretation of data.

Attitude Control

- Also the heating and cooling effects of sunlight and shadow may be used intelligently for thermal control, and also for guidance: short propulsive maneuvers must be executed in the right direction.
- Much of the equipment carried a satellite is there for the purpose of controlling its attitude.

Attitude Control

- To exercise attitude control, there must be available some measure of a satellite’s orientation in space and of any tendency for this to shift.
- In one method, infrared sensors, referred to as horizon detectors, are used to detect the rim of the earth against the background of space.

Attitude Control

- With the use of four such sensors, one for each quadrant, the centre of the earth can be readily established as a reference point.
- Any shift in orientation is detected by one or other of the sensors, and a corresponding control signal is generated which activates a restoring torque.
- Attitude of a satellite, is its orientation as determined by the relationship between its axes (yaw, pitch and roll) and some reference plane.

Attitude Control

- Usually, the attitude-control process takes place aboard the satellite, but it is also possible for control signals to be transmitted from Earth, based on attitude data obtained from the satellite.
- Also, where a shift in attitude is desired, an attitude maneuver is executed.

Attitude Control

- Passive attitude control refers to the use of mechanisms that stabilize the satellite without putting a drain on the satellite's energy supplies;
- At most, infrequent use is made of these supplies, when thruster jets are impulse to provide corrective torque.
- Examples of passive attitude control are spin stabilization, gravity gradient stabilization & and 3–axis stabilization.

Attitude Control

- The other form of attitude control is active control.
- With active attitude control, there is no overall stabilizing torque present to resist the disturbance torques.
- Instead of corrective torques are applied as required in response to disturbance torques.

Attitude Control

- Methods used to generate active control torques include momentum wheels, electromagnetic coils, and mass expulsion devices, such as gas jets and ion thrusters.
- The electromagnetic coil works on the principle that the earth’s magnetic field exerts a torque on a current-carrying coil and that this torque can be controlled through control of the current.

Station Keeping

- Station keeping is the process of maintenance of the satellite's orbit against different factors that cause temporal drift.
- Satellites need to have their orbits adjusted from time to time because the satellite, even though initially placed in the correct orbit, can undergo a progressive drift due to some natural forces such as minor gravitational perturbations due to the sun and moon, solar radiation pressure, Earth being an imperfect sphere, meteorite impact etc.

Types of Control Maneuver

- The orbital adjustments are usually made by releasing jets of gas or by firing small rockets tied to the body of the satellite.
- Most GEO satellites are specified to remain within a box of ±0.05° as seen from earth in azimuth and elevation, and so, in practice, corrections called a "*North–South station keeping maneuver*" are made every two to four weeks to keep the error small.

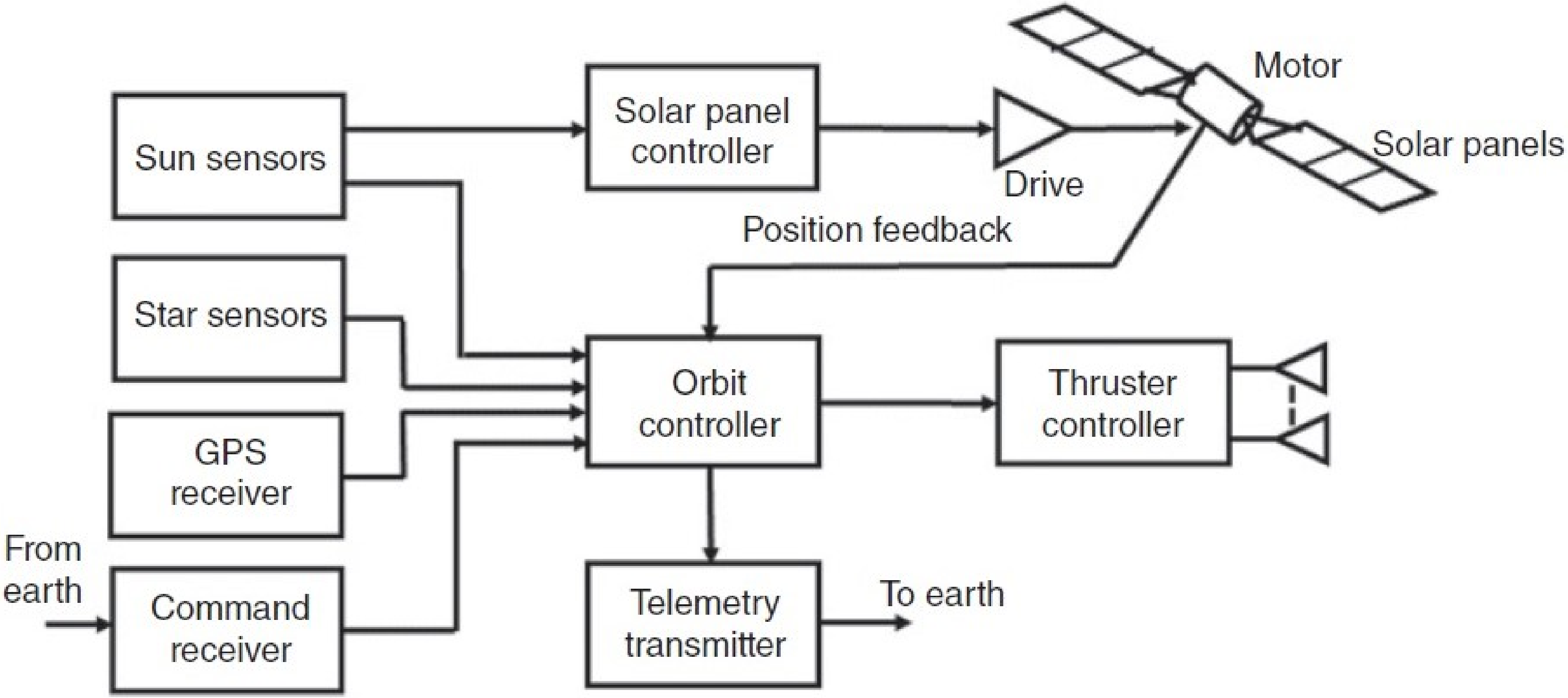
Types of Control Maneuver

- When ion thrusters are used for N–S station keeping maneuvers, they tend to operate almost continuously since their thrust levels are low when compared with liquid fueled engines.
- Correcting the inclination of a satellite orbit requires more fuel to be expended than for any other orbital correction.

Types of Control Maneuver

- As much as half the total satellite weight at launch may be station keeping fuel when liquid fuel thrusters are employed and the satellite's expected lifetime on orbit is 15 years.
- Figure shows a simplified diagram of the orbital control system of a three-axis stabilized GEO satellite.

Orbital Control System



Types of Control Maneuver

- LEO communications satellites do not need the very tight station keeping tolerance of GEO satellites, as they are less affected by the gravitational pull of the moon and sun because of the stronger gravitational force of the earth, so they do not need to carry as large a supply of fuel as a GEO satellite.

Types of Control Maneuver

- "East–West station keeping" is effected by the use of the X-axis thrusters of the satellite.
- For a satellite located away from the stable points at 75°E and 252°E, a slow drift toward these points will occur.
- Typically, the X-axis jets are pulsed every two or three weeks to counter the drift and add a small velocity increment in the opposite direction.

Types of Control Maneuver

- East–West station keeping requires only a modest amount of fuel and is necessary on all geostationary communications satellites to maintain the spacing between adjacent satellites.
- With orbital locations separated by two or three degrees, East–West drifts in excess of a fraction of a degree cannot be tolerated.

Spin Stabilization

- **Spin stabilization** is accomplished by setting the spacecraft spinning, using the gyroscopic action of the rotating spacecraft mass as the stabilizing mechanism.
- Propulsion system thrusters are fired only occasionally to make desired changes in spin rate, or in the spin-stabilized attitude.
- If desired, the spinning may be stopped through the use of thrusters or by yo-yo de-spin.
- The Pioneer 10 and Pioneer 11 probes in the outer solar system are examples of spin-stabilized spacecraft.

Spin Stabilization

- Spin stabilization may be achieved with cylindrical satellites.
- The satellite is constructed so that it is mechanically balanced about one particular axis and is then set spinning around this axis.
- For geostationary satellites, the spin axis is adjusted to be parallel to the N-S axis of the earth.
- Spin rate is typically in the range of 50 to 100 rev/min.
- Spin is initiated during the launch phase by means of small gas jets.

Spin Stabilization

- Due to disturbance torques, the overall effect is that the spin rate will decrease, and the direction of the angular spin axis will change.
- Impulse-type thrusters, or jets, can be used to increase the spin rate again and to shift the axis back to its correct N-S orientation.
- *Nutation, which is a form of wobbling, can occur* as a result of the disturbance torques and/or from misalignment or unbalance of the control jets.
- This nutation must be damped out by means of energy absorbers known as *nutation dampers.*

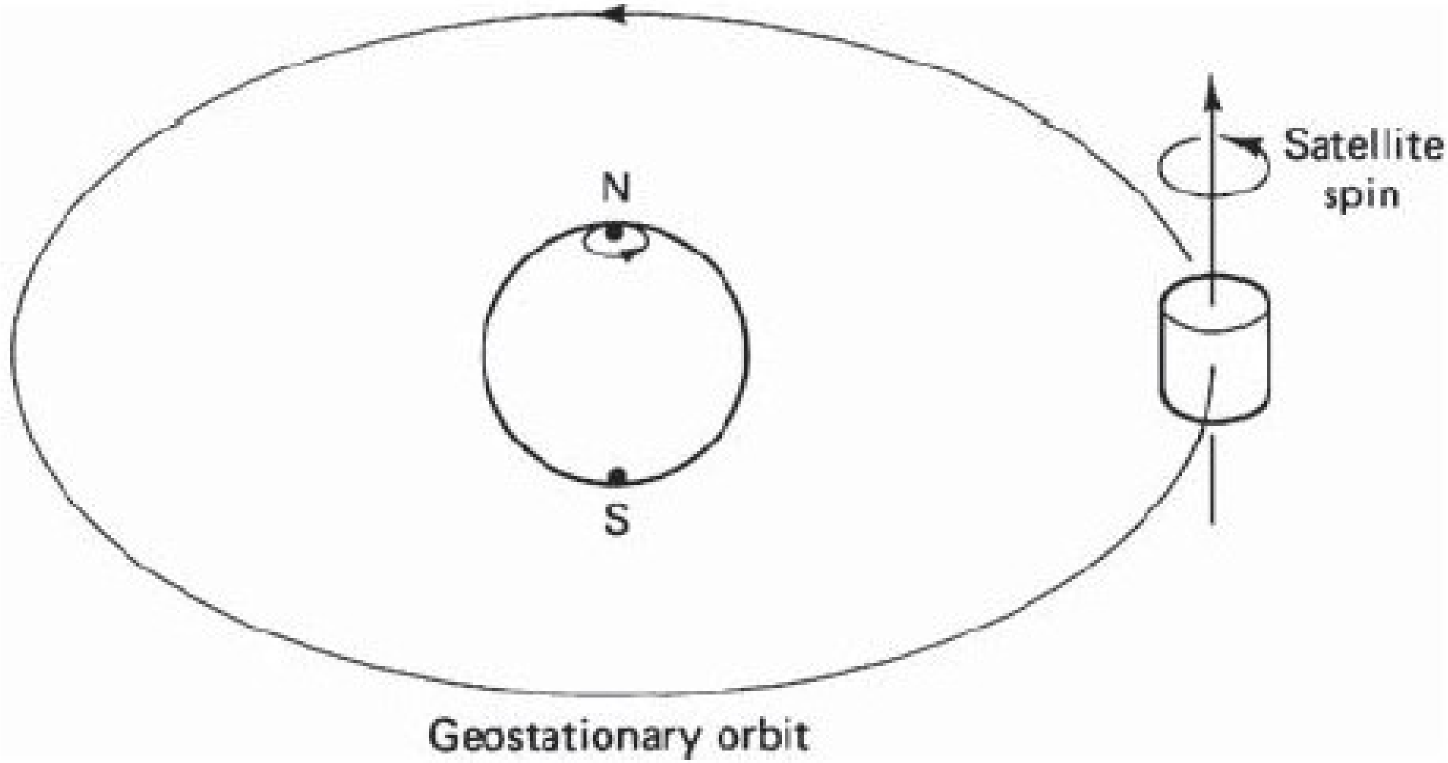
Spin Stabilization

- There are two types of spinning configurations employed in spin-stabilized satellites. These include the simple spinner configuration and the dual spinner configuration.
- In the simple spinner configuration, the satellite payload and other subsystems are placed in the spinning section, while the antenna and the feed are placed in the de-spun platform. The de-spun platform is spun
- in a direction opposite to that of the spinning satellite body.

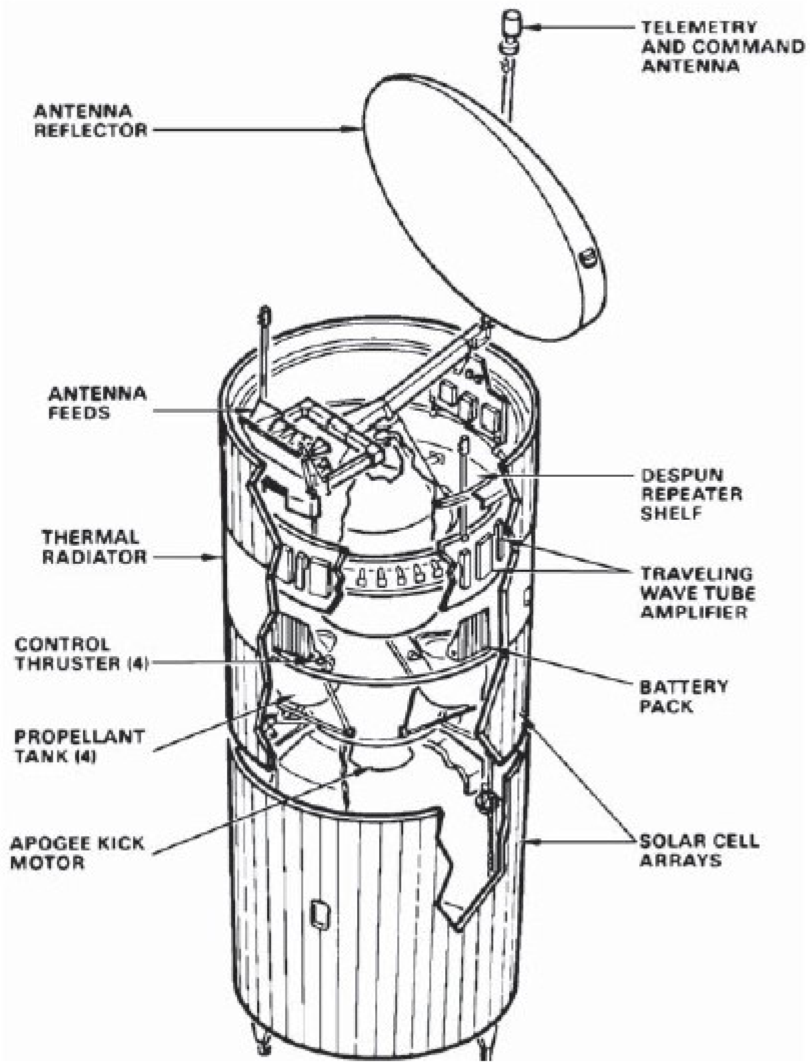
Spin Stabilization

- In the dual spinner configuration, the entire payload along with the antenna and the feed is placed on the de-spun platform and the other subsystems are located on the spinning body.

Geostationary Orbit



Details about Satellite



Gravity Gradient Stabilization

- **Gravity-gradient stabilization** is a method of stabilizing artificial satellites or space tethers in a fixed orientation using only the orbited body's mass distribution and gravitational field.
- The main advantage over using active stabilization with propellants, gyroscopes or reaction wheels is the low use of power and resources.

Gravity Gradient Stabilization

- The idea is to use the Earth's gravitational field and tidal forces to keep the spacecraft aligned in the desired orientation.
- The gravity of the Earth decreases according to the inverse-square law, and by extending the long axis perpendicular to the orbit, the "lower" part of the orbiting structure will be more attracted to the Earth.
- The effect is that the satellite will tend to align its axis of minimum moment of inertia vertically.

Gravity Gradient Stabilization

- The technique was first successfully used in a near-geosynchronous orbit on the Department of Defense Gravity Experiment (DODGE) satellite in July 1967.
- There were other success and failure stories too.

3-Axis Stabilization

- **Three-axis stabilization** is an alternative method of spacecraft attitude control in which the spacecraft is held fixed in the desired orientation without any rotation.
- One method is to use small thrusters to continually nudge the spacecraft back and forth within a deadband of allowed attitude error.
- Thrusters may also be referred to as mass-expulsion control (MEC) systems, or reaction control systems (RCS).

3-Axis Stabilization

- Another method for achieving three-axis stabilization is to use electrically powered reaction wheels, also called momentum wheels, which are mounted on three orthogonal axes aboard the spacecraft.
- They provide a means to trade angular momentum back and forth between spacecraft and wheels.
- To rotate the vehicle on a given axis, the reaction wheel on that axis is accelerated in the opposite direction.

3-Axis Stabilization

- To rotate the vehicle back, the wheel is slowed. Excess momentum that builds up in the system due to external torques from, for example, solar photon pressure or gravity gradients, must be occasionally removed from the system by applying controlled torque to the spacecraft to allowing the wheels to return to a desired speed under computer control.
- This is done during maneuvers called momentum desaturation or momentum unload maneuvers.
- Most spacecraft use a system of thrusters to apply the torque for desaturation maneuvers.

3-Axis Stabilization

- In the case of three-axis stabilization, also known as body stabilization, the stabilization is achieved by controlling the movement of the satellite along the three axes, i.e. yaw, pitch and roll, with respect to a reference
- The system uses reaction wheels/momentum wheels or thrusters/MES to correct orbit perturbations.
- The stability of the three-axis system is provided by the active control system, which applies small corrective forces on the wheels to correct the undesirable changes in the satellite orbit.

Control Systems

- Commonly used Control Systems:
  - Mass Expulsion Systems (MES) or also known as Reaction Control Systems (RCS)
  - Momentum Exchange Systems or also known as Momentum Wheels or Reaction Wheels

Mass Expulsion Systems

- A Mass Expulsion System(MES) or a Reaction Control System (RCS) is a spacecraft system that uses thrusters to provide attitude control, and sometimes propulsion.
- Use of diverted engine thrust to provide stable attitude control, a short-or-vertical takeoff and landing aircraft below conventional winged flight speeds, may also be referred to as a reaction control system.

Mass Expulsion Systems

- An RCS is capable of providing small amounts of thrust in any desired direction or combination of directions. An RCS is also capable of providing torque to allow control of rotation (roll, pitch, and yaw).
- Reaction control systems often use combinations of large and small (Vernier) thrusters, to allow different levels of response.

Mass Expulsion Systems

- Spacecraft reaction control systems are used for:
  - Attitude Control
  - Station Keeping
  - close maneuvering during docking procedures
  - control of orientation, or 'pointing the nose' of the craft
  - a backup means of de-orbiting

Mass Expulsion Systems

- For stationkeeping, some spacecraft (particularly those in geosynchronous orbit) use high-specific impulse engines such as arciets, ion thrusters, or hall effect thrusters.

Momentum Exchange Systems

- A **reaction wheel** (RW) is a type of flywheel used primarily by spacecraft for three-axis attitude control, which does not require rockets or external applicators of torque.
- They provide a high pointing accuracy, and are particularly useful when the spacecraft must be rotated by very small amounts, such as keeping a telescope pointed at a star.

Momentum Exchange Systems

- The complete unit, termed a momentum wheel, consists of a flywheel, the bearing assembly, the casing, and an electric drive motor with associated electronic control circuitry.
- The flywheel is attached to the rotor, which consists of a permanent magnet providing the magnetic field for motor action.

Momentum Exchange Systems

- The stator of the motor is attached to the body of the satellite. Thus the motor provides the coupling between the flywheel and the satellite structure.
- Speed and torque control of the motor is exercised through the currents fed to the stator. The housing for the momentum wheel is evacuated to protect the wheel from adverse environmental effects, and the bearings have controlled lubrication that lasts over the lifetime of the satellite.

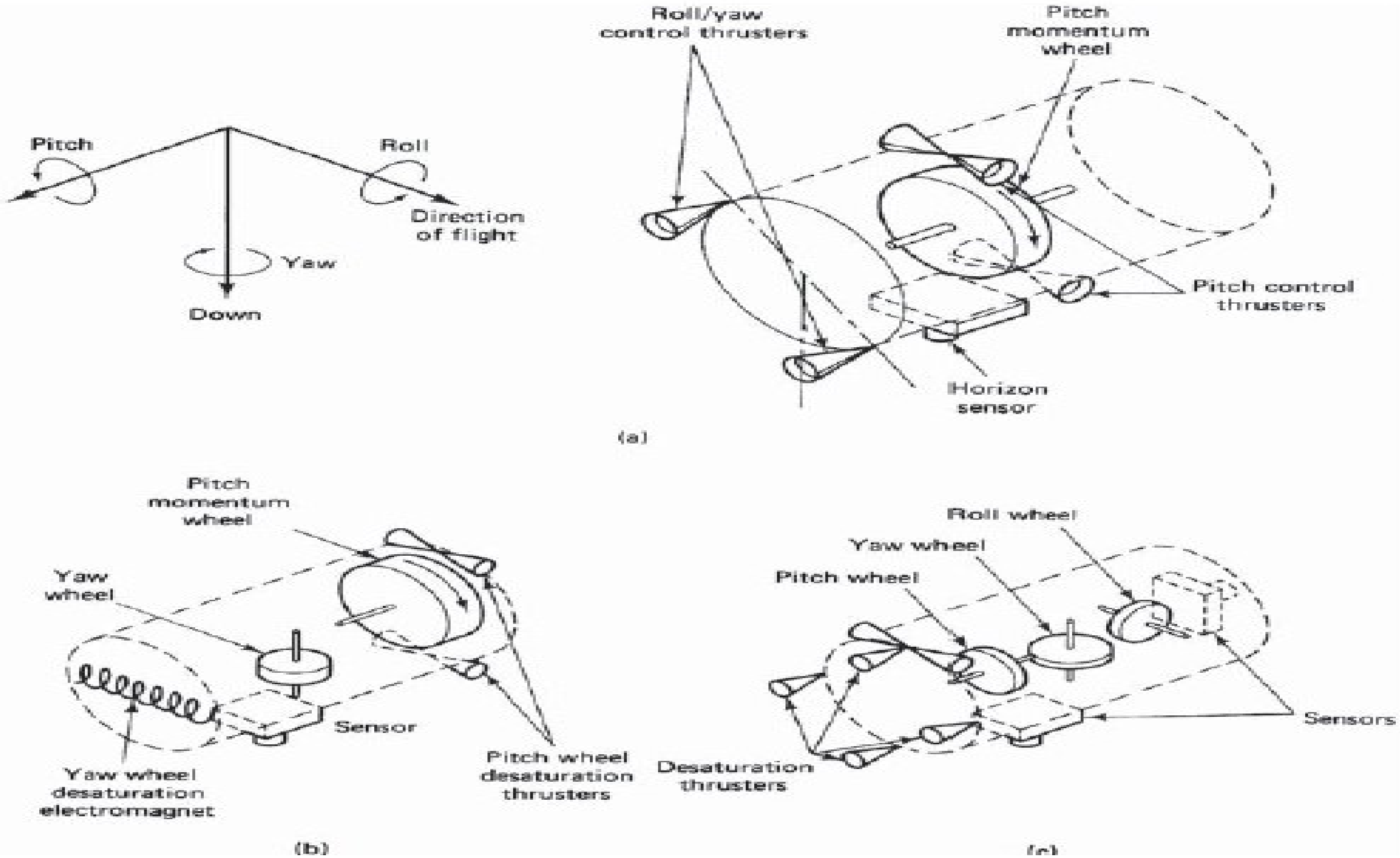
Momentum Exchange Systems

- The term momentum wheel is usually reserved for wheels that operate at nonzero momentum. This is termed a momentum bias.
- Such a wheel provides passive stabilization for the yaw and roll axes when the axis of rotation of the wheel lies along the pitch axis.
- *Control about the pitch axis is achieved by changing* the speed of the wheel.

Momentum Exchange Systems

- Mass expulsion devices are then used to unload the wheel, that is, remove momentum from momentum wheels.
- Figure on next slide shows momentum wheels and thrusters(MES)

Momentum Exchange Systems



Sensors

- Sensor Types:
  - Relative Attitude Sensors
    - Many sensors generate outputs that reflect the rate of change in attitude. These require a known initial attitude, or external information to use them to determine attitude. Many of these sensors have some noise, leading to inaccuracies if not corrected by absolute attitude sensors.
  - Absolute Attitude Sensors
    - This class of sensors sense the position or orientation of fields, objects or other phenomena outside the spacecraft.

Sensors

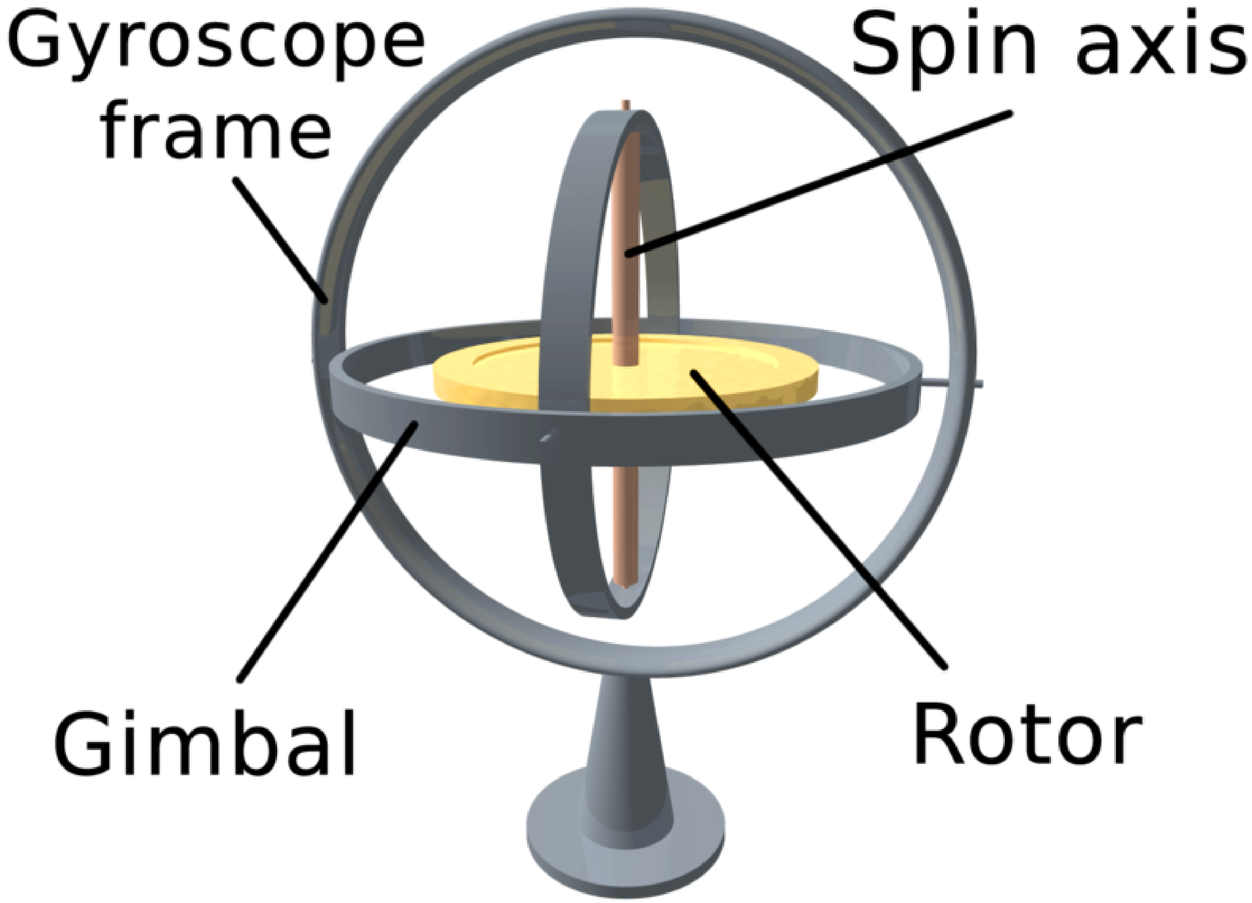
- Relative Attitude Sensors
  - Gyroscopes
  - Magnetic Torque Sensors
- Absolute Attitude Sensors
  - Sun Sensor
  - Star Sensor
  - Earth Sensor
  - Magnetometer
  - Inertial Sensor

Gyroscopes

- Gyroscopes are devices that sense rotation in three-dimensional space without reliance on the observation of external objects.
- Classically, a gyroscope consists of a spinning mass, but there are also "ring laser gyros" utilizing coherent light reflected around a closed path.

Gyroscopes

- Another type of "gyro" is a hemispherical resonator gyro where a crystal cup shaped like a wine glass can be driven into oscillation just as a wine glass "sings" as a finger is rubbed around its rim.
- The orientation of the oscillation is fixed in inertial space, so measuring the orientation of the oscillation relative to the spacecraft can be used to sense the motion of the spacecraft with respect to inertial space.


Gyroscope frame
Spin axis
Gimbal
Rotor

Magnetic Torque Sensors

- is a simple, low-cost technology that uses non-contact sensing to provide accurate torque measurements for rotating or stationary shafts.
- The key component in a magnetoelastic sensor is a ferromagnetic ring attached to the shaft being measured.

Magnetic Torque Sensors

- When torque (torsional stress) is applied, the magnetic moments inside the shaft (or ring) are reoriented, causing a magnetic flux to develop around outside circumference of the shaft.
- The strength of the magnetic field flux is linearly proportional to the stress — and therefore, the torque — on the shaft, and the polarity of the magnetic field indicates the direction of torque. Magnetic field sensors positioned around the shaft determine the amount and direction of torque based on this flux.

Sun Sensor

- A sun sensor is a device that senses the direction to the Sun. This can be as simple as some solar cells and shades, or as complex as a steerable telescope, depending on mission requi
- A **sun sensor** is a navigational instrument used by spacecraft to detect the position of the sun. Sun sensors are used for attitude control, solar array pointing, gyro updating, and fail-safe recovery.

Star Sensor

- A *star tracker* is an optical device that measures the position(s) of star(s) using photocell(s) or a camera. It uses magnitude of brightness and spectral type to identify and then calculate the relative position of stars around it.

Earth Sensor

- An *Earth sensor* is a device that senses the direction to Earth. It is usually an infrared camera;
- nowadays the main method to detect attitude is the star tracker, but Earth sensors are still integrated in satellites for their low cost and reliability.

Magnetometer

- A *magnetometer* is a device that senses magnetic field strength and, when used in a three-axis triad, magnetic field direction.
- As a spacecraft navigational aid, sensed field strength and direction is compared to a map of Earth's magnetic field stored in the memory of an on-board or ground-based guidance computer.
- If spacecraft position is known then attitude can be inferred.

Inertial Sensors

- Inertial sensors are sensors based on inertia and relevant measuring principles.
- These range from Micro Electro Mechanical Systems (MEMS) inertial sensors, measuring only few mm, up to ring laser gyroscopes that are high-precision devices with a size of up to 50cm.
- Inertial sensors typically come in the form of an Inertial Measurement Unit (IMU) which consists of accelerometers, gyroscopes and sometimes also magnetometers.

Thank You