Using a 3D printed gyroscope to calibrate the

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1/6/2022

Gyroscope simulator

1 Abstract

This project collected data from a 3D printed gyroscope to create a dynamic simulator on Creo Parametric. The motivation behind this project was to integrate additive manufacturing technologies, i.e. 3D printing in the teaching of a course at Habib University. The chosen course was PHY 101 Mechanics and thermodynamics. A gyroscope was chosen because it exhibits the principle of conservation of angular momentum. The idea was first to print a 3D prototype that exhibits gyroscopic properties, and then perform dynamic analysis on the CAD model on Creo. This was done so we could compute the values of some variables that were difficult to measure, e.g. rotor speed, angular momentum, etc. This paper will discuss the specifics of the gyroscope project, i.e. CAD modeling, 3D printing, and calibration.

2 Mathematical Background

3 Project detail

The project is divided into two parts:

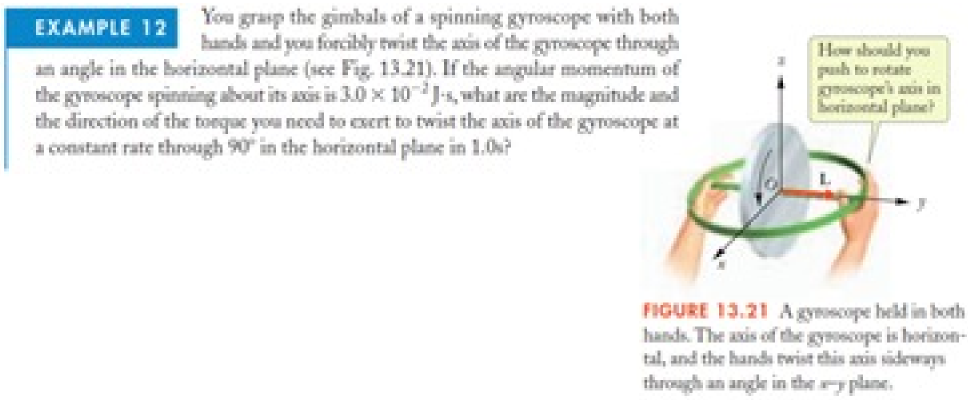
1. CAD modelling
2. 3D Printing
3. Calibration

4 CAD modelling

4.1 Problem Statement

The project was initially intended as a visual aid for a question in the PHY 101 course. The course instructor Professor Shah Zaman gave the idea and said that a visual aid would be helpful in an online learning classroom. Where she could easily demonstrate the direction of the torque on the gimbal of the gyroscope. The question is mentioned in figure (1).

Instead of just a simple visual aid the project aimed to create a prototype gyroscope that could be used would demonstrate the principle of conservation of angular momentum.And, later using the data collected from the 3D model to calibrate the Creo Parametric CAD model with dynamic properties. The later part of the aim was added mainly to cater to the shift in pedagogical world from in-person teaching to online learning. The idea behind it was that it would enhance student experience if the student would have a gyroscope simulator to tinker with at home.



EXAMPLE 12 You grasp the gimbals of a spinning gyroscope with both hands and you forcibly twist the axis of the gyroscope through an angle in the horizontal plane (see Fig. 13.21). If the angular momentum of the gyroscope spinning about its axis is 3.0×10^{-2} J·s, what are the magnitude and the direction of the torque you need to exert to twist the axis of the gyroscope at a constant rate through 90° in the horizontal plane in 1.0s?

FIGURE 13.21 A gyroscope held in both hands. The axis of the gyroscope is horizontal, and the hands twist this axis sideways through an angle in the x–y plane.

Figure 1: Problem statement

4.2 Computer Aided Design

The assembled CAD model of the gyroscope is shown in figure (2) below. The design was based on the gyroscope present in figure (1). The hands shown in the figure were replaced by the frame, and the foundation was added for support.

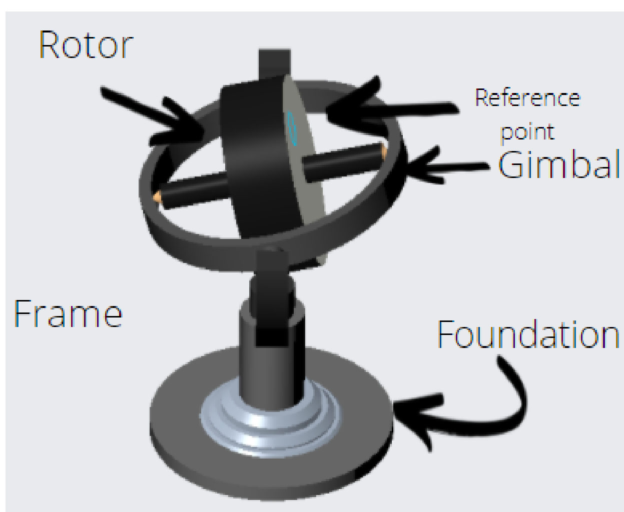


Figure 2: Labelled gyroscope

4.3 Engineering Drawings

Engineering drawings are a rich and specific outline that shows all the information and requirements needed to manufacture an item or product. As with all drawings, engineering drawings create 2D representations of 3D objects. Where for other drawings the principal object might be the creation of an aesthetically appealing 2D graphic, the primary purpose of engineering drawings is the accurate communication of the details of 3D designs. To achieve this goal, engineering drawings commonly use two types of "views", i.e. orientations of the design. These are:

1. **Multi-Views:** Information about only two dimensions of a 3D object is conveyed through multiple "projections" on a 2D plane. The idea here is that if an observer views an object from an infinite distance, they will only see the the part of the object that intersects with the plane orthogonal to their sight. The type of multi-view used in the engineering drawings used are third angle view.

2. **Isometric View:** A special type of pictorial representation of a 3D design such that information about all three dimensions is conveyed.

This section shows the engineering drawings of each part.

4.3.1 Rotor

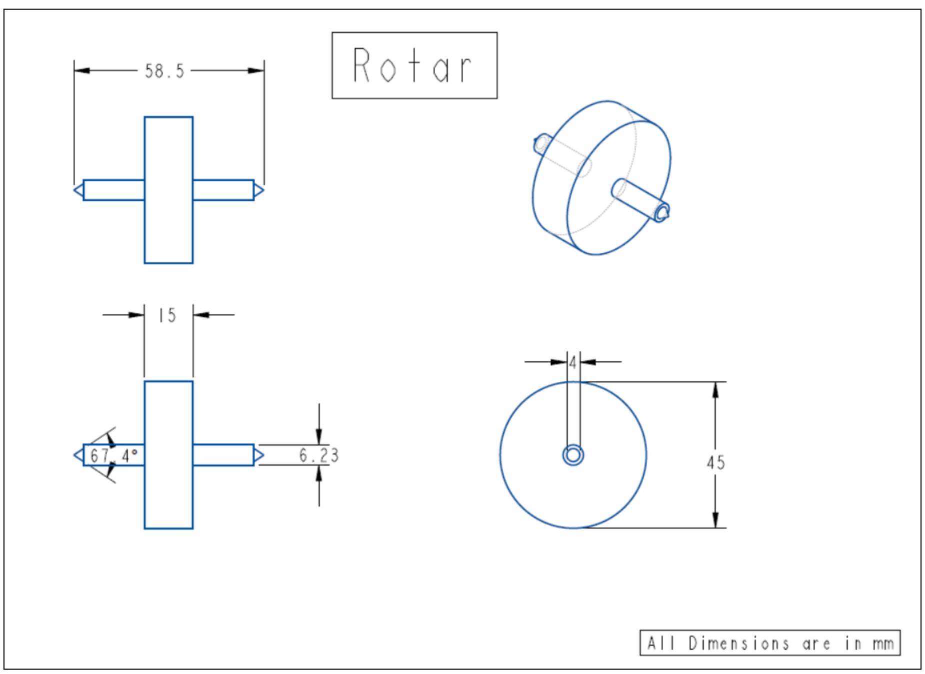


Figure 3: Rotor

4.4 Gimbal

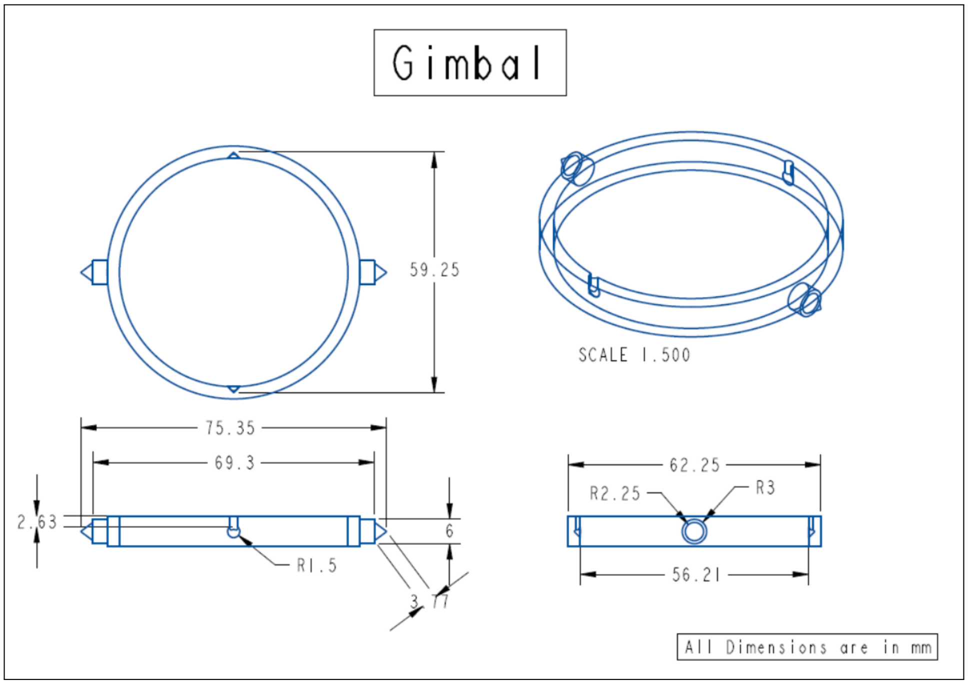


Figure 4: Gimbal

4.5 Frame

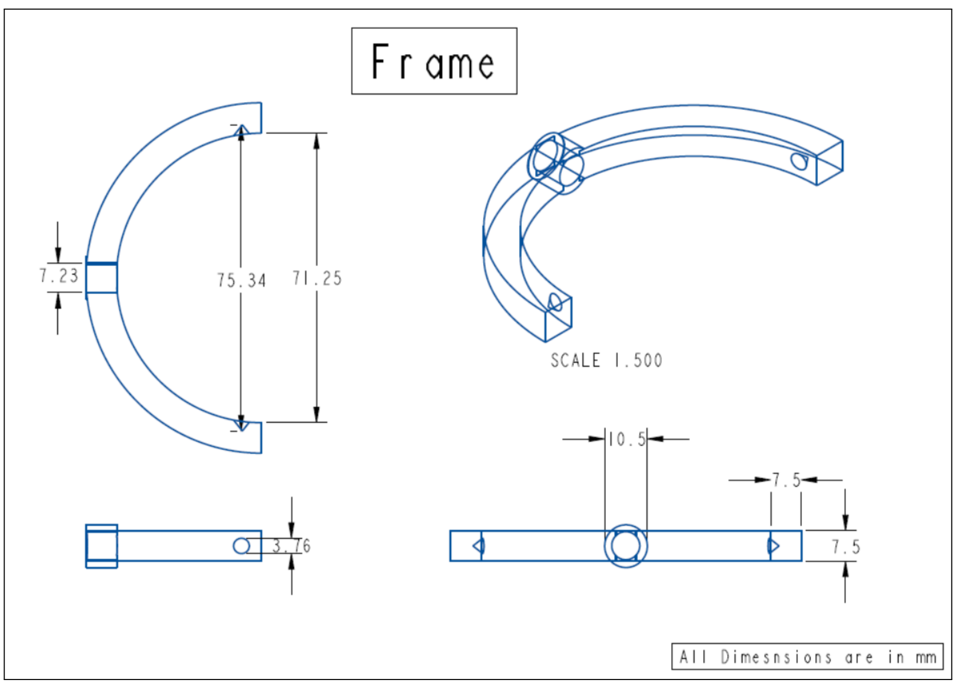


Figure 5: Frame

4.6 Foundation

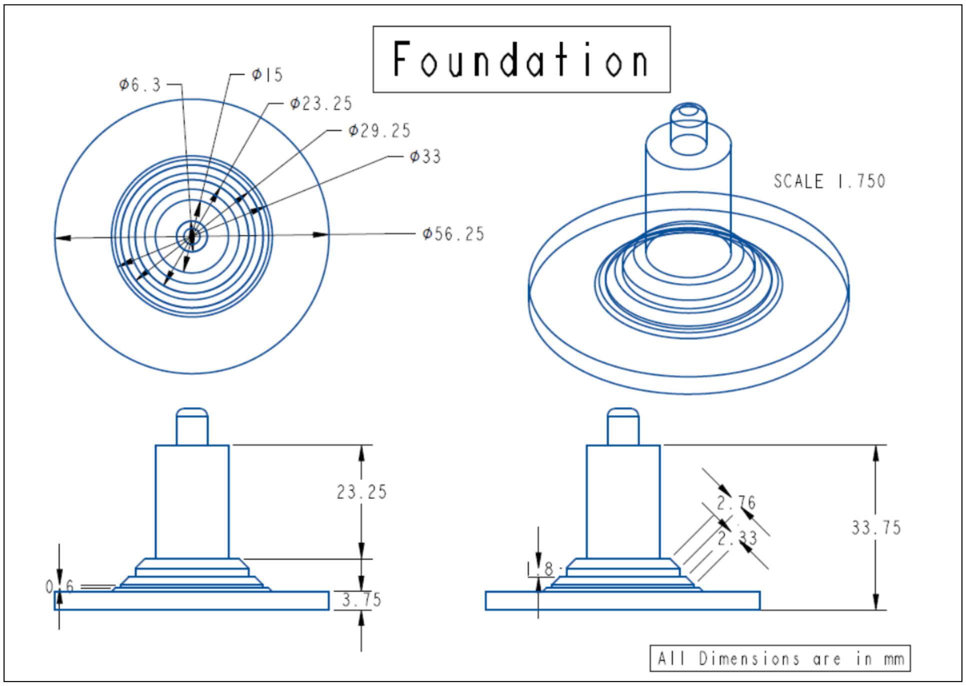


Figure 6: Foundation

Additive manufacturing allows for a unique design based learning model. 3D printing combines the job of the manufacturer and designer. Hence the designer gets a better idea of the limitation of the printer through test prints. After which, they can effectively change the CAD model. In other words additive manufacturing provides an opportunity for learning through trial and error. This means that instead of using the traditional approach to design and manufacture, the brick wall approach, 3D printing employs the newer concurrent engineering model. In Concurrent engineering different stages of the design and development occur simultaneously.

This project was no different, i.e. a similar trial and error method was required in the design and fabrication process. Multiple iterations of each parts were made to account for factors such as model strength, flexibility, tolerance/friction, effect of shrinkage of PLA (Poly lactate acid, the material used for 3D printing.) The final product was made after two test prototypes failed. I will go over each prototype, including the finished product, and the possible design for further improvement.

4.7 Trial and Error

4.7.1 First Model

The first prototype was a successful visual aid, i.e. it could be used by the Professor to explain the direction of various forces acting on it. However, the prototype failed to showcase any gyroscopic properties. As shown in figure (7) the equilibrium position of the gyroscope was such that the gimbal was tilted. In an ideal case, the gimbal would be parallel to the horizontal plane. Moreover, the movement of the gimbal upon rotating the rotor was random, i.e. the gimbal did not always move in the direction where the torque should've directed it.

Using the observations two hypothesis were made:

1. The friction between the frame and gimbal needed to be increased for the gimbal to be parallel to the horizontal plane in equilibrium. And, increasing the area of contact between the gimbal and the frame should be sufficient in dealing with this problem.

2. The shrinkage of the printing material (i.e. PLA) caused the randomness. A proposed solution of this would be to scale up the model. The reason being that the error in the measurements made by the FDM (Fused Deposition Modeling) printer was absolute, i.e. it was approximately the same for all parts. Hence, increasing scaling up the model would reduce the percentage uncertainty and hence reduce the randomness.

Figure 7: First iteration of fabrication

4.7.2 Second Model

Observation from the second model were:

1. The gimbal was now parallel with the horizontal plane when left at equilibrium. (Note in figure (8) the gimbal is purposefully tilted in order to distinguish the individual parts in the assembled model)

2. The randomness was reduced drastically reduced.

3. The effect of the torque produce was difficult to observe. Such that the gimbal only displaced a small angle when the rotor would move. So, even though the gyroscope was functioning as it should have been there was no significant rotation of the gimbal to observe.

Figure 8: Second iteration of fabrication

Using the observation gathered thus far another hypothesis was made:

1. Increasing the weight of the rotor should create a larger impulse and hence, create a larger torque.

In accordance to this hypothesis, another design for the rotor was made. The next section deals with the new design of the rotor.

4.7.3 Third Model

The objective of the third model was to increase the weight of the rotor. This was done by changing the design of the rotor. Three holes were made normal to the curve of the rotor. Each hole was at an angle of 120 to the other holes. The engineering drawing is given in figure (9).

The observations of the third model were:

1. Significant angle displacement of the gimbal.

2. Reduced Randomness.

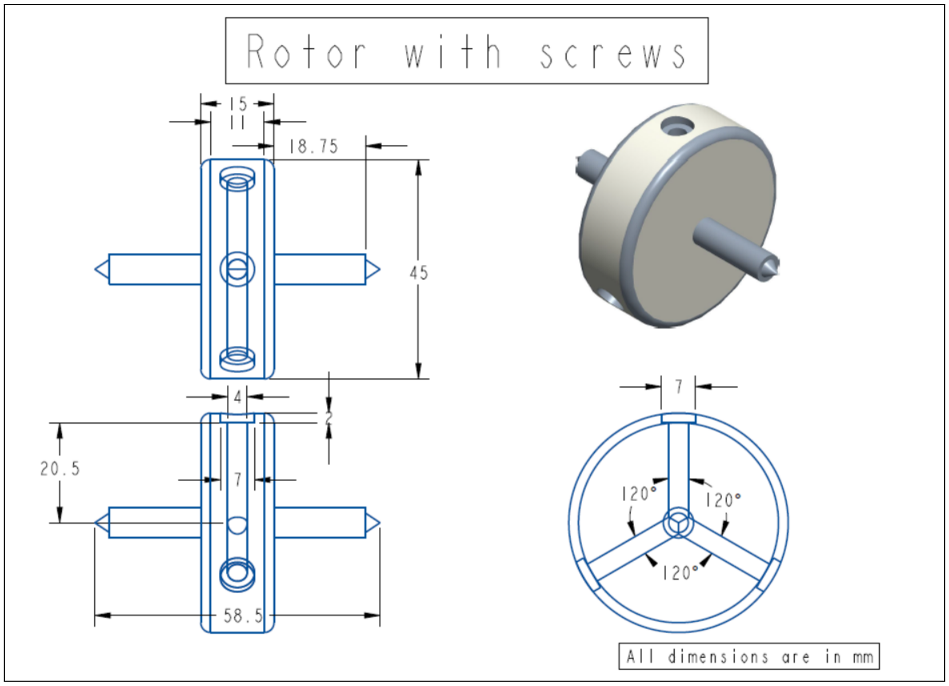


Figure 9: Engineering Drawing of rotor with screws

Figure 10: Final iteration of fabrication

4.7.4 Idea for further improvement

A way to further improve the gyroscope would be to make the rotor out of aluminium. The aluminium rotor would be produced through subtractive manufacturing. Since, aluminium has a much higher density than PLA, the magnitude of the torque produce would also be higher.

5 Calibrating the CAD model

This section includes details of calibrating the CAD model such that it would exhibit gyroscopic properties. This was done by adding material properties, gravity, friction, and then performing dynamic analysis.

Before discussing the calibration process it is important to note some important definitions.

1. **Mechanism**

   A mechanical device that transfers motion and/or forces in a predetermined fashion. A mechanism is made up of multiple links, linkages, or bodies connected through various types of joints. Each link should have at least two nodes -points of attachment to other links. At least one link is fixed to the global frame of reference -Ground Body

2. **Ground Body**

   Also called the global frame of reference. It is the body that remains stationary i.e. fixed to a point.

3. **Degree of Freedom (DoF)**

   The number of independent parameters is needed to uniquely define the position of a body in space at any instant of time.

4. **Connections/Joints.**

   Joints eliminate certain DoF and allow a motion for the remaining DoF. In Creo, Parametric Joints are called connections.

5. **Pin Joint**

   In the gyroscope project, only pin joints were used

   (a) Also known as the revolute joint.

   (b) It only allows for rotational movement about a selected axis of revolution.

5.1 Updating Dimensions

To accommodate for shrinkage, the dimensions of assembled parts were updated using measurements from the 3D printed model. This was done so that the calibrated model would be a more accurate depiction of the real-life model.

5.2 Adding Material Properties

Creo Parametric allows for material properties to be added to the CAD model. Material properties define the density, and mass of an object. The material is added to individual **.prt** file. The steps for adding material properties are given below.

1. **Opening part file**

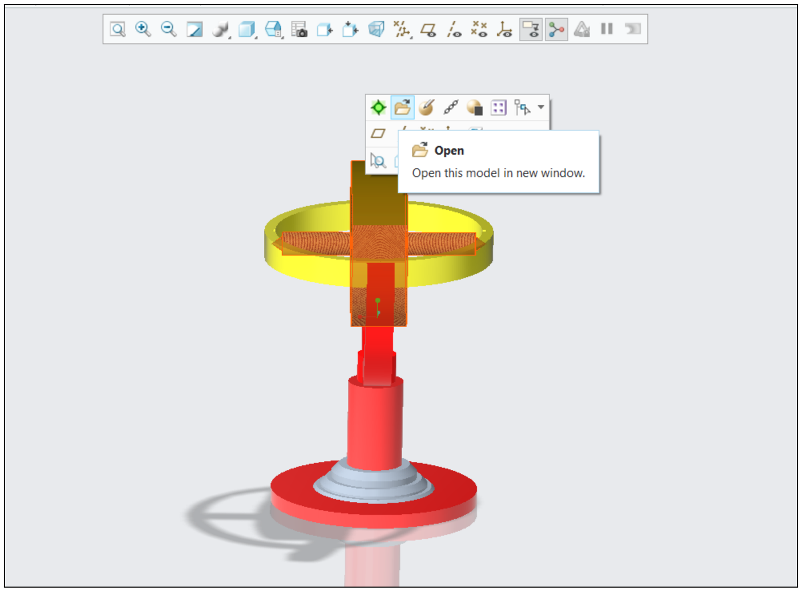


Figure 11: Opening part file

2. **Adding Material Properties 1**

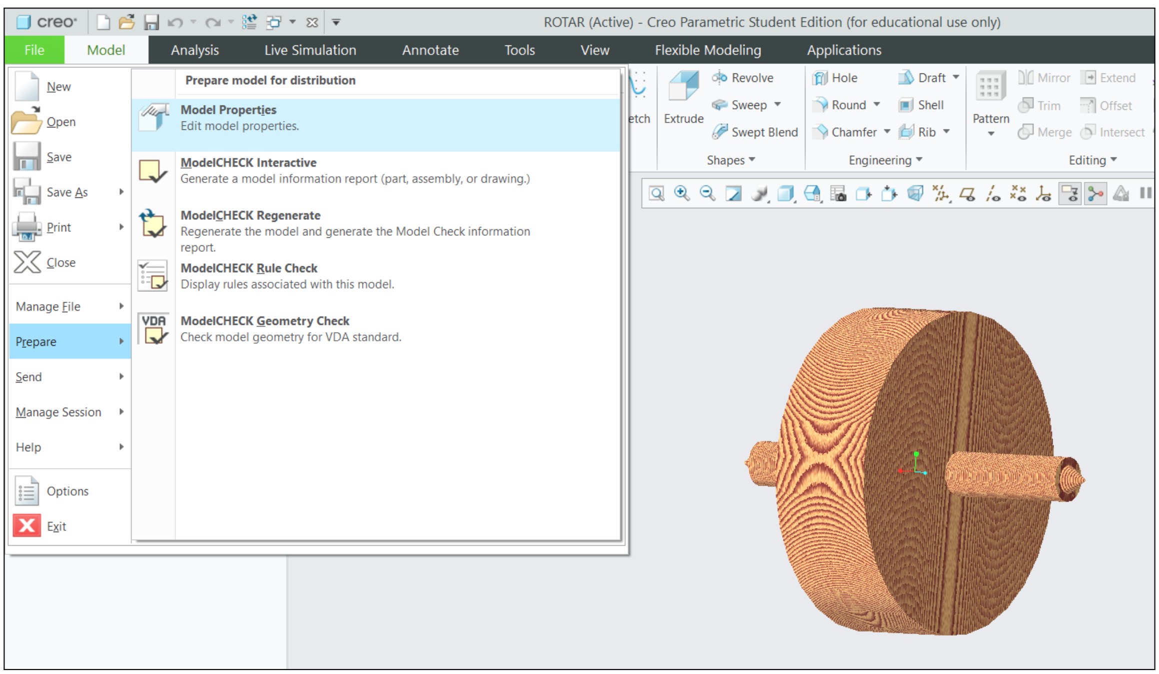


Figure 12: Adding Material Properties

3. **Adding Material Properties 2**

Material>Change>Standard-Material-Granta-Design>Plastic>PLA

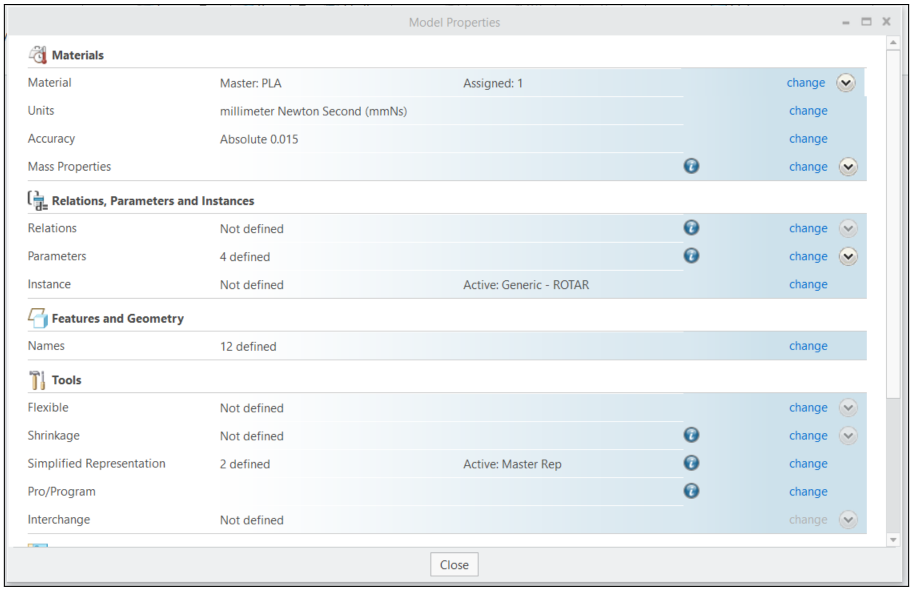


Figure 13: Adding Material Properties 2

5.3 Dynamic Analysis

Although Creo Parametric contains many useful tools for dynamic analysis, here we will only talk about those that are relevant to the project. To perform dynamic analysis we need to first decide values for the following parameters.

1. Adding Gravity

2. Adding Friction

3. Initial Conditions (Initial motion and forces)

The video of the dynamic analysis can be found at

6 Conclusion

Summarize and discuss the experimental results, what do the results say about your hypothesis, if such a hypothesis was made for the experiment. Mention the uncertainty in the calculated quantity Be precise and only include scientific discussion.