ME205M- Kinematics And Dynamics Of Machinery
Gyroscope

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Title: Modeling and Simulation of a Gyroscope System Using MATLAB Simscape Multibody.

Problem Formulation- Developing a MATLAB Simscape Multibody-Based Simulation Model for a Functional Gyroscope: Analysis of its Reaction Forces and Gyroscopic Couple.

Aim: The objective of this project is to comprehensively explore the operational principles of a gyroscope through the modeling and simulation of a functional gyroscope using MATLAB Simscape Multibody. The study includes an in-depth analysis of the gyroscope's behavior, encompassing various aspects such as:

- Development of a model characterized by high precision.
- Creation of a constrained & unconstrained model.
- Analysis of gyroscopic couple and reaction forces for the aforementioned models.

Scope:

The scope of a project aiming to model and simulate a gyroscope in MATLAB Simscape Multibody typically includes several key components:

Model Development: This involves the creation of the various components with their specified physical dimensions.

Simulation: Using MATLAB Simscape Multibody, the model is used to simulate the gyroscope's motion under various conditions and inputs.

Analysis: The model allows for detailed analysis of the gyroscope's behavior, such as its response to external torques, the effect of different initial conditions, and the stability of its motion.

Validation: The simulated results are compared with theoretical expectations or experimental data to validate the accuracy of the model.

Documentation and Reporting: Finally, the project scope includes the documentation of the Gyroscopic couple and reaction forces.

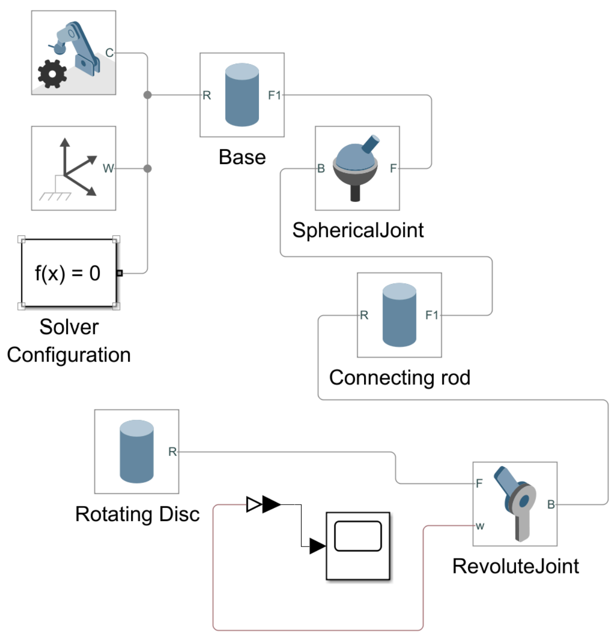
Assumptions:

- Gravity is taken along the negative z-axis.
- Friction is neglected.
- All the components are assumed to be rigid and vibrations are neglected.
- Density is assumed to be constant throughout the components-homogenous.

Description of the mechanism:

- ❖ In this model, an assortment of libraries available in MATLAB Simscape facilitated our design process.
- ❖ To construct the gyroscope, we employed cylindrical bodies, specifying dimensions to delineate the base, connecting rod, and rotating disc.
- ❖ These dimensions were precisely defined as follows:
- ❖ Base: Radius = 0.5m, Height = 2m
- ❖ Connecting Rod: Radius = 0.2m, Height = 4.5m
- ❖ Rotating Disc: Radius = 1.5m, Thickness = 0.5m
- ❖ A spherical joint was introduced between the connecting rod and the base to enable the rotational motion of the connecting rod.
- ❖ Similarly, a revolute joint was established between the connecting rod and the rotating disc.

- In the constrained model, a force (bearing) was applied to the revolute joint, while torque was imparted to the spherical joint.
- Conversely, force was exerted on the revolute joint in the non-constrained model, and torque was applied to the spherical joint.
- This meticulous configuration allowed us to accurately simulate and analyze both constrained and unconstrained precession scenarios, providing valuable insights into gyroscopic dynamics.
- The degree of freedom of this model is three as it can rotate independently about the 3 orthogonal axes.
- The sketches of our model:
    - Pure Precession:



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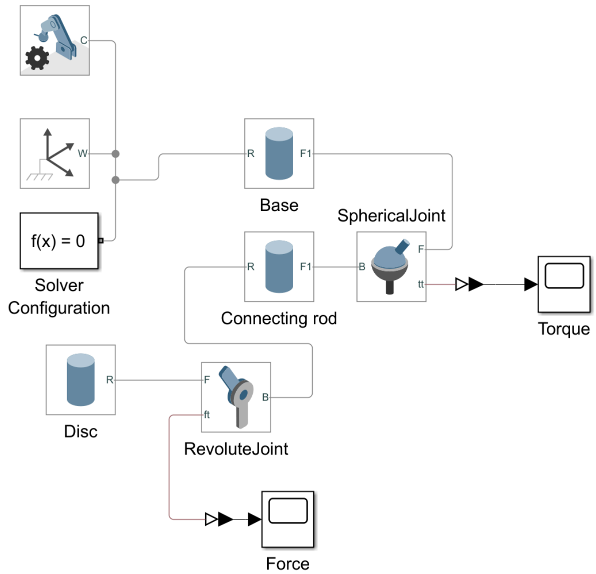
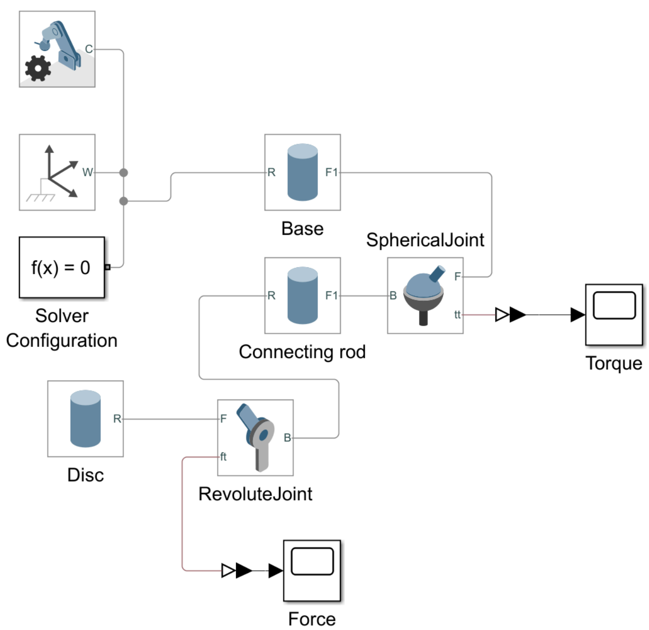
    - Constrained Precession:



❖ Non-constrained Precession:



Modeling Procedure:

- Upon launching MATLAB R2023b and accessing Simulink, we initiated our project focusing on gyroscopic precession phenomena.

- Beginning with a mechanical configuration, we established the World frame as a reference, defining gravity along the negative z-axis.

Pure Precession:

- For the "Pure Precession" scenario, our model comprised a cylindrical base with a radius of 0.5 m and a length of 2 m, alongside a connecting rod of 0.2 m radius and 4.5 m length.
- Employing a spherical joint, we facilitated rotation between these components, imparting an angular velocity of 70000 deg/s at the revolute joint.
- Additionally, we integrated a rotating disc with a radius of 1.5 m and a thickness of 0.5 m, interconnected with the connecting rod via a revolute joint.
- Running the simulation yielded conclusive outcomes.

Constrained Precession:

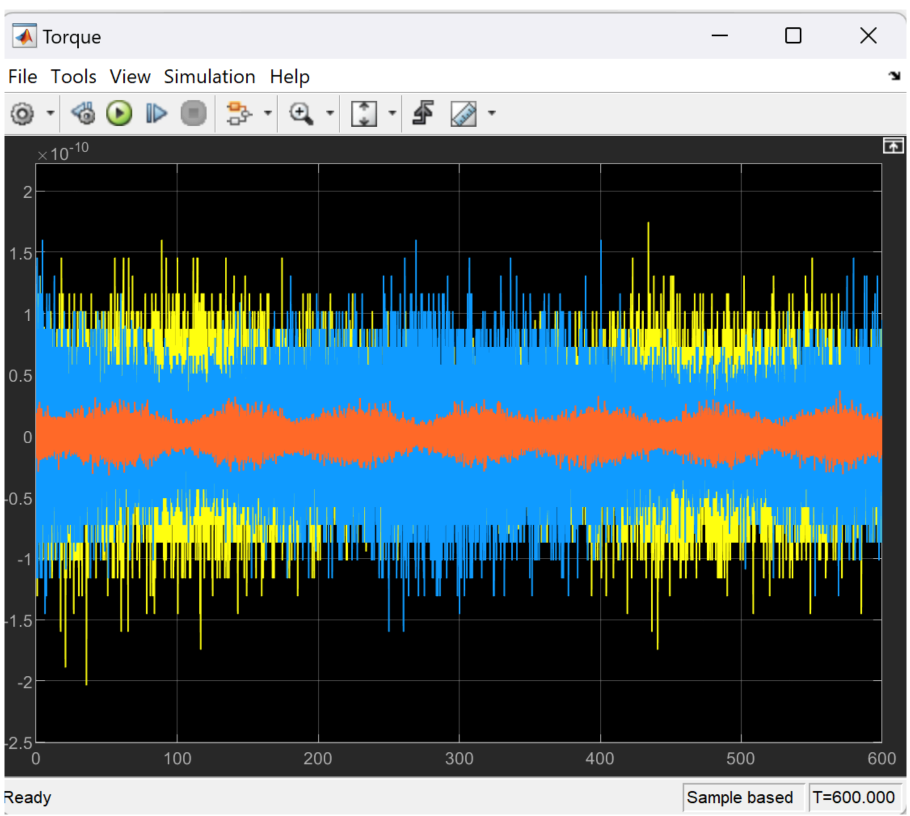
- Our model comprised a cylindrical base with a radius of 0.5 m and a length of 2 m, alongside a connecting rod of 0.2 m radius and 4.5 m length.
- Employing a spherical joint, we facilitated rotation between these components.
- We introduced a rotation sequence of [45 50 100], inducing angular displacement within the spherical joint.
- Furthermore, the angular velocity was maintained at 70000 deg/s.
- Running the simulation enabled us to analyze reaction forces and gyroscopic coupling, visualized through scopes.

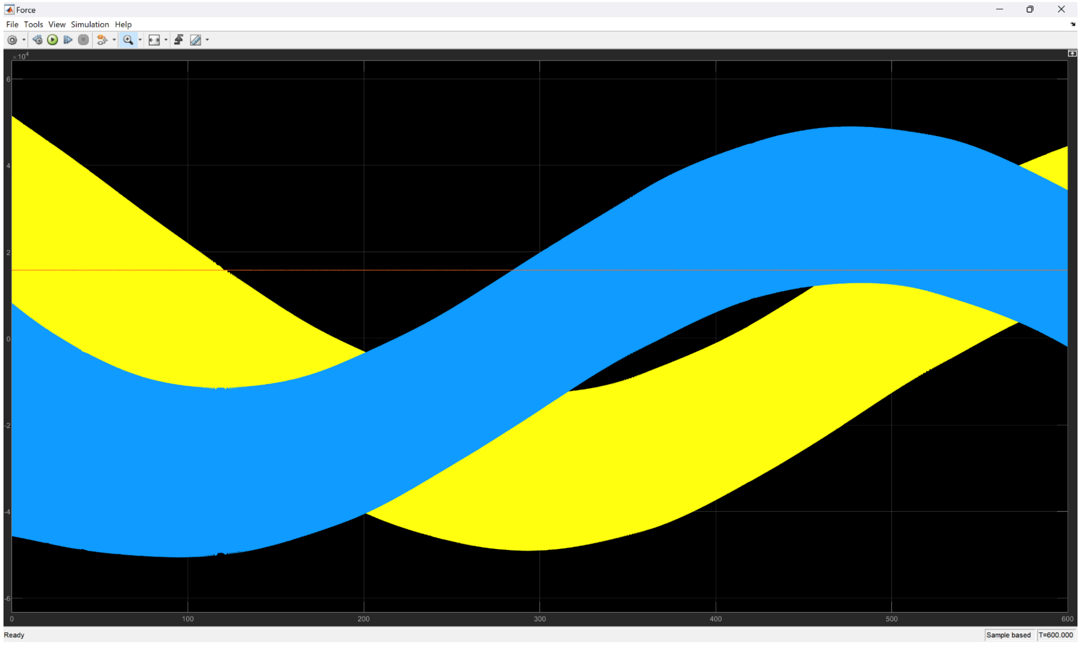
Non-constrained Precession:

- Our model comprised a cylindrical base with a radius of 0.5 m and a length of 2 m, alongside a connecting rod of 0.2 m radius and 4.5 m length.
- Employing a spherical joint, we facilitated rotation between these components
- We retained the foundational setup while augmenting the angular velocity to 100000 deg/s within the spherical joint.
- Introducing a rotation sequence of [45 50 100] induced angular displacement, and emulating non-constrained precession, additional angular velocities of [700 500 100] were imparted in different directions.
- Similar to previous iterations, reaction forces, and gyroscopic coupling were analyzed via scopes, elucidating comprehensive outcomes.

Results:

- To extract the results from our project, we utilized the scope to visualize the outcomes of our model.
- Our primary objective centered on discerning the reaction forces and gyroscopic couples inherent in both constrained and unconstrained precession scenarios.
- The versatility of our model lies in its capacity to simulate pure precession, constrained precession, and non-constrained precession.
- This breadth of functionality empowered us to conduct comprehensive analyses, particularly in evaluating reaction forces and gyroscopic coupling.
- In our investigation of constrained precession, we derived the following outcomes:

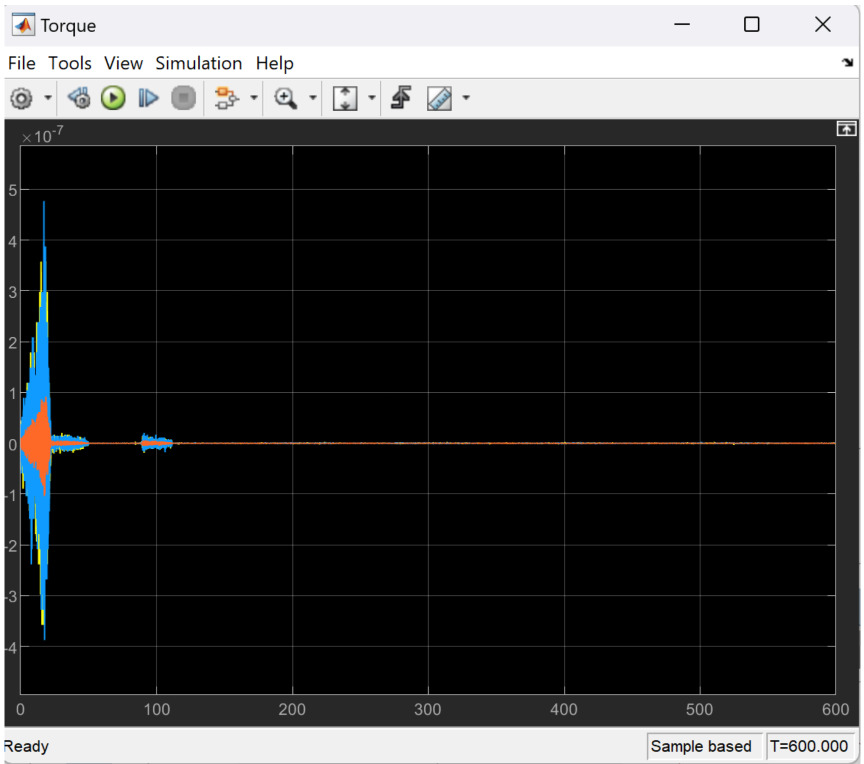




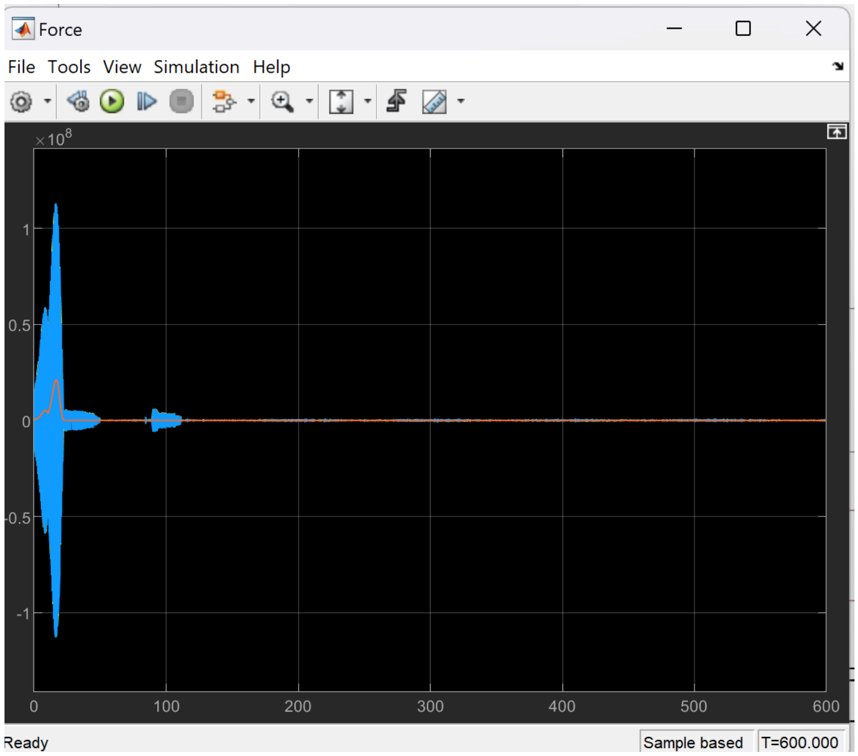
- Following the analysis of our project's outcome, a concise elucidation of the constrained precession is warranted:
- The torque diagram presents a comprehensive depiction of the gyroscope's behavior over time, with the x-axis denoting time (seconds) and the y-axis representing torque, scaled within the 10^-10 range.
- Distinct colors delineate torque components: orange signifies z-axis torque, yellow represents x-axis torque, and blue denotes y-axis torque.
- Likewise, the force diagram provides valuable insights, with the x-axis indicating time (seconds) and the y-axis depicting force within the 10^4 range.
- Here, color coding is employed to differentiate force components: orange signifies the z-axis force, yellow denotes the x-axis force, and blue represents the y-axis force.

- These visual representations, facilitated by Simscape Multibody, afford a comprehensive understanding of the gyroscope's constraint precision dynamics.
- For the non-constrained precession, we found the following outcomes:

TORQUE:



FORCE:



- In reviewing the outcome of our project, a succinct overview of the non-constrained precession is warranted:
- The torque diagram provides a comprehensive depiction of the gyroscope's behavior over time.
- Here, the x-axis denotes time (seconds), while the y-axis represents torque, scaled within the 10^{-7} range.
- Distinct colors signify torque components: orange represents z-axis torque, yellow represents x-axis torque, and blue denotes y-axis torque.
- Similarly, the force diagram offers insights into the system's dynamics. The x-axis represents time (seconds), and the y-axis illustrates force within the 10^{8} range.
- Color coding distinguishes force components: orange denotes the z-axis force, yellow represents the x-axis force, and blue signifies the y-axis force.

- This holistic assessment, facilitated by Simscape Multibody, elucidates the intricate dynamics of non-constrained precession.
- As external forces diminish, the gyroscope's torque values are expected to decrease correspondingly.
- We validated our results using the formulas we learned in class:

$$C = \underset{\delta t \to 0}{\mathrm{Lt}}\ I.\omega \times \frac{\delta\theta}{\delta t} = I.\omega \times \frac{d\theta}{dt} = I.\omega.\omega_P$$

- Through this, we were able to find the gyroscopic couple of the model and compared it with the outcome, we got using the model.

Uses:

Given the simplicity of our model, consisting of only 3 components, we believe that our model can be used to teach the basics of gyroscopes and its working.