

Control Moment Gyroscope

The Control Moment Gyro Experiment consists of the CMG mechanism and its actuators and sensors. The design features two high torque density (rare earth magnet type) DC servo motors for control effort transmission, high resolution encoders for gimbal (rotating ring) angle feedback, and low friction slip rings for signal and motor power transmission across all gimbals. It also includes inertial switches for high gimbal speed detection and safety shutdown and electromechanical brakes to facilitate changing dynamic degrees of freedom as well as securing the system during safety shutdown.

The plant, shown in Figure 1, consists of a high inertia brass rotor suspended in an assembly with four angular degrees of freedom. The rotor spin torque is provided by a rare earth magnet type DC motor (motor#1) whose angular position is measured by a 2000 count per revolution optical encoder (encoder #1). The motor drives the rotor through a 3.33:1 reduction ratio that amplifies both the torque and encoder resolution by this factor. In this laboratory, the other degrees of freedom will be locked using the electromagnetic brake switches on the control box. Thus, the system has a single motor/encoder for position and speed control, the most frequently observed applications in practice.

Checkout Procedure

- Step 1:** With power switched off to the Control Box, enter the ECP program by double clicking on its icon. You should see the Background Screen. Gently rotate the inner gimbal ring (the one that encloses the brass rotor). You should see changes in the Encoder 2 position and possibly small changes in the Encoder 1 (rotor) position. The Control Loop Status should indicate "OPEN" and the Motor 1 Status, Motor 2 Status, and Servo Time Limit should all indicate "OK".
- Step 2:** Now press the black "ON" button to turn on the power to the Control Box. You should notice the green power indicator LED lit, but the motors should remain in a disabled state. Turn off the Axis 3 and 4 Brakes via the toggle switches on the Control Box and *safety check* the controller as per the instructions in Appendix B on the course website. Now move Axes 3 and 4. You should see the corresponding Encoder position values change on the Background Screen of the Executive. Encoder 1 position will usually change as you move axis 3.

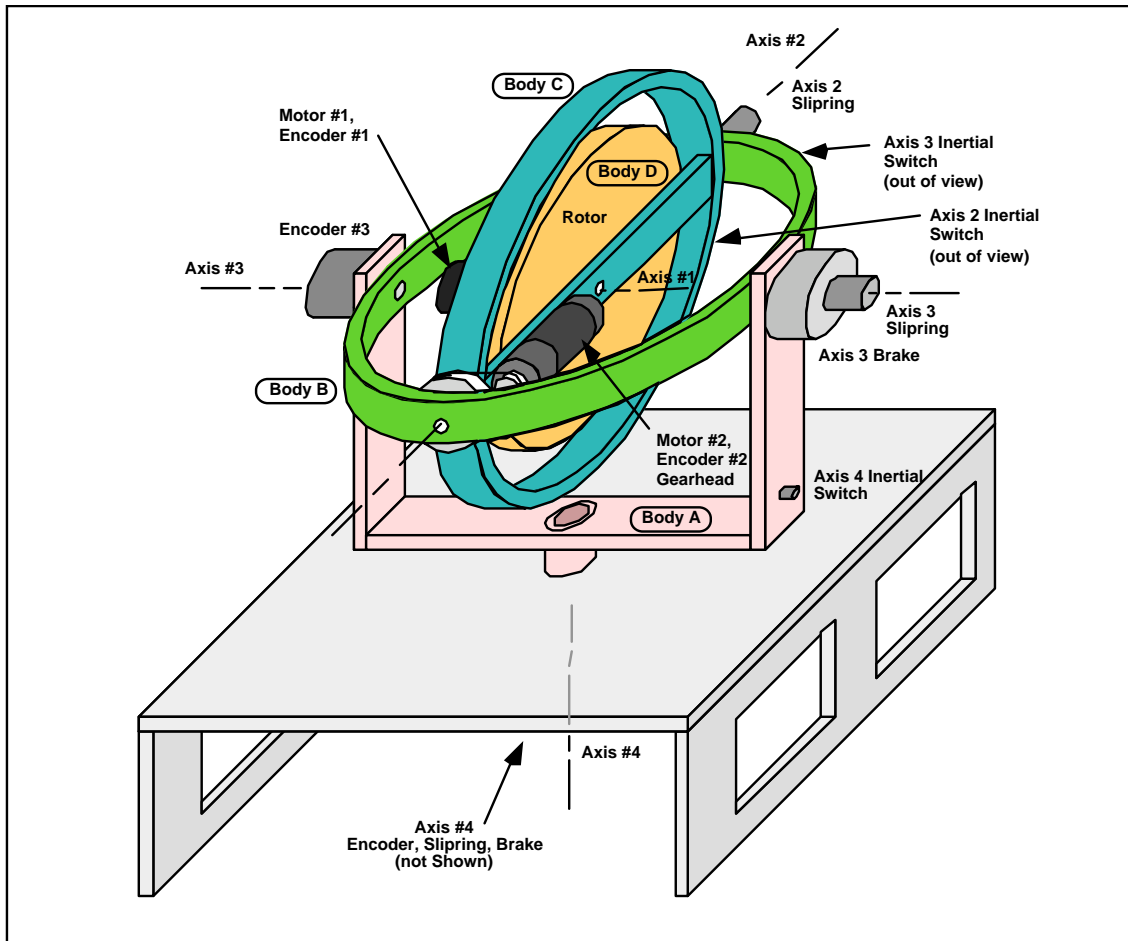


Figure 1: ECP Control Moment Gyro Experiment

- A. Read the safety information for the Control Moment Gyro (CMG) Experiment in Chapter 2 of the equipment manual (See also Appendix B on the course website).
- B. Identify the control elements and signals in the CMG Experiment*.

| | |
|------------------|------------------|
| Sensor: | Actuator: |
| Controller: | Reference Input: |
| Actuator Output: | System Output: |

*Refer to the Introduction Literature.

Experiment 6.1: System Identification

Follow the procedures in Section 6.1.1 of the ECP Lab Manual to determine the moments of inertia about the specified axes. When you are finished you should be able to complete Table 6.1.2. Note: You will need to use conservation of angular momentum to determine the moments of inertia given the coordinate systems defined in Figure 2 where $I = 1, J = 2,$ and $K = 3.$

$$J_1 \omega_{1o} + J_2 \omega_{2o} = J_1 \omega_{1f} + J_2 \omega_{2f}$$

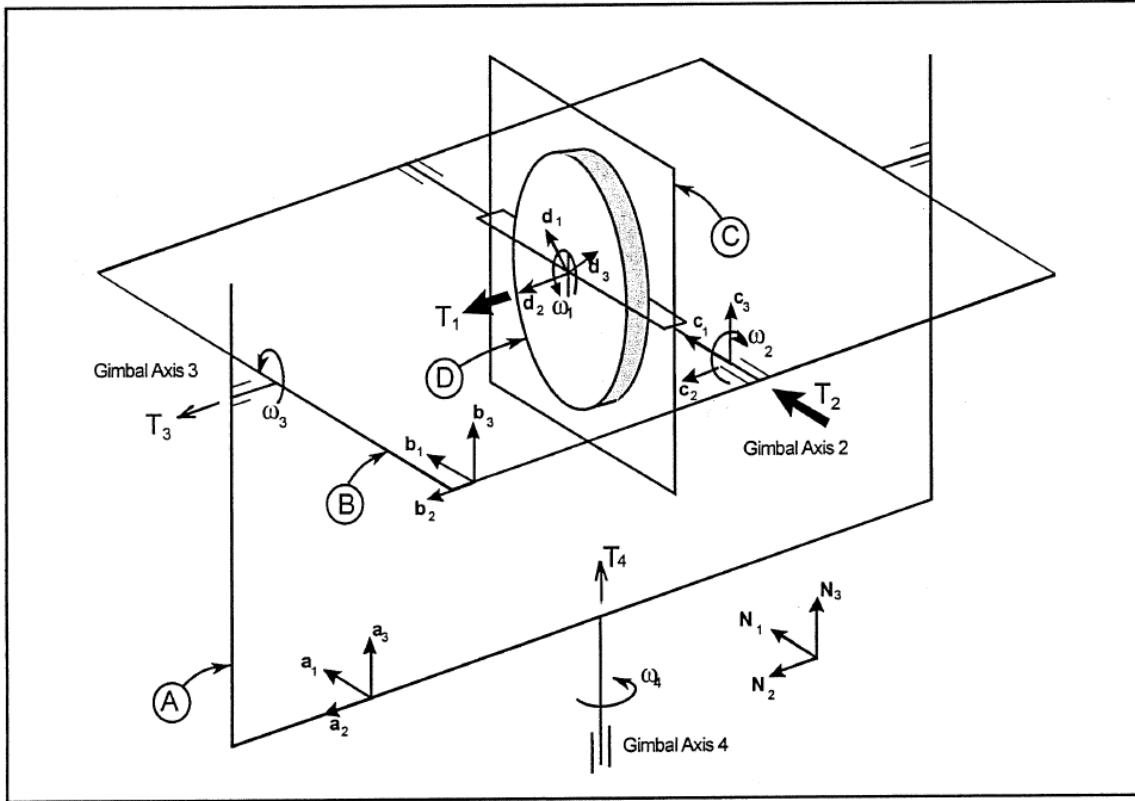


Figure 2: Coordinate System Orientations

Figure 2 above is the orientation setting with which inertias of various bodies are defined. In the figure, you see four bodies are labeled, A, B, C, and D. Also, three axes are labeled, 1, 2 and 3; these three axes are further named I, J and K and used to define various inertias in Table 6.1-2 next page.

In the first run, you are to determine inertia J_C . In this run, body D rotates as one piece and Bodies C and B together rotate as one piece. Both rotate about axis 2 or axis J. The inertia of Body D about axis 2 is given in Table 6.1-2 as J_D . The inertia of Body B about the same axis is also given in the table as J_B . Now, if you call J_D as J_1 in the equation at the bottom of last page, then J_2 in the equation would be equal to $J_B + J_C$. So, you can figure out what J_C would be using the equation along with measurement data used in this equation. You run two similar experiments and use the similar idea above to determine K_A and I_C .

Include the following plots:

Plot of Inertia Test #1 is on pg. _____.

Plot of Inertia Test #2 is on pg. _____.

Plot of Inertia Test #3 is on pg. _____.

| Table 6.1-2 Moment of Inertia Data | | |
|------------------------------------|-----------------|----------------------------|
| Body | Inertia Element | Value (kg-m ²) |
| A | K _A | |
| B | I _B | 0.012 |
| | J _B | 0.018 |
| | K _B | 0.030 |
| C | I _C | |
| | J _C | |
| | K _C | 0.022 |
| D | I _D | 0.015 |
| | J _D | 0.027 |
| | K _D | 0.015 |

The code that will be needed to perform this experiment will be a variation of the simple control law:

```
begin
control_effort1 = cmd1_pos/32
end
```

Follow the procedure in 6.1.2 to study the effects of a spinning mass on the gyroscopic precession and nutation. Create the requested plots and include them with this report:

Plot of Encoder #1 Velocity and Control Effort 1 is on pg._____.

Plot of Encoder #4 Velocity and Control Effort 2 is on pg._____.

For simplicity's sake the Control Effort gains are found to be:

$$k_{u1} = 1.28 \times 10^{-5} \text{ (N/count)}$$

$$k_{u2} = 9.07 \times 10^{-5} \text{ (N/count)}$$

DO NOT DO 6.1.3; however take note of the following information for future use.

| Axis Number (Encoder Number) | Output / Rev. (counts/rev) | Gain, k_{ei} (counts/rad) |
|---|---------------------------------------|---|
| 1 | 6667 | 1061*32 |
| 2 | 24400 | 3883*32 |
| 3 | 16000 | 2547*32 |
| 4 | 16000 | 2547*32 |

Experiment 6.2 Gyroscopic Dynamics: Nutation and Precession

Follow the procedure in 6.2.1 to study the nutation motion of the system. Create all the requested plots and include them with this report. Note: When plotting position and velocity on the same figure, place position variables on the left axis and velocity variables on the right axis to avoid scaling issues.

Plot of Encoder #2 and Encoder #4 data at 200 RPM is on pg._____.

Plot of Encoder #2 and Encoder #4 data at 400 RPM is on pg._____.

Plot of Encoder #2 and Encoder #4 data at 800 RPM is on pg._____.

Comment on the frequency of oscillations and phase between Encoder 2 and Encoder 4 motions. Further comment on these relationships between the three different speed trials.

Follow the procedure in 6.2.2 to study the precession motion of the gyroscope. Create all the requested plots and include them in this report.

Plot of Encoder #2 and Encoder #4 data at 200 RPM is on pg._____.

Plot of Encoder #2 and Encoder #4 data at 400 RPM is on pg._____.

Plot of Encoder #2 and Encoder #4 data at 800 RPM is on pg._____.

Comment on the change in steady state velocity for Encoder #4 with rotor speed.

Follow the procedure in 6.2.3 and implement the following control algorithm:

```
*****DEFINE USER VARIABLES*****  
;   
#define Ts q1  
#define kd q2  
#define kdd q3  
#define enc2_last q4  
  
*****INITIALIZE VARIABLES*****  
;   
Ts = 0.00884  
kv = 0.005  
kdd = kv/Ts  
  
*****REAL TIME CODE*****  
;   
begin  
;CONTROL LAW: output torque = demand – gimbal2 rate feedback  
control_effort2 = cmd1_pos/32 – kdd*(enc2_pos – enc2_last)  
;UPDATE VARIABLES  
enc2_last = enc2_pos  
end
```

Note: In Step 13 the Rotor Speed should be 200 RPM and then should be increased to 400 RPM and then 800 RPM if desired.

Experiment with at least three different values of k_v using at least 2 different angular speeds. Provide the plots that you generate with this report.

Plot of $k_v = \underline{\hspace{2cm}}$ with a Rotor Speed of 200 RPM is on pg._____.

Plot of $k_v = \underline{\hspace{2cm}}$ with a Rotor Speed of 400 RPM is on pg._____.

Plot of $k_v = \underline{\hspace{2cm}}$ with a Rotor Speed of 200 RPM is on pg._____.

Plot of $k_v = \underline{\hspace{2cm}}$ with a Rotor Speed of 400 RPM is on pg._____.

Plot of $k_v = \underline{\hspace{2cm}}$ with a Rotor Speed of 200 RPM is on pg. .

Plot of $k_v = \underline{\hspace{2cm}}$ with a Rotor Speed of 400 RPM is on pg. .

How are the nutation oscillations affected by increased rate feedback gain?

How does an increase in Rotor Speed affect the amplitude of the oscillations?

Not to do the part below (Fall 2007)

Frequency Response

Setup the CMG such that the motions of Axis 1 and Axis 3 are in the same plane; turn Break 4 ON, Break 3 OFF, and Break 2 ON. Implement the algorithm given in the box on page 4 of this report. Enter Trajectory 1 and select Sine Sweep then Setup. Select the *amplitude = 10000 counts, end freq.= 9.8 Hz, start freq.= 1 Hz, sweep time = 29.5 sec.*, and *Logarithmic Sweep* selected. Zero Position. Go to the Command menu and select Execute and with *Normal Data Sampling* and *Execute Trajectory 1 Only* selected, “Run” the trajectory. While running this trajectory, you should notice sinusoidal motion with increasing frequency for about thirty seconds. Now enter the Plotting menu and choose Setup Plot. Select only *Encoder 1 Position* for plotting (you may of course also view *Commanded Position 1* data if you wish). Choose *Linear Time* and *Linear Amplitude* scaling for the horizontal and vertical axes; select *Remove DC Bias*; then plot the data. Now return to Setup Plot and select *Logarithmic Frequency* and *Db* axis scaling with *Remove DC Bias* selected. Plot the data. The linear time / amplitude depiction shows the data in a manner that more directly represents the physical motion of the system as witnessed. The $\text{Log}(\omega)$ / Db scaling presents the data in a way that gives one a physical understanding of the Bode magnitude plots commonly found in the literature. (The upper limit of the data curve is the experimental Bode magnitude plot.) Plot the $\text{Log}(\omega)$ / Db of Encoder 3 Position. Plot Encoder 1 Position (dB) versus $\text{Log}(\omega)$.

Plot of Encoder 1 Position on a Linear Scale is on pg._____.

Plot of Encoder 1 Position on a Logarithmic Scale is on pg._____.

Plot of Encoder 3 Position on a Logarithmic Scale is on pg._____.

Using a colored pen (not black) indicate the break frequency and DC Gain on both of the logarithmic plots. Indicate the values you found below:

Break Frequency for Encoder 1 = _____

DC Gain for Encoder 1 = _____

Break Frequency for Encoder 3 = _____

DC Gain for Encoder 3 = _____