AE5545 – DYNAMICS AND CONTROL OF SPACECRAFT

Final Project (300 points)
Due: before 17 November 2017

13 October 2017

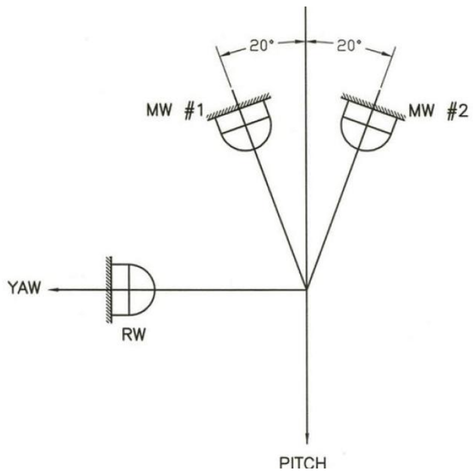
The purpose of the project is to design a preliminary attitude control system for a satellite. The satellite could be stabilized by any one of the stabilization methods, viz., (i) gravity gradient stabilized (ii) spin or dual spin stabilized with passive or active magnetic torque for damping (iii) a momentum-biased stabilizeds/c with earth sensor (measuring roll and pitch) as primary sensor with gyroscopes together with scheme for momentum dumping of the wheel using thrusters (iv) a zero-momentum biased spacecraft (three or 4 wheel configuration) with star sensor as its sensor providing roll, pitch and yaw Euler angles with gyroscopes which also addresses momentum dumping of all wheels.

a) Select your kinematical system for the spacecraft as either Euler angles or quaternions or both suitably
b) Using Euler's Equation derive the dynamical equations of motion and also include the gravity gradient torque.
c) Study the stability dynamics of the system (i) pitch motion and (ii) roll-yaw motion and figure out what kind of motion is possible. Describe why active control system is required?
d) Design a control system to control the spacecraft with PID control strategies.
e) Also, figure out a control strategy to momentum dump if you have selected wheel based control.
f) Select the proportional control gain for maximum allowable steady state error of 0.15 deg for roll and 0.4 deg for yaw (for momentum biased) and 0.005 deg about all axes (for zero-momentum biased system).
g) If somebody wants to work on gravity gradient and spin/dual-spin the parameters could be appropriately selected from internet. Appropriate passive and/or active nutation control should be addressed.

Parameter considerations for satellites: (Consult one of the Chapters 5, 6, 7 and 8 of Sidi depending upon your problem selected)

(a) A small momentum Biased Spacecraft (MAS) for communication purposes uses 2-axis sensor measuring pitch and roll and a momentum wheel about pitch axis. [x,y,z] axes are roll, pitch and yaw respectively; Ideal MI properties of the s/c after deployment $J_c = \begin{bmatrix} 313 & & \\ & 103 & \\ & & 295 \end{bmatrix}$ Kg m^2 and mass of s/c = 500 Kg. Design a PID control for $T_x = T_z$= 2× 10^{-5} Nm and $T_y = 10^{-4}$ Nm. The wheel capacity = 4Nms at 5000 rpm. ω_0 = 7.29× 10^{-5} rad/sec.The momentum dumping is provided using magnetorquers of capacity 200 Am^2. Suppose, we use a star sensor that provides roll, pitch and yaw as measurements how does the control of the spacecraft with additional yaw information provided changes. Discuss.

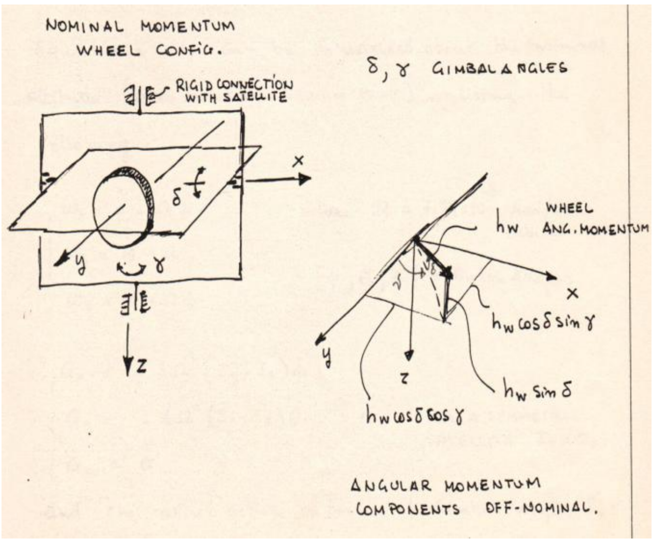
(b) Acommunication satellite with wheel configuration is as given below:



The wheels have the capacity of 60 NMs at 5400 rpm.Normally the s/c works with wheels in 'V' mode. The yaw wheel will be used when one of the wheels is failed and then the s/c works with 'L' mode. The magnetic torquers are used for roll-yaw desaturation of angular momentum and they are of capacity 350 Am^2. Each Wheel individually produces 10Nms. The MI matrix is given by $J_c = \begin{bmatrix} 1000 & 0 & 0 \\ 0 & 500 & 0 \\ 0 & 0 & 700 \end{bmatrix}$ Kg m^2. The wheels have the torque cut-off of 0.5 Nm and the wheel has its MI as$I_w = 0.1\ Kg\ m^2$. ω_0 = 7.29× 10^{-5} rad/sec.

(c) Momentum Biased Spacecraft (MAS) for communication purposes.

The satellite uses 2-axis sensor measuring pitch and roll and a 2 dof momentum wheel (ref to figure given below) which has gimbaling action about roll and pitch by δ and γ. [x,y,z] axes are roll, pitch and yaw respectively;



Ideal MI properties of the s/c after deployment $J_c = \begin{bmatrix} 2000 & & \\ & 400 & \\ & & 2000 \end{bmatrix}$ Kg m^2 and mass of s/c = 716 Kg. Design a PID control for $T_x = 2\times 10^{-5}(1 - 2\sin\omega_0 t)$ Nm and $T_y = 10^{-4}\cos\omega_0 t$ Nm. The wheel capacity = 200 Nms.ω_0 = 7.29$\times$ 10^{-5} rad/sec.The momentum dumping is achieved by using 150 Am^2 torque rods about the axes.

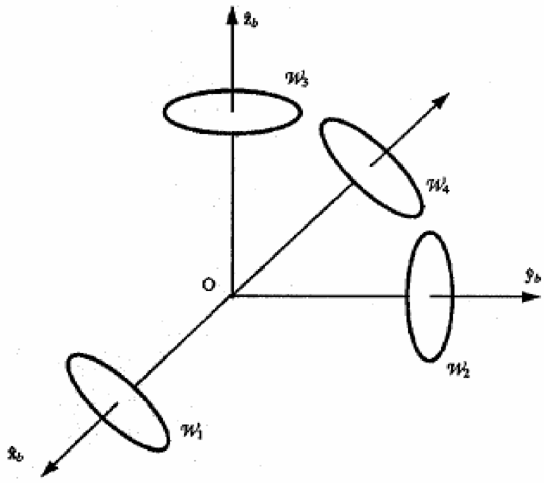
(d) ASTROSAT – an inertial pointing satellite in a 650 Km 6 deg inclined circular orbit; 4-wheel tetrahedron wheel system is used for momentum management; Actual MI properties of the s/c after deployment

$= J_c = \begin{bmatrix} 1763 & -52 & -16 \\ -52 & 1591 & 25 \\ -16 & 25 & 1185 \end{bmatrix}$ Kg m^2; Mass of the s/c = 1542 Kg.[x,y,z] axes are yaw, roll and pitch respectively.

Initially assume that the cross product of inertias is negligible and design the control system. Then when you actually apply the control, use the actual inertia matrix and compare and comment how the performance varies.

The momentum dumping is achieved by using 60 Am^2 torque rods about all the three axes. Design a PID control for $T_x = T_z = 2\times 10^{-3}$ Nm and $T_y = 10^{-4}$ Nm.ω_0 = 1.0741 × 10^{-3} rad/sec.

(e) Oceansat-1 is a 3-axis stabilized earth pointing satellite with a 4-wheel configuration which is traditional. That is the wheel configuration is with a wheel about each principal axis and the 4th wheel is mounted with 54.7 deg with respect to all three wheels. Nominally the principal axis wheels are rotated with 1000 rpm and the redundant wheel is rotated with -1732 rpm so that zero-momentum is achieved.



Configuration of energy/momentum wheels.

The momentum dumping is achieved by using 60 Am^2 torque rods about all the three axes. Actual MI properties of the s/c after deployment $= J_c = \begin{bmatrix} 1800 & -50 & -15 \\ -50 & 1600 & 25 \\ -15 & 25 & 1200 \end{bmatrix}$ Kg m^2; Mass of the s/c = 1600 Kg.[x,y,z] axes are yaw, roll and pitch respectively.

Initially assume that the cross product of inertias is negligible and design the control system. Then when you actually apply the control, use the actual inertia matrix and compare and comment how the performance varies.

The momentum dumping is achieved by using 60 Am^2 torque rods about all the three axes. Design a PID control for $T_x = T_z = 2\times 10^{-3}$ Nm and $T_y = 10^{-4}$ Nm. ω_0 = 1.0741×10^{-3} rad/sec.

Compare the control strategy and time responses when a tetrahedron / Pyramid configuration is employed.

Instructions:

- Assume wherever necessary suitable parameters or values and state them in your report
- The project work carries 60% of your final exam marks and therefore a thorough analysis and report is expected.
- Remaining 40% is allocated to your final examination in multiple-choice format with some small calculations involved.
- Since the class consists of 20 students, 5 groups are expected to be formed with not more than 4 students. Each group should take one of the problem given above.
- Report should contain a) assumptions b) kinematical equations whether based on Euler angles or Quaternions (Quarternions will have higher weightage) c) Dynamical equations of your selected system and analysis why a control is required to meet the given steady state error d) control system design along with converged attitude error plots e) momentum dumping using magnetorquers with a dipole based magnetic field f) final conclusions etc.
- The report will be orally presented to the instructor on 18/11/2017, Saturday from 9 am onwards group by group individually.
- Your final exam as per schedule is on 22 November 2017; if required this can be completed before with suitable arrangement.