

JUNE 12, 2019

CAE & STRESS ANALYSIS (M5X02064)

MOTION SIMULATION

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EXECUTIVE SUMMARY

The requirement of this assignment was to utilise SolidWorks Computer Aided Engineering software to construct an Assembly and Motion Simulation from a number of pre-modelled part files from a gearbox assembly. The components required positioning and constraint within an assembly file, which later required the design and modelling of an appropriate housing based on the geometry, position and dimensions of the gearbox components. Within the assembly and across part files, a Global Variable was created within a Text Editor file linking each bearing diameter to the gearbox housing; the file provided one location where dimensions could easily and rapidly be updated. Once the full assembly had been completed, a process of redundant constraint reduction was undertaken utilising Hinge Mates and Rigid Groups. The final assembly was left with seven redundant constraints and four degrees of freedom. From this a Motion Simulation was successfully conducted to analyse the angular velocity increase for the gear change within the assembly. During the Motion Simulation, experiments were performed on forces, motor speeds, frame rates and torsional dampers. The foremost outcome from these experiments was that by increasing the frame rate from the SolidWorks default 25fps to 600fps, which obtained data for every degree of revolution based on a motor speed setting of 100RPM, significantly improved the graphical analysis accuracy and precision. The desired outcome from the assignment was to demonstrate knowledge and understanding of part geometry, mating conditions, degrees of freedom, appropriate modelling tool selection, Motion Simulation and FEA techniques and their applications.

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1.0 INTRODUCTION

1.1 COMPUTER AIDED ENGINEERING (CAE).

Computer Aided Engineering (CAE) originated in the 1980s and quickly became popular within industry by providing design engineers with a simulation tool capable of studying the structural performance of new products before manufacture. In today's industry, with the increasing complexity of mechanical products and growing economic competition, organisations need to design and develop their products quicker in order to bring to market faster. Computer Aided Engineering can benefit this process by providing a quick and accurate solution to optimising product performance by predicting and quantifying how physical effects such as force, vibration, fluid flow and heat will react with their product during the developmental stage (Solidworks.com, 2019).

A conventional product development process is reliant on a design, build and test approach. A prototype is generally manufactured to enable physical testing in real world environments. The manufacture of a prototype may have a requirement for special purpose tooling; once design changes are factored in, the whole process can become costly, causing delays and disruption within the product development cycle. Stages are often rushed or overlooked and design for manufacture is sometimes not even considered in the attempt to speed things up. Chang proposes that “only eight percent of a total product budget is spent on design; however, design determines eighty percent of the lifetime cost of the budget in the early stages” (2013, p3). For organisations to stay competitive and survive in a global market, new products must be manufactured to better quality, lower costs and with shorter lead times. By adopting Computer Aided Engineering, the need for prototyping and physical testing can be reduced and often eliminated from the process altogether. Organisations are able to significantly reduce costs and lead times to manufacture by adopting the results of engineering analysis as a means of performance verification (Chang, 2013; Petrova & Chernev, 2012; Solidworks.com, 2019).

The fundamental process of product design using Computer Aided Engineering involves the generation of a parametric model within Computer Aided Design (CAD) software. The model provides a centralised location to all information that can be easily shared across the enterprise. Performance simulations and reliability evaluations can then be conducted on the model using CAE software. Many commercial Computer Aided Design Systems have integrated CAD/CAE suits, some with the addition of Computed Aided Manufacturing software, which can additionally conduct manufacturing simulations and cost estimates. Many third-party software designers are making a significant effort to integrate their systems into CAD software packages. An example of which would be the CAE and CAM software designers who collaborated with SolidWorks to integrate their analysis software seamlessly into the SolidWorks environments, such as CAMWorks. Pro/ENGINEER have also integrated CAD/CAE/CAM packages, with CATIA and NX supporting some aspects of engineering analysis. Computer Aided Engineering is a fast-emerging field and its popularity has increased substantially over the past twenty years. This can mainly be attributed to the aforementioned economic and market conditions; however, the growing increase of low-cost powerful computers and the development of many user friendly and different types of analysis software available has moved the need away from super computers or powerful work stations. Many free and commercial software packages are available for the different types of analysis required. Listed below are some of the analysis methods that can be used throughout a product design cycle (Chang, 2013; NPD-Solutions.com, 2019a).

- Finite element analysis (FEA)
- Computational fluid dynamics (CFD)
- Thermal analysis
- Kinematics and dynamics analysis
- Multi-physics analysis
- Electromagnetic analysis
- Structural analysis
- Moldflow analysis
- Stamping analysis
- Acoustic analysis
- Crash testing
- Product simulation
- Durability analysis
- Factory simulation
- Logic-timing and verification
- Electronic design simulation (logic simulation and circuit simulation)
- Design visualization and animation

(NPD-Solutions.com, 2019a).

1.2 FINITE ELEMENT ANALYSIS (FEA).

The first widely adopted simulation tool within computer aided engineering was finite element analysis (FEA). Finite Element Analysis was first introduced in 1943 by R. Courant, who utilised a method of numerical analysis called the Ritz to approximate solutions to vibration systems. Soon after, M. J. Turner, R. W. Clough, H. C. Martin and L. J. Topp published a paper in 1956 on a broader definition of this numerical analysis, determining the stiffness and deflection of complex structures. Nearing the early seventies FEA had been limited to expensive super computers owned by the aeronautic, automotive, defence and nuclear industries. With the evolution of computers and their declining cost, FEA has become very popular from its ability to predict accurate results for all types of parameters. (Formula1-dictionary.net, 2019).

FEA is the simulation of a physical phenomenon acting on an object utilising a mathematical technique called Finite Element Method (FEM). Where, mathematical calculations are used to quantify and predict how physical effects such as force, vibration, fluid flow and heat will react with an object. Most of these predictions can be described through Partial Differential Equations and FEA has developed these numerical techniques to enable computers to solve these problems. Differential equations and FEA only give an approximate solution to a problem, however, it enables engineers to identify failure points or areas under tension within their designs. This is achieved by breaking down real objects into a mesh of geometric shapes or finite elements. The mesh can be directly related to the accuracy that may be obtained from the analysis. Once a model is defined within CAD software, with outline material properties, applied loads and constraints. A finite element mesh is used to subdivide the CAD model into smaller domains called elements, over which the equations are solved. A process

of mesh refinement then takes place to reduce the element size, the smaller and more refined the mesh, the greater the chance of a true solution. These calculations can then be used by the computer to predict the behaviour of the object (Comsol.com, 2019; NPD-Solutions.com, 2019b).

The main limitations of FEA are that the analysis is not conducted on a real part, any results for stress, strain or displacement are approximated. The calculus model utilised can be subjective as the user is able to manipulate the model and cannot fully determine the accuracy; often results are further validated on real structures. Finite element analysis is often used to help predict:

- Mechanical stress
- Mechanical Vibration
- Fatigue
- Motion
- Heat Transfer
- Fluid Flow
- Electrostatics
- Plastic injection moulding

(Autodesk.co.uk, 2019; Designworld.com, 2019).

1.3 MOTION ANALYSIS

With the aforementioned increasing complexity of mechanical designs and market competition, engineers often need to extend beyond the scope of structural performance from FEA and evaluate the kinematics and dynamics of new designs before manufacture. Motion simulation or motion study, is a term generally used to describe a simulation of the movement of a mechanical assembly. Motion studies are subcategorised into two groups, Kinetics and dynamics. Dynamic analysis focuses on the study of motion that is a result of a force applied. Where, Kinetic analysis is the study of motion without consideration to forces acting on it (Solidworks.com, 2019a).

- Kinematic simulations illustrate the position of all components within an assembly in relation to time within a cycle. This type of simulation is used mainly during steady-state motion to identifying any interference within mechanical systems. These software packages often provide information on forces that are a result of the motion (reaction forces).
- Dynamic analysis is more complex and accurately simulates authentic motion, captures additional data to further define and account for forces. In general terms, Kinematic simulations help evaluate form, whereas, dynamic simulations can provide an analysis to function.

(Petrova & Chernev, 2012; NPD-Solutions.com, 2019c).

Contrasting to the flexible structural studies of FEA, motion analysis represents mechanisms within assemblies as rigid components with degrees of freedom. Motion analysis uses numerical solvers to calculate equations of motion to give information in regard to displacements, velocities, accelerations and joint reactions. The benefits of motion simulation is that it is almost a free byproduct of solid modelling. Engineers are able to simulate mechanisms to determine workable designs, calculate requirements for actuators or motors and view animations to highlight problems or to study aesthetics. (Chang, 2013; NPD-Solutions.com, 2019c).

2.0 GEARBOX HOUSING DESIGN

2.1 ASSUMPTIONS:

To facilitate design requirements, the following assumptions were generalised:

- The orientation of the gearbox will be maintained as per the example Gearbox Housing model given within the brief, i.e. as illustrated in the third angle projection assembly in Figure 1. This orientation is needed to ascertain the placement of the gearbox vent.

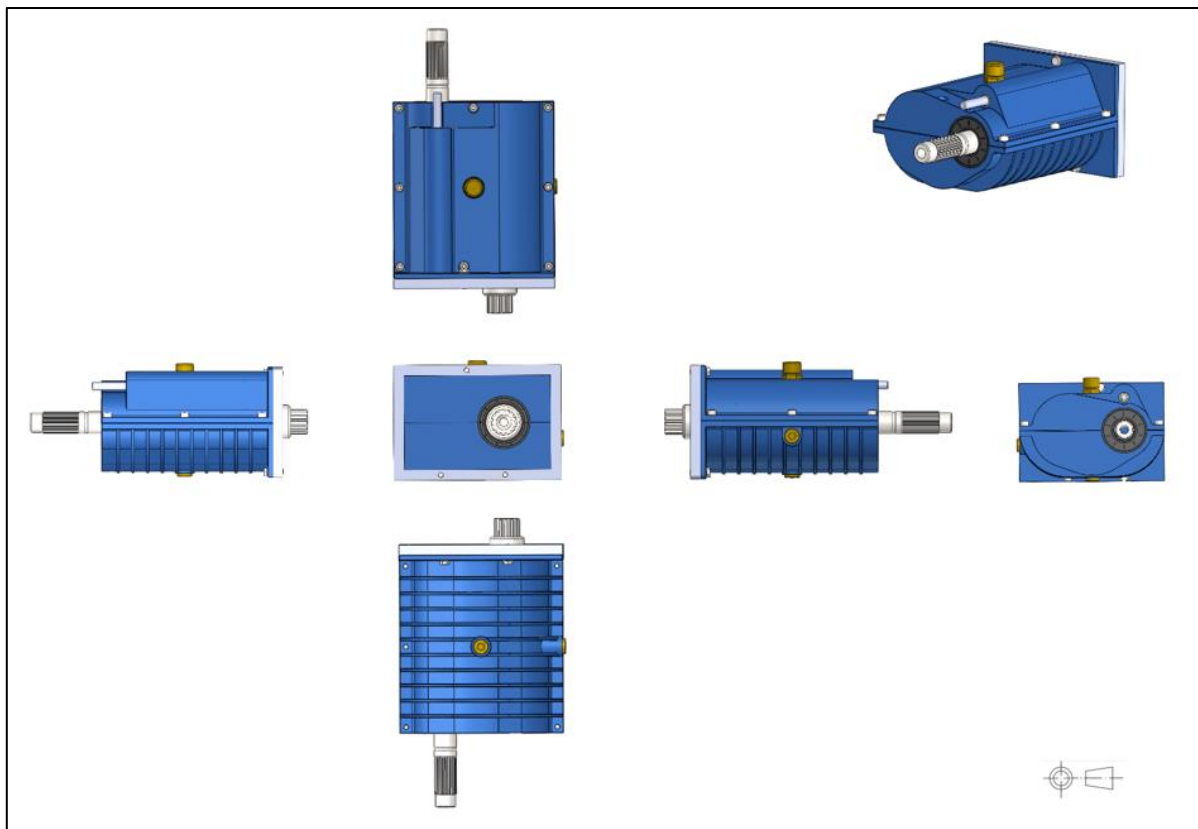


Figure 1: Third Angle Projection View of Gearbox Assembly (SolidWorks, 2018).

- The input and output shafts are not constrained to any dimensional requirements protruding from the housing.

- The gearbox housing is not constrained to any dimensional requirements other than mounting to the Frame.
- The gear Selector Shaft must be accessible from outside the housing. However, linkage to an additional assembly is not detailed and not required.

2.2 GEARBOX LUBRICATION

- The gearbox housing has been designed to maintain an oil bath to lubricate the bearings, gears and selector utilising splash lubrication. Splash lubrication involves using internal gears, or other rotating components, to dip into an oil bath and splash oil into the required areas to provide lubrication (KHKgears.net, 2019a).
- The housing incorporates a small sump to allow oil to return to a drain point to facilitate oil changes, or if an additional cooling or oil circulation system is required, the sump would provide an adequate return point.
- On top of the gearbox housing is a vent plug or sometimes referred to a gearbox breather. The top vent plug prevents contamination and also provides a filling point for oil changes.
- To maintain the required oil level inside the housing, an additional level plug has been fitted. The plug can be removed to inspect or achieve the desired lubrication level.
- The input and output shafts have been fitted with oil seals to prevent bearing contamination and to prevent oil leaks.

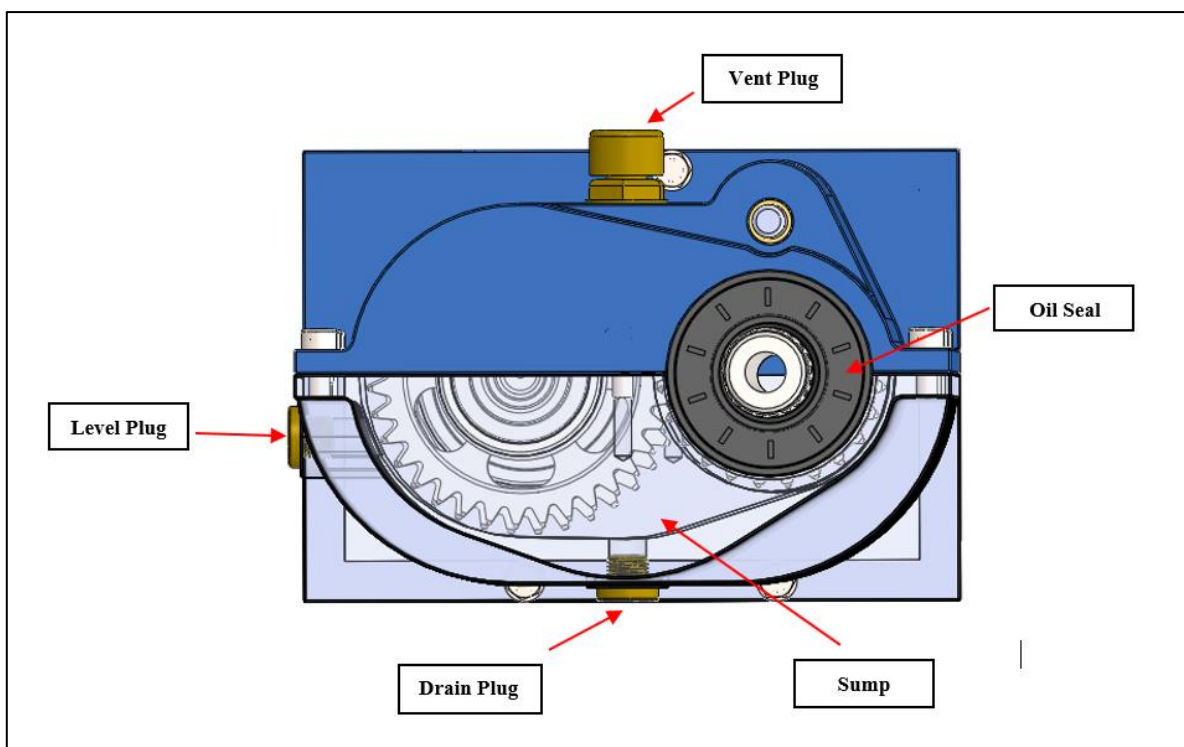


Figure 2: Gearbox Assembly - Sump Detail (SolidWorks, 2018).

2.3 MOUNT ALIGNMENT

- The gearbox housing has a recess to aid alignment when mounting to the Frame.

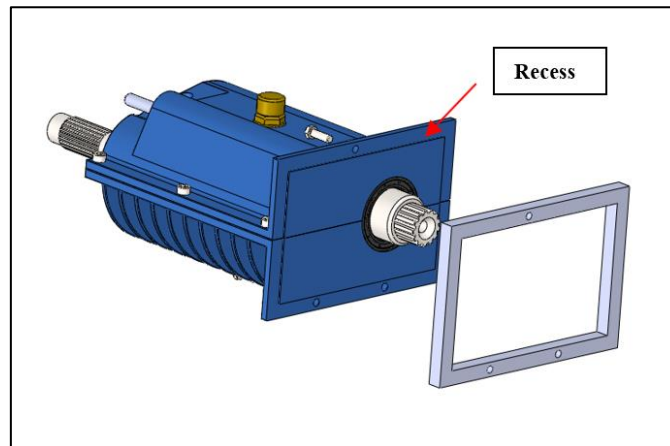


Figure 3: Gearbox Assembly - Frame Mount Detail (SolidWorks, 2018).

2.4 SHIFTER FORK ROD BRONZE BUSH

A bronze bush was added to the gearbox housing to provide a bearing for the Shifter Fork Rod's linear movement. Bearing bronzes offer many benefits from wear resistance, anti-seizing properties, tolerance to dirty environments, anti-corrosive properties and can be easily manufactured for one-of-a-kind configurations simply and economically (Copper.org, 2019).

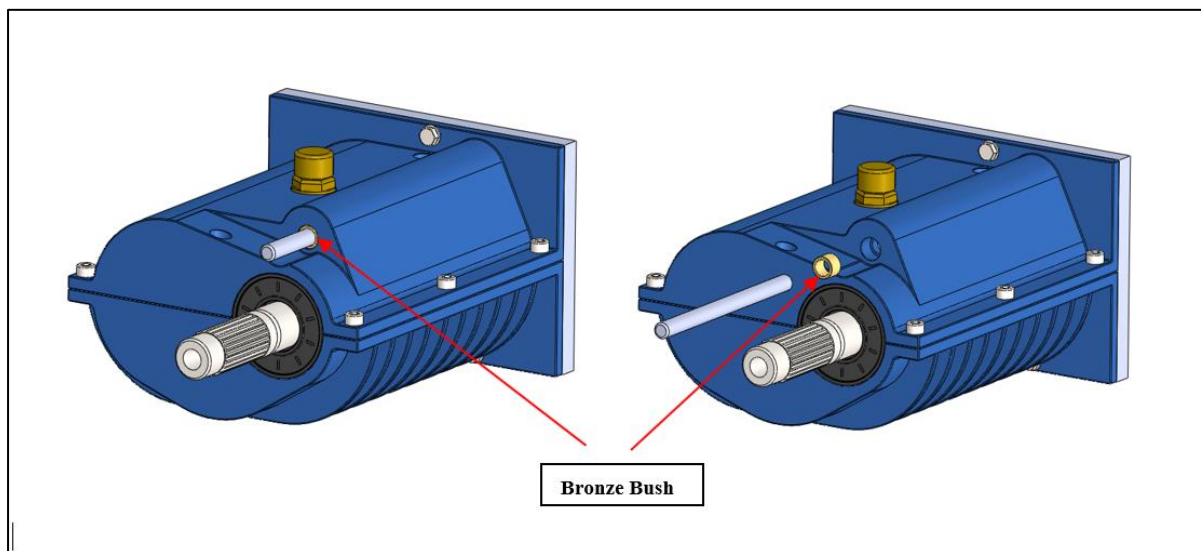


Figure 4: Gearbox Assembly - Frame Selector Fork Shaft Bush Detail (SolidWorks, 2018).

2.5 GEARBOX HOUSING FIXTURES

The gearbox housing has been designed as two parts to aid with assembly and manufacture. The two parts are clamped together by eight M5 bolts.

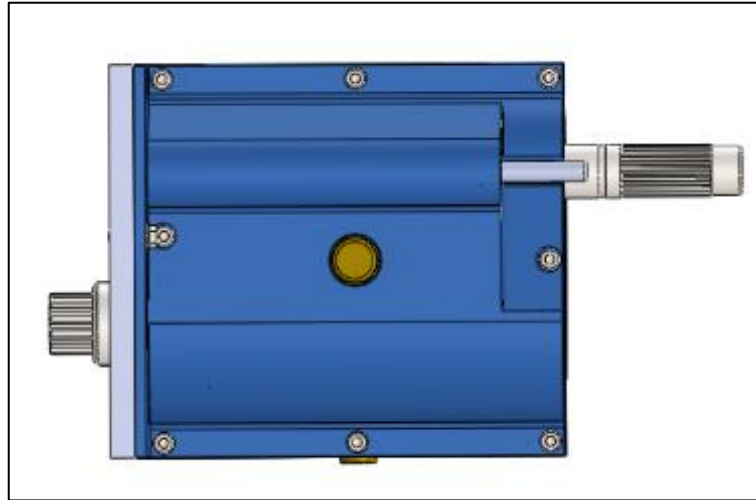


Figure 5: Gearbox Assembly - Fixture Detail (SolidWorks, 2018).

2.6 GEARBOX COOLING

The gearbox housing is currently reliant on natural cooling, using convection and radiation heat transfer to the surrounding air. The bottom half of the housing which contains the oil bath has been designed with cooling fins to assist with the heat dissipation. Cooling fins are commonly used to increase the surface area from which heat can be radiated away from an object. The fins project outwards and are commonly utilised on motor bike engines, however, the efficiency is greatly increased by applying force air (Cyberphysics.co.uk, 2019; Machinedesign.com, 2019).

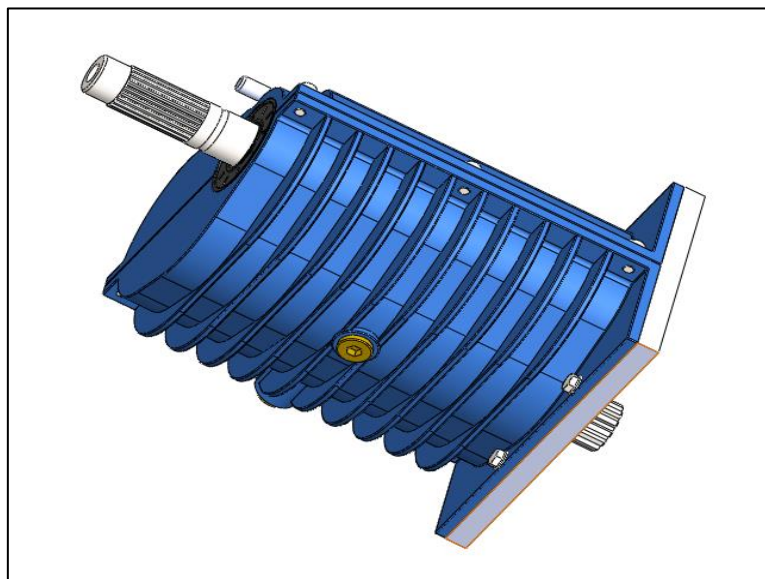


Figure 6: Gearbox Assembly - Cooling Fin Detail (SolidWorks, 2018).

2.7 GEAR CLEARANCE AND SHAFT CENTRES

The gear clearance and shaft centres were determined using the Standard spur gear equations below:

Standards

- AGMA 2001-C95 or AGMA-2101-C95 Fundamental Rating factors and Calculation Methods for involute Spur Gear and Helical Gear Teeth
- BS 436-4:1996, ISO 1328-1:1995. Spur and helical gears. Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth
- BS 436-5:1997, ISO 1328-2:1997. Spur and helical gears. Definitions and allowable values of deviations relevant to radial composite deviations and runout information
- BS ISO 6336-1:1996. Calculation of load capacity of spur and helical gears. Basic principles, introduction and general influence factors
- BS ISO 6336-2:1996. Calculation of load capacity of spur and helical gears. Calculation of surface durability (pitting)
- BS ISO 6336-3:1996. Calculation of load capacity of spur and helical gears. Calculation of tooth bending strength
- BS ISO 6336-5:2003. Calculation of load capacity of spur and helical gears. Strength and quality of materials

Figure 7: Reference to Standards for Formulas and Terminology (Roymech.co.uk, 2019).

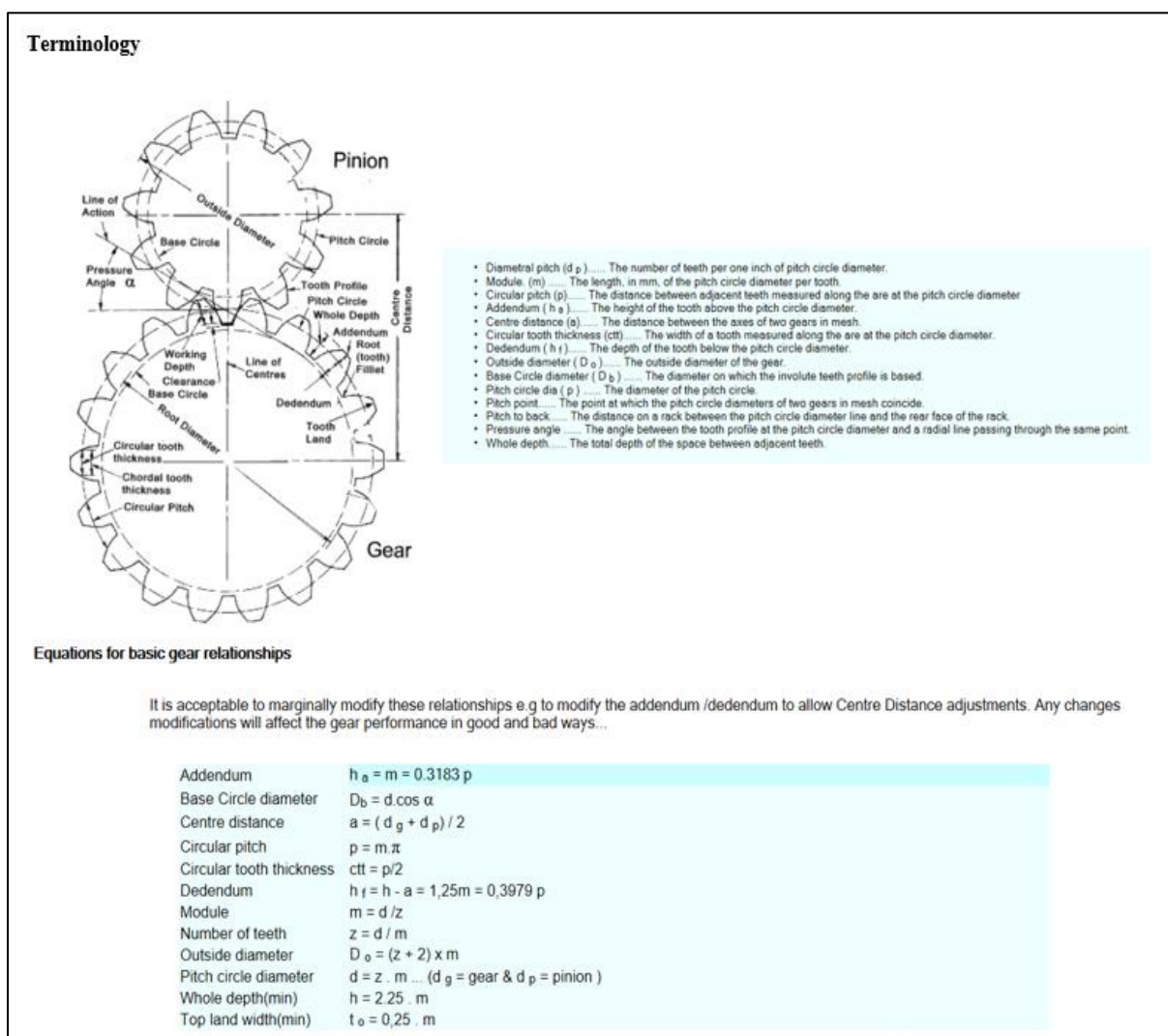


Figure 8: Gear Formulas and Terminology (Roymech.co.uk, 2019).

- The dimension for each gear and the required equations were entered into an Excel table to calculate the centre distances. However, it was necessary to rearrange the formula for calculating the outside diameter in order to calculate the module for each gear. The module is required to calculate the pitch circle diameter and the given formula presented too many unknowns. The pitch circle diameter was needed to calculate the centre distances.
- As shown in Table 1, the results for the centre distance of the two paired gear sets differed slightly. This can be justified by the variation in the modules calculated. Gear sets in mesh must have equal modules. The most probable reason for this outcome was that the SolidWorks Model from which the outside diameters were taken had some slight dimensional variation from the standard (Roymech.co.uk, 2019).
- To ensure the gears meshed correctly and did not foul one another, the largest centre distance was utilised; highlighted within the table below.

	Outside Diameter (mm)	No. of Teeth	Module	PCD	Centre Distance (mm)
			$D_o / (z + 2)$	$z \times m$	$(d_g + d_p) / 2$
Primary First Gear Pinion	52.5	23	2.1	48.3	60.81315789
Output First Gear	77.4	36	2.036842105	73.32631579	
Primary Second Gear Pinion	56	24	2.153846154	51.69230769	61.31912682
Output Second Gear	75	35	2.027027027	70.94594595	

Table 1: Gear Centre Distance Overview

3.0 SOLIDWORKS MODELLING

3.1 ADDING RELATIONS

To link relations and prevent unnecessary dimensioning the Equal relation was added during this sketch. Relations can be added by holding Control Key and selection entities.

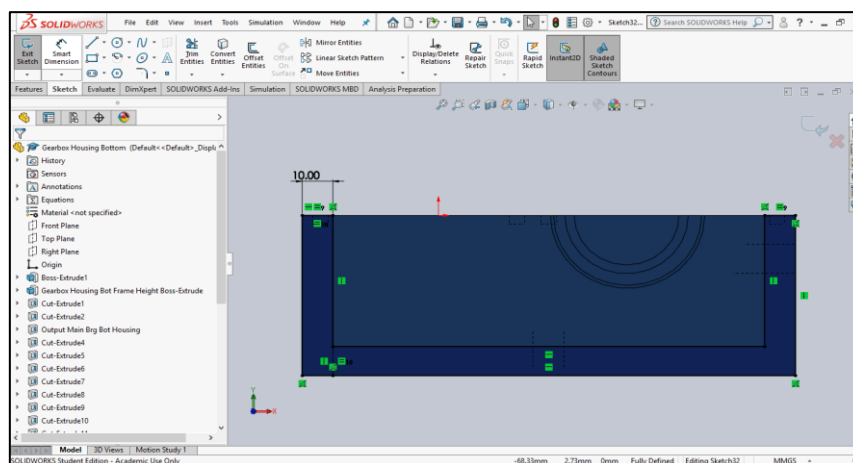


Figure 9: SolidWorks Adding Relations within a Sketch (SolidWorks, 2018).

3.2 SKETCH FILLET

All possible fillets were sketched before extruding.

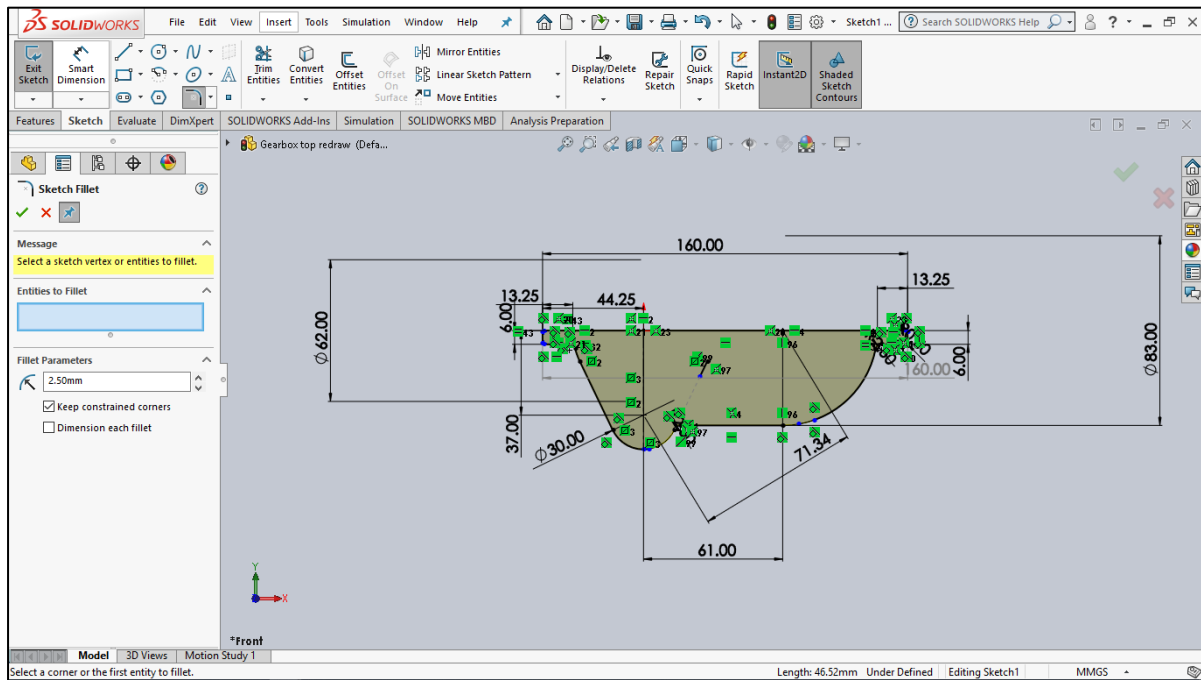


Figure 10: SolidWorks Sketch Fillet Feature (SolidWorks, 2018).

3.3 MIRROR ENTITIES

Mirror Entities was utilised during the sketch to obtain an equal and opposite angle.

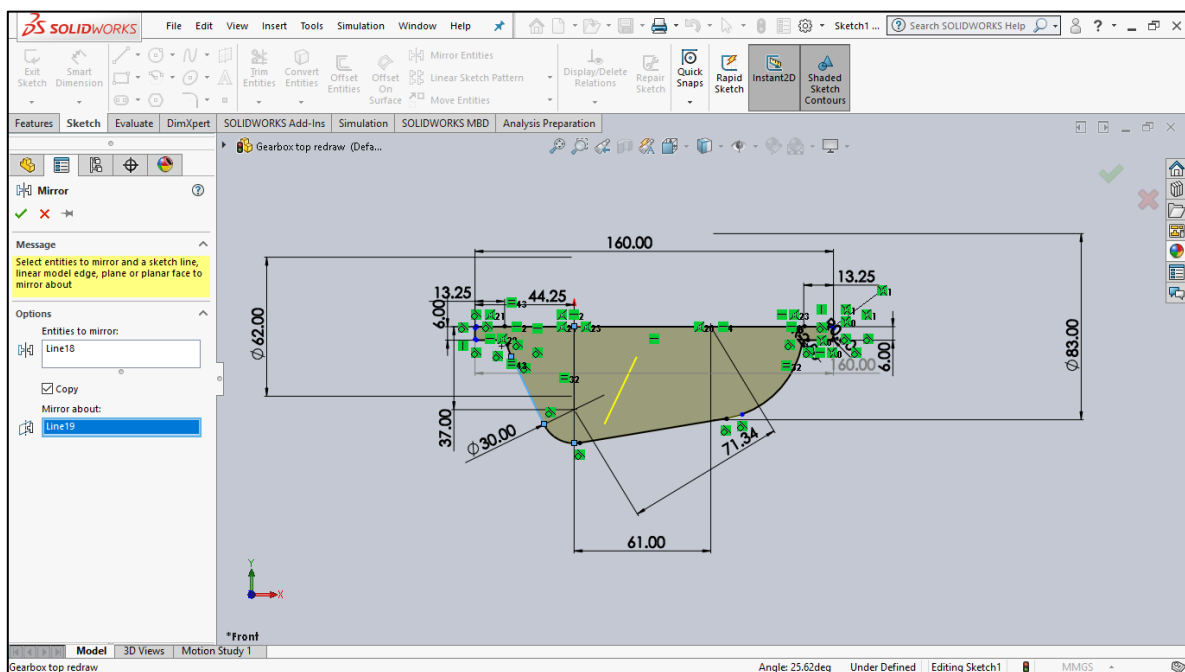


Figure 11: SolidWorks Mirror Entities Feature (SolidWorks, 2018).

3.4 MIRROR FEATURE

The Mirror Feature was used to mirror the body of the bottom of the housing to prevent repeat modelling.

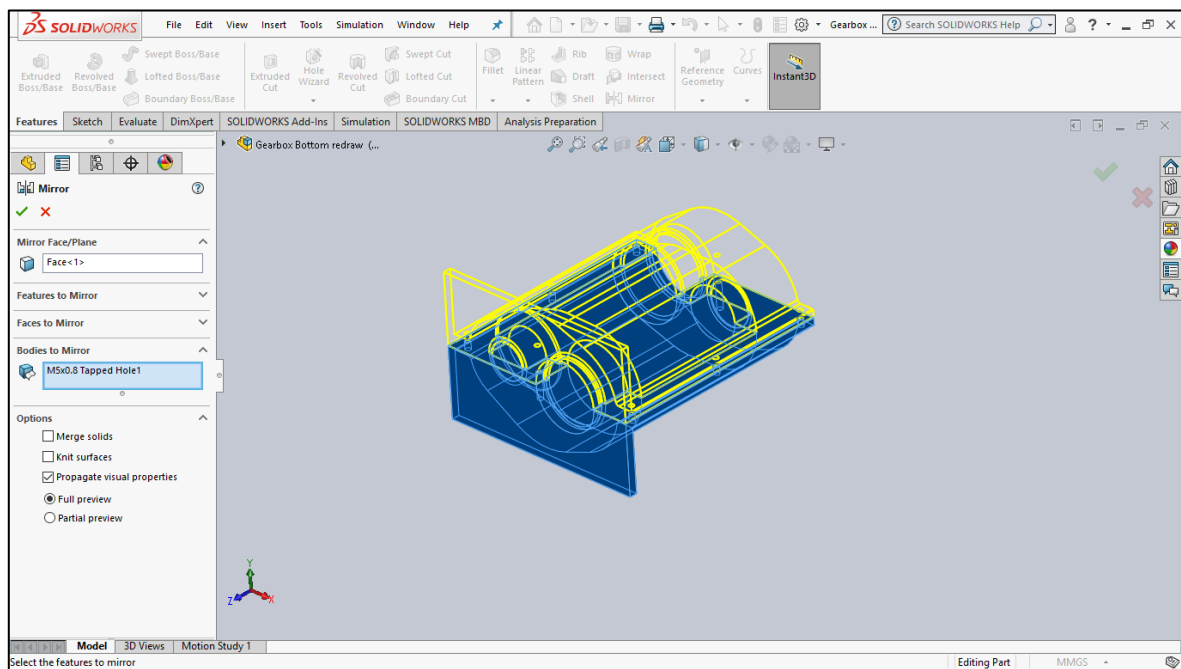


Figure 12: SolidWorks Mirror Feature (2018).

3.5 DELETE/KEEP BODY

The Delete/Keep Body feature was used to remove the lower half of the housing.

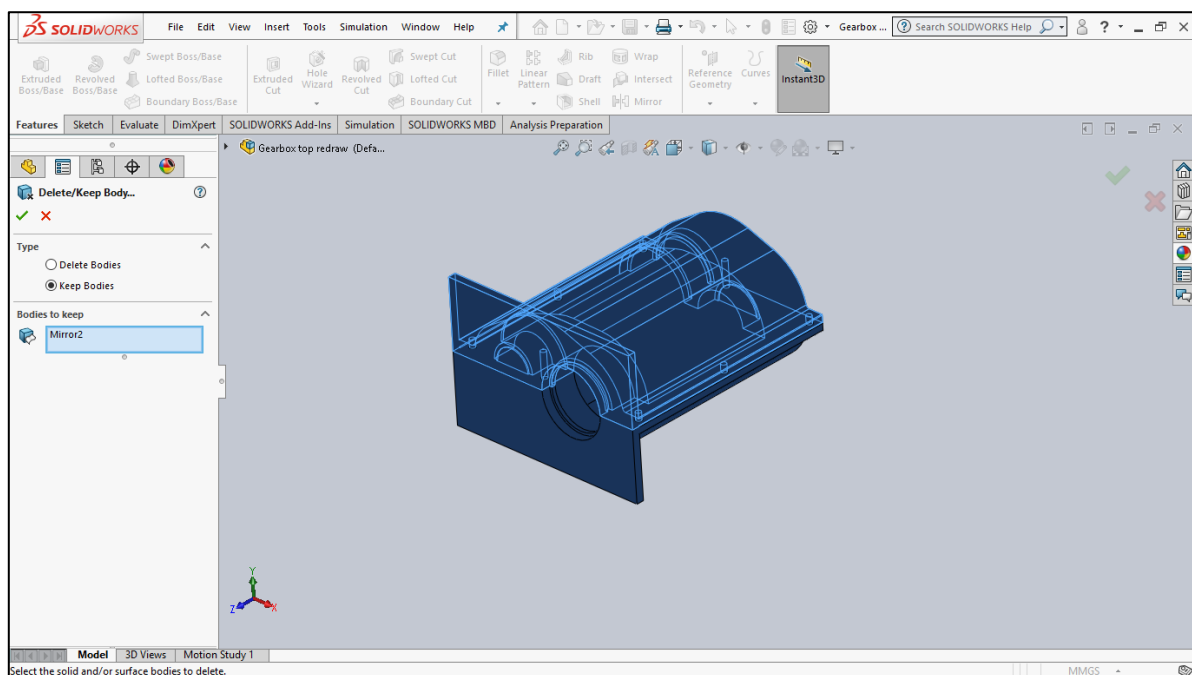


Figure 13: SolidWorks Delete/Keep Body Feature (SolidWorks, 2018).

3.6 HOLE WIZARD

The Hole Wizard feature was utilised to add multiple holes.

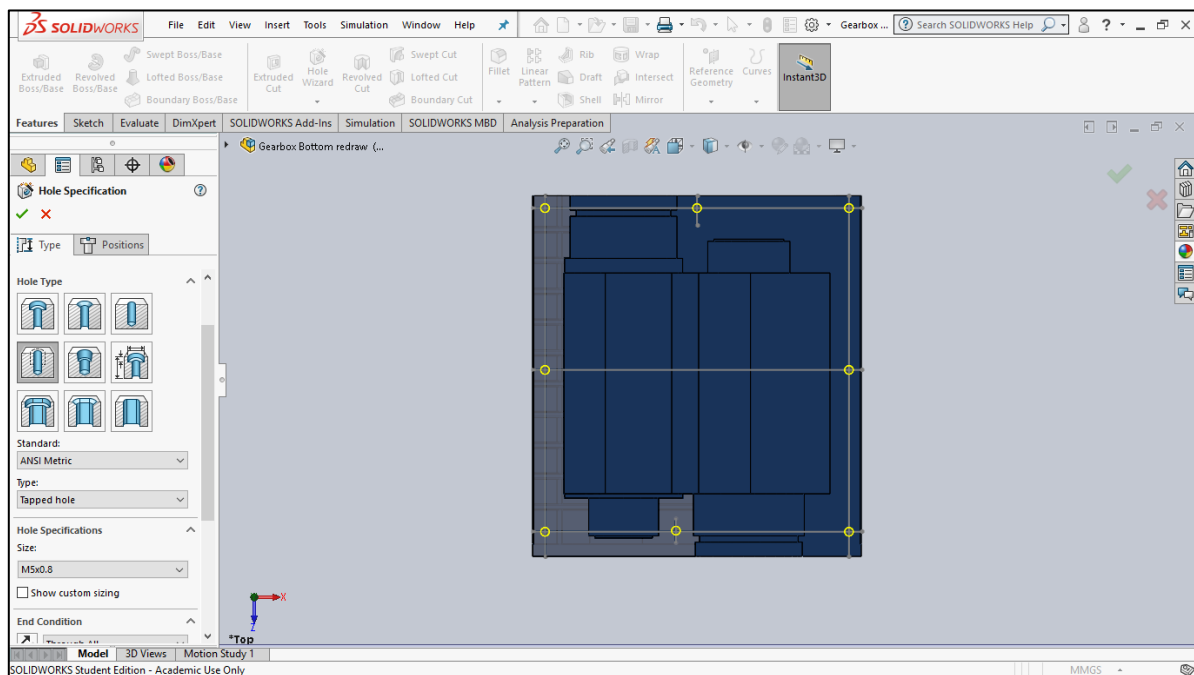


Figure 14: SolidWorks Hole Wizard Feature (SolidWorks, 2018).

3.7 LINEAR PATTERN

The Linear Pattern feature was utilised to copy the cooling fins on the motor housing.

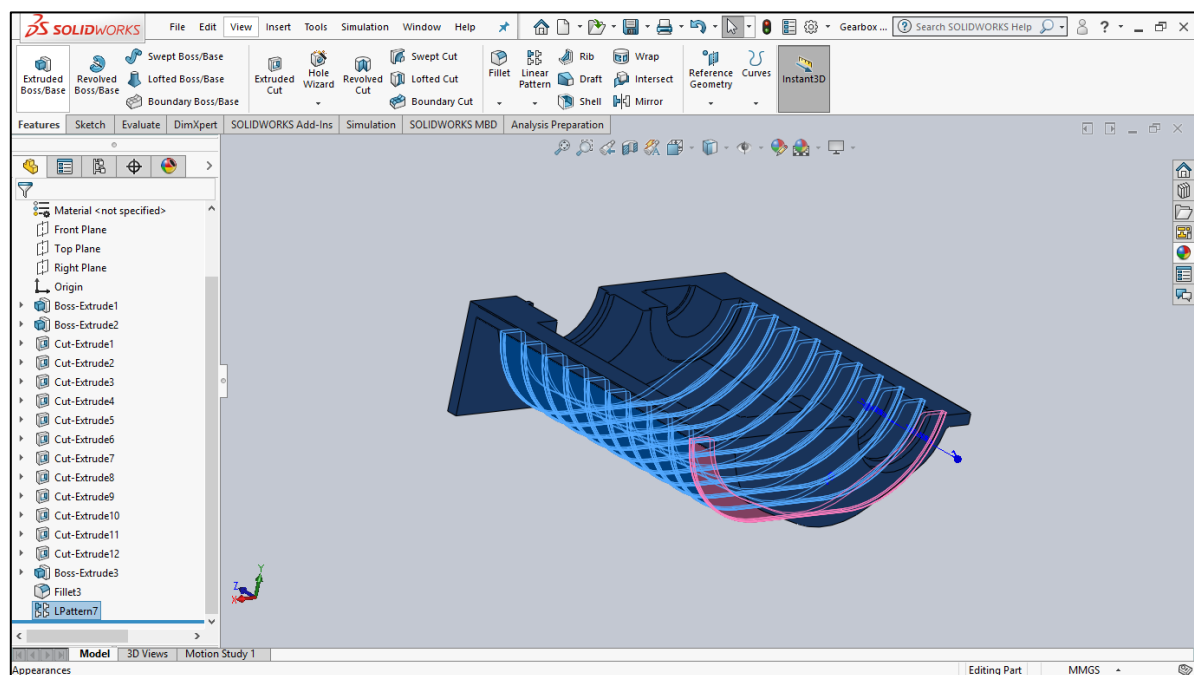


Figure 15: SolidWorks Linear Pattern Feature (SolidWorks, 2018).

3.9 REVOLVED BOSS/BASE

The Revolved Boss/Base feature was used to create the oil seals.

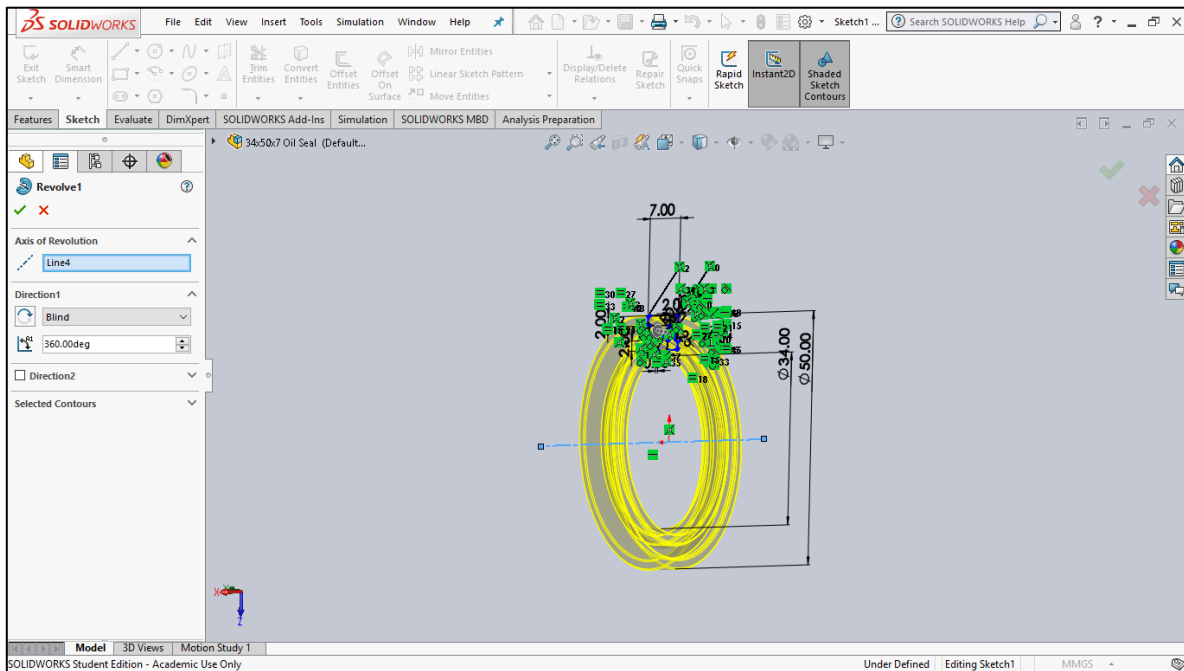


Figure 16: SolidWorks Revolved Boss/Base Feature (SolidWorks, 2018).

3.10 CIRCULAR PATTERN

The Circular Pattern feature created the seal detail.

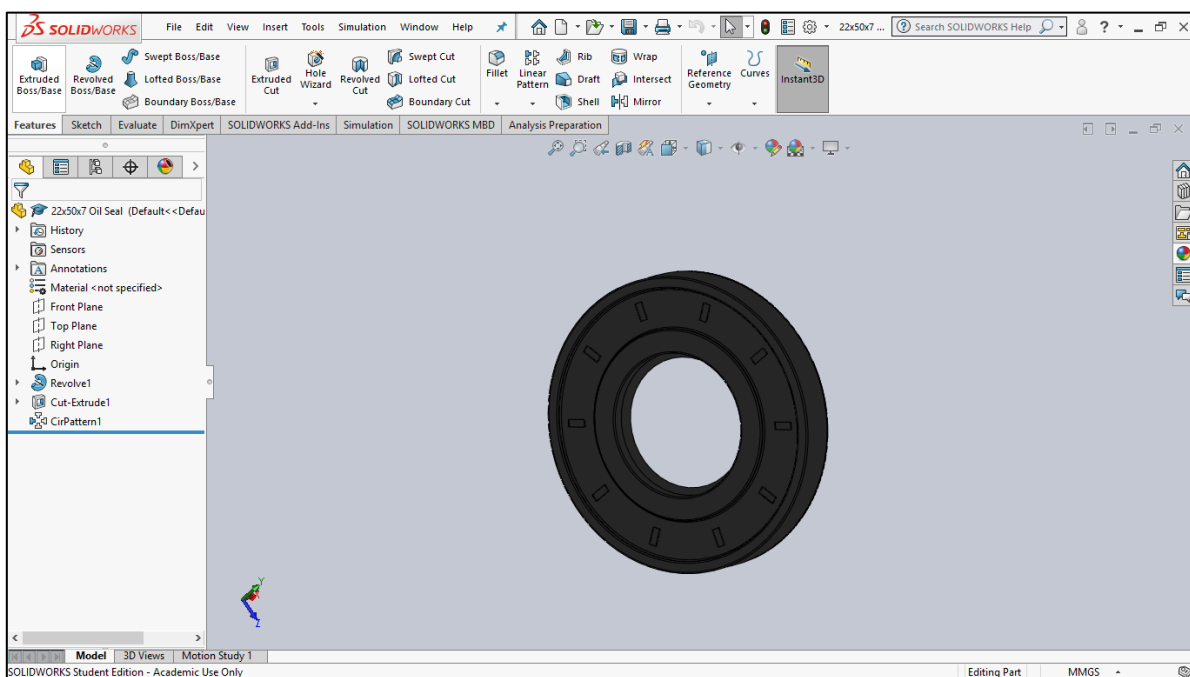


Figure 17: SolidWorks Circular Pattern Feature (SolidWorks, 2018).

3.11 MODEL GEOMETRY THREAD (BOSE/BASE SWEEP FEATURE).

- Although SolidWorks has a Thread feature tool that provides a variety of thread types that can be applied to a model. It is sometimes necessary to use model geometry threads; this is required when the part being modelled requires the thread as part of a tooling process, such as CNC machining or casting.
- In this example where the Bose/Base Sweep feature was utilised, along with thread standards; the SolidWorks Thread feature would have provided a satisfactory representation. However, this feature was chosen to demonstrate user knowledge and advanced practices.
- The standard thread profile was first calculated from the formulas in Figure 18.
- The Sweep tool was then used to sweep this profile over a helix to create the thread.

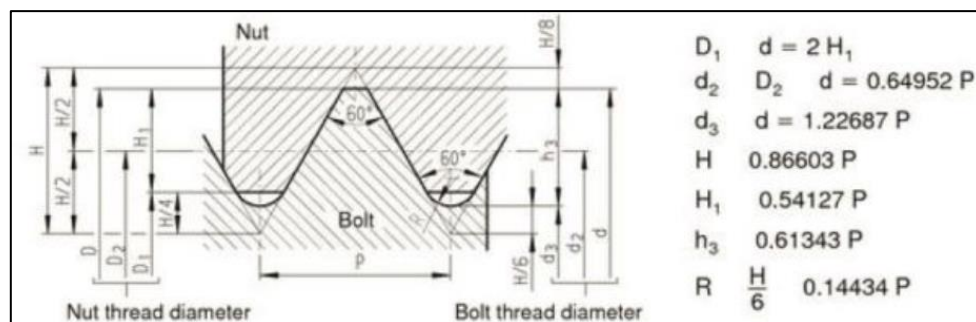


Figure 18: Thread Standard Formulas (Mdmetric.com, 2019).

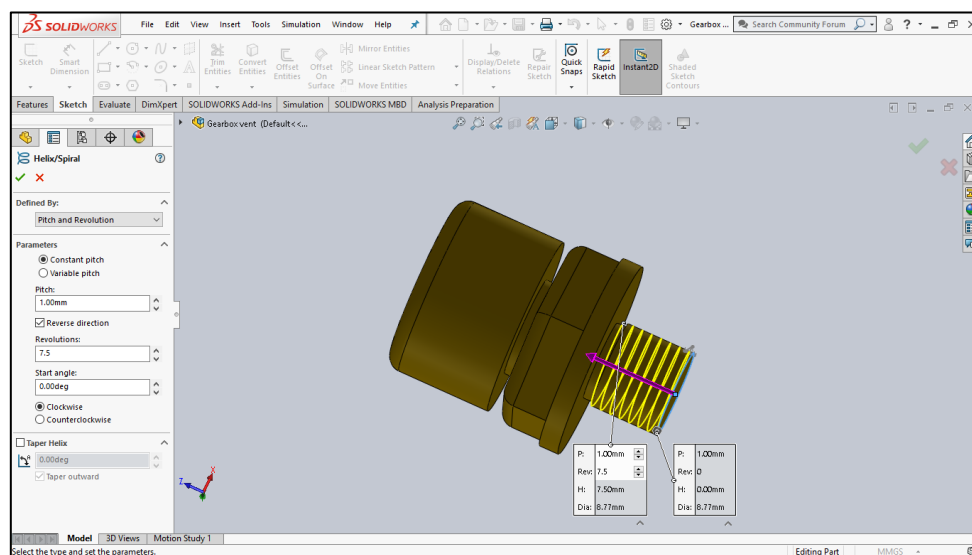


Figure 19: SolidWorks Helix/Spiral Feature (SolidWorks, 2018)

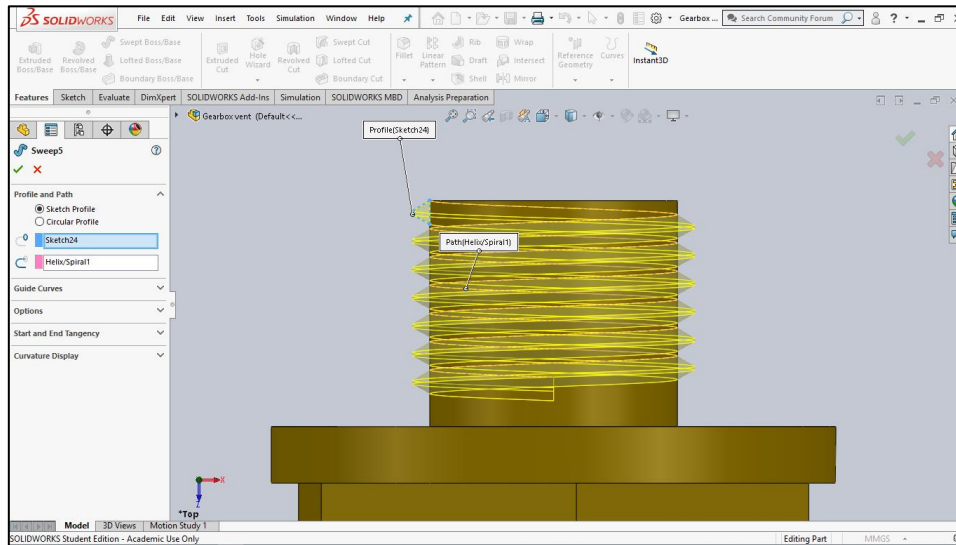


Figure 20: SolidWorks Base/Base Sweep Feature (SolidWorks, 2018).

4.0 SOLIDWORKS EQUATIONS

4.1 CREATING GLOBAL VARIABLE AND TEXT EDITOR FILE:

- Global variables were created for all of the bearing outside diameters and used within the part files for each bearing and the gearbox housing.
- A file was created to link the global variable values across different part files. The file enables editing of all equations from the Text Editor, where you can easily and rapidly update changes from one location.
- Any change to the 'Output Main Brg O/D' global variable, will automatically update sizes of the Gearbox Housing Top, Gearbox Housing Bottom and the Output Main Bearing part files.

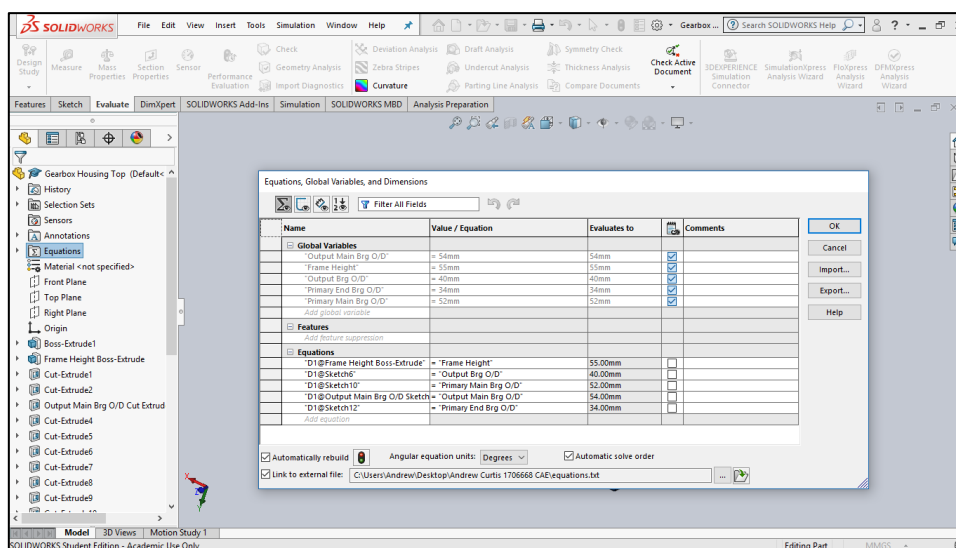


Figure 21: SolidWorks Equation Manager Feature (SolidWorks, 2018).

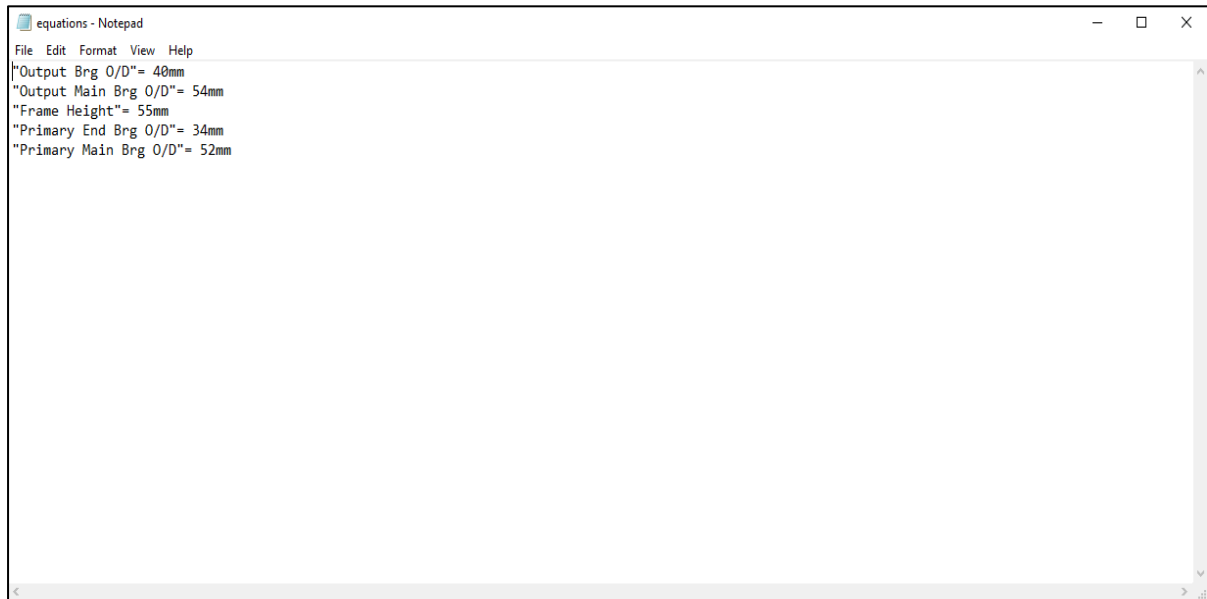


Figure 22: SolidWorks Text Editor File with saved Global Variables (SolidWorks, 2018).

4.2 ADDING VALUES TO GLOBAL VARIABLE AND TEXT EDITOR FILE:

- When replacing the Output Main Bearing model diameter with the global variable, it was necessary to alter the annotation as it was in reference to the radius and not the diameter. The equation is identified by the Epsilon symbol.

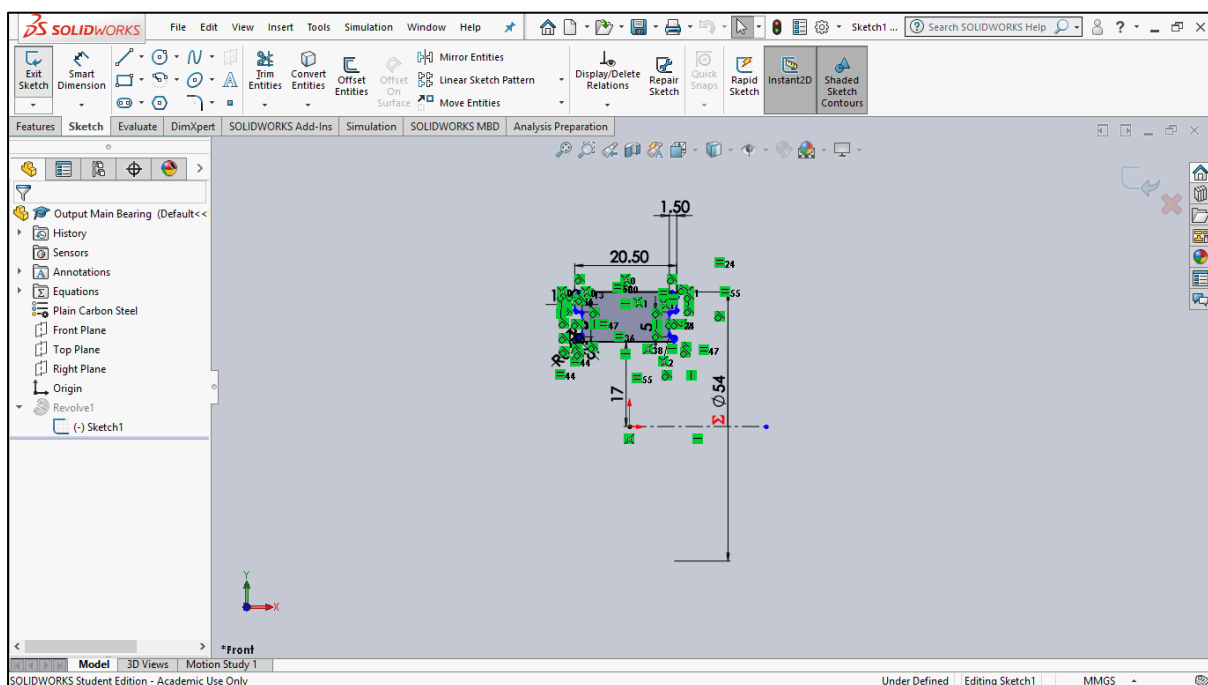


Figure 23: SolidWorks Output Main Bearing Outside Diameter Equation (SolidWorks 2018).

- Alternatively, equations can be added by displaying the annotations, selecting a dimension, deleting and selecting the Global Variable in the dialogue box.

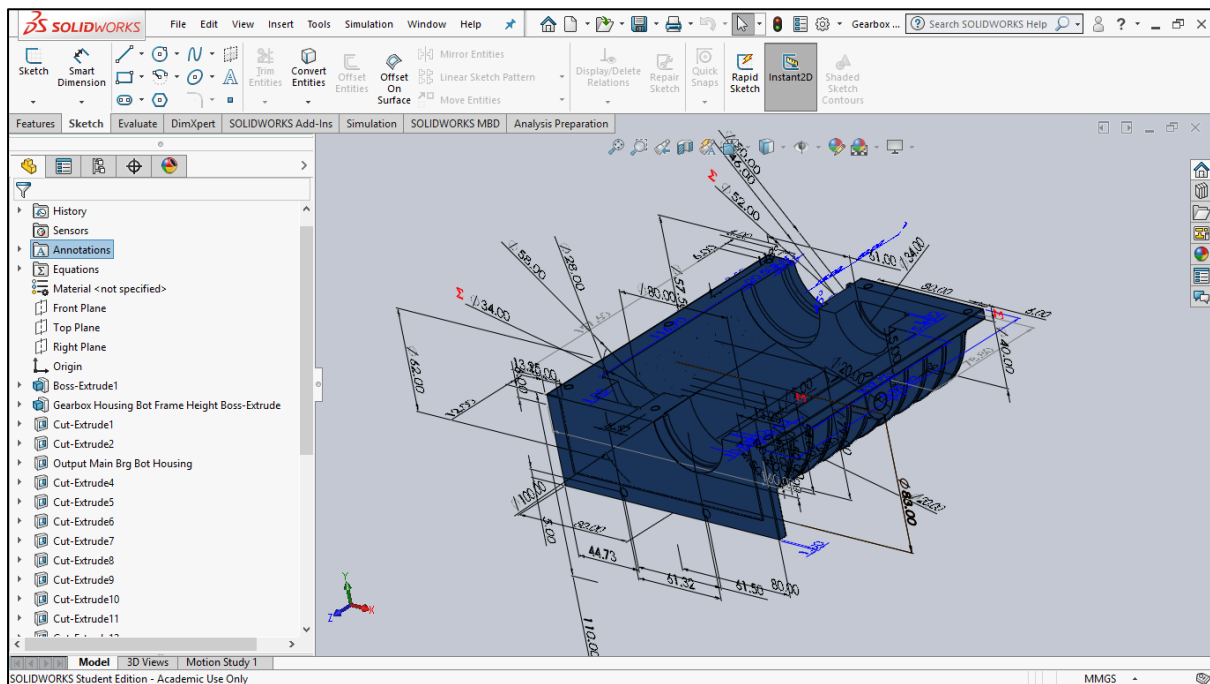


Figure 24: SolidWorks Gearbox Housing Equations (SolidWorks, 2018).

5.0 SOLIDWORKS MOTION ANALYSIS

5.1 BUILDING THE SOLIDWORKS MOTION ANALYSIS STUDY

- The assembly was prepared prior to the motion analysis study by removing any components that were not necessary for the study, therefore, bolts, drain plugs, oil seals, etc. were deleted.
- To ensure all features were enabled within the program, the SolidWorks Motion icon must be selected from the ribbon as in Figure 25.

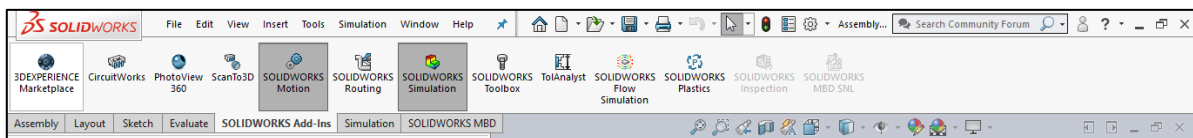


Figure 25: SolidWorks Add-Ins Icon Selection (SolidWorks, 2018).

- To enter SolidWorks Motion Manager, the Motion Study 1 tab on the bottom of the assembly file was selected. This is only available on assembly files.

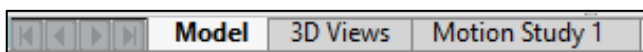


Figure 26: SolidWorks Motion Manager Motion Study 1 Tab Selection (SolidWorks, 2018).

- The type of study was selected by choosing Motion Analysis in the below tree.



Figure 27: SolidWorks Motion Analysis Selection (SolidWorks, 2018).

- To add motion to the assembly, a motor was added from the toolbar below. The motor was attached to the Input Shaft with a clockwise rotation and a constant speed of 100RPM.



Figure 28: SolidWorks Motion Analysis Motor Selection (SolidWorks, 2018).

- Two forces were added to the Gear Selection Fork, one in the direction of the Output Shaft to select the slowest gear set, the second in the opposite direction after half the duration of the timeline, once the first force was timed to switch off.
- A Torsion Damper was added to the Output Shaft to simulate a load on the gearbox.
- Contacts were selected between driven parts, six in total and the material selected was Steel (greasy).
- An appropriate frame rate was calculated based on the on the motor speed of 100RPM to obtain data for every degree of rotation. Calculation used:

$$100 \text{ RPM} / 60\text{s} \times 360^\circ = 600 \text{ fps}$$

- The cycle time was set to 5 seconds as default on the timeline within SolidWorks motion analysis. This was reduced to 2 seconds to save on simulation time, as only the time needed to record the step change in angular velocity on the output shaft was required for the simulation.

Torsional Damper	Force 1	Force 2	Cycle Time	Playback Speed	Frame Rate (FPS)
					$100 \text{ RPM} / 60\text{s} \times 360^\circ$
5.00 N-mm/(deg/s)	10N	10N	2s	5s	600

Table 2: Motion Analysis Value Overview

5.2 MOTION ANALYSIS MATE REDUCTION

- An unconstrained body within SolidWorks has six degrees of freedom (DOF); three translations and three rotations about X, Y and Z axis. By adding mates, you can remove these degrees of freedom. However, within a Motion Analysis study any duplication of degree of freedoms can lead to over constraining and introducing redundant constraint equations. In motion analysis studies, redundant

constraints are similar to over defining a SolidWorks model. If you create a redundant constraint, you have two mates trying to control one degree of freedom. SolidWorks will automatically remove redundant constraints; however, SolidWorks may not remove the correct redundancies within complex models, which can lead to an incorrect analysis or errors (SolidWorks, 2018b).

- In the Motion Analysis Manager, within the Mates folder is a list of all of the redundancies and degrees of freedom populated after a motion study is calculated as shown in Figure 29.

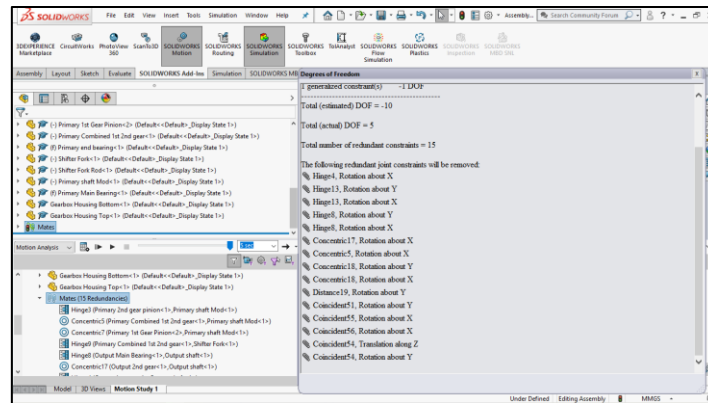


Figure 29: SolidWorks Motion Analysis DOF before Redundancy Reductions (SolidWorks, 2018).

- To reduce the number of redundancies a number of techniques can be applied:
 - Hinge mates can be utilised to replace any geometry that had both concentric mates and coincident mates. A hinge mate limits the movement between two components to one rotational degree of freedom (SolidWorks, 2018b).
 - Rigid groups can be established; rigid groups provide a method to simplify the motion analysis without the requirement of editing the assembly or its mates. All motion and mates between the components within the group are ignored by SolidWorks and instead treated as one solid body (Solidworks.com. 2019c),
 - Revaluation of all assembly mates to determine legitimacy.
- After undertaking the redundant constraint reduction techniques the final assembly had seven redundancies.

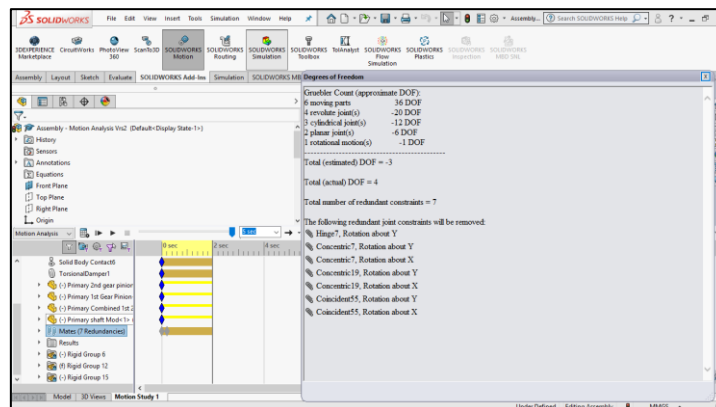


Figure 30: SolidWorks Motion Analysis DOF after Redundancy Reductions (SolidWorks, 2018).

5.3 MOTION ANALYSIS RESULTS

- From the motion simulation you can plot different types of motion studies from the absolute results calculated within the global coordinate system (Donnelly, 2018).
- For the purpose of this simulation it was necessary to plot the angular velocity over time to illustrate the variation in angular velocity of the Gearbox Assembly Output Shaft after the gear change.
- The plot was generated for the Gearbox Assembly Output Shaft as it rotated relative to the Z axis assembly origin. Figure 31 illustrates the plot which was generated with the SolidWorks default frame rate of 25fps. Although the angular velocity increase can be determined from the trend, the plot between gear changes was not harmonic, which was the expectation.

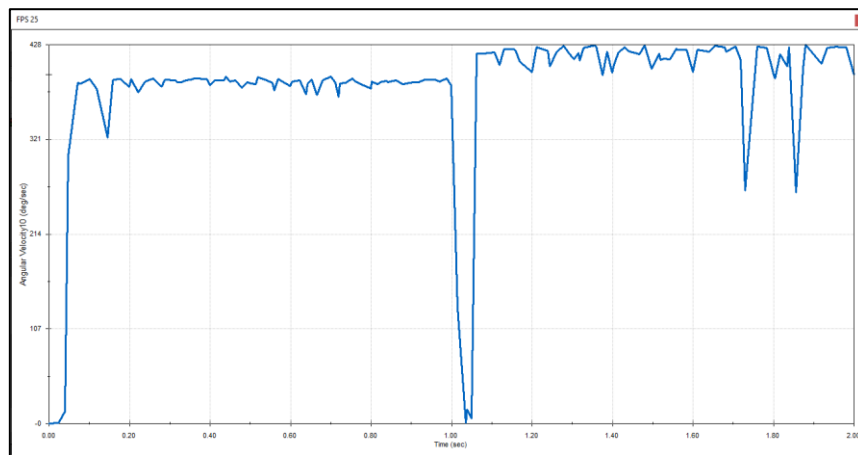


Figure 31: SolidWorks Angular Velocity Plot 25 FPS (SolidWorks, 2018).

- This can be reasoned by the frame rate determining the point of data collection; which was not aligned to the motor speed to obtain data for each degree of rotation. Therefore, data was being calculated at random intervals that were subjected to different influences.
- To improve on the obtained and plotted results, the frame rate was increased to 600fps utilising the aforementioned calculation ($100 \text{ RPM} / 60\text{s} \times 360^\circ = 600\text{fps}$).

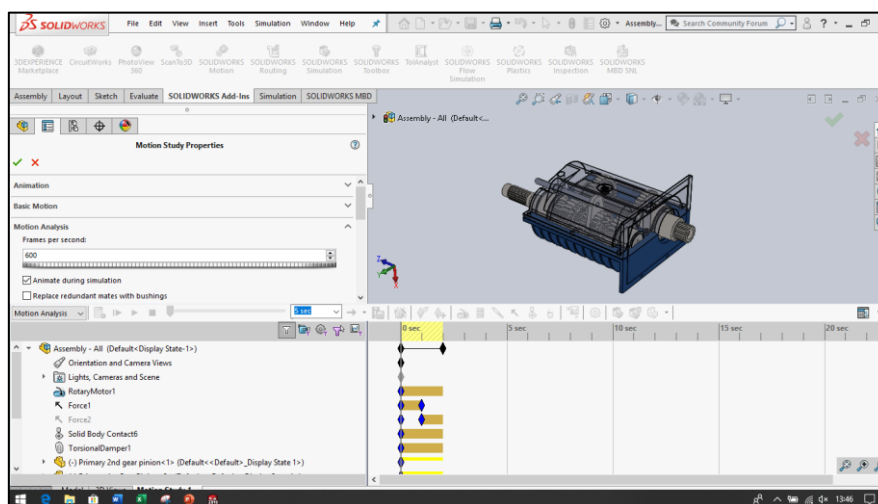


Figure 32: SolidWorks Motion Study Properties – Frames Per Second Entry

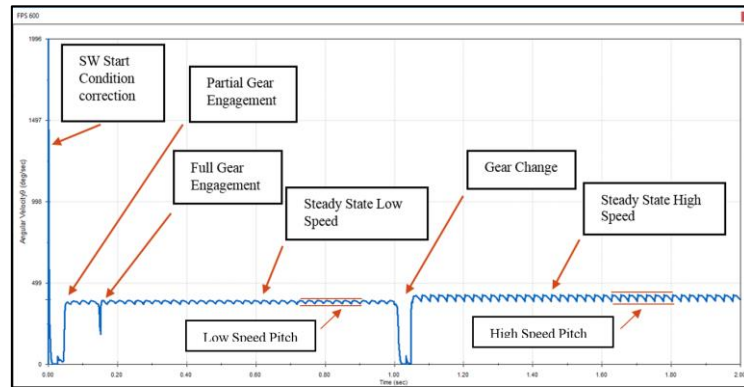


Figure 33: SolidWorks Angular Velocity Plot 600 FPS (SolidWorks, 2018).

- As is evident in Figure 33; the plot became far more regular and harmonic during steady state conditions after the frame rate correction.
- The slight variation within angular velocity between the steady state sections can be explained through gear mesh and backlash.
- The slight increase in pitch between low gear steady state and high gear steady state can be reasoned by the gear centre distance. The gear centre distance was determined from the gear module, which was found to have some variation across the different gears. The centre distance was calculated on the largest dimension to ensure the gears meshed correctly and did not foul one another. The adverse effect of this was to create greater backlash between the slightly smaller gear sets.
- The initial spike in velocity at the start of the plot can be attributed to gear misalignment; therefore, the teeth of the primary and output gears were overlapping. To enable a start condition for the simulation to run, SolidWorks must move these gears into mesh as they had been specified as solid contacts. The spike that is visible at the start is the simulation, is the simulation rapidly moving the gears into position. This spike at the start of the plot was not visible at 25fps as the data must have been missed; however, when the frame rate was set to 600fps this information was captured.
- The hesitation at approximately 0.17 seconds was influenced by the Selection Gear becoming fully engaged, as prior to this, the drive had been supplied by the faces of the gears instead of full mesh.

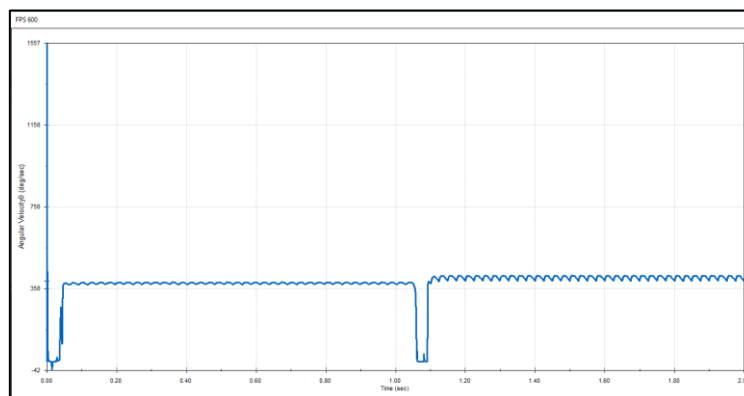


Figure 34: SolidWorks Angular Velocity Plot 600 FPS, Post Value Change (SolidWorks, 2018).

- To overcome the hesitation and to facilitate gear selection, Force 1 and Force 2 were increased to 50N. Also, the dampener on the output shaft was increased to 15 N.mm/(deg/s) to simulate greater load on the Gearbox.

ONEDRIVE LINK

https://uowtsd-my.sharepoint.com/:f:/g/personal/1706668_student_uwtsd_ac_uk/EkycMI6HMldOnmOIR5V4T9IBvGiA4U_xls7GSEKAx08XRQ?e=Lv1Qiq

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